THE UNIVERSITY OF CALGARY

AN ECOSYSTEM APPROACH TO GROUNDWATER MANAGEMENT IN THE GULF ISLANDS

by

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ABSTRACT

An Ecosystem Approach to Groundwater Management in the Gulf Islands

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Prepared in partial fulfilment of the requirements of the M.E.Des. degree in the Faculty of Environmental Design, The University of Calgary.

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The Gulf Islands are rapidly changing due to increasing population growth on the islands and in the surrounding areas placing demands on the limited freshwater supplies. There is a need for management of the groundwater resources to ensure a sustainable supply for the present and future on the islands. This document is intended to provide a groundwater management plan for the Gulf Islands based on an extensive review of groundwater resource issues on North and South Pender Islands.

The review included research into population growth, climate, geology, legal and institutional frameworks, island groundwater issues and the existing water practices on North and South Pender Islands. In addition, field work was conducted on the Pender Islands to map geology and gather information regarding climate and existing water practices.

Based on the research, a groundwater management plan was prepared which encompassed both short and long term perspectives for individual homeowners, island communities, and the province.

ACKNOWLEDGEMENTS

This project could not have been completed without the support of a number of individuals. Dr. Rich Revel played a significant role as a sounding board for ideas and for providing encouragement when other outside factors tended to slow progress. Dr. Ross McWhae was instrumental in ensuring that sufficient funding was available to conduct the research in a reasonable manner. He also acted as a mentor for the geological portion of the project devoting much of his own time to assist in fieldwork as well as review written material. When progress slowed on the project, Dr. McWhae would always find a way of calling and encouraging additional efforts on the project.

Mr. A. Kohut of B.C. Environment assisted in providing the background information on groundwater resources in the Gulf Islands. In addition, he made time available to answer any questions relating to groundwater issues on the Gulf Islands. B.C. Environment and the South Pender Board of Trustees both provided funding for the project and their support was gratefully appreciated.

The late Mr. Bob Allison was instrumental in ensuring that I had as much pertinent information as possible on groundwater issues and life in general on the Gulf Islands. Both Bob and his wife, Helen, made their home open to me and I will always have a warm spot for North Pender Island as a result of their hospitality. Ms. Christa Grace-Warwick is another individual who cannot be thanked enough. She also made sure that I was familiar with many issues related to life on the Gulf Islands and always tried to ensure that I was aware of both sides of the issues. I enjoyed receiving copies of her newspaper "Island Tides" which kept me abreast of island issues while far away in Calgary. There were many other individuals who answered questions, provided moral support, and provided services at reduced rates. Their support has certainly been appreciated.

I would like to pay special tribute to my friends, Martha Hope and Mark Bowman, who assisted with preparation of the document and in some instances covered for me at work so that I could concentrate more fully on my project. Last but certainly not least, I would like to thank my family - my wife, Patricia, and my two daughters, Jilian and Meredith - for providing support during what has a been a difficult and stressful time for us all.

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1.0 INTRODUCTION

" Benjamin Franklin warned in 1777 that when the well runs dry, we will know the worth of water. " (Horvath, 1985, p87).

Terrestrial ecosystems place a heavy reliance on freshwater (Heath, 1988, p73). In coastal island ecosystems, freshwater may be one of the most precious natural resources. Unfortunately, it is often taken for granted. Rarely do humans stop to think how their water needs are being or will be met in the future. On North and South Pender Islands, part of the Gulf Island complex of southwestern British Columbia, the water needs of the majority of residents (70% to 90%) are met by groundwater (B.C. Environment, 1993a). As of 1989, there were in excess of 590 wells on these two islands having a relatively low median yield (<1.5 gpm). At present, the use and protection of the aquifers are not within the mandate of the Water Act (B.C, Environment, 1993b, p6). Islands Trust, who are the governing body for the Gulf Islands, believe that groundwater studies are necessary in the Gulf Islands where development pressure is increasing and sources of surface water are limited or non-existent (Islands Trust, 1991).

It is not possible to adequately study the groundwater resources of an area without investigating the ecosystems which encompass it. Water sciences, in general, are interdisciplinary in nature (Hare, 1985, p5). For the Pender Islands, the island ecosystem can be viewed as an open system with interactions with the ocean and atmosphere. By utilizing an interdisciplinary approach, it is possible to better understand the inputs and outflows of water from the groundwater regime.

Protection of the quality and quantity of groundwater resources is one of the most difficult and complex environmental policy challenges of our time (Kenski, 1990, p1). In the absence of any specific groundwater legislation in the Province of British Columbia, groundwater resources have been developed on an *ad hoc* basis with little regard for the needs of all current users or future generations. The importance of groundwater, especially with regards to an island ecosystem, can not be overestimated.

In recent years, population growth on the Gulf Islands, contamination, and damage to ecological systems have placed stresses on the groundwater system. Unfortunately until recently, there was a general sense that water was ubiquitous in nature resulting in little effort being expended to sustainably manage groundwater resources. The maintenance of a reasonable standard of living and the preservation of the integrity of natural systems upon which life itself depends require a comprehensive management plan (Postel, 1984, p18). To manage the groundwater of these islands, a thorough knowledge of the inputs (rainfall) and outputs (evapotranspiration, surface-runoff, groundwater discharge and human usage) is necessary to understand the groundwater resources of the islands. In addition, the geology of the islands must be well known to enable the projection of storage capacity and groundwater flow rates. Geology also has a great impact on the migration of contaminants. Small amounts of contamination can render groundwater unfit for human consumption (Aulbauch, 1988, p34). Prevention of contamination through the appropriate policies and legislation can provide for a sustainable approach to resource management.

Good water management involves a blending of social goals, institutional systems, and a strong technical foundation (Viessman, 1988, p581). The challenge will be the distribution and ultimately the integration of the groundwater resource information into the short, medium and long term community plans. Many island ecosystems such as Guam, Jamaica, Bermuda, and Tinian face similar problems to the Gulf Islands. There are many lessons which can be learned from these distant island ecosystems to provide a cost effective and community oriented groundwater management plan for the Gulf Islands.

1.1 Objectives

The objectives of this study were to:

1) review the water balance for North and South Pender Islands
2) review the legal framework for groundwater management
3) assess the aquifer parameters on North and South Pender Islands
4) establish the geologic framework for the Islands
5) prepare a groundwater management plan using an ecosystem approach based on the above objectives

1.2 Methods

The methods of evaluation used in this study can be divided into literature review, field work, questionnaire, key informant interviews, laboratory analysis, and data analysis.

There has been human activity on the Gulf Islands since the last ice age. The Gulf Islands represent a case history of the problems faced by island ecosystems and the Biosphere itself resulting in the availability of a wide range of literature for review. The research for this project has been restricted to a review of the available literature in the following categories: geology and geomorphology of the Gulf Islands, history, population growth, climate, vegetation, groundwater management, water resources management, water policy, pertinent legislation, ecosystem approaches, saline intrusions, airphoto analysis, and remote sensing.

The literature search was conducted on the following databases: The University of Calgary Dobis and Nomads Systems. In addition, literature and data were solicited from Environment Canada, B.C. Environment, Groundwater Division and Islands Trust and local newspapers (Island Tides and Pender Post). Groundwater well log information and land use maps were supplied by B.C. Environment, Groundwater Division and Islands Trust, respectively.

The field work portion of the study was designed to confirm the information acquired during the literature review and to provide additional data to prepare a practical groundwater management plan. The field work consisted of mapping the stratigraphy and structure of the local geology, key informant interviews, tree coring, vegetation mapping and ground truthing of airphoto interpretations.

The geologic mapping was conducted using a canoe at low tide when many bedrock outcrops are well exposed. In addition, road cuts having bedrock exposures were examined. The strike, dip and rock type were recorded at each exposure. Rock samples were collected at a number of sites and shipped to Calgary, Alberta for further analysis. Laboratory measurements of porosity and permeability were performed on the rock samples by the Department of Geology and Geophysics at The University of Calgary. Several thin sections were made of representative rock samples to enable the mineralogy of the samples to be determined and its implications on groundwater flow evaluated.

Climatic data were acquired from residents of North Pender Island who have been conducting observations of temperature and precipitation for Environment Canada for a number of years. In addition, records for monthly precipitation dating back to 1925 were provided. Based on the information provided, calculations were made to estimate other parameters such as evapotranspiration.

Unstructured key informant interviews were conducted as a means of identifying concerns regarding water supply and septic disposal from both a regional and local perspective. Through the key informant interview process, it was revealed that the local Trustees of North Pender Island had distributed a groundwater questionnaire to residents of North and South Pender Islands during February, 1994. The results of the questionnaire were made available by Mr. B. Allison (former North Pender Island trustee) for subsequent analysis.

Tree cores were acquired at sites well removed from the coastline and situated in potentially stressed environments to ensure maximum variation in tree ring growth and thus allow for correlation with and confirmation of precipitation data. At several sites, vegetation types were recorded as a means of correlating vegetation type to groundwater availability. The tree types were used to assist airphoto analysis to confirm known spring locations and to identify other potential spring locations for ground truthing.

Airphoto analysis was used to complement the geological investigations of the Islands by identifying stratigraphic and structural features which may impact groundwater flow and availability.

Census information from 1966 to 1991 was provided by Islands Trust personnel and enabled a projection to be made regarding the maximum population which may be attained on the islands given the current community plans.

Other island environments having groundwater supply issues were reviewed to draw comparisons between how other areas have managed their groundwater resources and the management of groundwater resources on the Gulf Islands. As part of this review, the legal framework of areas having limited groundwater resources and frequently experiencing groundwater shortages were reviewed and compared with the B.C. legislation which impacts groundwater.

1.3 Document Organization

This document is divided into three sections. The first section provides an overview of groundwater issues, ecological setting of the Island, population, climatic conditions, geologic setting, and a descriptive overview of the hydrologic cycle. The second section provides an analysis of the existing groundwater usage on North and South Pender Islands, a discussion of local groundwater issues, and the legal and institutional framework.

The final section of this document presents a groundwater management plan for the Gulf Islands in general based on the specific example of North and South Pender Islands and concluding remarks which highlight areas of concern regarding the current groundwater management on the Gulf Islands.

Each chapter represents a specific feature related to groundwater management. As a result, there will be a brief discussion of the significance to groundwater in the introduction of most chapters. In addition, there will be a discussion at the end of each chapter to integrate the findings of each chapter to the overall groundwater management plan.

2.0 GROUNDWATER MANAGEMENT ISSUES IN ISLAND ENVIRONMENTS

> " A main objective is to provide appropriate levels of protection to groundwater in order to ensure that projected future use of that resource can be made. " (Josephson, 1980, p1030)

The groundwater management issues facing island environments are complex in nature. This is partially a result of limited size, geologic complexity, and isolation of island environments. The groundwater resource issues are accentuated by high demographic pressures and economic fragility. Groundwater, in an island ecosystem, can easily represent a "commons" scenario as described by Hardin (1968). Thompson and Stoutemyer (1991, p315) note that "tragedy of the commons" occurs at times when resources are overused so that the resource is depleted faster than it can renew itself. They imply that in a commons situation it may be possible to increase cooperation through increasing the individuals' awareness of long term consequences of their actions (Thompson and Stoutemyer, 1991, p316).

The major water resources issues of coastal island environments are summarized in Table 1. Not all of the following mentioned water resources issues are relevant to the Gulf Islands. The list does, however, illustrate that water issues are many and varied. A review of the existing literature indicates that these issues are not restricted in their occurrence but can be found in varying degrees in any coastal environment.

TABLE 1: Groundwater Issues in Coastal Island Environments
(compiled from Falkland, 1991, Kurtovich and Whyte, 1991, Nicolson, 1993 and Vonhoff, 1985)

- lack of data and need for groundwater resource definition;
- formulation of provincial water policies and plans;
- comprehensive water legislation for the use, protection and conservation of water resources and for the operation of water supply systems;
- appropriate institutional arrangements to ensure that water resources development and management occur in the planning context;
- greater coordination between government agencies responsible for water resources and water supplies;

- appropriate data collection for water resources assessment and monitoring;
- guidance on appropriate techniques for the assessment of all types of water resources; development or application of appropriate technology for water resources development schemes;
- adaptation of guidelines set by international and national agencies for island conditions;
- planning processes to recognize the close relationships between water resources and the total island environment, especially between water supply, sanitation and solid waste disposal activities;
- appropriate public health surveillance of water supply systems and responsive remedial action;
- guidance on operational and maintenance matters such as leak detection;
- guidance on water pricing policies and demand management;
- greater public awareness of water resource and supply issues including proper utilization, protection and conservation;
- greater awareness at the senior official and political levels of water problems;
- greater public involvement in the planning, coordination and control of water resources activities;
- better counter-disaster planning and management arrangements;
- guidance and assistance regarding the effects of climatic change and sea level rise on small islands and their water resources;
- groundwater withdrawal impacts; and
- protection of recharge areas.

Groundwater issues can be conveniently categorized in water management, water availability, water quality, and education. It should be noted that each of these categories are closely interrelated and provide a suitable framework for defining some of the major groundwater issues impacting coastal island environments.

2.1 Water Management

Management of groundwater resources becomes mandatory in island ecosystems as population and human activities increase. An *ad hoc* approach to water well drilling will result in reduced water availability and quality. To be useful in the development of long range community plans, it is important that the potable groundwater resources be delineated and their flow paths fully understood for responsible water management. Leetch (1994, p18) claims that insufficient attention has been paid to understanding water quantity and quality aspects of groundwater.

Water management can be impacted by the legal and institutional framework, political will, enforceable regulations or guidelines, and acceptance of ownership of the issue by the stakeholders. Without a legal framework, it is difficult, if not impossible, to implement an enforceable water management scheme. Pucci (1994, p984) found that from an institutional framework perspective planning and control by government departments required centralised decision making, complicated lines of authority, and large overhead costs and response times.

Resolution of many water management issues is contingent on the presence of an effective legal framework for the development and enforcement of a reasonable management strategy (Table 1). There is a requirement for adequate resource evaluation and ongoing monitoring in order for water management to be effective.

2.2 Water Availability

Many of the issues listed in Table 1 are related to water availability including data collection for monitoring and assessment, agency interaction, planning, protection of recharge areas and the impacts of groundwater withdrawal. Water availability poses a problem in island environments, especially small island environments, due to the variability in rainfall and geologic conditions such as highly permeable or impermeable bedrock and restricted areal extent which limit the availability of surface and groundwater resources.

Hydrological investigations in island environments require a different approach than is currently utilized for large continental land masses. Island environments require island specific studies to delineate the groundwater resources of the island and enable the development of specific management strategies. Groundwater resources investigations are, however, limited by economic and political constraints. It is not possible to properly manage the groundwater resources of an island unless a rigorous water resource assessment has been conducted to provide the physical basis for the management plan (Brassington, 1988, p5).

Climate plays an integral role in the availability of water in island environments. As a result, it is important to have an understanding of the climatic factors which may impact groundwater resources. Precipitation often represents the only source for replenishment of groundwater in island environments.

Variability of rainfall has implications since as Falkland (1991, p76) states that "the turnover time of groundwater systems on most small islands tends to be short, generally a few years at most, but may be shorter than a year". In the small groundwater basins of the Pender Islands turnover times are likely less than two years. A short turnover time of groundwater resources leads to the potential for water shortages during drought conditions which can also accentuate water quality problems such as saline intrusions due to increased stress of pumping from freshwater aquifers. As illustrated in Figure 2, pumping of groundwater in close proximity to the coast can result in a drawing in of the salt water.

Increased human activity in many island ecosystems results in decreased water availability due to a number of circumstances (for example, increased surface runoff as a negative side effect of construction of roads and homes). It is often the case that there is insufficient precipitation for the replenishment of aquifers.

Due to the limited areal extent of many island environments, population growth results in increased water demand placing additional stresses on the limited groundwater supplies. On a global scale, many island environments already have high population densities and birth rates which not only create a demand for potable water but also increase the risk of contaminating the potable groundwater.

One of the major sources of income on many island environments is tourism as exemplified by the Caribbean, Hawaii, and the Gulf Islands. The tourist industry places high demands on the groundwater supplies of island environments since many tourists are unfamiliar with the limited nature of the water supply and therefore often make excessive use of water. Tourism, also, demands large volumes of water which meet drinking water standards. Although tourism provides an economic base for many island residents, the tourist season occurs during the driest months of the year placing additional stresses on an already strained water supply.

2.3 Water Quality

In general, there are two perspectives from which to view water quality: health which is regulated by federal and provincial guidelines and aesthetics which is governed by personal preference. There are a number of contaminants such as chloride and iron which do not pose direct health risks and guidelines have been set to meet aesthetic objectives. According to the Federal-Provincial Subcommittee on Drinking Water (1993, p10):

> " aesthetic objectives apply to certain substances or characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good quality water. If concentrations far exceed the aesthetic objective for a substance, there is a possibility of a health hazard. "

Saline intrusions are a major problem in many coastal environments as a result of over exploitation of groundwater resources due to increased population and development (Spinks and Wilson, 1990, p475). Saline intrusion simply means the movement of saline water into the underground storage space previously occupied by freshwater. Figure 1 provides examples of different freshwater-saltwater interfaces for coastal aquifers in small islands. Since saline water has a higher density than fresh water (1.025 g/mL to 1.0 g/mL), there tends to be a lens of freshwater floating on top of saline water beneath islands. A general rule of thumb known as the Badon Ghijben-Herzberg (BGH) formula simply states that the thickness of the freshwater lens is approximately 40 times the elevation of the water table above sea level (Falkland, 1991, p90). It follows that the high water tables frequently encountered in the Gulf Islands would preclude saltwater intrusion of the aquifers with a threshold of 1200 metres for a water table at 30 metres above sea level.

It is often the case that high population density along coastal areas results in consumption of potable groundwater resources exceeding groundwater recharge. Bruington (1972, p150) suggests that saline

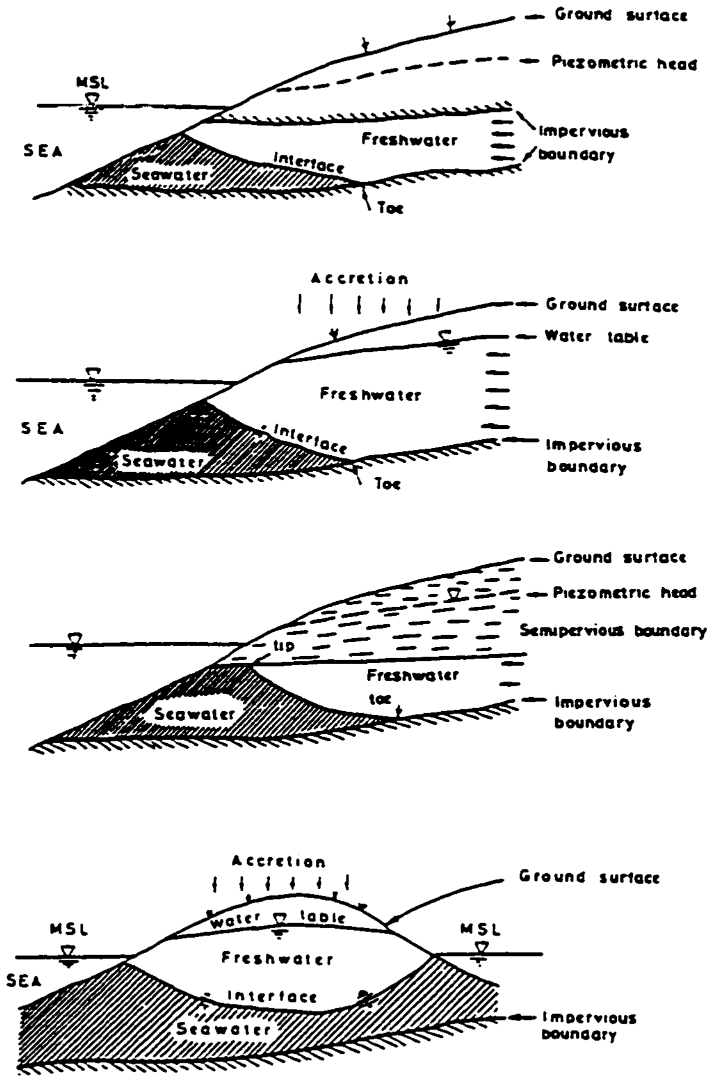


FIGURE 1: Different freshwater-saltwater situations in different types of coastal aquifers in small islands (Falkland, 1991, p89)

intrusion is almost always the result of human activity. Figure 2 illustrates the influence of overpumping freshwater in coastal regions.

Contamination of aquifers is the other major water quality issue. Groundwater pollution can occur from several sources which include septic fields, uncontrolled use of fertilizers, herbicides and pesticides, and industrial waste. On many small islands, the wastewater disposal systems are located in close proximity to the water supply systems which can result in a number of health concerns. This problem is most prevalent when there is only a thin soil cover overlying shallow impermeable bedrock. Falkland (1991) states that "serious conflicts between the required groundwater source protection measures and the applied wastewater treatment methods commonly occur".

Each of these water quality issues is related to human activity in island environments and will be dealt with when relevant to the Gulf Islands in subsequent portions of this document. As human activity increases, there is a tendency to reduce water quality and the availability of potable groundwater resources.

Water quality can also be impacted by the methodology utilised for water well completion. The water wells are usually of widely varying ages with well completion practices being a function of the age of the well and the particular drilling contractor used. Poor completion is most prevalent in older water wells and can result in drastically increased turbidity. In artesian wells, insufficient casing is often run in the wells, even in recent wells.

As is commonly the case, water quality issues are directly related to legislation and management issues. It is difficult to achieve a great deal in protection of water quality unless there is the appropriate legislation and enforcement to ensure compliance.

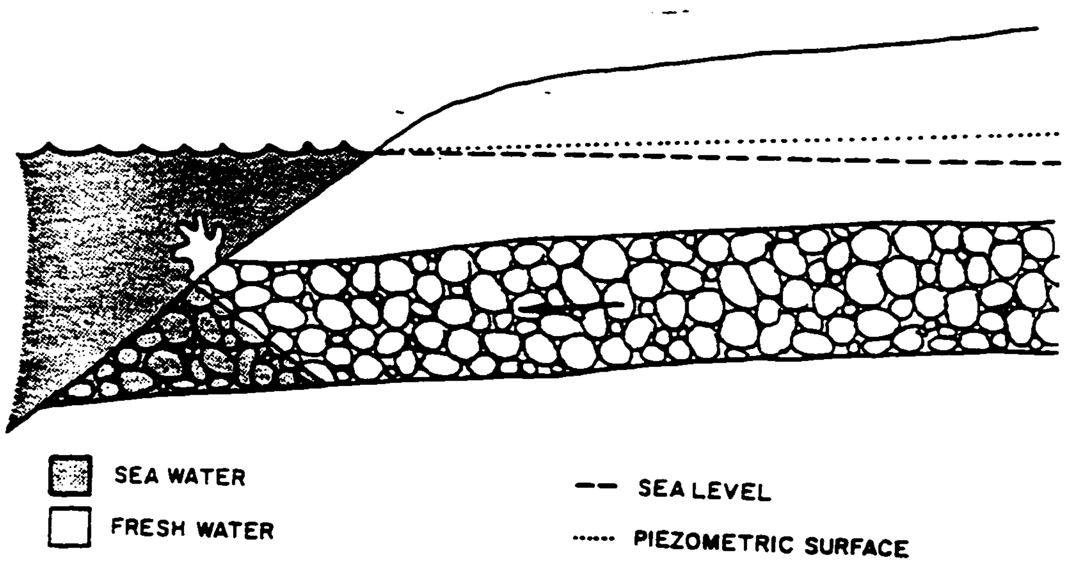


FIGURE 2a: Confined aquifer with no seawater intrusion (Bruington, 1972, p151)

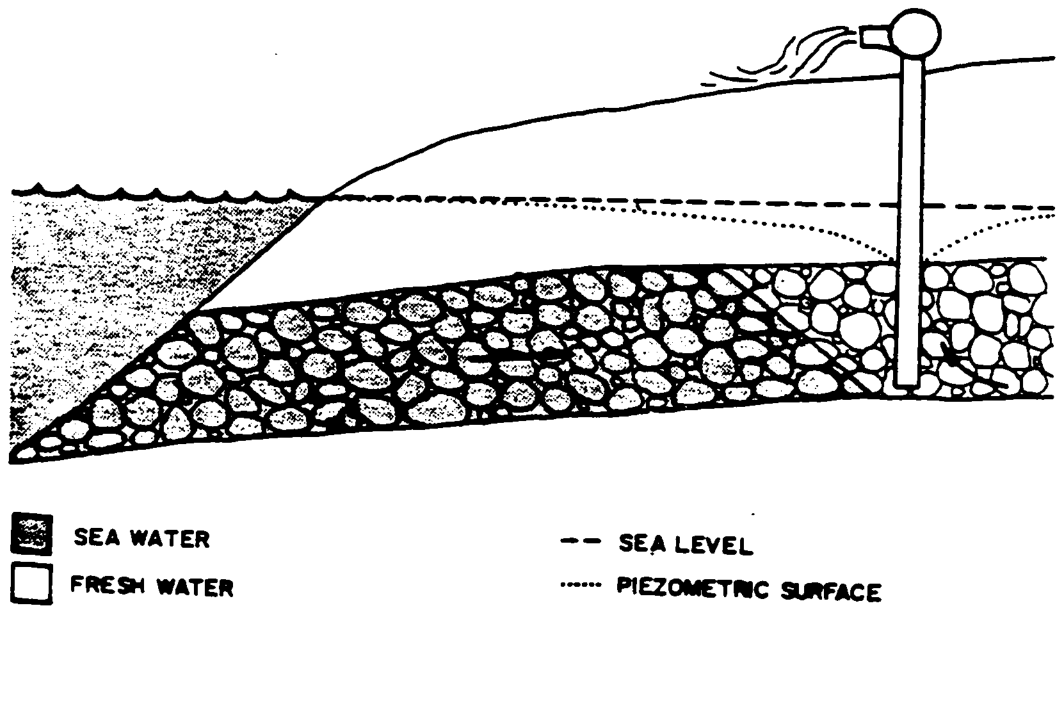


FIGURE 2b: Confined aquifer with seawater intrusion (Bruington, 1972, p151)

2.4 Education

Raising the level of public, senior official and political awareness can be instrumental in improving the legal framework, increasing water availability, and maintaining and/or improving water quality. Leetch (1994, p18) states that there is a general lack of understanding of groundwater issues by government decision makers leading to either excessive abstraction or under utilization of the resource. Increasing the base knowledge will require a proactive approach to educating the government decision makers and the public. Public education programs have been stressed in many coastal environments as well as in areas which are heavily reliant on groundwater such as the state of Wisconsin (Kraft *et al.*, 1993, p281).

The perception of groundwater issues by the public often results in conflicts between those for and against development. Creating a public awareness of water issues can play a role a significant role in resolving conflicts. Lyman (1993, p249) outlines a number of ways of increasing public awareness including: public forums on water topics, demonstrations on how water savings can be achieved, produce a water conservation booklet for local residents, work with schools, and educate planning committee on water topics related to planning.

