WATER MANAGEMENT AND WASTE WATER TREATMENT AT THE UNIVERSITY OF BRITISH COLUMBIA: A STUDY FOR SUSTAINABLE ALTERNATIVES

by

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Abstract

The purpose of this study was to determine whether or not alternative water management options could be applied to the University of British Columbia to maximize sustainability, research opportunities, and the degree of independence from the Greater Vancouver Regional District (GVRD) while being legally, logistically and financially reasonable. The main focus was on three aspects of water management: stormwater management, rooftop rainwater harvesting, and wastewater treatment. The stormwater management section attempts to evaluate the importance of numerous small detention ponds on water quality and erosion potential. A pilot project was developed to test some management options, but due to time and seasonal constraints final data could not be collected and conclusions could not be made. Rooftop rainwater harvesting evaluated the harvesting potential that UBC has and if this potential would be significant enough to make a difference to the overall water consumption on campus. It was determined that a relatively small amount of water could be collected, but that small amount could potentially save UBC money, decrease the demand on GVRD water, and create water reserves for times of emergency. Wastewater treatment was evaluated on the basis of using solar aquatics and conventional treatment methods to process UBC's wastewater and possibilities to reuse the treated effluent and sludge. After studying and evaluating the systems used in multiple case studies, a hybrid system was proposed. This was based upon the importance of plant-microbe interactions in solar aquatic systems and the cost effectiveness of conventional treatment. It was determined that potential exists for the reuse of effluent and sludge in experimental applications in agriculture, aquaculture, domestic and industrial settings. Overall, the options considered and evaluated in the thesis indicated that the University of British Columbia can implement these options to increase sustainability, research opportunities, and independence from the Greater Vancouver Regional District while being legally, logistically, and financially practical.

Table Of Contents

List of Tables

List of Figures

Preface

Originally our group of six started out as two groups of three. Both groups were talking to different parties and doing research on water use and treatment. In the end, to everyone's surprise, both groups came up with the same topic. After a few meetings and a little reluctance, we became a larger group composed of six members. We spent very little time as a group of six, which is probably what made the thesis do-able. Once we broke up into smaller groups we were mainly working within those groups, only meeting as a larger group to discuss details that needed the whole group's opinion.

One of our main objectives for choosing to focus the topic on UBC was because we wanted to write a thesis that may have an impact on the future of the campus. It is a campus that we have all spent a lot of time at and we wanted to be able to give something back to it. Whether our suggestions get used by UBC or whether they are used for further research in the years to come is yet to be seen. However, we do feel that our thesis has the potential to make an impact on the future of our campus.

We have also been working closely with the university Sustainability Office (SEEDS), and plan to incorporate parts of our thesis into a comprehensive report for their use. The SEEDS program has shown a strong interest in working towards the implementation of an alternative water treatment facility on campus, and is also concerned with other aspects of water sustainability covered in our thesis.

The major struggle of working in a large group was preparation for the interim report that was due at the beginning of December. None of us fully realized how hard it would be to make six writing styles flow smoothly as one. It was then that we decided to designate an editor to work out those kinks and put the paper together. Other than that, we have encountered no major difficulties in working in such a large group. In fact, our work has proved to be a valuable lesson on group dynamics and communication…a lesson that hopefully has helped to prepare us for the working world ahead.

Acknowledgments

The list of people that could have been acknowledged for their assistance and guidance during this thesis could be miles long. We would all like to thank our mothers and fathers, and those who are paying for our education if we are not doing so ourselves. Sheldon Duff, our advisor, provided excellent help when called upon. Though, we likely underutilized his experience, much thanks is provided. Our instructors, George Spiegelman and Christina Chociolko, and part time instructor Sandra Brown, gave excellent advice and guidance. The following list includes professors, staff, those in industry, commercial, and government sectors, who aided our thesis project: Eric Mazzi, Ken Hall, Rob Miller, Dan Moore, Hans Schrier, for stormwater, Jerry Maedel for aerial photograph, David Smith for irrigation data, Marvin Schaffer for multiple account evaluation, Freda Pagani, Brenda Sawada, Kim Rink, and Patrick Condon. For case studies in wastewater treatment: Nelson Porteous, Steve Chomolok, Jeanette Frost, Don Cardil, Craig Jowett, and Vern Gattinger. Thank you all, those mentioned, and those who felt they should have been.

Chapter 1 - Introduction And Overview

1.1 Introduction

The University of British Columbia (UBC) is a thriving academic institution, surrounded by the beauty and enchantment characteristic of the west coast. Situated on the Point Grey Cliffs, west of Vancouver, UBC overlooks an assortment of islands in the Georgia Strait. The UBC community, numbering over 46,925 people, is rapidly defining what the future will look like; putting UBC on the edge of more than just the Point Grey Cliffs (Pair UBC, 2000).

Becoming sustainable in all walks of life is vital for various reasons, the most prominent being the need to maintain a healthy planet for healthy people. Willingness to start in ones own backyard is paramount, especially at UBC. UBC should be a role model for the world; not only for its academia but also for its actions. Water management and wastewater treatment, the focus of our thesis, are logical next steps for UBC to embark on. UBC has the chance to become a leader in the independent management of its own environmental impact, a living and learning experiment. Not only do these areas address issues of sustainability, they possess considerable economic and social implications.

Water is a resource that is becoming increasingly scarce and needs to be sustained, globally and locally. One of the most serious problems faced by billions of people today, is the availability of fresh water. It has been estimated that 1.2 billion people have no water within 400 m of their dwelling (Gould, *et al*., 1995). Governments and organisations all over the world have realized that sustainable water and wastewater management is a necessary component of functioning communities. Efforts to find and implement alternative methods can be found from Texas to Thailand to Africa. Alternative practices that are implemented at UBC would provide research opportunities so that effective ideas can be passed on to the people who need it most. The alternatives addressed in this thesis provide a foundation for further work. Others can expand upon what we have started, continuing research to develop new and innovative practices.

British Columbia residents have the luxury of being able to use a large amount of water, and Vancouverites are no exception. UBC's water comes from the Greater Vancouver Water District (GVWD). The GVWD is already urging lower mainland residents to practice water conservation to reduce operational costs and serious upgrade expenses they will have to face to meet the increasing demand (GVRDe, 2000).

Many communities, including UBC, dispose of untreated stormwater directly into surrounding water bodies and in UBC's case, this water body is the Strait of Georgia. Contaminated stormwater has the ability to do environmental damage on receiving ecosystems, primarily a result of suspended sediment and heavy metals. This issue has prompted the Greater Vancouver Regional District (GVRD) to develop stormwater management strategies, the best of which have been incorporated into the GVRD BMP (Best Management Practice) Guide. This guide states that detention ponds provide optimum treatment of stormwater. Detention ponds require specific site conditions that are not abundantly available at UBC, therefore grass swales and temporary detention ponds, also listed in the guide, are more suited to UBC as they treat water quality in pre-existing channels. However, the studies these recommendations are based on exhibit a large range of effectiveness. UBC Utilities is reviewing a proposal put forward by Alpin & Martin in 2001, to build a biofiltration channel. The proposal is not accompanied by an assessment of its effectiveness. Campus stormwater flows over the Point Grey Cliffs, contributing to the erosion of the UBC/Point Grey area. Increased development of pervious areas produces higher quantities of stormwater and therefore exacerbates erosion. Reducing the peak flow and decreasing total suspended solids in UBC's stormwater may help reduce erosion and improve water quality.

Waste from UBC's water usage is also an issue. Vancouver drainpipes are combined drains, meaning both sewage and runoff are carried in the same pipe. During heavy rainfall, which is common to the Vancouver area, many of the storm drains overflow on to the surrounding area (GVRDa, 2001). UBC's sewage flows to the Greater Vancouver Sewage and Drainage District's (GVS&DD) Iona Island Wastewater Treatment Plant. This facility performs primary treatment of incoming wastewater. In the past, the Iona facility disposed of effluent by dumping it directly onto the beach. Since this resulted in eliminating all life in the vicinity, a pipe now carries the sewage over the shelf break into deep water. This improved beach conditions, but the Iona facility still fails to meet provincial guidelines for effluent disposal (GVRDb, 2001). Upgrading the plant to secondary treatment standards would cost around $400 million and is not currently part of the GVRD's future plans (Nenninger, 2001).

At UBC, work has already begun at different levels in different faculties looking into sustainable practices in water and wastewater management. The C.K. Choi building led the way, being the first "green" building on campus. Other buildings have followed including the recent Lui Center for the Study of Global Issues. Many projects in the Faculty of Applied Science have looked into the mechanics and design of alternative sewage treatment faculties. The UBC SEEDS Office put forward a Canada Foundation for Innovation proposal (CFI proposal) to acquire funding to introduce engineered wetlands, solar aquatic technology, and ultraviolet treatment to the UBC campus. This development would provide UBC with tertiary treatment of its wastewater and potentially produce a reusable source of potable water. The proposal was created for the CFI's approval in 2000; it was rejected but continues to be backed by the SEEDS Office and various faculty members, and is under revision for future submission. Our project intends to draw from past studies on water and wastewater management to propose alternatives to address these issues campus wide.

A range of costs and benefits, to UBC and the Vancouver community, arise from employing alternative water management and wastewater treatment systems. These alternatives have the potential to increase independence from the GVRD, make UBC a more sustainable campus, provide research opportunities, and allow UBC to be financially viable.

1.2 Research Objective

Research Questions: What are the alternative water management and wastewater treatment options available to UBC? How do these alternatives measure up in terms of sustainability, research opportunities and independence from the GVRD while being legally, logistically and financially reasonable?

Current water usage, stormwater management, rainwater harvesting, and wastewater treatment are analyzed as separate entities, and then these parameters are drawn together to give a holistic look at the options for UBC. Each option is assessed on its capacity to optimize cost, land base area, location, design, efficiency, and other benefits.

Since the University of British Columbia is located in a temperate rain forest area, with approximately 1233 mm of rain falling on campus each year, it is a prime location to use rainwater harvesting as an alternative for obtaining usable water (Environment Canada, 2001).

The rainwater harvesting research, addressed in Chapter 3, aims to devise a method and management strategy for harvesting, storing, treating, and reusing the rainwater falling on campus from daily to annual time scales.

We will also look at stormwater management in the hope of decreasing erosion and improving the quality of water that enters the Georgia Strait at the mouth of the Fraser River. Our goal is to look at temporary detention ponds in comparison to those suggested by the GVRD BMP Guide and the Alpin & Martin proposal, as an option for treating both quality and quantity of stormwater at UBC. A temporary detention pond pilot project is used to investigate both quality and quantity concerns. Chapter 3.1 focuses on stormwater management issues and the pilot project.

Another main objective of this study is to evaluate the benefits and disadvantages of using a more sustainable system for wastewater management; Chapter 4 develops this study. Examining sewage collection, treatment, and disposal was used to explore sustainable wastewater management options at UBC. Our study includes safe and cost-effective management options for grey and black wastewater on campus. Climate, temperature range, precipitation, and meteorology are just some of the factors that are considered in each case. Finally, recommendations for the implementation of a sustainable wastewater system at UBC are made.

1.3 Methods

In order to explore the array of alternatives we have set out to investigate, we employed a variety of research methods. Literature research and review provided background and fundamental information. Communication with experts through personal, telephone, and email interviews yielded up-to-date information, focus, and guidance. A research plan was developed for field experimentation to examine components of our system: specifically the temporary detention pond. A multiple account evaluation model was created as a tool to assess the alternatives in reference to the status quo or "business as usual" scenario over the next 10 to 20 years.

Chapter 2 - University Of British Columbia Background

2.1 UBC Community

From its construction, the UBC campus has grown from a few academic buildings to a multifaceted community. UBC began as an idea in 1877 and it took 33 years for that idea to become a reality as Point Grey was finally chosen as the site for the university campus in 1910. The University Endowment Lands, located on the east side of campus, were given to the University in 1920, and Pacific Spirit Region Park was created from that land in 1989 (UBC Library-archives, 1999). These areas add to the numerous residences that have been established surrounding the academic core. Many colleges, schools and centres are now affiliated with UBC and can be found scattered throughout the campus.

In the 2001-2002 winter session, UBC will impart knowledge to 37,873 minds, be home to 8,700 residents, and employ over 9,079 faculty and staff (UBC Library-archives, 1999). This adds up to a community of over 46,952 people and including summer session the year round total is approximately 53,000 people (UBC Library-enrolment, 2000). UBC did not start this large; the first admission in 1915 was 379 students, approximately the number found in a current first year biology class. Presently, at 140 times larger than its initial population, UBC continues to grow. By the year 2006, UBC plans to increase housing capacity by 4,000 residents and employ 700 additional faculty and staff. By 2010 these numbers are predicted to be 5,300 and 900 respectively (UBC Official Community Plan, 2002).

2.2 Current State

It takes approximately 5.3 billion litres of water a year to satisfy the UBC community; this is enough water to fill BC Place Stadium over 4 times a year (Marques, 2001). The water comes from the Seymour, Capilano and Coquitlum watersheds located north of Vancouver. The GVWD, a department of the GVRD, stores and distributes this water to member municipalities and neighbouring non-municipalities. The GVRD supplies water to the University Endowment Lands, a non-member municipality, which in turn sells it to UBC. The water is piped from the

Sasamat Reservoir to a supply pump station next to University Boulevard on the outskirts of campus. A 600 mm diameter pipe and a 300 mm diameter pipe supply UBC with water. The 600 mm pipe supplies areas requiring high pressure and some areas using low pressure by the way of reducing valves. The 300 mm pipe delivers water to the rest of the low-pressure areas. When the main pump station is deactivated there is an emergency supply pump station to the southeast from which a 500 mm pipe can supplement the water supply (UBC Utilities b, 2002).

The water that comes on to campus is used in diverse applications, from flushing toilets to running complex experiments. The allocation of this water to the academic portion of campus was determined from a recent water audit done by Enviro Energy International. The company found that in terms of water, UBC uses 23% for animal care, 40% for domestic purposes and 37% for miscellaneous use (Pate, 2001). Animal care includes water used in aqua culture and water to satisfy the requirements of different animals kept on campus. Domestic water includes that used in toilets, sinks, and showers and miscellaneous water refers to water used in irrigation, cooling, and lab work. The amount of water used on campus is approximately equivalent to a 50,000-person city and if you include the residences on campus, water usage would become comparable to a 100,000-person city (Pate, 2001). One of the reasons UBC can afford to use so much water is that the price does not reflect of its value. UBC pays $0.2507/m^3 for water and $0.1963/m^3 for sewage; this is approximately $0.44/m^3 for both, whereas people in Manitoba pay $1.25/m^3 and people in Edmonton pay $1.95/ m^3 for both (Pate, 2001). However, UBC's water costs do add up. In 2001, UBC spent $1.39 million on water usage. Aside from this being a sizable cost to UBC, it is also a sizable cost to the GVRD. The GVWD suffers from high operation costs and expansion. In order to cope with increasing demand, the GVRD is planning to upgrade their facilities, which could cost hundreds of millions of dollars over the next 20 years (GVRDe, 2000). Enviro Energy International has submitted a proposal outlining water reduction solutions they could implement on campus. The company estimated that their proposed changes would save UBC $80,000 per year in water and sewage costs. The financial savings arise from reducing current water usage by 2 million litres annually. The changes would, in turn, benefit the GVRD to some extent.

Of the 5.3 billion litres of water that came on to campus in 2001, 4.8 billion becomes wastewater, and the rest is used for irrigation. The wastewater produced on campus goes to the Iona Island Sewage Treatment facility via the GVRD sewer system. Alpin & Martin's

University of British Columbia Master Servicing Plan: Sanitary Sewers Technical Report examines the sanitary sewer system for the UBC campus in detail; the overview of the sanitary sewer system discussed in this chapter arises from that report. The sanitary sewer system is split into the north sewer system and the south sewer system. Both of these systems discharge into the Greater Vancouver Sewage and Drainage District (GVS&DD), the Spanish Banks Interceptor Line trunk main (north system), and the SW Marine Drive Interceptor trunk main (south side).

The north sanitary sewer system is comprised of three gravity trunk sewers and two large pump catchments while the south sanitary sewer system is composed of two gravity trunk mains. Both sewer systems recently added flow meter stations to allow the GVRD to monitor the flows coming from these pipes in order to charge UBC for the amount of wastewater it sends for treatment and disposal. In 2001, UBC was charged $934,918 for the 4.8 billion litres of wastewater it produced that year (Marques, 2001).

The wastewater flows can be separated into four major components: domestic, research oriented, coolant, and inflow/infiltration. People visiting, working, and living on campus produce domestic wastewater. Laboratories and research facilities generate research flows; these flows are difficult to measure because the flow can vary substantially from building to building. Various buildings on campus generate coolant wastewater. Sources of this wastewater include heat pumps, air conditioners, research equipment, walk in coolers, freezers, and fridges. Inflow and infiltration are the last major component of wastewater. These sources can enter the sewer system from saturated ground conditions, manhole covers or other storm drainage components. The infiltration rates are a function of the age and condition of the pipes, soil porosity, the water table, and the intensity of rainfall.

Both the north and the south sanitary sewer systems have the capacity to convey the wastewater flows under the current peak conditions. However, future scenarios for both of these sanitary sewer systems do not look promising. The current piping in south campus does not have the capacity to handle the planned developments, especially because a large portion of the development is taking place on previously undeveloped land. This will require the construction of new sewer mains. The SW Marine Drive Interceptor does not have the ability to handle future flows and would also need upgrading and/or modifications to the existing system. The cost of upgrading the sanitary sewer system to meet the current and future requirements is $389,000.

Any further improvements due to removal, relocation, and upsizing would cost an additional $4,950,000 (Alpin & Martin, 2000).

Water also comes on to campus as precipitation, usually in the form of rain. Rainwater either hits permeable surfaces such as forest or field, or impermeable surfaces such as roofs or paved areas. When rain falls on more permeable land it percolates into the soil where it can be used by plants, evaporated, or recharged into the ground water. Rainwater that becomes ground water will eventually flow over the Point Grey Cliffs. When rainwater hits impermeable developed surfaces it will flow down its hydrologic gradient (slope) and enter an underground sewer or a grassed channel. Rainwater in a sewer or channel is referred to as stormwater. The sewers and grass channels will take the stormwater water through UBC to one of the cliff exits, either the outflow at Trail 7 or 16 Ave, or to the spiral drain in North Campus. The stormwater flowing over the Point Grey Cliffs is untreated and enters the Georgia Strait near the mouth of the Fraser River. The stormwater while in the channels may also evaporate or drain into the soil, however, both of these loses are very small, as the water is often moving quickly and sometimes flowing through concrete pipes.

Alpin & Martin, a consulting group, is proposing to divert most of the water leaving South Campus from the Trail 7 and 16 Ave outflows into the "biofiltration channel" that they will construct. Enclosed sewers will be constructed to replace many of the grass channels to carry water into the biofiltration channel. The new channel is to be built along Southwest Marine Drive. Water, as it passes down the channel, will be treated for contaminates by the plants and shape of the channel. As the water reaches the end of the channel it will flow down a drop shaft to the ocean. This system is estimated to cost $1.45 million dollars (Alpin & Martin, 2001).

Besides being discharged into the Strait of Georgia, the stormwater going over the Point Grey Cliffs contributes to erosion. *The Point Grey Cliffs Need Your Help* - Consultation Discussion Document, examines the causes, both natural and anthropogenic, of erosion on the Point Grey Cliffs and is a source of the following information. Erosion is an important issue to many people; different groups that have a stake in the health of the Point Grey Cliffs include UBC, the GVRD, the Musqueam First Nations, the North Fraser Port Authority, the Fraser River Estuary Management Program (FREMP), and others. Stormwater running over the cliff face has caused major erosion events including the 1935 erosion next to Green Collage, which created a deep gully. The document states that stormwater runoff and hydrological forces are primary causes of erosion. A major contributor to stormwater runoff is development of natural landscapes into impermeable surfaces as this causes water to accumulate and facilitates surges in the drainage system. In some areas, UBC has the capacity to handle stormwater runoff for a 10-year storm, and in others a 20-year storm, but beyond this time frame major runoff could cause deleterious erosion. Whether or not UBC properly "handles" the runoff is currently being evaluated and several activities to deal with erosion have been developed. In fact, the very alternatives proposed in our project have been suggested to mitigate erosion: "[The] possible actions to address general drainage issues include: 1. Conduct drainage study of the South Campus including consideration of: a) Retention ponds in South Campus to decrease peak storm discharge b) Sustainable development principles using recycled rainwater" (UBC/Pacific Spirit Park, 2000). The document is both supportive of alternative practices and confident that these actions have the potential to reduce erosion of the Point Grey Cliffs.

In the past, UBC has not been required to have a rigorous water quality monitoring program, however, this changed as of 2001. The British Columbia Safe Drinking Water Regulation (BCSDWR) now requires a higher level of testing and monitoring. This prompted UBC Utilities to propose a sampling program for UBC described in the January 2002 report: *Drinking Water Quality Monitoring Program*. The report suggests implementing 16 stations around UBC in locations chosen on the basis of the Lower Mainland Medical Health Officers recommendations. The report discusses a range of sampling frequencies that span weekly to semi-annually time scales. The Guidelines for Canadian Drinking Water Quality (6^{th}) Ed. are for 1 sample per 1,000 people per month for populations ranging between 50,000-90,000 (UBC Utilities a, 2002). This means 40 samples should be taken a month at UBC. The report also specifies which parameters should be tested and details the workings of the monitoring program. The implementation of such a monitoring program could remove some of the obstacles towards using and reusing water from rainwater harvesting and sewage treatment.

2.3 Current Water Balance

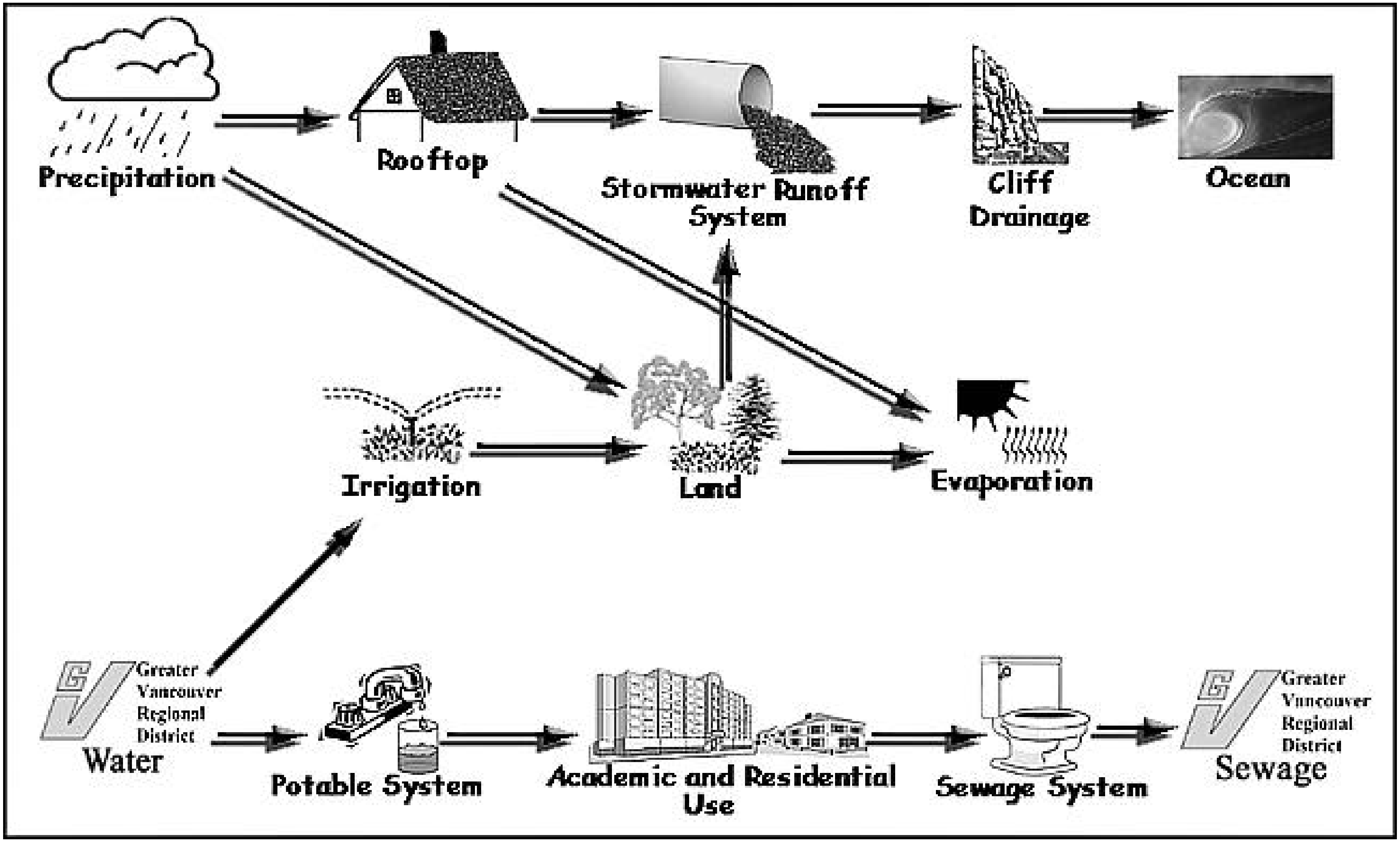

FIGURE 2.1 CURRENT WATER BALANCE FLOW CHART

The current water balance flow chart is a visual representation for the current movement of water through the system at the University of British Columbia. The arrows do not represent the volume of water flowing from one system to the next, just the direction.

The water from the GVRD enters campus and is distributed into two different systems, the potable system and the irrigation system. The water that enters the potable system will be used for potable and general applications for academic and residential use. The water gets disposed of via the sewage system and goes back to the GVRD for treatment.

The water that enters the irrigation system is applied to the land and either leaves UBC by evaporative modes or by the runoff system that carries the water down the cliffs and into the ocean.

The other addition of water to UBC campus is from precipitation. Precipitation either hits the land or the rooftops of buildings. From these two areas, the water will either evaporate or be transported to the ocean by means of the runoff system and cliff drainage.

Chapter 3 - Stormwater Management Options

3.1 Stormwater System

I. Stormwater Impacts And Management

a. Introduction / History

Stormwater management may sound quite technical and advanced, but the practices of managing water flows are very old. Thousands of years ago, humans began altering the flow of rainwater and groundwater for many purposes. Rain was collected for cultivation in areas that received less than 100 mm of rain per year (Gould, *et al*., 1995). Dams were created in natural basins to provide a more constant supply of water (Gould, *et al*., 1995). As time passed, populations increased, humans inhabited more land, and more extensive and advanced systems of management were required.

In the world today, the management of stormwater is a serious issue. Earth's human population has been exponentially increasing in the last ten thousand years. With increasing populations of humans, two main forces influence stormwater: the alteration of natural land for resource extraction and the alteration of land for urban areas. Before land alteration, vegetation had evolved specifically to the areas biophysical environment. Most subsequent human alteration decreased the land's natural ability to manage stormwater. Poor tree felling practices on steep slopes, for example, can cause excessive erosion of topsoil and catastrophic landslides. In 1996, seven people in Oregon died during one rainy week, due to landslides in clear-cut logged areas[1] (Mazza, 1997). Thus poor resource extraction, and human alteration of land, can result in poor stormwater management, endangering ecosystems and human life. Mining, agriculture, logging, and other resource industries that feed urban development and consumption, alter much of the land beyond its ability to naturally manage stormwater without disruption. With values for human health and the environment, it should be obvious that the management of stormwater is important in sustaining the natural systems around and within human utilized areas

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[1] Clear cuts increase slide rates 2 to 40 times over non clear cut areas (Mazza, 1997)

for the sake of ecosystems and human life. Our goal was to examine alternative stormwater management options at UBC and test them analytically, in order to improve the quality of water entering UBC's surrounding biophysical region.

b. Urbanization

Urban developments are also susceptible to the impacts of poorly managed stormwater. A World Bank study showed that between 1980 and 1999 almost every country in the world experienced an increase in the proportion of people living in urban areas (World Bank, 2001). The Urban Watershed Management CD-ROM by the Institute of Resources and Environment at UBC, provides an excellent summary of the impacts of stormwater in urbanized areas (Bestbier, *et al*, 2000). It delineates three methods of water flow alteration through urbanization. The first is the direct alteration of water bodies. Lakes, marshes, ponds, streams, and other bodies of water can be altered or removed from the water cycle through urban development. Secondly, natural runoff systems and processes can be changed. Vegetative cover can be removed, permeability of soil and surface area can be increased, evapotranspiration can be decreased, and surface runoff can be increased while base flow, or underground flow, can be decreased. Thirdly, contaminants and/or pollution can be added to water bodies through atmospheric deposition, runoff collection of particles, spills, dumping and discharge.

Of all types of water bodies, small streams are most disturbed by the above impacts of urbanization. Small streams can be impacted in four main sectors.

i ***Hydrology***

As imperviousness increases with increasing development (in the form of roofs, roads, soil compaction), more overland storm flow will occur. This will increase the frequency, magnitude, and annual volume of storm flow and flood events. The base flow, or underground water flow, will decrease as less water penetrates the ground, and less water will evapotranspire decreasing productivity.

ii ***Stream Channel Morphology***

Increased water flow rates and volumes increase erosion and widen stream bank channels.

iii ***Habitat***

In most small urban streams, diversity and abundance of species decrease due to habitat loss in the stream channel or in the riparian vegetation. Often, streamside vegetation is altered or removed. Channel morphology change also removes diversity and abundance of habitat by simplifying the channel (Forestry 395, 2000).

iv ***Water Quality***

Urban areas add point source and non point source contaminants that are labelled as pollutants if they show deleterious effects on an ecosystem. Industry discharge in streams can cause thermal pollution, which increases stream temperature, nutrients, and other uncommon elements (hydrocarbons). Automobiles add non point source pollution of heavy metals, oils, and greases. Sediment loads can increase in urban streams as the increased volumes and flow rates carry and remove more sediment from surfaces and stream banks.

The above paragraph only briefly outlines the potential impacts of stormwater. Many more impacts likely occur than are documented or that can be dealt with in this paper. Many researchers and policy makers have realized the importance that stormwater plays in the urban ecosystem. The management of stormwater is an integral component in the preservation of the biophysical environment. Much energy has been invested all over the world in the attempt to control stormwater from areas where land surfaces have been altered.

II. Lower Fraser Valley

a. Summary Of Stormwater Impacts Upon Water Bodies

The Greater Vancouver Regional District (GVRD) sits at the mouth of one of the largest rivers in Canada, the Fraser River (flows into the Georgia Strait). There are many smaller streams that feed into the Fraser River, especially during the winter months when precipitation is high. The GVRD also has one one of the largest collections of people in Canada. Management of water is a necessity to mitigate the impacts of the 3 million people in the GVRD on the biophysical system encompassing the GVRD. Much of the GVRD obtains its water from the Capilano reservoir on the North Shore mountains. This reservoir has been virtually off limits to development, alteration, and public access in order to preserve the watersheds ability to filter and clean stormwater. This is an excellent stormwater management action. But much of the water discharged in the Lower Mainland is not as well managed.

J.K.Finkenbine, J.W. Atwater, and D.S. Mavinic, conducted an excellent study on "Stream Health after Urbanization" with analysis of a number of streams in the Lower Mainland; a summary follows. From the 1800's onward, European settlement in the area of Vancouver and the GVRD has been extensive. Many streams that historically passed through settlement areas have been diverted, culverted, polluted, and degraded. The impacts of alteration and loss of streams often focus on pacific salmon populations, including Coho, Chinook, Sockeye, and Steelhead. 1996 saw the lowest returning fish numbers in recorded history (Finkenbine *et al.*, 2000). Finkenbine *et al*. discuss the impacts of increasing urbanization in the GVRD, specifically affecting these salmonids. These effects have been observed in small and large streams in the GVRD.

i ***Hydrology***

Increased water flow rates can wash salmonid eggs, alevins, and fry out of the protective gravel in the bottom of stream channels where they were spawned (Finkenbine *et al.*, 2000). Migration can become impossible when the water flows are greater than the swimming speeds of the fish (Finkenbine et al., 2000).

ii ***Stream Channel Morphology***

The removal of large woody debris (LWD) from streamside removes small pools from the stream channel where fish are often found. The LWD slows the flow and provides shade and refuge from predators. With the widening of the stream bank through erosion, sediments mobilize and decrease the water quality. Wider channels increase the surface area of streams, raising temperatures, and increasing salmonid mortality (Bestbier *et al*., 2000).

iii ***Habitat***

Less base flow during dry periods means less water is available for biota and water table regeneration. This decreased flow can cause an increase in salmon mortality with decreased depth of water, reduced flow, and cross sectional area which decrease foraging grounds, refuge, and habitat (Finkenbine *et al*., 2000).

iv ***Water Quality***

Salmonids are very sensitive to water contaminants. Heavy metals and chemicals can decrease survival rates. Water composition aids some salmonids in returning to spawning grounds. Thus alterations in the water composition can impact spawning stocks. Sediments can affect salmonid gills and can smother eggs, fry, and alevins inhabiting stream gravel (Finkenbine *et al*., 2000).

