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A DECISION MODEL FOR WATER RECYCLING IN VICTORIA, AUSTRALIA

An Interactive Qualifying Project Report

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by

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1. wastewater
2. recycling
3. decision model

Abstract

Recycling wastewater can prevent depletion and pollution of water supplies. Ove Arup & Partners, an engineering consulting firm in Melbourne, wants to promote this to clients. To aid them, we developed a decision model for water recycling opportunities in Victoria, Australia. We gathered information about the water system in Victoria, obtained expert opinions, and researched successful wastewater recycling projects. We organised this information into a logical Hypertext model, and improved the model based on the results of a feedback survey.

Executive Summary

New technology, advances, and studies in specific fields are often conducted by disparate groups and researchers, and sometimes have not been organized into databases or repositories. This problem is fairly common because many organizations and even entire countries treat environmental problems as local instead of global. Organized knowledge of the opportunities available to recycle water and about the related issues, such as legislation and infrastructure, would encourage and promote this environmental action.

This issue of disorganization and localisation of information is the basis for conducting a Worcester Polytechnic Institute *Interactive Qualifying Project* in Melbourne, Australia, for Ove Arup & Partners. Arup, an internationally renowned engineering firm, would like to promote recycling and reusing wastewater as a feasible and environmentally responsible option for their clients. To help Arup encourage and develop the use of water recycling systems, we have explored the legislative, technical, economic, and social aspects of recycling wastewater in a variety of different situations. Our findings have been compiled into a logical decision making model, providing Arup with a tool for easily presenting to their clients categorized information pertinent to different circumstances where grey water could be recycled and reused.

We reviewed current research and literature that relates to this project. We defined wastewater and identified its many sources, and explored the reasons to recycle water both in general and specifically in Australia. We discussed the existing barriers that discourage water reuse, outlined the possible uses of recycled water, and compared urban and rural water systems. In addition, we explained technical and chemical methods for treating wastewater, and outlined the legislation pertaining to water recycling in Australia.

Based on our background research, we established multiple research objectives. The objectives were: collect Victoria-specific information, interview experts, investigate current water recycling projects, and develop and pretest the decision model. We gathered information to meet our research objectives using several well-established research techniques. Primarily, we employed archival searches and interviews to gather the necessary information. Our research yielded: Victoria-specific information so we could understand the lcoal context and usage of water, the perspectives of local and national water experts, and valuable details about current water recycling projects.

We gathered information and organised it into a logical flow that reflects the development and planning of water recycling projects. The arrangement and linkage of topics were best represented by a Hypertext based model. We supplemented each category and topic in the model with clear and concise supporting material. This material included definitions, comparisons, tables, graphs, and case studies. The purpose of the supporting information was to communicate the basics of water recycling and the many available opportunities to as wide an audience as possible.

The content of the model was very important, and that is why we gathered such a significant amount of information through background research, literature review, and original research from interviews and archival research. However, the presentation and appearance of the model were just as important because the model will be used by Arup as a marketing tool to inform clients about the potential options for water recycling. Therefore, we also concentrated on the overall appearance and visual format to develop a model that would suit its intended purpose and appeal to the projected audience. The model was honed and revised by testing it with various groups. We generated and used a feedback survey so we could compare responses and opinions from different people and different groups to draw conclusions about what improvements should be made to the model. The survey focused on aspects such as content of the various sections, overall content and clarity, organisation, presentation, and aesthetics. We took the recommendations into account when revising the model.

The decision model was constructed in a Hypertext format to allow easy navigation through the model and between topics. We selected Hypertext markup language (HTML) as the programming language because of its widespread use and ability to be viewed in any web browser. The model is structured in a logical flow that begins with explaining why to recycle water and moves onto the options for wastewater reuse. Details about wastewater treatment, site and system controls, and the responsibilities of managing wastewater reuse schemes follow. The content of the model is supported by definitions, pictures, charts, and case studies. The model is over thirty individual webpages, some containing over four pages of information per single webpage. We developed an accompanying user's guide to provide instructions to users and technical information about how to update or upgrade the model.

Based on our preparation and the revising process, we feel that our decision model for water recycling in Victoria, Australia, clearly represents the opportunities and issues related to water recycling at a wide range of scales and a variety of purposes. Therefore, it fulfills Arup's needs. In addition, this model was designed to have a positive impact on society. Natural resources each have a unique niche in the global ecosystem. It is the responsibility of society to protect and preserve the natural resources of the earth by limiting damage and preventing further depletion of these precious resources. Water is one of these resources. Water supplies have been exhausted, polluted, and wasted. Recycling of wastewater can make a significant difference by reducing withdrawals from freshwater sources and preventing contaminants from entering the natural system. Our model clearly presents the advantages of water recycling with the intention of encouraging this environmentally responsible action. When used by Arup, our model will promote water recycling and protection of Australia's water resources. Additionally, the decision model itself and the methodology we employed can act as a platform for developing similar models for other areas and countries.

In conclusion, we developed the decision model for water recycling in Victoria, Australia, for Ove Arup & Partners and in partial fulfillment of WPI's graduation requirements. This project is significant because we assembled disparate information about water recycling into a coherent model that can be used by Arup consultants to encourage environmentally conscious water usage systems. The model and the development process met the objectives laid out in the project statement, and exceeded those objectives in some respects. The decision model is much more in-depth than originally planned and includes extra information in the form of case studies. We also incorporated the topics of total wastewater recycling and effluent purchase and developed the user guide to enhance and explain the final product. This project and the decision model have the potential to be further developed to expand the impact and application of the decision model.

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1. INTRODUCTION

The human species coexists with plants, animals, microorganisms, and the physical earth and its atmosphere. This interconnectedness means that our actions impact everything around us, often permanently. Over thousands of years, we have disregarded that concept, while we affected, altered, and even polluted the environment around us. We are now starting to understand the global consequences of our actions and the threats to both our future and that of the whole planet. The last forty years have marked an expansion of awareness, environmental research, and available technology that provides us with the will and tools to act responsibly towards our environment. Acting in an environmentally aware manner can be very difficult. Many parties have a stake in the use of resources. Individuals, communities, companies, governments, organisations and other countries must be considered when taking action against an environmental problem. At this point in time, environmentally friendly policies and techniques can be prohibitively expensive and time-consuming. Industrialised nations lead the world in environmentalism because they have the resources of time and money to commit. One country that has pioneered many initiatives and engineered creative solutions to environmental problems is Australia.

Australia has responded to environmental problems through legislation, research funding to study the extent of environmental problems and to develop new technology or alternatives, and by participation in international organisations. However, new technology, advances, and studies in specific fields are often conducted by disparate groups and researchers, and for the most part have not been organised into databases or repositories. This problem is fairly common because many organisations and even entire countries treat environmental problems as local instead of global. An example is legislation and policy across the states of Australia. Each state maintains a set of environmental policies that differ, resulting in confusion and possibly discouragement of cooperation and initiative among communities and companies across state borders. Creative solutions by individual communities are another instance. Efficient systems for recycling water and serving customers are in place around the world, but often not publicised beyond the local area. Organised knowledge of the opportunities available to recycle water and about the related issues, such as legislation and infrastructure, would encourage and promote this environmental action.

This issue of disorganisation and localisation of information is the basis for conducting a Worcester Polytechnic Institute *Interactive Qualifying Project* (IQP) in Melbourne, Australia, for Ove Arup & Partners. Arup, an internationally renowned engineering firm, would like to promote recycling and reusing wastewater as a feasible and environmentally responsible option for their clients. To help Arup encourage and develop the use of water recycling systems, we have explored the legislative, technical, and economic aspects of recycling water in a variety of different situations. Our findings have been compiled into a logical decision making model, providing Arup with a tool for easily presenting to their clients categorised information pertinent to different circumstances where wastewater could be recycled and reused.

This IQP has the potential to have significant societal and environmental impact. Recycling and other environmentally responsible actions are vital in protecting the earth and its organisms and ecosystems. This project aims to encourage the protection of these resources by facilitating wastewater recycling. Arups' commitment to the environment combined with our decision making model for water recycling will allow Arup to further develop measures to protect and conserve natural resources.

The Background and Literature Review, Chapter 2, introduces the reasons for conducting this project and presents pertinent background information on water and wastewater recycling. In addition, we review current research and literature that relates to this project. The Methodology section, Chapter 3, presents our research objectives for developing the decision model and outlines the methods we used to meet those objectives. The Results section, Chapter 4, details the results and outcomes of our Methodology. We present our final decision making model and discuss its use in the Conclusion and Recommendations section, Chapter 5.

2. BACKGROUND & LITERATURE REVIEW

This section introduces Ove Arup & Partners and the motivation for this Interactive Qualifying Project. It also defines wastewater and identifies its many sources, and explores the reasons to recycle water both in general and specifically in Australia. We discuss the existing barriers that discourage water reuse, outline the possible uses of recycled water, and compare urban and rural water systems. In addition, we explain technical and chemical methods for treating wastewater and outline the legislation pertaining to water recycling in Australia.

2.1. OVE ARUP & PARTNERS

Ove Arup & Partners offers consulting and project management services around the world in all major engineering disciplines, ranging from civil and environmental engineering to acoustics and fire protection engineering. The major goals of the firm are to continually strive for quality, honor in business, and prosperity, while utilising a multi-disciplinary engineering approach. Arup maintains a strong environmental focus in all stages of their projects. Since they are an international firm, their rigorous commitment to the environment has allowed them to spread environmental awareness and protection programs around the globe. Arup is particularly concerned with water. Most projects that they undertake deal with water in some respect, whether they are designing bridges and dams or planning hydraulic and sewage systems.

Arup's commitment to the environment and particularly water conservation is the motivation for commissioning this IQP. Having a thorough review and analysis of all the issues connected to wastewater recycling in Australia will provide them with a decision making tool appropriate to any situation and suitable for consultancy use (Arup Australasia website).

2.2. INTRODUCTION TO WASTEWATER

Wastewater is primarily made up of three different types of water: grey water, black water, and stormwater. This project does not consider stormwater and its related issues. Grey water is wastewater that results from domestic use but has not come into contact with toilet waste, which is called black water. The concentrations of common pollutants differ between grey and black water (see

Table 1). Black water constitutes only 35 percent of household wastewater, but it makes up 61 percent of suspended solids, 82 percent of nitrogen, and the majority of existing pathogens. Black water must be disposed of via a reticulated sewerage system or septic tank. Sewerage systems are found in both rural and urban areas, but septic systems are more common in rural areas. Approximately 88 percent of the Australian population is connected to centralised sewerage systems.

Sources of grey water include shower, bath, hand basin, laundry, and kitchen waters. These wastewaters are available for domestic reuse for purposes such as garden watering and toilet flushing. However, grey water must be treated to a minimum quality level suitable for the intended use. Treatment is necessary to protect humans, soil, and surrounding water supplies. The reuse of grey water is carefully regulated by local and national legislation. In addition, local authorities must be consulted before planning and installing grey water recycling systems. There are many reasons to recycle wastewater, and grey water in particular.

Table 1. *Pollutant Distribution of Household Wastewaters*. Adapted from Geary, 1998.

Grey Water	Pollutant	Black Water
65%	Domestic Flow	35%
63%	BOD5[1]	37%
39%	Suspended Solids	61%
18%	Nitrogen	82%
70%	Phosphorus	30%
Low	Pathogens	Majority

[1] Biological Oxygen Demand over five day period

2.3. WHY RECYCLE AND REUSE WATER?

Water is undeniably a vital resource. Living beings require it to live; human civilisations were founded on the basis of its location, and most industries rely on it. Even though two-thirds of the earth's surface is covered by water, available freshwater is only 3 percent of the global total. These freshwater sources are distributed unevenly around the earth, causing shortage problems for some areas and supply issues for areas afflicted by droughts. In the global water cycle, all human water withdrawals and wastewaters will eventually be returned naturally to sources. Currently, our consumption and use of potable water supplies exceed the natural return rate. While our effluents are being processed and cycled by the earth, the available supplies of freshwater are diminishing.

Gleick states that water withdrawal is dictated by three major factors: population growth, industrial development, and irrigated agriculture (1998). In the year 2000, each of these factors is increasing at unprecedented rates and threatening water supplies. These diminishing resources establish reasons to take action. Several suggestions by Gleick (1998) are: increased efficiency in industrial, residential and agricultural practices, adjusting economics and pricing policies, developing desalination plants, and reclaiming wastewater. Recycling water means treating wastewaters artificially and directly reusing the waters instead of releasing the flow into the environment. By doing so, we protect freshwater resources from pollution and repletion to help the natural cycle continue into the future.

Wastewater and treated sewage are a significant proportion of the water cycle, especially in urban areas. In 1994, Australia disposed of these waters in the following manners: coastal waters (67 percent), inland/fresh waters (19 percent), land (13 percent), and direct reuse (1 percent) (Newton, *et al*., 1998). Newton states that using wastewater and grey water outputs as resources can accomplish the following: "augment primary water sources, prevent excess diversion of water from alternative uses, manage in-situ water supplies, reduce water supply and distribution costs, reduce or eliminate release of sewage and wastewater into receiving waters, and meet political and institutional restraints" (1998). Gleick (1998) adds that recycled wastewater can be used for a variety of purposes, including recharging ground aquifers, supplying industrial needs, irrigating particular crops, or supplementing potable supplies. Reilly (1999: p. xii) further supports recycling from a commercial point of view by indicating the following advantages of pollution prevention: "[Recycling can] save raw materials, reduce disposal costs, lessen liability, improve community and employee relations, win customer loyalty, and trigger product innovation."

2.3.1. Sustainable development

The concept of *sustainable development* is relatively new and marks a paradigm shift in how humans interact with the surrounding environment. The *Australia: State of the Environment Report* defines sustainable development as fulfilling the needs and objectives of the present population without compromising those of future generations (1996). This concept is particularly applicable to environmental issues. The pollution and harm done to the earth and to other species have become more obvious as we study the consequences of human actions. A sustainable development perspective dictates that humans must consider and protect the areas and species around them, while striving to fulfill their own needs and agendas. Australia's support for this concept led to the creation of a National Strategy for Ecologically Sustainable Development (ESD) in 1992 (ASOER, 1996). ESD's ecological focus allowed the development of a more specific definition of sustainable development – "a pattern of development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends" (Mackey, 1998: p. 7). In 1992, over 178 governments drafted and adopted an international plan of action for sustainable development, called *Agenda 21* (ASOER, 1996).

Mackey lays out eight principles that relate to sustainable development; each of the principles can be applied directly to water usage and wastewater recycling. The principles are as follows:

1. Maintain the integrity of Earth's ecological systems.
2. Renewable resources should not be used at a rate, or in a manner, greater than at which they can be replenished.
3. Human activity should not result in substances entering the biosphere in concentrations that exceed the ecological assimilation capacity.
4. The characteristic biodiversity of ecosystems should be conserved *in situ*.
5. All human activity that impinges on the environment should follow the precautionary principle [minimise all possible impact].
6. Local actions must be evaluated in a global context, and modified accordingly.
7. Harmonise human population, resource use, and Earth's ecological carrying capacity.
8. [Consider] non-science derived principles. (1998: pp. 9-13)

Recycling and reusing wastewater can contribute to accomplishing principles 1, 2, 3, 4 and 7 of the above list. By reusing water, pollutants are prevented from entering the biosphere and affecting ecosystems. Moreover, initial withdrawals of potable water can be decreased since potable water consumption is reduced by recycling. Reducing the release of wastewater into the environment supports the precautionary principle (5) by eliminating or diminishing the potential for future damage and harm. In addition, recycling water and protecting the environment locally provides global benefits (6) as well. The non-science derived principles (8) govern the implementation and support of wastewater recycling systems. Legislative and economic incentives, along with community buy-in, encourage the development of water recycling programs.

Overall, wastewater recycling is an important step in achieving sustainable development. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is currently conducting a project that supports sustainable development and Australia's Ecologically Sustainable Development policy. CSIRO's *Urban Water*

Program is a project with the goal of "achieving improved environmental and economic performance for water systems within the context of socio-economic and climatic change" (Speers, 1999). This program is researching and analysing Australia's urban water systems in order to improve services and economic performance while simultaneously moving toward ecological sustainability. The Urban Water Program is an excellent model of applying sustainable development practices in an economic context. It also indicates Australia's commitment to sustainable development.