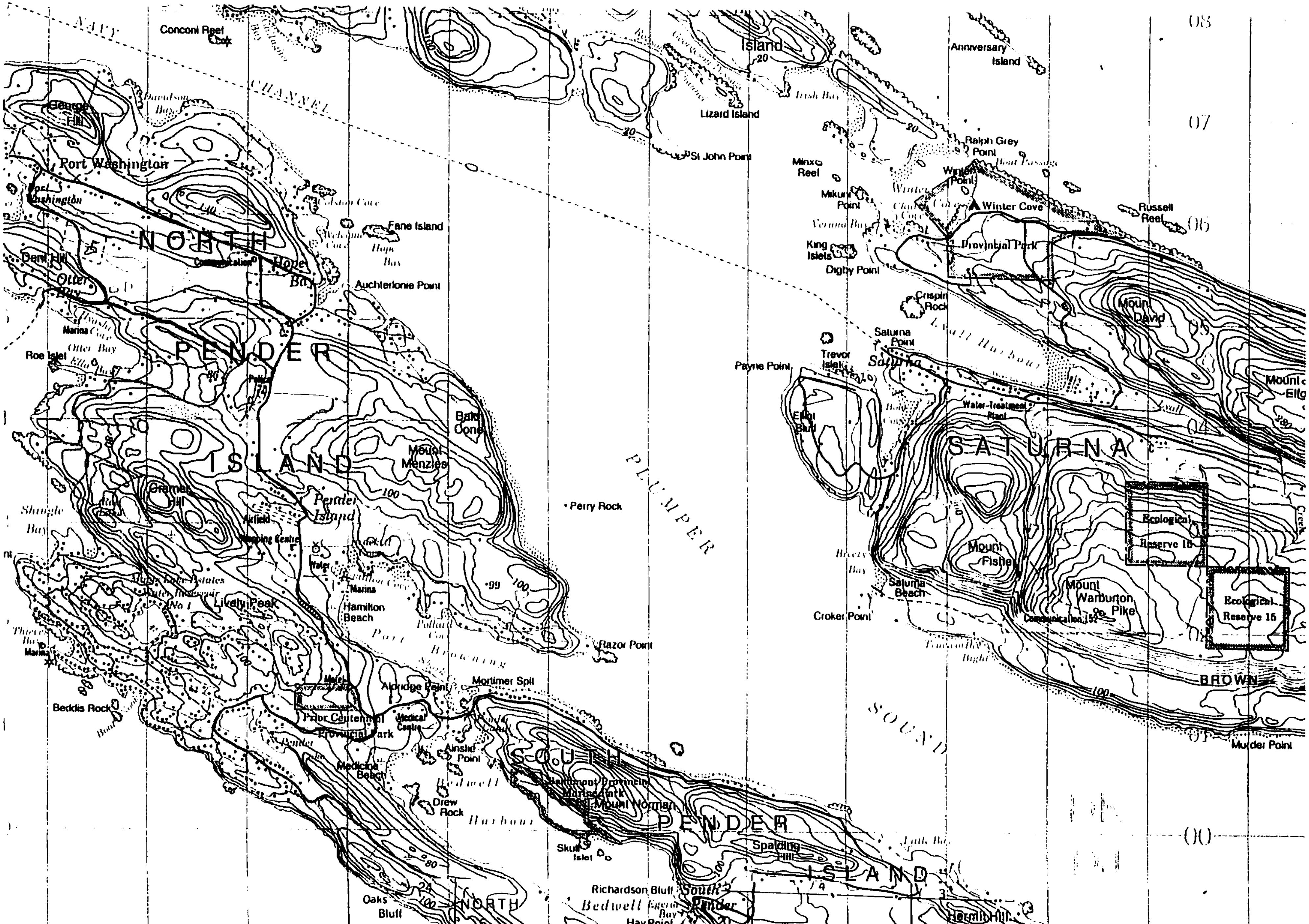
3.0 ECOLOGICAL SETTING

> " Water's seeming ubiquity has blinded society to the need to manage it sustainably and to adapt to the limits of a fixed supply. Mounting pressures are currently manifest in pervasive pollution, depletion of groundwater supplies, falling water tables, and damage to ecological systems. Failure to heed these signs of stress, and to place water use on a sustainable footing, threatens the viability of both the resource base itself and the economic systems that depend on it. " (Postel, 1984, p18)

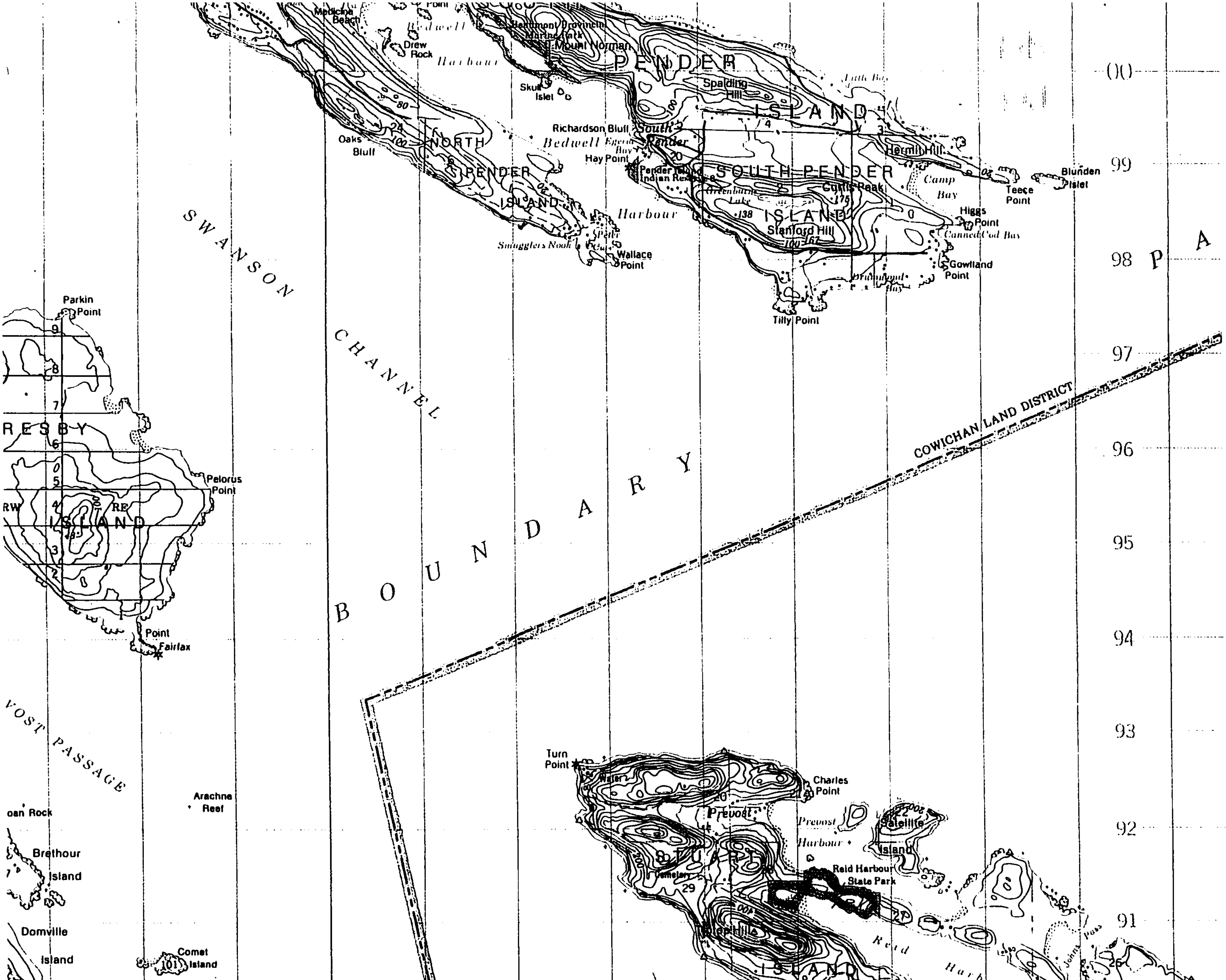
The Gulf Islands encompass a group of thirteen islands stretching over a distance of 160 kilometres, located off the southeast coast of Vancouver Island (Figure 3). The Islands are located in close proximity to the populated centres of Seattle, Vancouver and Victoria. The Gulf Islands can be subdivided into two basic groups: the northern islands consisting of Hornby and Denman Islands and the southern islands consisting of Saltspring, North Pender, South Pender, Saturna, Mayne, Galiano, Gabriola, Prevost, Thetis, Kuper, and Valdes. The two groups are separated by approximately 65 kilometres. This study has focussed on North Pender Island encompassing an area of 2730 ha and South Pender Island which is significantly smaller having an area of 930 ha.

The topography of the islands tends to be rolling with topographic highs oriented in a southeast to northwest direction (Figure 3). The topography tends to reflect the glacial history of the islands. The rounded nature of the topographic highs are indicative of extensive erosion. The topography on North Pender Island ranges from sea level to in excess of 200 metres above sea level (a.s.l.) on Cramer Hill. A similar range in topography is present on South Pender Island with the highest peak being Mount Norman at slightly greater than 200 metres (a.s.l.).

These islands are located in the Mesothermal Biogeoclimatic Formation as described by Krajina (1969a, p8). Within this formation, the Islands are part of the Coastal Douglas Fir Zone (CDFa) which represents the driest mesothermal zone within British Columbia. As can be inferred from the name of the zone, Douglas Fir (*Pseudotsuga menziesii*) is the dominant tree type. Other tree types mapped during field investigations on the islands include: Grand Fir (*Abies grandis*), Western Red



NORTH PENDER ISLAND
SOUTH PENDER ISLAND
SATURNA
PLUMPER SOUND
NAVY CHANNEL
Conconi Reef
George Hill
Port Washington
Dent Hill
Otter Bay
Roe Islet
Shingle Bay
Beddis Rock
Hope Bay
Fane Island
Auchterlonie Point
Bald Cone
Mount Menzies
Grimmer Hill
Lively Peak
Hamilton Beach
Port Browning
Aldridge Point
Mortimer Spit
Prior Centennial Provincial Park
Medical Centre
Medicine Beach
Ainslie Point
Drew Rock
Bedwell Harbour
Oaks Bluff
Skull Islet
Richardson Bluff
Mount Norman
Spalding Hill
Perry Rock
Razor Point
Lizard Island
St John Point
Minxo Reef
Mikuni Point
King Islets
Digby Point
Crispin Rock
Trevor Islet
Saturna Point
Payne Point
Lyall Harbour
Ralph Grey Point
Winter Point
Winter Cove
Provincial Park
Anniversary Island
Russell Reef
Mount David
Water-Treatment Plant
Mount Fisher
Saturna Beach
Croker Point
Mount Warburton Pike
Ecological Reserve 16
Ecological Reserve 15
Murder Point


PENDER ISLAND
Medicine Beach
Bedwell Harbour
Drew Rock
Beaumont Provincial Marine Park
Mount Norman
Spalding Hill
Little Bay
Skull Islet
Richardson Bluff
South Pender
Hay Point
Pender Island Indian Reserve
Oaks Bluff
NORTH PENDER ISLAND
SOUTH PENDER ISLAND
Hermit Hill
Gillis Peak
Camp Bay
Teece Point
Blunden Islet
Greenburn Lake
Stanford Hill
Higgs Point
Canned Cod Bay
Gowlland Point
Tilly Point
Harbour
Smugglers Nook
Wallace Point
SWANSON CHANNEL
BOUNDARY
COWICHAN LAND DISTRICT
PA
Parkin Point
Pelorus Point
Point Fairfax
ISLAND
VOST PASSAGE
Arachne Reef
Brethour Island
Domville Island
Comet Island
Turn Point
Charles Point
Prevost Harbour
Satellite Island
STUART ISLAND
Reid Harbour State Park
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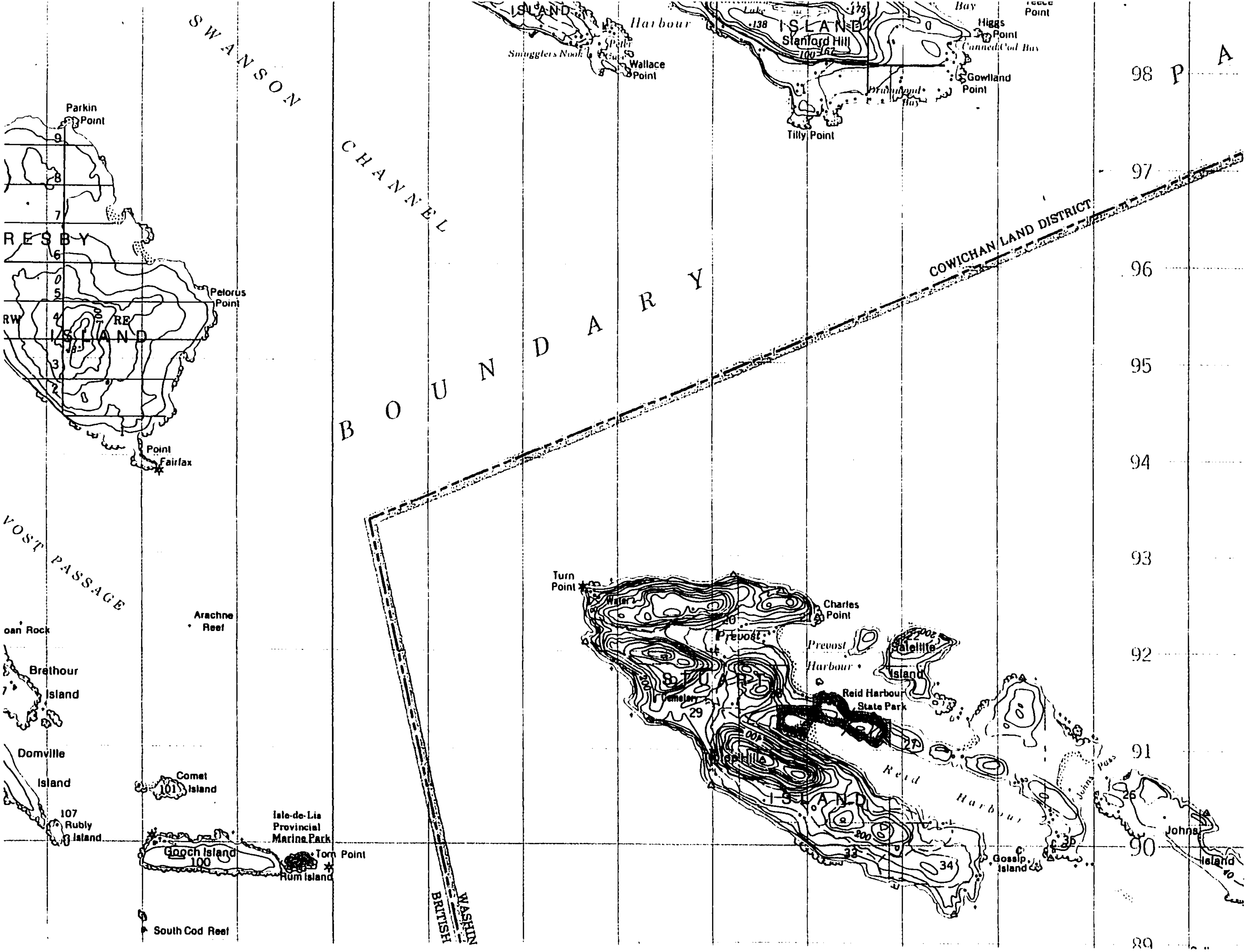


FIGURE 3: Gulf Islands location map

Cedar (*Thuja plicata*), Garry Oak (*Quercus garryana*), Arbutus (*Arbutus menziesii*), Red Alder (*Alnus rubra*), Maple (*Acer macrophyllum*), and Balsam Poplar (*Populus trichocarpa*). The distribution of tree types is indicative of availability of moisture. Douglas fir (*Pseudotsuga menziesii*) dominates the hot, dry southwest facing slopes with Grand fir (*Abies grandis*) and western red cedar (*Thuja plicata*) found in the wetter lower slopes and valleys. Western red cedar (*Thuja plicata*) dominate the wetter northeast facing slopes with occasional Douglas fir (*Pseudostuga menziesii*), Grand fir (*Abies grandis*), and western hemlock (*Tsuga heterophylla*). As illustrated in Figure 4, Garry Oak (*Quercus garryana*) and Arbutus (*Arbutus menziesii*) are found on the driest portions of the islands; typically on rock outcrops. Maple (*Acer macrophyllum*) is found in wetter regions of the islands. Red Alder (*Alnus rubra*) is located in logged or disturbed areas. Figure 5 illustrates the distribution of tree types with topographically controlled moisture conditions. The forests of the Pender Islands have been logged or burned at least once during the past century (Pender Island Conservancy Association).

The shrub layer on the islands tends to be dominated by salal (*Gaultheria shallon*) (Figure 6). Other constituents of the shrub layer are Oregon grape (*Mahonia nervosa*), red huckleberry (*Vaccinium parvifolium*), and evergreen huckleberry (*Vaccinium ovatum*) (Agriculture Canada, 1988, p15). In moist areas, salmonberry (*Rubus spectabilis*) is common. A number of introduced species are now common on the islands particularly in disturbed sites. These species include fireweed (*Epilobium angustifolium*), common gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*) (Figure 7), American stinging nettle (*Urtica dioica*), western fescue (*Festuca occidentalis*) and orchard grass (*Dactylis glomerata*) (Agriculture Canada, 1988, p15). There has been extensive disturbance on the islands from past logging activities and fires.

As illustrated in Figure 5 within a given ecological setting there can be significant variations in flora. Vegetation distribution is directly related to soil conditions, availability of moisture, and topography which makes it ideally suited as a cost effective means to identify regions with a perched or high water tables, springs, and intermittent streams. Species, within the shrub layer which are indicative of wet conditions, include: swordfern (*Polystichum munitum*), field horsetail (*Equisetum arvense*), skunk cabbage (*Lysichitum americanum*), and vanilla leaf (*Achlys triphylla*) (Figures 8 and 9).

FIGURE 4: Rock outcrop with arbutus (*Arbutus menziesii*) indicative of dry conditions.

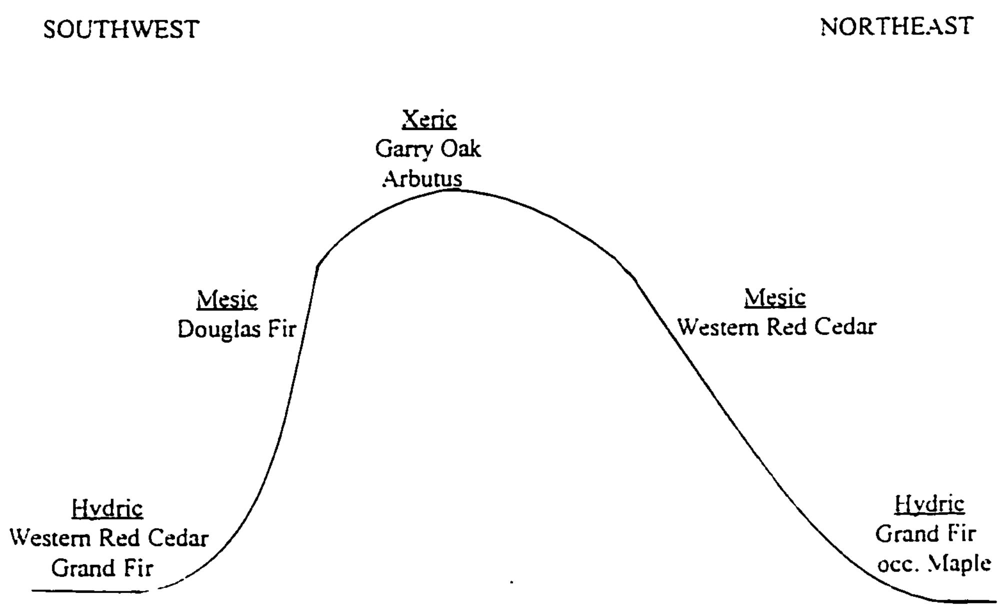


FIGURE 5: Distribution of tree types with topographically controlled moisture conditions.

FIGURE 6: Salal (*Gaultheria shallon*) on North Pender Island.

FIGURE 7: Scotch broom (*Cytisus scoparius*) is an introduced species common in disturbed areas. The trees are arbutus (*Arbutus menziesii).*

FIGURE 8: Field Horsetail (*Equisetum telmateia*).

FIGURE 9: Skunk Cabbage (*Lysichitum americanum*).

The mammals, which once occupied the Islands, have disappeared with the human settlement of the Islands with the exception of the coast deer. As Williams and Pillsbury (1958, p198) stated, it is difficult for wapiti, black bear, cougar and wolf to co-habitat on small islands with human development. There are also mink and otter along the coast and beaver and muskrat in some of the larger ponds.

There are abundant birds on and adjacent to the Islands. The Islands are also situated within migration routes making them an ideal place for birding. The Pender Island Conservancy Association estimate that there are at least 150 species of birds to be seen on the Islands.

There is abundant marine life as evidenced by the names of some of the locations on the Islands such as Otter Bay (see Figure 3). During field investigations of the geology of the Islands, the author had the pleasure of observing sea otters, harbour seals and porpoises. Orcas, Dall's porpoise and many fish species are found offshore. There is also abundant marine life in the shallow water and tidal pools.

4.0 POPULATION

The Pender Islands have been inhabited by humans for a lengthy period of time. They were used, historically, as a seasonal fishing and shell gathering base by the Coast Salish Indians (Agriculture Canada, 1988, p3). An Indian midden located on North Pender Island has been dated at 250 +/- 120 B.C. (Agriculture Canada, 1988, p3). The first nonaboriginal settlers arrived on the Pender Islands in the 1870s (Williams and Pillsbury, 1958, p192). By 1886, the voters list consisted of 7 men for the Pender Islands (B.C. Historical Association, 1961, p49). The early settlers were principally homesteaders and farmers. According to Williams and Pillsbury (1958, p192), the first white settlers had some troubles with the Cowichan Indians who came at intervals for clams. It is suggested that the Cowichan Indians viewed the settlers as intruders and occasionally attacked them (Williams and Pillsbury, 1958, p192).

The First and Second World Wars had a drastic effect on island population since all able bodied men volunteered for service. As a result between the wars, there was a reduction in development. After the Second World War, the climate of the islands became famous throughout Canada and the United States leading to a substantial growth in tourism (Williams and Pillsbury, 1958, p193).

Population data supplied by Islands Trust (Proposed North Pender Island Trust Committee Bylaw No. 83, 1993) indicate that there has been rapid growth on North Pender Island from 1966 to 1991 (Figure 10). There were 281 residents of North Pender recorded during the 1966 census. By 1991, 1400 residents were living on North Pender representing a 498% increase from the 1966 population level. It should, however, be remembered that statistics can be presented in a number of different ways to illustrate a point. A chart comparing the rate of growth for each census to 1966 indicates that there has been an astronomical rate of growth. The rate of growth does not appear as alarming when each census is compared to the previous five year period (Figure 11). In this instance, the greatest growth on North Pender occurred between 1971 and 1976. There has been increasing demand for residential land in conjunction with the population growth. As a consequence, land values have increased with the demand.

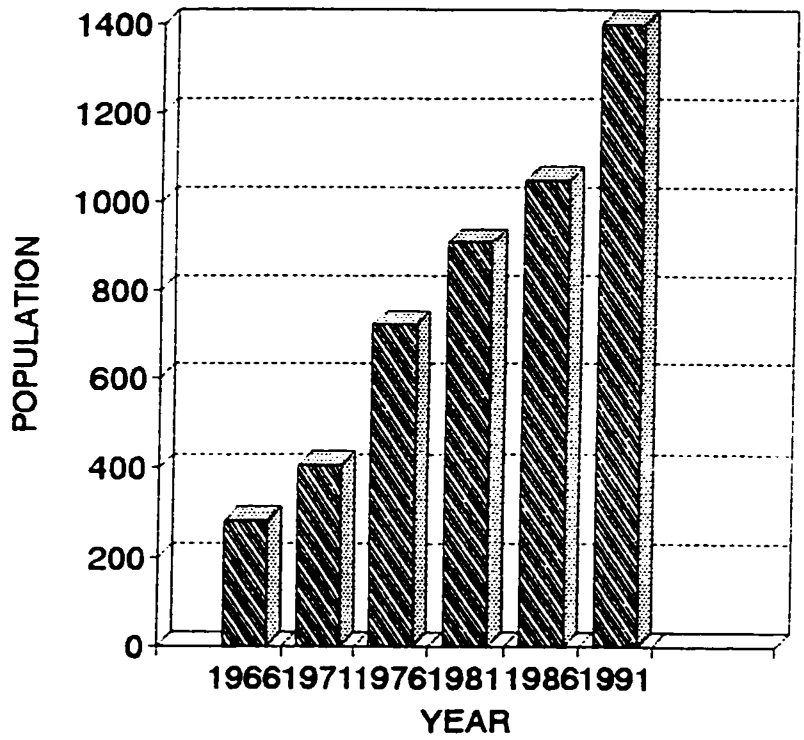


FIGURE 10: Population growth on North Pender Island, 1966 to 1991.

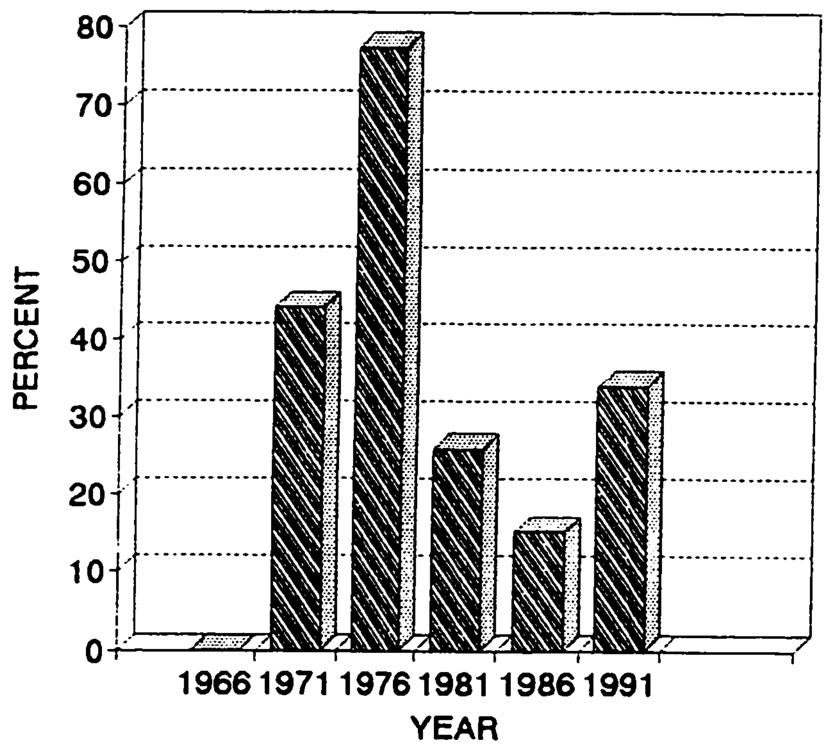


FIGURE 11: Change in population per 5 year period, North Pender Island, 1966 to 1991.