Finkenbine *et al*. also discuss the mitigation measures that can be taken to reduce riparian alteration, but the focus of our thesis paper will be on the characteristics of the stormwater system in the urban area rather than in the discharge stream. They then assert that management of stormwater and urban streams is important if the fish bearing characteristics of the Lower Mainland are to be maintained or improved.

In areas south and east of Vancouver, where North Shore mountain water is not available, such as Abbotsford, ground water is used as a drinking source. This ground water could become contaminated from the many chemicals that are produced in the industrial and agricultural sectors of the surrounding urban landscape. These contaminants can be caught up in storm flow and filter into the ground water, contaminating and polluting the water. Walkerton, Ontario, was an example of this type of water disaster. Stormwater washed contaminants from manure piles into the water table, causing ecological stress and human death.

b. GVRD BMP Guide To Stormwater Treatment

The GVRD has developed a guide that enables developers and land planners in the GVRD to better manage stormwater. This guide is relevant to our study because it has combined the above biophysical details, such as geography, ecology, and climatology, with development practices common to the GVRD in order to fit documented and experimented stormwater treatment methods to a specific site. It is known as the GVRD Best Management Practices Guide to Stormwater Management (BMP) (GVRDd, 2001). It provides structural as well as non-structural management plans. The non-structural practices include education for the developer regarding ecosystem sensitivity to pollution and riparian conservation to reduce impacts of development alteration.

Structural best management practices cover many goals and are thus quite diverse. Methods of stormwater treatment include porous pavement, coalescing plate separators, sediment traps, catch basins, dry ponds, dry vaults, engineered wetlands, vegetated swales, bioretention, under-drains, filters, and offline infiltration. The use of each is described in the GVRD BMP guide. These BMP's were used as a starting point in the search for a viable, analytically verifiable, treatment to implement at UBC. One goal of this project was to update the GVRD Guide with our analytically proven method of stormwater treatment.

III. University Of British Columbia

a. Current State

Now that the biophysical and political (GVRD) context of stormwater management has been laid, the University of British Columbia can be situated and analyzed. UBC is situated at the mouth of the Fraser River and the Georgia Strait. The Fraser River is a very productive and biologically diverse system. The river's ecosystems can support up to 20 million fish per day of

80 different species, 750,000 waterfowl, and 1.2 million shorebirds (River Works, 2000). UBC is attempting to reduce its impact upon these ecosystems through the management of stormwater.

Alpin & Martin Consultants ltd. is a consulting firm contracted by UBC to assess and upgrade UBC's stormwater system. The "University of British Columbia Master Servicing Plan, Stormwater Management Technical Report" is their summary of assessment and recommendations. UBC encompasses four watersheds: north, south, trail 7, and 16^{th} Ave (Figure 3.1). As noted earlier, UBC has planned for development to occur on much of the currently unoccupied lands, decreasing the land's permeability. The impacts of this development will most likely be consistent with those of increasing urbanization. The key implications of which have been described earlier in this chapter. The South Campus was the focus of stormwater analysis. Development will add houses, buildings, lawns, and concrete, all of which are less permeable than pre-existing forest and grassland. This loss of permeability will result in enhanced flows and volumes. Increasing development requires increasing management of stormwater if mitigation of impacts is to be effective.

Poor management of stormwater at UBC caused serious erosion and structural land failure in 1935 on the north segment of campus. Water flowed over the Point Grey Cliffs and down to Tower Beach destroying the cliff side and property (Figure 3.2). After this event, a drop shaft was installed to transport stormwater down to the ocean. The capacity of his shaft was exceeded in 1994, again resulting in cliff erosion and failure. Millions of dollars have been spent repairing the area, and upgrading the stormwater drain to ensure damage will not occur again with the same level of storm intensity. But the problem of overloading the stormwater system is not isolated to that one area of campus. All of the cliff side exit points of stormwater are in a "serious state of erosion" (Alpin & Martin, 2001). Mazzi compared the flow over the trail 7 exit to a large waterfall during storm events (Mazzi, 2002). Mitigation is needed to ensure these exits do not fail as the north stormwater exit did.

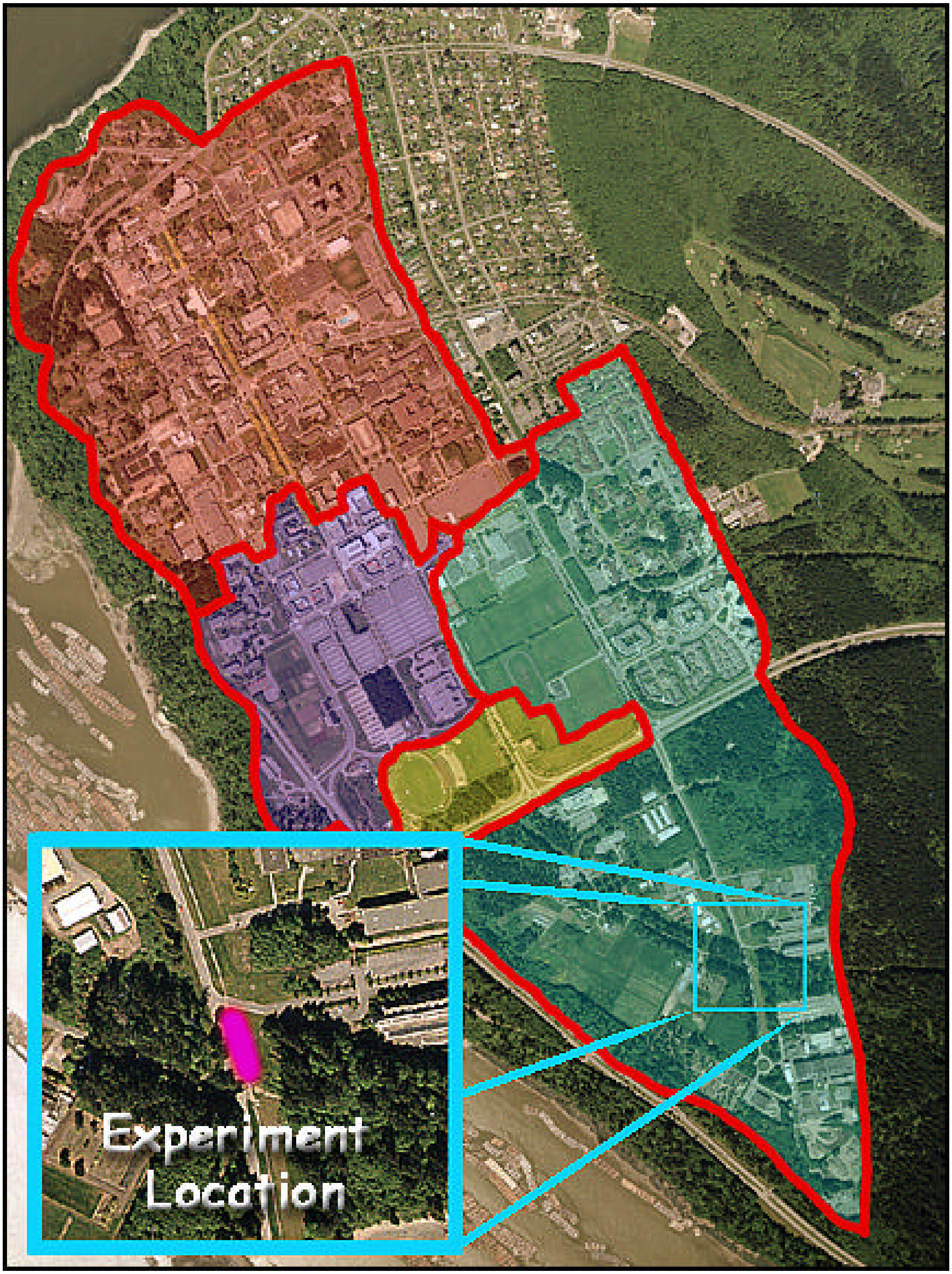

FIGURE 3.1 UBC'S FOUR WATERSHEDS AND LOCATION OF EXPERIMENT

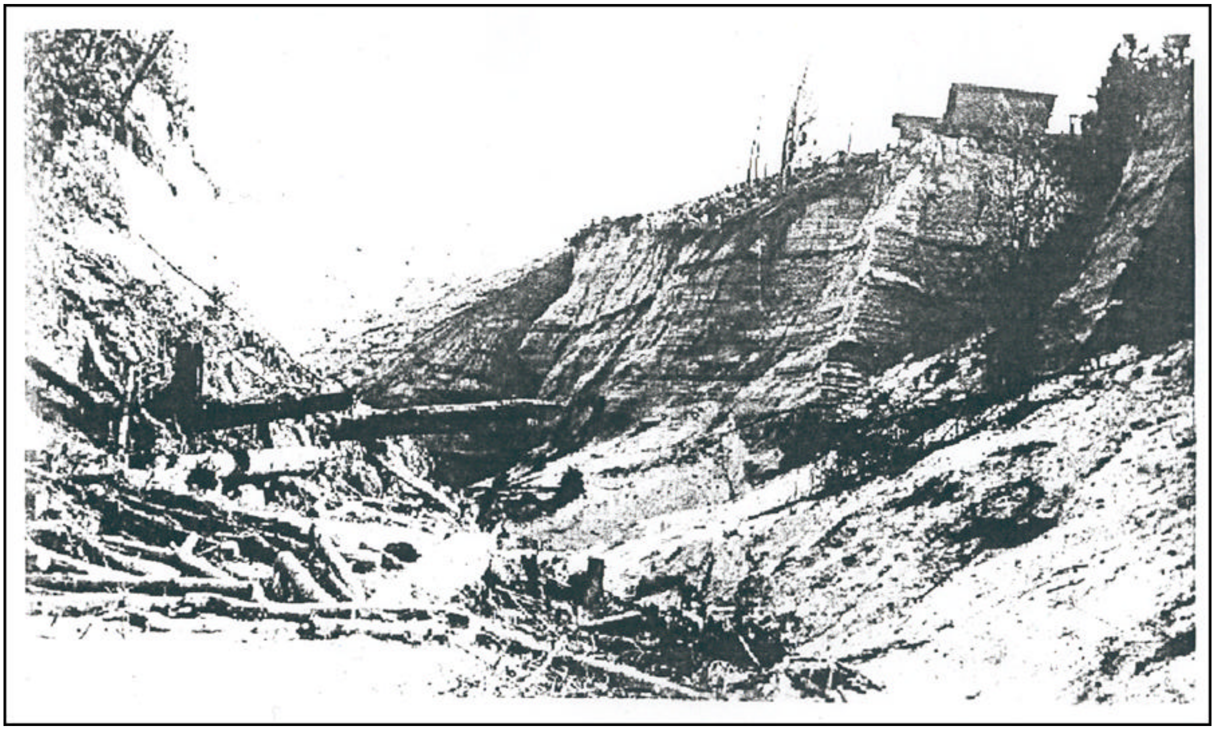

FIGURE 3.2 CLIFF EROSION OF 1935 (ALPIN & MARTIN, 2001)

b. **Stormwater Treatment Options**

There are many forms of stormwater treatment for sediments, heavy metals, nutrients, and oils; all of these pollutants are present in the UBC area. De-development, reclamation of land back to its natural state, and discontinuing usage of heavy metals, are likely the most effective options. But often these treatments do not mesh with economic development. One of the most effective forms of stormwater management and pollution removal suggested by the GVRDe (2000), Alpin & Martin (2001), and Pettersson *et al*. (1999), is the creation of wetlands and large detention ponds that hold stormwater and allow it to infiltrate into the ground. But it was found that recharge to the first aquifer below UBC would likely increase erosion of the cliff faces of Point Grey (Alpin & Martin, 2001). Thus, a large recharging wetland or permanent pond is eliminated from potential management options.

The following table was produced by Alpin & Martin (2001), which closely resembles tables in Bestbier, *et al* (2000), and the GVRD BMP guide (GVRDe, 2000).

Table 3.1 Potential Treatment Options For Stormwater (Alpin & Martin, 2001)

Management Method	Silt	Sand + Gravel	Garbage	Heavy Metals	Oils
Street Sweeping	Good	Excellent	Excellent	Good	Poor
Catch Basins	Not effective	Good	Good		Not effective
Stormceptor	Good	Excellent	Good	Good	Excellent
Detention Ponds	Good	Excellent	Good	Good	Not effective
Biofiltration Channel	Good	Excellent	Poor	Good	Poor
Biofiltration Pond	Excellent	Excellent	Good	Excellent	Excellent

From Table 3.1 it can be seen that combinations of treatments are often effective at treating a wider diversity of pollutants. This table helped us produce a new combined treatment option for UBC that will be discussed later. Alpin & Martin proposed a 'Biofiltration Channel' for stormwater management on UBC; it would be build along South West Marine Drive, south of 16th ave. to the end of UBC property (Figure 3.3). It was intended to treat all the water from South Campus and divert it into one drop shaft, thus increasing the quality of water and decreasing the erosion of the cliff face (Alpin & Martin, 2001). The costs of the channel and other storm system upgrades for enhanced management are quoted in Table 3.2. These upgrades were needed because much of the UBC system could not manage a 10-year return period storm. The 10-year storm is the standard for municipal stormwater management planning (Bestbier *et al.*, 2000). The South Campus upgrades are depicted in Figure 3.4. The dark lines indicate new piping infrastructure to upgrade the handling capacity. Future stormwater management, suggested by Alpin & Martin, included enclosing numerous grassed ditches with pipe and diverting water that would have exited over the eroded cliff exits, to the 'biofiltration channel'. After the 'biofiltration channel' the water would be routed down a drop shaft to the ocean.

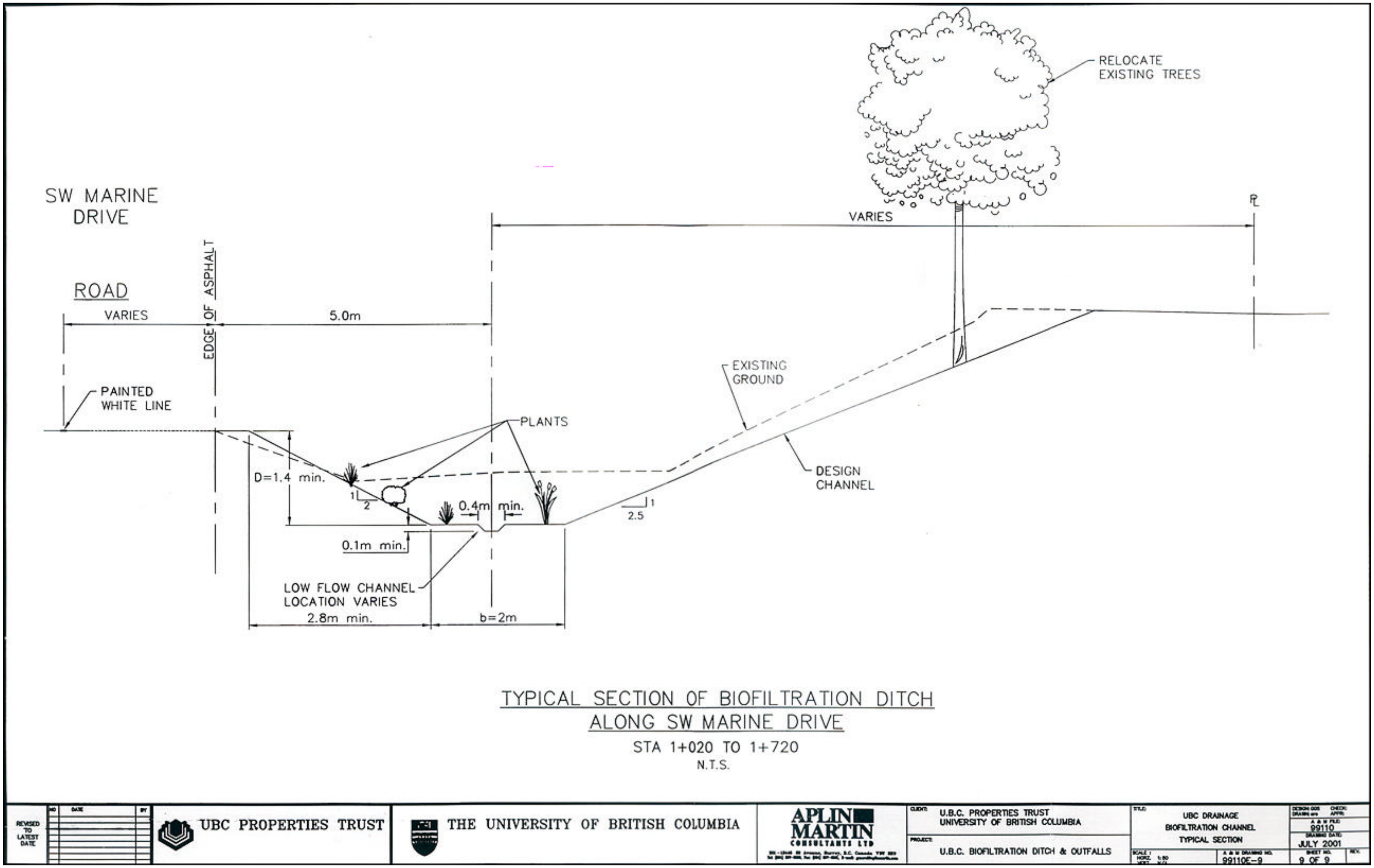

FIGURE 3.3 ALPIN & MARTIN BIOFILTRATION DITCH PROPOSAL

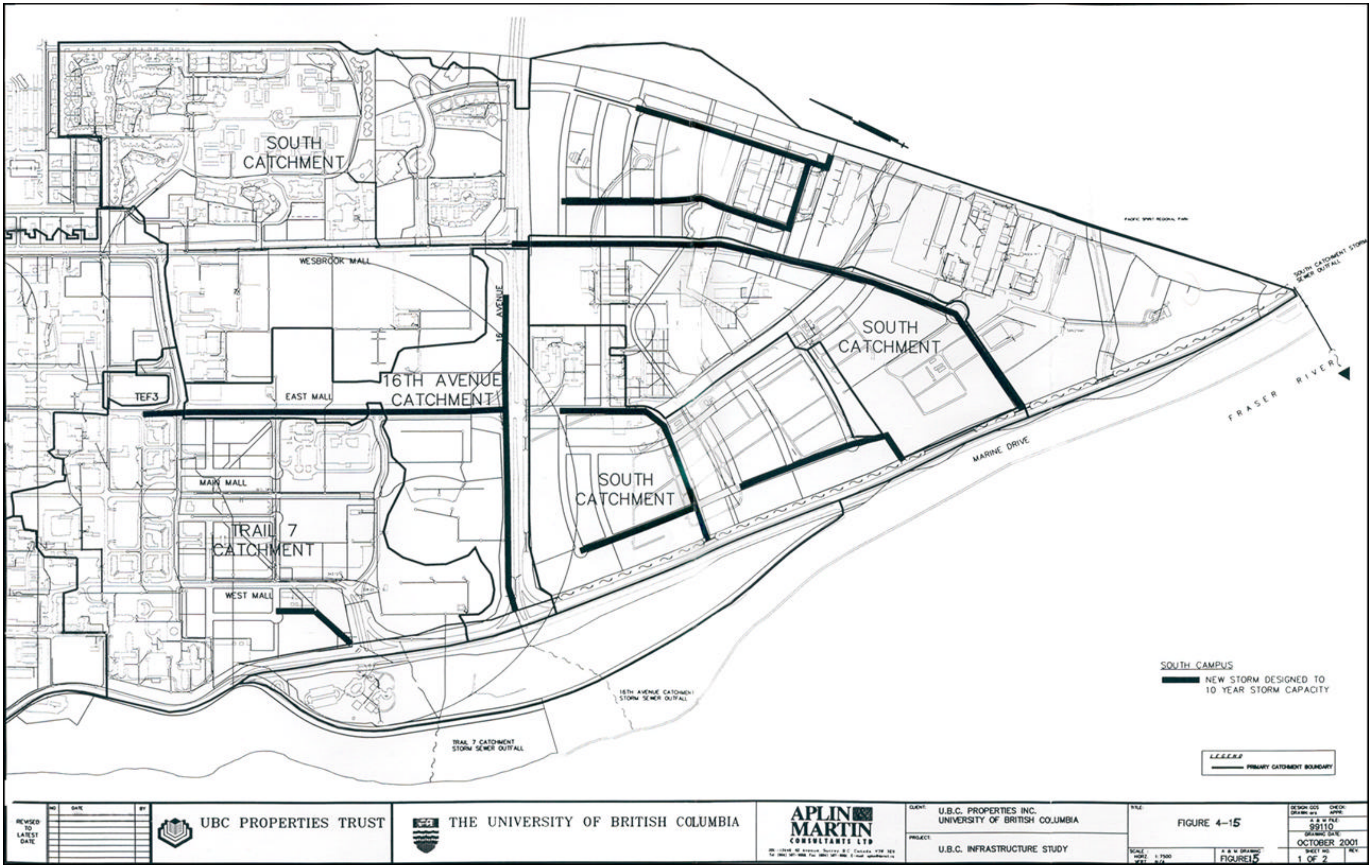

FIGURE 3.4 ALPIN & MARTIN 10-YEAR STORM INFRASTRUCTURE UPGRADE SYSTEM: SOUTH CAMPUS (ALPIN & MARTIN, 2001)

Table 3.2 Stormwater Distribution Cost Summary (Alpin & Martin, 2001)

North Catchment	Cost
Upgrades Existing System	411,000.00
Place Vanier Relief Sewer	448,000.00
West Mall Diversion	340,000.00
New Outfall	1,866,000.00
Subtotal	3,065,000.00
South Catchment	
Upgrades Existing System	802,000.00
New Outfall	2,000,000.00
Trail 7 and 16th ave Diversion	597,000.00
S.W. Marine Dr. Biofiltration Ditch	1,452,000.00
New Trunk System	2,693,000.00
Subtotal	7,544,000.00
Total Stormwater	10,609,000.00

IV. UBC Temporary Detention Pond Pilot Project

a. Objective

The literature strongly suggested that the utilization of detention ponds would result in the most effective stormwater quality management (Pettersson, *et al* 1998, 1999, Hares *et al*. 2000, Wong, 1999). The "biofiltration channel" proposed by Alpin & Martin was not well documented, did not have an analysis plan to verify the 1.4 million dollar project cost, and did not include detention as a treatment. The objective of this section of the thesis is to determine where UBC can enhance its stormwater management economically while decreasing its impact on the biophysical region. We felt that detention ponds, designed not to substantially recharge the ground water, were worth analyzing analytically, in order to enhance stormwater treatment and decrease cost.

We addressed these issues by developing a pilot project in conjunction with UBC Utilities and Eric Mazzi. The pilot project analyzed on site, the effectiveness of one specific feature of stormwater quality management: the ability of numerous, small, temporary, detention ponds to remove sediments and heavy metals. The detention ponds would not hold water long enough (days) for it to infiltrate and recharge the ground water and enhance erosion of the cliff (Mazzi, 2002). This concept was not addressed in the literature. The GVRD BMP guide suggested the usage of check dams only when the slope of the channel is greater than 4%, but theoretically, the concept of detention only requires ponding, and slope is not critical. Theoretically, detention ponds are most influenced by volume and surface area, and not underlying slope (Pettersson *et al*, 1999).

- Null hypothesis (H_o): numerous detention ponds will not enhance the quality of stormwater.
- Alternate hypothesis (H_a): numerous detention ponds will enhance the removal of sediments and heavy metals from stormwater.

b. **Methodology**

i ***Location***

The experiment site was located on South Campus Road in the South Campus of UBC (Figure 3.1). This location was chosen because of low foot traffic and a pre-existing grass channel. The channel shape was relatively uniform, and there was a small contributing area that would contribute small flow rates and volumes in natural storms (photos in Appendix III).

ii ***Design***

Researchers recommend detention ponds with long detention residence times and large volumes for pollutant removal (Wong *et al*. (1999), Hares *et al*. (2000), Pettersson *et al*. (1999)). One researcher showed that ponds with increased detention volumes, and thus residence times, have increased pollutant removal characteristics (Table 3.3) (Hares *et al*. 2000). A channel with check dams should have higher residence times over a channel without. Pettersson, *et al* (1998), recommends designing the detention ponds to collect all of the water a design-storm can discharge. Three-dimensional modelling of the detention basin was recommended to ensure no dead or re-circulation zones, which decrease effective pond volume and residence times (Pazwash 1990). The recommendations of these researchers aided our design, but as our concept was different in scale, only the general characteristics and theory of treatments could be applied. The classic detention pond referred to by researchers is large in volume to surface area (deep) and usually requires major construction with machines. Our design utilized pre-existing, shallow grassed channels. We altered them by adding sand bag check dams to create linear, high surface area to volume detention ponds. The linear detention pond design may not collect all the volume of a ten-year storm. Modelling was uneconomical as our goal involved installing these detention ponds in numerous grass channels throughout UBC land to maximize water quality improvement.

Table 3.3 Heavy Metal Removal In Two Detention Ponds (Hares, *et al*. 2000)

Heavy Metal (percent removal)	$1650 m^3$ pond	$888 m^3$ pond
Cr	99	87
Ni	93	91
Cu	98	87
Zn	97	86
Cd	96	87
Pb	97	86

To quantitatively test our experimental detention channel we needed to compare water quality impacts between treatments. Kantrowitz (1994), Pettersson, *et al* (1998), and many other stormwater researchers tested water quality through time by chasing storms. A number of storm events would be followed and quality would be monitored, in comparison with water quality before the design modifications. But as time was limited and replicated similar storm events were unlikely, we decided to construct a split channel with a control side and a modified detention channel side (photos in Appendix III). Eric Mazzi provided the initial idea for this split channel design. This allowed us to simultaneously measure both the control and the detention pond's ability to remove pollutants.

Our specific design can be seen in Figure 3.5. Plastic-wrapped (to prevent bleeding of sediment) sand bag check dams, were placed every 10 meters in our 30-meter channel to create detention ponds[2]. The ponds were made temporary by inserting a PVC (polyvinylchloride) pipe between the sandbags to pass water from one pond to the next. The two sides of the channel were separated by plywood, which had been buried under 5-10 cm of soil. This process greatly disturbed the vegetation of the channel delaying experimentation until re-growth occurred.

[2] Thirty meters is the minimum channel length recommendation by GVRD BMP guide (GVRDe, 2000).

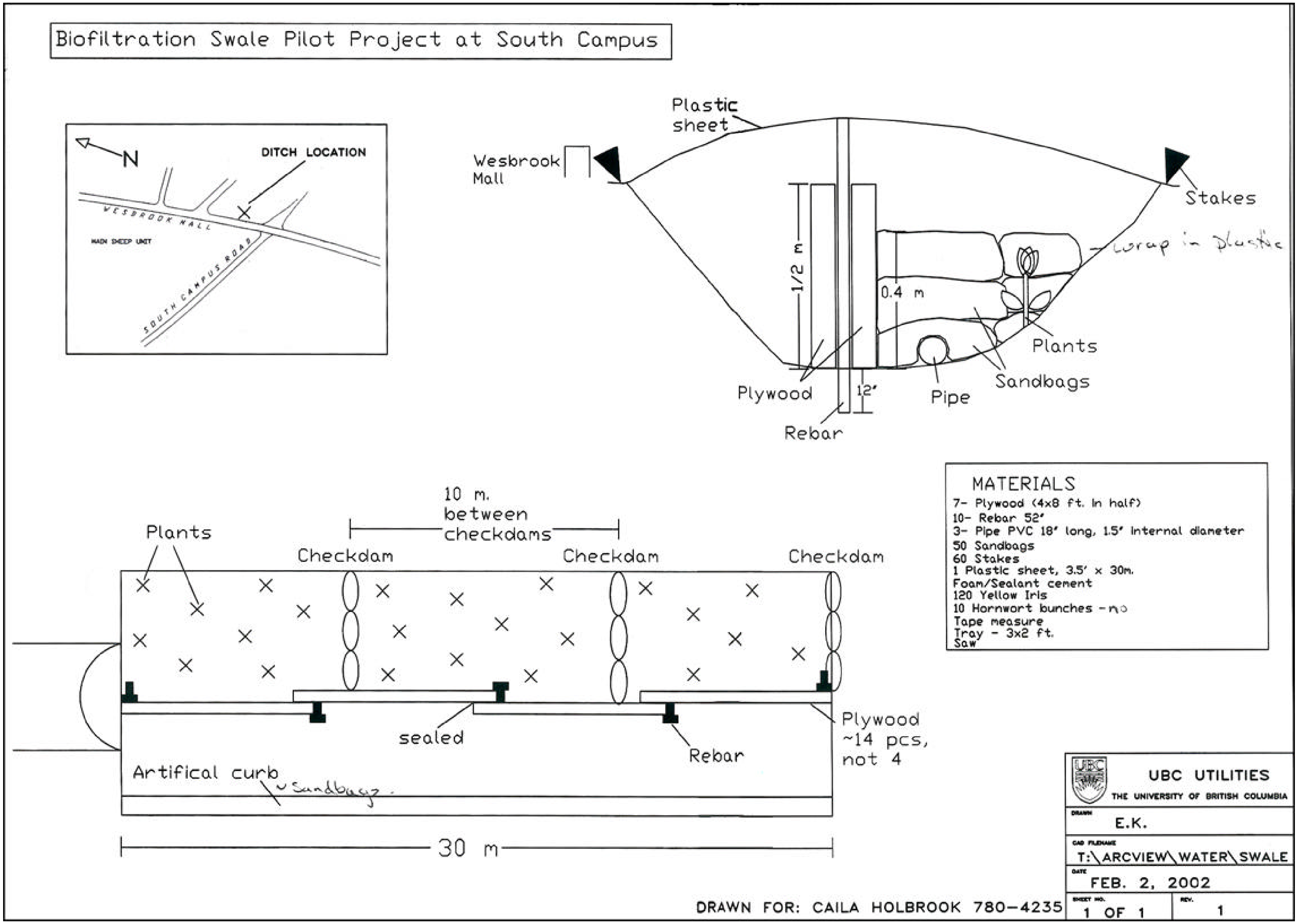

FIGURE 3.5 IMPLEMENTED DESIGN

Sediments were obtained from a street sweeper. A baseline sample was taken to identify the contents (sediment particles, salts, heavy metals and nutrients). Our measurements of pollutant removal capacity depended only upon total suspended sediment (TSS). Research reported that this simplification was valid; "the major mechanism for pollution removal is through particle settling as considerable amounts of pollutants are attached to sediments" (Pettersson, *et al* 1998). Sediments are also used as an indicator of heavy metals, as sediments often fluctuate less than heavy metals in the environment (Kominar, 1997). The maximum concentrations of suspended sediments in water samples taken from UBC stormwater on January 5, 2002, were in the 50-60 mg/L range (Coast River Env. Svc., 2002). To amplify the sediment signal and ensure that sediments could be detected in the experiment, 200 mg/L was used in the experimental trials. TSS were measured via filtration through glass filters in a similar fashion to Pettersson, *et al* (1998). Conductivity and turbidity were measured from the same dip bottle (on site) to provide more support for our hypothesis. These parameters were sampled one meter after each check dam, on both sides of the channel, the control and the detention pond, with dip bottles, every 30 seconds for the 15 minute design storm. A total of 180 samples were obtained.

A fire hydrant was used to replicate storm events, as flows could be controlled and maintained, thus reducing error and variability that natural storms would have brought. There were two flows mimicked in the channel. Those seeking to enhance water quality optimize their treatments to the low quality flow. The level of this flow is recommended not to be deeper than the height of the vegetation in the channel (GVRDe, 2000). Obtaining this flow involved increasing the pressure of the hydrant, until the required flow was obtained in the channel. The other type of flow tested was the larger storm event flow, a two to ten year, 15 minute storm. Large storms have the potential to scour and remobilize settled sediments and pollution. Plants are effective at taking up metals and securing sediments in the channel, but time did not allow us to incorporate plants in our analysis. These two flow patterns could show the benefits of the enhanced channel that otherwise might not be seen with only one flow.