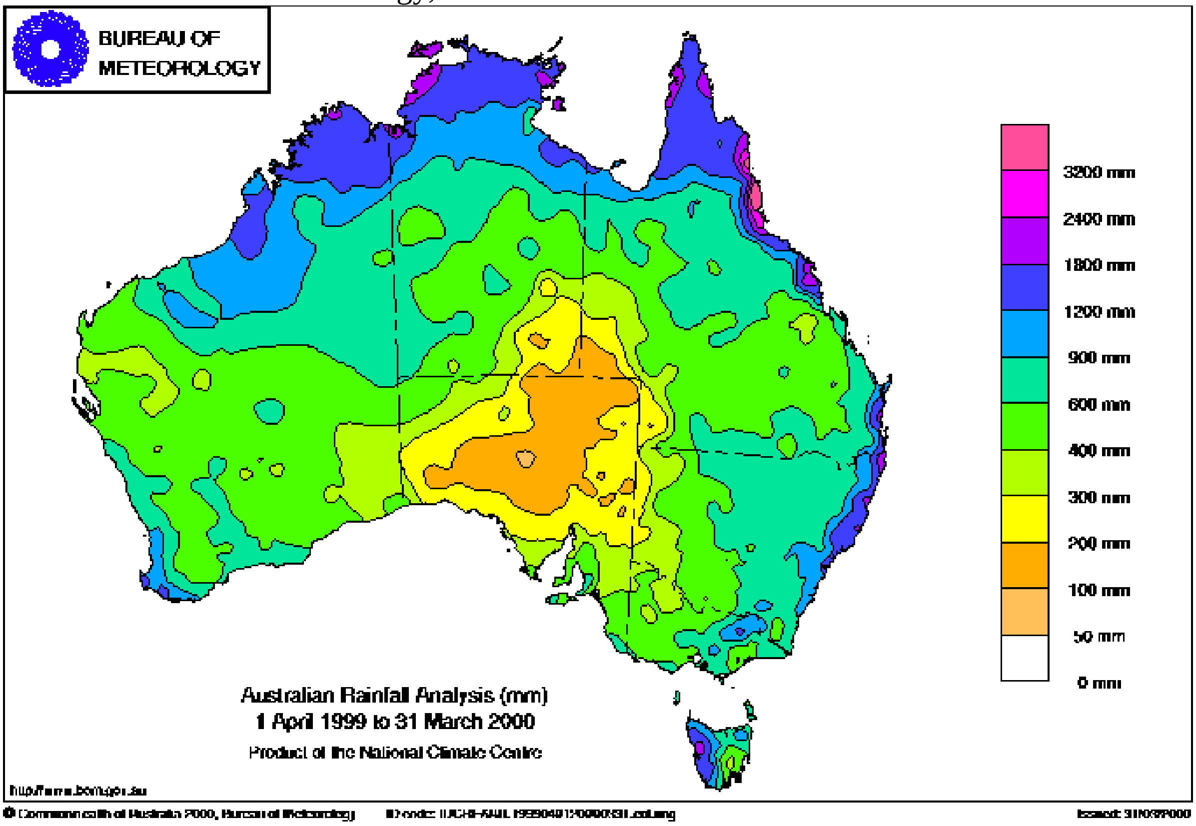
2.3.2. Reasons for recycling water in Australia

Australia stands as one of the most environmentally aware countries in the world. The 1996 *Australia State of the Environment Report* asserts that the Australian approach to environmental management has made considerable strides towards protecting the nation, but there is a responsibility shared by all citizens to do more (1996). In Australia and other places, environmental management is frequently an *ad hoc* response to a certain urgent problem in a specific area. These problems, such as droughts or the discovery of contaminated areas, often stimulate people to take environmental actions. Other problems that are not yet "urgent" still need to be addressed in order to implement fully the concept of sustainable development (Newton, *et al.*, 1998). Recycling water is an appropriate step toward this approach because of its preventative nature and reuse of a "raw material," i.e. water.

Aside from individual and organisational motivations to be environmentally conscious, Australia has significant and pressing reasons to recycle water. The

Australian continent has the lowest average precipitation of all inhabited continents. Over one-third of the country is classified as arid (annual average rainfall less than 250 mm) and another third is semi-arid (average precipitation between 250 and 500 mm yearly) (ASOER, 1996) (see Figure 1). On average, Australia receives 420 mm of precipitation annually, while Europe, Asia, and North America all benefit from over 600 mm yearly. Approximately 40 percent of Australia is too dry for agriculture (Australian Academy of Technological Sciences and Engineering, 1999). Africa and South America receive even more rainfall.

Figure 1. *Australian Rainfall Analysis: 1 April 1999 to 31 March 2000*, Commonwealth of Australia Bureau of Meteorology, 2000.



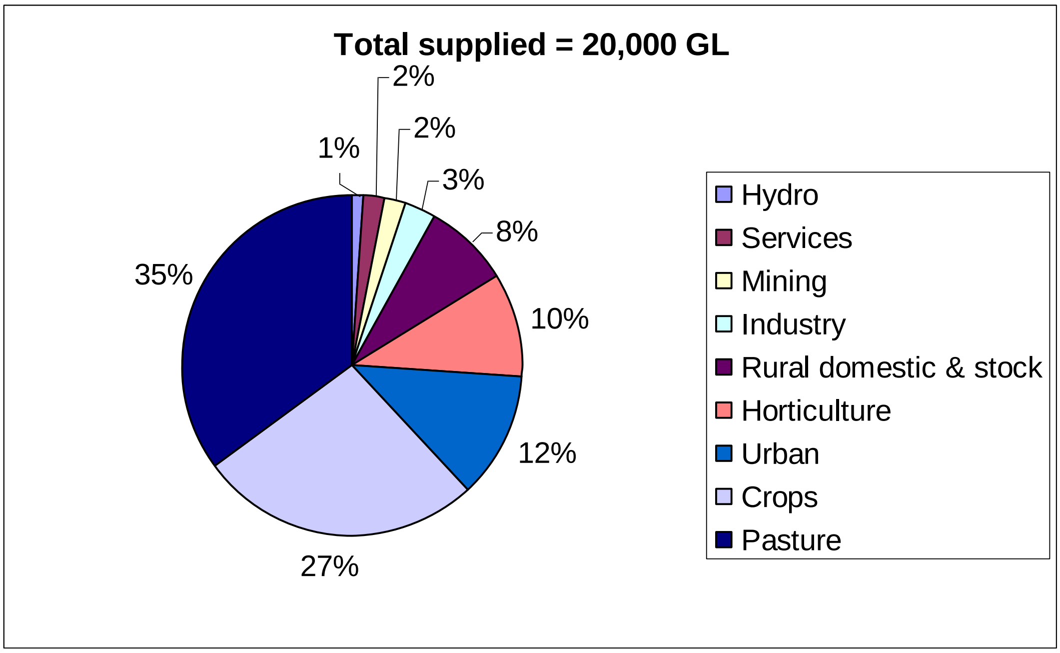
Runoff, the precipitation that ends up in bodies of water such as streams and rivers, is another significant problem for Australia. Only 12 percent of Australia's annual precipitation becomes runoff; whereas other continents enjoy runoff percentages from 25 to 38 percent (Crabb, 1997). High rates of infiltration and evaporation in Australia prevent a higher yield of runoff from precipitation. Not only are rates of evaporation high, but precipitation and runoff in Australia experience the greatest geographic variability when compared to any other continent. Spatial inequity has a significant impact. For example, Northern Australia and Tasmania receive 78 percent of the continent's precipitation, but are homes to relatively small proportions of the country's economic activity and inhabitants (Crabb, 1997).

Climate is another issue that affects Australian water consumption and supplies. Not only is Australia generally hot and dry, but the continent also experiences significant climate variability (ASOER, 1996). Frequent floods and droughts are constant worries in Australia because of their disastrous effects and costs. In fact, flooding alone costs Australia $400 million on average per year (Crabb, 1997). Both Queensland and New South Wales suffered from lengthy droughts from 1991-1995, and then they experienced flooding in 1998 (AATSE, 1999). Climate, rainfall, and the threats of droughts and flooding significantly influenced the development of Australian settlements and society. For example, the major cities are almost exclusively located in coastal regions where water supplies and rainfall are more predictable. The drier regions were developed only when sources of irrigation water were present (AATSE, 1999).

Despite these chronic problems, Australia has one of the highest per capita total water consumption levels in the world (Newton, *et al.*, 1998). From 1995 to 1996, Australia used about 20,000 gigalitres including both rural and urban areas, for production and consumption. In this case, water use is defined by the Department of Primary Industries and Energy as "gross water supplied" because the calculation takes into account all forms of use and includes water losses accrued in the distribution system. Based on the comparison to Australian water usage from 1983 to 1984, water use increased by about 25 percent (AATSE, 1999). Approximately nine categories of use dominate the demands for water. These categories and their share of the total water market are shown in Figure 2.

Total water use can be broken down into urban and rural sectors. From 1995 to 1996, urban uses accounted for 17.5 percent of total water supplied. The rural water uses, 78 percent of the total, can be further broken down into agricultural uses such as irrigation for pastures, crops, and horticulture (totaling 72 percent) with the remainder used for activities such as watering for stock and domestic purposes (AATSE, 1999).

Figure 2. *Estimated Gross Water Supplied in Australia, 1995-96, by Purpose of Use*. AATSE, 1999.



Irrigation water needs vary with seasonal and weather conditions. However these needs are increasing each year because the amount of irrigated land in Australia is growing rapidly (at approximately three times the global average). In 1994, the area of irrigated land in Australia was 2,317,000 hectares, more than double the amount in 1961. The increase during the early 1990s showed an annual change of +6.62 percent; whereas the global annual change during that same time period was only +1.22 percent (Gleick, 1998). Farmer data collected by the Australian Bureau of Statistics in 1996 indicate that “relatively few farmers use any objective method of irrigation scheduling” (AATSE, 1999: p. 37). Over 90 percent of farmers use local knowledge as a main technique for scheduling their irrigation. Three main irrigating methods are sprays, furrows or flood irrigation, and trickle irrigation. Spray systems are widely used, with 28 percent used to irrigate pastures and up to 15 percent used on cereals, fruits and vegetables. Flood or furrow irrigation is utilised for cereal, sugar cane and other crops. Trickle irrigation and microjets are used primarily for fruit and vegetables, most suitably fruit trees and vines (AATSE, 1999).

While the use of irrigation is increasing, the total population of Australia is expanding. In 1995, the population was 18,088,00 people, displaying a +1.42 percent annual increase. Approximately 85 percent of the population was classified as urban (Gleick, 1998). As Australia’s population increases, domestic water usage and water demands are rising. More citizens require more food, use more goods, and need more services – all of which further affect water demand and supplies. Another factor that affects the water usage is the efficiency of the water distribution system. The existing system is acknowledged to suffer significant losses from evaporation, leaks and lack of quality control in terms of schedule of delivery. These losses can account for up to 40 percent of the water delivered in some areas. The most common losses range between 5 and 10 percent (AATSE, 1999).

Australians clearly have important reasons to recycle their water for other uses. They have shown environmental initiative in many areas on an *ad hoc* basis, but are moving toward sustainable development. Exploring water recycling programs and systems in a variety of different situations, including rural and urban settings, will promote better water usage efficiency, reduce overall water demand and increase protection of the environment. In 1997, Crabb stated that approximately 5 percent of treated effluent in Australia was reused for other purposes such as watering golf courses and tree plantations. By further developing and researching water recycling systems and applications, Australia can easily raise the percentage of reused water above the current levels.

2.4. WHY MORE WATER IS NOT CURRENTLY RECYCLED

Recycling water appears to be a sound environmental measure, but there are several practical barriers that stand in the way. The most significant obstacles are cost and perception of environmental problems. Barnes and Wilson assert that cost is the major issue. They also state that polluting and discarding used water is less expensive than installing wastewater treatment plants and infrastructure (1978). Water quality and supply are often perceived as critical problems only when a significant pollution or contamination event occurs or during times of drought (Newton, *et al.*, 1998). Even when public awareness is raised, other barriers exist. The source or cause of the problem may not be known, and there is often a significant time lag between human action and environmental effects (ASOER, 1996). Moreover, environmental action on a local scale seems to generate only marginal impact (Mackey, 1998). Therefore, immediate changes and improvements are not obvious or visible to reinforce the necessity and importance of environmental projects such as recycling wastewater.

Some other issues that prevent water recycling programs and systems are public concerns about health risks, restrictive legislation, and institutional constraints (Newton, *et al*., 1998). The health risks from recycled water are genuine concerns and can be controlled through risk management. For example, raw grey water can contain a variety of organisms that have the potential to be pathogenic. For this reason, grey water should be treated to a level appropriate for its intended use. In addition, recycled waters can contain nutrients, salts, and trace elements that could be harmful to soil and plants, especially when accumulated. To control these factors and protect the area where recycled water is being used, a comprehensive water quality monitoring plan must be developed and strictly followed (Geary, 1998).

Australia suffers from the same general barriers to water recycling that exist around the world, but the country also has its own unique obstacles to water reuse. The *Australia: State of the Environment Report* lists the lack of information and integrated national databases as significant deficiencies that affect environmental action (1996). Crabb (1997) supports this assertion by pointing out that the only two national studies of water usage, demand and consumption in Australia were completed in 1977 and 1983-1984 and are therefore seriously out of date. He also states that these surveys were limited to water consumption or off-stream use (1997). The lack of recent data and absence of a central repository for information about Australia's water usage is a significant deterrent to water recycling. The extent that water recycling might alleviate water problems and provide viable alternative systems is difficult to assess because of these barriers. Another problem in Australia that relates specifically to grey water recycling is institutional restraints. Recycling grey water without any treatment is illegal in any location where a reticulated sewage system is in place. Also, permission and licenses for water recycling schemes can only be obtained on an individual basis, i.e. each project must go through the process of contacting the local authorities and acquiring certain permits and approvals from each one. This procedure can be difficult and time-consuming. Despite the potential problems and drawbacks to water recycling, there are many opportunities to reuse water for several different purposes (Geary, 1998).

2.5. USES OF RECYCLED WATER

Reclaimed water can be utilised for several purposes. The major reuse of processed water is for agricultural irrigation, amounting to about 60 percent of all recycled water use. Approximately 30 percent is used for industrial cooling and process waters. The remaining 10 percent of all reused water is for other categories, such as urban landscape irrigation, groundwater recharge and toilet flushing.

Wastewater irrigation utilises the water as a resource and maximises the agricultural benefits. It is a sustainable measure because economically treating and recycling wastewaters prevent pollution and long-term degeneration of the land while using valuable nutrients available in wastewater. The water can be applied in a variety of methods. The major techniques are flood, spray, or micro irrigation. Selection of an irrigation technique is site specific and depends on soil characteristics and the particular crop (Thomas, 1993). However, irrigation by reclaimed water introduces other considerations when choosing a system to apply water. Mist irrigation is not considered appropriate because of the increased potential for wind dispersion and human contact. Moreover, any technique where the water does not come into direct contact with the crops is preferred. Drip furrow irrigation is the main technique used. It consists of water lines embedded in the soil, with a regular pattern of holes along the line. As water is run through the system, it is dispersed through the subsurface of the soil without contacting the actual crop. Other factors that dictate the use of wastewater irrigation are proximity to the public and to groundwater supplies (EPA, 1996).

Agricultural irrigation can be broken down into two categories: restricted and unrestricted irrigation. These categories differ in terms of the quality of the reclaimed water, relative health risks and the ways in which the products can be used. Restricted irrigation refers to the use of low-quality reclaimed water in specific areas where only certain crops are grown. These fodder, fibre, and seed crops include alfalfa, cotton, and wheat. Public access is not granted onto these growing areas. Fences and signs must surround the perimeters of the area.

Unrestricted irrigation refers to the use of high-quality reclaimed water for irrigation of food crops for human consumption. Public access is not restricted at these sites. However, if there are any faucets discharging the reclaimed water, there must be signs warning the public not to use the water for drinking.

Urban landscape reuse can similarly be broken down into restricted landscape irrigation and unrestricted landscape irrigation. Restricted landscape irrigation can be used in areas where public access is limited or where water application is controlled to prevent direct contact with people. Such areas include highway medians and golf courses. Unrestricted landscape irrigation with high quality reclaimed water can be utilised for lawns, playgrounds, gardens, public parks, and other places where people might be in contact with the water.

2.6. THE CLASSES OF RECYCLED WATER

Current Victorian EPA regulations identify three classes of wastewater. Class C is wastewater that has received primary treatment only and is permitted to be used for a) fiber or seed crops; b) fodder crops for animals other than pigs, beef cattle or milking animals; and c) forestry areas or tree nurseries with no public access. This class of water can only be distributed by flood or furrow irrigation. Class B quality water is subdivided into three parts. Part (1) is wastewater that has received primary and secondary (biological or chemical) treatment and has characteristics which make it usable for a) landscaped areas; b) crops that will be commercially processed before human consumption; c) crops that will be cooked before human consumption; d) crops that will be peeled before human consumption; and e) pasture and fodder crops for animals except pigs, cattle, and milking animals. This class of water can be distributed by flood, furrow, drip or spray irrigation. Part (2) This wastewater has the same characteristics as Part (1) and is permitted for a) orchard and vineyard intended for human consumption (no windfallen fruit can be harvested) and b) any other purpose that the EPA may approve. It can only be distributed by furrow or drip irrigation. Part (3) This wastewater is permitted to be used for pasture and animal fodder crops for milking animals and beef cattle and can be distributed by flood, furrow or spray irrigation. Class A is essentially tertiary treated water and can be used for any purpose approved by the EPA and local authority (Eden, 1995).

All users of recycled water are required to operate so that there is no polluted run-off from the property, either to neighbors' land or to watercourses or other environmentally sensitive areas.

2.7. URBAN VS RURAL WATER SYSTEMS

For a sustainable future in both urban and rural areas, society and industry must move towards the goal of efficient and appropriate water use. Recycling wastewater is a step in this direction. Although the practice of water reuse has been hindered by social and economic factors, developments in technology and changes in social attitudes have prompted its implementation in many areas around the world. Some issues have different impacts in urban and rural settings, and these need to be taken into account when implementing water reuse systems.

In rural areas, water is usually obtained from on-site sources including, groundwater, streams and dams, or collected in domestic rainwater tanks. Wastewaters can be disposed of through on-site septic systems or reticulated sewerage systems for transport to treatment plants. Most aspects of rural environments are decentralised; for example, each household might supply its own water through a well. Because of this decentralisation, water systems are not strictly regulated by water authorities. Instead, general guidelines are in place to govern various rural situations, such a domestic dwellings and farms.

Rural wastewater recycling in areas such as farms can be especially advantageous. Depending on what crops the farmer produces, recycled water can be used for irrigation purposes. In all rural areas, treated wastewater can be reused for toilet flushing and lawn or garden irrigation. Rural water recycling systems appear to be easy to implement because of the factor of decentralisation, since infrastructure requirements are simple. However, they are also more costly, since each landowner must pay for the system's implementation directly (Geary, 1998).