The population of any island ecosystem can not reasonably be expected to increase forever. Islands Trust has computed that the population of North Pender Island will peak at approximately 4546 residents. This projected population figure has been calculated solely on the basis of lot size with little if any regard for the physical limits to growth such as water supply and sewage disposal nor any assessment of the impacts of increased population on the island ecosystem.

The average rate of growth over each five year period since 1966 has been 40%. At this rate, the population of the Island would reach 4546 by about 2008. This indicates that there is little time to conduct evaluations of the impact of this type of population growth on the Islands. Many other island communities face similar problems. Jamaica is an example of an island that appears to have attained the peak population. Until recently, Jamaica relied on emigration to maintain a population balance. Given the high cost of development on the Gulf Islands, it will be difficult for current residents to forego their investment to leave the island behind. It will certainly be the case that land values will decrease if water supply and ecosystem decay become common knowledge. Alternatives such as desalination and waste water treatment exist but are expensive and can have negative side effects such as disposal of highly saline wastes and increased costs. As a result presently from a tax revenue perspective, it is important for the Islands Trust to clearly establish maximum population levels by reviewing lot size in regions of groundwater discharge and recharge. By maintaining a reasonable population density which enables sustainable groundwater utilization, it will be possible to maximize property values and as a result tax revenues.

There is however as some Island residents and Islands Trust planners fear always the potential to turn the Gulf Islands into a playground for the affluent.

There has been no analysis of the age breakdown of the population of North and South Pender Island. By 1958, Williams and Pillsbury (p194) reported that the islands were becoming a popular retirement location. The Islands still provide an idyllic setting for retirees.

The major economic base on the islands appears to be the tourist trade. There are a wide variety of lodges, bed and breakfast, marinas, and hotels established to meet the demands of tourism (Table 2). A service industry has developed on the islands to meet the needs of residents. There is also a small farming community still active on the islands. It has been projected that the population of the islands triples during the summer months (Agriculture Canada, 1988, p3). This places a great deal of stress on the groundwater supplies of the islands since as will be discussed in Section 7.0 the summer months represent the driest times. The very features which attract tourists (sunshine, warm temperatures) also have the net result of taxing the water supply system through increased tourism.

TABLE 2: Tourist Accommodation on North and South Pender Island

- Beauty Rest By the Sea
- Camelot-by-the-Sea
- Cliffside Inn On-the-Sea
- Corbett House Bed & Breakfast
- Cutlass Court Bed & Breakfast
- Eatenton House Bed & Breakfast
- Fircrest Bed & Breakfast
- Hummingbird Hollow
- Pender-itis Bed & Breakfast
- South Pender Island Bed & Breakfast
- Sunnyside Bed & Breakfast
- The Log House
- Whalepoint Bed & Breakfast
- Bedwell Harbour Island Resort
- Inn on Pender Island
- Pender Lodge Resort

Dovetail (1992, Appendix) indicate that the population of the areas surrounding the Gulf Islands will increase to 7.7 million by the year 2010 which will likely result in increased numbers of tourists visiting the islands. Evidence for recent increasing levels of tourism can be garnered from the 39% increase in B.C. Ferry passengers with Gulf Islands destinations (Dovetail, 1992, Appendix).

McRae (1992, p7) states that the components which will drive population growth in British Columbia during the next 25 years will be natural increase, which is the excess of births over deaths, and migration which can be broken down between international and interprovincial migration flows. It is anticipated that for the Gulf Islands the major increase in population will result from interprovincial migration. Based on regional economic development policies and regional planning through zoning laws, it should be possible to control human migration patterns.

Eis and Craigdallie (1980, p11) indicate that heavy population pressure has resulted from residential and recreational pursuits. Large scale developments, such as Magic Lake Estates, have taken place with little regard for the capacity of the land to support such development. At recent public forums, some residents indicated that they are well aware of the pressures which will result from increased population (Pender Islands Pilot Project Committee, 1994). Dovetail (1992, p29) state that some participants in a public forum had stressed the need for a population cap for the Islands with limits also placed on tourism. Without an understanding of the availability of freshwater resources, it is difficult to determine the carrying capacity of the islands. It may be the case that given recent growth rates and increased tourism that the carrying capacity of at least portions of the islands has been reached but additional research is required to prove or disprove this point.

There is obviously some urgency in defining the physical limits to growth on the Island. If the projections for North Pender Island are remotely close to being correct then there are only 12 years (2008) until the population has peaked. This situation does not provide sufficient time to prepare a proactive framework for development on the island. It certainly would not enable a sustainable development strategy for the islands. It is unlikely that the current residents are aware of the potential impact of increased development on the island and steps should be taken during the development of Community Plans to educate residents.

South Pender Island has had the same history of growth as North Pender Island but with population numbers which are an order of magnitude lower. There is growing pressure for further development on South Pender Island. Residents of South Pender Island should be able to learn from the mistakes on North Pender Island to properly manage development.

Given that the potable water supply is limited, increasing population places additional strains on an already stressed system. DeWalle and Schaff (1980, p645) found that increasing population, in the San Francisco Bay area, was directly correlatable to decreasing water quality with most of the pollution emanating from septic systems.

With respect to the demands placed on the island ecosystem by population growth, the Pender Islands can be viewed as a microcosm of the global population and water resource problems. Additional research should be conducted to study population growth patterns on the Gulf Islands as part of programs stressing sustainable development.

5.0 CLIMATE

" Effective planning for use of water resources requires accurate information on hydrologic variability induced by climatic fluctuations. " (Meko and Graybill, 1995, p605)

There are generally strong interactions between climate and water resources in general. Figure 12 shows the relationship between climate, water resources and water management illustrating that the interrelationships are complex requiring an interdisciplinary approach to investigations (da Cunha, 1989, p640).

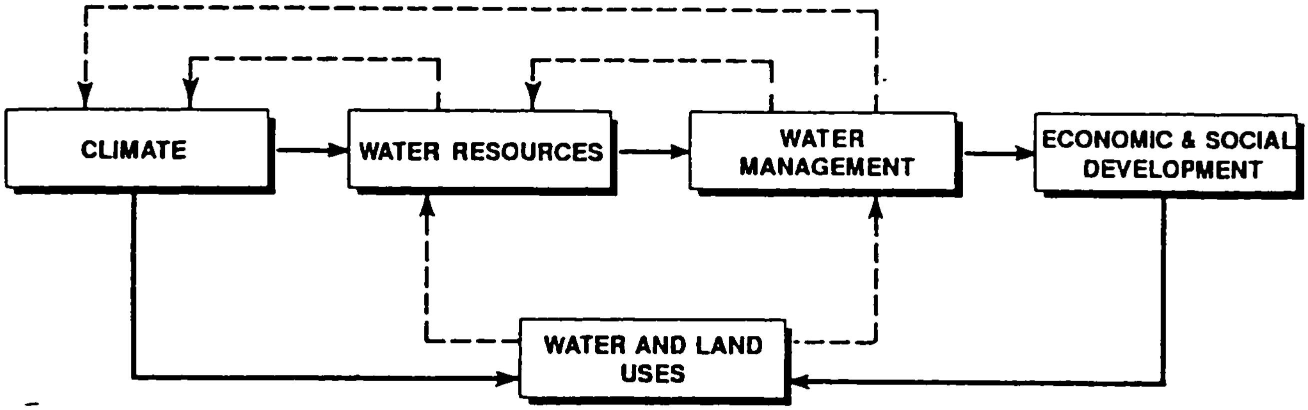


FIGURE 12: Relation between climate, resources and development (da Cunha, 1989, p640).

Climate is important in the study of groundwater resources on small islands since it affects the key input and output components of the water balance. A water balance study can be viewed as an application of the principle of conservation of mass and can be expressed by the equation:

$$\text{Inputs} - \text{Outputs} - \text{Increases in storage} = \epsilon$$

In a perfectly balanced system, $\epsilon = 0$. Balek (1989, p20) uses the water balance equation:

$$P = R \pm O \pm G \pm S \pm I \pm C \pm M + E$$

where P = precipitation, R = surface runoff, E = evapotranspiration, O = groundwater outflow,

G = groundwater storage increment/deficit, S = soil moisture increment/deficit,

I = amount of water intercepted, C = communication with surrounding area,

M = water recharge or discharge from human activity

Factors R, I, C, E, and M are influenced by human activity (i.e. development) on the islands and will have strong negative impacts on the island ecosystem.

Falkland (1991, p10) stated that "in terms of climatic influences on freshwater resources on small islands, the two most important criteria are precipitation and evaporation". Transpiration is also a significant parameter. The spatial and temporal distribution of these parameters has a great impact on the water resources potential.

The local climate of North and South Pender Islands is determined in part by their geographic location, area, altitude, orientation and proximity to continental and larger island land masses. The islands are situated in the rainshadow of the mountains on Vancouver Island and have the westerlies as the main driving force of their weather. Climatic variables are beyond the control of the residents of the Pender Islands and as a result there should be a strong emphasis placed on understanding the climatic controls of the local climate to effectively manage the water resources.

The climate of North and South Pender Islands is a critical factor in the development of the ecology and ultimately the human habitability. As discussed previously, the moderate climate of the Pender Islands is at least partially responsible for the population growth during the past few decades. Precipitation, evapotranspiration, and temperature are the most relevant climatic factors which will be considered in the evaluation of climate and its relationship to groundwater management.

Vegetation cover has a great impact on climate. Plant canopies have important effects on the water and energy balances of the surface since rainfall which falls directly on a plant canopy can be either intercepted by the plant or fall directly onto the soil (Hartmann, 1994, p123) with the intercepted precipitation either evaporating or dripping to the ground surface. Shade from the plant canopy also results in decreased evaporation from the ground surface (Sulman, 1982, p54).

In addition to the effect vegetation can have on rainfall, there is a clear interdependance between climate and vegetation growth. An example is the investigation of tree-rings which have been studied in considerable detail throughout the world to provide a means of paleoclimatologic dating (Sulman, 1982, p54).

5.1 Precipitation

Of the climatic factors, precipitation is the most significant, the most variable, and the best documented (Stoddart and Walsh, 1992, p14). Precipitation represents the only source of replenishment of the potable groundwater supply on the Pender Islands. As such, an understanding of precipitation trends is essential in designing a groundwater management plan.

Precipitation records exist on the Pender Islands from 1925 to present with only minor gaps in the data. One of the difficulties with the records is that they have not been recorded at the same location over their history. At present, precipitation data are collected at Port Washington, Boat Nook, and Trincomali. The residents of Trincomali have maintained records of precipitation from 1988 to present (J. Roberts, personal communication, 1994). Precipitation data have been collected at Boat Nook on the west side of North Pender Island since 1970 (J. Crawford, personal communicaiton, 1994). The records from Port Washington have been recorded since 1992 (M. Armstrong, personal communication, 1994). Prior to the early records at Boat Nook, precipitation data were acquired at Port Hope on North Pender Island and at an unknown location on South Pender Island.

The records enable a review of the historical variation in precipitation for the Pender Islands. To adequately reflect the ecosystem requirements for moisture, the precipitation data are reviewed from April through to March rather than on a calender basis of January to December. This data grouping more accurately reflects the winter rainfall which is necessary for groundwater recharge on the Islands. In addition from an ecological perspective, it makes intuitive sense to commence a study of climatic data from the commencement of plant and animal rejuvenation in the spring.

5.1.1 Rainfall Regime and Seasonality

Precipitation can occur as rainfall, snowfall, dew condensation, and fog interception. Due to the moderate winter temperatures on the Pender Islands, the majority of the precipitation falls as rainfall. Precipitation is recorded using a rain gauge placed on a level, grassy surface where it is free from the sheltering influence of buildings and trees (Figure 13).

Figure 14 presents the annual precipitation from 1925 to present. The long term average annual precipitation of 762.5 mm tends to obscure the fact that the annual precipitation varies significantly with a low of 399.8 mm in 1943 to a high of 1072.6 mm in 1934. The highs and lows in annual precipitation tend to form a broad envelope centred around the average annual precipitation. It is important to point out that neither the average nor the mean annual precipitation is rarely attained. The annual precipitation is, however, normally within one standard deviation of the mean. This can have a significant impact on species diversity of flora and fauna that have adapted to the Islands since species, out of necessity, would require a wide water tolerance limit. Woodward (1987, p63) states that the mass of vegetation increases with water availability. The range in precipitation has an impact on the water storage available for future use by plants and animals. Plants possess mechanisms which effectively control the flow of water according to availability (Simpson, 1981, p34).

Studies have shown that seasonal variations in precipitation can have an impact on groundwater quality. DeWalle and Schaff (1980, p639) noted that increased nitrates and coliform concentrations were observed in the San Fransisco Bay area during winter months when infiltrating rainfall had the potential to dissolve and leach these contaminants downwards.

For the Pender Islands, there is a seasonal nature to rainfall. Figure 15 illustrates the average monthly rainfall for the Pender Islands. The months of October to March represent the wet period while June to August represents the dry period. In general, the wet season receives three times the rainfall of the dry period. The wettest month is December receiving on average 128 mm of precipitation while July which is the driest month receives on average 20.1 mm. Based on the assumption that the soil moisture is depleted at the commencement of the wet winter season, the accumulated winter precipitation should be equal to or greater than the storage capacity of the root zone to refill the reservoir in preparation for the next dry summer season (Vaccaro, 1992, p2827).

Figure 16 illustrates the precipitation for July and December from 1925 to present. The historical data for July and December precipitation clearly show that there has been significant variability. Table 3 presents the mean and median precipitation for July and December as well as measures of the variability (standard deviation and coefficient of variability). The average monthly rainfall for all months tends to obscure the fact that there are significant variations in monthly precipitation. The range of precipitation for the month of December has a low of 10.7 mm in 1985 and a high of 267.7 mm in 1933. Similar wide fluctuations in the range of precipitation are present for the month of July which has a rainfall low of 0 mm recorded 5 times over the 69 year record and a high of 101.1 mm recorded in 1932.

The statistical data for annual precipitation presented in Table 4 indicate that the average precipitation figures can not be used with any degree of certainty for planning when considering the groundwater resources of the Islands. The standard deviation, which is a measure of the variability of the average annual rainfall, is approximately 20% of the average annual rainfall indicating that the rainfall, for any given year, could range between 640.6 and 938 mm. This clearly makes it difficult to predict rainfall and groundwater replenishment. Given the variability in annual precipitation, the selection of a figure for annual precipitation poses a problem for planners when attempting to plan for sustainable development on the Islands. A reasonable approach is to select an annual precipitation figure which is one standard deviation below the average to provide a factor of safety during low precipitation years.

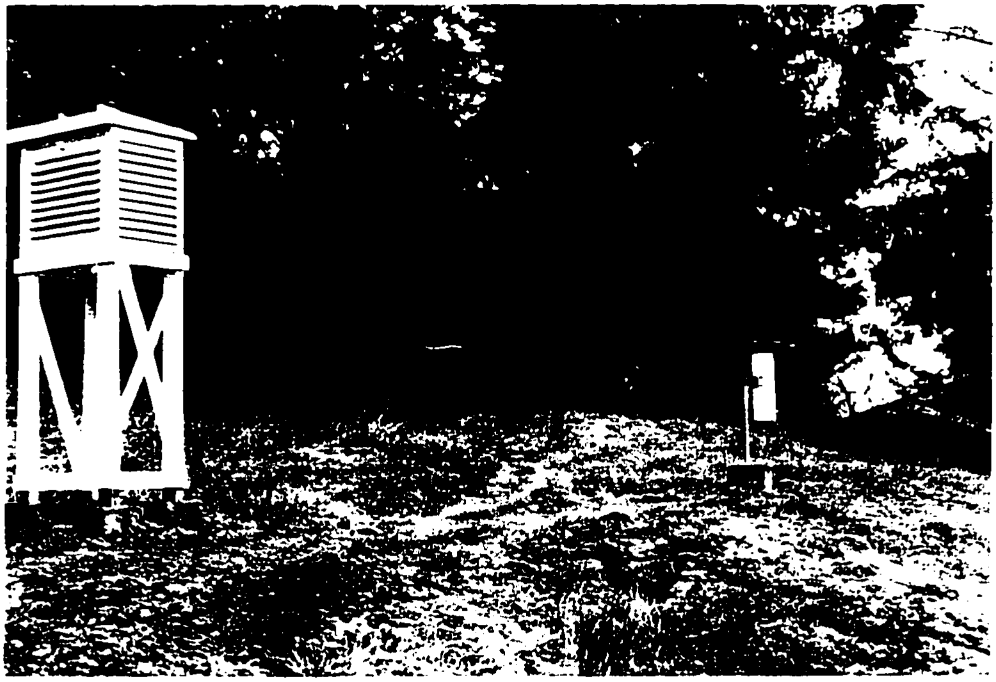


FIGURE 13: Rain Gauge And Temperature Recording Station At Boat Nook, North Pender Island

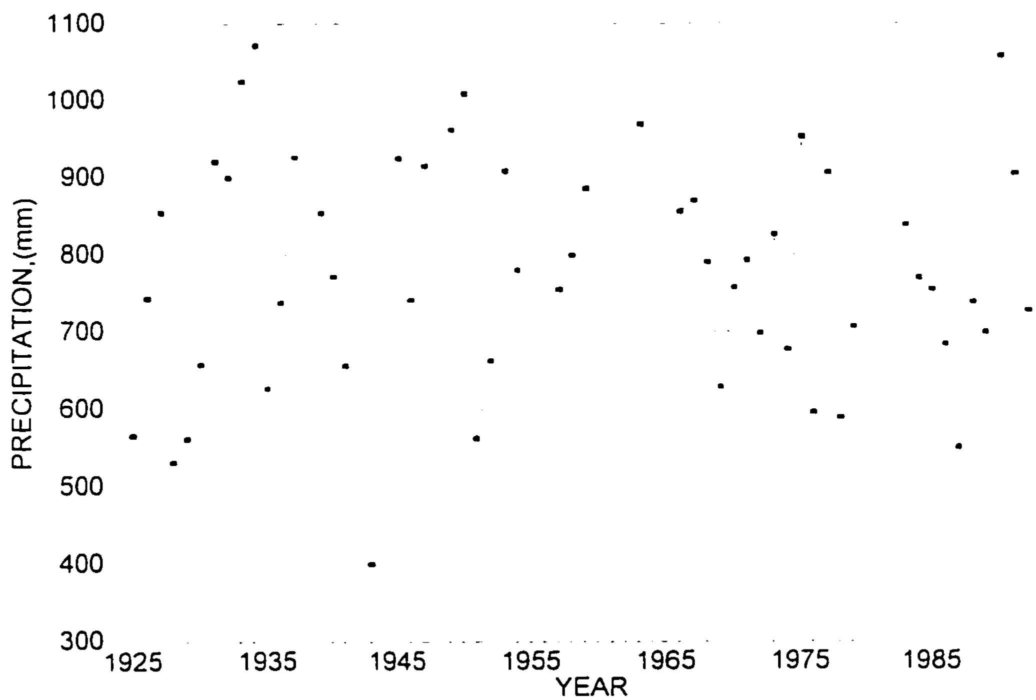


FIGURE 14: Annual Precipitation from 1925 to 1994

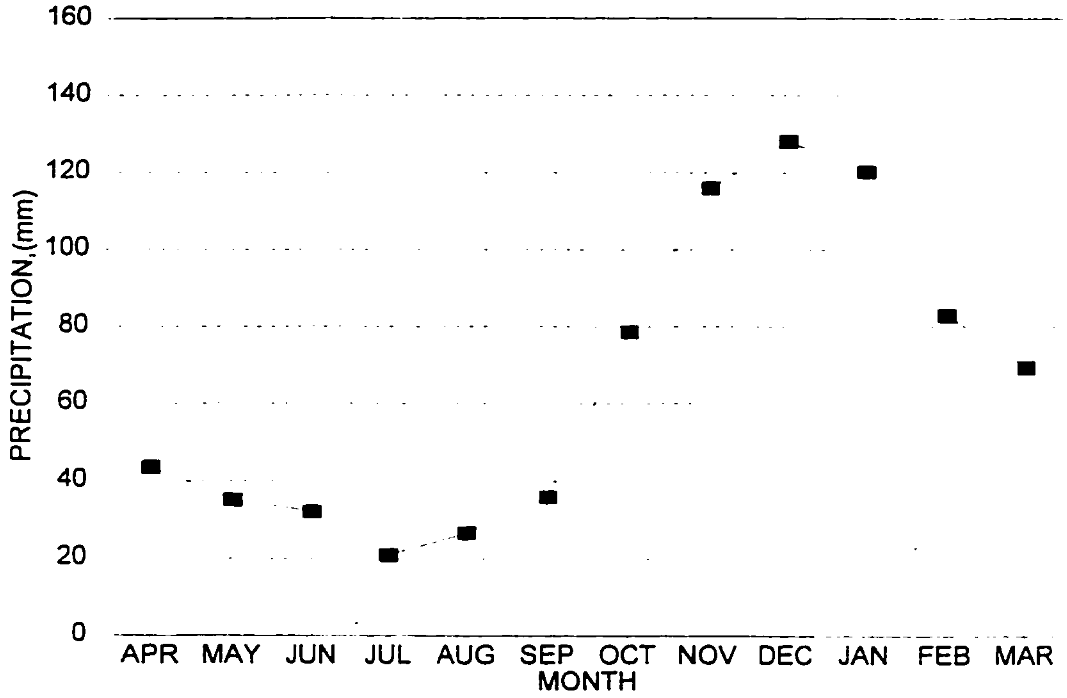


FIGURE 15: Average Monthly Precipitation (1925 to 1994)

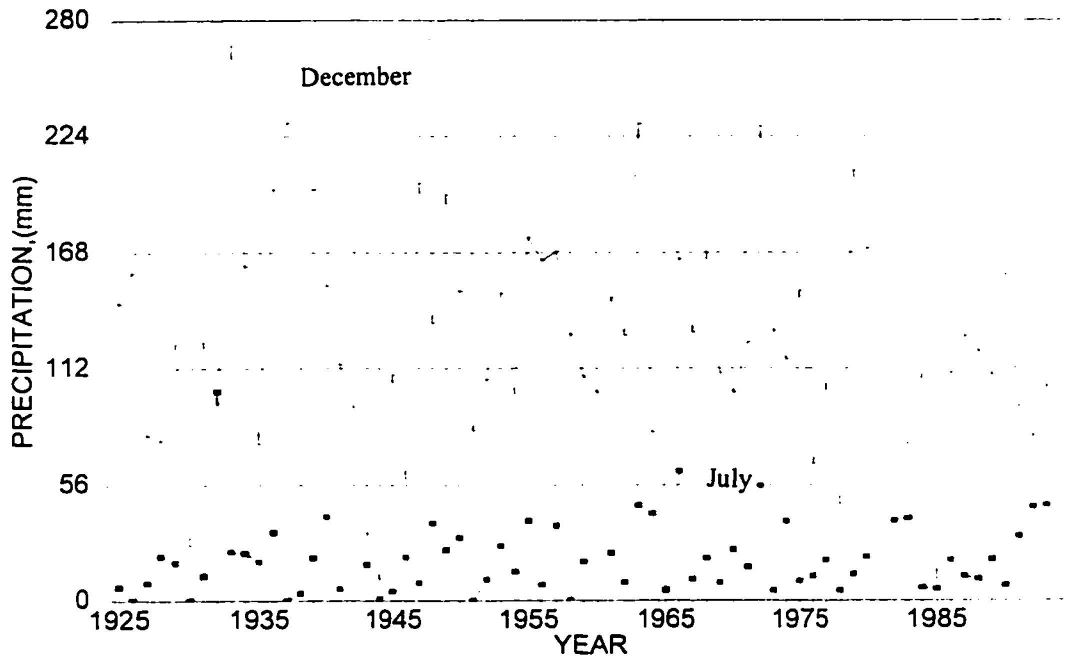


FIGURE 16: July and December Precipitation (1925 to 1994)

TABLE 3: Comparison of Statistical Data for July and December Precipitation

	JULY	DECEMBER
Average Rainfall	20.9 mm	128 mm
Median Rainfall	18.5 mm	124 mm
Standard Deviation	18.1 mm	53.9 mm
Range	0 - 101.1 mm	10.5 - 267.7 mm

TABLE 4: Statistical Data for Annual Precipitation

Average Rainfall	789.5 mm
Median Rainfall	763.4 mm
Standard Deviation	148.94 mm
Range in Annual Rainfall	399.8 - 1072.6 mm

5.1.2 Temporal Variation in Precipitation

In order to investigate the temporal nature of precipitation, the spatial distribution for a dry year and a wet year have been compared to the long term average rainfall (Figure 17). In 1943, the annual precipitation was only 399.8 mm which is approximately 50% below the mean annual precipitation. The precipitation for 1990 was 1057.1 mm which represents 25% above the mean annual precipitation. The major differences in precipitation for these years can be accounted for by increased precipitation between September and April during 1990/1991. There is little difference in precipitation during the dry summer months.

A comparison of the 5 and 10 year running averages of annual precipitation is presented in Figure 18. There are a number of wet and dry periods which are readily identifiable from Figure 18 (Table 5). There are, however, no discernible trends based on the running averages. As a result, it remains a difficult task to predict with any degree of certainty the occurrence of wet and dry cycles.

TABLE 5: Wet and Dry Periods on the Pender Islands (1925 to 1990)

1925 - 1928	relatively dry
1929 - 1938	relatively wet
1939 - 1943	dry
1944 - 1949	wet
1950 - 1957	average
1958 - 1965	wet
1966 - 1976	average
1977 - 1979	dry
1980 - 1983	average
1984 - 1986	dry
1987 - 1990	wet

The changes in annual rainfall totals must clearly represent the sum of changes in monthly totals. Unless all monthly rainfall figures change proportionately, there must be changes in the seasonal distribution of rainfall (Stoddart and Walsh, 1992, p31). Changes in rainfall from one year to another have an impact on the water balance of small islands and consequently water resources (Falkland, 1991, p81). As a result in planning an appropriate groundwater management scheme, sequences of wet and dry years must be considered.

5.1.3 Magnitude of Daily Precipitation

Of prime importance to groundwater recharge is the distribution of precipitation throughout a given period of time. It is common in studies of precipitation to review precipitation on an hourly, 3 hour, 6 hour, 12 hour, daily and monthly basis. There are little historical data from the Pender Islands which can be reviewed in this regard. There are, however, data on the 24 hour maximum precipitation for each month from 1925 to present. The graph of the monthly average 24 hour maximum precipitation is similar in shape to the monthly average rainfall (Figure 19). The maximum 24 hour precipitation of 76.5 mm was recorded in November, 1955.