Plants were to be planted in the channel. But as the season was not conducive to rooting and growth, the plants were saved for a later experiment where their effectiveness could be tested while other aspects of stormwater management are kept constant. The list of wetland plants, Table 3.4, brings together plants that were recommended due to their ability to efficiently take up nutrients and metals. The plants are local to the Fraser Valley. All of the plants listed are emergent; they are rooted in the ground and extend above the water level. These types of plants are well suited for a stormwater channel, as they could resist water flow disturbance. They also possess aesthetic value, and communities are more likely to accept the detention ponds if flowing plants are present (North Carolina State University, 2002). In the long term, these plants take up nutrients and metals in the settled sediment ensuring that remobilization into the stream channel and ecosystem does not occur (North Carolina State University, 2002). In the short term, the plants provide structure, impede water flow, decrease velocity, and increase residence time and sediment settling.

Table 3.4 Plants For A Stormwater Channel (Cronk and Fennessy, 2001)

Latin Name	Common Name	Flowers
Typha species	Cattails	
Scripus	Bulrushes	
Iris pseudacorus	Iris	Yellow flowers
Alisma species	Plantain	White or pink flowers
Phargmites australes	Common reed	
Cyperus species	Sedges	
Elecharis species	Sedges	
Glyceria maxima	Giant mana grass	

iii ***Results***

At the time of writing, the results have not been collected[3]. The experimental channel created by dividing the channel in South Campus in two parts with plywood was not in a state to be tested. There were substantial sections of exposed soil where vegetated ground cover used to be prior to construction. This exposed soil would have been carried in the water flow, rendering any results useless. Once the channel has been re-vegetated, UBC Utilities need only to determine the rate of water needed for each flow type, quality and storm event flow, before testing can begin. The data collection is simple and can be conducted by non-experts.

Three possible outcomes can be speculated in the absence of real results. Results should be replicated to obtain statistically significant results. Sediment removal could be greater in the

[3] The verb tense used in the stormwater section is in the past, to prepare the report for when the experimental results have been obtained

detention pond channel than the grass channel, during both flows; H_o would be rejected. The detention ponds were only effective at removing sediments, to a greater degree than the grass channel, during the quality flow. Or there was no difference in sediment removal between treatments.

If the null hypothesis proved true, and there was no difference in sediment removal between temporary detention ponds and the control (grass channel), then there was either; a) not enough of a signal to detect, or b) no relation between detention ponds and sediment removal. If the sediment removal differences were not strong enough to observe, changes in the design would be needed. Smaller particle sizes may be missing from the street sample, and thus the detention ponds would not have tested the more easily suspended small sediments. More check dams could hold more volume for a longer time, potentially increasing sediment removal. Though, the dams would become redundant if placed close together unless the slope was very steep. Wider channels would more closely resemble the classic detention pond for which there is much research on. Off line stilling basins could be tested if water flows scoured out deposited sediments. These off line basins could act the same as the temporary detention pond, but they would be outside the direct line of flow. More construction would be needed. The costs involved would increase by orders of magnitude.

If sediment removal is greater in the detention pond side than the control side during the quality water test, but no different during the storm flow, manual dredging would be required. The manual dredging of the channels would need to be more frequent than the return period of the storm that would scour the sediments out of the channel. The experiment would need to be repeated, decreasing the intensity of water flow until the check dams held sediments during the storm flow. Every 10-20 years detention ponds should be dredged of sediments (North Carolina State University, 2002). Dredging more frequently than 10-20 years could prove to be uneconomical as plants, if used to enhance the aesthetics and water quality, would need to be replanted after every dredging.

Sediments could be shown to settle more rapidly and effectively in the detention ponds during both flow events measured. Statistical significance, and this result, could lead us to reject the null hypothesis. With confidence, recommendations regarding numerous, temporary check dams could be given to UBC and the GVRD.

More maintenance of detention ponds would be required when compared to grass channels. An estimated three to five percent of construction costs annually, are required for classical detention ponds (North Carolina State University, 2002). Temporary detention pond maintenance at UBC would require even more money, as there are many inflows and outflows in our design, compared to the single inflow and outflow of the classical detention pond. The inflows and outflows are the main source of maintenance cost, as debris jams impede the flow of water into and out of the pond (North Carolina State University, 2002). It is vital that our detention ponds do not become permanent. Temporary ponds ensure that excessive ground water recharge will not occur.

3.2 Rainwater Harvesting

I. Background

The earliest evidence for rainwater harvesting dates back to 3,700 BP, at the centre of Minoan Crete. Located there is the palace of Knossos, which was designed to harvest rain from its rooftops. The wings of the palace had openings to let light penetrate into the lower floors and at the same time, collect rainwater. The water was drained through stone drainages that led to six oblong cisterns for storage. (United Nations Environment Program, 1983)

Further evidence has been found in many other ancient European civilizations. Residential houses had rain-harvesting capabilities built right into the design of the house to allow rooftop collection. Paved courts were also used to collect rainwater. All the water collected was stored in cisterns for later use. Domestic usage is speculated as the main application. (United Nations Environment Program, 1983)

The Roman Empire used rain harvesting on a larger scale. Not only was the water used for domestic purposes, it was used for backup and for times of siege, where there was the possibility of water supply shortages. The skilled engineers of the time had deep, large cisterns built to collect roof drainage from larger areas and more buildings than previous systems. Though, once the cities of Rome grew and superseded the abilities of rainwater harvesting to provide all the water required, the Romans turned to a central water supply system. (United Nations Environment Program, 1983)

Historians believe that by the 9th or 10th century, rainwater-harvesting technologies were wide spread throughout many parts of the world. Rooftop collection and a broad spectrum of moisture management techniques for agriculture were practised in Mexico, the Middle East, North Africa, China, and India. Near the beginning of the 20th century the demand for water became too high and rain collection lost its importance. Although still used in many parts of the world, rainwater collection is generally not an accepted practice for large industrial cities in many nations due to the large availability of centralized sources. (United Nations Environment Program, 1983)

Today, areas such as Africa, Israel, and India, widely practice rain collection to obtain water for many purposes. Rain collection from rooftops is largely used for domestic purposes, while ground catchments are managed to collect water for agricultural use. (United Nations Environment Program, 1983)

Some countries depend almost entirely on rainwater for their primary source of fresh water. Government action in Bermuda helps to ensure adequate water supply. Even though there is an average annual rainfall of 1430 mm, the small island has very little area and natural land basins or catchments that can be used for reservoirs. Therefore, the government ensures that all buildings have properly constructed roofs, gutters, and storage tanks to efficiently collect water. Each house stores its own water in cisterns that are located beneath the house. The collection systems are able to supply an average demand of 80 litres of water per day per capita. Only during times of drought does the government have to transport water in from off the island. (United Nations Environment Program, 1983)

Ground catchments are commonly used to collect water via silt traps and check dams, but usually only for agricultural purposes. The water collected from ground flow contains higher levels of sediments and contaminants that may cause health risks if used as potable water. On the other hand, roof top collection dramatically reduces the sediment load and the contamination problem because the water never comes in contact with the ground. Tile is one material that is commonly used to collect water because it is quiet during rain events, and it is cheap. The only problem is it is heavy and requires stronger or reinforced supports to support the rooftop load. Other materials include corrugated galvanized iron sheet metal and corrugated aluminum sheet metal. Iron is less commonly used in coastal regions where they tend to rust due to the more saline conditions. Aluminum is just as durable, but is much lighter and easier to handle when installing. It can also withstand the salt action that corrodes iron in coastal regions. (United Nations Environment Program, 1983)

Dust and contaminants also collect on the surface of rooftops, but the majority of it is washed away during the first flush. Diverting this water away and not collecting it is the easiest way to keep the water potable without having to treat it. There are a few simple methods available to dispose of the first flush water. Australia introduced what is called a swing funnel. As shown in Figure 3.6, the swing funnel will initially fill up faster than can be leaked out through a little hole. Once the funnel has reached a certain point, it swings aside and allows the rest of the flow to be captured. Another device is called the baffle tank as shown in Figure 3.7. The first flush and all proceeding water flows into a tank where it is stilled by vertical baffles. The sediment then settles to the bottom of the tank and the clean water continues to flow through the system to storage. The downside to using the baffle tank is that the sediment must be periodically cleaned. (United Nations Environment Program, 1983)

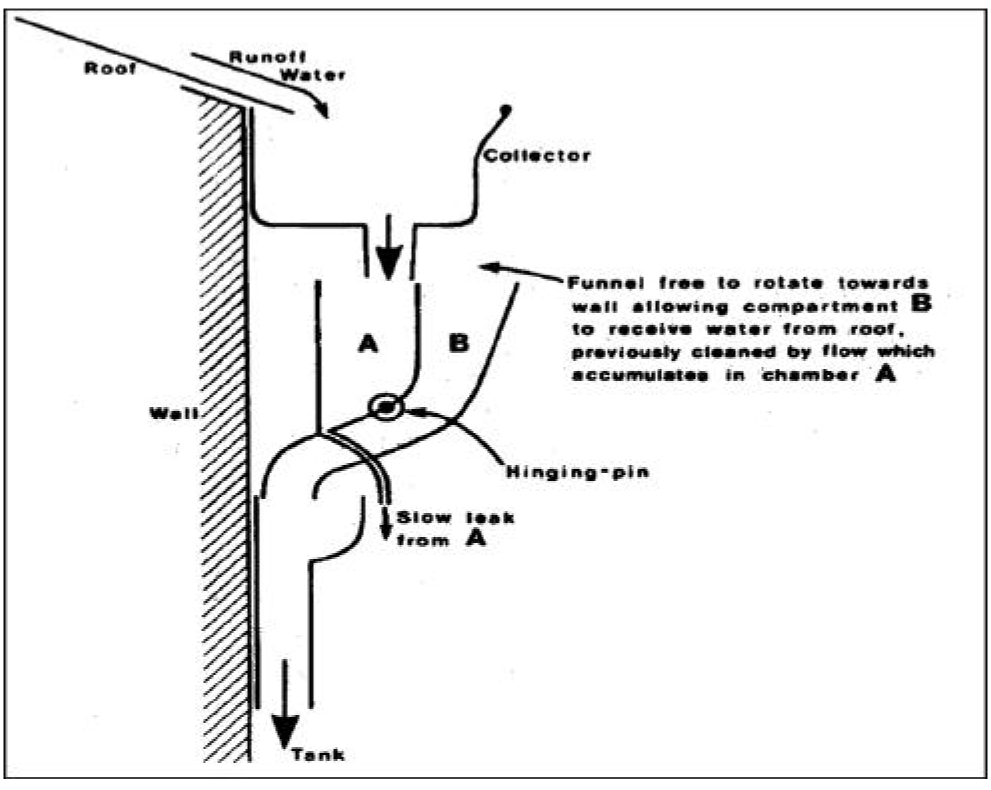

FIGURE 3.6 SWING FUNNEL DESIGN TO REMOVE FIRST FLUSH (UNITED NATIONS ENVIRONMENT PROGRAM, 1983)

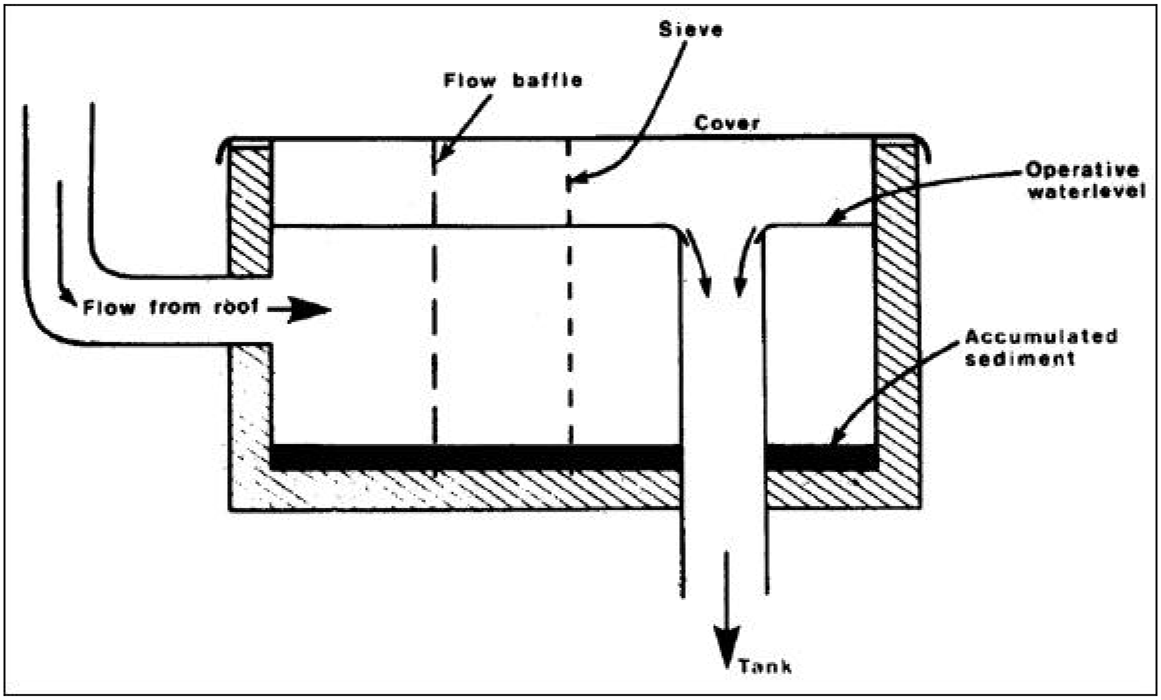

FIGURE 3.7 BAFFLE TANK TO REMOVE DUST AND CONTAMINANTS (UNITED NATIONS ENVIRONMENT PROGRAM, 1983)

Once passed the collection phase, there is the option to filter the water (which will be discussed later) and then the water has to be stored. Although there are numerous options for water storage, only a few main points should be considered when developing storage potentials. The first is that the containers should be closed to prevent evaporative loses and contamination from dust and pollution. Location of storage is important. Underground storage will maintain the water at a cooler temperature, will conserve land space, and will save on construction. If underground, the construction will be cheaper, as the walls will be reinforced naturally by the surrounding soil. Thirdly, there is usually limited capacity for long-term storage and untreated water degrades over time (United Nations Environment Program, 1983). Unless the system complexity is enhanced to treat the collected water, the storage time should remain minimal.

From storage, the water would be distributed to different systems upon withdrawal. If it were a simple residential collection system that uses the water it collects, then the water would be pumped back into the house to be used for domestic purposes. If it is a larger scale system then the water in storage can be distributed to different application systems. For example, if the water were to be used for irrigation, the water would simply be pumped from storage to either the storage for irrigation or directly to the piping system for irrigation. A pump, the proper connecting pipes, and a regulating system (manual or automatic) would be all that is required to connect the two systems.

II. Main Proposal

Although Vancouver may appear to have a vast resource of fresh water, there are many issues that suggest it should not be taken for granted. One issue is climate change. In the future, it is possible that a shift in climatic conditions (wetter or dryer) could affect the amount of rain and snow that supplies Vancouver's reservoirs. Another issue is the increasing population in the lower mainland and the demand for potable water. Either the population will have to be limited, the consumption rate limited, or new water sources would have to be found. The increase in demand may also increase the cost of water. A third issue arises in times of emergency and natural disaster. It is possible that the GVRD water system could be damaged or contaminated in large-scale events such as earthquakes or floods. This could potentially leave many residents without water. Although not unusual, it is risky to have such a large population dependent upon a single water source. It would be prudent to have back up water sources.

Rainwater harvesting can act as a back up water source. A system could be set up for emergency and general use. This would decrease the demand on the GVRD water supply and thus limit the extent of upgrades needed to the system over time.

The proposed system would consist of four main parts. In the first part, starting with the input of water as precipitation, the rain would be collected from as many building rooftops as possible on UBC campus. No load modification would have to be done to the existing rooftops since the water would not be stored there. Though, to decrease toxic chemicals from asphalt roofing and to increase the runoff coefficient, the rooftops should be covered with corrugated aluminum (Chau, 2001). The second part would consist of a filtering system to filter the rainwater at the point of collection. The water would then flow to the third part, which is the storage system. The final part of the system would be the distribution system. This would move the water from storage to other water systems on campus for application.

III. Rainwater Rooftop Collection

Many of the rooftops of the buildings on UBC campus contain tar and other chemicals that can potentially contaminate the harvested water. In order to overcome this potential contamination, the water should be prevented from coming in contact with the existing rooftops. Because Vancouver is located in a coastal region, the best option would be to use corrugated aluminum to cover the rooftops. Corrugated aluminum has a runoff coefficient of 0.80, which helps prevent major evaporation loss (Chau, 2001). The rooftops would not require further structural support because the weight of the corrugated aluminum is negligible.

In order to provide an estimate of how much water could be harvested using the buildings on UBC campus, the rooftop areas of those buildings were measured. The measurements were estimated from a 1999 aerial photograph of the Point Grey area. Error calculations were made and an estimated total area was summed. The values for the measurements of each building and the total rooftop area for UBC campus can be viewed in Appendix I. The total rooftop area from 197 buildings (or groups of buildings) is 387,000 +/- 47,000 m^2.

The rainfall data (in Appendix II) for UBC indicates that the normal rainfall in a year is approximately 1233 mm (Environment Canada, 2001). The formula used to calculate the amount of water available for harvest is:

$$R = KPA$$

The variables are as follows: R is the volume of total runoff that can be collected for a given time period, K is the runoff coefficient (estimated at 0.80 from Chau, 2001), P is the total precipitation for the given time period, and A is the total area of the catchment used to collect the water. The calculation for the total water that can be collected in a year is

$$R = KPA = (0.80)*(1.233\text{m})*(387000\text{m}^2) \approx 400{,}000 \text{ m}^3 = 400 \text{ million litres.}$$

If all the UBC buildings were used in the harvesting of that rain then it would be possible to collect 400 +/- 48 million litres of water per year. The total volume of potable water that UBC uses per annum is approximately 5.3 billion litres (UBC Campus Sustainability Office, 2001). In relation to the total volume, approximately eight percent of UBC's water usage could be harvested from rain.

IV. Filtration

Rain picks up impurities as it develops in clouds and as it falls to earth. These impurities include many metals, ions, bacterium and viruses, some of which pose a threat to human health. For the water produced from our proposed harvesting system to meet health standards and gain public acceptance these impurities must be dealt with. Five types of filtration, all of which are widely used for water quality improvement, are discussed in this section: slow sand, chlorination, chlorine dioxide, ozone, and UV.

a. Slow Sand Filtration

Slow sand filters remove small particles, pathogenic organisms, and turbidity, by the simple process of passing water through a bed of media (Collins, 1999). The removal process depends on sedimentation, flocculation, chemical processes and biological mechanisms; the actual interactions of which are not fully understood. After percolating through the media the water is collected in the under-drain system and distributed to users. The three basic parts of a slow sand filter are the filter box, the media and under-drain system, and the flow control system (Collins, 1999). Containers can be made of almost any material from concrete to corrugated iron to plastic (Slow Sand Filtration, 1995). High surface area and uniformity are important characteristics of suitable media particles (Droste, 1997). Usable media substances include sand, gravel, garnet, crushed hard coals, and manufactured plastic particles. The most commonly used substance is sand as it is cost effective and readily available in most locations. Almost any sand has a portion of particles that are the optimum size and weight for filtration, as some particles will be too fine and others too coarse (Droste, 1997).

The top layers of the filter are the most active at suspended and colloidal particle removal as this is where the biological organisms accumulate. At the activation of a slow sand filter this dense biological layer must be established. The period of time this takes is called the ripening phase and lasts a few weeks. This phase requires small layers to be scraped off the top, allowing for periods of re-growth between scrapings, until the minimum depth of medium desired has been created (Droste, 1997).

Cleaning the filter should occur approximately every 30 days and can be preformed in two ways; either the surface layers are removed and washed or they stay in place and are washed by a traveling washer. After cleaning, it takes the filter a few days to run at full operation. To bypass this delay, two filters can be used for continuous service (Droste, 1997).

Benefits of the system include simplicity to operate and maintain, relative inexpensiveness for large-scale projects (Doeksen & Barnes, 1998), and excellent pathogen removal.

The drawbacks, especially for UBC, are that the filtering process is slow as high filter rates are 10 gal/min, the system requires a large amount of land in comparison to other methods, and maintenance is labour intensive.

b. **Chlorination**

Governing bodies all over the world, including the GVWD, use chlorine for disinfecting water. Facilities utilize either chlorine gas (Cl_2), or sodium hypochlorite liquid (NaOCl) or calcium hypochlorite solid ($Ca(OCl)_2$ (GeoFlow, 2002). Chlorine is usually added at a constant rate, although variable rates may also be desired, by a feeder typically at concentrations of 2 mg/l (Connell, 1999). Other equipment necessary includes piping, tanks, detectors, and safety supplies.

The three reactions that chlorine participates in as an effective disinfectant are oxidation, substitution and disinfection. At pH's between 6 and 8 most chlorine is in the form of hypochlorus acid (HOCl) and some is in the form of hypochlorite ion (OCl^-), both are strong disinfectants (Connell, 1999). Hypochlorus acid, when reacted with ammonia, produces chloramines. They are weaker, more volatile and more easily removed by aeration but are longer lasting disinfectants. Chloramines provide some residual protection of water as they travel to the point of use and are responsible for the bad odour. Trihalomethanes are by-products of chlorine reactions involving certain organics and they may be linked to cancer and adverse reproductive effects in humans (GeoFlow, 2002). The effectiveness of chlorine water treatment depends upon exposure time and dosage. Other factors that can affect chlorines ability to treat water are temperature and, to a greater extent, pH.

Chlorine feeders cost approximately $7,000- $9,000 each and at least two are recommended, although this bulk cost does not include the other equipment listed earlier. Operation and maintenance costs can be estimated as 10-20% of equipment costs.

The benefit of using chlorine is that it is widely used and accepted for reliable water treatment. The drawbacks are that chlorine requires more infrastructure, equipment, safety gear, training, and emergency plans, as all forms of chlorine are potentially dangerous to human health (Connell, 1999). Chlorine is ineffective at removing some pathogens such as cryptosporidium and can also produce potentially harmful by-products and unpleasant odours in finished water.

c. **Chlorine Dioxide**

Chlorine dioxide (ClO_2) works much the same as chlorine and requires similar infrastructure. Chlorine dioxide comes in either liquid or solid form. Liquid chlorine dioxide degrades quickly and is therefore manufactured on site by reacting chlorine and sodium chlorite. This reaction needs to be carefully controlled so that neither chemical is wasted and undesirable by-products are not produced (Budd *et al*., 1999).

Chlorine dioxide is as powerful a disinfectant as chlorine but it does not produce chlorinated by-products and it eliminates chlorine resistant pathogens (Budd *et al*., 1999). Compared to chlorine, chlorine dioxide has lower initial capital costs.

Many of the drawbacks associated with chlorine are also associated with chlorine dioxide and make it unfeasible for water treatment at UBC.

d. **Ozone**

Ozone treatment systems are much smaller than any of the above options. Ozone is created by passing oxygen gas, oxygen liquid, or air through a chamber where a current is discharged across a gap between two electrodes, known as an electrical corona discharge (Budd *et al*., 1999). The bubbles produced are saturated with ozone and flow through the tank circulating and disinfecting the water (Promolife, 2002). Ozone disinfection depends upon contact time with substances; therefore, it takes time for a large amount of water to be treated. This means that only about 25% of the water in a storage tank can be used a day (Promolife, 2002). Ozone removes odour, taste, colour and deals with metals and pathogens such as cryptosporidium. It does produce organic oxygenated by-products including ketones, aldehydes, and peroxides but most are unstable or removed by a biodegradation in a biofilter (Budd *et al*., 1999). The system costs approximately $2,300 and includes ozone generation, feed gas preparation, ozone contacting and off gas destruction components, no pump is needed as the ozone flow circulates the water (Promolife, 2002).

Ozone systems are small, but it has the ability to treat substances that chlorine does not and with few by-products. Drawbacks are that it does not treat water quickly and it leaves no residual effects to finished water so other methods need to be employed for this function.

e. Ultraviolet Light (UV)

UV is another small system for treating water. Mercury vapour lamps are typically used to produce UV wavelengths ranging from 240 to 280 nm, and this disinfects water at a rate of microwatt seconds per cm^2 (Budd *et al*., 1999). Water is pumped around the UV lamp's sleeve, and the UV treats the water by preventing replication in microorganisms as the UV damages their DNA. Disinfection depends upon UV intensity and exposure time. Costs for UV systems depend on the volume of water to be treated per minute; for a system that treats 6 gallons/minute the cost is approximately $470 and for a system that treats 24 gallons per minute it costs approximately $2,000 (Pure Rain Over Texas, 2001).

UV systems are compact, easy to operate, require low in maintenance demands, and are able to treat water quickly. The drawbacks are that UV treatment does not produce residual protection, it only affects small biological organisms, and some bacteria can be reactivated after a few days exposure to visible light (Budd *et al*., 1999).

The most feasible system for filtering rainwater appears to be ultraviolet light, especially since the water produced from the system is general application water not drinking water. The UV system is coupled with a screen to remove the large organics that system cannot handle.

V. Water Application Options

Irrigation water does not have to be potable and thus the rainwater would not have to be filtered for irrigation purposes (Smith, 2002). UBC contains approximately 268 hectares of landscape, of which only half is irrigated (Smith, 2002). With a deteriorating irrigation system and limited employees to manage the irrigation, the system functions with less efficiency than new and updated systems (Smith, 2002). Without flow meter data, a crude estimate is used to approximate the annual irrigation volume.

Approximately 134 hectares of landscape is irrigated twice a week from the beginning of May to the beginning of October (Smith, 2002). An estimated 2.5 cm is applied to the irrigated land each week. Spanning 20 weeks of irrigation, this would amount to an estimate of 670 million litres of water per year.

Due to the seasonal variation (Figure 3.8) in precipitation and irrigation use, the only way that all the harvested rain could be applied to irrigation is if 300 +/- 36 million litres of water were stored long-term. Almost 100 million litres could be collected during the irrigation season, which could go directly to irrigation use and not have to be stored. Storing 300 million litres over the winter would require large storage volumes and, unless built underground, would take up a lot of valuable space on campus. Therefore instead of storing the water it could be filtered as it is collected and used for general purposes. General purpose application is discussed further in section 4.6.

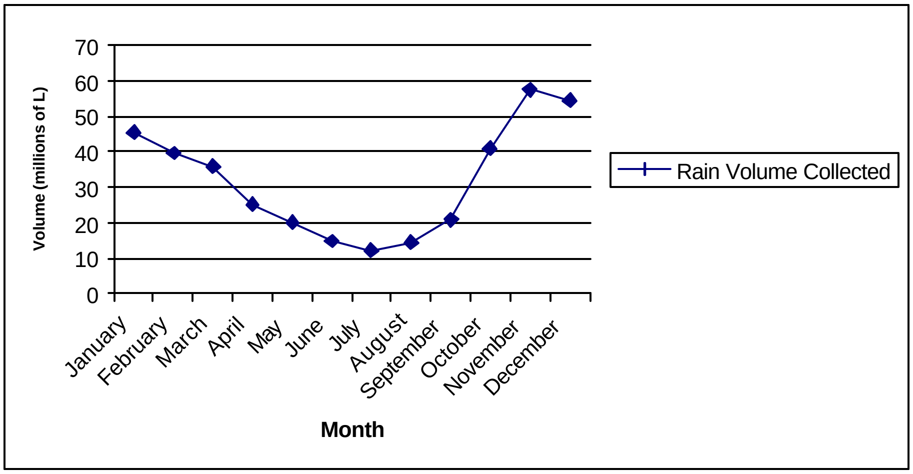

FIGURE 3.8 SEASONAL VARIATIONS IN PRECIPITATION COLLECTION

It is recommended to store at least 53 litres (14 gallons) per person. This would allow for one person to use one gallon a day for two weeks with the possibility that potable water services may not be restored for up to two weeks. The one gallon a day would provide an individual with half a gallon (~2 litres) of drinking and cooking water and half a gallon for sanitation purposes. (Safety Central, 2001)

The predicted residence population on UBC campus is expected to reach 14,000 people by 2010 (UBC Official Community Plan, 2002). With faculty, staff, other students on campus, and the surrounding residences, it would be reasonable to assume that emergency water should be stored for at least double that number. Therefore, assuming that 30,000 people would require water, the volume of storage should be able to hold 420,000 gallons (~1.6 million litres). The only problem is that non-treated water should not be stored for long periods of time, so unless the rainwater is to be treated, the treated GVRD water should be used for the storage and the collected rainwater can be used for domestic purposes in substitute for the water taken out for emergency storage.

When it comes to fire fighting, the more water the better. The problem is that more storage is needed for greater water volumes and that costs money. The water would be consumed very quickly with flow rates up to 1000 gallons per minute from the yellow or orange hydrants (NFPA, 2002). To maintain this flow rate for more than 30 minutes, more than 136,000 litres of water would need to be stored. Therefore, the storage proposed for firefighting would be good for no longer than 30 minutes.

VI. Storage And Distribution

Large portions of water will have to be stored for different periods of time. The emergency potable water will have to be stored indefinitely until there is an emergency and it is needed. This also applies for the emergency fire fighting water. Since these two water uses could use the same water supply in emergencies, the water should be stored in the same cisterns. To store the recommended amount of water for both applications (1.7 million litres) large underground storage cisterns should be used. The larger the storage, the cheaper it is and if it is underground it will take up little to no land area. Ten 48,000-gallon storage tanks would be required to hold 450,000 gallons (1.7 million litres). The only reasonable place to place these containers would be either in south campus or under the soccer fields located south of the Osborne facilities. This would cause little disturbance to buildings and the surrounding area.

Since the harvested rainwater doesn't have to go into long-term storage (unless treated), it can be collected and used as soon as possible. Storage should be made to accommodate daily maximum precipitation rates in order to prevent overloading of the system. The daily maximum precipitation rate is determined using the maximum daily flow during the wettest month. During the wettest month of the year (November), Vancouver has an average rainfall of 186 mm (Environment Canada, 2001). The average daily rainfall for that month would be approximately 6.2 mm. Since there are still residents on campus at all times, the only significant variation would be a diurnal fluctuation. So, water would have to be stored for a maximum time of eight hours overnight. Therefore, assuming water would have to be filtered and stored for a maximum of 8 hours, buildings could be organized into 20 sections with a central storage unit for each section. A plausible grouping of the buildings can be noted on the side bar of Appendix I, with the different shadings for the buildings. Each section would require filtering to obtain the desired water quality (based on filtering section). Grouping the buildings in this manner reduces the number of small storage cisterns required, but still keeps the storage units close to the collection sources. It also eliminates the need for large storage cisterns and extensive infrastructure and pumping to distribute the water to and from the large storage tanks.

Based on the estimates for the maximum flow rates and the time required to store the water, each of the 20 sections would require storage large enough to hold approximately 12,000 gallons of water. Firefighting water storage would be large enough to hold 36,000 gallons of water, and 420,000 gallons of storage would be required for emergency use. In total, 696,000 gallons of storage would be required to hold all the water. This amounts to twenty, 12,000-gallon storage tanks and ten, 48,000 gallon storage tanks.

To set up the distribution, a change to the infrastructure and piping will need to take place. Water from the rooftops can go through the filtering or treatment process by setting up new pipes that would carry the water through those systems and eventually to storage. From storage, there are a few options for the distribution of water.

The water can be added to the emergency water storage (if treated), used for irrigation, or used for general applications (discussed in section 4.6). If it is to be used for emergency storage or for irrigation, the water simply has to be added to each system via the 'existing or to be built' pipes. If the water is to be used for general applications then it will have to be distributed to academic and/or residential buildings. To do this, a backflow pressure prevention device would be required to prevent backflow into the public system. This is only necessary because rainwater is not exclusively being used (not enough can be harvested). If it were being used exclusively then there would be no worry of backflow contamination (Raindrop Laboratories, 2002).

The emergency water can be distributed in two ways. The emergency fire fighting water will have to be hooked up to the fire water system. It would have to be brought up to the same pressure and thus may need additional pumps enhance the pressure to meet the system stand. If the emergency water is just going to be used for human use, then a point source distribution system can be created for times of emergency. This would keep the access to the water within the location of storage, decreasing the chance that water mains could be damaged, ultimately cutting off access to the water. A simple pump would be required to access the stored water.