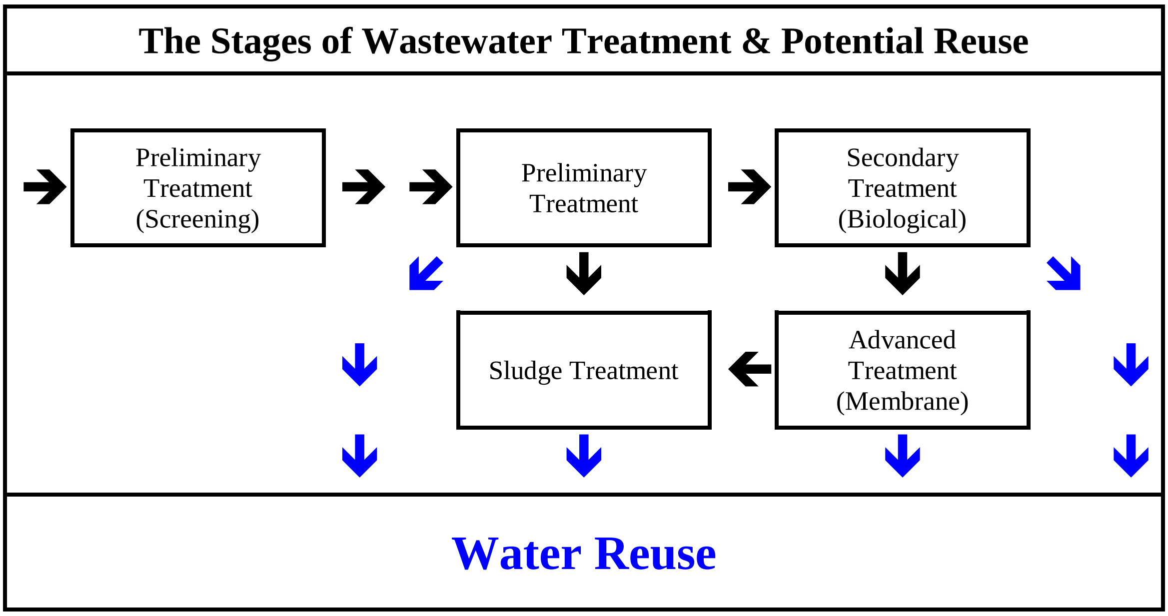
In contrast, urban sewage and water networks constitute centralised systems. In the urban environment, water is recycled through the use of centralised water treatment plants. Because of this fact, water usage and any water related system are strictly regulated by the local water authorities. Cities are sectioned off with influent lines running from industrial firms and domestic areas to water treatment plants. Instead of each household or firm owning and operating its own water recycling system, a local water treatment plant serves an entire section of city or area through a connected pipe system. Often, centralised systems save customers more money than localised water supply and disposal, because city subsidies promote the use of the system. It is also less expensive for additional end users to connect to an existing plant grid, when compared with building a separate localised system for that user. However, specialised systems can be applied to rural or urban settings on a domestic level. The systems and potential reuse options are the same; the regulations that govern the systems in alternate settings differ.

Although there are differences between urban and rural recycling schemes, the chemical processes of water treatment are standard. The next section explains the different stages of water treatment.

2.8. PROCESSES OF TREATING WATER

Physical, chemical, and biological treatment methods are used to treat wastewater. These processes are used together in different phases of wastewater treatment. The specifics of the treatment processes are unique to the water supply and the proposed use of the effluent. However, there are general measures that are almost always followed. When water enters a treatment plant, it travels through a series of treatment units. Treatment units can be divided into preliminary, primary, and secondary treatment and sludge disposal (see Figure 3). In some instances, advanced treatment is necessary (Hammer & Viessman, 1998).

Figure 3. The Wastewater Treatment Process and Potential Water Reuse at Each Stage.



2.8.1. Preliminary treatment

Preliminary treatment units remove heavy pollutants in the water. These physical methods may include screens, grit removal units, and shredders. This phase of treatment is conducted to protect downstream pumps and pipes from large debris. Occasionally in a preliminary treatment unit, some chemical treatments are involved, such as chlorination for odor control.

Shredding of solids during water treatment is much less common, yet it is still used in some instances. Shredders are used to reduce the size of the solid waste in the water immediately before screens and grit removal units.

Screening is the simplest form of water treatment. Different kinds of screens involve various types of maintenance. Screens are often set up in series or trains, to prevent clogging downstream in the treatment process. The sizes of the holes in the screens decrease as the water proceeds down the train (Shuval, 1977).

Similar to screening, grit removal also removes solids in the water and protects pumps located downstream. However, the method used to remove the solids is quite different. Grit removal is a simple settling process. Over time, small solids in the water settle to the bottom of the treated water tank and are combined with sludge (Arceivala, 1981).

2.8.2. Primary treatment

Primary treatment uses physical and chemical techniques. Physical treatment consists of storing wastewater in a primary sedimentation tank and allowing solids to settle to the bottom of the tank in the form of sludge. The chemical processes include neutralisation, coagulation and flocculation. Neutralisation controls the pH of the water. Coagulation and flocculation cause solids in the water to consolidate in order to remove nutrients and heavy metals. Primary treatment usually removes 30%-50% of the suspended solids in the water.

Occasionally water can be recycled to irrigation processes immediately after this phase of treatment. This, of course, depends on the source of the influent and the intended use of the effluent (Sundstrom, 1979).

2.8.3. *Secondary treatment*

Secondary treatment generally involves biological methods to remove organic compounds in the water. The most commonly used biological processes are activated sludge reactors and trickling filters.

In the activated sludge process, wastewater is fed into an aerated tank where microorganisms consume organic wastes from the water for use in cellular processes such as metabolism and new cell generation. The resulting activated sludge is settled in a secondary sedimentation tank called a clarifier or thickener. The terms clarifier and thickener are interchangeable when describing a secondary sedimentation tank. A portion of the activated sludge is usually recycled to the reactor to gain a higher concentration of microorganisms, which will consume higher amounts of organic wastes in the water, thus improving performance.

Trickling filters are beds packed with rocks, plastic, or other media. Microbial films grow over the packing and water is trickled over these films. When water flows over the films, soluble organics are removed from the wastewater. Excess growth washes the microbial film off the packing and is then removed in the clarifier (Sundstrom, 1979).

2.8.4. *Advanced treatment*

Advanced treatment is necessary for all unrestricted water reuse where the processed water will have direct contact with people. These treatments chemically return water to its original state so that it may be used directly instead of fed back into a lake or the ocean. However, even water that has been through advanced treatment is not allowed for use as a potable source. Several processes are used in these advanced states, including membrane and chemical techniques.

Ultrafiltration (UF) and reverse osmosis (RO) are both membrane processes used to remove particles from water. They are similar processes, with the only difference lying in the manufacture of the membrane. UF and RO are related in a manner similar to the train of screens mentioned in section 2.6.1. UF and RO are often positioned in series to prevent clogging. UF filters out the larger particles, while RO filters out the tiniest of particles and is capable of producing pure H_2O. In most cases if the water is too pure it may need some additional treatment to add some desired nutrients before release into environmental systems. Specifically if the processed water is being fed into a lake or river, some nutrients may need to be added for the benefit of certain aquatic life.

Some chemical processes used in tertiary treatment are phosphate and nitrogen removal for biological reasons. If excess phosphate and nitrogen are present in the water, they could promote excessive growth of plant life. If necessary, other processes are employed such as fluoridation or chlorination for odor purposes (Hammer & Veissman, 1998).

2.8.5. Sludge disposal

The processes above concentrate waste organics into sludge. Various forms of sludge disposal are available, depending on what the sludge actually contains. Some sludge may be used as fertilizer on agricultural land. Landfills and incineration are also options. The wide range of treatment and disposal methods for sludge requires the use of physical, chemical, and biological processes, depending on its content and disposal site.

The use of water treatment processes is regulated heavily by local guidelines and legislation. The next section details the guidelines and regulations that govern water treatment and reuse in Australia. We also discuss the government agencies and organisations that enforce and oversee these regulations.

2.9. LEGISLATION IN AUSTRALIA REGULATING WATER

In this section, we outline the laws and legislation governing the treatment and reuse of water in Australia. Currently in the year 2000, Australia is developing new legislation dealing with water treatment and reuse. Different regulatory frameworks for water recycling have evolved in each state, but a uniform national set of laws and regulations has been the goal of many new proposed laws and guidelines in Australia. In this section, current local legislation, pre-existing national laws, and newly proposed regulations for water recycling are discussed.

2.9.1. Water reuse regulatory framework

Currently, Australia has no national regulatory framework for water recycling. Regulations governing approval for wastewater treatment and recycling differ depending on the state and territories in question. However, similar regulations exist among some states and territories in Australia. We outline general similarities shared across Australia in this section. In later sections, we detail the specific policies and authorities in Victoria since our project focuses on the state of Victoria.

The use of wastewater is controlled by two sections of federal legislation: the Health Act of 1958 and the Environment Protection Act of 1970, along with their respective regulations, the Health Regulations of 1985 and the Environment Protection Regulations of 1984 (Eden, 1995). In order to keep laws relevant and in accord with changes in time and technology, all regulations have a maximum life of 10 years before they are automatically put to rest or "sunset." Government departments cannot revalidate regulations without justifying to Parliament and the general public that the proposed regulation is still valid and necessary. Regulatory Impact Statements are used to outline and justify the objectives and impacts of proposed regulations. The current Environment Protection (Scheduled Premises and Exemptions) Regulations "sunset" at the end of 2004, and the Health Regulations (Use of Wastewater) "sunset" in the middle of 2005.

2.9.2. Proposed laws and regulations

Australia realises the advantages of having national guidelines established covering the treatment, storage, distribution, and application of reclaimed water, including guidelines for system management and monitoring. National guideline documents have been proposed for development in the following classes of recycled water:

1) municipal wastewater
2) domestic wastewater (on-site and local systems)
3) domestic grey water
4) roofwater
5) stormwater runoff
6) industrial wastewater and
7) agricultural wastewater.

The *Australian and New Zealand Environment and Conservation Council* (ANZECC) has drawn up national guidelines for environmental water quality. The guidelines allow for some community discretion in setting the environmental water quality that will apply to certain water bodies (Anderson, 1996).

The Australian States and Territories have constitutional responsibilities for managing water. Therefore each has an institutional framework to direct the water utilities, environmental managers, and farmers. The Federal government is involved primarily through funding only. The National Agenda for Water Reform (called the Agenda) was established in 1994 to research and recommend organisational reform. The results of the Agenda were reported in the Neil Report. The Agenda basically encompasses competition policies and ecologically sustainable development principles. Completion of stages of the Neil Report recommendations by individual states is rewarded by payments from the Federal government under the National Competition Policy. These payments compensate the states for losses incurred as a result of implementing competition reforms and they can be used for any purpose the state would like. Some of the key recommendations of the Agenda include: basing the water industries on commercial principles, creating wholesale bulk water supply organisations separate from retailers, setting prices based only on consumption that cover all supply costs, defining water rights separate from property rights, allocating water for the environment, and involving the public in the decision making process. These recommendations have had significant changes on the water industry since the release of the Neil report (AATSE, 1999).

2.10. SUMMARY

This Literature Review covered the background of water recycling in general and in Australia specifically that was necessary to conduct this Interactive Qualifying Project. It introduced Arup, defined wastewater, detailed the motivations to recycle and presented barriers that stand in the way of implementation of water recycling systems. In addition, this chapter discussed potential uses of recycled water, the differences between urban and rural recycling schemes and the chemical processes to recycle water. This review also explained the regulations and guidelines that govern water treatment and reuse in Australia. In conducting this review, we discovered that several areas were not covered adequately in current literature. How we obtained this information is the focus of the Methodology section.

3. METHODOLOGY

The goal of this Interactive Qualifying Project was to assemble information about wastewater recycling into an organised and logical model for decision making. Arup will use this compilation to advise clients about the potential for water recycling for their particular situation. The Literature Review (Chapter 2) explained why water recycling is a vital step toward sustainable development for Australia, outlined several barriers that prevent water reuse, presented potential uses for recycled water, and detailed the chemical processes to treat wastewater. We also explored urban versus rural settings and stated pertinent regulations and laws in Australia. During our literature search, we discovered that several topic areas had not been covered adequately to complete this IQP. Researching these topics formed the basis of the Methodology section and dictated our tasks in Australia.

During the primary stages of our methodology design, we considered and rejected questionnaires as a method. These methods were questionnaires and surveys. Initially we planned on sending questionnaires to water recycling project managers in order to obtain standardised data that would be compared across all projects. When we arrived in Australia, we discovered that each project is unique in many ways, and that the amount of standard data was minimal. Eventually, we ruled out questionnaires because we concluded that more information could be gathered through face-to-face interviews, and the small amount of standardised data could be obtained through a few short questions at the beginning of an interview. Studying the perceptions of the general public about water recycling was one of our original research ideas; however, the focus of the project had shifted away from the perceptions of the public. When we adjusted the project to focus on the water industry, the number of people we wished to gather information from was reduced significantly. Since questionnaires are only useful when gathering information from a large number of people, we decided that interviews would be the most useful method for our purposes.

The Methodology Chapter outlines our research objectives, details the methods we used to meet these objectives, and explains how we compiled our findings into an organised decision making model for Arup.

3.1. RESEARCH OBJECTIVES

The objectives for this project consisted of:

1. Collect Victoria-specific information ranging from the history of water supply to current regulations governing water use.
2. Interview local and national experts in the fields of water engineering and water regulations.
3. Research current water recycling projects.
4. Develop and pretest a water recycling decision model for Arup's use in consulting.

The information gathered from researching these objectives supplemented the information in our literature review. This data also provided us with the means to construct the final product for Arup – a decision making model for evaluating the implementation and use of water recycling systems in different situations in Victoria.

3.2. METHODS TO MEET OUR RESEARCH OBJECTIVES

Arup seeks a model outlining the issues and regulations related to implementing water recycling systems for clients, such as companies or building complexes. We conducted extensive research into water recycling methods currently used and regulations governing such recycling systems and compiled this information into a clear, logical model. We gathered information to answer our research questions using several well-established research techniques. Primarily, we employed archival searches and interviews to gather the necessary information. This section explains how we made use of these techniques to answer our questions.

3.2.1. Archival searches

Conducting a thorough investigation of the background information related to our project topic was important so we could represent the different issues related to water recycling in Australia. While in Australia, we had access to different resources than those at WPI. Although we still had the Internet as a resource, we were able to use local resources within Arup and in the Melbourne area. Archival searches were an important resource for our project because we needed to supplement the information we gathered while at WPI with local information specific to Victoria and Australia. However, archival searches were not a comprehensive method for gathering all the information necessary. Therefore, we utilised interviews as well.

3.2.2. Interviews

Interviews are a conversational method for gathering qualitative information. Three major interview structures exist, each with specific advantages. The three types are standardised, unstandardised, and semistandardised interviews (Berg, 1989). We selected our interview structure on the basis of the type of information needed, how much information on the topic we already had, and the person being interviewed.

We chose the semistandardised interview format because it is a combination of the standardised and unstandardised interviews. The interviewer begins with a set of predetermined, standardised questions. At any time during the interview, the interviewer has the freedom to investigate certain questions in more depth by asking probing questions. We primarily employed the method of semistandardised interviews because this format provided the structure we needed in order to have comparable data, and at the same time the flexibility to investigate deeper into subjects as we saw fit. We utilised the semistandardised interview format and its advantages to develop several surveys as well. These surveys were constructed to gather standardised data, such as ratings for the model survey, and also allowed for open comments and suggestions.

We considered several factors while planning interviews. We carefully selected interviewees to reflect the sector of the population that actually has the expertise and information we needed. We also specifically designed the interviews to collect the data necessary to meet our research objectives. Since question design is vital, we pretested the interview scripts with a professional in the field.

3.3. VICTORIA SPECIFIC INFORMATION

Victoria specific information regarding water use was vital to our project. We needed to understand a number of different aspects of the Victorian water industry in order to make confident recommendations about how water recycling is conducted and regulated here. These aspects included: the history of the water supply, the history of sewerage, how water is currently supplied, opportunities effluent reuse, the authorities involved, and the support available for water recycling projects.

We located this information through archival research conducted at a number of different sources. We researched in the Arup office library, the Victoria State Library, at the Environment Protection Authority (EPA), and over the Internet. All of these sources were very helpful. The Arup library contained recent journals and pertinent case studies; the Victoria State Library and the EPA both provided much of the governmental and legislative information we were searching for, and the Internet supplied most of our historical information. The Internet also allowed us to collect specific information about the water authorities in Victoria, since each authority has a website. We used this specific information to tailor our model specifically to the state of Victoria.

The approval of the local main water supplier and the local Environment Protection Authority is required before a proposed project can commence. We planned interviews of each of the main water suppliers and EPA branches in Victoria to get their opinion on water recycling projects. We created an interview script and pretested it with our contacts at Arup. The script was short, with eight questions, and covered general topics such as the approval process, grey water recycling, and purchasing treated effluent. The interview script can be seen as APPENDIX J. The most feasible method of conducting these interviews was via telephone because we could conduct many interviews over a short period of time.

3.4. INTERVIEWING EXPERTS

In order to verify the information we retrieved during our archival researches, we interviewed experts in the water industry. We located these experts through Arup Stokes in Adelaide, SA. We interviewed Dr. David Cunliffe, Dr. Peter Dillon, and Borvin Kracman. They represent a variety of fields related to water, and therefore a variety of opinions and perspectives.

Dr. Dillon is a research scientist from CSIRO with expertise in water systems and water quality. Dr. Cunliffe is employed by the Department of Health Services where he is involved in the approval process for water recycling projects. Borvin Kracman is a principal and the office manager at Arup Stokes and has been in the water industry for over 20 years.

We developed our interview scripts based on our plans for the model. By analysing the topics we wanted to include in our model, we wrote an interview script to verify the most important topics and to fill any holes or answer any questions we had. After writing the interview script, we went through several rounds of editing. The group critiqued it several times. We also met with Helen Weston, an environmental planner at Arup with significant experience in interviews and community consultation. She analysed our script and offered feedback. She reminded us to be specific whenever possible, for instance by offering examples so interviewees would know what we want. We made the changes that Ms. Weston suggested, and also consulted with our liaison, Mr. Barry Steinmeyer. He approved our script and suggested that we expand the introduction. After adding to the introduction, we sent our interview scripts (see APPENDIX B) ahead to all of our interviewees via email. This gave them a better understanding of what we wished to gain from the interview and allowed for much more productive interviews.

3.5. WATER RECYCLING PROJECTS

To better understand how water recycling projects are implemented and maintained, we researched current water recycling projects in Australia. Information about the project location, how these projects were established, and site specific details were particularly useful. While archival searches about local water recycling projects provided some information, on-site visits and interviews were our primary method of collecting this information.