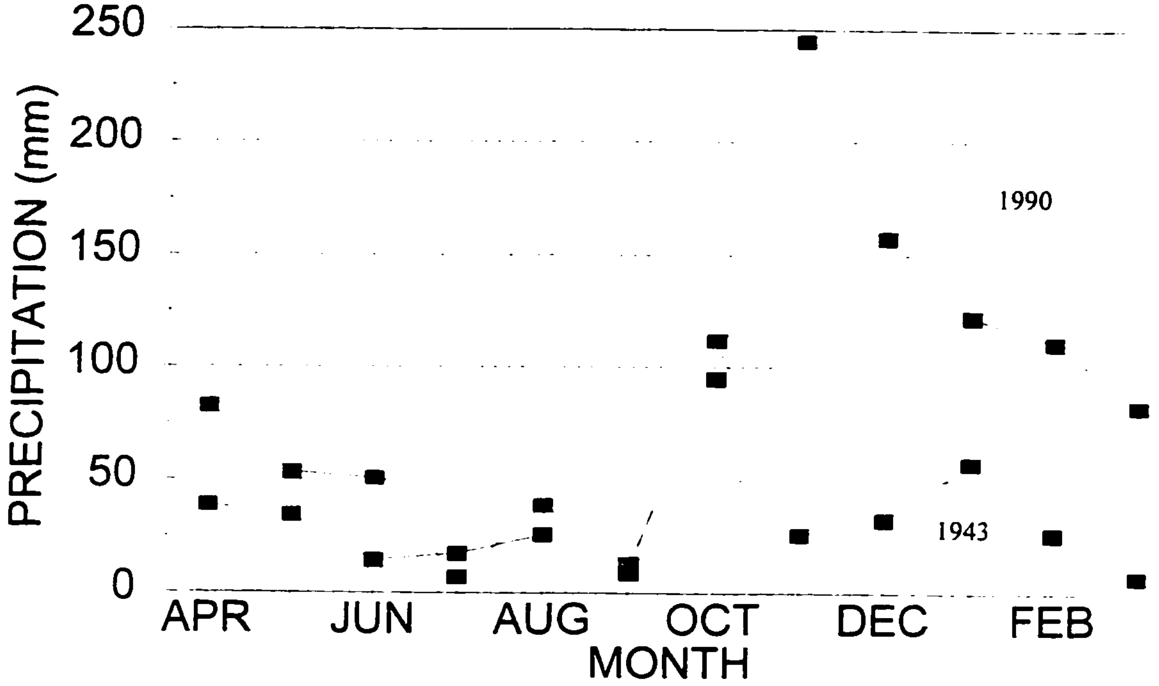


FIGURE 17: Comparison of Precipitation for Wet Year (1990) and Dry Year (1943)

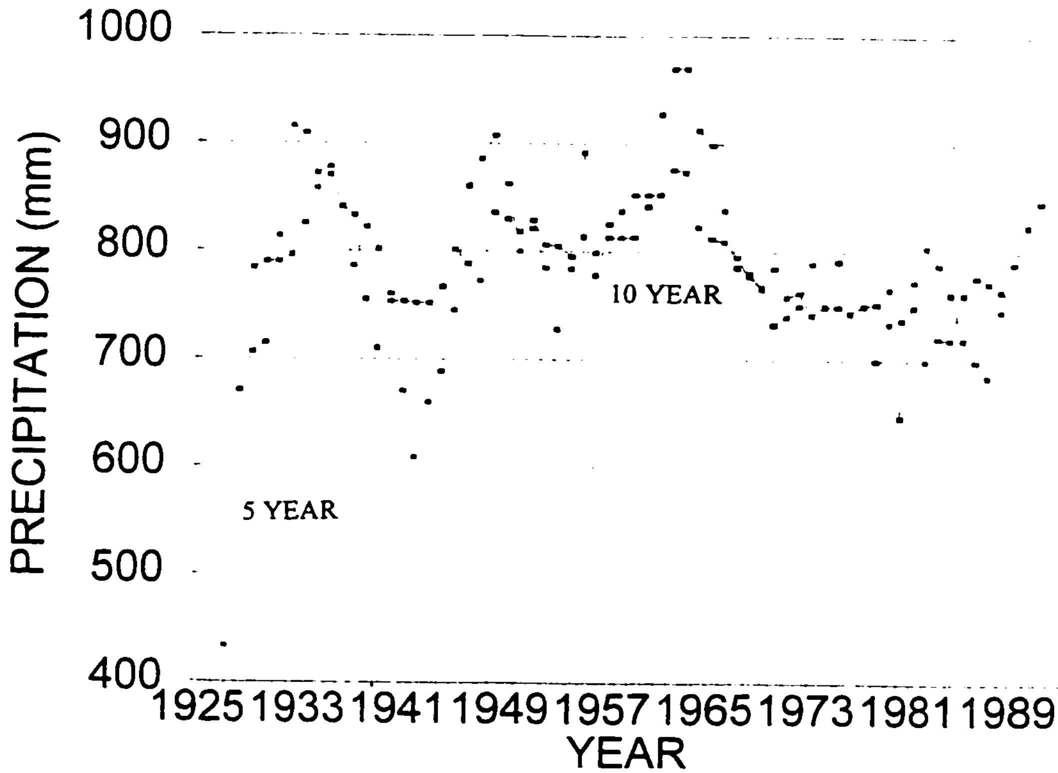


FIGURE 18: 5 and 10 Year Running Average of Annual Precipitation

Figure 20 presents the 24 hour maximum precipitation for July and December, respectively. The order of magnitude of the 24 hour maximum exhibits seasonal variations in that they are substantially higher during the winter months than during the remainder of the year.

To fully evaluate this data, the 24 hour maximum are presented as a percentage of the total monthly rainfall. During the summer months, typically 50 to 60 percent of the monthly rainfall occurs within a 24 hour period (Figure 21). Figure 22 shows the ratio of 24 hour maximum precipitation to total monthly precipitation for July and December. The ratio has been one or close to one a number of times in the past during July. In general, it is rare for the ratio in December to exceed 30 per cent. One of the problems, during the summer months with this type of rainfall distribution, is that rather than recharging the groundwater supplies a majority of the rainfall will be lost as surface run-off. In addition, potential water resources are being lost during winter months due to surface runoff once the maximum groundwater storage capacity has been attained. Surface run-off does not contribute to groundwater recharge. If methods could be established to increase retention, then infiltration could be maximized resulting in significant contributions to groundwater recharge.

Additional research is required to determine if variations in annual rainfall can be correlated to increases or decreases in the frequency of high intensity rainfalls. Given the development which is occurring on the Islands, this type of data may be important in determining the impact of any further development on soil erosion, soil water retention, surface runoff etc.. Development, in general terms, tends to increase surface runoff which does not make any significant contribution to groundwater recharge. Increased surface retention of water, on the other hand, maximizes infiltration of precipitation into the subsurface. Retention can be enhanced through increased density of surface vegetation.

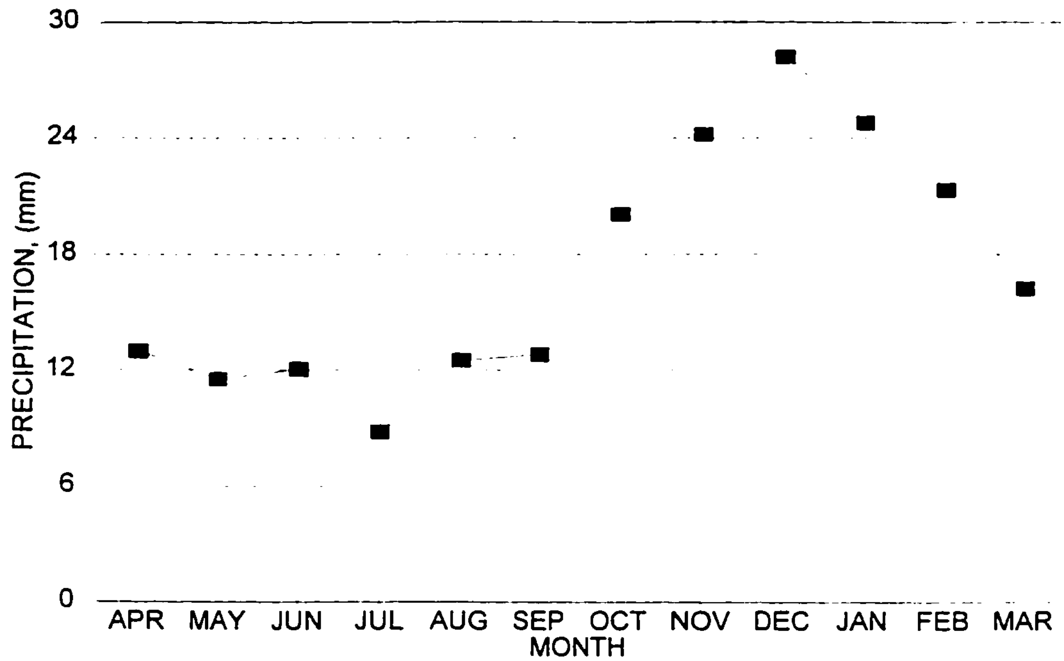


FIGURE 19: Monthly Average 24 Hour Maximum Precipitation (1925 to 1994)

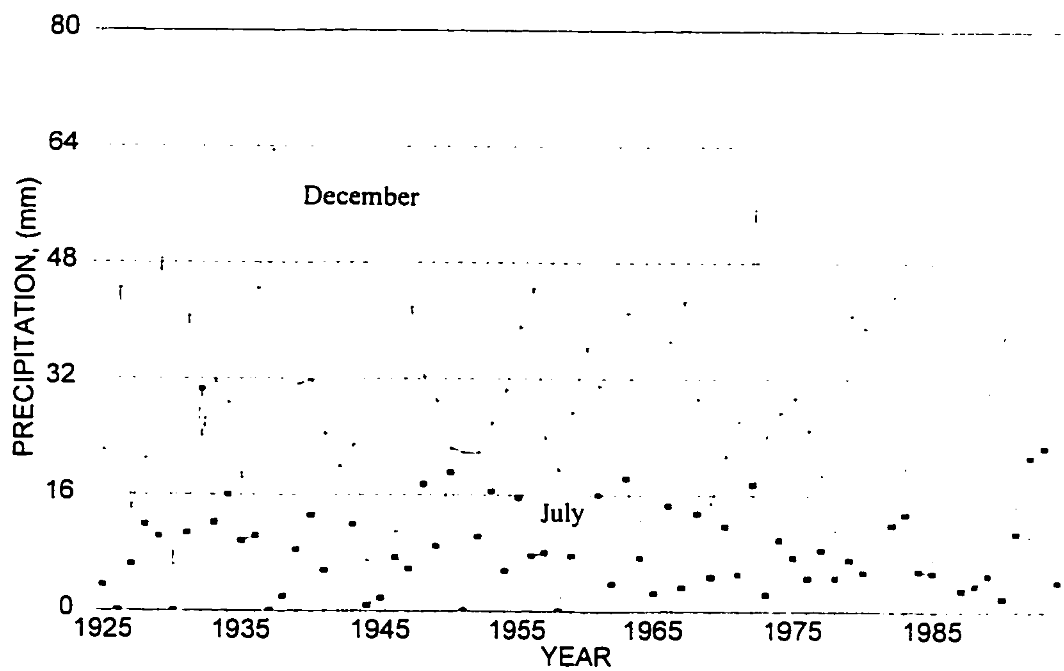


FIGURE 20: 24 Hour Maximum Precipitation for July and December (1925 to 1994)

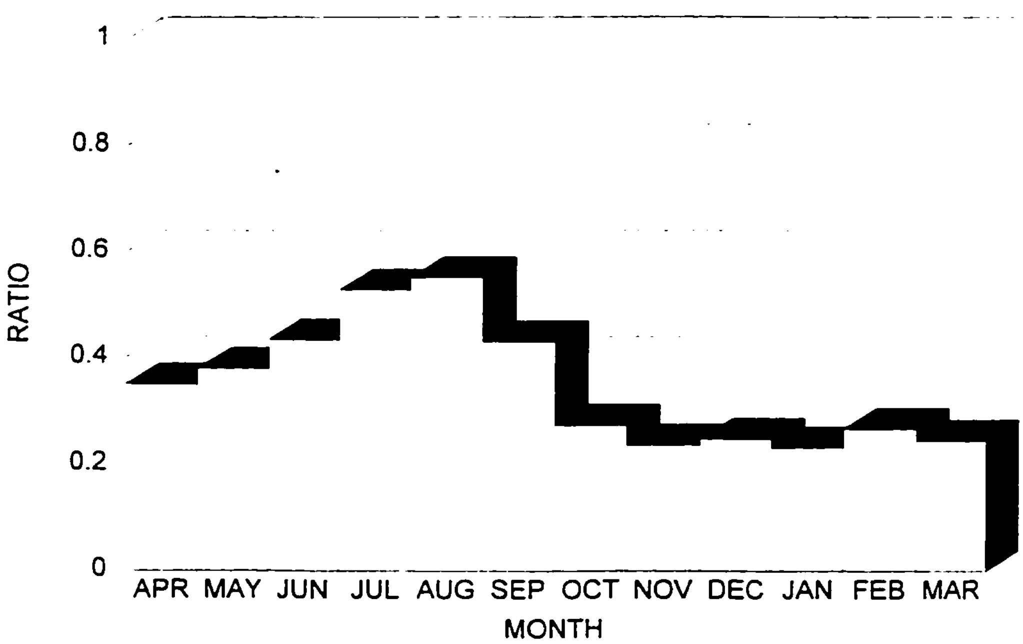


FIGURE 21: Ratio of 24 Hour Maximum Precipitation to Total Monthly Precipitation (1925 to 1994)

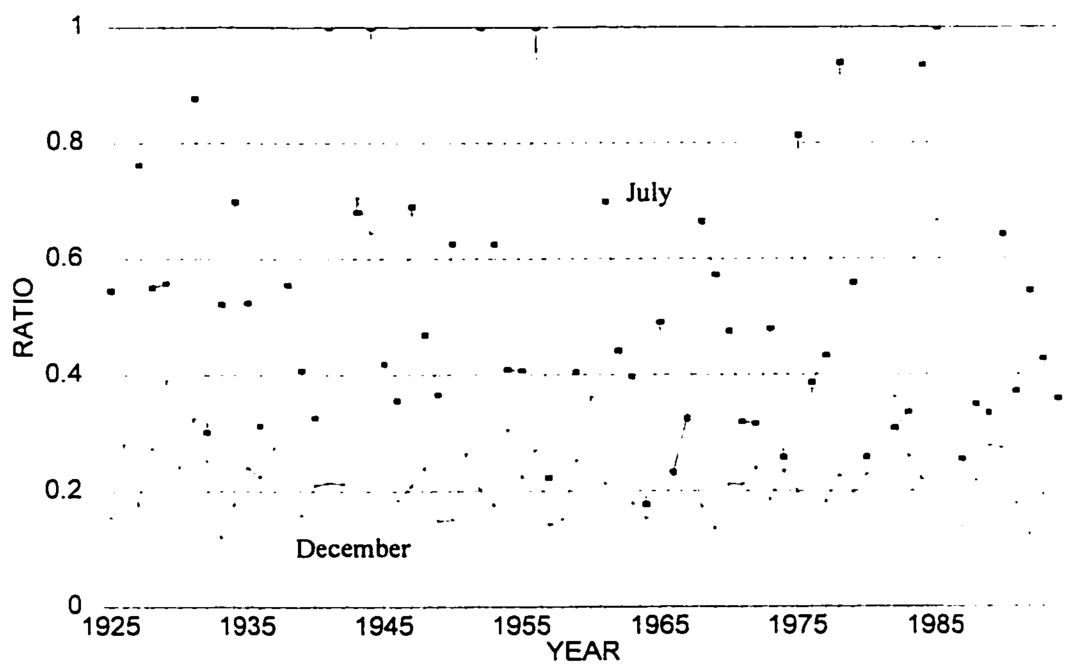


FIGURE 22: Ratio of 24 Hour Maximum Precipitation to Total Monthly Precipitation for July and December (1925 to 1994)

5.1.4 Drought Frequency

The study of droughts is one of the most seriously neglected considerations of hydrology (Dracup *et al.*, 1980, p.289). Information regarding drought is an important aspect for water resources management. In order to determine the frequency of droughts, it is necessary to clearly define what constitutes a drought. Koshida (1991, p1) uses the definition: "a prolonged period of abnormally dry weather producing a moisture shortage that affects crops and forests, and reduces water resources to a degree, thus creating serious environmental, economic or social problems". A hydrological drought is considered to be a result of long periods of below-normal precipitation and often high temperatures.

The severity of a drought is a function of the time of occurrence, duration and climatic factors such as above-normal temperatures, low humidity and high winds. A drought is considered to be more severe as the water shortage becomes more serious and the number of activities affected increases.

Environment Canada's Atmospheric Environment Service calculates a Cumulative Precipitation Index (CPI) to identify wet and dry regions (Koshida, 1991, p6). The CPI is a ratio which compares precipitation totals accumulated over eight-week periods with normal precipitation values for the same period. Values of less than 60% represent drought warning whereas values of less than 40% represent drought emergency (Koshida, 1991, p6).

For North Pender Island, CPI values indicating drought conditions were recorded in the following years: 1925, 1928, 1929, 1930, 1935, 1942, 1943, 1944, 1952, 1956, 1978, 1985 and 1987. The most severe drought conditions occurred in the period from 1942 to 1944 when drought conditions occurred between August, 1942 and September, 1944. A total of 19 out of 27 months during this period received less than 60% of average precipitation. Fortunately, drought conditions occurred when the human population of the Island was low. Similar climatic conditions, should they occur in the future, would result in serious water shortages for human consumption and a decline in water quality. This is based on the fact that there has been significant development along the coastal areas of the islands resulting in increased pumping under normal precipitation. In drought conditions, the normal pumping of wells in close proximity to the coast would result in increased saline intrusions as indicated by the tendency for increased saline intrusions at present in the developed regions along the coast.

Table 6 shows the months meeting the CPI requirements for drought conditions. In general, the drought conditions occur during the summer months. There are exceptions, as mentioned previously, such as 1943 when drought conditions occurred during the winter months. There is no predictable pattern for drought periods. Any ground water management plan should consider the implications of drought conditions. It should, also, be noted that drought conditions increase the fire hazard possibly placing further demands on water supplies. There is no distinguishable pattern which emerges from Table 6 in terms of repeatability of drought.

TABLE 6: Months Meeting CPI Requirements for Drought Conditions

YEAR	MONTHS OF BELOW 60% NORMAL PRECIPITATION
1925	May, June', July', September', October', November
1928	May, June, August', October, January, February'
1929	September', October', November', January'
1930	July', August', September, November, December'
1935	April', May', June
1942	August', September', October, January', February'
1943	June, September', November', December', January, February', March'
1944	April', May, June, July', August, September
1952	May, July, August', September', October', November'
1956	April', May', July', November
1978	June', July', October', December', January', March
1985	July', August', September, November, December'
1987	June', July, August', September', October', February'

' denotes <40% CPI

5.1.5 Tree Ring Correlation

Tree rings represent the yearly growth rates of trees with the newest or youngest cells located next to the bark. Tree rings are formed by variations in moisture content with a succession from larger cells and softer wood during the spring to smaller cells and harder wood during the summer and fall (Sulman, 1982, p85).

Climatic events such as droughts can be identifed by anomalous tree rings and can therefore be accurately dated by simply counting the tree rings. There was a good correlation between the rainfall records on the Islands and the tree cores acquired for tree ring analysis.

Tree cores were obtained at sites which represented potentially stressed environments to ensure maximum variation in tree ring growth. Such sites for the purposes of providing precipitation correlation are those with a shallow soil cover having low moisture holding capacity (R. Revel, personal communication, 1996). Many areas of North and South Pender Island have been logged in the past resulting in few stands of old growth forest. It is generally the case that the tree ring analysis does not provide information on climatic variations prior to 1925 when climate data recording commenced.

5.2 Temperature

In general, temperature should be considered in conjunction with humidity since together they affect the water balance by influencing the type of precipitation and evaporation rate. The temperature, also, impacts the type and distribution of vegetation on the Islands which in turn impacts evapotranspiration. Woodward (1987, p80) suggests that the type of vegetation is controlled to some extent by the minimum temperatures and the physiological ability of the plant to survive low temperatures. Unfortunately since there is no information available for humidity on the Pender Islands, temperature must be considered separately.

Air temperatures are measured using self-registering maximum and minimum thermometers set in a louvred, wooden shelter known as a "Stephenson screen" (Figure 13). The shelter is mounted on a stand so that the thermometer is approximately 1.5 metres above ground surface. As with the rain gauge, the shelter is located on a level, grassy surface at least 6.0 metres removed from the influence of any buildings or vegetation (Environment Canada, 1982).

Figure 23 illustrates the average monthly temperatures for North Pender Island. The average monthly temperatures range from a low of 4.0°C in January to a high of 16.5°C in July and August. The warmest temperatures occur during the driest period of the year. The warm temperatures and dry conditions result in a net moisture loss during this portion of the year.

The mean daily temperatures are obtained using readings from a maximum-minimum thermometer which is read once daily recording the maximum and minimum temperatures for the day (J. Crawford, personal communication, 1994). The mean temperature is simply obtained by adding the maximum and minimum temperatures and dividing by two.

The average annual temperatures for North Pender Island from 1970 to 1994 are presented in Figure 24. There is little variation in the average annual temperature. A warming trend is evident in the data. Between 1970 and 1984, temperatures range between 8.7°C and 11.2°C with only two average temperatures in excess of 10°C while during the period from 1985 to present the average annual temperatures range from 10.3°C to 11.4°C with no average temperatures below 10°C. Although there is an increase in mean annual temperature during the past decade little if any significance can be attached to the increase given the short period of record keeping in the area. Since climate is influenced by factors beyond the control of Island residents, the cause of this temperature change has not been investigated.

The mean daily temperatures for July and December are presented in Figure 25. This data set indicates that winter temperatures appear to be more variable than summer temperatures. In addition, the increase in average annual temperature since 1985 appears to be related to warmer

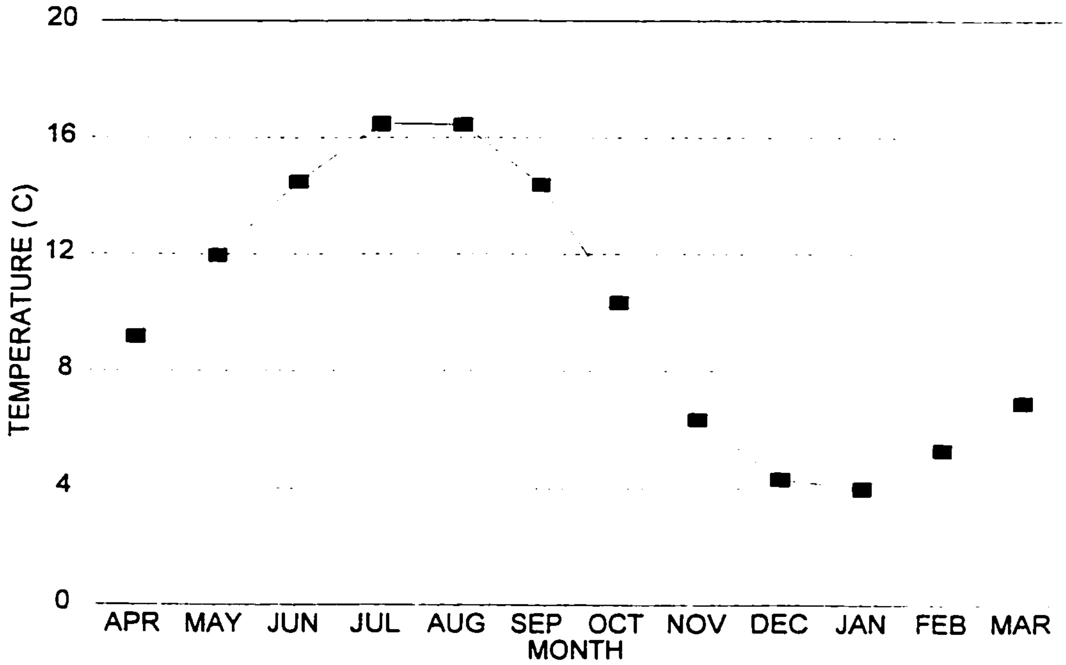


FIGURE 23: Average Monthly Temperatures on North Pender Island (1970 to 1994)

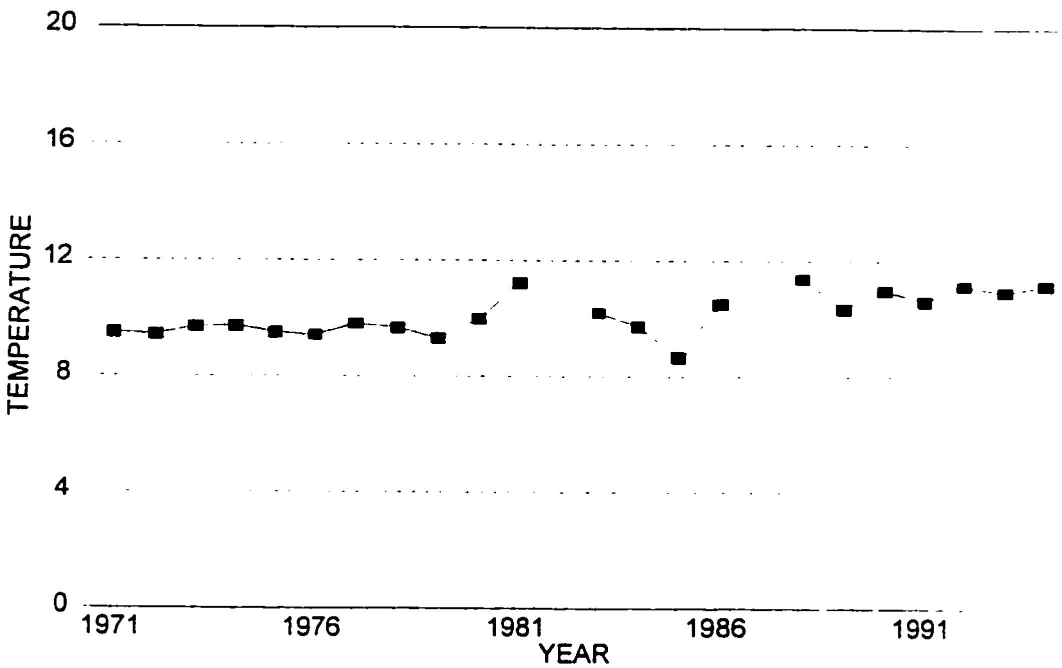


FIGURE 24: Average Annual Temperature on North Pender Island (1970 to 1994)