VII. Brief Summary

Vancouver receives an average rainfall of 1233 mm per year. The estimated rooftop area for the buildings on UBC campus is 387,000 m^2. Taking into account the runoff coefficient, UBC has the ability to collect 400 million litres of rainwater a year. This water can be filtered and used for multiple applications. The main applications for the harvested rainwater would be for irrigation, emergency use, fire fighting, and general use. Water would be used for irrigation during the irrigation season and would amount to approximately 100 million litres. The rest of the irrigation needs would be met by the GVRD supply. Emergency use and fire fighting water would be stored on a long-term basis. Approximately 1.7 million litres of water would ideally be stored in the case of severe emergencies. The rest of the water collected would be stored on a short-term basis and redistributed for general applications. Overall, the rainwater collected should be able to relieve eight percent of UBC's total annual water usage.

Chapter 4 - Wastewater Management Options

4.1 Background To UBC Sewage And Current Treatment

I. UBC Sanitary Piping System

The University of British Columbia has a complex sanitary piping system. It is split into two systems, the north sanitary sewer system and the south sanitary sewer system. The north system is composed of three gravity trunk sewers and two large pump catchment areas. These flow into a single gravity trunk sewer which then discharges into the Greater Vancouver Sewerage and Drainage District (GVS&DD) Spanish Banks Interceptor Line. The south sewer system is comprised of two gravity trunk mains that drain into a single gravity trunk sewer that flows into the GVS&DD SW Marine Drive Interceptor. Both the Spanish Banks Interceptor Line and the SW Marine Drive Interceptor Line eventually flow into the Iona Sewage Treatment Plant (Alpin & Martin, 2001).

The north and south sewer systems have recently had flow meter stations constructed to allow the GVRD to monitor the flows coming from these pipes. This will allow the GVRD to charge UBC for the amount of wastewater that it generates. Currently UBC pays 19.63 cents per 1000L to the GVRD (Marques, 2001).

Wastewater generated on campus can be separated into four major components: domestic, research oriented, coolant and inflow/infiltration. These flows vary throughout the year due to weather, time of day, and the number of people on campus (Alpin & Martin, 2001).

Of these four components, related to human consumption and activity, the domestic flow is the primary contributor to the overall campus flows. The people that produce the domestic flow can be separated into four population groups: core campus population (university staff, faculty members, and students), on campus residence (student, faculty, and family residences), visitors, and non-UBC tenants (Alpin & Martin, 2001).

The research oriented flow is generated by the laboratories and research facilities on campus. These flows are hard to measure because the amount can vary substantially from building to building on any given day. The coolant wastewater is generated by a number of different buildings on campus and it is discharged directly into the sanitary sewers. There are a number of different sources that use coolant water. These include: heat pumps, air conditioners, research equipment, walk-in coolers, freezers, and fridges. Inflow and infiltration are the last major components of wastewater. These sources can enter the sewer system from saturated ground conditions, manhole covers or other storm drainage components. The infiltration rates are a function of the age and condition of the pipes, soil porosity, the water table, and the intensity of the rainfall (Alpin & Martin, 2001).

The north catchment flows are generated mainly from the core campus population, with a small portion of the wastewater produced by the residential population. The south catchment services the residential population and the non-UBC research oriented facilities.

Currently, the north and south sanitary sewers generally have adequate capacity to handle the wastewater flows under existing peak conditions (Alpin & Martin, 2001). As our campus plans to expand its market housing and campus infill, some of the sanitary sewer system will need to be upgraded. The south sanitary sewer system will need the most attention as much of the current system is inadequately sized to accommodate plans for future development. Not only would more sewer mains need to be constructed, the existing mains would be undersized and need upgrading to handle the increase in wastewater flows (Alpin & Martin, 2001). Also, the SW Marine Drive Interceptor is currently reaching capacity for open channel flow within the University Endowment Lands (Alpin & Martin, 2001). This means that it would not have sufficient capacity to handle the future flows coming from the south sanitary sewer system without some upgrading or modification.

The cost to upgrade the sanitary sewer system to meet existing conditions and to meet future requirements has been assessed by Alpin & Martin Consultants Ltd to cost approximately $400,000. Further improvements of the sanitary system (which include the removal, relocation, and upsizing of mains to allow for increased flow from new development, for both the north and south campus) are estimated to cost the university an additional $5 million (Alpin & Martin, 2001).

II. Iona Island Wastewater Treatment Plant

Iona Island Wastewater Treatment Plant was opened in 1963 and treats the wastewater from Vancouver, the University Endowment Lands, and parts of Burnaby and Richmond. Since the plant was opened, it has undergone a number of upgrades. In 1973 the capacity of the system was doubled and in 1982 the capacity was again increased by 30% (GVRDb, 2001). The most recent large scale improvement was made in 1988 when $40 million was invested in the 7.5 km outfall that currently transports the primary treated effluent and discharges it into the Strait of Georgia (GVRDb, 2001).

The sewer system tributary to the Iona Island WWTP is mainly a combined sewer system, which contains both stormwater and wastewater. The system includes approximately 125 km of pipe and 8 pumping stations (GVRDa, 2001). During dry weather, the combined sewer wastewater is transported to Iona by a network of large interceptors and pumping stations. Problems arise during wet weather when the stormwater exceeds the capacity of the combined sewer system. This overflow will go directly into the Burrard Inlet and the North Arm of the Fraser River without being treated. The pollution created by the overflows is a major problem for the GVRD because of the risks to aquatic life and public health. In one study done by the Sierra Legal Defence Fund (1999) it was estimated that there are approximately 185 overflow events per year throughout the GVRD. Moreover, the GVRD estimates that 36 billion litres of combined sewage overflows every year (GVRDa, 2001).

Once the raw sewage reaches Iona, it goes through three processes before being discharged into the Strait of Georgia. Screening is the first stage of the primary treatment process (GVRDb, 2001). It involves passing the raw sewage through large filters to remove rags, sticks, plastic and other large debris. The sewage is then pumped into a grit removal system, which reduces the inorganic material, such as gravel or sand (GVRDb, 2001). Lastly, the primary settling tanks remove organic material through gravitational settling of these solids, otherwise known as sludge. From these tanks the liquid effluent is pumped to the outfall and discharged into the Strait of Georgia. There is no disinfection of the liquid effluent prior to its discharge into the Strait.

The sludge is removed from the Primary Settling tanks and treated in a series of steps. First, the sludge goes through the sludge thickening chamber. It is here that gravity thickens the sludge and the liquid effluent is removed as the sludge thickens. The liquid effluent is then pumped into the outfall. It is then passed into an anaerobic digester where mesophylic anaerobic microbes digest and stabilize the solids (GVRDb, 2001). After digestion, the liquid biosolids are pumped into lagoons to remove the water through evaporation and settling processes. Over a period of approximately eight years the lagoons dry up and the semi-solid biosolids can be removed. Of the four lagoons, one half of one of them would be emptied each year (GVRDb, 2001). These biosolids are further dried. The drying process completes the pathogen destruction and stabilizes the biosolids into a soil-like medium.

The GVRD markets its sludge as Nutrifor, a soil conditioner. It is applied to agricultural and forestland as fertilizer, golf courses as a top dress material, soil for landfill reclamation, and to gravel or ore mines as a soil amendment (GVRDc, 2001). From the five wastewater treatment facilities in the GVRD, approximately 70,000 tonnes of Nutrifor are produced each year (GVRDc, 2001). The sludge is tested for heavy metals and is retreated if the levels are higher than the allowable levels set by the permit (Sierra Legal Defence Fund, 1999).

4.2 <u>The Role Of Aquatic Plants In Wastewater Treatment</u>

I. Introduction

The concept of using aquatic plants as a natural means of wastewater treatment was initially given serious consideration in the early 1970's. The First International Conference on Biological Control of Water Pollution was held at the University of Pennsylvania in 1976 (Wolverton a, 1987). Only six papers, put forth by the primary leaders in this field, were presented at this International Conference. Some of the major contributors to the conference were Germany's Max Plank Institute, the National Space Technology Laboratories and NASA. The implications of these biologically mediated systems were of great interest to space exploration, due to the possibilities for Closed Ecological Life Support Systems (CELSS). A bloom of research throughout the world had begun.

The science behind biological treatment systems lies in the symbiotic relationship between plant and microbial communities. Plant species can be submerged, floating, or emergent. Commonly used species include water hyacinth, duckweed, and reeds. These, and other species, will be discussed in detail below. Plant roots and stems provide an ideal medium for microbial attachment, retaining the microbes within the system (Wolverton a, 1987). Microbes are a vital component behind biological treatment systems. Not only do they degrade organic matter in the water (both dissolved and particulate), they also convert carbon and other nutrients from an organic to inorganic state. As plants cannot use elements in an organic state, this conversion is necessary for plant production. In turn, plants provide oxygen to the upper water column (via photosynthesis and translocation), enabling the growth and productivity of microorganisms.

Since both plants and microbes are able to make use of the other's waste products, their relationship is not only symbiotic, but also synergistic as production will not be as inhibited by waste accumulation. Furthermore, the root hairs of aquatic plants may emit a slight electrical charge, which attracts colloidal matter in the water (Wolverton a, 1987). This attraction facilitates microbial digestion near the root surface. Wolverton also maintains that plants do in fact serve more of a purpose than simply acting as microbial medium, although he acknowledges that details of the processes surrounding this are not well known.

Plant-based treatment concepts can be extended to a variety of systems. Artificial wetlands are probably the most studied option. As wetlands are typically outdoor facilities, plant species must be compatible with external climate. Local wetland plants are often a good choice; however, there are some generally recommended species that have been extensively studied. Indoor contained ecosystems are another option. Solar aquatics, in which plants are grown in greenhouse environments with sewage tanks/vats, are a good example of an indoor system. Plant/microbial filters form yet another option, and may be adequate indoors and out. For all of the systems discussed in this section, the assumption is made that the wastewater entering the system has previously undergone at least primary treatment.

II. Floating Aquatic Macrophytes

There are 3 classes of aquatic macrophytes that must be considered for the biological treatment of wastewater: submerged, floating, and emergent species. However, due to the much slower rate of diffusion for nutrients and dissolved inorganic carbon (DIC) in water compared to air, submerged plants typically are more nutrient-limited and have a much slower growth rate

(Bowes, 1987). Therefore, they are not well suited to wastewater treatment and will not be discussed in detail in this report. Floating and emergent species are discussed below.

Of the floating plants, the most studied species is the water hyacinth (*Eichhornia crassipes*). The aggressively dominant nature of this plant has often been hard to control in its natural environment and has led to the clogging of streams, among other problems (Wolverton a, 1987). This same growth rate also makes this species desirable for wastewater treatment, since increased growth and metabolic levels are inherently linked to increased nutrient uptake rates.

The water hyacinth has been used in numerous treatment facilities, both practical and experimental, in many countries. The Walt Disney World Resort in Florida and the National Space Technology Laboratories are two examples of such facilities, which ran water hyacinth systems for at least 10 years (Wolverton a, 1987). This species has one of the highest rates of nutrient uptake among the aquatic plants studied, and can be harvested relatively easily. However, the water hyacinth performs best in tropical and semi-tropical climates, and cannot withstand cold periods or frost. This makes the use of this species in temperate regions (such as Vancouver) somewhat limited. However, use in these regions has been proven effective if grown in combination with duckweed or another temperate species. Ideally, even if productivity may decline in winter months, plants should survive through to the next spring.

Duckweed (*Lemaceae* family) is a floating aquatic species that is more tolerant of colder climates. It has been used in treatment projects across Canada and is found naturally in many temperate wetlands. Duckweed remains productive at temperatures as low as 1°C, and can withstand frosts and temperatures below freezing for short periods of time. Three species of duckweed can be used: *Lemna gibba, Spirodela polyrrhiza,* and *Wolffia arrhiza*. *Lemna* is the most competitive of these, but *Spirodela* has the fastest growth rate. A combination of all species can be used to cover a wider range of environmental conditions. *Lemna* and *Spirodela* species are commonly found in British Columbia (Whitehead, 1987). Duckweed possesses a high nutrient and protein content, and can be used as animal fodder after harvest (Aabasi, 1987).

Individual duckweed plants may be small, but they will typically form a floating mat over the water surface (Wolverton a, 1987). This mat is beneficial in that it shades the lower water and prevents the development of algal blooms, a common problem in nutrient-rich wastewater, which can lead to eutrophication. It also acts as a barrier to mosquito breeding. The effect of the mosquitoes can range from annoying to harmful consequences for the surrounding environment.

Furthermore, the floating mat can decrease the effect of wind on the surface, which can lead to re-suspension of sediments in the water column and an inhibition of growth (Tchobanoglous, 1987). It should be noted that the mat might also impair oxygen exchange between the water surface and the atmosphere. With this decrease in air exchange through the surface water, the plants have the sole responsibility of introducing oxygen to the water column. For this reason, it is recommended that water depth be shallow (<1m) to allow the roots to affect most of the water column (Wolverton a, 1987).

Water pennywort (*Hydrocotyle umbellata*) is another floating macrophyte that is adapted to temperate climates. Like duckweed, pennywort is also productive during winter months. It also works well in combination with duckweed (Wolverton b, 1987). This species is noted for its efficient oxygenation of the rhizosphere (DeBusk, T. and Reddy, 1987).

III. Emergent Aquatic Macrophytes

Emergent plants used in wastewater treatment are usually found in natural wetlands. Selection of specific species for the treatment system should ideally mimic natural wetlands in the area. Reeds (*Scirpus* and *Phragmites* spp.) have a wide geographic range and are a common choice. Cattails (*Typha* spp.) and rushes (*Juncus* spp.) are also often used. Optimum growth for most emergent aquatic species occurs in 30-60 cm of water (Lakshman, 1987; Tchobanaglous, 1987). Cattails and reeds have been noted for their ability to tolerate wide pH ranges (Lakshman, 1987). For biological treatment, emergent plants are usually applied to plant-microbial filters.

IV. Removal of N, P, BOD, TSS, And Pathogens

Productivity of the system is the primary factor determining nutrient uptake rates, plant growth rate, nutrient concentration in tissue, and standing crop biomass (DeBusk, W. and Reddy, 1987). Some research has also attributed soil properties in wetlands with enhancing the year-round ability to biologically treat wastewater. These properties include sorption, filtration, and the natural biological activity of the soil (Sundblad, 1987). Emergent macrophytes have been found to have the highest storage capacity for nitrogen and phosphorus (DeBusk, W. and Reddy, 1987). Limiting factors affecting the nutrient uptake capacity of floating plants include the composition of the wastewater effluent, climate, age, density of plants, and harvesting frequency.

Table 4.1 Biological Nitrogen and Phosphorus Removal (Debusk, W. and Reddy, 1987)

	Nitrogen Removal	Phosphorus Removal
Water Hyacinth	1950 kg/ha.yr	350-1125 kg/ha.yr
Duckweed (*Lemna*)	350-1700 kg/ha.yr	116-400 kg/ha.yr
Pennywort	540-3200 kg/ha.yr	130-770 kg/ha.yr

According to W. DeBusk and Reddy (1987), nitrogen removal occurs via plant uptake, microbial immobilization, and nitrification/denitrification. Stengel, *et al* (1987), estimates that nitrate removal via bacterial denitrification is approximately ten times that by plant uptake. Table 4.1 gives the nitrogen uptake rates for floating macrophytes. Phosphorus removal is dependant on plant growth, senescence, and chemical precipitation. Harvesting is thought to increase the amount of phosphorus removed from the system, and is estimated to be the most significant mechanism of phosphate removal (DeBusk, W. and Reddy, 1987). Alternatively, non-biologically mediated phosphorus removal is also possible (see section 4.8). Pennywort and water hyacinth are the most effective species at oxygenating the water and helping maintain an aerobic environment (DeBusk, T. and Reddy, 1987; Wolverton a, 1987). This oxygenation facilitates nitrification, which produces nitrate, which can be further used by bacteria and lost through denitrification. T. Debusk and Reddy (1987) recommended a system using a pennywort/water hyacinth combination for optimal nitrogen and phosphorus removal.

Generally, the rate of biological oxygen demand (BOD) removal from the system increases with higher levels of BOD loading. Under high loading conditions, a system can achieve 300-400 kg BOD/ha/d. For yearly averages of BOD removal, a system involving pennywort and/or duckweed is the most effective at lowering BOD. BOD is removed via microbial oxidation in the rhizosphere, water column, and sediments. Table 4.2 shows the effect of a marsh wastewater treatment system on BOD:

Table 4.2 BOD losses through an Artificial Marsh *(adapted from Wolverton b, 1987)*

ARTIFICIAL MARSH FILTERS: EFFECT ON BOD.	*Before (mg/L)*	*After (mg/L)*	*Percent Change*
Reed	306.0 71.1	36.0 2.8	88.2% 96.1%
Cattail	80.1	8.3	89.6%
Arrowhead	75.0	5.0	93.3%
Arrow-arum	53.0	2.0	96.2%
Canna lily	116.0 64.0	12.0 3.0	89.7% 95.3%

These results clearly indicate the potential impact of biological systems on BOD removal from wastewater.

Pathogens are of great concern in any wastewater system, especially if reuse is to be considered. In biological treatment options this concern is extended to both the health of the ecological system as well the health of any workers or consumers exposed. Aabasi (1987) examined the survival of coliform bacteria in artificial wetlands. Results showed that coliform levels were reduced by 99.1% after the wetland system. Without plants, only 97.5% of coliform was reduced, indicating that plants serve a greater role than simply as a microbial media. It was also shown that some aquatic plants (i.e. reeds) can excrete chemical inhibitors against coliform and other faecal indicators. Some bacteria, such as *Pseudomonads*, had a similar inhibitory effect in the rhizosphere. Longer retention times in wetland systems also contribute to natural die-off of microbial populations over time.

Harvesting of aquatic plants is an important part of nutrient removal from the system. It is a recommended procedure to remove the nutrients that have been assimilated into plant tissue, so that they are not re-introduced to the water when the plant dies and decomposes (Wolverton a, 1987). Harvesting of water hyacinth, duckweed, and pennywort is easily accomplished, usually using surface skimming devices. The harvesting also keeps the plants in the most productive growth stage, as the maximum population level is never obtained. Harvested biomass could potentially be used for energy production, either through incineration or anaerobic methane production. Aquatic plants can also be used as animal fodder. Duckweed is especially high in nutrients and protein, and serves as an excellent source of nutrition (Wolverton a, 1987).

4.3 Wastewater Treatment Options

I. Wetlands And Lagoons

Constructed wetlands have typically favoured floating macrophytes as the primary plants due to their high productivity, nutritive value, and ease of harvest (DeBusk, W. and Reddy, 1987). According to Kadlec (1987), there are six 'compartments' in a typical wetland ecosystem: macrophytes, algae, organic sediments, water, and microbes. All of these components work together to form an integrated system.

While they may share some common biological processes, wetland and lagoon systems are not the same as stabilisation ponds often found at conventional facilities. Stabilisation ponds employ only algae as a means of primary production, while wetland and lagoons rely on a much more complex ecosystem of higher vascular plants. In fact, algal growth must be kept strictly under control as it can lead to eutrophication and may destroy the system dynamics.

The main difference between wetlands and lagoons is the optimal depth. For wastewater treatment, wetlands should be relatively shallow (<1m). They usually consist of a gravel bed planted with wetland species, such as reeds. Wastewater flows laterally through the system, and organic matter is oxidized by microbial populations on the gravel and root substrates. Lagoons are deeper than wetlands (1-2m) and typically involve floating macrophytes at the surface. Lagoons can be classified as anaerobic, aerobic, or facultative depending on BOD levels and the oxygen status of the water (Ho, 2000).

Since wetlands incorporate gravel with a more complex root system than lagoons, they provide a much greater surface area for microbial attachment. A larger microbial population drastically increases the level of BOD reduction that can be incurred by the system, and leads to a faster, more efficient system for wastewater treatment.

II. Plant-Microbial Filters

Plant-microbial filters are an alternative to open wetlands. These systems focus more on microbial action than that of plants, and require much less space than wetlands. These filters usually consist of a gravel (or an artificial media) bed in which vascular, rooted plants are grown.

The basis of this system lies in the growth of bacteria using the gravel and roots as a substrate. Wastewater passes through the system by way of a subsurface horizontal flow. The attachment of bacteria to roots/rocks maintains microbial presence in the system, and allows their continued degradation of organic material. According to Wolverton a, (1987): "*The integration of emergent aquatic plants with microbial filters has produced one of the most promising wastewater technologies since the development of the trickling filter process in 1893.*"

Plant-microbial filters usually involve a long flow length through a shallow system in order to maximize microbial contact with the water while maintaining an oxic environment. They do not require the extent of land needed for wetlands due to the high concentration of bacteria. In addition, tertiary wastewater standards for BOD and TSS can be reached with this system (Wolverton a, 1987). If a greenhouse is used, an additional advantage of this system is that more aesthetically pleasing plant species can be utilized. The canna lily (*Canna flaccida*), arrowhead (*Sagittaria latifolia)*, water lily, and water iris are all examples of such aesthetically pleasing plants.

III. Solar Aquatics Overview

The Solar Aquatic wastewater treatment process is centred around a series of aerated tanks which contain microbes, insects, and invertebrates that digest wastewater as well as aquatic plants which cover the surface of the tanks. Solar Aquatics (SA) is a generic name for these systems, which are also called Living Machines, or Advanced Ecological Engineering Systems (AEES). These names are a reflection of the principles of ecological engineering, which the process is based upon. The idea behind ecological engineering is that mesocosms, which mimic natural ecosystems, can be used to solve human technological problems – in this case, the treatment of sewage. The goal is to design a treatment system, which is supracritical, meaning that it contains sufficient biological diversity to allow it to adapt itself through natural selection. This adaptation to changing conditions should affect species proportions and lead to evolution of individual species (Todd, 1996). Through these processes the treatment system can optimize itself. Those running the treatment plant need only to introduce species to the system and maintain a relatively constant environment.

The choice of biological tools in an ecological engineered system is limited only by the biodiversity found in nature, and so the possibilities for combining species in different proportions to treat wastewater are virtually limitless. Arguably the most attractive aspect of solar aquatic treatment is that ecological engineering is a relatively new science, which, because it relies on the vast complexities of nature, may continue to become more efficient in the future as our knowledge in this area grows.

The aerated tanks are normally used in conjunction with a primary aerated mixing tank or anaerobic digester, clarifiers, media filters, and constructed marshes. In cold climates most of these components are usually contained within a greenhouse to provide a suitably warm environment for the plants used in this process. While the plants do remove a small amount of the nutrients and toxins from the water, their principle role is to allow for the colonisation of microbes on their roots, which are submerged in the wastewater column. These roots provide complex surfaces with surface areas many times greater than those of synthetic media (Todd, 1996). SA systems are also characterized by modular design, which allows components to be added or altered, and facilitates the creation of steep gradients in abiotic conditions in order to maximize biodiversity and to allow different chemical and biological processes to take place. A typical SA treatment plant produces tertiary quality effluent with little sludge produced and high decontamination of pathogens.

a. **Primary Settling Tanks**

The first step in most treatment processes is the removal of solids by gravitational settling in a primary settling tank. Most treatment plants experience a diurnal fluctuation in loads due to the fact that most wastewater is produced during the waking hours of the day (Melcer *et al*, 1987). At UBC, the vast majority of the student, faculty, and staff are only on campus on weekdays between 8 am and 5 pm so the water consumption swings are very large. The primary tank stores wastewater during periods of high flow so that the rest of the system receives water at a fixed rate. A very large part of the treatment occurs at this stage, largely due to the settling out of solids caused by the slow flow of water. This tank is usually anaerobic and is commonly referred to as a septic tank or sump. It contains large populations of bacteria, which digest the sewage and reduce the biological oxygen demand. The solar aquatic system in Fredrick County, MD, uses an anaerobic settling tank to effectively remove 66% of the BOD, 83% of the TSS, 23% of the total nitrogen and 40% of the phosphorus from the wastewater stream (USEPA, 1996). These tanks can be built underground in order to reduce the land area occupied by the treatment facility. Methane produced by bacteria in the anaerobic reactor has the potential to be harvested and used as a heating source for the greenhouse. Unpleasant odours from this component can be dealt with by sending the effluent to an enclosed aeration chamber or passing the exhaust through a charcoal filter. One negative aspect of this form of treatment is that it produces large volumes of sludge, which must be removed and disposed of. Wastewater leaving this first stage is referred to as 'primary treated effluent.' Many treatment centres, including the Iona wastewater treatment plant, release primary treated wastewater into the environment without any further treatment.

b. **Blending Tanks**

Another approach to primary treatment commonly used in solar aquatics is a blending tank. This is used as a first step in the treatment process and serves to mix the effluent in order for the solar aquatic tanks to receive a consistent quality of wastewater. Instead of settling the solids in the wastewater, they are kept suspended and aerated; this reduces sludge produced in an activated sludge process (see below). By using this type of primary treatment, many solar aquatic systems produce very little sludge to be disposed of (Rink, 2001).

c. **Solar Aquatic Aerated Tanks**

This system is comprised of a series of open topped tanks with the water surface covered by floating aquatic plants such as water hyacinth, pennywort, and duckweed. Air is pumped into the bottom of the tanks so that most of the solids remain suspended. These tanks are normally arranged in two or more rows so the wastewater flow is distributed to tanks in parallel. This configuration has the advantage of allowing one row to be taken off line or undergo maintenance without totally shutting down the system. To determine the optimum treatment, one can experiment with different populations of plants/animals and different detention times between different rows.

These tanks must have a high surface area to depth ratio if the plants are to have an appreciable effect on water quality. If the tank volume is large with respect to the available growing area on the surface, the roots will not penetrate sufficiently deep into the water column. As a result, the microbial populations on the plants' roots will be insignificant when compared to the overall microbial population in the tank. Also, the plants are intended to take up nutrients and toxins from the wastewater, but clearly this will be only a small fraction of the overall nutrient load if large volumes of wastewater are passing under them. These tanks are the principle component of solar aquatics and are what make these systems unique; however, the use of these tanks create some problems for the plant designer, and may raise questions as to the usefulness of this technology in colder climates and where space is limited.

In Canada, the cold temperatures and lack of sunlight in the winter months require that solar aquatics be housed within a greenhouse. This is necessary to allow the plants, which are often tropical and subtropical species, to survive and limits the loss of heat from the system. Because greenhouses and land itself are expensive there are pressures on the designer to conserve space. As a result, large aerated tanks are often built despite the resultant loss in the effectiveness of the plants in the process. At the AEES in Fredrick County MD, the tanks were 9 feet deep and ten-feet in diameter. Because of this, when plants were completely removed from the process with no other alterations made, the quality of the effluent was not significantly affected, except in total nitrogen which was not as effectively reduced (USEPA, 1996). Without the plants, the system is not radically different from some other technologies and is simply an extended aeration tank (Brix, 1999). Therefore, in order for the merits of solar aquatics to extend beyond aesthetics and social acceptance due to perceived "greenness", the aerated tanks must be shallower. Because of this, the system lends itself to smaller scale operations or to applications in warmer climates.

d. **Extended Aeration, Activated Sludge Reactors**

These units, which are often very large, use air and mechanical mixers to maintain high dissolved oxygen levels and keep all the solids suspended. Activated sludge reactors maintain a very high level of suspended solids, which are broken down by bacteria resulting in less sludge to be removed and disposed of. The solids help with the nitrification of ammonia and the high dissolved oxygen reduces the BOD. While this process is reliant on energy for pumps and mechanical systems, it has the advantage of being applicable on both large and small scales and does not need the addition of chemicals. Also, the sludge removed from the effluent would undergo extended aeration and microbial digestion and as a result is more suitable for potential use as a fertiliser than is the sludge from a primary settling tank.

e. **Clarifiers**

Clarifiers are often used in treatment systems in order to remove suspended solids from the wastewater. They are basically short residence time settling tanks that simply use gravity to separate solids from the water prior to treatment processes where low TSS is desired. For example, a clarifier is used at the Errington, BC solar aquatic system prior to treatment in a polishing media filter in order to prevent the filter from becoming clogged (Chomolok, 2001). The sludge accumulates in the tank's cone shaped base and is periodically pumped out. This sludge can then be dewatered and disposed of, or can be returned to earlier components of the system for further solids reduction and to retain much of the bacteria.

f. **Ecological Fluidized Bed (EFB)**

EFB's can be used as a later step in a treatment process to eliminate the last of the suspended solids and reduce total nitrogen. The general premise behind this technology is that wastewater can be poured down through a medium with a specific gravity close to 1.0, which filters out any remaining suspended solids. When air or water is back-washed up through the column, the medium becomes suspended or "fluidised" and the material caught in the medium is washed out. The expelled solids are settled in a larger tank, which surrounds the EFB and can be pumped out for disposal or recycling. This technique is useful as it is basically a media filter that has a simple, automated self-cleaning capacity when operated in a counter current fashion. Media used for this system commonly include granular pumice, lightweight volcanic rock, or synthetic pellets. These filters can be used under oxic or anoxic conditions with nitrification occurring in the aerobic beds and denitrification in the anaerobic beds. When both are used in series they can be very effective in lowering the total nitrogen, provided there is a carbon source to facilitate denitrification (USEPA, 1996). Denitrification is performed by heterotrophic bacteria that use nitrate as an electron acceptor under suboxic or anoxic conditions. The nitrogen gas produced is not incorporated into biomass and is lost to the surrounding atmosphere. EFB's are often a component of solar aquatic based systems and are used in all treatment plants produced by Living Machines Inc. A diagram for the process involved in an EFB is shown below.

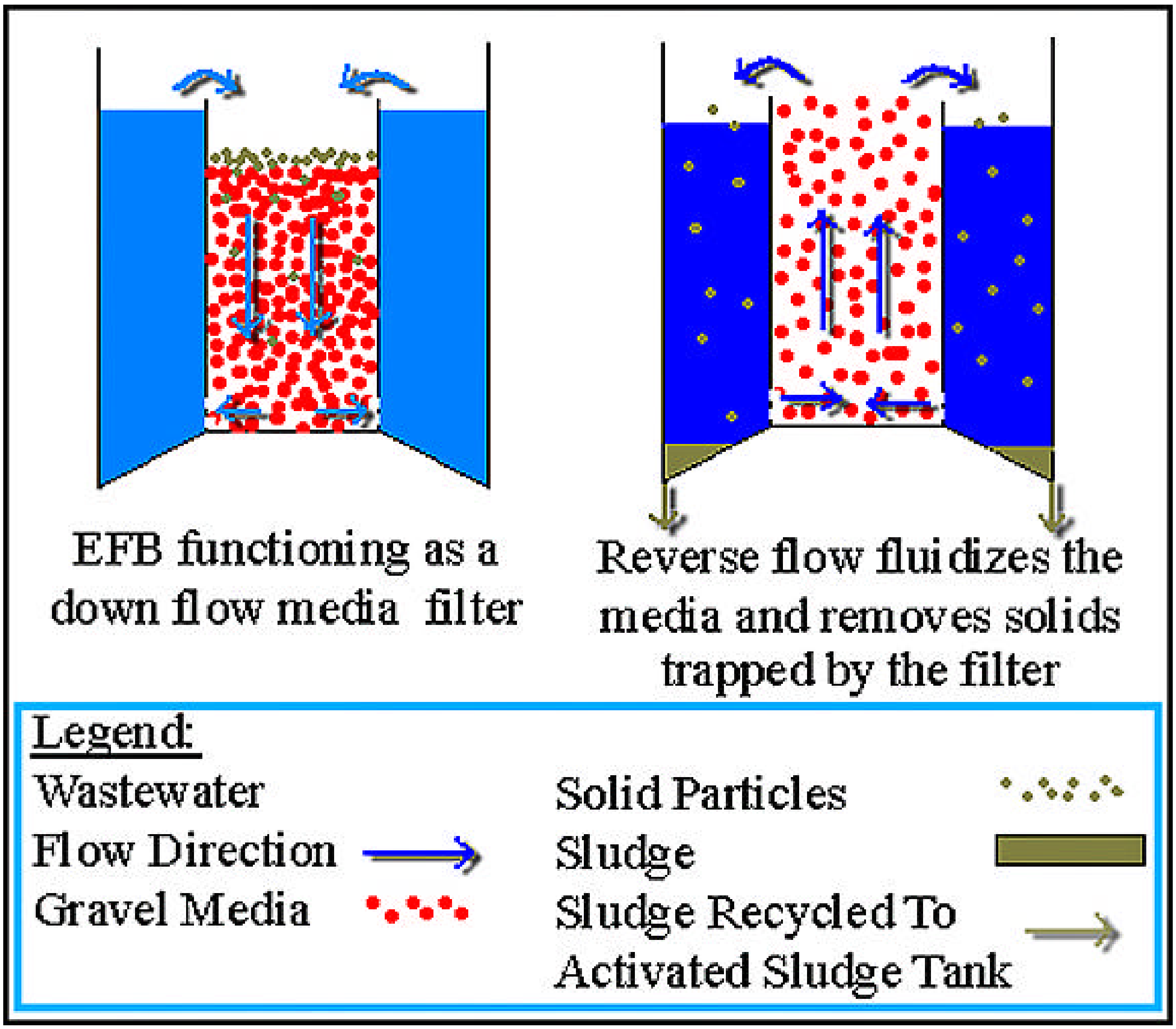

FIGURE 4.1 ECOLOGICAL FLUIDIZED BED

4.4 Case Studies

There are many options available for treating wastewater. These case studies are proof that non conventional wastewater treatment systems are workable on a larger scale in a variety of different climates. For these communities described, the alternative option was feasible and provided an excellent solution to treating their wastewater. By reviewing these eight specific examples, it is possible to see the benefits and the problems of each of the systems. It is also possible to compare each of the systems against the others for cost effectiveness for our campus.