We located these local water recycling projects through our sponsors at Arup in Melbourne and through references from our interviewees. We identified current projects that characterise a variety of different circumstances in order to gather information about specific situations and to distinguish broad themes among water recycling projects. Some of these circumstances include rural and urban locations, different scale of building size, infrastructure considerations, and a variety of uses for the recycled water.

We interviewed Dennis Mitchell of the Southern Australian Housing Trust and Sue McCormack of Land Management Corporation. Mr. Mitchell was extensively involved in the design and construction of New Haven Village, a community of 65 houses that recycles its wastewater for landscape irrigation and toilet flushing. Sue McCormack is involved in a similar project, The Mawson Lakes Development.

Mawson Lakes is still in the construction phase; however, a key objective is establishing a recycled water supply capable of providing at least 50% of household water and all open space irrigation water needs.

We conducted semistandardised interviews with these project managers. The interview scripts were developed in a similar manner to the academic interviews (see section 3.4). We based our questions on the development process of a water recycling project. For example, the first questions ask about motivations for the project and funding and later questions ask about water quality monitoring and annual reporting. We sent our interview scripts to the project managers ahead of time via email (see APPENDIX C). By sending these scripts ahead we gave the interviewees proper time to collect documentation on their respective projects. The documentation they provided formed the basis of our case studies. This form of interview allowed us to gather some standard information about each project, but also provided us with the freedom to ask further questions about the unique aspects of certain water recycling projects.

3.6. COMPILATION OF INFORMATION INTO A MODEL

After we collected the pertinent information related to our research objectives, we assembled and organised our information into a single model for Arup to use when consulting on water recycling projects. We constructed this model specifically for Victoria, Australia. The most vital topics were: reuse options, responsibilities, waste water quality, treatment system, system controls, monitoring, and reporting (EPA, 1996). The model is hypertext based, allowing for easy navigation through different levels and options. The model presents definitions of terms, options, and case studies to explain to Arup's clients the different considerations of water recycling in Victoria.

3.6.1. Development of the Decision Model

The main audience of the model is the clientele of Arup. The concepts and recycling systems that we present must be tailored to fit this audience. Since we can assume no common level of engineering or water system expertise, the model must be clear and easy to follow. We must define any terms that we use, and support our content with pictures, tables, graphs, and examples wherever possible. For this reason, we have included case studies of water recycling projects. Not only do these case studies show current examples of different water recycling systems, but they act as examples of the content of our model.

There are many possibilities for the actual format of the model. We considered a basic flowchart presented either on paper or in a single computer document. However, we had collected so much information and had such a complex organisational tree that we decided a flowchart would be too simple and therefore unsuitable. We then decided that Hypertext is an ideal method to represent the information that we had organised. Hypertext allows us to use an intuitive organisational system of branches and links. Another advantage is that users, both engineers and clients, would already be familiar with Hypertext from using the Internet. Employing branches and links is an effective format for our decision model because it allows the user to trace a path of particular interest without spending time on extraneous information. For example, a client who is considering recycling grey water for toilet flushing can omit the material on large-scale irrigation schemes. The system of links allows engineers and consultants to move forward and backwards through the model as needed and to visit several topics of interest in the same presentation. By using Hypertext for the model, we could make certain that users see information pertinent to all water recycling projects, such as responsibilities, by organising the structure to lead to those topics. Another advantage to using HTML is the fact that it has multi-platform potential. Any web browser and many other programs are capable of reading and displaying our model, making it very versatile and portable.

The next decision we made in regard to the model was which computer program to use for displaying the model. We wanted to use a program that people would be familiar with and would be installed on most computers. We considered *Microsoft PowerPoint, Microsoft Word,* and a web browser such as *Microsoft Internet Explorer*. All of these programs have Hypertext capabilities and are common programs to which many people have been exposed. The three program options had different advantages and disadvantages. Word would be beneficial because we could work easily from our IQP report, transferring text, pictures, or graphs as needed. However, having the final model in Word would not be the most ideal mode of presentation because the toolbars and visual format do not look professional. PowerPoint would yield excellent presentations because that is its main purpose. However, working in PowerPoint can be difficult because a text box or object box is required before anything can be entered on the slide. In addition, for the amount of information we needed to present, the landscape format of the slides was less preferable than the traditional portrait format. Also, large amounts of text cannot fit onto slides. The linear format of PowerPoint presentations would hinder the intuitive flow of designing the model as well. The final option, a web browser, counteracted the disadvantages of Word and PowerPoint. A program such a Internet Explorer would be sufficiently professional for the formal presentations of the model, and can also accommodate as much text and as many diagrams and pictures as we wanted to include. We decided to use a web browser to display the final model because it balanced the advantages and disadvantages of all our options.

Actual development of the model could be conducted using several programs, such as *Microsoft Word, Microsoft FrontPage Express*, or any HTML development tool. Although we are quite familiar and comfortable with Word, constructing hypertext documents can be problematic because the formatting in Word is often changed or altered when the program switches between Word documents and HTML documents. We eliminated Word as an option to prevent the added hassle of having to adjust the final HTML documents multiple times to achieve appropriate formatting. Although HTML is a simple straightforward programming language, we do not have sufficient experience to work exclusively in this format. We selected FrontPage Express for the model development because it is a Word-based program that includes many of Word's shortcuts and toolbars. In addition, it is a webpage preparation program, so the appearance of the document in FrontPage Express is exactly what it will look like in any web browser, eliminating the formatting problems of building HTML documents in Word.

Since Arup will be using the decision model as a marketing model for water recycling systems, we designed the model to start with a presentation of the motivations and reasons to recycle. Water recycling is an important environmental action, and coupling that concept with the idea of economic benefits further strengthens our argument to the audience that wastewater can and should be reused.

The rest of the model outline was based upon a framework adapted from the Environment Protection Authority *Guidelines for Wastewater Reuse* (1996). The EPA suggests a logical flow of topics that should be considered when contemplating or implementing a water recycling system. The seven elements of their model are: potential reuse options, roles and responsibilities, wastewater quality, wastewater treatment, site and system control, performance monitoring, and reporting and notification. This organisation was a good example for us because it is thorough and EPA-approved.

Next, we modified the organisation of the EPA model to better suit our needs. We combined the roles and responsibilities section with the performance monitoring and reporting sections because they fit together and should be discussed concurrently. We moved the new responsibilities section to the end of our model because these details are not necessary for the earlier informative stages of the model. We basically adopted the organisation of the EPA model, with the mentioned changes; however, the specific information we included is different from what the EPA presented. We have a different audience with a different base level of understanding. We explored in greater depth the reuse options because these are the main interest for Arup's clients. Our model also added in the concept of purchasing recycled effluent from a supplier, such as a water treatment plant. We felt that this was a significant option for any large-scale water user, and accordingly, we represented this opportunity in our model.

The next step in the development of our decision model was making a complete flowchart detailing the organisation and layout we would use. We constructed this flowchart on paper, listing each page that would be in the model, its main topics and what information would be included. We also used arrows to illustrate the logic flow of the whole document. For example, the page that covers information about buying recycled water from a supplier is linked off the agriculture and commercial categories of water reuse because only these two categories of water reuse would qualify to buy recycled water. The buy water page is then linked back into the wastewater section, where users who did not follow the purchase option were directed. This diagram allowed us to organise our thoughts and the information we had collected prior to any computer work. This level of organisation helped us to work more efficiently on further development of the model because it was easy to divide up sections and assign them to an individual to complete. There was no confusion among the group about what information belonged in which section or how the pages all fit together.

3.6.2. Pretest of model

To pretest our decision model, we created a survey. The survey combines a series of standardised questions and several opportunities for open comments. We designed the survey this way because we could compare responses from the variety of people that pretested the model, and we could get open feedback and suggestions about the model. The questions cover four basic categories: content, organisation, presentation, and aesthetics. The content category is divided into two sections: overall content and sections content. This division is significant because it allows us to evaluate the response to each particular section and obtain feedback about general content themes, such as definitions and clarity. Each standardised question presents an aspect of the model, such as Colour Scheme or Links, and then asks the survey taker to circle a 1, 2, 3, or 4; representing poor, adequate, good, and excellent respectively. Each section concludes with a space for comments, and the end of the survey asks for overall comments as well. The survey is attached as APPENDIX K.

We selectively chose the people to test the model with the feedback survey so we could get a wide range of perspectives. We surveyed engineers from Arup. We also interviewed university students who are studying in a variety of different fields, and a computer science professor. Although some of the subjects are not professionals in the field of water, it was still appropriate to use their input to aid us in creating an easy-to-use model. We feel that the range of testers we established would assist the development and refinement of the model. The engineers, who would be using the model as consultants and also have technical and professional experience, could provide a point of view suitable for evaluating the content of the model, its professionalism, and its suitability as a consulting tool. The university students could supply valuable feedback on the general organisation, clarity, format, and logic of the model. Since the students represented a range of areas of studies, including computer science, technical communications, and civil engineering, they also supplied some unique and very helpful opinions and suggestions.

3.6.3. Final model

To revise earlier drafts of the decision model for water recycling, we used the results of the feedback survey. The quantitative data obtained in the form of ratings of the items in the survey is summarised in APPENDIX L. These ratings were helpful because we could compare responses between surveys. We received the most help from the written comments. We analysed the surveys and identified general themes in the written comments. These themes were taken as recommended changes, and we accordingly made the revisions and improvements. The surveys also assisted in locating editorial errors in the model.

4. RESULTS

The results of our data collection and the compilation of information into a comprehensive model for water recycling are detailed in this chapter. This chapter is organised by the research objectives stated earlier in the Methodology section. The Victoria specific information is presented first; the results of the expert interviews are next, followed by the case studies of current water recycling projects. The last section contains the development of the model, the results of the pretest, and a discussion of the final form of the decision model.

4.1. VICTORIA SPECIFIC INFORMATION

To tailor our water recycling model to fit Victoria, we needed to collect Victoria specific information in several topic areas. We researched the history of water supply and sewage in Victoria and investigated the current status of the water supply system. We collected information about the local authorities and their roles in water recycling projects. We covered the topics of effluent reuse and also subsidies and funding opportunities.

4.1.1. History of Victoria's water supply

The first settlement in the Port Philip area was a camp on Sullivan's Bay near Sorrento established by Colonel David Collins in 1803. Water supply was a primary concern from the beginning. The only source of water was several wooden barrels dug into the ground to tap into groundwater supplies. The city of Melbourne was not founded until 1835. By 1840, the five-year old city was home to over 7,000 inhabitants. At this time, barrels of water were sold door-to-door by local traders. This water was pumped from the northern bank of the Yarra River. The surrounding rural areas and farms utilised local creeks and springs, and also tapped into the abundant groundwater supplies. The demand for a dependable water supply system led to the founding of The Board of Commissionaires of Sewer and Water Supply. Although the Board facilitated and organised the water supply, it did not provide any sewage services. In 1857, the Yan Yean Reservoir began to supply water to the Melbourne area, whose population had topped 100,000. The rate system charged one shilling per pound property value (5 cents on the dollar) for services and a fee of four shillings per 100 gallons of water (1 cents per 114 litres.)

The Melbourne Metropolitan Board of Works (MMBW) was founded in 1891. The MMBW was charged with providing water to over 500,000 people in the Melbourne area. To do so, the Watts River near Healesville was utilised. Its waters were sent through the Maroondah aqueduct into the city. In 1910, water quality and lack of water pressure were significant topics of complaints. The concerns of Mornington Peninsula residents about the lack of reliability in the water supply led to the construction of the Bunyip Main Race aqueduct and the Beaconsfield and Frankston Reservoirs by the State Rivers and Water Supply Commission (SR&WSC). These projects were completed by 1930, providing reticulated water supply access to most major towns in the northern area of the Mornington Peninsula. During the construction period, the Silvan Reservoir was also built. It was Melbourne’s first off-stream storage facility, increasing the water storage capacity by 75 percent. By 1943, the southern bayside towns from Dromana to Portsea also had reticulated water supplies.

The water supply experienced significant stress during the very dry summer of 1937-38. As a result, water restrictions and other measures were imposed and the MMBW decided to build the Upper Yarra Reservoir to double Melbourne's water supply. Further dry summers and increasing populations led to the construction of other reservoirs and aqueducts from 1950 up to 1985. These projects include the aqueduct connecting the Tarago and Bunyip Rivers, Devilbend Reservoir, and the Cardinia and Thompson Reservoirs. In 1974, the Victorian Government adopted a fluoridation policy, and began building local fluoridation plants.

Since 1984, there have been many governmental and organisational structural changes. The SR&WSC changed its name to the Rural Water Commission (RWC) in 1984. Two years later, six local sewerage authorities and the Mornington Peninsula water works district of the RWC merged into the Mornington Peninsula and District Water Board (MPDWB). In 1991, Melbourne Water was formed from the MMBW, Dandenong Valley and Western Port Authority, Dandenong-Springvale Water Board, Pakenham Water Board, Lang Lang Water Board and Emerald Water Board. Melbourne Water was divided into three regions: Maribyrnong, Yarra, and the South East Region. Melbourne Water underwent further adaptation in 1994, when the Victorian Government divided it into three retail water companies and a wholesale water company. The companies are Yarra Valley Water, City West Water, and South East Water, while Melbourne Water retained control as the wholesale water supplier.

Several major public awareness campaigns and policy changes were conducted during the 1980s and 1990s. The 1984 "Don't be a Wally with Water" campaign aimed to change public attitude toward wasting water. At that time, dual flush toilets became a requirement for all new installations. In 1992, Melbourne Water initiated a water quality campaign entitled “Naturally Better.” A notable change in the method of water pricing was made in 1998. The Victorian Government modified the water pricing system based on property value into a “user pays” system (Yarra Valley Water website (a)).

4.1.2. History of sewage in Victoria

While Victoria’s water supply was an important issue from the founding of the first settlement and was carefully managed by various government organisations, a regulated sewerage system was postponed and neglected up until 1891. For many years, removing sewage and waste was the responsibility of individual households and businesses in Victoria. In the early days, every sort of household sewage, including kitchen, bathroom and laundry wastes, was disposed in open drains that flowed into channels that ran along the streets. In these channels, household wastes combined with disposals from stables and industries. The wastes flowed along the channels into the nearest streams or rivers. In essence, local waterways became open sewers that emptied into Port Philip Bay. Human wastes were contained in early toilets consisting of a bucket in a wooden structure.

Without any control or regulation of sewerage by the government, the growing city of Melbourne earned the title of “Marvellous Smellbourne.” In 1891, the Melbourne Metropolitan Board of Works (MMBW) was given the responsibility of overseeing the treatment of sewage. Although it was expensive, the only viable option was to pipe sewage away in sewers. Construction of Melbourne’s first sewerage system began in May of 1892. The system consisted of a network of main underground pipes that would carry wastes to a sewerage farm at Werribee. Unlike Sydney, which disposed of untreated sewage directly into the sea, Melbourne's sewerage was treated at Werribee before release into Port Philip Bay.

Up until 1939, the more dispersed outer suburbs of the Melbourne area did not have reticulated sewerage systems. Septic systems were the main mode of waste disposal. Mornington was the first town in the outer regions on the city to build its own reticulated sewerage system. By the late 1960s, Mornington was still the only town south of Mordialloc with such a system. However, groundwater pollution caused by septic wastes soon became a significant problem. As a result, multiple sewerage authorities were formed in the district to install reticulated sewerage systems. The capacity of Werribee to treat the full amount of waste was exceeded, and the MMBW constructed the Eastern Treatment Plant (ETP) at Carrum in 1975. The ETP now treats approximately 40 percent of Melbourne's sewage, and releases the treated effluent into Bass Strait. The Western Treatment Plant (formerly Werribee) also treats Melbourne's wastewater and then discharges it into Port Philip Bay. The treatment process consists of screening, primary and secondary treatment before discharge into the environment (Yarra Valley Water website (b)).

4.1.3. Victoria's current water supply system

The water supply and sewerage systems in Victoria are currently divided up into three sections: Melbourne, rural, and urban water authorities. These authorities regulate all local water usage, disposal, and treatments. They work closely with the

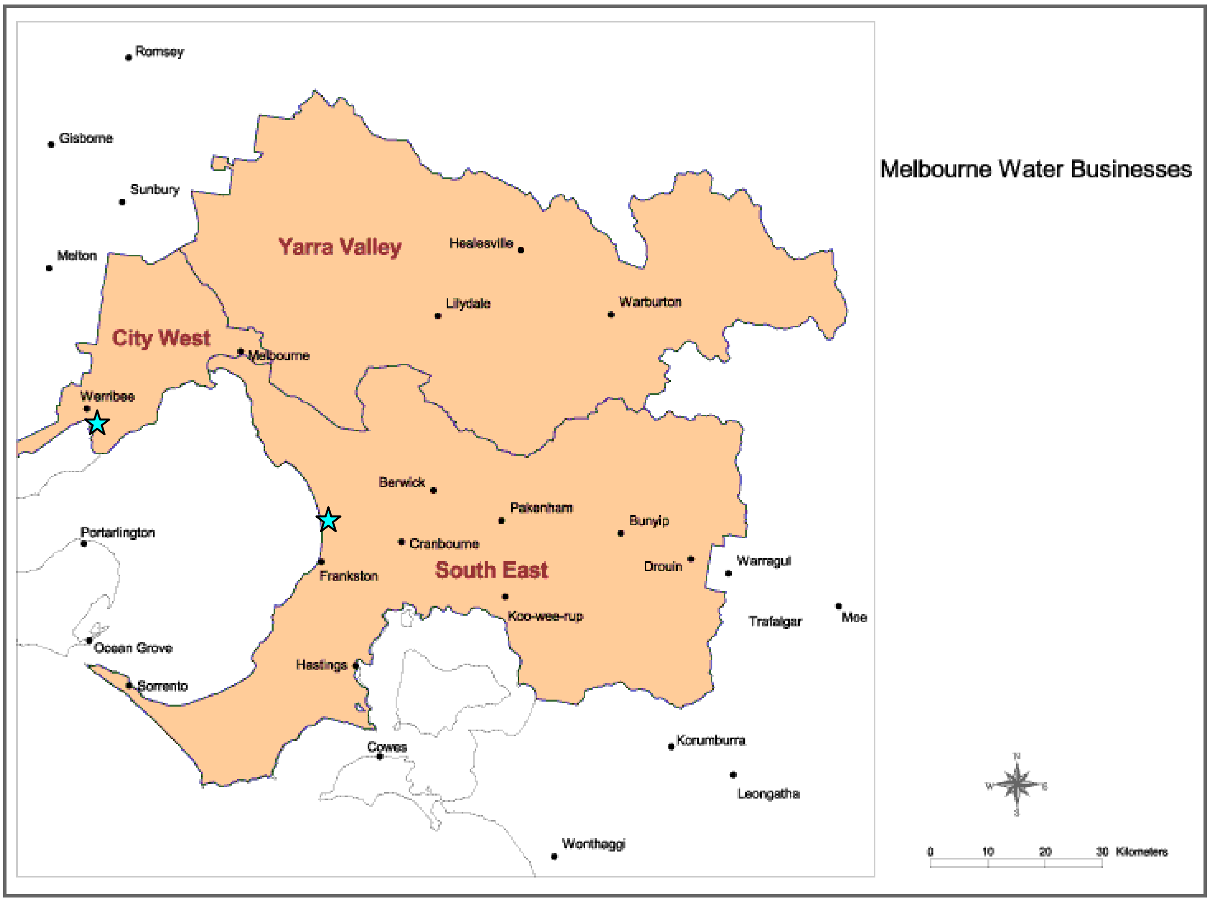
Environment Protection Authority of Victoria (EPAV) to monitor water conditions and to protect consumers, water supplies, and the surrounding environment. Any project that involves water or may affect an aquatic environment must be approved by the local water authority and the EPAV (Victoria Resource Online, 2000).