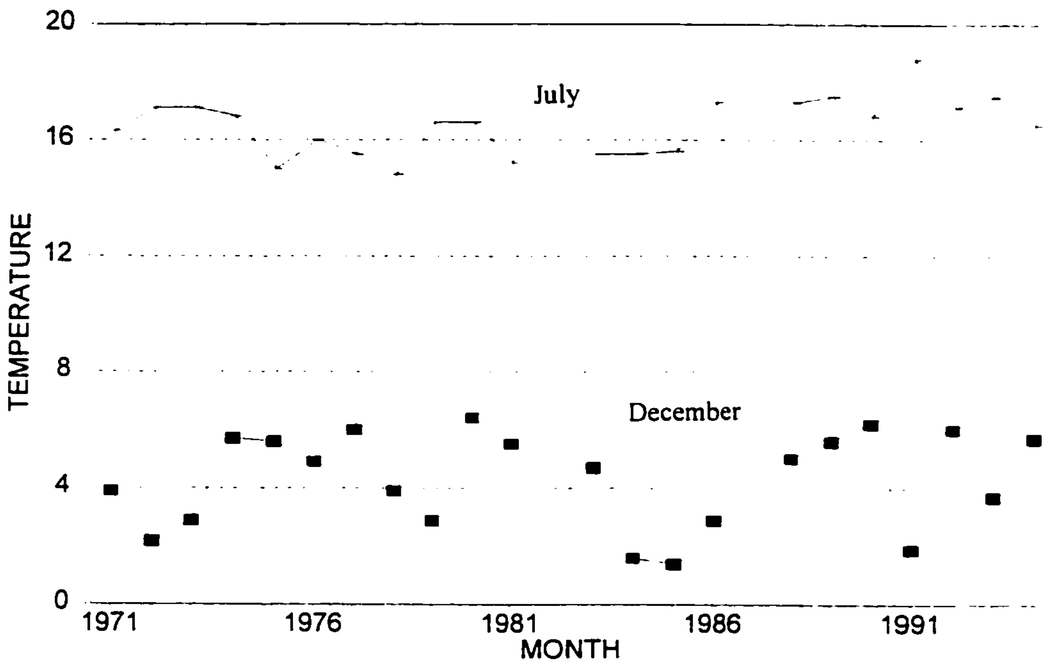


FIGURE 25: Average Daily Temperatures for July and December on North Pender Island (1970 to 1994)

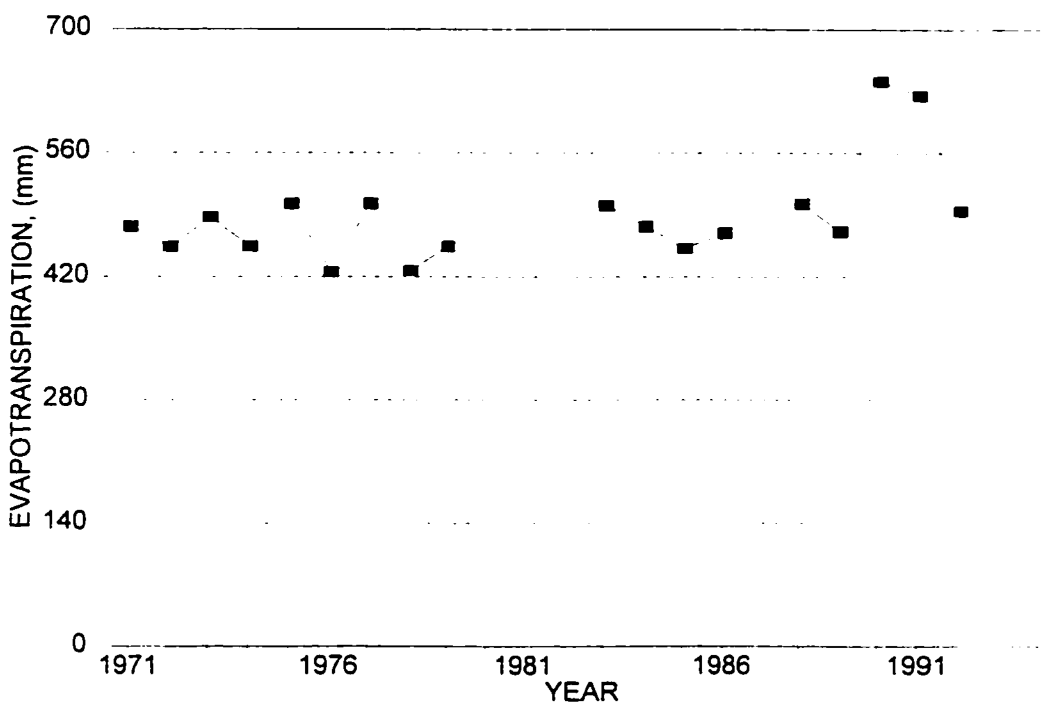


FIGURE 26: Estimated Annual Evapotranspiration for North Pender Island (1970 to 1993)

summer temperatures rather than an even distribution of increased temperature throughout the year. The higher temperatures during the summer months will increase the net moisture loss (see Section 5.3) placing additional stresses on the vegetation of the Island and increasing the risk of forest fires.

For future climate studies on the Islands, it is recommended that humidity data be collected to provide a more complete overview of the water balance by enabling more accurate estimates of the evaporation rate to be determined. Given the importance of water resources on the Islands, the parameters which comprise the water balance equation should be well understood to enable a framework for future planning to be devised.

5.3 . Evapotranspiration

To adequately discuss evapotranspiration, it is best to define both evaporation and transpiration. Evaporation is the removal of water from the surface to the air with the conversion of water from a liquid or solid phase to the vapour phase while transpiration is the passage of water from plants to the atmosphere through leaf pores. Transpiration is the most difficult parameter to measure (Balek, 1989, p47) since in practice it is difficult to separate evaporation from transpiration, they are added to form a single term in the water balance equation (Hartmann, 1994, p122).

Evapotranspiration is controlled to a great extent by net solar radiation. Since North and South Pender Islands have among the highest number of sunshine hours during the summer months in Canada (Agriculture Canada, 1988, p11), the evapotranspiration rates will also be very high. Evapotranspiration is, also, controlled by the ability of the atmosphere to transport water vapour away which is a function of air humidity and temperature, and vertical gradients in wind velocity (Falkland, 1991, p50). In addition, it is a function of the density and type of vegetation present as well as the nature of the soil moisture status of the soils which work together to influence the ability of the soil/plant associations to transfer water to the atmosphere (Falkland, 1991, p50). Actual evapotranspiration equals potential evapotranspiration when precipitation exceeds potential water needs of plants. However, when soil moisture content decreases below the water holding capacity of the soil, actual evapotranspiration equals precipitation plus whatever moisture plants can remove from the soil (Mather, 1965, p299). Woodward (1987, p67) estimates that a 30 metre tall Douglas fir (*Pseudotsuga menziesii*) could store 4000 litres of water of which 75% can be removed by evapotranspiration.

Given the lack of accurate measured meteorological data, an empirical formula has been used to provide an estimate of evapotranspiration on the Islands. The equation (Balek, 1989, p52) is:

$$E_t = \frac{P}{(0.9 + (P/L)^2)^{1/2}} \text{ mm/yr}$$

where P is annual precipitation in mm
L $= 300+25T+0.05T^3$
T is mean annual temperature in °C
E_t is total evapotranspiration in mm/year

Based on this equation, estimates for evapotranspiration have been calculated from 1970 to 1993 and are presented in Figure 26. These data indicate that during this time period evapotranspiration may have ranged from approximately 425 mm/year to 645 mm/year. These results can be misleading, however, and should be compared to precipitation. Figure 27 presents the estimated ratio of evapotranspiration to annual precipitation. The ratio of the annual potential evaporation to annual precipitation (known as the drying index), to a great extent, controls the portion of precipitation which is lost to surface runoff (Milly, 1994, p19). It appears that the moisture lost due to evapotranspiration could be as high as 65% of the total annual precipitation. Given its importance to the water balance of island ecosystems, evapotranspiration is likely the least quantified component (Falkland, 1991, p54). This would indicate that more research is necessary to more accurately measure moisture losses due to evapotranspiration.

There is a strong relationship between the near surface geology and evapotranspiration. In areas having little or no soil cover, the rocks are not capable of retaining water for subsequent evapotranspiration (Milly, 1994, p20.).

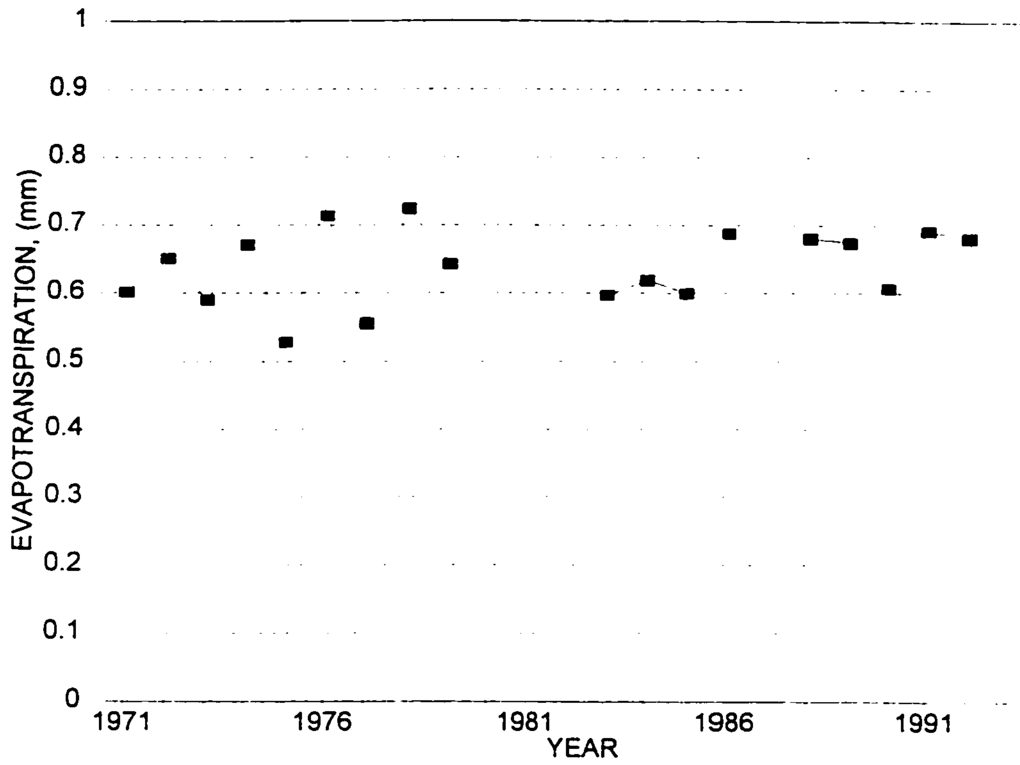


FIGURE 27: Estimated Ratio of Evapotranspiration to Annual Precipitation (1970 to 1993)

5.4 Summary

To this point, climatic data have been presented from a historical perspective. The review of climatic data illustrates significant annual variations in the input of fresh water to the groundwater system of the Gulf Islands. Miwa *et al.* (1988, pxvi) note that uncertainties of weather and climate do not change and when combined with steadily increasing water demands, the potential seriousness of water supply shortfalls increases. The climatic data clearly show that the availability of groundwater resources are a function of annual precipitation, seasonal distribution of precipitation, temperature and evapotranspiration. From a water management perspective, given the lack of predictability of rainfall from year to year, it is important that a conservative approach to community planning be taken on the Islands to ensure that there are adequate groundwater supplies to meet the needs of the human population as well as to maintain the integrity of the island ecosystem. Human activities such as removal of the vegetation cover and building of roads, associated with the development of the islands have impacts on the climatic factors which influence groundwater recharge.

Studies have shown that interannual variations in climate can have important impacts on variability in groundwater recharge (Vaccaro, 1992, p2821). When considered in conjuntion with variations in soil properties, vegetative cover, topography and local geology, climatic variability becomes an interdisciplinary study of groundwater recharge variability.

As population continues to grow accompanied by expectations of increased standards of living, there will be increased demands placed on a limited water supply system (da Cunha, 1989, p641). Further research is recommended regarding variations in climatic factors to provide a better understanding of the input and output parameters to the water balance equation to assist in adequate education and planning to properly manage groundwater resources.

5.5 Implications Of Global Warming

It is equally important to review future climate changes that may be due to a predicted global warming which may impact the water resources of the Islands. The concept of global warming can be very ambiguous. Many scientists believe that global warming is happening rather quickly while others question whether it is occurring at all. Wall (1993) states that a working hypothesis should be adopted which presumes significant climate change in the near future is probable.

By affecting patterns of rainfall, temperature, and evapotranspiration, global warming will impact the forest ecosystems on the Islands, as well as human habitability. Predictions of climatic change for the Pacific Northwest indicate that temperatures may increase by 2° to 6°C and be accompanied by an increase in winter precipitation (Wall, 1993).

Since a groundwater management plan must be based on historical data, it is important to remember that the future may not be the same as the recent past. Additional research is required to determine in greater detail the potential impact of global warming on the Islands.

6.0 GEOLOGY OF PENDER ISLANDS

> " The first step in establishing a management strategy is to understand the detailed behaviour of the aquifer. If the flow mechanisms operating in a particular aquifer are not adequately understood then problems are almost inevitable. " (Spinks and Wilson, 1990, p475)

Geology plays a major role in the determination of the fresh water resources available in island ecosystems. The type and history of bedrock in conjunction with the surficial geology control the storage capacity and flow of groundwater resources. The type and thickness of surficial sediments in conjunction with climatic factors have an impact on the vegetation density and diversity which in turn determine the amount of precipitation lost to interception and surface runoff. In order to develop a groundwater management plan, it is important to have a basic understanding of the controls placed on the availability of groundwater resources by the local geology. Ozoray (1973, p1) states that there can not be any effective management without a reasonable estimation of the resource in question.

This section describes the previous geologic investigations, bedrock geology, structural geology, surficial geology and the hydrogeological characteristics of the strata encountered on the Pender Islands. Each of these topics will include a section describing their influence on the groundwater supply for the Islands.

6.1 Previous Work

The previous geologic investigations conducted on the Gulf Islands were part of much larger studies resulting in the delineation of generally only the macroscale features. The most prominent works are those of England (1989) and Muller and Jeletsky (1970). Other works include Clowes *et al.* (1987), Pacht (1984), Agriculture Canada (1988), Clague (1977), Holland (1976), Eis and Craigdallie (1980), Halstead and Treichel (1966), Golder Associates (1993), and Williams and Pillsbury (1958).

The majority of these works are based on the early geological studies conducted by Clapp (1912, 1913, 1914).

There is often very little mention of the relationship between groundwater and geology in the previous investigations. This is simply a result of the limited importance of the subject at the time of the previous studies. A paper by Mordaunt (1981) places some emphasis on the importance of the regional geology but little field work was conducted to corroborate the geology described by previous researchers.

For this investigation, the geological data acquired by previous authors were used as the basis for designing a field program to check the existing data and to utilize the geological information to better understand the physical restrictions of groundwater availability on the Gulf Islands through a sampling and testing program. In addition, aerial photographs and satellite imagery were reviewed to further assist in the delineation of stratigraphy and structure.

The bedrock type was identifiable on the aerial photographs for the coastal portions of the Island. In areas having a jagged coastline, the bedrock is composed of conglomerates, while in regions having a somewhat linear coastline sandstones are the predominant bedrock type. Shales are found along the heads of rectangular shaped inlets. In coastal areas where sandstones are predominant, it is possible to identify the macro jointing system.

Structure was identified using both satellite imagery and aerial photographs. Both structure and stratigraphy, which were mapped remotely, were field checked.

6.2 Bedrock Geology

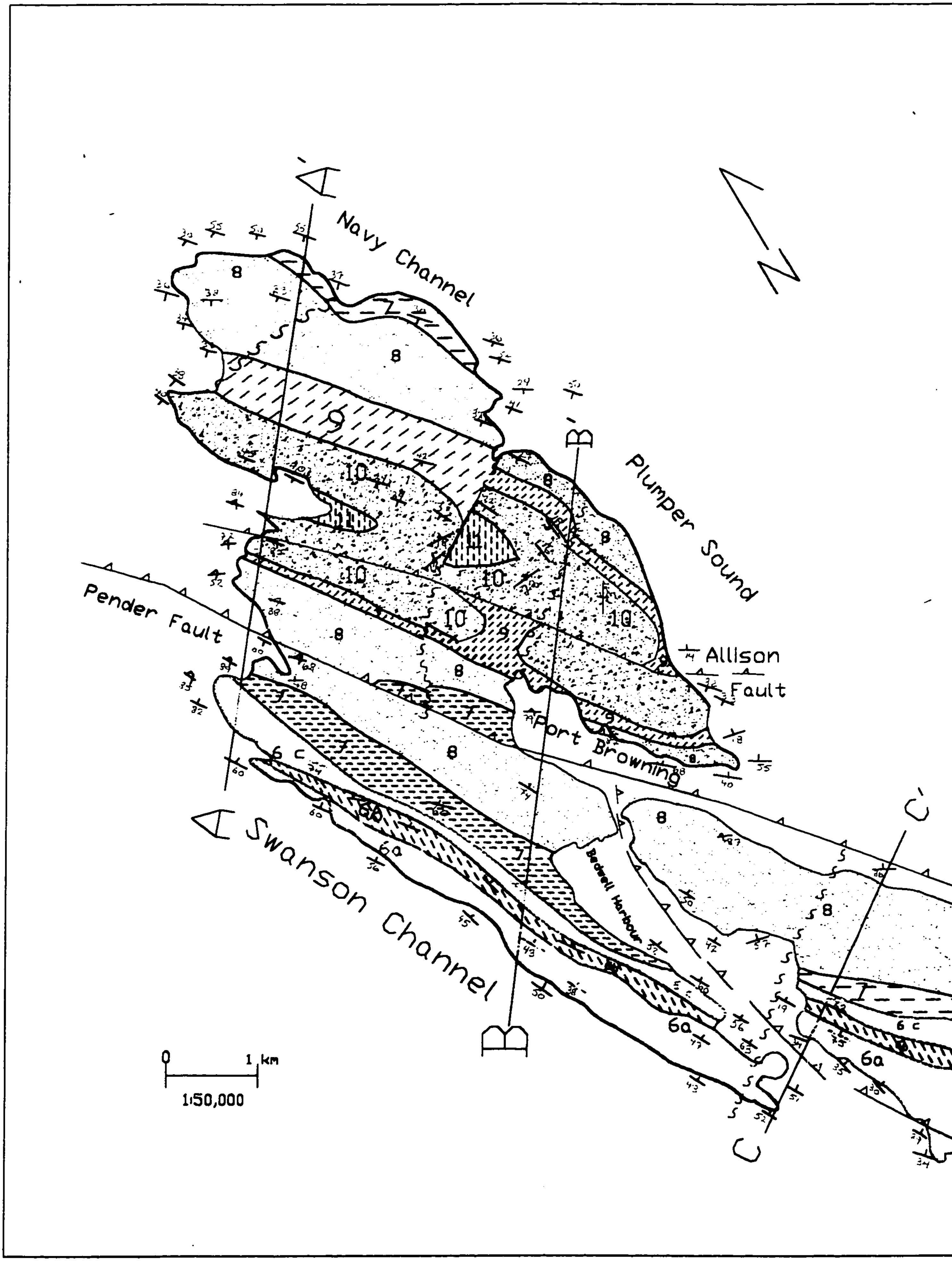
The bedrock units exposed on North and South Pender Islands are comprised of sediments of the Nanaimo Group of Upper Cretaceous age (80 million years ago (mya)). The sandstones, shales and conglomerates rest unconformably on older rock formations consisting of volcanics and metasediments of the Insular Belt of Carboniferous (315 mya) and Devonian age (360 mya) (Pacht, 1984, p778). The topography of the Islands can be readily correlated to the bedrock type. Fine grained shales and siltstones are present in the low lying areas while the topographic highs are comprised of more resistant sandstones and conglomerates.

6.2.1 Stratigraphy

Stratigraphy generally plays a significant role in the determination of the storage capacity for groundwater resources. The stratigraphy, in conjunction with geologic structure, controls the primary porosity and permeability which directly impacts groundwater storage and flow. The coarse grained sandstones would generally have the greatest potential for storage capacity and under normal circumstances would represent the most favourable aquifer.

The Nanaimo Group is an assemblage of conglomerate, sandstone, siltstone, and shale derived from four major tectonic provinces: the North Cascades; terranes of the San Juan Islands; the Insular Belt; and, the Coastal Plutonic Belt (Pacht, 1984, p766). The nomenclature utilized in this report for the stratigraphic units present on the Pender Islands is that which was defined by Clapp (1912, 1914) and revised by England (1989). Table 7 presents a description of the stratigraphic units. The stratigraphic units were mapped as part of the field investigations and are presented inplan view in Figure 28. The following section provides a brief description of each of the stratigraphic units.

In the Gulf Islands, the rapid accumulation of sediments comprising the Nanaimo Group accounts for their being poorly sorted, massive and, in general, lacking pore spaces and conduits for the transmission of water (Halstead and Treichel, 1966, p6). A general knowledge of the stratigraphic units can be important in the development of an overall groundwater management program but should be viewed in combination with the structural geologic setting.



A'
Navy Channel
N
Plumper Sound
B'
Pender Fault
Allison
Fault
Port Browning
Bedwell Harbour
C'
A
Swanson Channel
B
C
0
1 km
1:50,000

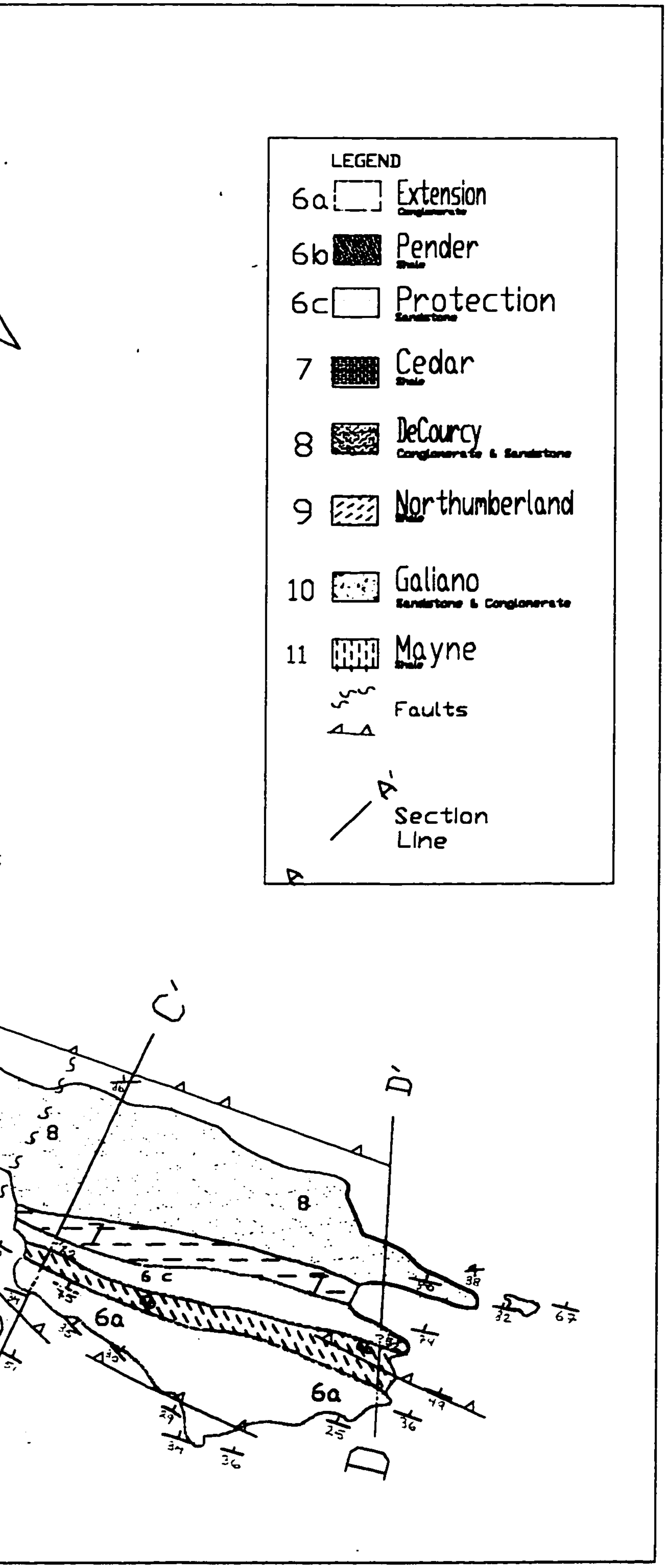


FIGURE 28: Bedrock geology map

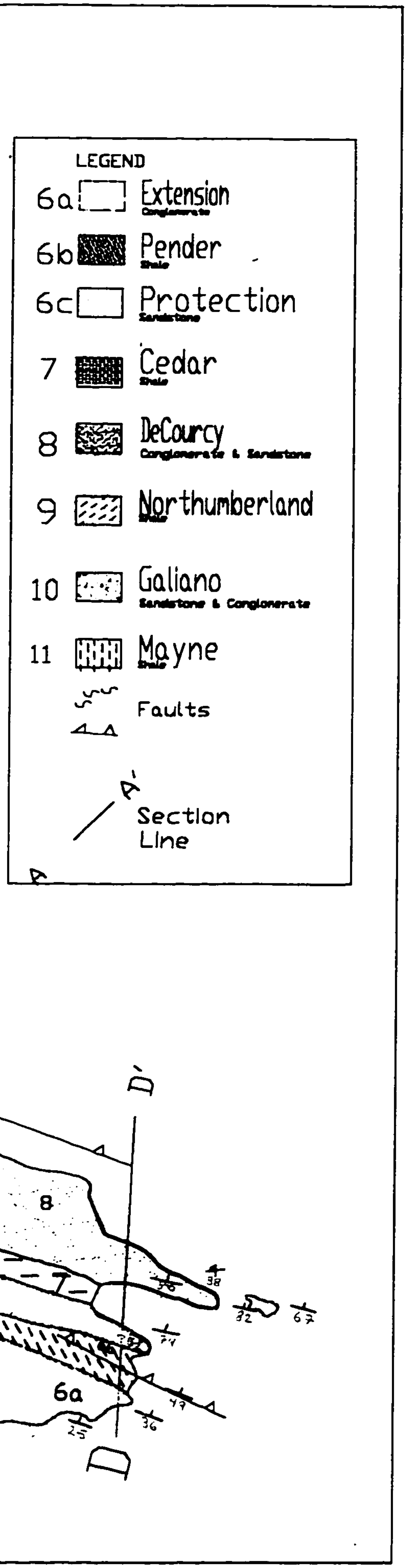


FIGURE 28: Bedrock geology map

TABLE 7: Stratigraphic Units Occurring on the Pender Islands (based on England, 1989)

Formation	Thickness	Depositional Environment	General Stratigraphy	Principal Outcrop Locations
Extension	up to 480 m	Marine	Conglomerate with minor shale, sandstone, and coal.	May, Gowlland and Tilly points southwestern coast of North Pender Island from Wallace Point to Thieves Bay.
Pender	150 m	Marine (paleo-water depths of 150 - 1200 m)	Mudstone, siltstone and fine-grained sandstone.	From Egeria Bay to Canned Cod Bay. From Thieves Bay to cove south of Arbutus Bay.
Protection	200 - 550 m	Marine (paleo-water depths of 20 -50 m)	Coarse grained sandstone with fine grained sandstone, siltstone.	From Mowat Point to Bedwell Harbour. From Richardson Bluff to Higgs Point.
Cedar	~ 500 m	Marine (paleo-water depths of 20 - 600 m)	Shale, siltstone, and fine grained sandstone.	Between Shingle Bay, Port Browning, and Bedwell Harbour. Forms shoreline along Navy Channel. At Mortimer Spit, and at Little Bay.
De Courcy	450 m	Marine (paleo-water depths of 100 - 300 m)	Medium to coarse grained sandstone with fine grained sandstone, siltstone and mudstone interbeds, minor conglomerate.	From Stanley Pt. to Willy Pt. along east coast of North Pender from Willy Pt. to Bold Cove. Between Shingle Bay and Ella Bay, Port Browning, Cove Bay, Bedwell Harbour, Mount Norman and Spalding Hill.
Northumberland	100 - 350 m	Marine (paleo-water depths of 100 - 1200 m)	Shale interbedded with very fine grained sandstone and siltstone and minor medium to coarse grained sandstone.	Brackett Cove to just south of Ella Bay.
Galiano	150 - 550 m	Marine	Medium to coarse grained sandstone and pebble to cobble conglomerate.	James Point and Dent Hill.
Mayne	220 - 340 m	Marine (paleo-water depths of 100 - 800 m)	Brownish-grey siltstone and grey mudstone with fine grained sandstone.	Otter Bay.