I. Case Study Evaluation

a. Questions Considered

1. What is the description of the system?
2. What is the capacity of the system?
3. What are the capital costs?
4. What are the maintenance and operating costs?
5. How much space does it take up?
6. Have there been any problems (technological or social)?

b. Bear River Solar Aquatics Wastewater Treatment Facility

(Information gathered from www.collections.ic.gc.ca/western/bearriver.html *and via email with Nelson Porteous, the Public Works Coordinator for the Municipality of Annapolis County)*

(1) This treatment facility uses the solar aquatic system designed by Ecological Engineering Associates (EEA) of Marion, Massachusetts. The Municipality of Annapolis County, Nova Scotia purchased the rights to use this system through Environmental Design and Management Ltd. (EDM). EDM is a multidisciplinary planning, designing, and consulting firm located in Maritime Canada and is in association with EEA.

The purification of the wastewater starts with a blending tank. It is in the blending tank that the solids in the wastewater are broken up and the bacteria are added. This process is known as bioaugmentation and is helpful to convert the solids into usable material for the ecosystem

(Bear River Solar Aquatics, 2000). By breaking up the solid material, the facility avoids producing sludge like conventional systems. The sewage is then passed onto the solar tanks. There are presently twelve circular solar tanks measuring 5 feet deep by 6 feet in diameter. The tanks are gravity fed from one to the next. Each tank is a self-contained ecosystem. As the wastewater progresses from one tank to the next, more and more of the organic compounds are removed. After the wastewater has passed through all twelve solar tanks it flows into a 31 foot by 19.5-foot aerated solar pond which is approximately 9.5 feet deep. The pond contains the same types of plants and organisms as the solar tanks. The sewage is further degraded in the pond.

Some of the effluent is pumped into a marsh filled with grasses where the final water polishing takes place. The water is then passed through a "swirl separator" and a "rotary drum filter" where any remaining solids are removed and digested aerobically in underground stabilizing tanks and then applied to a "reed bed" compost. The effluent is then UV treated and gravity fed into the Bear River Estuary. While the "reed bed" is in place to deal with any remaining solids that may still be present at the end of the process this has never been required.

The provincial permit stipulations for the Bear River Solar Aquatic system are the same as those for any other municipal sewage treatment plant discharging into a similar aquatic environment in Nova Scotia (Bear River Solar Aquatics, 2000). However, the solar aquatic system treats the water to tertiary level, which exceeds any other treatment plant in the province.

(2) This system has the capacity to treat 56,775 L of sewage per day, which works out to be approximately 100 homes. Currently the system is not at capacity and is connected to only 45 households (Bear River Solar Aquatics, 2000).

(3) The system cost approximately $300,000-$400,000 to design and build. These capital costs were shared between the Federal, Provincial and Municipal governments. The Municipality only supplied between $100,000 and $135,000 of the total cost (Bear River Solar Aquatics, 2000). Money was provided from the Federal and Provincial governments because the treatment plant was the first of its kind to be built in Canada.

(4) The maintenance costs for the year (1997/1998) were roughly $40,000 which did not include the $5000 spent on guided tours in response to interest generated by the treatment plant. The goal is to reduce the operating costs to approximately $25,000 per year. Part of the initial operating cost was used for the monthly visits by EDM to ensure that the system was running smoothly (Bear River Solar Aquatics, 2000).

(5) The complete system (greenhouse/treatment area and the mechanical building) sits on an area of approximately 50' by 100'.

(6) Social problems have never been an issue for the treatment plant. The interested parties overcame the initial "not in my backyard" fears through constant involvement from the community in all stages of development. The reliability of the system is the same as any other properly run conventional system. Unpleasant odours for the treatment process are virtually non-existent due to the greenhouse system. But, when strong smells do occur they are an indicator of an overload, improper operation, or lack of housekeeping.

c. Beausoleil Solar Aquatic Water Reclamation Site

(Information was gathered from www.greenbuildingsbc.com/new_buildings/case_studies/Beausolell_Solar.pdf *and via phone with Steve Chomolok, the Operator of the facility)*

(1) The solar aquatic treatment facility is located in Errington, British Columbia and was designed by EcoTek Wastewater Treatment Inc (Green Buildings BC, 2001). It treats the wastewater from 40 mobile home units. The community was desperate to find a solution to the environmental and health hazards that were imposed on them from a problematic septic field. Due to a shallow water table, which reaches one inch below the ground surface in the winter, the soil could not absorb the septic tank effluent being pumped into it. The solar aquatic system was constructed in 1996 and was the first of its kind operating in British Columbia. It took five weeks to set up with seven people working on the site full time.

The wastewater from the mobile homes is gravity fed to a pump station where it is then pumped into an underground collection tank. From there the effluent is pumped into the greenhouse. The greenhouse is made simply of galvanized slip tube and two inflated plastic films with a four-inch separation between the two. There are multiple tanks within the greenhouse through which the effluent passes. The first few tanks are aerated, while the last tank is anaerobic. From these tanks the effluent is then passed to a polishing wetland, which is also contained within the greenhouse.

The facility grows bedding plants within the greenhouse for their own use. It also grows tropical and wetland plants that it sells to the local nurseries. A bioponic system (currently not in use) was installed to test what can be grown and sold to create revenue from the greenhouse crops.

(2) The capacity flow of the system is 56,775 L/day. However the average flow is 37,850 L/day (Green Buildings BC, 2001).

(3) The capital costs of the system were $200,000 (Green Buildings BC, 2001)

(4) The maintenance costs are approximately $14,000. One person comes to maintain the site and works for around one to two hours a day. However, according to Steve Chomolok, the operational costs were around $3 a day, which does not include the cost of power.

(5) The site area is 210 m^2 of floor space (Green Buildings BC, 2001).

(6) There are no problems associated with the smell of the sewage being treated.

d. **Cannon Beach: Wooded Wetlands For Wastewater Treatment**

(Information provided by www.epa.gov/owow/wetlands/construc/cannon/9design.html)

(1) Cannon Beach is located on the western coast of Oregon, USA. The Cannon Beach treatment system consists of a four-celled lagoon complex followed by two wooded wetland cells (EPA, 2002). The lagoon system is comprised of both facultative and aerated cells. There is also a chlorine contact chamber to provide disinfection before the wastewater enters the wetland marshes. Dikes form the wetland cells, constituting the only physical alteration to the natural wetland. The wetlands are composed of red alder, slough sedge, twinberry, and old growth spruce (EPA, 2002). The wetlands serve to reduce the biological oxygen demand (BOD) and the total suspended solids (TSS) of the wastewater. The principal mechanisms in achieving BOD and TSS reductions in wetland systems are sedimentation and microbial metabolism (EPA, 2002). Absence of sunlight in the canopy covered wooded wetland contributes to significant algae die-off and subsequent decomposition. The two-celled wetland system was designed with multiple influent ports into the first cell, multiple gravity overflows into the second cell, and a single discharge from the second cell to Ecola Creek (EPA, 2002).

(2) There was inadequate information provided to answer this question.

(3) The system cost approximately $1.5 million US. Of that, around 40% was classified as innovative and alternative, therefore higher funding was provided by the EPA. A large portion of the City's share of the cost was financed through a loan from the Farmers Home Administration (EPA, 2002).

(4) Operational costs of the wetland treatment facility are approximately $72,000 US per year. The staff employed under this budget includes one full time operator, a weekend public utility person, and a summer student intern (EPA, 2002).

(5) The two wetland cells take up a total area of 60,702.84 m^2 (EPA, 2002).

(6) There was inadequate information provided to answer this question.

e. CK Choi Building, UBC: Grey Water Trench

(Information gathered from www.iar.ubc.ca/choibuilding/Index.htm and from a phone conversation with Jeanette Frost, the mechanical engineer for the building)

(1) The CK Choi Building was built with a focus on sustainability in water use and treatment of wastewater. Efficient use of water reduced the energy that would have been used for filtering, pumping, and treating the water. The low water use fixtures and composting toilets generate minimum amounts of wastewater to be treated by the grey water constructed wetland trench (Institute of Asian Research, 2001). The water is collected from the sinks, laboratories, and fountains. It is combined with the composting tea from the toilets in the sump and pumped into the grey water trench located outside the building. Once the wastewater is passed through the trench it is collected at an outflow. From the outflow the effluent is returned to the soil through a perforated pipe.

(2) The system was made to handle a maximum flow of approximately 946.25 L per day. Currently the building does not generate capacity flow.

(3) Inadequate information was provided to answer this question.

(4) One Utility Worker, employed by UBC Plant Operations, looks after the composting toilets. He spends approximately one hour every two weeks, at a cost of $35 per hour, maintaining the composting bins and cleaning the grey water filter (Institute of Asian Research, 2001). No chemicals are added to the urinals or composting toilets for cleaning. Steve Dieter, a local representative from Clivus Multrum (the supplier of the composting toilets), is brought in to check the composting bins on a six month basis. This costs approximately $100 a visit (Institute of Asian Research, 2001). In order to eliminate any odours from the composting system, a fan runs 24 hours a day 7 days a week (Institute of Asian Research, 2001). This would be an additional operational cost to the system.

(5) The trench is approximately 36.58 meters long and approximately 30.5 cm deep.

(6) During the summer of 1996 the trench was over irrigated and the majority of the plants died off. The plants had to be replaced and it caused much delay in the treatment progress. The project engineers faced constant problems from the beginning. Problems included: the uncertainty of composting toilets, the concerns regarding human health, and trying to make a system that everyone agreed upon that would still be completely self sustainable. The problem was overcome by connecting the system to a sanitary connection just in case of an emergency. The system had to be passed by the City of Vancouver Health Board with effluent being under the allowable levels of containments (fecal coliform levels set at 200 counts per 100 mL). The only time that tests were conducted was on October 2, 1996. The city tested the fecal coliforms at the collection sump in the building and at two test ports on the trench. The results were 40 counts per 100 mL and less than 10 counts per 100 mL, respectively.

f. **Modular Peat Bed Wastewater Treatment System: Greely, Ontario**

(Information was gathered from www.chmc-schl.gc.ca/en/imquaf/himu/wacon/wacon_004.cfm and from a conversation via phone with Don Cardil, Shadow River Estates)

(1) This treatment system will be located at the Shadow River Estates in Greely, Municipality of Ottawa-Carleton, Ontario. It will treat a 600 unit housing complex (CHMC, 2001). Each of these houses will have a sewage "holding tank" where the solid waste will be diverted. The liquid sewage (grey water) is passed through pipes to the modular peat bed system, where it continues to flow through the sloped peat beds (CHMC, 2001). In the peat, the microorganisms aerobically digest the waste. The effluent is rendered acidic by the peat, so the liquid is then diverted to a limestone lined constructed wetland to further clean and neutralize its pH. The water from the constructed wetland will then flow into a nearby creek that leads to two manmade lakes. These manmade lakes were originally gravel pits and they back onto a large peat bog. The effluent at this point will meet Ontario Ministry of the Environment regulatory standards and will be of potable quality (CHMC, 2001). As peat does not freeze, it makes the peat beds especially appealing in Ontario's climate.

(2) As this type of system has never been used in a residential setting, the maximum amount of effluent that the peat beds can handle is unknown. It is thought that each module has the maximum capacity to treat the waste coming from approximately 55-75 homes. This means that at least 10 peat bed modules will have to be installed. The government wants the peat beds to be monitored when initially installed to assess the treatment capacity.

(3) The cost of each peat module is approximately $100,000; therefore the total system will cost $600,000 to create (CHMC, 2001).

(4) There is virtually no maintenance or operating costs to this self-sustaining system. However, once a year the reeds and rushes growing in the limestone wetland need to be cut and composted to prevent the accumulation of organic material. Also, the beds have a life span of approximately 55 years, so after that amount of time they will need to be replaced.

(5) The dimensions of two peat bed modules are 40m by 109m.

(6) The system is not yet in place so information regarding problems associated with the system has not been discovered.

g. **Waterloo Biofilter Systems Inc.: Prince Albert, Saskatchewan**

(Information was gathered from www.waterloo-biofilter.com*, from a conversation with Craig Jowett who works with Waterloo Biofilter Systems Inc. and via email with Vern Gattinger, an engineer involved in the project.)*

(1) The city of Prince Albert, Saskatchewan had a pilot project that included five biofilters to treat wastewater (Waterloo Biofilter Systems Inc, 2001). This system ran for approximately three years, but was finally shut down for reasons discussed below. Both the

BOD and the TSS were low, at levels of 75 mg/L and 20-30 mg/L, respectively. The Waterloo Biofilter Systems are approved and classed both as Class 10 (tertiary) and Class 4 (secondary) treatment systems by the government of Ontario (Waterloo Biofilter Systems Inc, 2001). This treatment system is a single-pass aerobic filter system designed for the biological treatment of wastewater. The process used an absorbent synthetic filter medium designed to optimize the biological degradation of the wastewater. Its high porosity and large surface area allow for excellent air passage and make the filter medium an attractive environment for the microbes. The filter medium has flow characteristics that allow for a high loading rate while still maintaining a compact size (Waterloo Biofilter Systems Inc, 2001). Allowable loading rates are typically ten times greater than sand or soil filters. The liquid effluent was treated with ultra violet disinfection and discharged directly into a nearby river, while the sludge was trucked over to the main treatment plant once a month and incinerated.

(2) The capacity of the system is 105,000 L/day.

(3) The capital costs of the system were approximately $250,000.

(4) The maintenance and operating costs were under $30 a day. This price does not include the cost of labour.

(5) The single level building, which has been described as looking like a big garage, was 15.24 meters by 9.14 meters.

(6) There were many problems that were encountered from the beginning of the pilot project. The city engineers were against the idea from the beginning because they thought that the traditional system in place was adequate. The people living in the area were never informed that the system was being tested and were unaware, because of lack of smell and the garage-like appearance, that sewage was being treated nearby. There were also many technological problems with the operation of the pilot project. The biggest problem was extracting the sludge from the clarifier without changing the pressure of the system. Changing the pressure would cause the flow to jump. This would then make the clarifier oscillate for a few cycles, disrupting the filtering process. The other big problem was timing of the bio filters to receive the clarified effluent. Once the timing was correct the bio filters performance increased. The plant effluent was then averaging <1 mg/L TSS and <5 mg/L BOD. The plant engineers later tried an idea that began dumping sludge into the bio filters. It was at this time that the money for the operation ran out and the plant was dismantled.

h. **Advanced Ecological Engineering System (AEES) "Living Machine"**

(Information was gathered from www.epa.gov/clariton/clhtml/pubtitle.html. case number: 832-B-96002)

(1) The AEES system was designed by Dr. John Todd, the President of Ocean Arks International (OAI). This particular treatment system is located in Fredrick County, MD, USA. It was built in 1993 and has been running successfully since then. The system is located across from the Ballenger Creek Sewage Treatment facility. It receives screened and degritted effluent from this treatment facility. Once this effluent is treated by the AEES the sludge and effluent is pumped back to the Ballenger Creek Sewage Treatment plant for its disposal (USEPA, 1996).

The solar aquatic system was designed using the framework of John Todd's "Living Machines". It has a variety of treatment steps. First, the effluent is pumped into an anaerobic bioreactor where the sludge is separated from the liquid effluent. From here, the liquid effluent is sent to a closed aerated tank to remove the smell from the effluent. The exhaust is pumped into an underground earth filter. The effluent is then pumped into two solar aquatic aerated tanks, the tops of which are covered by water hyacinth and pennywort plants. Bactapure N, morich powder for plant health, and kelp meal for plant growth, are added to improve the efficiency of these tanks. Both of the aerated tanks are 3.05 m wide, 2.74 m deep and 1.22 m above ground. From here, a small clarifier tank removes the solids and pumps them back to the anaerobic bioreactor. The liquid effluent is passed on to the ecological fluidized beds (EFB's), which act as down flow coarse media filters. The bed is lined with pumice gravel and air is pumped from the bottom of this pumice when cleaning of the filtered solids is required. The air is turned on to lift the pumice and remove any clogged sludge. There are three ecological fluidized beds. The last bed is anoxic and is used for further denitrification. Methanol is added at this stage as a carbon source for the denitrifying microbes. The next step is a clarifier colonized by duckweed and lastly the effluent is pumped into a high rate marsh. The high rate marsh is a constructed wetland, which is used as a polishing filter for horticultural purposes. The plants from the system have a low enough metal concentration that they can be composted

(USEPA, 1996). The sludge, collected from the anaerobic digester and the small clarifier, is too high in fecal coliform to be used for unrestricted land application (USEPA, 1996).

Table 4.3 The Influent and Effluent Parameter Measurements of AEES (USEPA, 1996)

parameter measured	units	sewage influent	effluent from marsh	overall removal (%)
total COD	mg/L	1307.0	53.2	96
total BOD	mg/L	468.8	12.5	97
TSS	mg/L	470.4	3.5	99
Ammonia	mg/L-N	25.6	5.5	79
Nitrate	mg/L-N	10.16	5.4	49
Total Phosphorus	mg/L-P	13.6	6.8	50
fecal coliform	cfu/100mL	8109.1	7.3	99.998

(2) The system treats 151,400 L per day.

(3) The capital cost of the system totalled $428,875 US. The "Living Machine" system cost $402,475 US, while the addition of the reed beds cost $26,400 US. The system was funded partially by the US Congress grant to the Massachusetts Foundation for Excellence in Marine and Polymer Sciences (MFEMPS) (USEPA, 1996).

(4) In 1995, the operation and maintenance costs totalled $50,400 US. This can be broken down into several categories: $9,000 US for energy $26,000 US for labour $4,288 for maintenance and other costs equalling $11,112 US. However, the money generated from the sale of plants has been deducted from the total operation and maintenance cost. In 1995, the system generated $2,400 US from plant sales, 75% of which was generated by the marsh (USEPA, 1996).

(5) The system takes up approximately 752 m^3.

(6) There are a few problems associated with the system. The EPA study concluded that the plants are not as effective as was initially thought by the system designers (USEPA, 1996). It was suggested that the tanks were too deep for effective treatment by microbes, which colonize the plant roots. Another conclusion reached by the study was that the duckweed clarifier was not necessary and the effluent could pass directly from the anoxic EFB to the high rate marsh (USEPA, 1996).

4.5 Post Treatment For UBC

A variety of options exist for the safe disinfection of water. These include Chlorination, Ozonation, and UV exposure. All of these have strengths and weaknesses that must be considered when making a decision about purification methods. Different situations may require different treatment options for the best results. The details and priorities of each situation should be taken into account prior to deciding on the method of disinfection.

Chlorination is the most common method of water purification in the modern world. It is fast, relatively easy and can treat large volumes of water at a time. Economically, it also has a much lower cost per litre than most other options. It is this low cost that allows chlorine to be the primary method of disinfection in most large-scale treatment facilities. An advantage of chlorine is its residual disinfection activity, which allows continued protection throughout the municipal water system. However, if water usage occurs soon after treatment (as in the proposed UBC system), long-lasting residual effects are not needed.

A negative aspect of chlorination is its ability to produce toxic by-products such as PCBs (Gottschalk *et al.*, 2000). At high dosage levels taste and odour can also pose problems (Orians, 2000). Chlorine dioxide is an alternative when this occurs, but it is very expensive and hazardous to store on site due to a high risk of explosion. It also lacks residual effects, so a lasting disinfectant must be added if needed.

Treatment using ozone is an alternative to chlorination. The overall process is similar, but ozone uses a different gas than chlorine. This method is much more effective than chlorine at destroying microorganisms in the water. Moreover, it is the only known disinfectant to kill the gastro-intestinal parasite *Cryptosporidium*. Ozonation is applicable on a large-scale as shown by the city of Milwaukee, where they have used this method since a major *Cryptosporidium* outbreak in 1979 (Deadly Parasites, 2002). While expensive on a small scale, ozone treatment can be cost-efficient for large facilities. As ozone lacks residual effects, post-treatment with chlorine may be required (Orians, 2000).

Yet another possibility for water disinfection is through ultraviolet (UV) radiation. UV radiation kills microorganisms quickly and efficiently. A contact time of only a few seconds is needed, as opposed to chlorine and ozone, which require exposure for up to an hour. The effectiveness of UV is advantageous, as it is not hampered by external factors, such as pH or temperature. Like ozone, however, UV treated water should be post-treated with chlorine to provide residual protection if needed, although this is not expected for UBC's applications. This is also one of the least expensive options for disinfection (Orians, 2000).

4.6 Applications of Water Reuse

The concepts of water reuse and 'reclaimed water' have important global consequences. In western society, approximately 80% of all domestic water finds itself in the "wastewater" category. This can be up to an exorbitant 300 L per person per day (Feigin *et al.*, 1991). Improved water use patterns would be beneficial in all areas, whether water-limited or not. Regions that regularly face water shortages may be especially affected by the many applications of reclaimed wastewater.

Benefits of water reuse in arid (and other) areas include the ability to recycle water for household or agricultural purposes. In most western societies, clean (potable) water is used each day for activities such as toilet flushing and irrigation. This water is subsequently discharged to the local wastewater treatment facility. If a community faces potable water shortages, many people may question the use of this valued resource in areas that do not necessarily require potable standards. For example, why use potable water for flushing toilets and watering the lawn when there may be barely enough to satisfy drinking requirements? The wastefulness of this lifestyle may lead to unnecessary water shortages, but these problems can potentially be alleviated through safe and efficient recycling systems.

Health aspects of water reclamation are an immediate concern. If domestic sewage (including human excrement) is to be reused, safety from pathogenic organisms must be the foremost consideration. Faecal coliform, *E. coli*, and C*ryptosporidium* are a just a few of the well-known organisms that may pose a threat to human health through contamination of the wastewater. This is an obvious barrier to be dealt with.

Social acceptability is another constraint to consider. The public must be informed of the benefits of water reuse, as well as educated about any misconceptions. They must learn to avoid viewing reclaimed water as 'sewage,' and ideally be given a basic knowledge and faith in the processes of treatment and disinfection.

Options for the application of reclaimed water are discussed below. Agricultural irrigation is one of the most common uses, and has important implications for areas facing potable water shortages. Aquaculture can also be used to grow marketable fish and aquatic plants. Further applications include domestic uses for various in-house functions, as well as industrial cooling systems.

I. Proposed Reuse Applications at UBC

One of the major benefits of producing high quality effluent from wastewater onsite is the potential for reusing this water to fulfil needs which are currently being met by the potable water supply. Drinking and food preparation account for only a small fraction of UBC's total water use. While there are no technological reasons why wastewater cannot be treated to potable standards, the availability of high quality potable water at UBC make the problems and risks associated with providing recycled drinking water too great to be reasonably considered in this context. There also are no current regulations to allow reused wastewater for drinking, cooking, or for personal hygiene and it is unlikely to be permitted in the near future (Rouse, 2002). A more realistic and promising aspect of water recycling and reuse is the use of treated water to flush toilets and urinals, wash sidewalks and buildings, cool mechanical systems, irrigate lawns, and be used in laboratories where high purity water is not required. This of course would require considerable reworking of the piping that carries water to buildings and distributes it within the buildings.

The first step in the reuse system following the treatment and disinfection of the water would be to provide water pressure comparable to that of the water currently provided by the GVRD. For this it would be necessary to build a pump house at the treatment plant to pressurize the water. From here, water mains would have to be installed to distribute water to the areas where it is to be used. The buildings that are to receive the water would have to add non-potable piping to their existing plumbing infrastructure. This would be a relatively easy task at UBC as many of the buildings on campus are built with false ceilings that would facilitate this type of change. Also, because this water will only be used for flushing toilets/urinals and cooling systems, the distribution will be limited to those areas. It is standard practice to site washrooms in a central location on each floor (i.e. one on top of the other) so many buildings would require only one principle non-potable pipe which could service all the washrooms (Ministry of Land, Water, and Air Protection, 1999). For a pilot scale treatment plant the water would only be used in one or two buildings so that the plumbing, which delivers water to the buildings, can be kept to a minimum. New buildings being built could incorporate non-potable plumbing into their design which would be even more cost effective than retrofitting existing buildings. All pipes used for non-potable water would have to be labelled and colour coded and all devices using this water would have to be signed in order to inform the user that the water should not be taken internally (Ministry of Land, Water, and Air Protection, 1999).

Systems using both potable and non-potable water, called dual water systems, are in limited use throughout Canada, and while there are no absolute barriers to implementing them, there are regulatory barriers which must be dealt with in order to reuse wastewater. The National Plumbing Code states that all water systems must be connected to a potable water supply and prohibits discharge of non-potable water through faucets, toilets and any other systems. However, there are allowances in the Code's appendix, which give some leeway to authorities in approving alternatives to the Code if these alternatives are proven to be safe (CMHC, 1997). The BC Municipal Sewage Regulation permits many uses of treated wastewater including toilet and urinal flushing, systems cooling, and irrigation. The regulation identifies two classes of reusable water, based on the probability of contact with the public. *Unrestricted public access water* has been deemed suitable by the Ministry of Land, Water, and Air Protection for irrigation of parks and school grounds, toilet flushing, outdoor washing and food crops eaten raw. Water used for these applications has a high likelihood of human contact and therefore has more stringent quality parameters than those used in restricted public access areas. *Restricted public access water* may be used for air conditioning, systems cooling, boiler feed, nurseries, and for irrigation of food crops, which will undergo processing prior to consumption. The following chart, created from schedule 2 of the Municipal Sewage Regulation, outlines the quality parameters necessary to register for wastewater reuse (Ministry of Land, Water, and Air Protection, 1999).

Table 4.4: Water Quality Standards for Reuse (adapted from Ministry of Land, Water, and Air Protection, 1999).

reuse category	pH	fecal coliform	BOD	Turbdity/TSS
unrestricted public acccess	6-9	<2.2 counts/100 mL	<10 mg/L	turbidity<2 NTU
restricted public access	6-9	<200 counts/100 mL	<45 mg/L	TSS < 45 mg/L

In the above table, the fecal coliform limit is an average for samples taken on the same day and coliform should never exceed 14 counts/100 mL in any one sample. (Ministry of Land, Water, and Air Protection, 1999). It should be noted that although the parameters given above are those generally needed to register for wastewater reuse, some applications may require additional limits. For example if water was being reused for boiler feed it would have to contain only very low levels of iron, copper, and TSS in order to not damage the equipment. (Ministry of Land, Water, and Air Protection, 1991).

II. Water Quality Issues And Monitoring

It will be extremely important to ensure that the wastewater treatment process functions properly and that it produces high quality effluent at all times. The first step is to have a continuous monitoring system in place in order to detect any problems with treatment and to make sure that the treatment plant is working at optimum efficiency. Our goal is to produce advanced tertiary quality treated effluent, which can be used for non-potable reuse throughout the campus. This requires that all of our effluent must meet strict water quality parameters (see Table 4.4). The Municipal Sewage Regulations require that there be a monitoring program in place to demonstrate that the standards for reuse are being met. For water to be safe and aesthetically acceptable to the end user, it must be virtually free of pathogens, have little or no colour or odour, and must be free of environmentally damaging substances such as heavy metals.

Other physical and chemical water characteristics that may be included in a monitoring program are BOD, turbidity, inorganic chemicals, and total suspended solids (TSS). Turbidity affects the appearance of the water, diminishes the operators ability to disinfect it, and promotes the growth of bacteria. Particles in the water may "hide" pathogens from chlorine disinfection requiring more chlorine be used (Dunn and Stidwill, 2000) and because turbid water does not readily transmit light, UV disinfection is also less effective. These issues become a problem when turbidity exceeds 5 NTU (nephelometric turbidity units) (Dunn and Stidwill, 2000). Colour is a purely aesthetic property of the water but should be kept below 30 TCU (True colour units) as not to offend the users (Dunn and Stidwill, 2000). This is particularly important here at UBC as the water currently being used has little discernible colour. Also, the intended use of the water determines how important colour is, for example, water used for irrigation need not be as colourless as that for flushing toilets. However, in our situation we must provide one quality of reuse water that is acceptable for all applications in order to simplify the plumbing infrastructure. Both turbidity and colour should be monitored continuously by an online measuring device that can log the data on a computer (Ministry of Land, Water, and Air Protection, 1999). Odour, while not quantifiably measurable, must not be detectable by the users for social reasons and offensive odours may be indicative of large populations of bacteria.

Of course the most important water quality consideration for wastewater reuse is that it poses no health risks to the public. For this we must ensure that the levels of bacteria and viruses in the water are below those that could cause people to become sick. As it is not practical to assess the presence and concentrations of all potentially hazardous organisms in the water, fecal coliform bacteria are counted as an indicator group of organisms. The absence of these bacteria, which inhabit the gut of warm-blooded animals, infers the absence of all pathogens. In the USEPA's standards for urban reuse a range of 0-200 coliform counts per 100 ml sample is suggested, although most states will not allow counts over 75 per 100 ml (Dunn and Stidwill, 2000). Here in B.C. the limit is much stricter at only 2.2 counts/ 100 mL. At the present time there are no continuous, electronic methods for counting fecal coliform so laboratory techniques, such as membrane filtration, must be used. This technique uses a fine filter to trap bacteria, which are then grown on a medium and counted. Coliform must be monitored daily and from a number of different sources around campus. If there are acceptable levels of coliform for 60 consecutive days, a simple presence/absence test may be performed weekly instead of the daily lab testing (Ministry of Land, Water, and Air Protection, 1999). This test involves simply adding a sample to a solution which changes colour if coliform bacteria are present. If a sample tests positive to the presence of fecal coliform, daily monitoring must be reinstated. If chlorine is to be used as a disinfectant, chlorine residuals are an easier, indirect way to monitor pathogens, as continuous online monitoring is available. A chlorine residual of > 0.5 mg/L will ensure that fecal coliform populations will not increase during the water's distribution (Ministry of Land, Water, and Air Protection, 1999) However, as discussed above, turbidity must also be monitored, as well as pH, since any rise in pH above 6.5 significantly reduces chlorine's effectiveness (see disinfection section).

In order to use the water for irrigation, where wastewater is being introduced into the environment, a full water analysis must be conducted. This would include assessing pH and concentrations of BOD, nitrogen, and phosphorus, as well as heavy metals and other potentially toxic substances. Following this, an environmental impact assessment would have to be conducted in order to ensure that the renovated water would not cause a negative impact. These laboratory tests could be performed weekly in order to verify the system's performance. In solar aquatic systems, the plants and animals in the system can act as alarms should a chemical upset occur. For example, aquatic snails will leave the water and crawl up the vegetation and container walls if the chemistry of the water is significantly altered. Once the treatment plant is up and running the treated effluent stream should remain fairly consistent. Most conceivable problems will result from mechanical failures. These systems will all have backups and will be monitored in order to ensure their immediate repair.

III. Other Reuse Applications

a. **Agriculture**

One of the most studied applications of reclaimed wastewater is for irrigation in agriculture. Overall, agriculture is the largest consumer of municipal water, using 70-80% of the total water supply (Feigin *et al.*, 1991). It does not, however, significantly contribute to the wastewater system, as this water is incorporated into plants and soil, or lost by evaporation. The heavy use of fertilisers can lead to problems with groundwater contamination and/or surface runoff (Feigin *et al.,* 1991), which could create hazards within the drinking water supply. Thus, the use of fertilisers should be strictly controlled to prevent excess application.

Wastewater is often high in nutrients (N, P) which can be advantageous for agriculture. This natural fertiliser has the potential to replace chemical products that are designed for the same purpose. Thus, the agricultural treated wastewater provides a convenient and beneficial method of wastewater disposal (Feigin *et al.*, 1991), since the nutrients contained within will have a practical benefit, rather than being disposed into a body of water which will then likely suffer damaging eutrophic effects.