4.1.3.1. The Melbourne water system

Melbourne's water supply and sewerage system consists of a central water wholesaler, Melbourne Water, and three retail water companies, Yarra Valley, City West, and South East (see Figure 4). Transporting and treating Melbourne's sewage costs about $35 million per year for new or replacement sewerage infrastructure, and another $2.8 million for inspection and cleaning of the system of pipes. Over 380 kilometres of sewers serve the city. Melbourne generates approximately 900 million litres of waste each day, which includes both domestic and commercial wastes.

Two major treatment plants serve the Melbourne area, processing 90 percent of the waste produced. The plants are marked by stars in Figure 4. Local treatment plants run by the retail water companies handle the remaining 10 percent. The larger of the two plants, the Western Treatment Plant (formally known as Werribee Farm), is located on the western side of Port Phillip Bay in Werribee. The plant handles around 470 ML per day of the wastewater from the western and northern areas of Melbourne, containing most of the industrial firms that contribute approximately 17% by volume and 50% load of Biochemical Oxygen Demand (BOD). The plant treats this wastewater through combinations of land filtration, grass filtration, and lagoon systems. By the year 2003, the lagoon system will be used exclusively for all water treatments, with grass and land filtration utilised for specific water quality improvements where necessary. Finally, the treated effluent is discharged into Port Phillip Bay via four outlets (Wilkie, Hatzimihalis, Koutoufides, & Connor: 1996).

Figure 4. *Melbourne Water Businesses*. Victoria Resources Online, 2000.



The second major plant is the Eastern Treatment Plant (formally known as the South-Eastern Purification Plant). The plant is located in the southeast portion of Melbourne at Carrum. The ETP is a conventional activated sludge plant handling around 380 ML of wastewater daily or about 42 percent of Melbourne's waste. This plant services fewer industrial areas and receives approximately 6% of its flow and 20% of its BOD load from industrial firms. The 35 kilometre South Eastern Trunk

Sewer and the 25 kilometre Dandenong Valley Trunk Sewer use gravity to transport sewage to the ETP. The treated effluent is pumped into the 56 kilometre South Eastern Outfall to Boags Rock in Rye, where it is discharged directly into the Bass Strait.

4.1.3.2. The urban and rural water systems

The second of the water authority sectors is the Non-Metropolitan Urban Water Authority (NMUWA). The NMUWA consists of fifteen separate water authorities: Lower Murray, Coliban, Grampians, Central Highlands, Glenelg, Barwon, Portland Coast, South West, Western, Goulburn Valley, Westernport, North East, Central Gippsland, East Gippsland, and South Gippsland (see Figure 5).

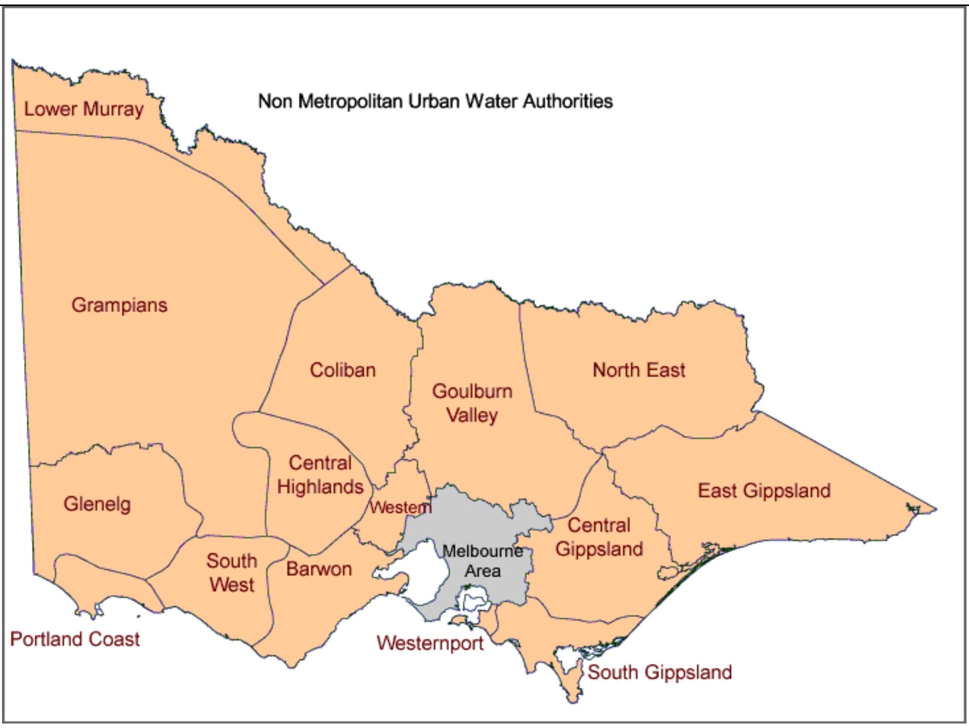


Figure 5. *Non-Metropolitan Urban Water Authorities*. From Victoria Resources Online, 2000.

The third sector of Victoria's water supply system is the rural water system. Four authorities make up the Rural Water Authorities (RWA): Sunraysia, Goulburn-Murray, Wimmera Mallee, and Gippsland & Southern (also called Southern) (see Figure 6).

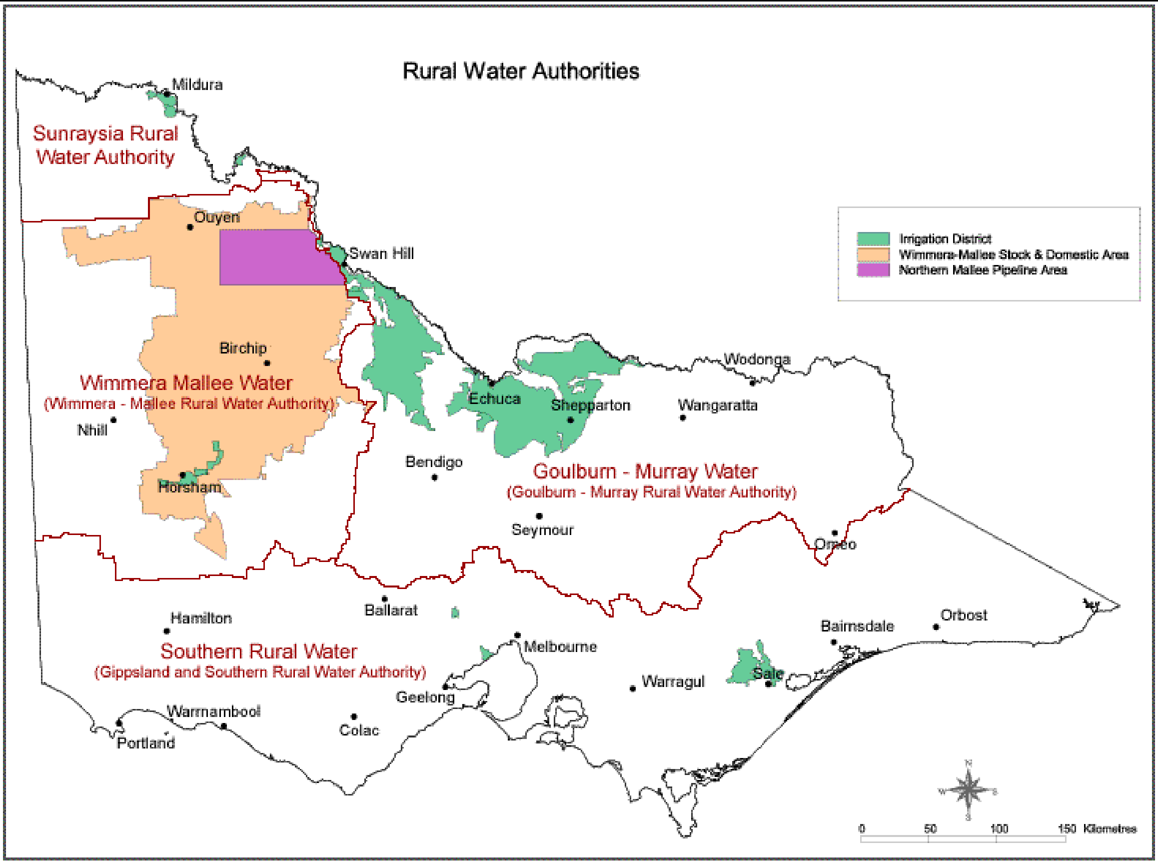


Figure 6. *Rural Water Authorities*. Victoria Resources Online, 2000.

4.1.4. Effluent reuse in Victoria

Melbourne Water also organises programs for reuse of treated effluents. Waste waters are treated to secondary or tertiary levels, depending on intent of use, and dispensed from the major pipelines leading from the treatment plants to customers. In 1996/1997, over 30 customers participated in the effluent reuse program. The Melbourne Water “Managing Our Water Resources: Effluent Reuse” pamphlet offers three practical economic reasons for reusing effluents. Since charges per unit for effluent are less than per unit freshwater, organisations and companies that have high water usage can save significant amounts of money. In Victoria, per unit prices for recycled water are between one half and one-third the per unit cost of potable water. Despite infrastructure additions, water reuse can be cost effective where the location is close to the main pipeline because the cost of connecting to the effluent supply is offset by savings. In addition, effluent used for agriculture provides added nutrients not available in drinking-quality water, therefore helping plants to grow better. Padua College on the Mornington Peninsula uses effluent to water a sports oval. The business manager, Charles Foran, reported cutting the water bill in half, even during a particularly hot summer. The Mornington Vineyards Estate uses effluent for drip irrigation of its vines. With the savings, the vineyard was able to irrigate 30 more hectacres. It also benefited from doubled grape yield (Melbourne Water website, 2000). Effluent sale by water authorities is increasing around Victoria and Australia. The environmental consequences of disposing treated wastewaters into waterways are being recognised, and many authorities have set goals and established plans to reuse as much effluent as possible.

4.1.5. Relevant authorities

Up to 1996, all wastewater reuse proposals in Victoria were overseen by both the Environment Protection Authority (EPA) and Department of Health and Community Services (HCS). However, the inefficiency from overlapping roles was recognised and the regulatory control for wastewater reuse was given exclusively to the EPA (Sherman, 1998). Currently all proposals for wastewater use are handled by the EPA.

The EPA *works approval* process covers all expected discharges to the environment at the planning stages of project development. This process involves informing interested parties and the general public, as well as referring details of the project application to the various official organisations. Approval of a project can take up to six months. EPA application fees for works approval are based on the value of the work to be undertaken, and often incur an annual fee for the license. A typical fee for work costing up to $10,000AU is $480AU (Eden, 1995).

In 1996, the Victorian EPA published *Guidelines for Wastewater Reuse*. These guidelines were significant because the EPA's policy changed to state that if the reuse guidelines are satisfied, they no longer required any formal license or permit (Sherman, 1998). However, the EPA is still responsible for setting appropriate conditions to minimise risks involved with using wastewater produced by treatment plants. Supply of wastewater is prohibited immediately if the quality is found to have fallen below the prescribed standard (Eden, 1995).

4.1.6. Authority survey results

We created a brief survey to administer to all of Victoria's water authorities and Environment Protection Authority branches. We had hoped to collect information such as the authority's stance on water recycling and the status of wastewater purchase in the jurisdiction. However, the contacts at the authorities referred us to the EPA *Guidelines for Wastewater Reuse* and did not give any further information to answer our questions. We decided that although the survey was a good idea, the result were unusable and refining the survey to fit our original intentions was not possible within the time frame of this project.

4.1.7. Subsidies

Subsidies and government funding for water recycling projects are available on a situational basis. There are currently no subsidy programs set up exclusively for water recycling projects; however, there are funding opportunities available through different environmental groups. An application for these grants must be submitted for consideration to the particular environmental groups. The purpose of these grants is to encourage environment protection programs and projects. Therefore, in order to receive funding, project proposals must show the environmental advantages and innovations of the project. These grants are difficult to obtain because there are projects for many other environmental areas in competition for the funds. Occasionally the government will provide assistance in the form of funding; however, this is very unlikely. The few projects that have received government assistance have either significant research value or were in a situation where the project saved the government a considerable amount of money or effort.

4.2. INTERVIEWING EXPERTS

Allowing our interviewees to preview our interview script (APPENDIX B) gave them a better understanding of our research and what we wished to gain from the interview, therefore allowing for more productive interviews. Our interviewees represented a wide range of perspectives and experiences. We interviewed experts in the legislative, community health, water research, and project management areas. The purpose of our interviews was not only collection of information, but also clarification. We had done extensive background and Victoria specific research prior to our interviews. Speaking with these experts helped us to assemble all the information we had and to verify that we understood the status of water recycling in Australia.

We traveled to South Australia (SA) to conduct the majority of our interviews. SA is the driest state in Australia, and is also having trouble with pollution in the Murray River, its main water supply. These two problems are leading to a multitude of innovations in the water industry by engineers, legislators, and water suppliers. These innovations drew us to SA in search of the latest information in water technology. We believed grey water recycling would be a large part of the water conservation effort in SA; however, there are currently fewer than twenty grey water recycling projects approved in all of SA. These projects were all very small scale; in fact, they were all individual homes.

We interviewed a range of experts in the water field. Members of the academic, governmental, and legislative communities were all represented in our group of interviewees. (Interview summaries are attached as APPENDIX D through APPENDIX F.) Each interviewee, regardless of his or her area of expertise, held the opinion that the recycling of grey water exclusively is not an economical or practical method to reuse water, nor is it expected to be in the future. The recycling of total effluent, however, is a more promising endeavor. The fact that each expert shared this same opinion gave us reason to broaden the scope of this project. We expanded the focus of the project from recycling grey water exclusively to include information regarding the recycling of total wastewater and effluent purchase.

4.3. WATER RECYCLING PROJECTS

We identified water recycling projects through Arup, Arup Stokes, and our interviewees. We conducted interviews of the project managers for the New Haven Village and the Mawson Lakes Development. We also received documentation on the Virginia Pipeline Scheme, the Willunga Pipeline, the Olympic Village and Venues, and the Sustainable House. The information we gathered has been summarised and compiled into case studies.

Sending our interview scripts (see APPENDIX C) ahead to our the interviewees via email gave them a better understanding of our research and what we wished to gain from the interview, and therefore enabled more productive interviews. When we sent the interview scripts ahead to project managers, we also requested that they bring to our meeting any documentation that they have regarding their specific project. This documentation and the information gathered in the interviews formed the basis of our case studies. Interview summaries are attached as APPENDIX F through APPENDIX I.

4.3.1. The Sustainable House, in Sydney, NSW

The Sustainable House is an urban single-family house that is almost completely self-sustaining. The house is located in Sydney, New South Wales, and is a paragon of environmental urban engineering. The house was a traditional urban home before it was completely renovated into a self-sufficient home. The house includes many innovations in the use and treatment of wastewater. No waste and barely any water leave the site. Solid and liquid waste is reprocessed to become recycled water. The treated wastewater is used for toilet flushing, garden watering, and as cold water for washing clothes. All hot water for the house comes from the drinking water stored in a rainwater tank. The appliances, from toilets to washing machines, are standard home appliances. The wastewater system was bought "off the shelf" and was installed in the old septic tank to utilise the existing infrastructure. The only modification to the wastewater system was an ultraviolet light added for disinfecting purposes (Mobbs, 1998).

The Sustainable House is a good case study for small-scale urban domestic house projects. Everything that was accomplished in this house can be reproduced, making this a good model to evaluate. The book *Sustainable House: Living for our Future* was published to detail every aspect of the development and construction of this project.

4.3.2. New Haven Village Project, North Haven, SA

New Haven Village is a small-scale urban domestic development located in North Haven, South Australia. This high-density development incorporates 65 houses on only 2 hectares of land. The project was developed to demonstrate and evaluate energy efficient design ideas for housing, and urban and environmental design. One of the project objectives is to reduce potable water usage by more than 25%, and to reduce pollution of waterways by re-using all site wastewater. This reduction is accomplished by recycling all effluent from the village in a single plant located on-site. The plant is capable of treating 90 KL of water at a time and provides storage capacity of treated water in a 50 KL holding tank. Plant maintenance is overseen by council jurisdiction of the village, and all expenses for maintenance and potable water usage is compiled into a single monthly statement for the residents. Treated wastewater is supplied to the houses via dual reticulation pipes and provides water for flushing toilets, irrigating landscapes, and watering gardens. The plant treats village wastewater to class A standards (Mitchell, 2000).

The New Haven Village is a representation of how recycled wastewater can be used for domestic purposes. The village is also an example of how a small-scale, on-site wastewater treatment plant can be successfully operated.