6.2.1.1 Extension Formation

The Extension Formation consists primarily of thick bedded, polymictic, pebble to boulder conglomerate and medium to coarse grained sandstone (Figure 29) (England, 1989, p64) having an estimated thickness of 480 metres. Based on an examination of index fossils, the age of the formation was established by Ward (1978) and McClellan (1927) as early Campanian (84 mya).

The principal outcrops of the Extension Formation are found along the southwest coast of North Pender Island from Wallace Point to Thieves Bay (Figure 3). This formation, also, outcrops along the southwest coast of South Pender Island from Hay Point to Gowlland Point (Figure 3).

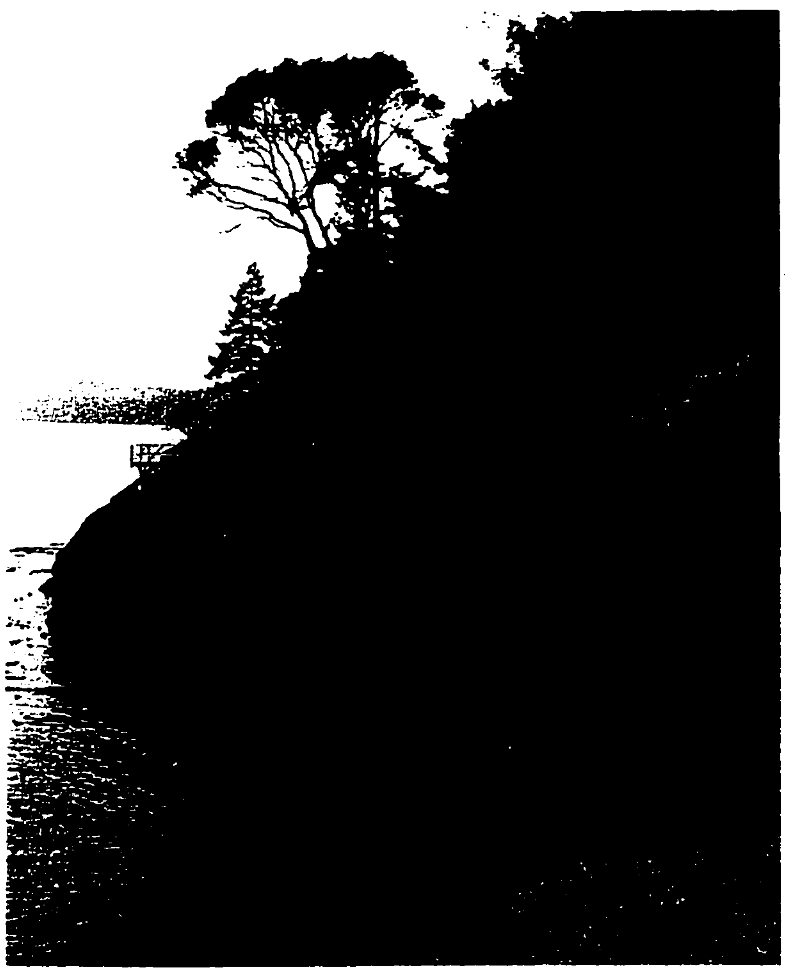


FIGURE 29: Extension Formation conglomerates

6.2.1.2 Pender Formation

The Pender Formation is predominantly fine grained consisting of thin bedded, fossiliferous mudstone, siltstone, and fine grained sandstone (England, 1989, p65) which is locally in excess of 320 metres in thickness. Within this unit, both macrofossils and microfossils are locally abundant (England, 1989, p65). Cameron (1988a, b) estimated that a study of the microfauna indicates paleo-depths of 150 to 1200 metres.

The major outcrops of the Pender Formation are found at Thieves Bay on North Pender Island and Canned Cod Bay and Egaria Bay on South Pender Island (Figure 3).

6.2.1.3 Protection Formation

The Protection Formation consists of thin to thick bedded, medium to coarse grained sandstone which is commonly crossbedded with planar laminated, fine grained sandstone, siltstone, and rare mudstone and coal (England, 1989, p66). Pacht (1980) estimated the thickness of the formation to be 200 metres. Since there have been no age diagnostic fossils recovered from this formation, Ward (1978) estimated the age by using the overlying and underlying strata. Based on the overlying upper Campanian Cedar District Formation and the underlying lower Campanian Pender Formation, the Protection Formation is mid-Campanian. Cameron (1988b) found that foraminifers indicate that the paleo-water depths were between 20 and 50 metres.

The major outcrop locations of the Protection Formation are along the coast in the vicinity of Mouat Point and the southwest end of Bedwell Harbour on North Pender Island and Richardson Bluff and Higgs Point on South Pender Island (Figure 3).

6.2.1.4 Cedar District Formation

The Cedar District Formation consists of thin bedded silty shale, siltstone, and fine grained sandstone, or massive to crudely laminated silty shale (Figure 30) (England, 1989, p67) with estimated thicknesses ranging up to 500 metres. England (1989, p67) anticipates that locally the Cedar District Formation may be tectonically thickened. Cameron (1988a, b) interpreted the foraminifers to be indicative of two paleo-water depths. Most of the foraminifers indicate paleo-water depth of 200 to 600 m while the remainder of the foraminifers project paleo-water depths of 20 to 200 metres.

The major outcrops of the Cedar District Formation occur in Shingle Bay, in the vicinity of Hamilton Beach, along the northwest shore of Bedwell Harbour and along the shoreline of Navy Channel in the vicinity of Clam Bay on North Pender Island and at Camp Bay on South Pender Island (Figure 3).

6.2.1.5 DeCourcy Formation

The DeCourcy Formation is typically comprised of thick bedded, medium to very coarse grained sandstone, with fine grained sandstone, siltstone, and mudstone interbeds, and minor conglomerate and pebbly sandstone (Figure 31) (England, 1989, p69). The DeCourcy sandstones represent the most abundant rock type on the islands (Figure 28). The formation thickness is in excess of 450 m (Pacht, 1980). Cameron (1988a,b) found that the foraminifers indicate a paleo-water depth of 100 to 300 metres. The formation is estimated to be late Campanian in age (England, 1989, p69).

The major outcrops of the DeCourcy Formation occur from Stanley Point to Willy Point along the northeast coast of North Pender Island, between Shingle Bay and Ella Bay, and at Port Browning on North Pender Island and Cove Bay, Bedwell Harbour, Mount Norman and Spalding Hill on South Pender Island (Figure 3).

FIGURE 30: Cedar Formation shales

FIGURE 31: DeCourcy Formation sandstone and conglomerate. Note the vertical nature of the contact.

6.2.1.6 Northumberland Formation

The Northumberland Formation is comprised of grey, silty shales interbedded with thin, very fine grained sandstone and siltstone, and minor thick bedded, medium to coarse grained sandstone (Figure 32) (England, 1989, p70). Muller and Jeletsky (1970) determined the age of the formation to be late Campanian based on a study of index fossils. Cameron (1988a,b) reports that microfauna indicate paleo-water depths of 100 to 1200 metres.

The major outcrops of the Northumberland Formation are located along the shoreline of Brackett Cove, Grimmer Bay, and along the coastline adjacent to Mount Menzies on North Pender Island (Figure 3). The Northumberland Formation does not outcrop on South Pender Island.

6.2.1.7 Galiano Formation

The Galiano Formation consists predominantly of thick bedded, medium to coarse grained sandstone and pebble to cobble conglomerate. and associated finer grained beds (Figure 33) (England, 1989, p71). No diagnostic fossils have been found to provide an age estimate of the formation, however, it is estimated to be latest Campanian to early Maastrichtian in age based on the overlying and underlying strata.

The major outcrops of the Galiano Formation occur on Mount Menzies, James Point and along the eastern shoreline of Otter Bay on North Pender Island (Figure 3). The Galiano Formation does not outcrop on South Pender Island.

6.2.1.8 Mayne Formation

The Mayne Formation is generally comprised of thin bedded, brownish-grey siltstone and grey mudstone, with fine grained sandstone (England, 1989, p72). Fossil evidence has been used to date the Mayne Formation as Maastrichtian (England, 1989, p73). Cameron (1988a, b) used microfauna to establish a paleo-water depth of between 100 to 800 metres.

FIGURE 32: Steeply dipping Northumberland Formation shales

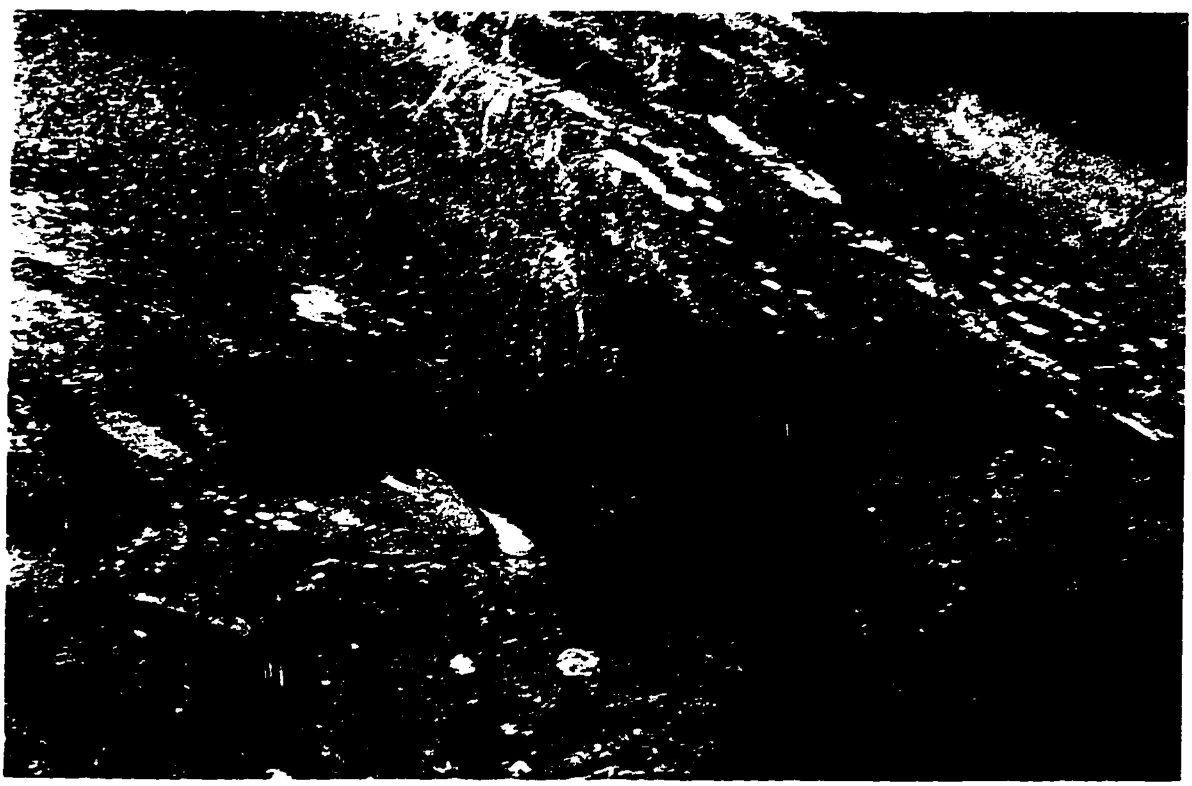


FIGURE 33: Massive Galiano Formation sandstone. Note the seepage from the grassy area in centre of photo

The major outcrop location of the Mayne Formation is along the shoreline of Otter Bay on North Pender Island (Figure 3). The Mayne Formation does not outcrop on South Pender Island.

6.2.2 Structural Geology

The structural geology represents the cumulative effect of the geologic events which have shaped the Islands. In the sedimentary rocks of the Gulf Islands, groundwater is transmitted along bedding planes or fractures and only wells that encounter such openings are productive (Halstead and Treichel, 1966, p6). The strata of the Nanaimo Group have undergone post-depositional folding and faulting (Williams and Pillsbury, 1958, p187) which has had a dramatic impact on the secondary porosity and permeability. As previously mentioned, a knowledge of the structural geology in combination with stratigraphy is necessary to fully understand the groundwater resources and establish a meaningful approach to groundwater management. The Late Cretaceous represented a time of readjustment along the west coast of Canada following the collision of Wrangellia (Pacht, 1980).

The major structural features of North and South Pender Island are illustrated in Figure 28. The major structural features were mapped utilizing a combination of airphoto interpretation and field mapping.

The major fault is the Pender Fault which is oriented in a northwest-southeast direction. The Pender Fault can be observed along the north shore of Shingle Bay (Figure 28). Another northwest-southeast trending fault is located approximately 1.5 kilometres north of the Pender Fault. This fault is located along the south side of Mount Menzies. A number of springs are associated with this fault. The author recommends that this fault be named the Allison Fault after the late Bob Allison who was a local trustee on North Pender Island for a number of years and whose property the fault transects.

A number of smaller scale northeast-southwest trending faults (probably younger cross faults) are found on the Pender Islands (Figure 28). There are a number of springs associated with these faults indicating that the faults, at least in places, act as discharge zones for groundwater (Figure 28). A review of groundwater flow rates in the water wells drilled on the Pender Islands until 1985 indicates that above average flow rates are found in the vicinity of many of the major and minor faults.

Structural geology may be the most important control on water supply in the Gulf Islands. There is a strong influence on fracture density which can enhance the secondary porosity and permeability resulting in improved well yields. In general, there should be increased numbers of fractures in close proximity to faults and folds. In addition, the dip of the stratigraphic units can influence groundwater resources. If the stratagraphic unit which is the aquifer for an area, outcrops beneath the ocean and dips landward, recharge for the aquifer will be comprised of salt water.

A series of four geologic cross-sections are presented in Figures 36 to 39 and illustrate the simplest representation of the complex geology of the Pender Islands. There are no detailed drill logs available to either confirm or contradict the geologic interpretation. Nevertheless, the sections have been used to assist in the delineation of groundwater discharge and recharge zones on the Islands.

FIGURE 34: Honeycomb structure in massive sandstones due to weathering (photo courtesty of Ross McWhae)

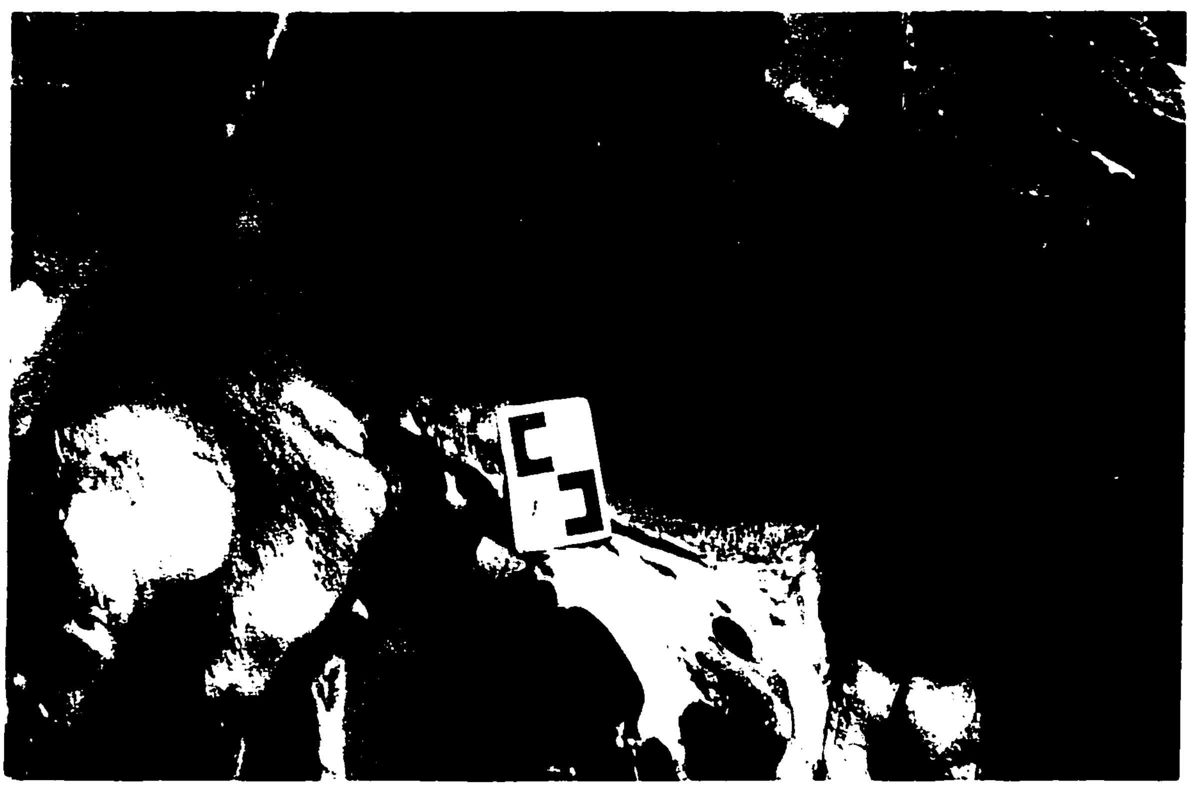
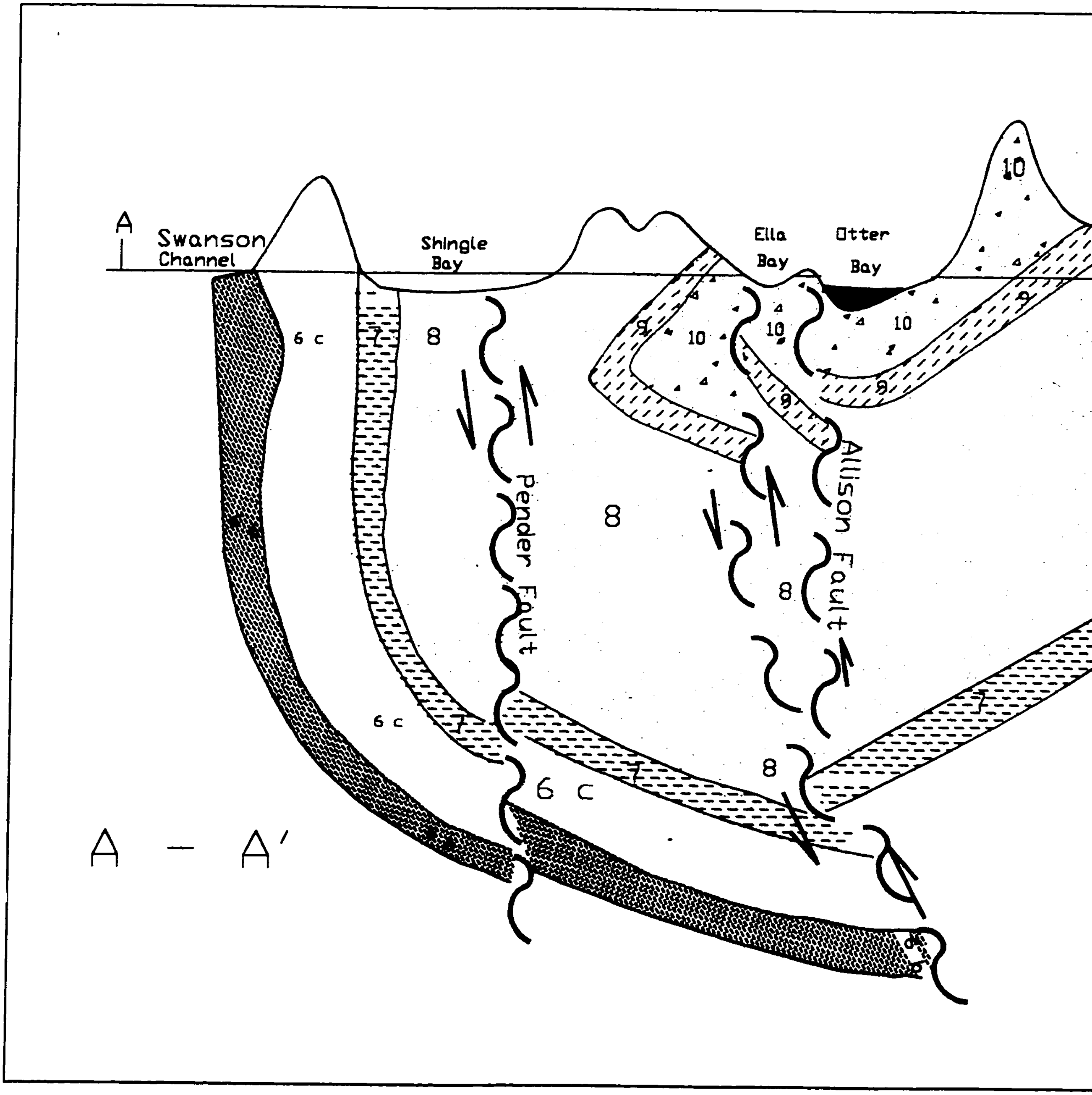


FIGURE 35: Jointing pattern in the DeCourcy Formation sandstones, Stanley Point, North Pender Island



A
Swanson
Channel
Shingle
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Ella
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Otter
Bay
10
9
10
10
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A – A′

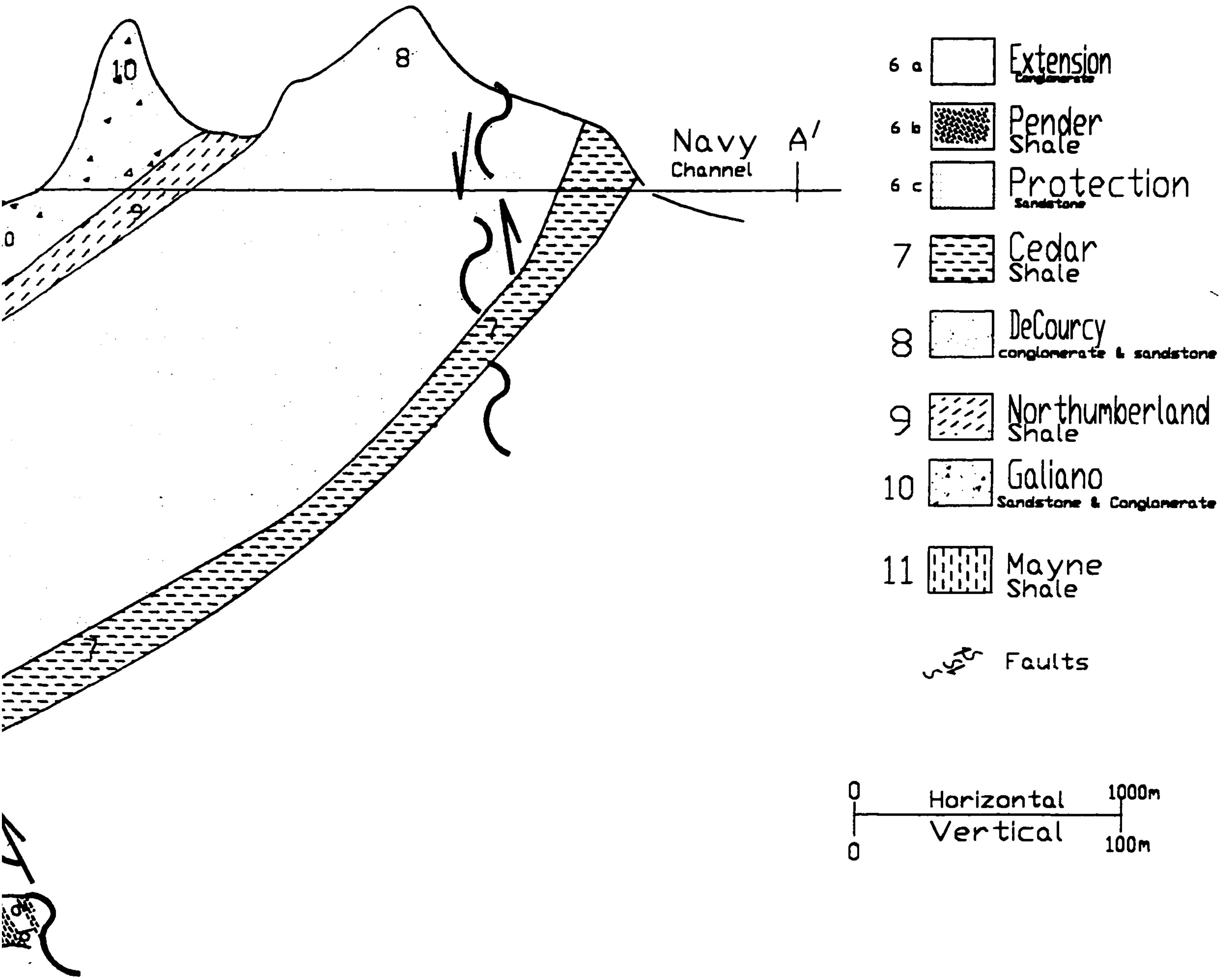


FIGURE 36: Geological cross-section A' - A"