To determine the appropriateness of using reclaimed water in agriculture, certain factors should be considered. Human health and safety is a foremost concern surrounding field workers, consumers, and nearby residents. The content and quality of water, type of irrigation, and crop type are other determining factors in using reclaimed water for agriculture (Pescod, 1992).

There are five main genera of irrigation systems: flood, furrow, sprinkler, sub-surface, and localized (Pescod, 1992). Flood irrigation involves applying water to the soil surface and allowing natural infiltration to the rhizosphere. Furrow irrigation is similar, but uses shallow ditches to transport water. Sprinkler systems use airborne irrigation, and water enters the soil like natural rain. Sub-surface irrigation uses buried pipes to supply water below the root zone, where the water enters the rhizosphere by capillary action. Localized systems use sub-surface irrigation to wet the root zone of each plant separately.

Although workers can be protected through hygiene education, the health risks associated with irrigation invariably depend upon the system (Pescod, 1992). Flooded systems are the most dangerous, as both workers and lower vegetables (*etc.*) will be in contact with the water. Furrow systems reduce exposure to the plant, but crop workers are still at risk with open water. Sprinkler systems, while not involving pools of water, may still contaminate plant surfaces. There is also an associated risk of transport downwind. Sub-surface and localized irrigation methods provide the greatest degree of protection to workers, as there is never a direct exposure to reclaimed water. This protection can be further enhanced with the use of a mulch to cover the ground. It should be noted that these systems require a higher standard of wastewater treatment, as water turbidity can clog the system (Pescod, 1992). Overall, the higher the risk to workers, the higher the water treatment needed. Therefore sub-surface and localized irrigation require less treatment, although the highest degree possible is recommended.

The type of crop and its intended use is another necessary consideration for the reuse of water. The required water quality will be decided by whether the irrigation is to be used for crops, for human or animal consumption, or for landscaping. Food crops for human consumption demand a much higher degree of treatment for irrigating water than the other options (Pescod, 1992).

Many characteristics of treated wastewater may differ from the normal water supply (Feigin *et al.*, 1991; Pescod, 1992). Specific characteristics and their magnitude will depend on the type and amount of treatment prior to irrigation. Domestic wastewater typically has elevated BOD and nutrient levels, but these can be removed during secondary treatment (see section 4.6). If it is necessary to remove excess BOD, TSS, or nutrients, this can be done via flocculation with a coagulant such as alum (Feigin *et al.*, 1991). Agricultural water usage may also lead to an increase in the salinity and/or sodicity of the soil due to the presence of salt ions in the irrigation water. However, this occurs to a greater degree when chemical fertilisers are used. Pathogenic organisms are another serious concern, and are the focus of water quality guidelines for agricultural irrigation. Heavy metals and industrial toxins should not be a major issue for domestic wastewater, but may need consideration if industrial sources are present (Pescod, 1992).

b. **Aquaculture**

The objective in aquaculture is to use reclaimed wastewater as a natural source of nutrition for fish, and possibly other aquatic organisms. If fish are not desired for the aquaculture system, harvestable plants can also be grown. As in biological wastewater treatment systems, the basis for aquaculture lies in the microbial community. Bacteria convert organic carbon and organic nutrients into inorganic form, which are then used by autotrophs such as algae and phytoplankton, or other plants. Larger organisms can feed on these small plants, ultimately producing fish at the highest level. As with agriculture, human health hazards are also a concern for aquaculture systems.

Common species of fish in wastewater reuse systems include carp, catfish, tilapia, and the freshwater prawn (Pescod, 1992). Tilapia is probably the most suited due to its ability to withstand unfavourable conditions, such as low oxygen levels, to which other species are usually susceptible. Tilapia is also one of the only species known to feed on blue-green algae, a common problem species in aquaculture (Pescod, 1992). Fish have the potential to be harvested for marketable purposes, or could remain in the system for aesthetic value.

While some types of aquatic plants may be grown and harvested for human consumption, this is not particularly common. The use of these plants for animal feed is much more prevalent, especially with high-protein plants such as duckweed (Wolverton a, 1987).

Pescod (1992) described the success of aquaculture systems as being centred on two key factors. Firstly, an "organismal balance" is needed to ensure that appropriate, natural food is available at every level of the food chain, and that energy is transferred efficiently between levels. The second factor is that of "chemical balance," which stipulates the need for a balance between nutrients and waste products. Specifically, there must be enough dissolved oxygen to facilitate bacterial growth, and wastes must not reach levels of inhibition. These two balances are intrinsically linked, in that the chemical balance is dictated by organismal use and production. Conversely, the water must maintain certain chemical properties (aerobic; available nutrients) in order to support the desired ecosystem.

Dissolved oxygen levels in aquaculture ponds are very important for maintaining production. If the DO level drops enough, the ecosystem can turn anoxic. Problems associated with anaerobic ponds include increased odour and gas production. It is important to remember that too much algae/phytoplankton can actually *lower* DO levels in the water, as they respire at night. A DO concentration of 5 mg/L (Pescod, 1992) is the minimum for most fish, although air-breathing fish, such as catfish, are usually tolerable of lower limits.

If the fish produced by aquaculture are to be used for human consumption, the accumulation and transmission of bacteria and pathogens may be cause for concern. The test for safety in this respect, is typically determined by the concentration of bacteria in the muscles of fish (Buras *et al.*, 1987). The concentration of bacteria in the ambient water is proportional to the concentration in the fish, but may not be specifically related to muscle content. Buras *et al*. (1987) showed that the presence of bacteria such as *Salmonella* and faecal coliform are not always found in muscle tissue, and suggested that guidelines be amended to consider <u>any</u> bacterial presence in muscles. It has also been shown that bacterial presence is normal in the intestinal systems of fish, and to a small degree, in organs. Care should still be taken for intestinal bacteria to prevent contamination during cleaning and gutting.

Microbial levels in reclaimed water for aquaculture should be monitored to maintain health standards. Concentrations of 0-10 bacteria per mL are considered very good, while more than 50 bact./mL is unacceptable (Pescod, 1992). The World Health Organisation (WHO) sets regulations for faecal coliform at similar levels. Common practice for aquaculture directed at consumption is to grow fish (or plants) in pure, clean water for at least 2 weeks before harvesting (Ho, 2000). This allows fish to purge their digestive system of bacteria, and improves safety for both consumers and fish-handlers.

c. **Reuse Applications Of Sludge**

The disposal of sludge is a problem encountered by all wastewater treatment facilities. Sludge is inevitably produced, but disposal and reuse options are limited. Conventionally, sludge has either been buried in sanitary landfills, left in stabilisation ponds to be digested by bacteria, or incinerated (releasing possibly harmful compounds to the atmosphere). Alternatives include the application of waste sludge as a natural fertiliser, although this also may pose problems such as nutrient overloading (Feigin *et al.*, 1991). Heavy metal and toxic substances could be harmful to the soil environment, although this is not usually a concern with domestic wastewater. Sludge can also be dried and used as animal fodder (Feigin *et al.*, 1991).

Before the use of sludge as a fertilizing compound, it must undergo a number of initial steps (Feigin *et al.*, 1991). First, the sludge must be digested. This can occur under either aerobic or anaerobic conditions, depending on the conditions of the system. It must then undergo a composting stage, followed by drying. Finally, lime is added as a stabilizing agent. If the crops are for human consumption, it will also be necessary to treat pathogens using pasteurization or irradiation. Pathogens can also be removed through composting the sludge for an extended period of time. On top of all these procedures, public access to the site of application must be strictly limited for 12 months, and animal grazing for 1 month (Feigin *et al.*, 1991). This restriction to the application site is necessary to protect the public from possilbly hazourdous exposure, as well as to protect the applier from legal implications arising from this.

There are some definite advantages to the use of domestic sludge as a fertilizer (Ho, 2000). Faecal matter has naturally very high concentrations of nitrogen and phosphorus, which are essential macronutrients for plant growth. The high organic content also provides added structure to soils, allowing for more efficient aeration and water transport. Overall, the pros and cons of sludge application must be determined and evaluated for the individual site.

4.7 Applications For UBC

I. Pilot Scale Wastewater Treatment Plant

It is the opinion of our group that UBC is unlikely to take on the enormous task of treating all of its wastewater in the near future. This is especially true if it is to be using non-conventional methods of treatment. What is more realistic is that the UBC administration may embrace the idea of a small, pilot scale treatment plant. This would certainly cost far less than a full sized plant, but would realise some of the benefits. For example a small treatment plant would provide research and educational opportunities on campus as well as enhance UBC's reputation for being an innovator in sustainable infrastructure. If the plant performs reliably with a consistently high quality of effluent, it could serve as a first step towards total sewage disposal self-sufficiency on campus. This could lead to increased public support encouraging the GVRD to increase the level of treatment of their wastewater, which often fails to meet Environment Canada's standards.

A similar proposal to the one which we are presenting, was submitted to the CFI in 2001, but failed to be approved. The CFI's role is to provide funding for research and our pilot system has been designed with several different components to maximize on the research possibilities. It is crucial that the proposal has the backing of a professor at UBC willing to use the system for research. It is our hope that by designing a system and presenting it in this thesis it may help to spark more interest in the CFI proposal with academics on campus.

Although the university would gain some environmental benefits from the pilot plant's treatment of wastewater, the pilot plant will treat less than 3% of the campus' water, so the effects on the Strait of Georgia would not be noticeable (Harrison, 2001). A pilot plant would also demonstrate the implementation of non-potable reuse for the effluent which it produces. Unfortunately, a small pilot plant will not realise the economies of scale which would come from treating the almost 3.5 million gallons of wastewater that are produced each day. Also, there is some evidence that the system which we are proposing becomes less economically favourable, when compared to other treatment systems, once they get beyond an 80,000 gal/day (302.8 m^3/day) capacity (USEPA, 1996). This is due to the solar aquatic tanks requiring a large surface area and to the fact that the system is designed with many different modules. We have addressed this by fusing solar aquatics with more conventional technologies that lend themselves to being built on a larger scale. More adjustments needed to expand the pilot system will be discussed in the *Full Scale Treatment Plant* section below.

a. **Disclaimer**

The following design for a proposed wastewater treatment plant is a variation on those that have been built by companies such as Living Machines and Vancouver-based Ecotek. However, it is different in a number of areas in an attempt to keep the best features of these systems while solving some of the problems associated with these technologies. Many of these shortcomings and suggestions for their amelioration were brought to light by a USEPA report, which provided insight into solar aquatic systems (USEPA, 1996). Some aspects of the following design are direct implementations of suggestions made in this report, while others are original ideas to address issues for which solutions were not proposed. Our group has no previous experience in the design of wastewater treatment plants and any implementation of the following plan would require the consultation of experts in this field. That said, the system outlined below is entirely based on existing technology, which has proven its effectiveness in other configurations. It is the belief of this group that by sketching a rough outline of how this pilot plant might be designed, it may provide a base for future discussions of treatment options to be built upon.

b. **System Overview**

The proposed pilot plant will have a maximum flow treatment capacity of 100,000 gal/day (378.5 m^3/day). This number was chosen as it is on the upper end in terms of treatment capacity of solar aquatic systems currently in use. Because treatment plants of this size have been built and operated successfully it provides an element of security in the sense that costs can be fairly accurately estimated, which is important at this stage. We have made alterations to the typical solar aquatics design which should allow this plant to be cheaper to build and operate than current plants and realise steeper economies of scale should a full scale plant be built. The plant will be housed in a building 30 m long by 20 m wide by 5 m tall for a total floor area of

600 m^2, half of which will be greenhouse. This is actually relatively small when compared to systems with similar treatment goals like the one designed by Living Machines in Findhorn, England, which is 300 m^2 and treats less than one fifth of our proposed sewage volume (Living Machines Ltd, 2001). It could most easily be located on the south campus as that area has the most undeveloped land and the sewage could be gravity fed to the facility. However, it would be more interesting to see it be built in a more central location in order to attract more interest from the public. It is the firm belief of this group that this proposed pilot plant has the potential to be one of the most beautiful and interesting buildings on campus – an attractive fusion of architectural design, nature, and utility. The system will be fed from wastewater generated from a number of sources in order to get a representative sample of wastewater for the entire campus. This water would include wastes from housing, labs, academic and service buildings. If the plant were located on south campus, the wastes could simply be diverted from the south wastewater outflow. In the event of an overall systems failure at the plant, sewage could be sent back to the main outflow and on to Iona treatment plant.

c. **Anaerobic Reactor**

The anaerobic reactor consists of a rectangular fibreglass-lined concrete tank 6m by 15m by 5m deep. In order to conserve valuable land, this tank will be located just under the ground surface. Before entering this chamber the water will pass through a coarse 3 cm screen in order to remove any large objects in the waste stream. The anaerobic reactor represents the first step in the treatment process where most of the solids are settled out and all chemicals dissolved in the water are diluted. To encourage particle settling, a 4m high wall will span its width dividing the tank into two stages with most of the settling occurring in the first. Liquid wastes in this tank will have a residence time of approximately 18 hours and with a 450 m^3 capacity, will be able to store excess wastewater in the event that the rest of the plant needs to be shut down for a few hours. This large capacity is also important, as sludge will accumulate in the bottom of the tank. As well as the physical processes of settling and dilution, anaerobic bacteria will be at work digesting the wastewater and sludge. The largest reductions in solids, BOD, and phosphorus should be seen at this stage. The sludge from this reactor will have to be removed, dewatered and disposed of periodically. This anaerobic reactor is very similar to that used in the Frederick

County AEES except that it is larger (USEPA, 1996). This tank should be insulated to conserve heat generated in biological activity and will produce a certain amount of gas, including methane. This methane could potentially be captured and used to heat the water in the rest of the treatment process. In order to eliminate unpleasant odours from this water prior to entry into the main building, the water will pass into an 8 m^3 sealed tank where it will be aerated using air pumps for half an hour. The exhaust from this compartment will be passed through a carbon filter to extract remaining odours and will exit out a chimney at the top of the building. The water exiting this stage would be almost odour free and is of basic secondary quality.

d. **Activated Sludge Extended Aeration Reactor**

This reactor consists of a large cylinder 6 m in diameter and 7 m high with 3 m of that extending below the floor of the facility. Wastewater will spend approximately 12 hours in this 198 m^3 reactor. The reactor will be closed and insulated and the water will be heated in order to encourage biological activity. A turbine at the bottom of the tank will ensure that solids remain suspended in the water column and air will be pumped into the water to oxidize wastes and maintain aerobic conditions for the microorganisms.

Sludge collected from later steps in the process will be recycled to this tank in order to keep TSS high to facilitate nitrification of ammonia by bacteria (USEPA, 1996). This step is not generally used in solar aquatics but is the central component of many large-scale conventional secondary treatment plants. It was added to this system to avoid the dilemma of deciding between having high TSS for nitrification or using plants in an aerated tank. Because high TSS coat plant roots, they limit their interactions with the water stream and significantly reduce their effectiveness. Traditionally, solar aquatics has sought a middle ground that limits the effectiveness of both technologies. We have avoided this here by treating the water to activated sludge in this tank and then water with very low TSS can be treated in the solar aquatic tanks. Also, as this component is often a major part of larger conventional systems it can be incorporated into the design of a full sized plant.

e. **Clarifier**

From the activated sludge extended aeration reactor, the water will flow to a 5.2 m diameter, 5 m high cylindrical tank with a conical hopper bottom and a volume of 95 m^3. Wastewater in this stage will sit stagnantly for 6 hours and the sludge, which precipitates out, will be periodically pumped back to the previous activated sludge aerated tank. The clarified water will then be piped from the top of the tank and will be split into two streams. This type of clarifier is used in many SA systems and is a larger version of the clarifier at the Errington SA facility on Vancouver Island.

f. **Solar Aquatics / Biomedia Aerated Tanks**

One of the streams from the clarifier will be treated in a series of two wide and shallow tanks with a variety of aquatic plants. These tanks will be open topped cylinders with 6 m diameters and 1.77 m depth with capacities of 50 m^3 each. The tanks will be made of glass or a transparent plastic and will be supported by a steel frame which will allow light into the water column to support algae and submerged plants. We will use mostly duckweed and water hyacinth as they are effective at removing nitrogen and do well in our climate (see section 4.2). Both of these tanks will be aerated by an air pump and may support a variety of insects, snails, and fresh water fish. These solar aquatics tanks are wider versions of the ones at the Errington SA facility. They will however receive water with lower TSS and will be made of stronger material than those at Errington as that facility has had trouble with tanks being punctured (Chomolok, 2001).

The second stream of wastewater will be treated in two consecutive tanks filled with a medium, which will be colonized by bacteria. The two tanks will be 4 m in diameter and 4 m high with 50 m^3 volumes and will both contain a high surface area plastic medium. The reason for the two methods being used at this stage is to compare the relative effectiveness of these two processes. Because the media filled tanks take up much less floor space in the plant than the solar aquatics do, they may be more practical if the plant is to be expanded, provided they provide a similar level of treatment. After a 12 hour residence time, the effluent coming from these tanks should be of basic tertiary quality with virtually no TSS or BOD and an almost 50%

reduction in both total nitrogen and phosphorus, most of which will have been removed in the sludge. Nitrification will also be almost complete, meaning that the majority of nitrogen remaining will be in the form of nitrate. Also, at least 99% of the fecal coliform bacteria will have been eliminated from the wastewater. It is at this point that water could be diverted for hydroponic cultivation of plants within the greenhouse or for aquaculture as relatively high nutrient levels still remain in the water.

g. **Ecological Fluidized Bed (EFB)**

For final polishing of the water in order to take out the last of the last of the solids, including biosolids, which may have been added in the previous step, and to complete the nitrification of ammonia, the water will spend 8 hours being circulated through an ecological fluidized bed. This tank will be 6 m in diameter and 5.3 m in height for a total capacity of 150 m^3. The volcanic rock filled core will be 3 m in diameter and will only be open to the annular space at the open top and through a screen at the bottom. A pump will circulate water into the top of the central column and another pump will backwash the rocks for cleaning hourly. All solids will be collected from the bottom of the annular outer compartment and recycled back to the primary aerated tank. This EFB is similar to that used in the Frederick County AEES except that the bottom will be sloped in order to collect the sludge and pumice is not used as a medium as pumice degrades easily (USEPA, 1996).

h. **Anoxic Denitrifying Media Tank**

Water from the EFB should be almost completely free of ammonia and TSS and be ready for denitrification. This step will involve a series of two 150 m^3 tanks that will both be ¾ filled with the same very slightly negatively buoyant volcanic rocks that were used in the EFB. The water at the top of the tank will be pumped back down to the bottom so the water will flow up through the media. The tank will be closed at the top so all processes within the tank will be anaerobic. Methanol will be added as a carbon source for denitrifying bacteria such as Pseudomonas, Micrococcus, Archromobacter, and Bacillus. These are all facultative bacteria which will denitrify under anaerobic conditions (Bridle *et al*., 1979). The added methanol could have the disadvantage of raising the BOD if added in excess of requirements (USEPA, 1996). Because of this, experimentation must be done to determine the minimum amount of methanol that can be used and we could also try putting this step before the EFB in order to oxidize the BOD.

Total residence time for this step should be about 12 hours depending on the porosity of the media layer. At this point the water is of advanced tertiary quality with very low levels of all contaminants except for phosphorus. The water exiting the denitrifying media tank should be suitable for non-potable reuse. This is conditional upon the fecal coliform levels being suitably low and some disinfection may be required (see Table 4.4). A denitrifying tank was used in the Frederick County AEES, but it was simply an EFB with a closed top and no aeration to create anoxic conditions. The pilot project tanks are different in that they are completely filled with media and will therefore be more efficient.

i. **Sub-surface Wetland**

The final component of the system will consist of a sub-surface wetland system, similar to the wetland discussed in section 4.3. Wetland plants will be grown in a gravel medium (1m deep), and both roots and rocks will serve as substrates for microbial attachment. Because a long narrow wetland is desirable for maintaining a constant flow rate the wetland will follow a serpentine path, in order to minimize the total ground area needed. This component will have a hydraulic capacity of 189 m^3, with dimensions of 9.45 m by 20 m. The channel will be 3 m wide and will consist of a series of switchbacks within the stipulated areas. The wastewater in the wetland will be retained for approximately 12 hours.

Using processes previously discussed, microbes will degrade any remaining organic compounds to inorganic forms, to be taken up by the plants. Both nitrogen and phosphorus can be removed from the wastewater this way. Removal rate is dependant on plant growth, and can be optimized by regular harvesting of the plants. Phosphorus removal can be further enhanced with filtration of the effluent through a slow sand and bauxite filter. Bauxite refining residue (a red mud) has been found to be an effective phosphate remover (Ho, 2000), and can be easily mixed with sand.

j. **Conclusion**

The water which leaves the treatment centre will be of the highest quality for renovated wastewater with less than 10 mg/L BOD, 10 mg/L TSS, 5 mg/L total N, and 3 mg/L P (Living Machines Ltd, 2001). It will be suitable for many applications throughout campus, which are detailed in the reuse section. If sufficient non-potable infrastructure is not in place at the time of plant completion, it could be sent to the Iona treatment plant through the existing piping system. It is the hope of this group, however, that all of this water be reused to satisfy all of the non-potable water needs of a small portion of the campus. If all new buildings were designed with dual water supplies prior to their being built, the implementation of water reuse would be much less expensive. A summary of the treatment process is illustrated in the following diagram.

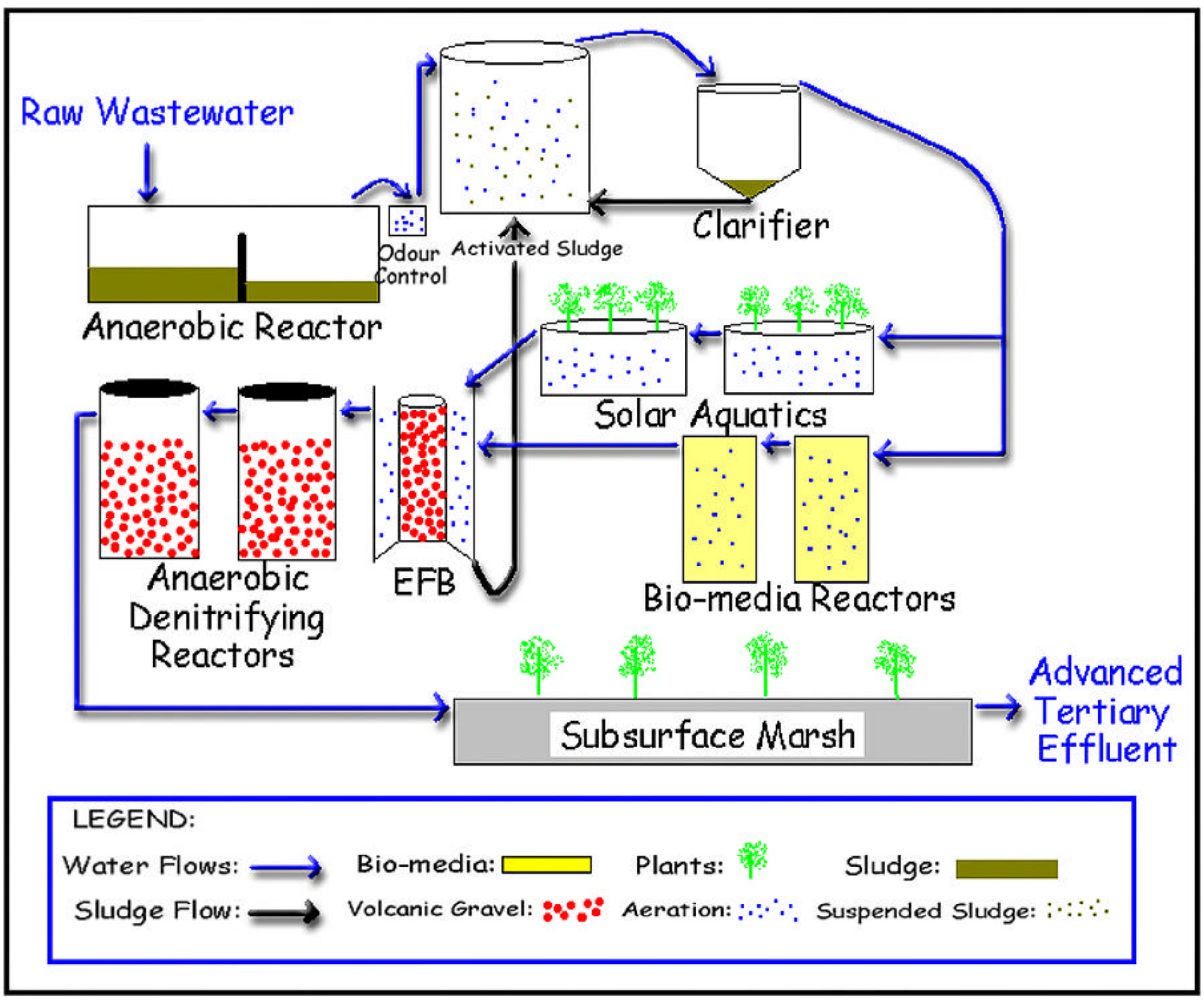

FIGURE 4.2 SUMMARY DIAGRAM FOR PILOT SCALE WASTEWATER TREATMENT

k. **Costs Of The Pilot Plant**

It is beyond the scope of this thesis and the ability of those working on it to come up with exact numbers of what our specific system would cost. But, as cost is one of the most important aspects of any proposed project some approximate figures are given here. These numbers are based on the cost of existing treatment systems. The USEPA evaluation of the Fredrick county AEES breaks down the cost of three different technologies for 80,000 gal/day (302.8 m^3/day) systems. The costs of all three systems were about the same and all share similarities with ours. From this it can be estimated that this system will have a capital cost of $1,150,000 and an annual operational cost of $215,000, which would include labour, maintenance, energy, and chemicals used. To corroborate these figures, Kim Rink, the president of Ecotek, a company which builds solar aquatics, said that a 600,000 gal/day (2271 m^3/day) system would cost about $5.6 million. So from that you arrive in the same area of a little over $1 million for our system given a slight loss in economy due to its smaller scale (Rink, 2001).

II. Full Scale Treatment Plant

Following UBC's successful operation of the pilot plant a larger plant could be built in order to treat all of the school's almost 3.5 million gallons/day (13,247.5 m^3/day) of current sewage as well as future increases in wastewater production which are inevitable as new housing developments are built on campus. Because of the large size of any plant capable of treating such large sewage volumes, it could only be located on the south area of campus and most likely on the south side of 16th avenue. Wastewater generated on the north side of campus would have to be drained to a central pump station and pumped over to the plant. The larger plant could be an expanded version of the pilot plant with some adjustments based upon experience gained through operation of the smaller plant. There may also have to be some changes made due to cost and land use constraints of the full sized plant. For example, the solar aquatics aspect of the system may play a smaller role, as it cannot be as efficiently expanded to a larger scale due to the necessity of shallow tanks and sunlight. A 4 million gal/day (15,140 m^3/day) treatment plant would cost over $18 million to build and could cost as much as $2 million per year to operate (USEPA, 1996).

Chapter 5 - Synthesis Of Stormwater And Wastewater

5.1 Summary Of Proposed System

The proposed system is comprised of three different parts, all of which affect UBC's current system: the management of storm flow runoff, the rainwater harvesting from rooftops, and the management of UBC's sewage. Management of storm flow runoff attempts to limit two main characteristics of the water: water quality and peak flows. Currently, UBC's runoff contains sediments, metals, and other pollutants typical of urban runoff. Some of this water flows through vegetated channels, which naturally act to increase water quality by filtering and contaminant uptake, but no direct attempt to ameliorate water quality has been made. There is also no attempt to directly attenuate the peak flow of storm events. Measures are being proposed to upgrade the system to handle peak flows, treat water quality, and reduce Point Grey Cliff erosion. A proposal was put forth (by Alpin & Martin) to build a large, and costly biofiltration swale, which would theoretically act to remove sediments and metals from the water. Our proposed system suggests a cheaper and simpler method that can be set up throughout the campus. The numerous small detention ponds, developed from best management practices, would temporarily pool the water behind small check dams; ultimately dissipating the peak flows of storm events. Additional benefits of the ponding allow for more settling of solids to occur and potentially more time for plants to incorporate pollutants into their biomass. The overall effect would be a decrease in the erosive capacity of the water and an increase in the quality of the water. This directly improves the erosion situation for the Point Grey Cliffs and it directly improves the water quality in the Fraser River estuary.

Of the rainwater that falls on the UBC campus, the majority of it hits the ground. Although only a small fraction of water hits the rooftops of buildings, upon proper management, it can still significantly improve many aspects of the overall water situation in the lower mainland. If the water is collected, it would take away from the storm flow water that, at high flows, can be damaging to the environment. The collected water can also be filtered and used for many applications. Using the water to fulfill needs currently met by the GVRD, would decrease the demand on the GVRD water supply. There is also an indirect effect in that it would decrease the number of overflows in the GVRD sewage treatment system.

The wastewater that leaves UBC and goes to the GVRD enters the Iona Sewage Treatment Plant. It is here that millions of dollars in upgrades are required because the plant does not meet current standards for the effluent that is dumped into the Fraser River. The effluent potentially has deleterious effects on aquatic species and may have adverse health effects on humans. By implementing sewage treatment on the UBC campus, the volume of sewage outgoing to Iona will be reduced allowing the GVRD to spend their savings upgrading the quality of the treatment at Iona and not just the quantity of treatment. On UBC campus, the proposal for a treatment facility carries many more implications. The proposed system uses a combination of solar aquatic technology and conventional technologies. A facility of this type on campus will allow for research and experimental applications for a variety of uses. Some of which could decrease the water used from the GVRD, which again, decreases the demand on the GVRD for both water and sewage treatment and disposal. Research could be done on the facility itself with the new solar aquatic technology and the use of different plants in temperate regions, or research could be done with the application and reuse of the effluent and sludge obtained from the treatment.

Overall, the three different parts of the proposed water management system have multiple and diverse improvements to some part of environment. All parts also act to accomplish the thesis goals of improving sustainability, research opportunities, and UBC independence from the GVRD.

5.2 Proposed Water Balance

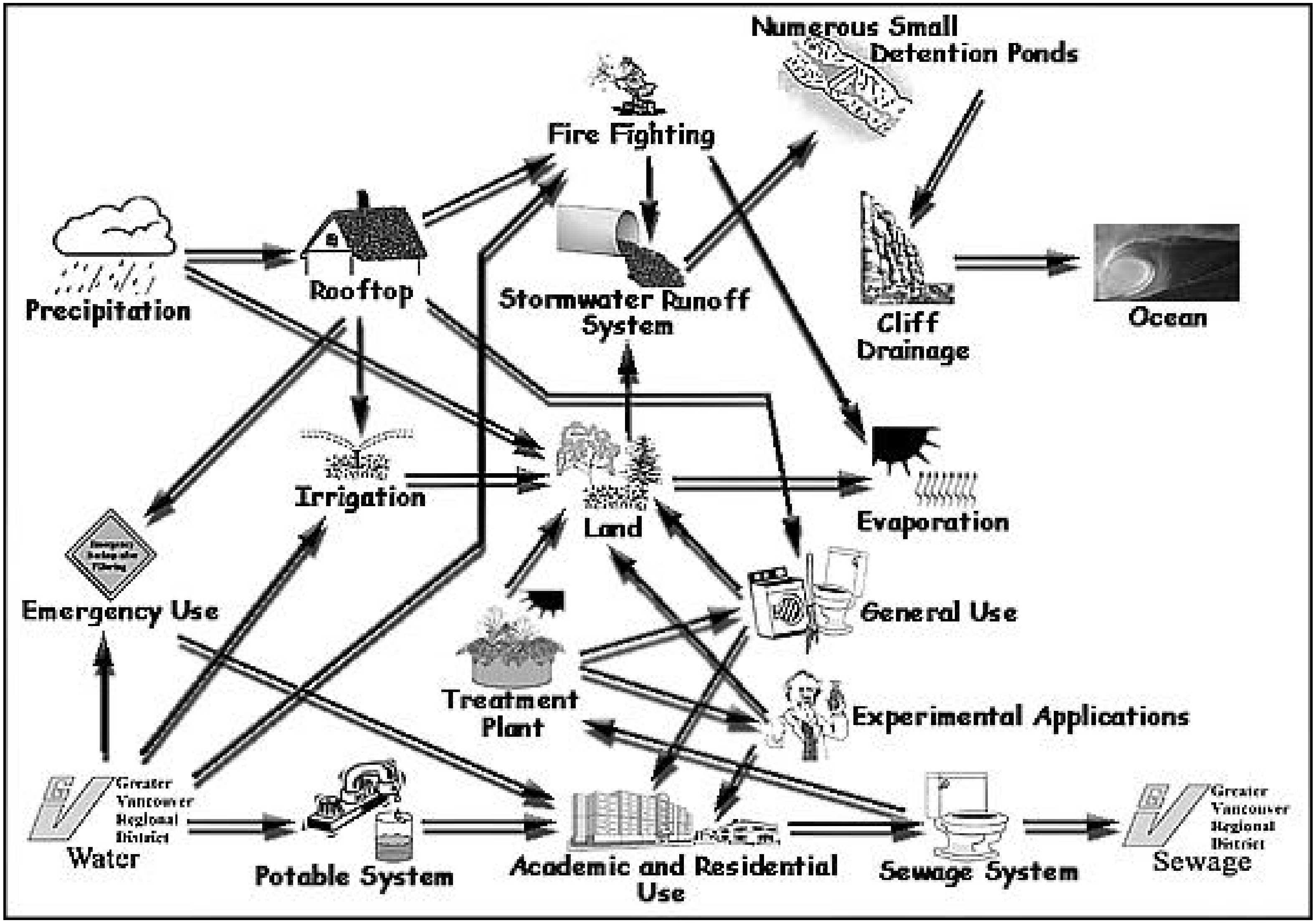

FIGURE 5.1 PROPOSED WATER BALANCE FLOW CHART

The proposed water balance flow chart is a visual representation for the proposed movement of water through the system at the University of British Columbia. The arrows do not represent the volume of water flowing from one system to the next, just the direction.