4.3.3. The Olympic Village, Homebush Bay, NSW

The Olympic Co-ordination Authority's (OCA) water reclamation scheme aims to minimise the use of potable water at Homebush Bay and at the same time maximise the recycling of water on the site. Recycled water will be used for irrigation, wash down, ornamental water features, industrial use, and toilet flushing. The treatment of this water will take place at an on-site wastewater treatment plant. The wastewater will come from a number of sources including stormwater, sewage from Sydney water system, and sewage from the site itself. An extensive water conservation effort is also planned. Efficient appliances and fittings, including water-flow reduction valves, roof-fed rainwater tanks, dual flush toilets, efficient shower heads and appliances, and drip irrigation systems, will be used to minimise the use of potable water. Irrigation will take place during nighttime hours to minimise evaporation and will be controlled by a central computer to reduce over-watering, which can occur when employing manual methods. The combined benefit of these innovations is expected to result in a halving of water use across the Homebush Bay site and provide an annual saving of 500 million litres of drinking water.

The Homebush Bay effort is a large scale domestic project with an on-site waste water treatment plant. This site is one of the most recent water recycling projects and uses creative techniques for water reuse and conservation. This case study complements the Mawson Lakes case study as an example of a large scale commercial and domestic water recycling project.

4.3.4. Mawson Lakes, SA

The Mawson Lakes Economic Development Joint Venture is an innovative large-scale urban development located north of Adelaide, South Australia, on 620 hectares of land. The goal of the project is to integrate evolutionary strategies in economics, and social and environmental activity. Funding for the project is through a joint venture between the South Australian Government and Delfin Lend Lease Consortium. The development will house 8,000 to 9,000 residents in 3,200 dwellings and will boast a town centre as well as many commercial properties. One third of the total land in the development will be open space used for parks or public areas. Both stormwater and wastewater will be collected and treated to class A quality via on-site plants. These sources will provide at least 50% of household water and all open space irrigation water needs. The recycled water will be stored and recovered in local aquifers. The agency responsible for the recycled water system has yet to be established. The development is scheduled for completion in 2009 (McCormack, 2000).

We decided to include Mawson Lakes as a case study for two reasons. It is an example of a large-scale water recycling project in an urban setting incorporating domestic and commercial uses for the recycled water. Also, The Mawson Lakes Development will house an on-site wastewater treatment plant.

4.3.5. Anglesea Golf Club, Anglesea, VIC

Barwon Water and the Anglesea Golf Club have reached an agreement on the use of reclaimed water from the Anglesea sewage treatment plant. Under the partnership, treated and disinfected water will be piped from the plant to a storage facility on the golf course. The club proposes taking 50 million litres of reclaimed water - or a quarter of the plant's annual production - each year to irrigate fairways and greens. The 20-year agreement includes an environmental management plan to ensure the project meets Environment Protection Authority guidelines. Barwon Water Acting Chief Executive, Grant Green, hails the project as another step forward in the management and protection of the environment. "The authority is leading the way in encouraging the commercial use of a valuable but under-utilised resource, as well as ensuring the highest environmental standards in land use and water/wastewater management", he said. Mr. Green commended the club for its vision and initiative and acknowledged the contribution of Barwon Water officers in assisting the club in securing the Government grant. The Anglesea sewage treatment plant has had a $4.2 million upgrade. Incorporating world-class technology, it uses a chemical-free process with ultra-violet disinfection (UV) to produce high quality reclaimed water suitable for re-use. The authority already has a number of significant re-use projects and is investigating other re-use opportunities. Other notable features of the project include: - a 100mm PVC pipeline and use of "Class B" effluent (Howie, 2000).

The Anglesea Golf Club is a valuable case study for inclusion in the model because it represents turf and landscape irrigation and effluent purchase. Turf and landscape irrigation is the most common application of recycled water.

4.3.6. Willunga Pipeline, McLaren Vale, SA

One of the most widely varied and highly developed wine-growing areas in Australia is the Willunga Basin in South Australia. With the increase in demand for wine, the availability of water is a pressing issue for growers and winemakers in the area.

The members of the Willunga Basin Water Users Group formed the Willunga Basin Water Company. This company's goal was to gain access to some of the 10 billion litres of treated wastewater discharged into the sea every year from the Christies Beach wastewater treatment plant. Once the company reached a 35-year agreement with SA Water the construction of the Willunga Basin Pipeline Scheme was under way. The scheme was funded entirely by 40 local grape-growers for a cost of approximately $7.2 million. The company built, and now operates, a pipeline and management system to deliver water to the growers.

The scheme delivers water from a dam at the Christies wastewater treatment plant to a 12-megalitre dam. A pump maintains a constant-pressure delivery through a 24 km network of pipes, which range from 150 mm to 500 mm, thereby providing water for irrigation to the region's grape-growers. This pipeline is capable of delivering 1 million litres an hour (Keys, 2000).

The Willunga pipeline scheme is a valuable case study to our project because it is a large-scale irrigation project that was completely funded by the users. The fact that the growers created their own company to fund this project is also an interesting aspect of this project.

4.3.7. Virginia Pipeline Scheme, Virginia, SA

The Virginia Pipeline Scheme (VPS) supplies high quality, Class A reclaimed water for unrestricted crop irrigation in the Virginia region of South Australia. Virginia is the hub of a major vegetable growing industry that relies heavily on a high quality irrigation water supply. The industry depended on groundwater resources so exclusively that this resource was being used far beyond its sustainable limits. Despite some 12,000 hectares of good quality soil being available, the annual area of irrigated cultivation is limited by water to only 3,500 hectares. The Bolivar Wastewater Treatment Plant is located adjacent to this farmable area. Before the VPS was in place, the Bolivar plant discharged all of its secondary wastewater into the sea. This damaged the nearby seagrass meadows, which are crucial to the local fishing industry, and promoted the growth of harmful sea weeds. The VPS further treats and re-uses the water from the Bolivar plant by pumping the effluent north through the pipeline for irrigation use. The goals of this scheme are as follows:

- To underpin and expand the existing horticultural industry on the northern Adelaide Plains.
- To reduce the heavy withdrawals of groundwater from the underlying aquifer.
- To reduce the discharge of nutrients to the marine environment.
- To optimise the use of the total water resources of the northern Adelaide Plains.

We are using the VPS as a case study due to the fact that irrigation is a significant opportunity for wastewater recycling. The VPS is Australia's largest water recycling project, and quite possibly its most successful. The scheme is used to irrigate a wide array of crops ranging from fodder crops to crops meant for human consumption. The diversity of the uses of the treated wastewater makes the VPS an important reference for our project. VPS is also an example of wastewater purchased from a supplier. This option is often the most economic one for large scale water users.

4.4. COMPILATION OF INFORMATION INTO A MODEL

The background research we have completed and the information gathered by meeting our other research objectives gave us the means to build our decision model for Arup. This section presents the mid-development forms of our model and the further revisions. Our reasoning for choosing certain formats or organisations and for making certain changes is discussed.

4.4.1. Development of Decision Model

The first iteration of the decision model for wastewater recycling was in the form of an organisational tree drawn out on paper. We constructed this tree as an overview of the entire model and to keep us organised while working on the development. We detailed the different pages, what the main topic was, and outlined the information that needed to be included on each page. The model starts with a title page that identifies the members of the project group, WPI, and Arup. This page leads into an introduction of the model, how it works, and what users can expect. The next page explains reasons to recycle water. It details the environmental and economic reasons to recycle water, and included Australia and Victoria-specific motivations.

The first major section introduces the potential reuse options for wastewater. We have broken down the reuse options into three categories: residential, agricultural, and commercial. At this point, the model branches to follow each of those three choices. The residential section covers toilet flushing and lawn/garden irrigation. The agricultural section explains wastewater use for irrigating crops for human consumption and crops not meant for human consumption. The commercial section details turf and landscape irrigation and wastewater use for other purposes such as agroforestry, aquaculture, and horticulture. Each of these three sections presents definitions and explanations of the particular reuse option. In addition, it covers precautions, restrictions, requirements, and any special considerations.

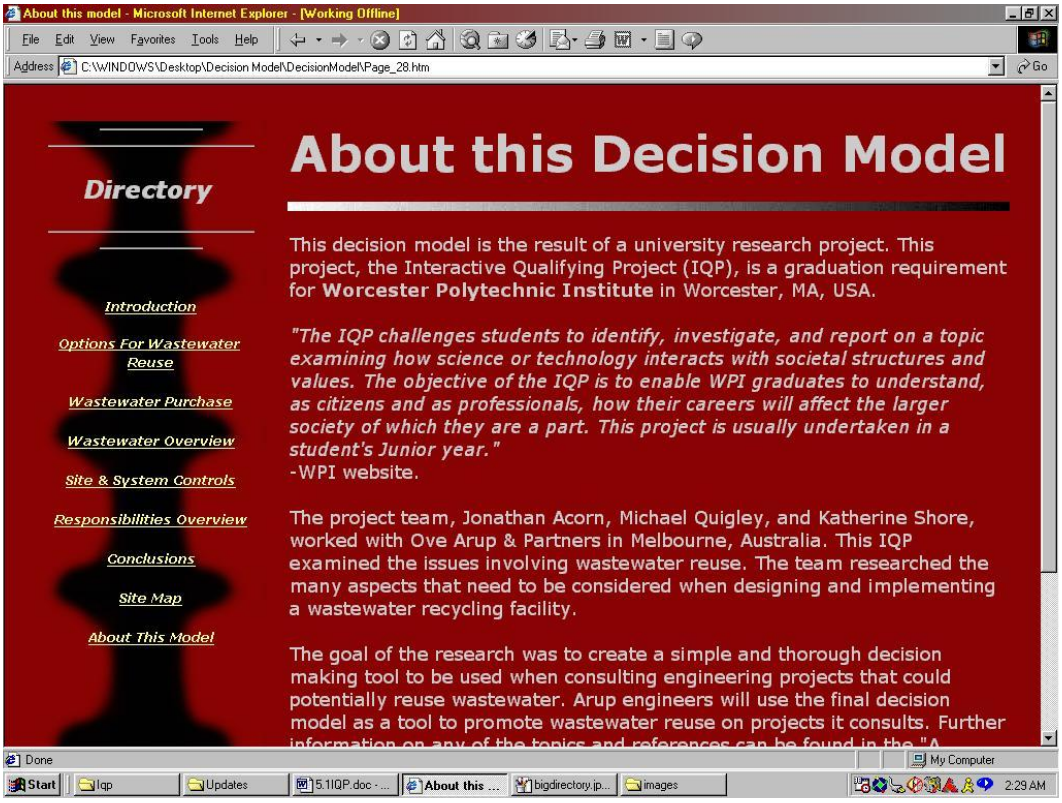
At this point, the agriculture and commercial sections have the option to explore buying wastewater from a supplier. This side branch informs the user of the opportunities available in this area, what the benefits can be, and what it involved. The users who choose not to explore buying water continue with all the other branches into the wastewater section. EPA objectives for wastewater quality and treatment are presented here. In addition, we define black and grey water and explain the constituents of each waste stream. Grey water is further broken down into its components, whose characteristics are also discussed. The EPA required classes of treatment are presented and the uses for each class are detailed.

The next section is wastewater treatment. We overview the general water treatment process and show how the different classes of water quality can be achieved. At this point, there are multiple water treatment systems presented as examples to users. For instance, those interested in recycling water for toilet flushing can view the system used by the Sustainable House in Sydney, NSW. The next section details requirements for site and system controls, which can be broken down into two main categories: irrigation and domestic controls. The following section covers roles and responsibilities and includes quality monitoring and performance monitoring. The EPA requirements and guidelines in these areas are presented and discussed. The next major section is the conclusion and recommendations, where we summarise the model and detail what we hope the user got out of using it to explore water recycling opportunities in Victoria. Several small sections follow to represent our references and acknowledgements.

The next major step in the model development was filling in the content material. We used the information gathered through our research to fill in all of the sections of the model. The resources we had gathered also supplied pictures and diagrams to add to the model. We also provide definitions for any technical terms we used and kept the language simple and straightforward.

When we added content, we had to expand several pages to fit all of the information we had. For instance the Responsibilities section was originally one page that displayed three topics: Roles & Responsibilities, Quality Monitoring, and Reporting. When we entered the material, we made an additional separate page for each of those items. A lengthy checklist and an important chart for those topics merited adding two more pages. Having a section overview at the beginning of this section was useful because these page additions were clearly delineated and did not create any confusion. We also added a section entitled "About this Model" so we could include some details about the history and development of the model (see Figure 7).

Figure 7. "About This Model" Page

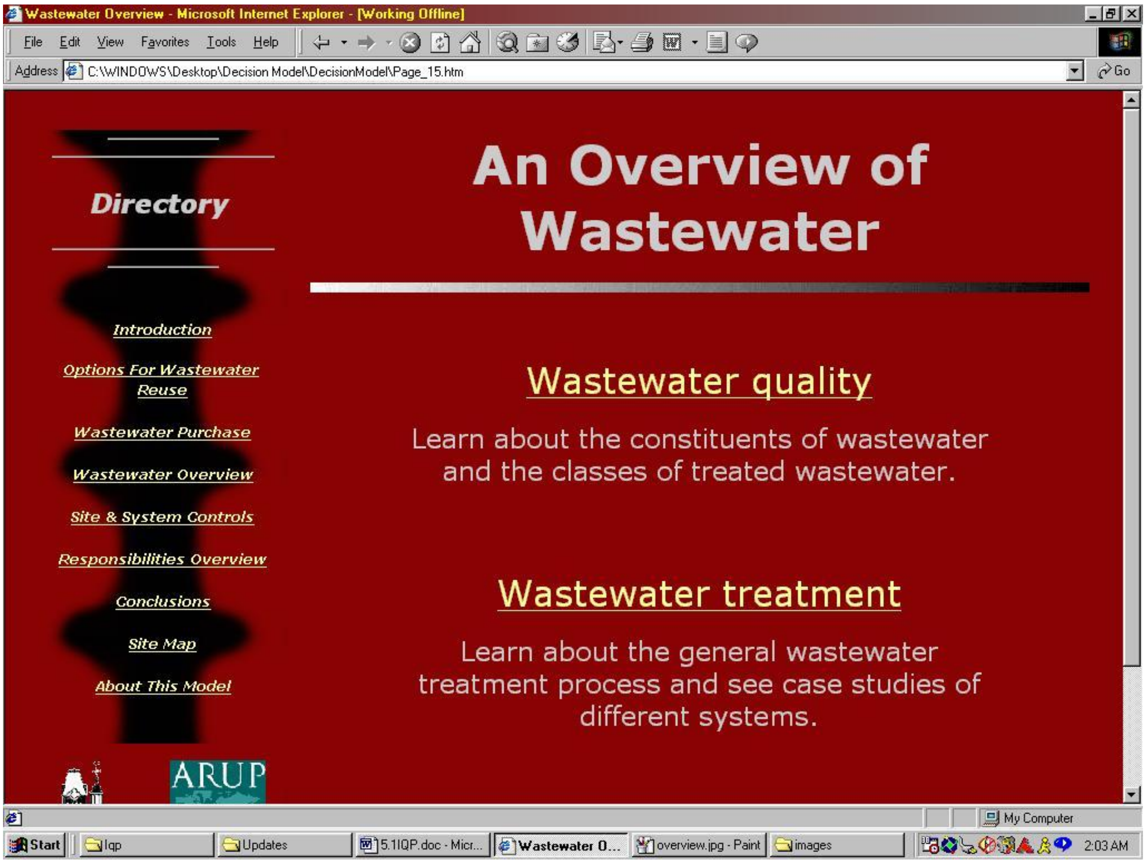


Ease of use was a main concern when constructing the model. To allow for easier navigation throughout the model we created a site directory, which is located on the left side of every page. It provides links to each major page of the model. The directory allows complete freedom for the user because the sections can be accessed in any order (see Figure 8).

Figure 8. Closeup of Model Directory.

This directory feature can be advantageous to users with an existing background in the material. For instance, a golf course owner who is interested in buying wastewater, but already has the irrigation infrastructure set up, can jump to the purchasing wastewater section and skip the wastewater treatment material. “Back buttons” were also placed at the bottom of every page. These give the user the opportunity to go back to the previous page or the beginning of the section. In addition, we provided introductions to each new topic section and clear transitions into new sections so the users would understand the progression of ideas and know where they were in the model. As further enhancement of this concept, we structured the major content sections to include an overview page at the beginning so users would understand what section they were entering and the organisation of the upcoming sections (see Figure 9).

Figure 9. Example of Overview Page: "Wastewater Overview"



4.4.2. The pretest and revision of the decision model

The first group that tested the decision model and filled out the feedback survey was a group of university students. These students are all engineering or science majors, and have completed three years of university work. Their feedback and comments were very helpful. They acted as general editors, pointing out grammatical errors and inconsistencies. In addition, they voiced reminders to keep the decision model and its content at a level appropriate for audience without civil or water engineering expertise. We did take that into account during earlier stages of model development, and having the students point out specific instances where further clarity was needed served to reinforce our concentration on making the model open to all audiences.

Specifically, the feedback from the survey indicated support for the directory consistently placed on the left side of each page. Students noted that it helped navigation and showed a general outline of the whole model. One student who studies computer science had particularly helpful comments. He specified that the directory should contain every single page of the model in an indented format to show the organisation. He also stressed consistency in the bottom bar that contains links to the previous and upcoming sections. Many of the students also expressed navigation concerns, stating that they had "gotten lost" in the system of links. A site map was recommended to provide a clear picture of how the pages are linked together.

Analysing the feedback from the students and translating their suggestions into changes in the model introduced several difficulties. Personal preferences were expressed in the survey. For instance, some students favoured using bold and italic formats for certain words for emphasis, while others found it distracting. We took the comments into consideration, but we also recognised that we would be unable to please all parties. Balancing our response to the feedback was also important in another sense. Some people noted items or formats as issues or problems. However, we had made these choices for particular reasons and they are actually necessities. One example is font size. Although several comments were made about the font size being too small in some places, we had to use that particular size to fit all the information onto the page or into the section. Another situation where this conflict arose was feedback from the computer science student. He strongly recommended a standard link bar on the bottom of every page that included only "back" and "forward" links. We are unable to set up the link bar in this manner because of the branch format of the model. In several cases, one page leads to five or six other pages. Therefore a "forward" link cannot be inserted. Learning to balance our knowledge of the model development and the feedback from the surveys was an important lesson for us. This concept helped us to analyse further data gathered from the feedback surveys and to take the suggestions into account.