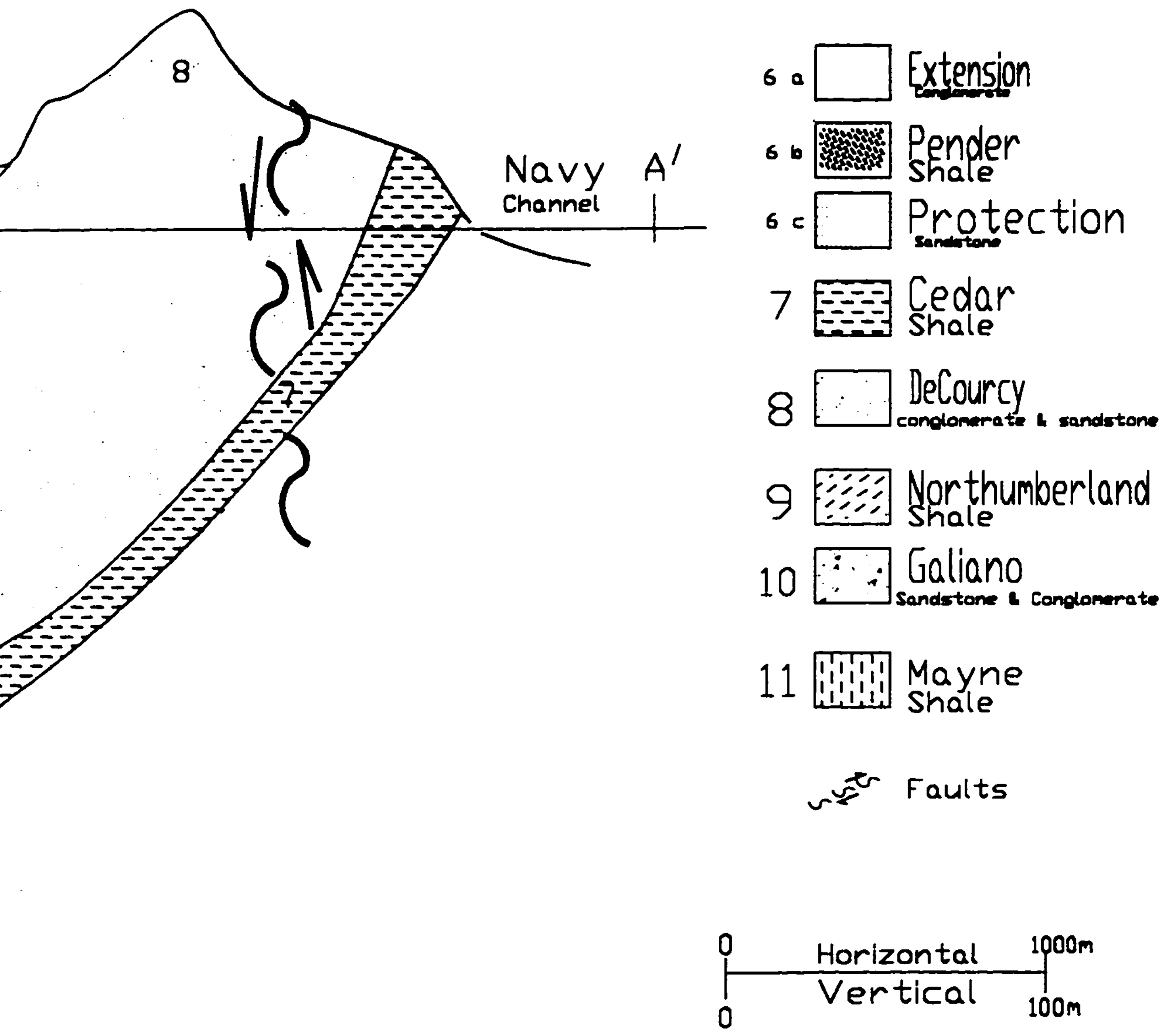
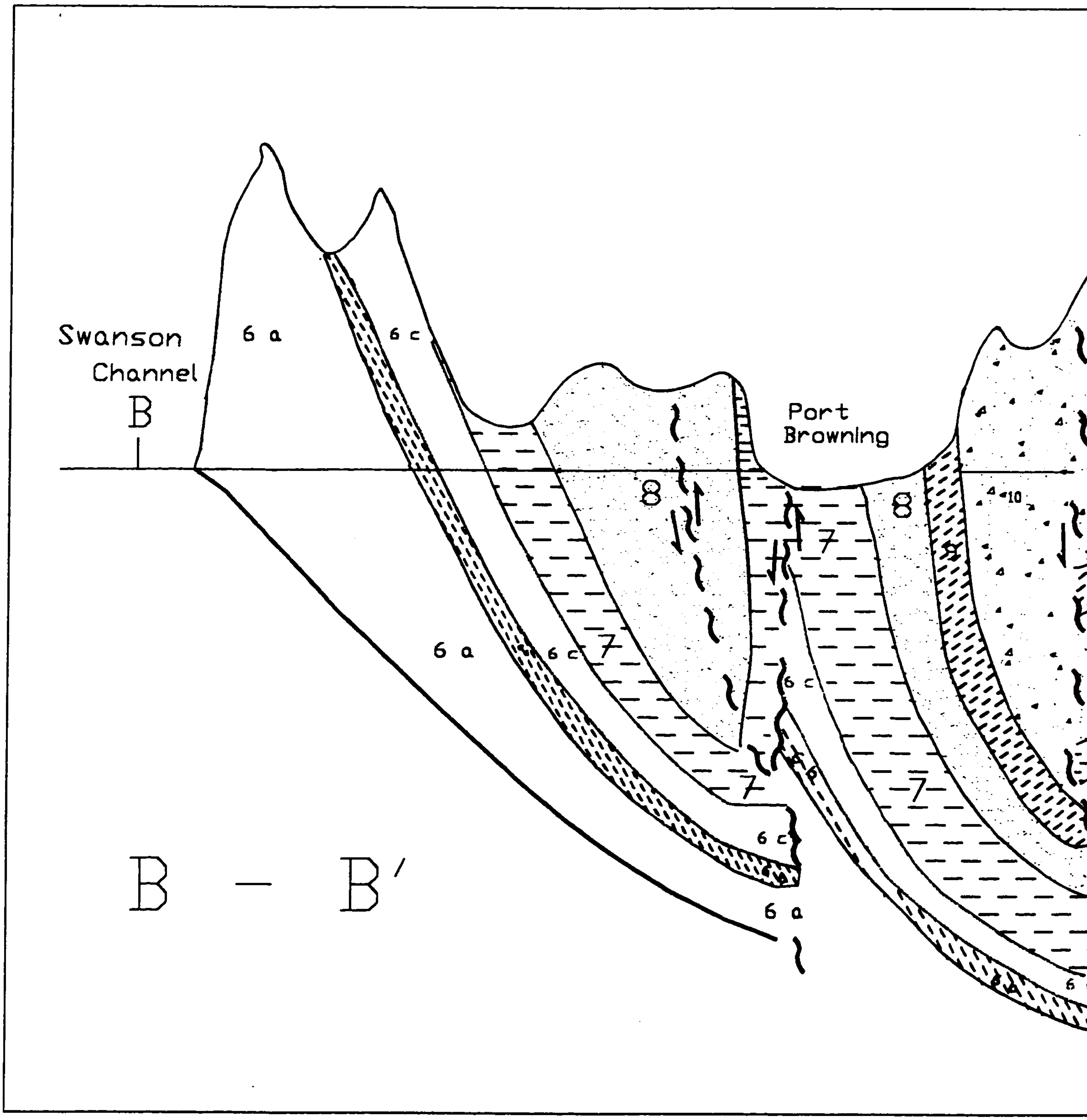


FIGURE 36: Geological cross-section A' - A"


Swanson
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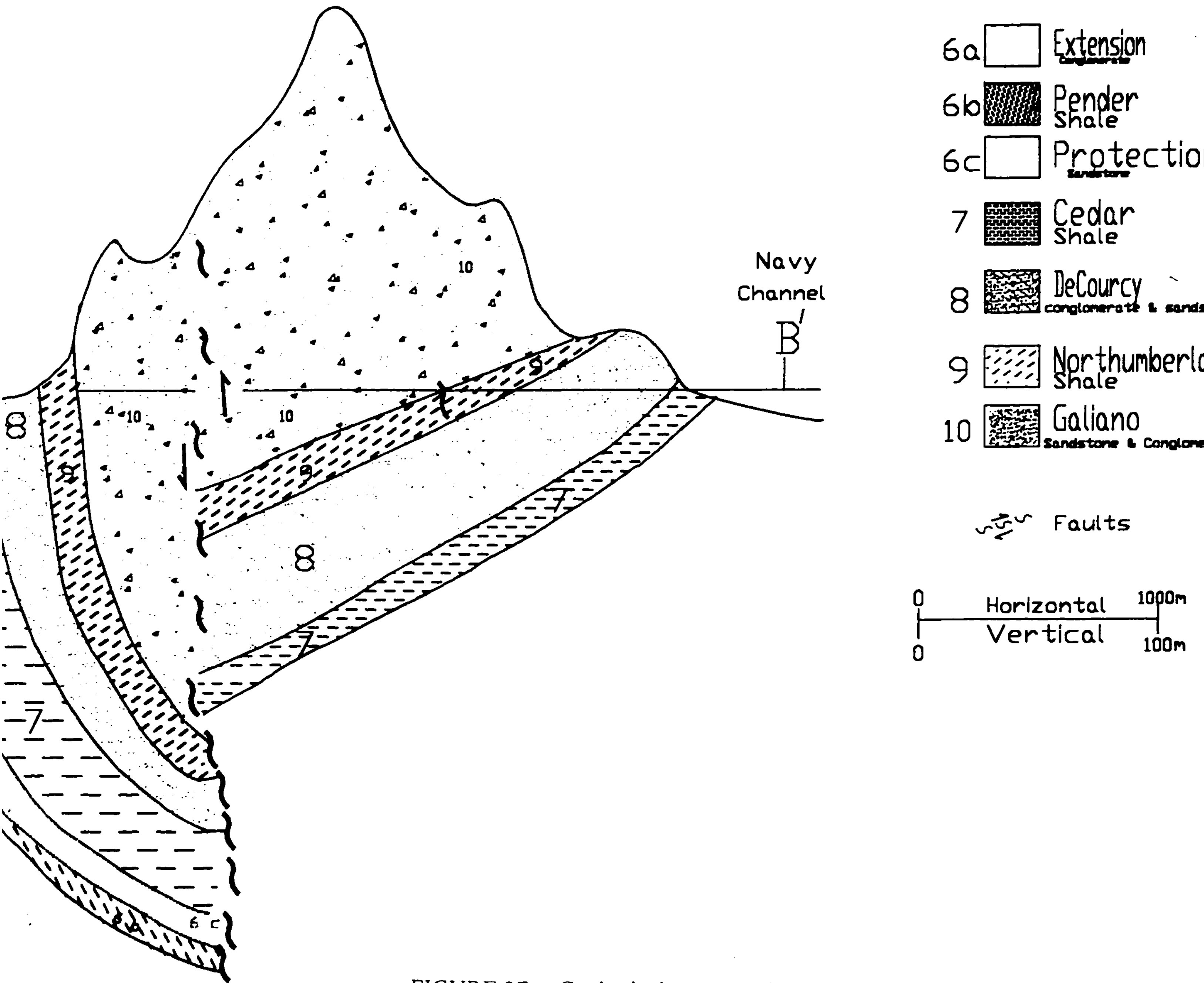


FIGURE 37: Geological cross-section B' - B"

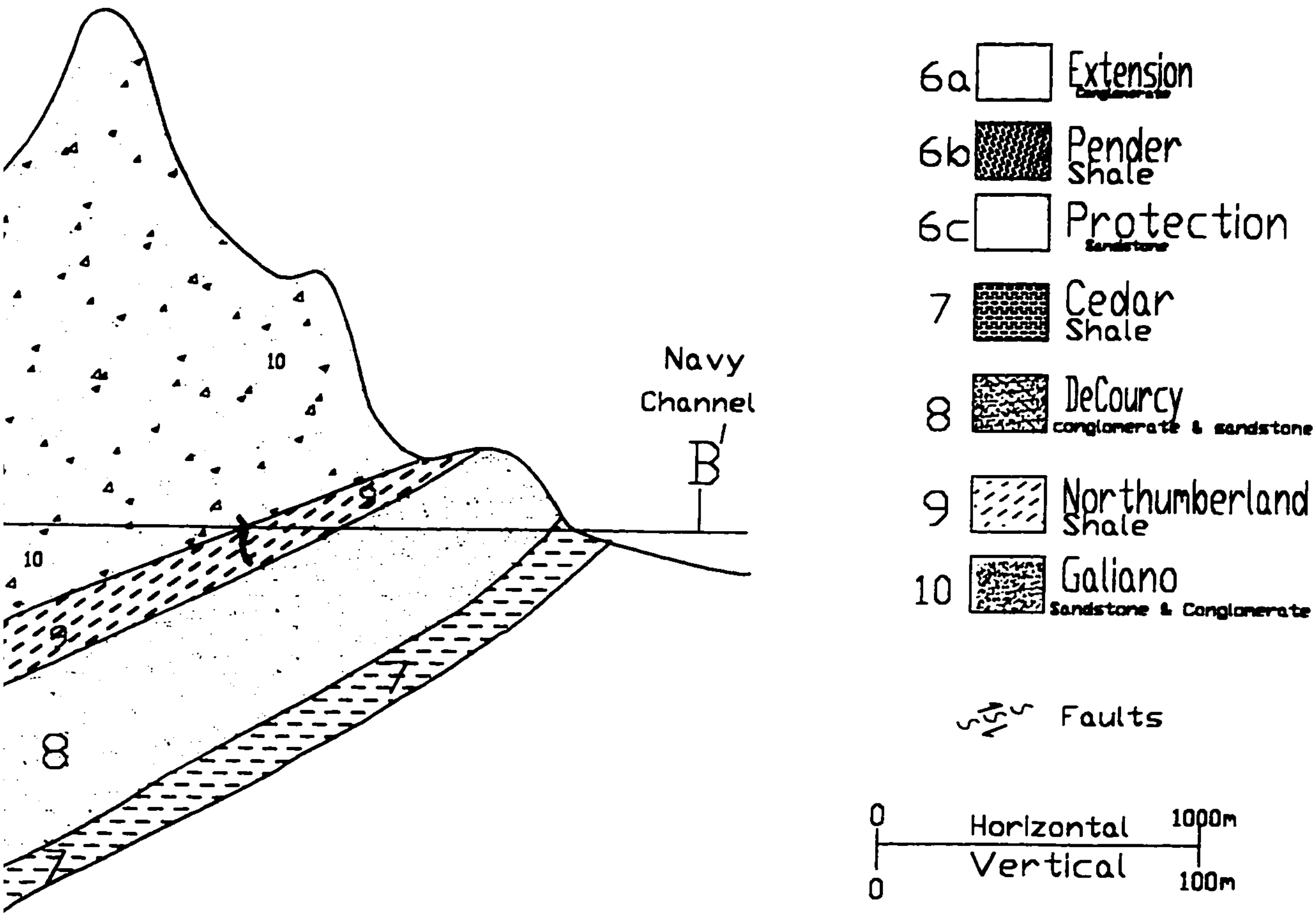
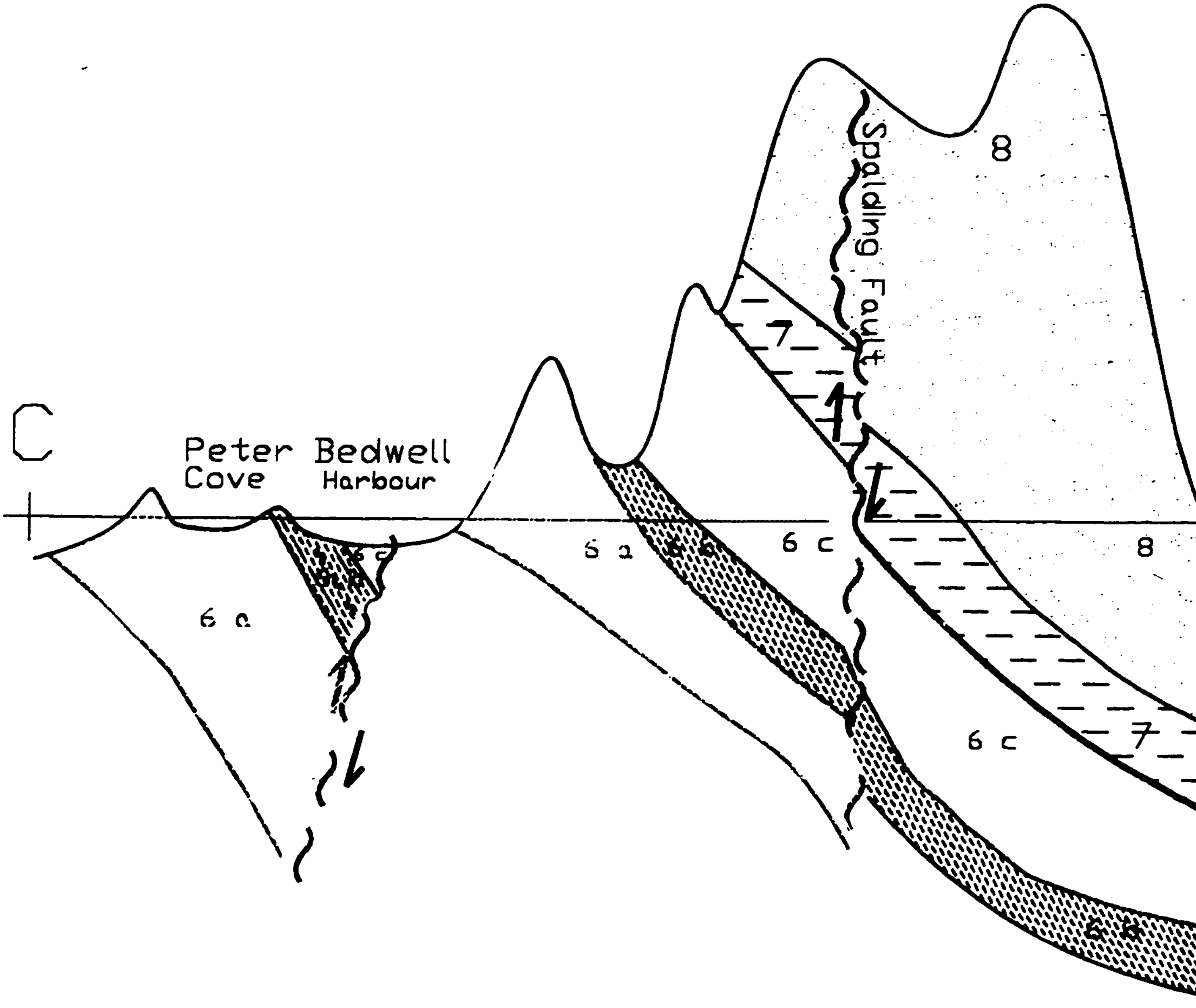


FIGURE 37: Geological cross-section B' - B"



C — C′

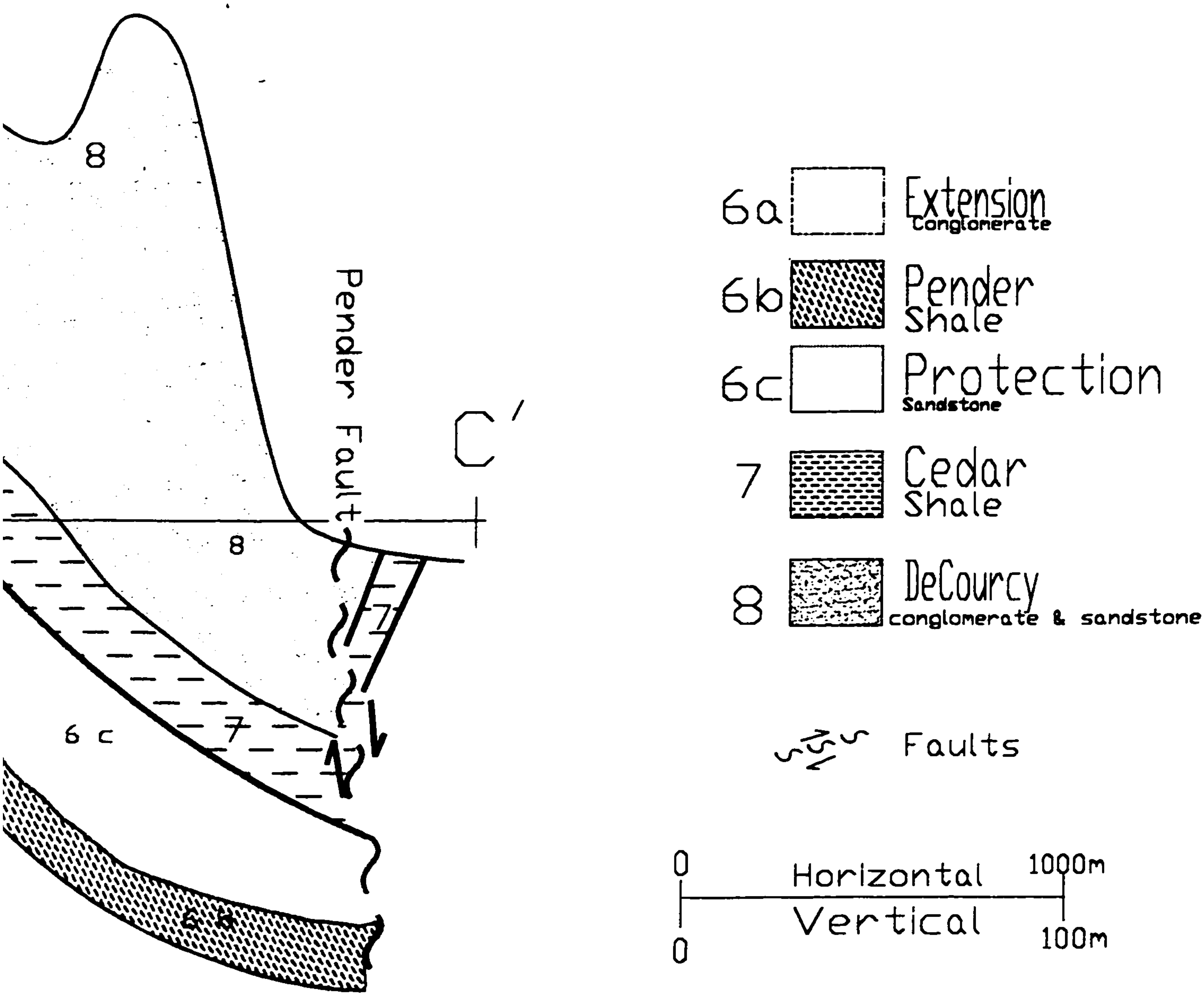


FIGURE 38: Geological cross-section C' - C"

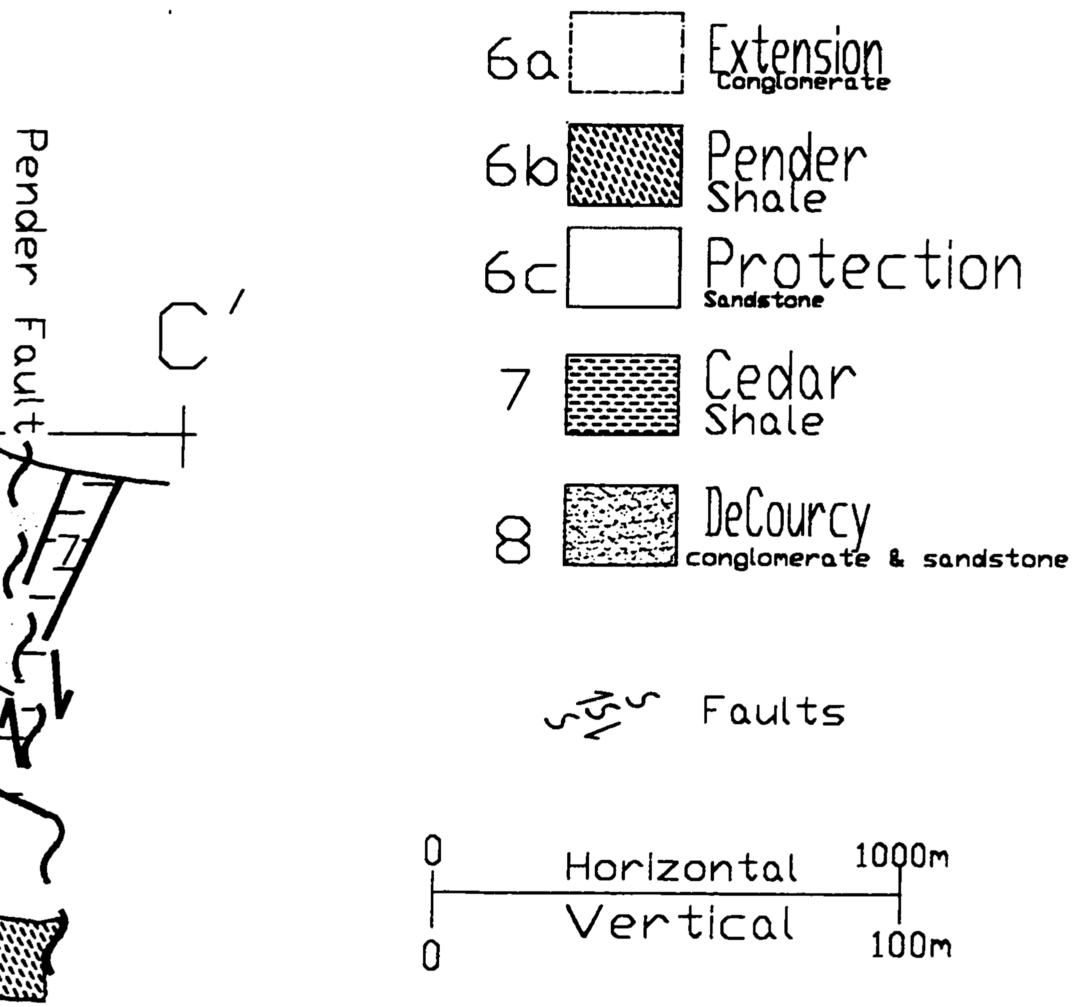
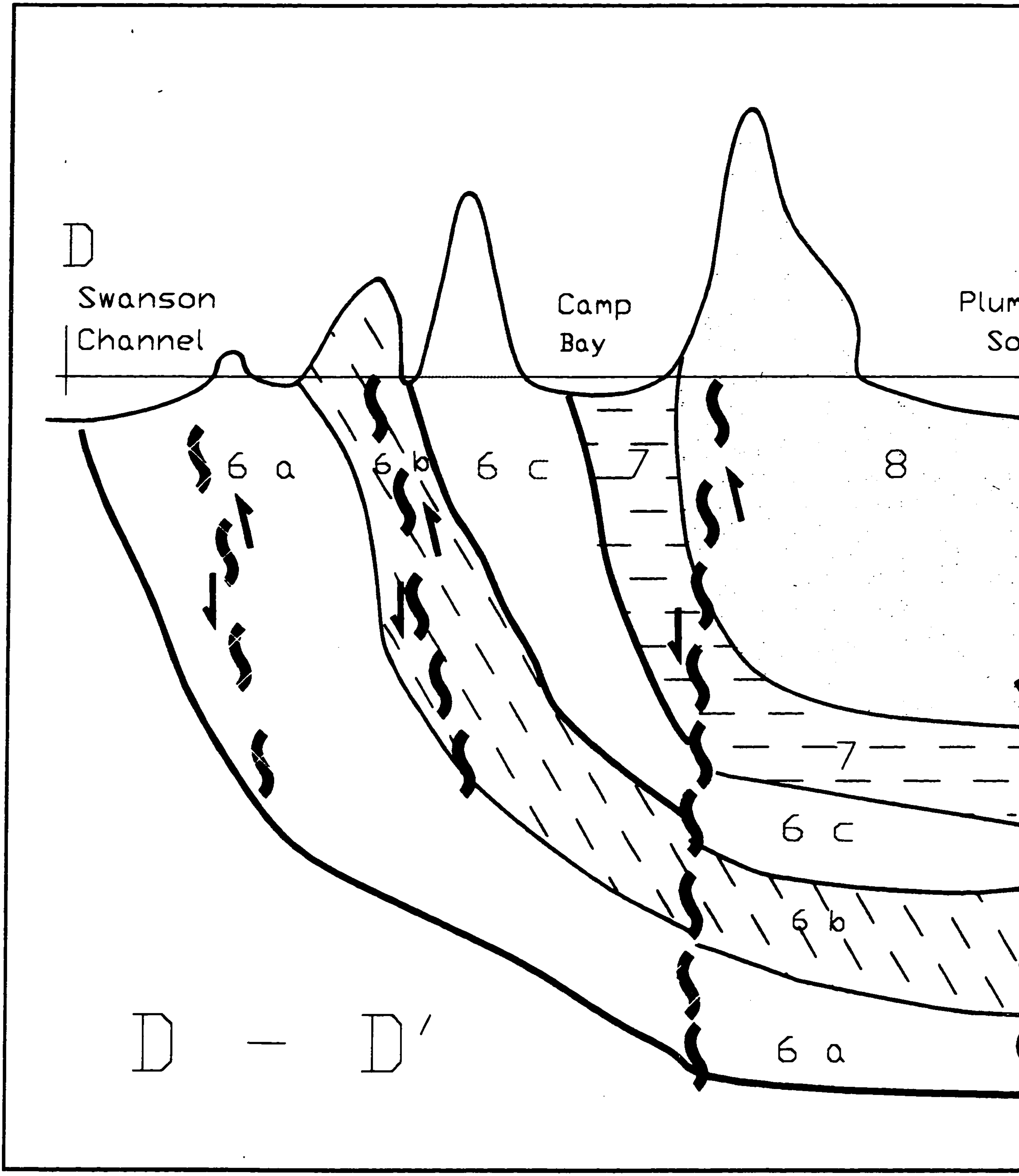