Much of the proposed system still flows in a similar manner to the current system. The only difference is a few new stages were created that redirect some of the water to different areas for treatment or reuse.

It is easiest to look at the new stages in terms of water management and water usage. Water management is composed of three new stages: 'Rooftop' rainwater harvesting, 'Numerous Small Detention Ponds' as a subsystem of the stormwater runoff system, and 'Treatment Plant' for sewage treatment. Rainwater harvesting redirects precipitation away from simply entering the 'stormwater runoff system' to more useful applications such as 'fire fighting', 'emergency use', 'general use', and 'irrigation'. The 'numerous small detention ponds' process the stormwater runoff before going over the cliff and entering the ocean. While passing this stage, the ponds act to slow the rainwater and potentially clean the water to cause less damage to the cliff side and to life in the ocean. The 'treatment plant' stage plays a large role in reducing the amount of sewage that will be sent to the GVRD for processing. The treatment plant system has the potential to convert the sewage into usable forms for experimentation, general applications, and land applications.

Water usage is composed of four new stages: 'emergency use', 'fire fighting' use, 'general use', and 'experimental application'. The 'emergency use' stage is a storage stage that holds water for times of emergency. The 'fire fighting' stage is the same as the emergency stage in that water is stored for times of emergency. Both stages can receive treated water from the GVRD or from rooftop harvesting. The 'general use' stage is for the re-application of harvested and treated water. The water can be used for a multitude of applications such as domestic use, academic use, and industrial cooling. UBC is the perfect institution to develop this technology and test 'experimental applications' to see where and how this treated sewage can be used and distributed.

5.3 Multiple Account Analysis

I. Introduction

A multiple account evaluation is used to evaluate the costs and benefits that emerge from the alternative water management strategies and wastewater treatment systems discussed in this paper. This method highlights benefits and costs that should be included in decision-making. It compares options by assessing each from the perspective of categories, called accounts, previously defined by the evaluator(s). There is an array of categories that could be accounted for, but not all are relevant to every project. The evaluator or group of evaluators decides which accounts are relevant to their project. The types of impacts and effects distinguish each category; for instance the ecological damage to a fish-bearing stream is a cost under the environment account not the financial account. The benefit of a multiple account evaluation is that it does not aggregate all costs and benefits or require that they be expressed in monetary terms. Multiple account evaluation is used as a tool for decision-making but does not yield a “yes or no” answer.

The costs and benefits of our proposed alternatives for UBC, (rainwater harvesting, wastewater treatment and temporary detention ponds), are assessed and compared to the status quo. Each system is compared to its respective component in the status quo and all systems as a unit are compared to the total status quo. Accounts for financial, environmental and social effects are used in this evaluation. The financial account, discussed first, is evaluated in monetary terms and the other two accounts are qualitatively assessed in reference to the critical value (see Glossary), which is calculated from that account.

The costs and benefits are evaluated over a 20-year period from the beginning of 2002 to the end of 2022. A discount rate (r) of 7%, as recommended by Tietenberg, is used to calculate the costs in terms of present value (PV) by Equation 5.3.1 (1996). The variable t represents the years from implementation of the project, therefore in 2002 t = 0. A discount rate of 5% is also used to test the sensitivity of results to future costs. All costs are real values not nominal values as nominal values include inflation.

Equation 5.3.1

$$PV = V_t \times \frac{1}{(1+r)^t}$$

In places all over the world and especially in BC, there are problems with how water is priced. In Vancouver water is priced by the GVRD, which forecasts the next year's demand and then determines the cost of producing that amount of water. The average price they will charge for water next year is the total cost of the forecasted demand divided by the total volume. There are a few problems with this system. As Tom Tietenberg states, " in order to adequately balance conservation with the use, the customer should be paying the marginal cost of supplying the last unit of water"(1996), this is not done in Vancouver. Since the average, not marginal cost is used, if the forecast were to fall short of actual demand, the GVRD would not be charging enough to offset the production costs on that supply of water. Another problem is that the cost of water in Vancouver does not include "marginal scarcity rent", which incorporates the marginal user cost (Tietenberg, 1996). For these reasons, water prices in Vancouver are unsustainably low. To account for the low cost of water the discount rate will not be lowered, as this would create problems such as the putting off the project indefinitely on the basis that it will be more cost effective next year. It would also problematically discount all factors including sewage and labour at a low discount rate when it is not merited. Instead, the price of water is allowed to increase from year to year, an approach that is supported by both Tietenberg (1996) and Winipenney (1991). The underlying principle is, as future water supply becomes increasingly scarce, it also becomes more precious to us. The increase is estimated at 8%, and is used to calculate the cost of water per 1000L in year t, (W_t), by Equation 5.3.2, where C is the price of water per 1000L in 2001. In 20 years an increase in water prices of 8% each year results in a price of $1.36/1000L for water and sewage ($1.16/1000L for water plus $0.20 for sewage) this does not seem unreasonable as Edmonton currently pays $1.95/1000L for water and sewage (Pate, 2001).

Equation 5.3.2

$$W_t = C_{2001} \text{ x } 2\%$$

II. The Financial Account

The financial account looks at the present cost of the project in comparison to the status quo. The present value of the status quo is determined by summing the present value of costs

UBC will incur from 2002 to 2022 due to water usage and sewage production. The cost of water, for reasons explained above, is given in Equation 5.3.2, C_{2001} = 25.07 cents/1000L (Marques, 2001). The cost of sewage is 19.63 cent/1000L and is assumed constant throughout the project, as sewage disposal does not increase in value.

The amount of water used and sewage produced is assumed to increase with population growth. UBC estimates population growth in terms of residence and employees in their Official Community Plan. Since this does not address students living off campus, the average increase from these areas will be used as the increase for the UBC population as a whole. By 2006, UBC is planning to increase the number of people living on campus (R_{2006}) by 4,000 and increase the number of jobs (E_{2006}) by 700, by 2021 these increases will be 5,300 (R_{2021}) and 900 (E_{2021}) respectively (UBC Official Community Plan, 2002). Currently there are 8,700 people living on campus (R_{2001}) and 9, 079 working on campus (E_{2001}), therefore the average increase per year is calculated by Equation 5.3.3. From this equation the increase each year up to 2006 (I_1) is 5.4%, and 1.6% per year after that till 2021(I_2). The growth form 2021 to 2022 is assumed to be the same as the growth per year estimated to 2021.

Equation 5.3.3

$$I_1 = \left(\frac{R_{2006}}{R_{2001}} + \frac{E_{2006}}{E_{2001}}\right) \times \frac{1}{2} \times \frac{1}{2006-2001}.$$

$$I_2 = \left(\frac{R_{2021}}{R_{2006}} + \frac{E_{2021}}{E_{2006}}\right) \times \frac{1}{2} \times \frac{1}{2021-2006}.$$

Using I_1 and I_2 calculated above, Equation 5.3.4 is used to extrapolate the 2001 amount of water usage and sewage production (A) to 2002 and later years. It is assumed that all water and sewage on campus is affected by this population growth. These assumptions are not necessarily an accurate representation of what occurs from one year to the next: expansion is geared more heavily toward some years than others, not all water use is population dependant and the population increases based on averages. However, they do allow for a reasonable estimate of future water use and sewage production.

Equation 5.3.4

$$A_t = A_{2001}(1+ I)$$

Table a, Appendix IV, provides the costs of both water usage and sewage production each year until 2022. The total cost of the status quo over the next 20 years is roughly $65.4 million. Costs were also summed per year to give the cost since 2002 to any year after, the cost to present column in Table a, Appendix IV. This information is illustrated in Figure 5.2.

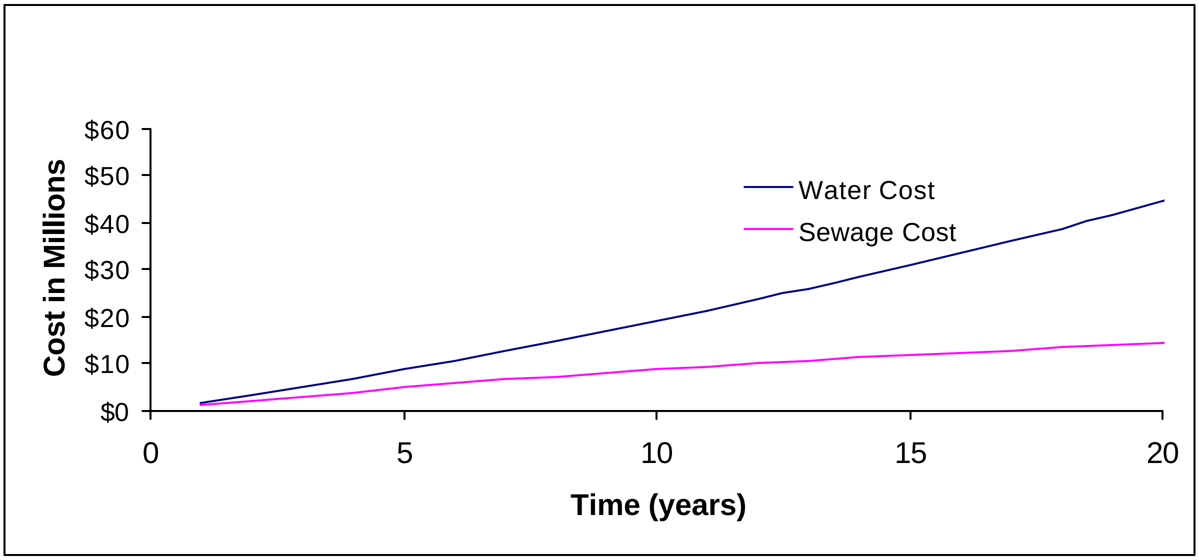

FIGURE 5.2 WATER AND SEWAGE COSTS OVER THE NEXT 20 YEARS

Our proposed system would allow UBC to be more independent from the GVRD, cutting water demand and thus cost. There are three components of our proposed system: rainwater collection (Table b, Appendix IV), wastewater treatment (Table c, Appendix IV), and temporary detention (Table d, Appendix IV). Each component is analysed separately and, since the rainwater harvesting system could be hooked up to the wastewater treatment facility, these two components are analysed as one system. Costs include one-time purchases such as the materials, installation and land, as well as costs that will occur over the next 10 years such as maintenance.

The costs of the rainwater collection system include installation, maintenance, storage tanks, corrugated aluminium sheets, pipes and filters (the last three costs are aggregated under system costs. The storage tanks are the most expensive parts of the system costing $30,713 for the 12,000-gallon tanks and $92,141 for the 48,000-gallon tanks (Water Tanks, 2001). Maintenance costs are low for the collection system as it is relatively simple and could be woven into a Plant Operations job. Maintenance and installation costs were estimated at $50/hr, the price UBC pays for skilled labour (Mazzi, 2002). Installation of the rainwater harvesting system is estimated to take 8 labourers, 8 hrs/day, three weeks and maintenance one labourer 8 hrs/month every year. The system has the ability to supplement 400,000,000 L of water demand with rainwater each year. Figure 5.3 shows how costs of the system, maintenance and installation compare to water savings over the next 20 years. As illustrated in the graph, by the intersection of the cost and savings lines, the project pays for itself in just over 15 years. Even if the rainwater system only supplemented 100 million litres it would pay for itself within a 20-year time frame. Table 5.2 shows the cost of the rainwater system plus the cost of water demand that is not supplemented by the system over the 20-year period.

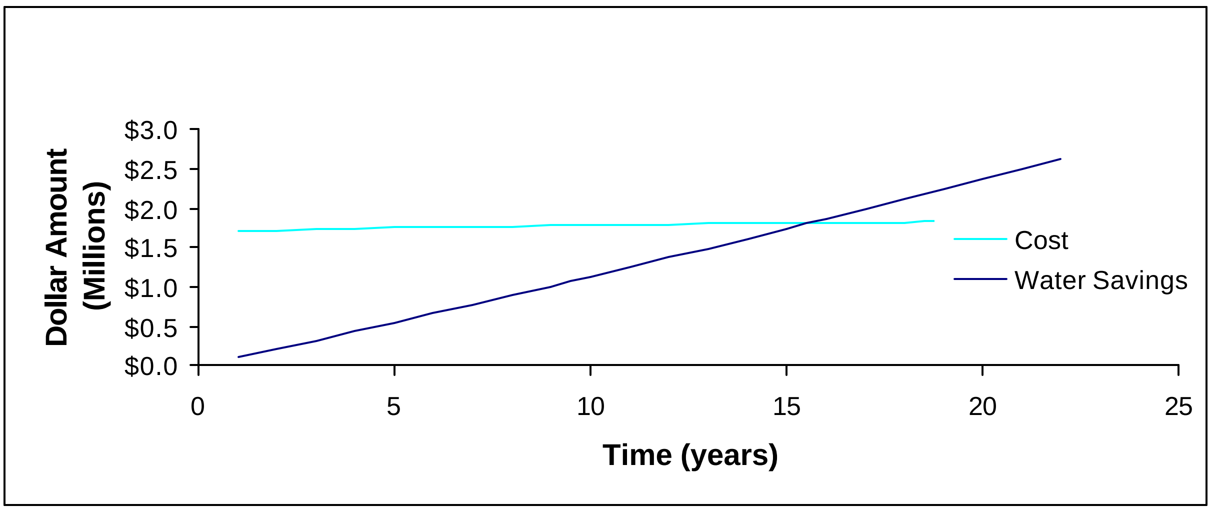

FIGURE 5.3 RAINWATER HARVESTING COST AND SAVINGS OVER TIME

The pilot wastewater treatment facility has the capacity to treat 378,541 L of the sewage and reduce water demand by the equivalent amount. The costs include the system and installation at $1.15 million, storage and treatment $190,000, maintenance at $210,000/year, and land $519/m^2 (Barrs, 1995). The pilot facility costs $18.9 million generates saving both from supplemented sewage treatment and water production. Figure 5.4 shows that these savings do not pay for the system in 20 years, but it may in the future.

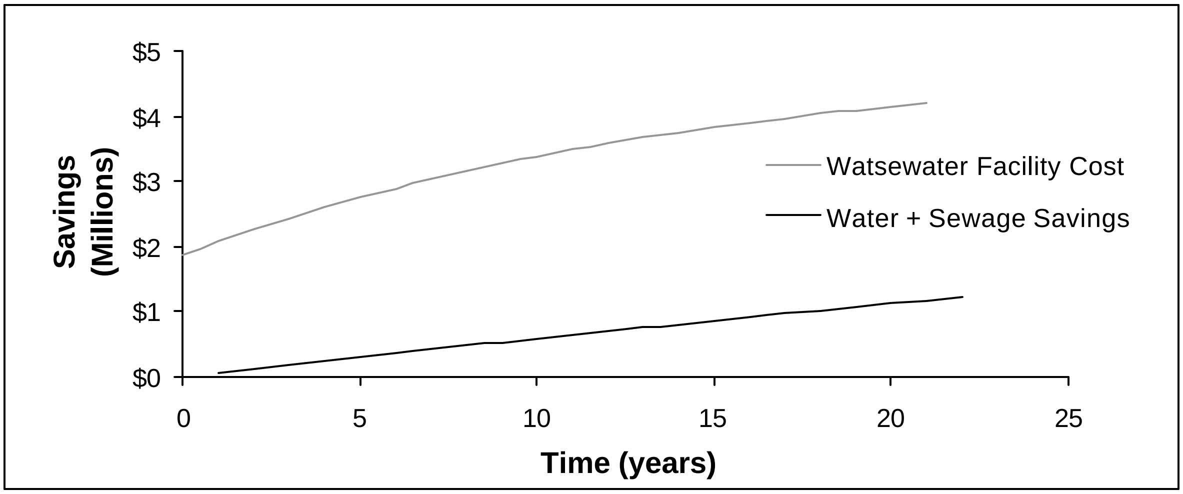

FIGURE 5.4 WASTEWATER FACILITY AND SAVINGS OVER THE NEXT 20 YEARS

The costs of the rainwater harvesting and wastewater facility sums to $68.3 million and comparing this to the above estimate places the cost of the project at $2.9 million more than the status quo. The comparison of savings to system costs is represented in Figure 5.5. $2.9 million as listed in Table 5.4, is referred to as the critical value. Theoretically, since reduction of water demand from the GVRD is a function of our project and the GVRD benefits from this reduction, they may be willing to contribute to the overall cost of the project, thus reducing the critical value.

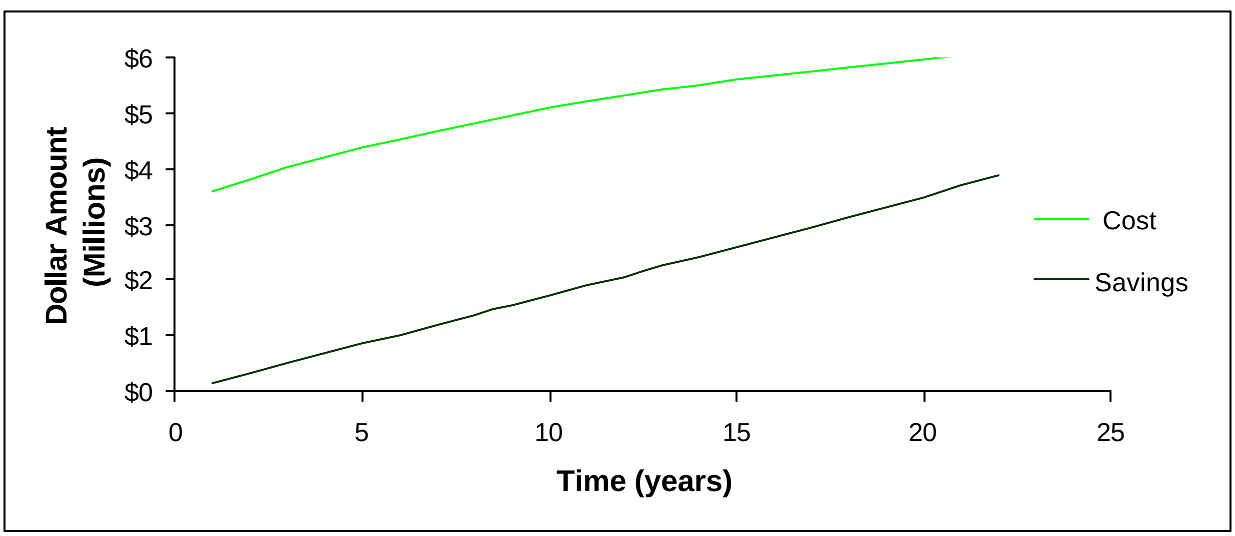

FIGURE 5.5 WASTEWATER FACILITY AND RAINWATER HARVESTING COST AND SAVINGS OVER THE NEXT 20 YEARS

Our temporary detention ponds are compared to the Alpin & Martin proposal, which costs approximately $1.45 million. The supplies for our temporary detention pond channel include sandbags ($0.46/bag), 10ft by 5ft pieces of plastic ($0.15/sheet), and PVC pipes($1/ft) (Dawson, 2002). These costs sum to $5.75/10m length of channel, and since there are approximately 10,000m of ditch that could be changed into temporary detention pond channels on campus, this amounts to $5,750 in supplies. The channel will also contain 20 plants/10m and each plant is priced at $2 (Pinette, 2002). Installation is estimated to take 2½ hrs/10 m at $48/hr and maintenance 1 hr/week also at $48/hr (Dawson, 2002). Maintenance every 10 years includes dredging and replanting, which is estimated to take twice the time as regular maintenance, on top of regular maintenance costs. The comparison shown in Table 5.1 makes it apparent that our proposed channel would be more cost effective than theirs, serve the same function, as well as improving aesthetics and increasing habitat for wildlife.

Table 5.1-Temporary Detention Pond Channel Compared to The Alpin & Martin Proposal (2001)

Account	Temp. Detention Pond Channels	Alpin & Martin
Financial	♦ $0.36 million	♦ $1.45 million
Social	♦ Aesthetic ♦ Decreased Erosion	♦ Decreased Erosion
Environmental	♦ Improved water quality	♦ Improved water Quality

III. The Social and Environmental Accounts

The social account includes different social benefits that occur to slightly different parts of society. Many in the UBC community will attribute an existence value to our project because UBC has increased independence from the GVRD and has become more sustainable and environmentally responsible. The sewage treatment plant, a solar aquatic system, could be used as a research and educational facility and thus has a use value to researchers as well as users. SFU has estimated this to be worth $60,000 over 10 years from the cost benefit analysis of a solar aquatic system in a proposal they created (SFU, 1999). This is an underestimate, as SFU only included revenue from specific educational programs and did not include research value. There would also be a positive option value inherent in having two supplies of water, if one supply is cut-off then the other could supplement as a back up. For instance, if there is an earthquake that severed the pipes running from the GVRD to campus, or the GVRD watersheds became infected with Cryptosporidium or Giardia, the water from the sewage treatment and rainwater collection could be rationed out for use or visa versa if water produced on campus becomes unusable. Since we are decreasing our reliance on the GVRD, but not severing our connection with them, UBC only increases its options. The actual benefit of this may very likely be small as the likelihood of these events is low, however the perceived benefit will probably be greater especially in light of recent water contamination issues in Ontario. Another benefit of our project is that UBC will decrease its demand on the GVRD watersheds. Decreased erosion is another benefit due to rainwater harvesting and stormwater detention. Erosion is a major issue on campus that involves various groups from all over Vancouver. Erosion is a natural process, so the account that suffers most from high erosion is the social account. A lot of money is spent on erosion control, as it is socially undesired. Therefore, erosion control could also be categorized in the financial account. However, it is difficult to estimate the dollar savings that could arise from our alternatives as the relationship between runoff and erosion amounts is largely unknown and the number of interest groups involved is large. Therefore the best way to include erosion in this evaluation is as a non-monetary factor.

From an environmental perspective these alternatives help UBC become more environmentally friendly by reducing our impact on our natural resources. If the project were implemented, UBC would decrease its impact on the GVRD watersheds. The watersheds have been manipulated to produce water Vancouver and its surrounding municipalities. At present the impact of this activity has little detrimental effect on the surrounding area, however, increasing demand and climate change bring the possibility of more severe strain on the water supply and biophysical region. The situation at the Iona Island Sewage Treatment Facility is much the same; impacts on the environment are poorly understood, but may be found to be serious over time. If deleterious environmental effects of the facility become prominent, the cost to upgrade the Iona Island Sewage treatment system to secondary treatment would be in the $400 million range (Nenninger, 2001). The UBC facility would treat water one step further through tertiary treatment. The environmental benefit is that UBC decreases the possibility for environmental damage. Another environmental benefit that is difficult to put a value on involves the ability of temporary detention ponds to improve stormwater quality. The levels of pollution that have entered the Georgia Strait and the Fraser River from UBC have not been documented, therefore the effects of poor quality water going into the Georgia Strait are unknown and there is no data to compare improvements in quality to.

IV. Results and Conclusion

Tables 5.3 to 5.3 show each alternative system compared to the status quo. The social and environmental accounts in the tables only show benefits; costs of the alternatives are the opposite of the benefits of the status quo and visa versa. As Table 5.2 shows rainwater harvesting is economically cost effective and is associated with a variety of benefits. The on campus wastewater treatment facility cost is more than the status quo revealing that it is the most expensive component of our proposal. The $2.9 million dollar difference in Table 5.4 is due to the treatment facility. Combining the two systems allows the rainwater savings to go towards paying for the wastewater system. The integration of the two systems also cuts cost by at least $190,000, as some of the components can be shared.

Table 5.2-Rainwater Harvesting Compared to Receiving all Water from the GVRD

Account	Rainwater Harvesting	Just GVRD
Financial	• $49.6 million	• $50.4 million
Social	• Independence + sustainability • Decreased Erosion	• Reliable
Environmental	• Less impact on the Capilano and Seymour watersheds	•

Table 5.3-Wastewater Treatment on Campus Compared to Sending all Wastewater to the GVRD

Account	On Campus Treatment	Just Iona Island
Financial	• $18.9 million	• $15.0 million
Social	• Independence from the GVRD+ more sustainable and environmentally responsible • Research facility • Backup plan	• Out of sight out of mind
Environmental	• Less sewage to Iona • Decreased impact on the watersheds	•

Table 5.4 The Rainwater Harvesting and Wastewater Treatment at UBC vs. the Status Quo

Account	Factors
Financial	♦ $2.9- the cost of the project above the status quo
Social	♦ Independence from the GVRD+ more sustainable and environmentally responsible -existence value ♦ Research facility-use value ♦ Backup plan –option value ♦ Decreased erosion
Environmental	♦ Less impact on the Capilano and Seymour watersheds ♦ Less sewage to Iona ♦ Cleaner Water going into the Georgia Strait

Table 5.4 summarises the multiple account information for the rainwater harvesting and the wastewater treatment facility. It is likely that the social benefits of the project have more value then the environmental benefits, at least in the short term. For the project to be cost effective, the benefits of the social and environmental accounts would have to outweigh or balance the critical value $2.9 million dollars over a 20-year period. The trade-off is financial cost for the decreased risk of environmental damage, increased flexibility to respond to uncertain events, and social benefits.

Table 5.5 Cost and Pay off Period for the project Under Different Discount Rates

Discount Rate, Water Increase	Cost at 20 years (millions)
7% Discount, 8% H_2O increase	$2.9
4% Discount, 8% H_2O increase	$2.5

Table 5.5 shows that changing the discount rate to 4% increases the cost of the project in comparison to the status quo by about $0.4 million dollars. Lowering the discount rate has this effect because the project is capital intensive; it incurs higher costs upfront and lower costs in the future. The 4% discount rate shows that the assumed cost of capital does have a noteworthy effect on the evaluation of the project in respect to the status quo, but would still leave the status quo less expensive than the alternative in a 20-year timeframe.

The evaluation, and thus decision for project implementation depends not only on the costs and benefits of the project, but also on the valuation of the benefits, the assumed cost of capital, and the timeframe in question. $2.9 million dollars over the next 20 years is not an unfeasible or unreasonable cost for UBC to incur in comparison the value of the benefits.

Chapter 6 - Conclusion And Future Recommendations

6.1 Conclusion

This project has encompassed a variety of water management issues as they apply to the University of British Columbia, as well as implications of these issues to the larger world. We have examined possible stormwater management and rainwater collection systems, and alternatives to the current wastewater management strategy. A broad overview of these topics is included as well as detailed discussions regarding the applications of these systems to UBC. A comprehensive analysis has been produced that will hopefully lead to the further application of such systems at UBC. In the end, we hope to have demonstrated the values of undertaking the proposed changes, and we hope that some (or all!) of our proposals will be incorporated into the UBC water system in the future. It is our opinion that considerable environmental, social, and (in some instances) economic benefits can result from the use of such sustainable practices. It is hoped that our project will not only affect the views of the UBC community, but also those of the GVRD, the nation, and beyond.

The proposed stormwater treatment system would realise a number of environmental benefits, including the protection of natural waters from hydrocarbon, heavy metal and sediment contamination. While no official treatment is currently underway at UBC or in the GVRD, we have proposed a system involving temporary detention ponds. This system is shown to be more cost-effective than biofiltration options, and also includes aesthetic benefits.

The benefits of on-site rainwater harvesting are discussed in this thesis. These include the roof-top collection of rainwater for a variety of applications, primarily for use in irrigation of UBC's lawns and gardens and for general domestic use (not including drinking needs). The collected water can also be stored as an emergency water supply, or for firefighting. An extended benefit of rainwater harvesting on campus is the decreased dependence on the GVRD's water system and decreased contribution to erosion.

With respect to the current wastewater system for UBC, we feel that major changes must be made to improve environmental sustainability. Currently wastewater from UBC is sent to the Iona Wastewater Treatment Plant, where it is discharged to the Strait of Georgia after only

primary treatment. Effluent from Iona and other Lower Mainland WWTPs has failed recent quality standards. The development of the pilot wastewater treatment system proposed in this project would hopefully act as an example of an effective and sustainable treatment option that may induce upgrading of the current infrastructure. Aesthetic values are also incorporated into the proposed wastewater system with the growth of plants in the subsurface wetland.
Overall, this project has presented a detailed and holistic analysis of the current water system at UBC. We have proposed alternatives that are aimed at decreasing the amount of wastewater produced while increasing the effectiveness and sustainability of rainwater, stormwater, and wastewater systems.

6.2 Future Direction

I. Stormwater Future

The potential future direction of stormwater treatment much depends on the results of the detention pond experiment. If the Ho of the experiment conducted could be rejected, then our design and ideas were solid and sound. These ideas could be adopted into UBC stormwater management with the installation of check dams in every suitable grassed channel throughout UBC. Those channels that were deemed prone to flooding or debris jams, could be left unaltered. Managers would like to have accurate information about the effectiveness of the campus wide system. This could involve large scale testing by injecting tracer dies upstream in the UBC stormwater system, and following its flow rate, before and after the modifications of the system. This could determine the amount of peak flow attenuation (similar process to Pettersson, *et al* (1999)). Analyzing the concentration of the tracer dye before and after modification would give an estimate of particle settlement, and removal, assuming that the tracer chosen sorbs to organic or inorganic material. Maintenance schedules would need to be updated to ensure 'temporary' detention ponds do not become clogged and permanent ponds. Natural storms could be monitored in the same way our replicated storms were analyzed to bring confidence that the results obtained were not correlated to the artificial storm flows.

Plants could be planted and tested for their role in decreasing flow velocity, nutrient uptake, metal removal, habitat for wildlife, and aesthetic value. Plants species, as recommended by Table 3.4, require planting a number of months before testing during warm weather. The same monitoring stations used in the experiment could be used to collect the conductivity, turbidity, and suspended sediment. But a new protocol would need to be used to determine the amount of heavy metal removal by a plant. Tissue samples of the plants would need to be taken before and after experimentation to determine if specialized plants are more effective at removing metals than grass. The grass would also need to be tested as a control for comparison.

The GVRD could include the usage of numerous small check dams in their stormwater treatment section of their Best Management Practices Guide. This would enable others communities to make modifications to their existing channels or enable them to design numerous detention ponds at the planning stage.

II. Rain Harvesting

The proposed rainwater harvesting, filtering, and storage system does not have to be implemented all at once. Small adjustments can be made over time to reach the goal of the proposed system. Other options for rainwater harvesting include courtyard and ground catchments.

Courtyard catchments would include any paved or terra formed ground that can act as a collection watershed. The water can be funnelled into storage facilities and can later be used for irrigation purposes. The water would contain more sediments and pollutants than water collected from rooftops, but with proper filtering it too could be used for general applications.

Ground catchments on UBC campus will basically involve the stormwater runoff system (i.e. swales and check dams). Instead of directing the stormwater flow off the cliffs, the water could be used in other ways. Similar to courtyard catchments, it could either be used for irrigation or for general applications (after filtering).

If all these management techniques are used and the water is not to be filtered, but more water is collected than needed for irrigation needs, the water could be used off campus. The water could be sold to surrounding communities for the irrigation of lawns and fields. Ultimately, this would reduce the demand of water from the GVRD.