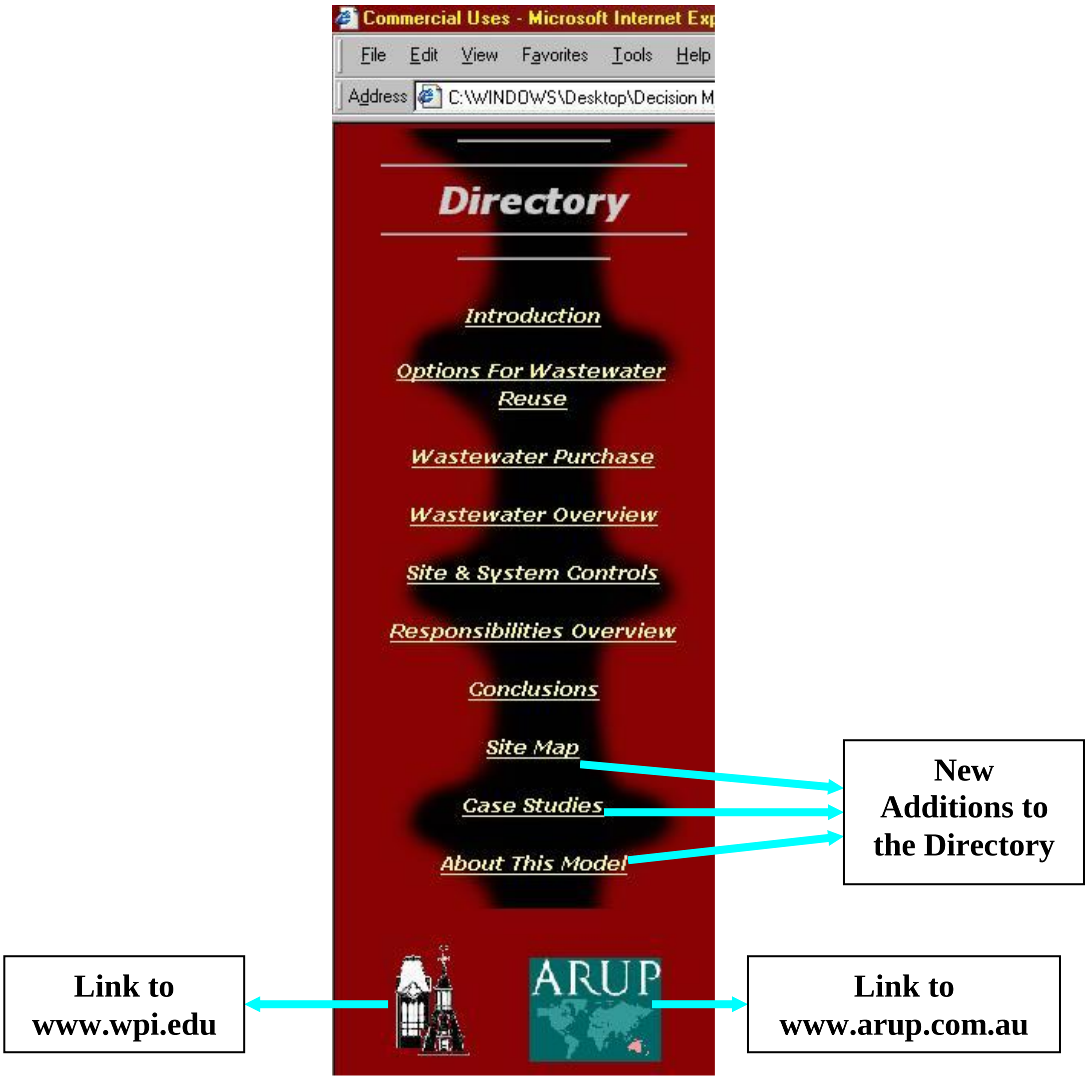
We also tested the decision model with Professor Matthew Ward, a computer science professor from Worcester Polytechnic Institute, Worcester, MA. He was familiar with this project and its objectives because of his position as the academic advisor of the project. His general comments were consistent with the responses of other groups, and he added several other suggestions. Prof. Ward recommended clarifying several terms and the title of some pages. He also offered ideas for adding and improving the system of links in certain places, including a direct link to the case studies in the model.

Several Arup engineers, Mr. Barry Steinmeyer, Mr. Neil Paynter, and Mr. Matthew Elliot, also pretested the model. They expressed interest in having a contact page. This page would provide an area for listing contact information of consultants at Arup and possibly Arup Stokes. They also recommended providing a link from the model to the Arup webpage.

The results of the standardised questions from the feedback survey gave us valuable information (see APPENDIX L). Only two categories received ratings less than 3.0: the Introduction section and System of Links. We did not alter the introduction page because it was necessary to include all of that information. During every iteration of improvement, we revised the system of links to connect the pages in intuitive ways. We later added a site map and enhanced the side directory as well to improve the system of links. The 31 other categories (out of the total 33) received ratings over 3.0, which was classified as "good." These results supported our methods for planning, organising, and presenting the model. Moreover, 9 categories received ratings over 3.5, which is between the classes of "good" and "excellent." These categories included the content of several sections, the clear definition of terms, and the appearance of links. Most importantly, these high ratings praised the professionalism of the model, its visual appearance, overall layout, and overall appearance. We had focused on these aspects of the model, and the ratings supported our decisions and choices.

As a result of the comments on the survey from the university students, Professor Ward and Arup engineers, we made several significant changes to our model. A site map was created to give users a better understanding of their position in the model. The site map also provides links to every page in the model. A new page was added to allow direct access to the case studies. Previously, the case studies could only be accessed through the wastewater treatment section. The directory on the left side of each screen was updated to include links to the site map and case studies page. Links to the Arup and WPI webpages are also present on the bottom left corner of every page (see Figure 10). The majority of the changes were made to provide easier navigation throughout the model; the content remained the same.

Figure 10. Updates to Directory



4.4.3. Final model

The final decision model is a comprehensive representation of the opportunities for water recycling Victoria. It employs an intuitive Hypertext model and uses a web browser to direct users through a network of sections and pages. The content of the model includes the potential reuse options, purchasing wastewater, water quality and treatment, case studies, site and system controls, and responsibilities. Pictures, charts, graphs, and tables were used to support and emphasise the content of the model. The format of the decision model has been designed to be as user-friendly and clear as possible. There is a permanent directory on the left side of every single page with links to the sections of the model. A comprehensive site map illustrates the organisation of the model and has links to each page. The case studies can be easily accessed through a separate case study page, and a contact page has been added to list information about contacts at Arup. The decision model has been through many rounds of revision and testing. Over ten people and the project group have critically analysed the decision model for content, organisation, presentation and appearance.

We created a user guide to accompany the model. The user guide has three sections. . The first section, background information, explains what we hope the user will gain from the model, how the model was developed, and how it is organised. The second section, technical information, discusses the potential for expanding and upgrading the model to include more information. The final segment, user instructions, is a list that describes how to run the model on a computer. This guide is included as a booklet with the CD-ROM containing the decision making model. It is also attached as APPENDIX M.

The model can be easily updated or expanded by Arup. While designing the model, we carefully commented the HTML code for the model to facilitate updating. We also constructed two template pages, one with a two column table for links and one with three columns. These templates make it easy for pages to be added by Arup. In addition, our use of HTML is an advantage because the HTML can be modified directly by a qualified programmer or it can be modified indirectly through a webpage development program, such a *Microsoft FrontPage Express.* Instructions on how to update the model are included in a "Read Me" file on the CD-ROM that contains the decision model (see APPENDIX **N**).

5. CONCLUSION & RECOMMENDATIONS

The decision model for water recycling in Victoria, Australia is the culmination of background research, literature review, and independent research conducted by this project team. The research was performed to obtain Victoria-specific information, the perspectives of local and national water experts, and valuable details about current water recycling projects. We took the gathered information and organised it into a logical flow that reflected the development and planning of water recycling projects. The arrangement and linkage of topics were best represented by a Hypertext based model. We supplemented each category and topic in the model with clear and concise supporting material. This material included definitions, comparisons, tables, graphs, and case studies. The purpose of the supporting information was to communicate the basics of water recycling and the many available opportunities to as wide an audience as possible.

The model was honed and revised by testing it with various groups. We generated and used a feedback survey so we could compare responses and opinions from different people and different groups to draw conclusions about what improvements should be made to the model. We took the recommendations into account when revising and improving the model. We concentrated on aspects such as content of the various sections, overall content and clarity, organisation, presentation, and aesthetics. The content of the model was very important, and that is why we gathered such a significant amount of information through background research, literature review, and original research from interviews and archival research. However, the presentation and appearance of the model were just as important because the model will be used by Arup as a marketing tool to inform clients about the potential options for water recycling. Therefore, we also focused on the overall appearance and visual format to develop a model that would suit its intended purpose and appeal to the projected audience.

Based on our preparation and the revising process, we feel that our decision model for water recycling in Victoria, Australia clearly represents the opportunities and issues related to water recycling at a wide range of scales and a variety of purposes. Therefore, we believe it fulfills Arup's needs. In addition, this model was designed to have a positive impact on society. Natural resources each have a unique niche in the global ecosystem. It is the responsibility of society to protect and preserve the natural resources of the earth by limiting damage and preventing further depletion of these precious resources. Water is one of these resources. Water supplies have been exhausted, polluted, and wasted. Recycling of wastewater can make a significant difference by reducing withdrawals from freshwater sources and preventing contaminants from entering the natural system. Our model clearly presents the advantages of water recycling with the intention of encouraging this environmentally responsible action. When used by Arup, our model will promote water recycling and protection of Australia's water resources. In addition, the decision model itself and the methodology we employed can act as a platform for developing similar models for other areas and countries.

Our project and decision model for water recycling can be expanded and further developed as future work. The Hypertext layout of the decision model means that the model can easily be updated or expanded because the programming language used here, Hypertext Markup Language (HTML), is not platform dependent. We have facilitated the process of updating and changing the model by carefully labeling and commented the code. The accompanying user guide (APPENDIX M) and this report provide specific information about how the model was developed and our reasoning for the design and content. This information provides a useful base for others to build upon. The model should be updated regularly to reflect changes in technology and legislation, as well as the development of new water recycling projects. The scope of this project initially covered grey water recycling, and was later expanded to include total wastewater recycling and treated effluent purchase in some instances. The model could be enhanced by adding stormwater and rainwater recycling and by conducting more research into total wastewater recycling and effluent purchase. Adding more case studies would also further support the content of the model. The model could also be focused into a more technical direction by having a civil or water engineer adding this dimension. The current form of the model focuses mainly on Victoria, Australia. The model could be generalised to apply to broader areas, such as Australia as a whole, or specified to other areas, including other countries.

In conclusion, we developed the decision model for water recycling in Victoria, Australia, for Ove Arup & Partners and in partial fulfillment of WPI's graduation requirements. This project is significant because we assembled disparate information about water recycling into a coherent model that can be used to encourage implementation of environmentally conscious water usage systems. The model and the development process met the objectives laid out in the project statement, and exceeded those objectives in some respects. The decision model is much more in-depth than originally planned and includes extra information in the form of case studies. We also incorporated the topics of total wastewater recycling and effluent purchase and developed the user pamphlet to enhance and explain the final product. This project and the decision model have the potential to be further developed to expand their impact and application.

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APPENDIX A. OVE ARUP & PARTNERS

Arup offers consulting and project management services in all major engineering disciplines ranging from civil and environmental engineering to acoustical and fire protection engineering. There are nine office centers, including one in Melbourne, Victoria, which was opened in 1972. This office has grown to over 100 employees.

Ove Arup and Partners was founded in 1946 as a consulting engineering firm serving the United Kingdom. An entrepreneur named Ove Arup started the firm to pioneer architectural services by providing advanced and economical solutions for building projects. The firm later expanded to include many types of specialty engineering concepts and incorporated a multi-disciplinary approach to its consulting practices. At the same time, Arup expanded globally by undertaking specialised projects throughout Europe, in the Americas, and in Asia. The company maintained its connections to Sir Ove Arup's founding principles as expressed in his 1970 Key Speech. The three goals of the firm are to continually strive for quality, honorability, and prosperity, while utilising a multi-disciplinary engineering approach and respecting the environment.

Today, Arup employs over 5,000 people in 75 offices worldwide, operating in over 50 countries. Some of the acclaimed projects that Arup has completed include: the Sydney Opera House in Australia; Shajiao B and C Power Stations in the Guangdong Province, China; the Republic Plaza in Singapore, Centre Pompidou in Paris, France; the International Arrivals Building at John F. Kennedy International Airport in New York, USA; and Eastgate in Harare, Zimbabwe.

Arup is a world leader in engineering consulting and management because of its commitment to excellence and integrity. The firm's focus on environmental issues and client satisfaction, and its wide range of engineering expertise, have allowed Arup to grow and serve society concurrently.

APPENDIX B. INTERVIEW SCRIPT

Interview Outline

Introduction:

Worcester Polytechnic Institute is an engineering and science university located in Worcester, Massachusetts, USA. The university emphasises the development of students' teamwork and communication skills through a project based curriculum. Several projects are required for graduation. One of these projects is the Interactive Qualifying Project (IQP), which is a project outside the student's major area of study that links technology with societal issues.

Our IQP examines the issues involving grey water recycling. Jonathan Acorn, Kate Shore, and Mike Quigley are researching the many aspects that need to be considered when designing and implementing a grey water recycling system. We are focusing on domestic grey water and its possible uses in urban and rural settings for homes, building complexes, and commercial facilities.

The goal of this research is to create a simple and thorough decision making tool for use in consulting engineering projects that will potentially reuse domestic grey water. Ove Arup & Partners is sponsoring this research. Arup engineers will use the final decision-making model as a tool to promote greywater reuse on projects they consult.

Water supplies are being polluted and depleted, and are an important issue of concern in Australia. Finding ways to conserve and recycle water will help preserve these scarce resources. Having a tool to direct engineers when consulting on grey water reuse projects will assist efforts to conserve the supplies of potable water being used from natural sources. Our model will outline the following details: guidelines to follow, level of water treatment needed, health issues, maintenance issues, common barriers, environmental benefits, and relative cost. We also plan to provide case studies similar to the potential site. Ove Arup and Partners will use this model to present grey water recycling as an option for their clients.

Questions:

<u>Status of Grey Water Recycling</u>
What are the most/least promising uses for greywater? What are the advantages and disadvantages of each? Are they economically feasible? Can they be combined? What sort of infrastructure or system is required?

What are the main reasons greywater is not reused?

Do you know of any changes (legislative/regulatory or technological advances, etc.) being made that would potentially eliminate some of the barriers to greywater recycling? What are they? What effect do you think they will have?

What is your opinion on the government's stand on greywater recycling? Are they pushing for it? Advising against it? What are their reasons? How about the EPA and the water authorities?

Subsidies and Funding
What government subsidies are available for greywater recycling projects? What are the conditions? How are they obtained?

What non-government organisations provide funding or grants for greywater recycling projects? What are the conditions? How are these grants obtained? Do you know of any examples of grey water recycling projects that have received these grants/subsidies?

Other Projects
Do you know of any successful grey water recycling projects in Melbourne or Victoria?

Do you know of any grey water recycling projects in the planning stages? What stage are they in? Why are these water recycling projects being constructed? What obstacles have they encountered? Do you know of anyone at these projects we could contact to interview?

APPENDIX C. SITE INTERVIEW SCRIPT

Site Interview Outline

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Grey Water Recycling Project Background

Name of grey water recycling project: ____

Setting: __ Urban or __ Rural

Local water authority: ________________________________

When was the grey water recycling project started? What groups or individuals founded the recycling project?

Were other grey water recycling projects used for references or guidance? Which ones and why?

What were the motivations for the recycling project?

What licenses and permits were required? Which authorities had to be consulted? Was this process difficult or lengthy?

What obstacles or problems did the water recycling project face in the planning stage? In the construction phase? In operation?

How was the water recycling project funded? Did the project receive any grants? From what organisations or agencies? What were the conditions of the grant(s)?

Site Characteristics
Was a site analysis conducted prior to the grey water recycling project? By whom?

What are the soil and water characteristics of the site? Are there any problems or special considerations in terms of soil, water sources, etc. with this specific site?

Contours & drainage lines ____
____
Proximity of ground & surface waters ______________________________________
____
Winds & wind breaks ____
____
Residential areas (current & future) ______________________________________
____
Vegetation & soil (type, conditions & drainage) ____________________________
____
Rainfall & evaporation rates ____
____
Flooding potential ____
____
Impact on groundwater ____
____

What are the effects of daily and seasonal variations in water use and supply? How are the variations managed or accounted for?

How is stormwater runoff managed? Are there any problems or issues related to stormwater? Has flooding ever been a problem? How was it dealt with?

Infrastructure
What kind of grey water recycling infrastructure is used? Why was this selected?

How is the grey water recycling infrastructure maintained? Who is in charge of the maintenance? What types of tasks are necessary? How often are they performed?

What are the issues and relative costs related to the recycling infrastructure?

How is backflow prevented? What are the other plumbing controls in the water recycling infrastructure?

Wastewater
What are the specific sources of the waste/grey water? What volumes are contributed from each?

What is the capacity of the treatment plant for wastewater?

How is the grey water transported to the treatment plant?

Wastewater Reuse

How is the recycled water reused? For what purposes?

What sites reuse the treated water? Size and location of the sites?

How do they receive the recycled grey water?

Water Treatment & Monitoring

How is the grey water treated?

__ Preliminary ____

__ Primary ____

__ Secondary ____

__ Advanced ____

  __ Nitrogen ____

  __ Phosphorus ____

  __ Suspended solids ______________________________________

  __ Organics & metals _____________________________________

  __ Dissolved solids ______________________________________

  __ Others ____

__ Disinfection ____

How is the quality of the recycled water monitored? What characteristics are tested and how often?

Are they tested on-site or sent off-site? If sent off-site, where are they sent?

Project Management

If the waters are sold or distributed: What agreements are in place between the distributor and users? Is it a formal agreement?

What kind of environmental management plan is in place for the project? What does it cover? Who is responsible for enforcing it? What kind of feedback loops are in place?

How are the users/neighbours part of the management plan?

Community Status

How is the water recycling project received in the community?

Is there a community education/outreach program? How is that run? Who organises it? Has it been successful?

Have there been any studies on public perception? What were the results? What changes or adjustments were made as a result of the study?

Reporting
Are annual-type reports submitted? How often are they submitted? Who are they submitted to? Are they required?

Issues & problems
What are the major continuing issues with the grey water recycling plant?

Have there ever been any emergencies or crises? How was it managed? What was the result?

Are there other people we should speak with or projects we should research?

APPENDIX D. SUMMARY OF DR. DAVID CUNLIFFE INTERVIEW

We interviewed Dr. Cunliffe on Wednesday, 5 April 2000 at 11AM at the Department of Health Services in Adelaide, SA. Dr. Cunliffe is involved in the process of approving wastewater recycling projects.

Dr. Cunliffe provided us with a government perspective of wastewater recycling; pointing out reasons certain sites get approved, and why others do not. He also informed us that there are only approximately 20 approved grey water recycling projects in the Adelaide area. All of these grey water projects are maintained and operated by individual households. The reasons he gave for the small number of grey water specific projects were nearly all cost and maintenance related. He also added that he does not see a large future in greywater recycling. In his terms, grey water is too "tricky" to become practical.

Waste water recycling, however, receives a lot of support. Two of the four waste water treatment plants in Adelaide reuse 100% of their treated effluent. Normally, once the effluent is treated to class "B" standards, it is sent out to sea. Since there are many uses for class "B" level water, there are many opportunities for the plants to sell the treated water, rather than dumping it into the ocean. Some of the uses for class B water in the Adelaide area include irrigation for grapes, horticulture, golf courses, and public parks. The main condition for class B water is that it either has to be underground, or a buffer zone must be allotted.

The approval of a waste water recycling project is tedious, but not difficult. There are a couple grants that certain environmental improvement agencies award; however, these are difficult to obtain. In conclusion, we learned that strictly grey water recycling projects do not seem feasible at the moment; whereas, total waste water treatment and reuse projects seem much more promising.

APPENDIX E. SUMMARY OF DR. PETER DILLON INTERVIEW

We interviewed Dr. Peter Dillon on 5 April 2000 at 9AM in the Arup Stokes office. Dr. Dillon is a research scientist at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the Land and Water Division. His current research interest is aquifer recharge with storm water and recycled wastewater.

Dr. Dillon gave us some insights into the changes that may pose problems to the water industry in the future. He indicated that through his experiences he is confident that treatment of black water and grey water that makes use of existing infrastructure while employing sewer mining will be the most efficient way to recycle waste water. Sewer mining is the process of harvesting wastewater for treatment and reuse from the sewer system as opposed to the source of the wastewater. He also raised some interesting issues about the reuse of wastewater, such as soil quality, pathogens, and nitrate excesses.

When asked to compare grey water recycling to complete waste water reuse, Dr. Dillon stated his suspicions are that the whole of effluent reuse has the appearance of being more economic, more easily managed, more certifiable, and provides greater confidence of soil, groundwater, and human health protection. He also warned not to come down too hard on struggling pilot projects, to encourage innovations and learn from their problems. The main difficulty in the field of water recycling, in his opinion, is the transport of information from site to site. Dr. Dillon also provided a number of contacts in the field of water recycling.

APPENDIX F. SUMMARY OF BORVIN KRACMAN INTERVIEW

We met with Borvin Kracman at 1:30 Wednesday afternoon 5 April 2000. Kracman is the principal manager of Arup Stokes in Adelaide, South Australia. He has been in the water industry for over 20 years and has been involved with many water recycling projects. A major project of interest that he was involved with extensively is the Virginia Pipeline Scheme.

This massive pipeline supplies water for irrigation from one of Adelaide's major wastewater treatment plants (Bolivar Treatment facility) to vineyards and farms in the Adelaide suburb of Virginia. This pipeline is the largest of its kind in the Southern Hemisphere. Kracman provided a quick overview of this project in our interview and supplied us with packets of information on this project. He also affirmed our findings that total effluent, as opposed to exclusively grey water, is usually recycled. He attributed total effluent recycling to economic and infrastructure considerations.

APPENDIX G. SUMMARY OF DENNIS MITCHELL INTERVIEW

Dennis Mitchell is a contact that was provided by Borvin Kracman at Arup Stokes. Mr. Mitchell is employed by the South Australian Housing Trust (SAHT) in Adelaide, SA. We interviewed him on Tuesday, 4 April 2000, at 11AM.

A few days prior to our interview we forwarded Mr. Mitchell an interview script. By sending him the interview script ahead of time, he knew exactly what we wished to gain from the interview. He had retrieved paperwork and schematical drawings in preparation for our meeting, which allowed for a very productive interview.

Mr. Mitchell was involved with an SAHT project titled New Haven Village, which deals extensively with wastewater recycling for domestic purposes. The New Haven Village was designed with the following aims and objectives:

- Promote well-designed, higher density, affordable housing.
- Incorporate various environmentally-friendly energy, water and waste water strategies that are practical and cost-effective.
- Recognise home buyers preference for detached housing with variety.
- Take advantage of existing urban infrastructure, especially where infrastructure has been under-utilised.
- Demonstrate new forms of streetscape that put people first and cars second in a shared public space.
- Encourage greater communal interaction.

Virtually none of the wastewater or storm water runoff that is generated by the village ever leaves the site. The wastewater treatment plant located on-site treats all of the effluent. The treated effluent is then used to water gardens, to irrigate landscapes, and to flush toilets.

Mr. Mitchell provided us with a wide range of facts about the New Haven Village that was helpful when we organised our case study. He also took us out to visit the site on Thursday, 6 April 2000. The on-site wastewater treatment plant was surprisingly small. All of the holding and irrigation tanks are maintained underground and a small shed with the treating equipment is above ground. The shed is about three meters long and three meters across. More information, including pictures, is provided in the case study for the New Haven Village.

APPENDIX H. SUMMARY OF SUE MCCORMACK INTERVIEW

On Tuesday 4 April 2000, we interviewed Sue McCormack from the Land Management Corporation in Adelaide, SA. Ms. McCormack has been involved in the planning stages of a 600 hectare development called Mawson Lakes. The Mawson Lakes project is hoping to be one of Australia's first totally self-sustaining mixed-use urban environmental developments of its kind.

Although the project is still in its early stages of development, (the project was started in 1998 and has been scheduled to last 10 years from start to finish), Sue was able to provide us with some good general ideas and innovations that this project has hopes of achieving. The project explores six key elements: 1) environment and energy, 2) information technology and transfer, 3) education, 4) social development, 5) economic development, and 6) urban design. One of the main goals is to reduce potable water use by 50% through recycling domestic grey water, black water, and storm run-off. Water will also be taken from surrounding wetlands. Wastewater will be treated to class A quality via on-site plants, and then reticulated to the aquifer, wetlands, and inhabitants.

The South Australian government provided funding for the plant and parts of the drainage, and developers funded the rest of the drainage cost. The New Haven project was used as a reference for this project; however the Mawson Lakes project is a much larger and more innovative endeavor. Licensing and permits were required for disposing treated water into the aquifer and withdrawing water from the aquifer. These licenses are renewed on an annual basis. The storm water run-off will be collected on site and will never leave the site.

This particular site was chosen for its location and its land characteristics. A proposed site was abandoned in the earlier stages of the project when it was found to be too low-lying. The maintenance issues and user billing have not been resolved yet. Two separate water meters will be installed to measure both potable and non-potable water usages. The possible uses for the treated water will include toilet flushing, gardening, and landscape irrigation.

APPENDIX I. SUMMARY OF KARL ROGERS INTERVIEW

We met with Karl Rogers on Tuesday, 11 April 2000 at 11AM in the Arup office. Karl Rogers is employed by W.P. Brown & Partners in the Engineers and Managers division. W.P. Brown is overseeing the construction of the Tomara Resort Golf course, which uses reclaimed water to irrigate the course. Mr. Rogers was not involved in the early stages of the project; however, he provided us with some basic information and also gave us references to sources that could supply more information about the project. Mr. Austin was involved in the design phases of this project so interviewing him may prove beneficial to our project.

APPENDIX J. AUTHORITY SURVEY

1. Does your authority allow grey water reuse?
    ❑ Yes   ❑ No

2. Who within the authority has the primary responsibility for approving grey water reuse?
    __ Health
    __ Engineering
    __ Building Surveyor
    __ Planning
    __ Other ______________________________________

3. Does you require a license for grey water reuse or wastewater reuse?
    ❑ Yes   ❑ No
    How much does it cost and how long is it valid?
    Cost: ___________   Duration: ____________

4. Is (EPA/Water Authority) approval required? Or approval by any other authority?
    ❑ Yes   ❑ No
    Other: ❑ Yes   ❑ No   authority: ___________________
    Other: ❑ Yes   ❑ No   authority: ___________________

5. Does you inspect installations on a regular basis?
    ❑ Yes   ❑ No
    If so, how often and what does the inspection comprise?
    How often: ____________
    Inspection details:

6. Does you require regular reports on water quality testing for water recycling projects?
    ❑ Yes   ❑ No
    What must be reported and how often?
    How often: ____________
    Report details:

7. What is the regular water rate per KL?
    Cost: ___________/KL

8. Does you sell recycled effluent from treatment plants?
    ❑ Yes   ❑ No
    What is the rate per KL charged for the effluent?
    Cost: ___________/KL

APPENDIX K. MODEL TESTING SURVEY

Water Recycling Decision Model
Feedback Survey

Contents: Sections	Poor	Adequate	Good	Excellent
1. Introduction	1	2	3	4
2. Reasons to Recycle	1	2	3	4
3. Options for Wastewater Reuse	1	2	3	4
4. Domestic Opportunities	1	2	3	4
5. Agricultural Opportunities	1	2	3	4
6. Commercial Opportunities	1	2	3	4
7. Purchasing Treated Wastewater	1	2	3	4
8. Wastewater Quality	1	2	3	4
9. Wastewater Treatment	1	2	3	4
10. Site & System Controls	1	2	3	4
11. Roles & Responsibilities	1	2	3	4
12. Conclusion	1	2	3	4
Comments:				
Content: Overall				
13. Terms defined clearly	1	2	3	4
14. Appropriate explanations	1	2	3	4
15. Examples & case studies	1	2	3	4
16. Supporting pictures & diagrams	1	2	3	4
17. Appropriate depth of information	1	2	3	4
18. Coverage of pertinent topics	1	2	3	4
Comments:				
Organisation:				

19. Flow of topics	1	2	3	4
20. System of links	1	2	3	4
21. Logics	1	2	3	4
22. User friendly?	1	2	3	4
Comments: **Presentation:**				
23. Professionalism	1	2	3	4
24. Visual appearance	1	2	3	4
25. Mobility & versatility	1	2	3	4
26. Perceived value to clients				
Comments: **Aesthetics:**				
27. Overall layout	1	2	3	4
28. Colour scheme	1	2	3	4
29. Titles	1	2	3	4
30. Font	1	2	3	4
31. Location of links	1	2	3	4
32. Appearance of links	1	2	3	4
33. Overall appearance	1	2	3	4
Comments:				
Overall Comments: Thank you!				

APPENDIX L. RESULTS OF MODEL TESTING SURVEY

Contents: Sections	**Average Score**
1. Introduction	2.889
2. Reasons to Recycle	3.333
3. Options for Wastewater Reuse	3.222
4. Domestic Opportunities	3.222
5. Agricultural Opportunities	3.222
6. Commercial Opportunities	3.444
7. Purchasing Treated Wastewater	3.444
8. Wastewater Quality	3.556
9. Wastewater Treatment	3.333
10. Site & System Controls	3.556
11. Roles & Responsibilities	3.667
12. Conclusion	3.111
Content: Overall	
13. Terms defined clearly	3.500
14. Appropriate explanations	3.222
15. Examples & case studies	3.222
16. Supporting pictures & diagrams	3.375
17. Appropriate depth of information	3.444
18. Coverage of pertinent topics	3.111
Organisation:	
19. Flow of topics	3.111
20. System of links	2.667
21. Logics	3.333
22. User friendly?	3.167
Presentation:	
23. Professionalism	3.778
24. Visual appearance	3.667
25. Mobility & versatility	3.438
26. Perceived value to clients	3.000
Aesthetics:	
27. Overall layout	3.556
28. Colour scheme	3.222
29. Titles	3.444
30. Font	3.222
31. Location of links	3.333
32. Appearance of links	3.556
33. Overall appearance	3.500

Rating Scale Color Scheme		
2.5 – 3.0	3.0-3.5	3.5-4.0

These results are based upon 9 responses.

APPENDIX M. USER GUIDE

Background:

The decision model for water recycling in Victoria, Australia aims to help the user better understand the processes of reusing wastewater. To achieve this goal, the model identifies the reasons to recycle wastewater, the methods used to recycle wastewater, and finally presents case studies of successful projects.

The model was designed in a hypertext format, providing a familiar environment for users to navigate through. At the bottom of each page, the next logical link is presented on the right hand side. Back buttons are available wherever appropriate. On the left hand side of each page is a site directory that provides the user with links to each of the main pages of the model, as well as links to the Arup (www.arup.com.au) and WPI (www.wpi.edu) websites. A contact page is also listed on the left hand side. This page includes information of consulting engineers at Arup.

The model starts with an introduction, explaining how it works, and what users can expect. The next page offers reasons to recycle water. It details the environmental and economic reasons to recycle water, and includes Australia and Victoria-specific motivations. The first main section introduces the potential reuse options for wastewater. The reuse options have been broken down into three categories: residential, agricultural, and commercial. At this point, the model branches to follow each of those three choices. The residential section covers toilet flushing and lawn/garden irrigation. The agricultural section explains wastewater use for irrigating crops for human consumption and crops not for human consumption. The commercial section details turf and landscape irrigation and wastewater use for other uses such as agroforestry, aquaculture, and horticulture. Each of these three sections presents definitions and explanations of the particular reuse option. In addition, it covers precautions, restrictions, requirements, and any special considerations.

The agricultural and commercial sections present the user with the option to explore buying wastewater from a supplier. This side branch informs the user of the opportunities available in this area, what the benefits can be, and what is involved. The users who choose not to explore buying water continue with all the other branches into the wastewater section. EPA objectives for wastewater quality and treatment are presented here. In addition, we define black and grey water and explain the constituents of each waste stream. Grey water is further broken down into its components, whose characteristics are also discussed. The EPA required classes of treatment are presented and the uses for each class are detailed.

The next section is wastewater treatment where the general water treatment process is displayed and it explains how the different classes of water quality can be achieved. On this page there are multiple water treatment systems presented as examples to users. For instance, those interested in recycling water for toilet flushing can view the system used by the Sustainable House in Sydney, NSW. The next section details requirements for site and system controls, which can be broken down into two main categories, irrigation and domestic controls. The following section is a responsibility overview that includes roles and responsibilities, quality monitoring, and reporting. The EPA requirements and guidelines in these areas are presented and discussed. The next major section is the conclusion and recommendations, where the model is summarized. References and acknowledgements follow.

Technical Information:

This decision model can be expanded and further developed for future use. The Hypertext layout makes the model easy to update or expand because the programming language, Hypertext Markup Language (HTML), is not platform dependent. The project team has facilitated the process of updating and changing the model by carefully labeling and commented the code.

The model should be updated regularly to reflect changes in technology and legislation, and the development of new water recycling projects. It could be enhanced by adding stormwater and rainwater recycling and by conducting more research into total wastewater recycling and effluent purchase. Adding more case studies would also further support the content of the model. It could also be focused into a more technical direction by having a civil or water engineer adding this dimension. The current form of the model focuses mainly on Victoria, Australia. It could be generalised to apply to broader areas, such as Australia as a whole, or specified to other areas, including other countries.

User Instructions:

1. Insert “Decision Model” CD into CD-ROM drive
2. Click Start
3. Click Run
4. Type in the drive location of CD-ROM (usually D: or E:) and press enter
5. Double click folder titled “Decision Model”
6. Double click the “Launch Model” icon
7. Follow on-screen directions

APPENDIX N. READ ME FILE

Comments from the Creators!

What's on this CD?

This CD contains 3 folders: 'Decision Model', 'Client Decision Model', and 'IQP Final Report'. The 'Decision Model' folder contains all components of the Decision Model and is intended for modification and update development purposes. The 'Client Decision Model' folder is the Decision Model with all files hidden from the users' view, except for the 'Launch Model' page, which starts the Decision Model program. This version is intended for client use since all the components, except the launching page, are hidden from the eyes and hands of the user. The 'IQP Final Report' folder contains the full IQP report, which documents the background, methodologies, and development of the final Decision Model.

How do I update the Model?

The contents in the 'Decision Model' folder are set up for updating or changing pages in the model. All the HTML code in this model has been commented for ease of updating. The comments in the code correspond to what can be seen visually on the model pages when viewed through a browser. There are a few ways one can go about updating this model. One way is by opening the pages in a text editor, such as 'notepad', and modifying the code by hand. This is highly recommended for programmers familiar with the HTML language. Another way to modify the pages is by using a website-development tool, such as Microsoft 'FrontPage Express'. This tool is part of the Microsoft 'Internet Explorer' web browser and is recommended for easy text modifications to the model. If major revision of layout needs to be done, it is recommended that someone with HTML experience make the changes.

Also included in the 'Decision Model' folder are two templates, which can be used to quickly add new pages to expand the model. These two templates contain the two different layouts that were used in the model. The templates have labels instructing where to add titles, content, and links. Using the templates and 'FrontPage Express' any user familiar with Microsoft 'Word' can easily make additions to the model.