III. Wastewater Treatment At UBC

Any treatment system implemented at UBC would require the allocation of some land, which will be occupied by a treatment plant. As land is quite limited on campus, with many different interests competing to develop it, it is an important first step to secure an area for a treatment plant. Energy use in a treatment process is a very important factor when assessing the sustainability of a process for a given level of treatment. Energy is used for heating of the wastewater and for the operation of mechanical systems such as pumps and air compressors. Further research and consideration is needed to make the pilot treatment plant as energy efficient as possible. This would include the use of materials in the SA greenhouse, which minimise the heat lost from the process and using gravity to transport the wastewater as much as possible. There is also a biological component to energy efficiency as different species of plants and microbes could be experimented with to determine which help treat wastewater most efficiently at cooler temperatures. If a pilot plant is built at UBC the potential for experimentation will be great in fields such as microbiology, materials engineering, botany, biology, civil engineering, and landscape architecture. From a social standpoint, a pilot plant, like the one proposed in this thesis, could help change the way in which our society views wastewater. Just as discarded paper was once thought of as a waste to be disposed of, and is now considered a commodity to be conserved and reused, we may begin to view wastewater as a resource. Future experiments in using both wastewater and sludge in agriculture or aquaculture could be conducted at UBC. Also, reusing water within buildings for flushing toilets and urinals may pave the way for the acceptance of reused water for other uses, like washing clothes, which are currently prohibited in BC.

IV. Environmentally Sound Initiatives

The alternatives addressed here are only some of the possible changes that could make UBC a more environmentally sound institution. There are a myriad of other issues that the university could take responsibility for, in order to reduce its ecological footprint. Transportation to and from the University is especially important, as Vancouver's topography facilitates air quality problems. As air quality gets worse and single occupancy vehicles become more common, UBC is an establishment that can step forward and act as the catalyst for change. Programs and initiatives have already started in this area; however, UBC has not given them the priority they deserve. A strong commitment to improving transportation options means making less popular changes. UBC also has the ability to ensure that products sold and used on campus come from institutions that participate in fair trade, equitable practices and ecologically sound operation. The most prominently future initiative should be to make environmental responsibility synonymous with UBC. For instance, when the slogan, *Tuum Est* or 'it's yours' is used, the underlying principle should be that it is each individual's opportunity and responsibility to make a difference.

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Appendix I – Rooftop Area

	Building Name	Real Area (based on aerial map)	error column
		m^2	+/- m^2
1	Thunderbird Stadium	6700	520
2	Garden Pavillion	202	37
3	Botanical Garden Center	755	127
4	Totem Park Field Station	965	126
5	Landscape Architecture Studio	444	67
6	Other (Botanical Garden)	95.8	23.6
7	Other (Thunderbird Stadium)	221	40
8	Wolfsen II Fields	47.6	15.5
9	J. Owen	853	100
10	Fornitek	12200	900
11	Feric	1270	140
12	Salish/Haida	2200	290
13	Nootka/Dene	1930	270
14	Shushwap/Kwakitla	1930	270
15	Totem Park Commons Block	2120	200
16	Ritsumeikan	2110	300
17	University Services Building	7620	600
18	Agricultural Canada	3590	400
19	Food Sciences	1490	150
20	St. Johns College	4670	570
21	Sherwood Lett	422	68
22	Twedsmuir	422	68
23	Kootenay	422	68
24	Caribou	422	68
25	Robson	422	68
26	Okanogan	422	68
27	Mawdsley	422	68
28	Hamber	422	68
29	Ross	422	68
30	Mackenzie	422	68
31	Vanier Commons Block	1490	150
32	Norman Mackenzie House	573	96
33	Museum of Anthropolgy	6180	480
34	Archeolgy, Anthropology and Sociology	215	29
35	Extra Sessional Studies	162	33
36	Cecil Green House	704	90
37	Social Work	3260	420
38	Bollert Hall	582	89
39	Performing Arts Centre	1960	190
40	Vancouver School of Theology (Chancellor)	2840	250
41	St. Marks College	1740	260
42	Duke Hall	411	63

43	Other (VST)	194	39
44	Carey Hall	2640	300
45	Vancouver School of Theology (Iona)	1510	180
46	Other (VST,Iona)	542	73
47	Columbian House	516	76
48	St. Andrews Hall	2880	430
49	Curtis Building	5500	440
50	Legal Clinic	591	80
51	Faculty of Law Annex	449	66
52	Brock Hall	4190	390
53	Hillel House	234	47
54	Woman's Studies	333	56
55	North Tower	611	78
56	South Tower	611	78
57	East Tower	611	78
58	Gage Apartments	2620	360
59	Gage Residencs Conference Centre	2070	200
60	Buchanan Tower	835	99
61	Buchanan A	1700	170
62	Buchanan B	1640	180
63	Buchanan C	695	104
64	Buchanan D	1620	180
65	Buchanan E	528	80
66	Main Library	4640	510
67	Koerner Library	1030	130
68	Belkin Art Gallery	734	126
69	Faculty Club	1270	160
70	Graduate Student Centre	1000	160
71	Frederic Wood Theatre	1580	200
72	Lasserre	1140	130
73	Music	1620	160
74	Asia Centre	1950	190
75	SingTao School of Journalism	532	73
76	C.K. Choi Building	754	131
77	International House	501	68
78	West Mall Annex	1070	140
79	First Nations House of Learning	2020	230
80	Geography	2390	290
81	Auditorium Annex	1360	190
82	Old Auditorium	1110	170
83	Old Administration Building	939	107
84	Mathematics	1520	230
85	Mathematics Annex	794	102
86	Math/Stats Resource Centre	325	51
87	Ponderosa Annex A	367	57
88	Ponderosa Annex B	611	86
89	Ponderosa Annex C	322	53

90	Ponderosa Annex D	335	53
91	Ponderosa Annex E	788	116
92	Ponderosa Annex F	422	62
93	Ponderosa Annex G	624	85
94	Ponderosa Annex H	771	96
95	Ponderosa	1650	160
96	Printmaking Hut	651	112
97	Old Computer Science Building (LSK)	2320	280
98	Power House	1480	210
99	Other (Power House)	193	37
100	Henry Angus/David Lam Building	5250	600
101	Hut M-17/18	2300	210
102	Jack Bell Building	702	93
103	Botany Annex	307	50
104	Arts One	444	80
105	Kenny	2880	360
106	Scarfe	5030	580
107	Campus Planning and Development	748	111
108	Plant Operations Annex F	1170	160
109	Geolgical Sciences Building	2720	310
110	Geophysics and Astronomy Building	1160	180
111	Engineering Annex	422	93
112	Old Barn Coffee House	234	42
113	Forward Building	1140	150
114	Coal and Mineral Processing Lab	744	90
115	Wood Products Laboratory	572	94
116	Horticulture Building/Greenhouse	1780	170
117	Plant Sciences Greenhouse	330	57
118	Header House	198	37
119	MacMillan	3010	430
120	Other (MacMillan)	926	107
121	Bio-Resource Engineering Annex	324	52
122	Thunderbird Residence (west)	4770	600
123	Old Barn	323	51
124	Thunderbird Residence 2	3070	380
125	Pulp & Paper Centre	1390	150
126	CICSR/ Computer Science	3140	340
127	Advanced Materials	2330	250
128	Mcleod Electrical Engineering	1900	230
129	Civil & Mechanical Engineering	5770	630
130	Civil Engineering/Mechanical Lab	4130	390
131	Chemical Engineering	881	114
132	Family Nutrition Services	1780	240
133	Fisheries Centre	1170	130
134	Sustainable Development	1320	180
135	Biological Science Building	5970	690
136	Bookstore	4360	360

137	Chemistry	3970	490
138	Physics	1430	180
139	Hebb Theatre	1320	200
140	Hennigs	3600	310
141	Student Union Building (SUB)	6990	530
142	Aquatic Centre	2950	290
143	War Memorial Gym	3700	310
144	Administration Building	2400	260
145	Copp	2100	290
146	Pharmacology	736	99
147	MacDonald	2400	260
148	Friedman	1570	220
149	Instructional Resources Centre (IRC)	3120	370
150	Woodward Library	1940	190
151	Wesbrook	3180	400
152	Library Processing Centre	1700	250
153	Biochemical Research	1030	140
154	UBC Hospital	8580	790
155	Purdy Pavilion	2240	330
156	Detwiller Pavilion	3540	420
157	S.E.R.F. Task Force	1750	230
158	PE Centre	2550	230
159	Osborne Centre	2750	250
160	Tennis Courts	2290	220
161	Rugby Pavilion	401	59
162	Thunderbird Winter Sports Centre	9360	860
163	Thames Court	5550	880
164	West Hampstead	5270	710
165	Sandringham	4980	740
166	St. James House	4410	520
167	The Chatham	1030	120
168	Bristol	4070	470
169	Windham Hall	1580	210
170	The Stratford	784	94
171	The Regency	830	98
172	Balmoral	1080	120
173	Pemberly	2450	220
174	RCMP	1780	290
175	Child Care Services Office	2650	550
176	Naramata Ct	303	49
177	Revelstoke Ct houses	2030	370
178	Chilk Study Area	1280	140
179	Salmo Ct houses	2030	370
180	Oyama Ct houses	1210	220
181	Keremeos Ct houses	2030	370
182	Melfa Ct houses	1800	330
183	Osoyoos Cr. Buildings	6630	710

184	Other (Fariview)	458	66
185	University Apartments Sopron House	1750	280
186	Acadia House	1620	250
187	Acadia Highrise	622	119
188	Commons	911	109
189	Acadia Family Housing	13700	2400
190	Fariview Crescent Residence	7320	1040
191	Presidents Row Faculty housing	1340	230
192	Counselling Psychology	239	42
193	Adult Education Research Centre	344	66
194	Fraternity Houses	2720	370
195	Psychiatric Day House	294	62
196	Lutheran Campus Centre	514	102
197	Regent College	1690	170
	total	387000	47000

Appendix II – UBC Rain Data

Time Period	Total Rainfall (mm)	Total Rainfall (m)	Total Volume Collected (m^3)	Error Volume Collected (m^3)	Total Volume Collected (L)	Error Volume Collected (L)
January	147.2	0.1472	56966.4	6918.4	56966400	6918400
February	128.1	0.1281	49574.7	6020.7	49574700	6020700
March	116	0.116	44892	5452	44892000	5452000
April	81.4	0.0814	31501.8	3825.8	31501800	3825800
May	65	0.065	25155	3055	25155000	3055000
June	47.9	0.0479	18537.3	2251.3	18537300	2251300
July	39.6	0.0396	15325.2	1861.2	15325200	1861200
August	46.4	0.0464	17956.8	2180.8	17956800	2180800
September	68	0.068	26316	3196	26316000	3196000
October	132.5	0.1325	51277.5	6227.5	51277500	6227500
November	186	0.186	71982	8742	71982000	8742000
December	175.7	0.1757	67995.9	8257.9	67995900	8257900
year	1233.8	1.2338	477480.6	57988.6	477480600	57988600
				Total (rounded)	500 million	60 million
				Scaled due to runoff coefficient of 0.8	400 million	48 million

Appendix III – Stormwater Pilot Project Pictures

Before Photos

During Photos

After Photos

Appendix IV – Multiple Account Analysis Tables

Table a. Costs of the Status Quo at a 7% Discount Rate

Source	Cost/Unit	**Units**	**PV cost 7%**	**Cost to Present**
Water GVRD **2002**	0.27	5607307736	$1,518,212	$1,518,212
2003	0.29	5910102354	$1,615,151	$3,133,363
2004	0.32	6229247881	$1,718,279	$4,851,642
2005	0.34	6565627266	$1,827,992	$6,679,634
2006	0.37	6920171139	$1,944,710	$8,624,344
2007	0.40	7030893877	$1,994,291	$10,618,635
2008	0.43	7143388179	$2,045,136	$12,663,771
2009	0.46	7257682390	$2,097,277	$14,761,048
2010	0.50	7373805308	$2,150,748	$16,911,796
2011	0.54	7491786193	$2,205,582	$19,117,379
2012	0.58	7611654772	$2,261,814	$21,379,193
2013	0.63	7733441249	$2,319,480	$23,698,673
2014	0.68	7857176309	$2,378,616	$26,077,289
2015	0.74	7982891129	$2,439,260	$28,516,548
2016	0.80	8110617388	$2,501,449	$31,017,998
2017	0.86	8240387266	$2,565,224	$33,583,222
2018	0.93	8372233462	$2,630,626	$36,213,848
2019	1.00	8506189197	$2,697,694	$38,911,542
2020	1.08	8642288225	$2,766,473	$41,678,015
2021	1.17	8780564836	$2,837,005	$44,515,020
2022	1.26	8921053873	$2,909,336	$47,424,356
2023	1.36	9063790735	$2,983,510	$50,407,866
Sewage GVRD **2002**	0.1963	5019885800	$985,404	$985,404
2003	0.1963	5290959633	$970,669	$1,956,072
2004	0.1963	5576671453	$956,154	$2,912,226
2005	0.1963	5877811712	$941,856	$3,854,082
2006	0.1963	6195213544	$927,772	$4,781,855
2007	0.1963	6294336961	$880,950	$5,662,805
2008	0.1963	6395046352	$836,491	$6,499,296
2009	0.1963	6497367094	$794,276	$7,293,572
2010	0.1963	6601324968	$754,191	$8,047,763
2011	0.1963	6706946167	$716,129	$8,763,891
2012	0.1963	6814257306	$679,988	$9,443,879
2013	0.1963	6923285423	$645,671	$10,089,550
2014	0.1963	7034057989	$613,085	$10,702,635
2015	0.1963	7146602917	$582,145	$11,284,779
2016	0.1963	7260948564	$552,765	$11,837,545
2017	0.1963	7377123741	$524,869	$12,362,414
2018	0.1963	7495157721	$498,380	$12,860,794
2019	0.1963	7615080244	$473,228	$13,334,022
2020	0.1963	7736921528	$449,346	$13,783,367
2021	0.1963	7860712273	$426,668	$14,210,036
2022	0.1963	7986483669	$405,136	$14,615,171

2023	0.1963	8114267408	$384,689	$14,999,861
	Net Present Cost-20yrs		$65,407,727	

Table b. Costs of the Rainwater Harvesting Collection System at a 7% Discount Rate

Sources	**Cost/Unit**	**Units**	**PV cost 7%**	**Cost to Present**	
Tanks	92141	10	$921,413		
	30714	20	$614,275		
Filters	2033	30	$61,004		
System	1000	30	$30,000		
installation	50	1344	$67,200		
maintenece 2002	50	240	$12,000	$1,705,892	
2003	50	240	$11,215	$1,717,107	
2004	50	240	$10,481	$1,727,588	
2005	50	240	$9,796	$1,737,384	
2006	50	240	$9,155	$1,746,538	
2007	50	240	$8,556	$1,755,094	
2008	50	240	$7,996	$1,763,090	
2009	50	240	$7,473	$1,770,563	
2010	50	240	$6,984	$1,777,547	
2011	50	240	$6,527	$1,784,075	
2012	50	240	$6,100	$1,790,175	
2013	50	240	$5,701	$1,795,876	
2014	50	240	$5,328	$1,801,204	
2015	50	240	$4,980	$1,806,184	
2016	50	240	$4,654	$1,810,837	
2017	50	240	$4,349	$1,815,187	
2018	50	240	$4,065	$1,819,252	
2019	50	240	$3,799	$1,823,050	
2020	50	240	$3,550	$1,826,601	
2021	50	240	$3,318	$1,829,919	
2022	50	240	$3,101	$1,833,020	
2023	50	240	$2,898	$1,835,918	
			PV cost 7%	**PV Savings**	**Savings to Present**
Water GVRD 2002	0.27	5507307736	$1,491,137	$108,302	$108,302
2003	0.29	5810102354	$1,587,822	$109,315	$217,617
2004	0.32	6129247881	$1,690,695	$110,336	$327,953
2005	0.34	6465627266	$1,800,150	$111,367	$439,321
2006	0.37	6820171139	$1,916,608	$112,408	$551,729
2007	0.40	6930893877	$1,965,926	$113,459	$665,188
2008	0.43	7043388179	$2,016,506	$114,519	$779,707
2009	0.46	7157682390	$2,068,380	$115,589	$895,296
2010	0.50	7273805308	$2,121,581	$116,670	$1,011,966
2011	0.54	7391786193	$2,176,142	$117,760	$1,129,726
2012	0.58	7511654772	$2,232,099	$118,861	$1,248,586
2013	0.63	7633441249	$2,289,487	$119,971	$1,368,558
2014	0.68	7757176309	$2,348,343	$121,093	$1,489,650
2015	0.74	7882891129	$2,408,703	$122,224	$1,611,875

2016	0.80	8010617388	$2,470,608	$123,367	$1,735,241
2017	0.86	8140387266	$2,534,095	$124,520	$1,859,761
2018	0.93	8272233462	$2,599,205	$125,683	$1,985,444
2019	1.00	8406189197	$2,665,980	$126,858	$2,112,302
2020	1.08	8542288225	$2,734,462	$128,044	$2,240,346
2021	1.17	8680564836	$2,804,695	$129,240	$2,369,586
2022	1.26	8821053873	$2,876,723	$130,448	$2,500,034
2023	1.36	8963790735	$2,950,593	$131,667	$2,631,701
	Net Present Cost-20yrs		$51,585,859		

Table c. Cost of the Wastewater Treatment Pilot Facility					
Source	**Cost /Unit**	**Units**	**PV cost 7%**	**Cost to Present**	
system &	1150000	1	$1,150,000		
land	375	519	$194,625		
Storage	92,141	2	$184,282		
UV treatment	3,087	2	$6,174		
maintenece 2002	215000		$215,000	$1,559,625	
2003	215000		$200,935	$1,760,560	
2004	215000		$187,789	$1,948,349	
2005	215000		$175,504	$2,123,853	
2006	215000		$164,022	$2,287,875	
2007	215000		$153,292	$2,441,167	
2008	215000		$143,264	$2,584,431	
2009	215000		$133,891	$2,718,322	
2010	215000		$125,132	$2,843,454	
2011	215000		$116,946	$2,960,400	
2012	215000		$109,295	$3,069,695	
2013	215000		$102,145	$3,171,840	
2014	215000		$95,463	$3,267,303	
2015	215000		$89,217	$3,356,520	
2016	215000		$83,381	$3,439,901	
2017	215000		$77,926	$3,517,827	
2018	215000		$72,828	$3,590,654	
2019	215000		$68,063	$3,658,718	
2020	215000		$63,611	$3,722,329	
2021	215000		$59,449	$3,781,778	
2022	215000		$55,560	$3,837,338	
2023	215000		$51,925	$3,889,263	
			PV cost 7%	**PV Savings**	**Savings to Present**
Sewage GVRD	0.1963	5019507259	$985,329	$177	$177
2003	0.1963	5290581092	$970,599	$173	$350
2004	0.1963	5576292912	$956,089	$169	$519
2005	0.1963	5877433171	$941,796	$166	$685
2006	0.1963	6194835003	$927,716	$163	$848
2007	0.1963	6293958420	$880,897	$160	$1,008
2008	0.1963	6394667811	$836,442	$158	$1,166
2009	0.1963	6496988553	$794,229	$156	$1,322
2010	0.1963	6600946427	$754,147	$154	$1,476
2011	0.1963	6706567626	$716,088	$152	$1,628
2012	0.1963	6813878765	$679,950	$150	$1,778
2013	0.1963	6922906882	$645,635	$149	$1,927
2014	0.1963	7033679448	$613,052	$148	$2,074

2015	0.1963	7146224376	$582,114	$147	$2,221
2016	0.1963	7260570023	$552,736	$146	$2,366
2017	0.1963	7376745200	$524,842	$145	$2,511
2018	0.1963	7494779180	$498,355	$144	$2,655
2019	0.1963	7614701703	$473,205	$144	$2,799
2020	0.1963	7736542987	$449,324	$143	$2,942
2021	0.1963	7860333732	$426,648	$143	$3,085
2022	0.1963	7986105128	$405,116	$143	$3,227
2023	0.1963	8113888867	$384,672	$143	$3,370
	Net Present Cost-20vrs		$18.875.349		
	Net Present Cost-20vrs		$18.684.893	shared	

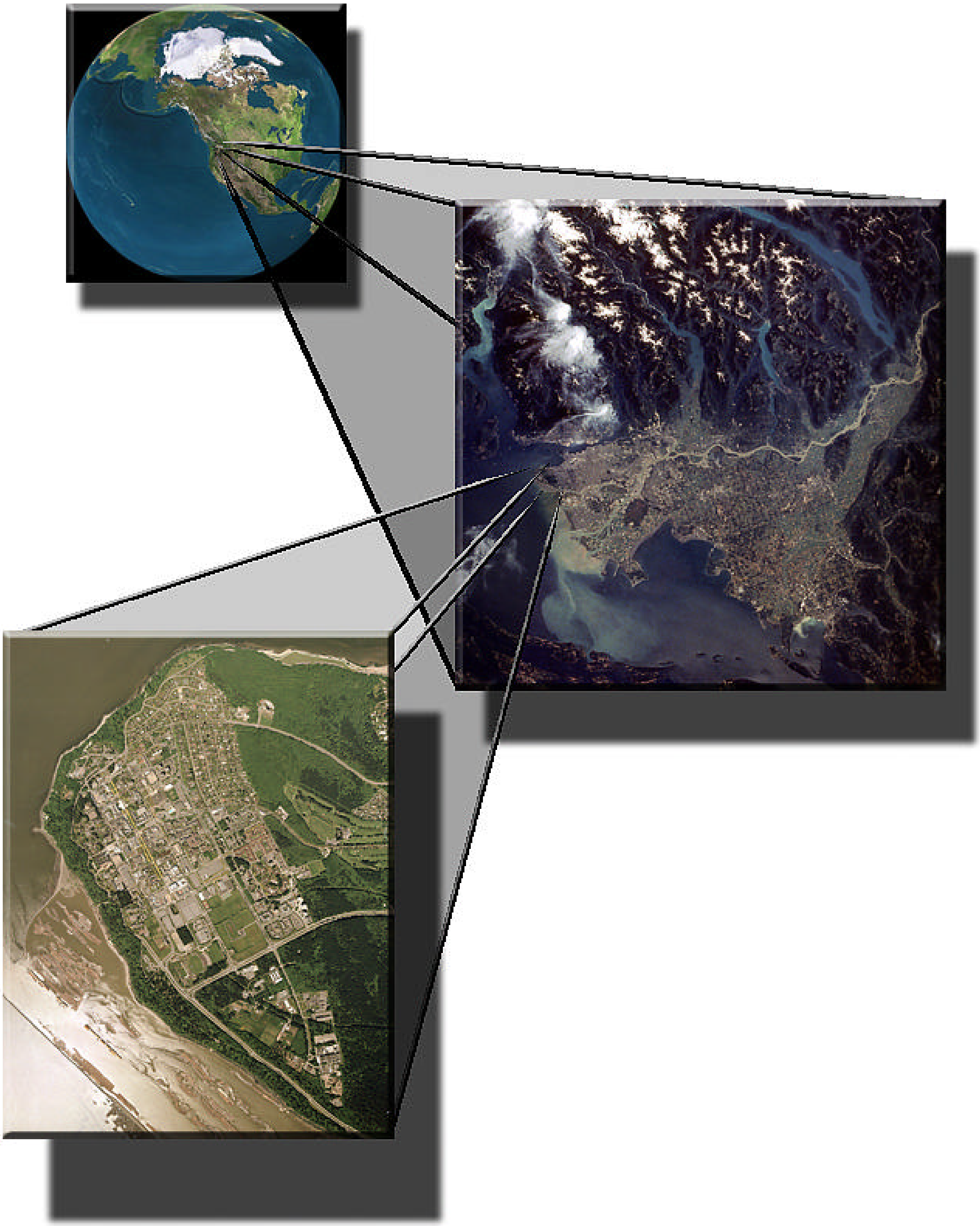
Table d-The Connected System

Net Present Cost of Harvesting and Wastewater-20yrs	$68,328,579
Net Present Cost of The Status Quo	$65,407,727
The Rainwater and Wastewater -Status Quo =	$2,920,852

Table e-Biofiltration Channel

	Cost/unit	Unit	PV Cost 7%	Cost to Present
Supplies	5.75	10000	$5,750	
Plants	20	1000	$20,000	
Construction	48	2500	$120,000	
Maintenance 2002	48	52	$2,496	$148,246
2003	48	52	$2,333	$150,579
2004	48	52	$2,180	$152,759
2005	48	52	$2,037	$154,796
2006	48	52	$1,904	$156,700
2007	48	52	$1,780	$158,480
2008	48	52	$1,663	$160,143
2009	48	52	$1,554	$161,698
2010	48	52	$1,453	$163,150
2011	48	52	$1,358	$164,508
2012	48	5052	$123,273	$287,781
2013	48	52	$1,186	$288,967
2014	48	52	$1,108	$290,075
2015	48	52	$1,036	$291,111
2016	48	52	$968	$292,079
2017	48	52	$905	$292,983
2018	48	52	$845	$293,829
2019	48	52	$790	$294,619
2020	48	52	$738	$295,357
2021	48	52	$690	$296,047
2022	48	5052	$62,666	$358,713
2022	48	156	$1,808	$360,522
			Net Present Cost	$360,522

Appendix V – Vancouver And UBC Location Map



Glossary

A

Abiotic – non-living environmental factors, including chemical and physical effects.

Aerobic – having oxygen available as an oxidizing agent (electron acceptor).

Anaerobic – not using oxygen as an electron acceptor; the presence of oxygen is detrimental.

Anoxic – oxygen is not present.

B

Biofiltration channel – a modified grass swale proposal by Alpin & Martin to treat stormwater for quality.

Biophysical – the combination of biological and physical/abiotic processes.

Black water – toilet wastewater.

BMP – Best Management Practices for land developers, managers, etc… to decrease their environmental impacts.

BOD – Biological Oxygen Demand. The amount of oxygen required to degrade a given amount of organic matter.

C

Catchment – the amount or water collected from rainfall.

Cistern – a container for the storage of water.

Coagulant – An agent that causes a liquid or colloidal solution to transform into a soft, semisolid, or solid mass.

Composting tea – the liquid effluent after being broken down in the composting toilets.

Contaminant – a particle/compound/chemical/substance/object that is not naturally present at the site.

Critical Value – the financial difference between the two options being assessed in a multiple account analysis. The benefits, from the other account(s) of the more expensive option, would have to qualitatively be worth at least this amount to the decision maker for the more expensive option to be feasible.

D

Denitrification – the anoxic reduction of nitrate to nitrate to atmospheric nitrogen, resulting in a loss of nitrogen from the aquatic system. Requires large amounts of organic matter.

Detention – the holding back and containment of water by dams.

Discount Rate – a method for expressing future costs and benefits as present values, so that the worth of a project to the present decision makers can be assessed. Discounting is used because money that goes towards a project could have been invested and that investment could produce returns. Since you forgo the opportunity to invest, you forgo the returns from that investment.

DO – Dissolved Oxygen (aqueous solution).

Dual Water System – a building which has both potable and non-potable water supplies.

E

Effluent – the treated solution leaving the treatment system.

Emergent (macrophytes) – species that are partially both above and below the water surface.

Eutrophication – the condition that can result after a large increase in organic matter, as the BOD is dramatically greater than the available oxygen, leading to anaerobic conditions.

Existence Value – The willingness to pay for a good to exist above the willingness to pay for use of that good. For instance, most people are willing to pay to keep rainforests from deforestation because the rainforest's existence is valued in and of itself.

F

Facultative – being able to function efficiently under both aerobic and anaerobic conditions.

Floating (macrophytes) – species whose leaves float on the water surface, while stems and roots are submerged. May or may not be rooted in bottom sediments.

Flocculation – the process by which small particles come together to for clumps, or flocs.

First Flush – The first rainwater running off roofs, courtyards, or impermeable/semi-permeable surfaces.

G

Grass swale – a grassy ditch to channel stormwater flow.

"Green" – a term used to describe environmentally friendly ideas or technologies (i.e./ green buildings).

Grey water-Household wastewater not including waste from toilets.

H

Hydrograph – a graphical plot of data comparing discharge vs. time or distance.

I

Influent – the solution entering the treatment system.

Irrigation – the act of transporting and distributing water for the purposes of watering crops/gardens/etc.

L

Lower Mainland – a term describing the land area of Vancouver and the GVRD in southwestern BC.

M

Macrophytes – multi-cellular aquatic plants, including various submerged, floating, and aquatic species.

Marginal Scarcity Rent – The price of being a marginal user of a scarce good or service. A marginal user is one who purchases small units of a good or service at a price that covers the cost of producing those units.

N

Nitrification – oxidative processes converting ammonium to nitrite to nitrate, using the bacteria *Nitrosomonas* and *Nitrobacter* (respectively).

O

Open channel flow – An enclosed pipe that is less than 100% full of liquid.

Option Value – The willingness to pay for a good because it decreases the risk that you will need that good in the future and not have it. The good gives you the option to use it in the future, given that at the present you don't know what will happen in the future.

Oxic – in the presence of oxygen.

P

Pathogen/pathogenic – an organism that detrimentally affects its host as its sole means of survival.

PCB – Polychlorinated biphenyl.

Peak Flow – the largest amplitude peak on a hydrograph.

Permeability – the ability of water to penetrate into a medium (such as soil).

Pollutant – a contaminant which exhibits harmful or detrimental effects.

Potable – water that has been classified as safe for human consumption.

Primary Production – the amount of carbon fixed by photosynthetic/autotrophic organisms, serving as the base of the trophic food chain.

Primary (1°) Treatment – the initial stage of wastewater treatment that removes solid/particulate matter; the removed solids are known as 'sludge.'

R

Reclaimed water – wastewater that has been treated and recycled for reuse.

Renovated water – wastewater that has been treated to tertiary standards and is suitable for reuse.

Reservoir – a containment area/facility designed to store large amounts of water before its use.

Rhizosphere – a term referring to the root zone of soil/sediments, physically characterized by the depth of root activity.

Riparian – vegetation in and alongside a body of water.

Runoff coefficient – The ratio of the volume of water which runs off a surface to the volume of rain which falls on the surface.

S

Salinity – grams of ionic solutes per 1000 grams of water.

Secondary (2°) Treatment – the stage of wastewater treatment that serves to decrease the BOD of the effluent.

Sludge – the solid residue removed from wastewater during primary treatment.

Sodicity – the amount of exchangeable sodium (Na+) in soils.

Solar Aquatics – a wastewater treatment system utilising aquatic plants within a greenhouse environment.

Specific Gravity – the relative density of an object compared to that of water (i.e. an object with a specific gravity of 1.0 is neutrally buoyant in water).

Stormwater – the overland flow and runoff of precipitation.

Submerged (macrophytes) – species that have all physical parts (stems, leaves, etc) below the water surface.

Sump – a tank which collects the effluent from both the composting toilets and the sinks, laboratories, and water fountains.

T

Tertiary (3) Treatment – the stage of wastewater treatment that removes excess nutrients (including N, P) from the effluent.

Trunk Sewer/Main – Main line transport system for sewage or stormwater. Includes largest volume pipes and channels.

TSS – Total Suspended Solids (in solution).

Turbidity – the degree to which a solution scatters incident light due to suspended particles.

U

Use Value – the willingness to pay for a good or service because you directly consume or experience it.

UV – the ultraviolet region of the light spectrum.

Acronyms

AEES – Advanced Ecological Engineering Systems
BCSDWR – British Columbia Safe Drinking Water Regulation
BMP – Best Management Practice
BOD – Biological Oxygen Demand
CELSS – Closed Ecological Life Support Systems
CFI – Canadian Foundation for Innovation
DIC – Dissolved Inorganic Carbon
DO – Dissolved Oxygen
EDM – Environmental Design and Management Ltd
EEA – Ecological Engineering Associates
EFB – Ecological Fluidized Bed
EPA – Environmental Protection Agency
FREMP – Fraser River Estuary Management Program
GVRD – Greater Vancouver Regional District
GVS&DD – Greater Vancouver Sewage and Drainage District
GVWD – Greater Vancouver Water District
H_a – Alternate Hypothesis
H_o – Null Hypothesis
LWD – Large Woody Debris
MFEMPS – Massachusetts Foundation for Excellence in Marine and Polymer Sciences
N – nitrogen
NASA – National Aeronautics & Space Administration
NTU – Nephelometric Turbidity Units
OAI – Ocean Arks International
P – phosphorus
PCB – Polychlorinated Biphenyls
SA – Solar Aquatics
SEEDS – Social, Ecological, Economic Development Studies
TCU – True Colour Units
TSS – Total Suspended Sediment
UBC – the University of British Columbia; located in Vancouver, BC, Canada.
US – United States
UV – Ultraviolet
WHO – World Health Organisation
WWTP – Waste Water Treatment Plant