FIGURE 38: Geological cross-section C' - C"


D
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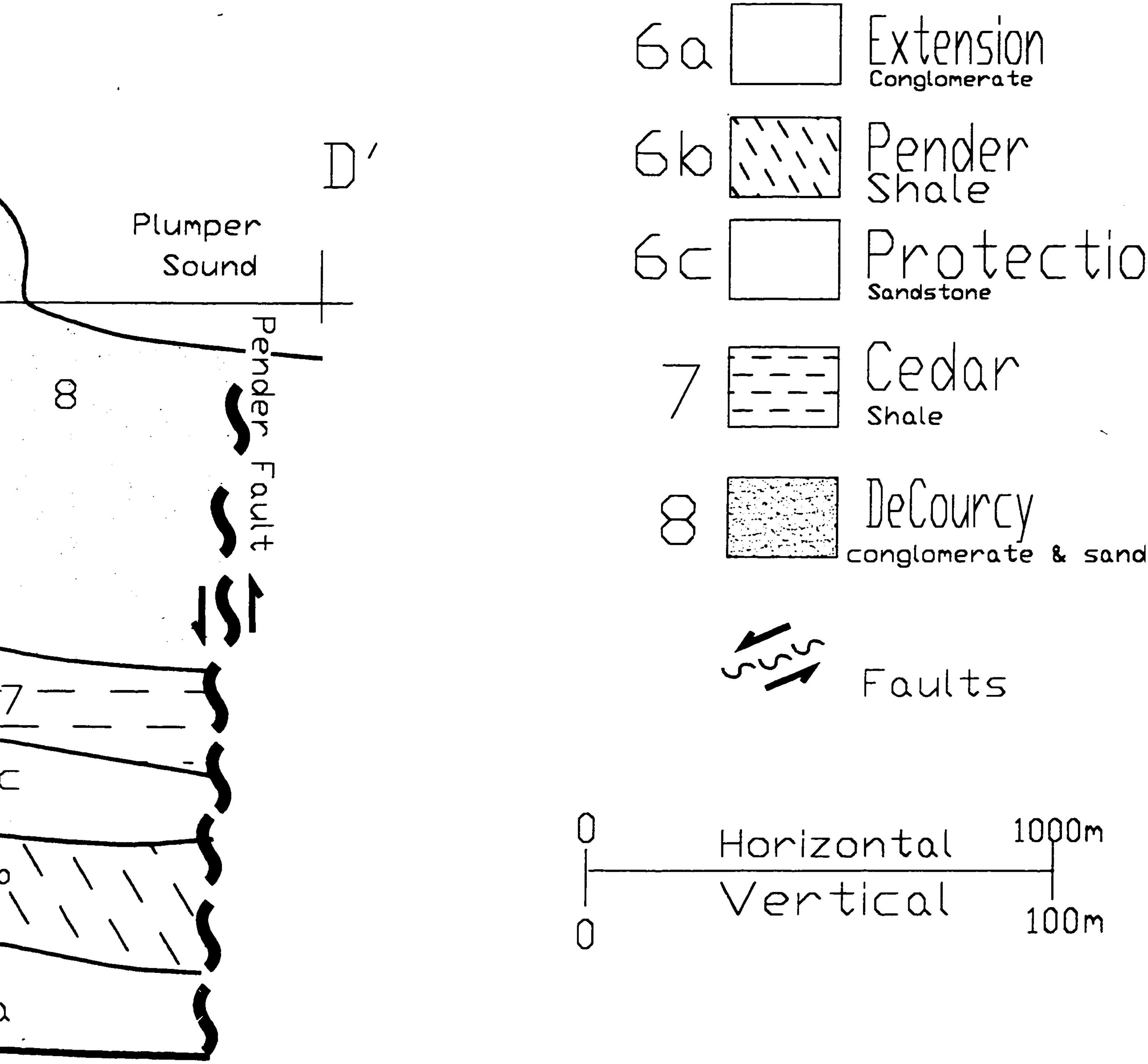


FIGURE 39: Geological cross-section D' - D"

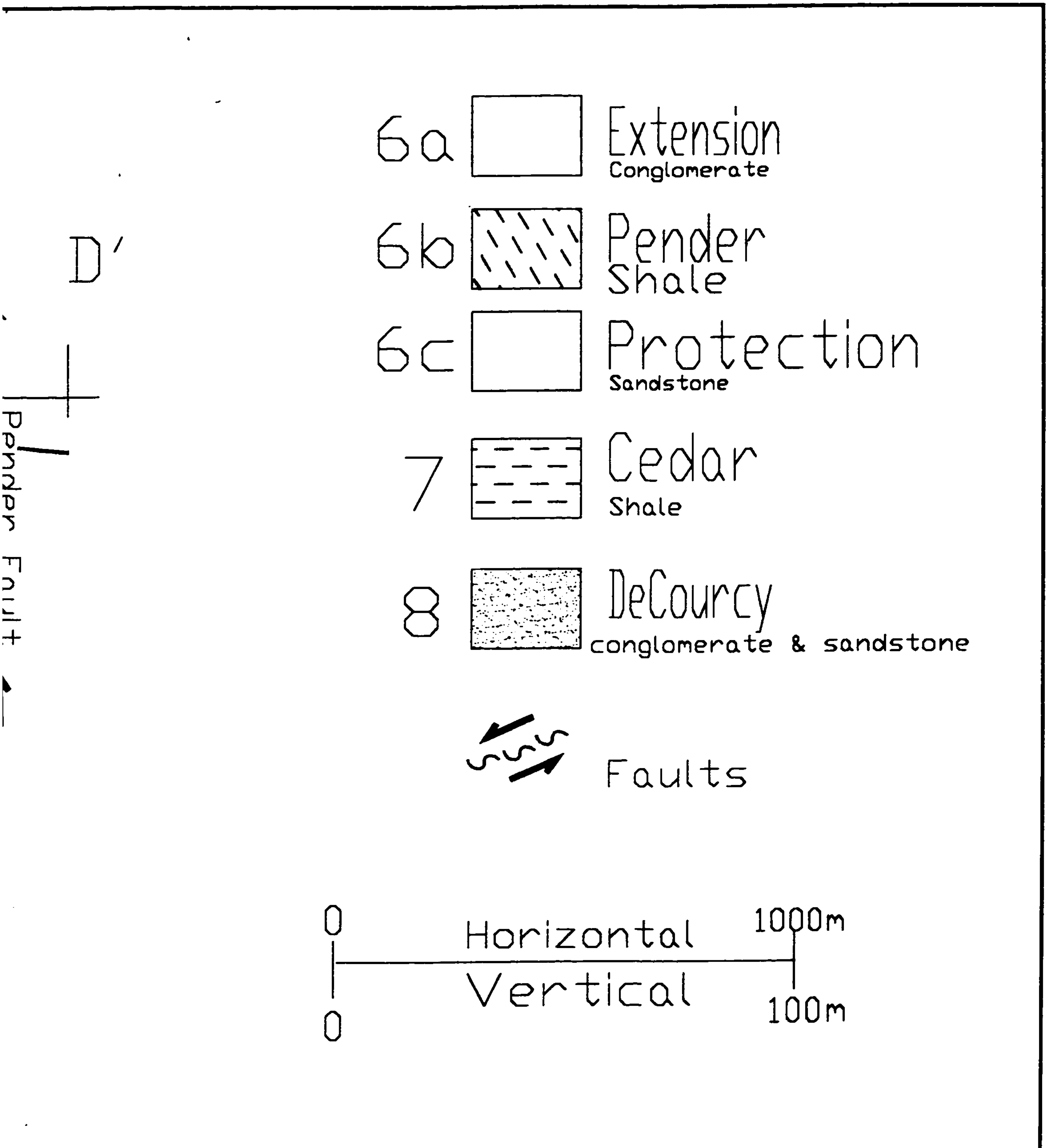


FIGURE 39: Geological cross-section D' - D"

6.3 Surficial Geology

The recent geologic history of the Gulf Islands has been dynamic. From ice ages to changing sea levels, the recent geologic past has helped shape the Islands. An outline of Pleistocene stratigraphic units is presented in Table 8. The current geologic setting of the Islands, in combination with climatic conditions, controls the type, distribution and density of the flora and fauna.

TABLE 8: Stratigraphic Framework of Surficial Sediments in the Georgia Depression (Clague, 1977, p1)

STRATIGRAPHIC UNIT	GEOLOGIC-CLIMATIC INTERVAL
Salish Sediments Sumas Drift	Postglacial
Fraser Glaciation Drift Capilano Sediments Fort Langley Fm. Vashon Drift Quadra Sand	Fraser Glaciation
Cowichan Head Formation	Olympia nonglacial interval
Dashwood Drift	?
Highbury and Mapleguard Sediments	?
Westlynn Drift	?

During the late Tertiary, the Strait of Georgia was a wide valley with the Gulf Islands being comparable to the foothills of the adjacent Vancouver Island Insular Mountains. The Strait of Georgia was a well developed drainage basin discharging by a main river through the Juan de Fuca Strait into the Pacific Ocean (Williams and Pillsbury, 1958, p190). Glaciation resulted in substantial thicknesses of ice (1.5 kilometres at the glacial maximum) occupying the Strait of Georgia (Mathews *et al.*, 1970, p691). Figure 40 presents a cross-section of the ice thickness from Vancouver Island

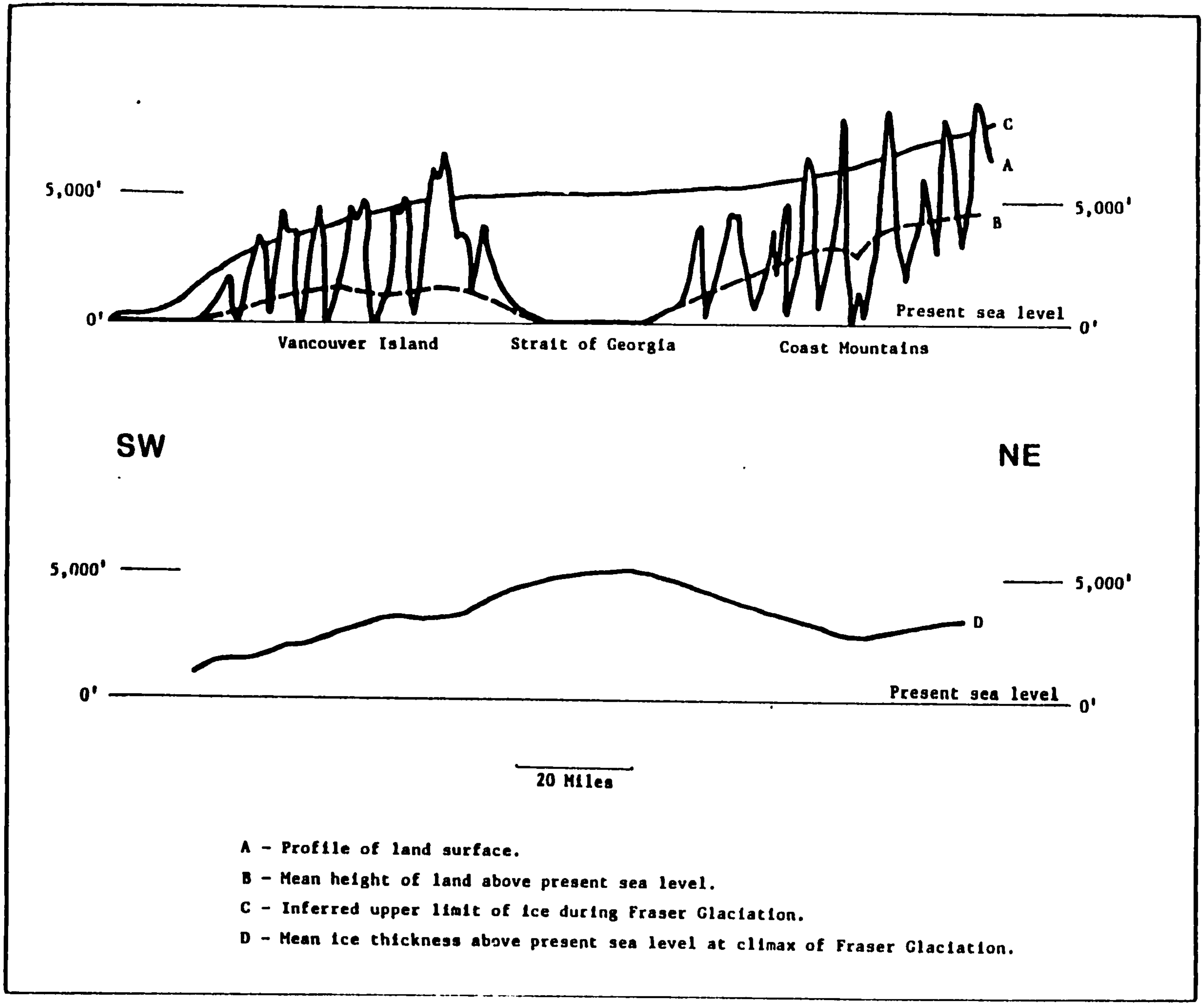


FIGURE 40: Pleistocene ice thickness in the Strait of Georgia (after Mathew *et al.*, 1970)

to the Coast Mountains. The last glaciation (Fraser Glaciation) occurred between about 20,000 and 10,000 years ago (Halstead, 1968, p1414). In general, the ice movement was to the southwest following the existing drainage pattern. The Strait of Georgia ice lobe was fed by glaciers emerging from both the Coast Mountains and the Insular Mountains of Vancouver Island (Golder Associates, 1993, p12).

The thick ice masses melted by downwasting or lowering of the ice surface rather than via the retreat of a well defined glacial snout. Large volumes of water were released by the melting ice resulting in the reworking, retransport and redeposition of glacial debris. Eis and Craigdallie, (1980, p17) outline two periods of glacial deposition on the Gulf Islands. The first occurred beneath the ice sheet and resulted from the abrasion and crushing of rocks beneath the weight of the ice. This material is comprised of sand, silt, and rock compressed into a consistency of concrete. An upper layer was deposited of material carried within or on the ice and consists of unsorted, unstratified, gravelly, sandy and loamy till.

The extreme weight of the ice sheet caused a substantial depression of the land surface. Once the glaciers had receded, there was a long period of rebound or isostatic readjustment. Isostatic rebound commenced during deglaciation and continued for several thousand years after ice melt. Isostatic rebound is still occurring today. Coincident with isostatic readjustment, large volumes of rapidly moving water eroded glacial deposits from higher elevations (Eis and Craigdallie, 1980, p17). Fyles (1963, p73) states:

> " upon retreat of glaciers (from Strait of Georgia about 13,000 to 14,000 years ago) the sea entered the Strait of Juan de Fuca, the Strait of Georgia, and the inlets along the west coast of Vancouver Island and covered the greater part of the present lowlands. "

This depression of the land relative to the sea is attributed to the weight of the glaciers. Vancouver Island has risen and tilted relative to the sea since the retreat of the glaciers, so that now the highest marine deposits, formed while the glaciers were melting, are found at an elevation of 50 feet (15.25 metres) along the west coast of the Island, 300 feet (91.5 metres) at Victoria and Alberni, 400 feet

(122 metres) at Nanaimo, 500 feet (152.5 metres) at Qualicum, and 600 feet (183 metres) at Campbell River (Halstead and Treichel, 1966, p3).

Mathews *et al.* (1970, p700) are of the opinion that the uplift occurred at a rapid rate and they have calculated that the uplift rate is measurable in hundreds of years rather than thousands of years, with the first 300 feet (90 metres) occurring within a few hundred years.

Today, the landscape present on the Gulf Islands reflects the glacial history and bedrock geology. In many upland areas, the rock outcrops having been smoothed by glacier movement or are covered by a thin veneer of organic material.

From a groundwater perspective, the surficial geology of the islands is important for a number of reasons including control of surface runoff, impact on groundwater recharge, location of dug wells, and location of septic disposal systems. In general terms, there is increased surface runoff as the grain size of the sediment decreases. This simply reflects the reduction in primary porosity and permeability which accompanies decreasing grain size. Joints and fractures may result in enhanced secondary porosity and permeability.

Of the 590 wells existing on North and South Pender Islands, 67 are dug wells which have usually been excavated to the bedrock surface. There can be significant groundwater flow at the overburden/bedrock interface due to the lack of primary permeability and porosity of the underlying bedrock. Typical flow rates for the dug wells are not recorded. In a recent study conducted by the local North Pender Island Trustees (Section 7.0), it appears to be common for dug wells to run dry towards the end of the summer season. This indicates a very strong relationship between the groundwater flow at the bedrock interface and precipitation. It is generally the case that the late spring and summer are very dry on the Gulf Islands resulting in lack of available water in dug wells late in the summer season or after prolonged dry periods. Drilled wells may also run dry during the late summer but this a function of more than lack of recharge during the summer months including rate of pumping of the aquifer (see Figure 43).

The type and thickness of surficial sediments also plays an extremely important role in the location of septic facilities on the islands. A comparison to surface topography indicates that in general the thickest surficial deposits are found in the valleys and little or no surficial sediments occur on the uplands.

The surficial geology also plays a significant role in the siting of septic systems. According to the Central Mortgage and Housing Corporation (1978, p5) guidelines, there must be a minimum of 900 mm of soil available from the bottom absorption trench to bedrock or high water table. Given the thin overburden cover typical of topographically high areas on the Pender Islands, septic systems have the potential to pose some difficulties. It is also recommended that when a disposal field is to be constructed on exposed rock containing faults and fractures, the area beneath the field should be sealed with a minimum of 300 mm of clay (CMHC, 1978, p5). Fractured and faulted bedrock exposed at surface or covered by a thin veneer of soil allows for easy entry of many types of contaminants into the groundwater system (Cherry, 1987, p390). Many of the areas on North and South Pender Islands which have little or no surficial deposits also correspond to recharge areas in individual groundwater basins and as a result development in these regions should be restricted to a greater extent than in discharge areas.

FIGURE 41: Till exposure, Spalding Hill, South Pender Island

6.4 Hydrogeological Characteristics

Characteristics of the bedrock and surface sediments, specifically open pore spaces and cracks, control the storage capacity and flow rate of groundwater. Of prime importance are the porosity and permeability of the bedrock. Porosity determines the pore spaces which are available for storage of groundwater resources while the permeability is a measurement of the interconnectedness of these pore spaces. The porosity and permeability are functions of the geological history of the stratigraphic units and can be enhanced by the presence of faults, fractures and joints.

Samples of the bedrock units which occur on the Pender Islands were obtained at outcrop locations. Unfortunately, it was not possible to obtain samples of the shale units due a high degree of superficial weathering. It is anticipated, based on oil field drilling, that the shales becomes progressively compacted and indurated with depth resulting in water movement being restricted to infrequent joints and cracks. In addition, it was not possible to obtain laboratory measurements on the conglomerate samples acquired during the field investigations. As a result, measurements of porosity and permeability were only acquired for the sandstone units. These results are presented in Table 9.

TABLE 9: Hydrogeological Characteristics of Pender Island Sandstone Units

SAMPLING LOCATION	STRATIGRAPHIC UNIT	POROSITY	PERMEABILITY DARCYS (cm^2)
1 N.E. Shingle Bay	DeCourcy	3.47%	2.9×10^{-5}
6 South Pender	DeCourcy	4.38%	0.3×10^{-5}
2 Magic Lake	Protection	3.31%	1.0×10^{-5}
5 Higgs Point	Protection	3.37%	0.3×10^{-5}
7 S.W. Bedwell Harbour	Protection	3.82%	0.5×10^{-5}
3 4823 Cannon Cres.	Extension	5.55%	3.5×10^{-5}
9 4823 Cannon Cres.	Extension	5.74%	1.3×10^{-5}
4	Galiano	5.75%	3.3×10^{-5}
8 N.E. Otter Bay	Galiano	3.51%	7.6×10^{-4}

Porosity can be viewed from two different perspectives; specific yield which is that part of pore water that will drain and specific retention which is that part of the pore water which will be retained (Heath, 1988, p77). Davis and DeWiest (1966, p350) indicate that the porosity of sandstones can vary from less than 5 percent to approximately 30 percent. The porosity of sandstones is a function of clay content and degree of cementation. For the sandstone stratigraphic units present on the Pender Islands, there tends to be a significant clay content due to their rapid deposition and later cementation. Pacht (1984, p770) found the clay content to be less than 15 percent but that there was additional pore filling of 5 to 25 percent from cementation after deposition. The Pender Island sandstones have porosities of less than 5 percent indicating that there is limited storage capacity for groundwater resources. The lack of storage capacity can also be interpreted as poor specific yield since not all of the water in storage can be produced. Storage capacity is controlled to some extent by the frequency of fractures and joints within the bedrock units.

The permeability of the Pender Island sandstone units is typical of poorly sorted sandstone units which are characteristically poor aquifers (Table 9). Table 10 presents average permeability values for various geologic strata for comparison.

TABLE 10: Representative Values for Porosity and Permeability
(Davis and DeWiest, 1966, p164)

GEOLOGICAL CLASSIFICATION	POROSITY (%)	PERMEABILITY (DARCYS)
Argillaceous limestone	2	1.0×10^{-4}
Limestone	16	1.4×10^{-1}
Sandstone, silty	12	2.6×10^{-3}
Sandstone, coarse	12	1.1
Sandstone	29	2.4
Very find sand	well sorted	9.9
Medium sand	well sorted	2.6×10^{2}
Coarse sand	well sorted	3.1×10^{3}
Gravel	well sorted	4.3×10^{4}
Montmorillonite clay		10^{-5}
Kaolinite clay		10^{-3}

The porosity and permeability discussed above are known as the primary porosity and primary permeability. Secondary porosity and permeability, which occur along faults, joints and in fracture zones can enhance both the primary porosity and permeability of the sandstones. In the Pender Islands, it is expected that the optimum location for water wells would be at the intersection of zones of increased secondary porosity and permeability. It should be noted that not all faults and fractures increase the secondary porosity and permeability but rather they may act as aquicludes or barriers to groundwater flow (UNESCO, 1984, p49). It is clear that an understanding of the secondary porosity and permeability is a necessity if groundwater management is to be successful. There are several problems related to the study of groundwater availability due to fracture flow. These include: difficulty in determining the direction of groundwater flow, and joints and fractures may die out with depth thereby decreasing storage capacity and reducing permeability (UNESCO, 1984, p53).

Hydraulic fracturing is a method used to potentially increase the yields of water wells with apparent limited porosity and permeability. Davis and DeWiest (1966, p357) point out that well yields can be increased by fracturing the rocks using explosives or with fluids pumped into the well at high pressure. This technique of fracturing the rock is very common in the oil industry to increase flow rates resulting in increased oil production but the technology has not been transferred to the groundwater drilling industry until recently. In instances where this technique has been used by groundwater well drillers, the specific capacities have increased by up to 800 percent (Davis and DeWiest, 1966, p358). There are only a few examples of hydraulic fracturing of water wells on the Gulf Islands (Kohut, 1995, personal communication) but the results are promising with regard to short term increased flow rates (Emmings, 1995, personal communication).

Water availability, as has been illustrated above, is reliant upon the hydrogeological characteristics of the geological units. Residents should have sufficient information available to them to provide a basic understanding of the storage capacity and groundwater flow parameters which impact the availability of groundwater on the Islands. Porosity and permeability also impact water quality by controlling the rate at which pollutants move through the subsurface. To adequately manage the groundwater resources, a detailed knowledge of the local geology is required.

In order to have a basic understanding of the hydrogeology of the Islands, it is important to begin with the hydrologic cycle. Hydrogeology represents a complicated interaction between climate, geology and vegetation. Any impacts on the hydrologic cycle will have an impact on the component parts. The hydrologic cycle illustrates the source for the groundwater supply as well as the outflows of water from the system (Figure 42).

To comprehend the many facets of groundwater recharge and discharge, a knowledge of the factors comprising the inflows and outflows of moisture to the system is required. From a recharge perspective, the only source of moisture for groundwater recharge is precipitation. Prior to determining the volume of moisture which is available for groundwater recharge, it is important to identify the volumes which are lost as a result of outflows from the system.

Outflows of water from the system consist of surface runoff, evapotranspiration, springs and seepage to the ocean. Of these, evapotranspiration and offshore seepage are the most difficult to measure with any degree of accuracy. Evapotranspiration was discussed in Section 5.3 and was shown to have the potential to be a large component of groundwater outflow on the Gulf Islands.

The surface runoff component is dependent on several factors including thickness and type of soil cover, vegetation cover, soil moisture content, intensity and duration of precipitation (Balek, 1989, p25). If soils are saturated, the surface runoff will be high. Soils with a high clay content may have a tendency to swell once they are saturated which may result in an impermeable near surface layer limiting groundwater penetration and increasing surface runoff. Surface runoff is also a major component of water outflow in regions with little or no soil or vegetative cover. Vegetation can intercept a significant amount of precipitation.

The critical parameters which influence the hydrogeology of an area include soil type and thickness, bedrock stratigraphy and structure, cultural interference by humans, and vegetation density and type. Roads, residential development and a reduced vegetative cover have caused reduced percolation of rainwater resulting in increased surface runoff.

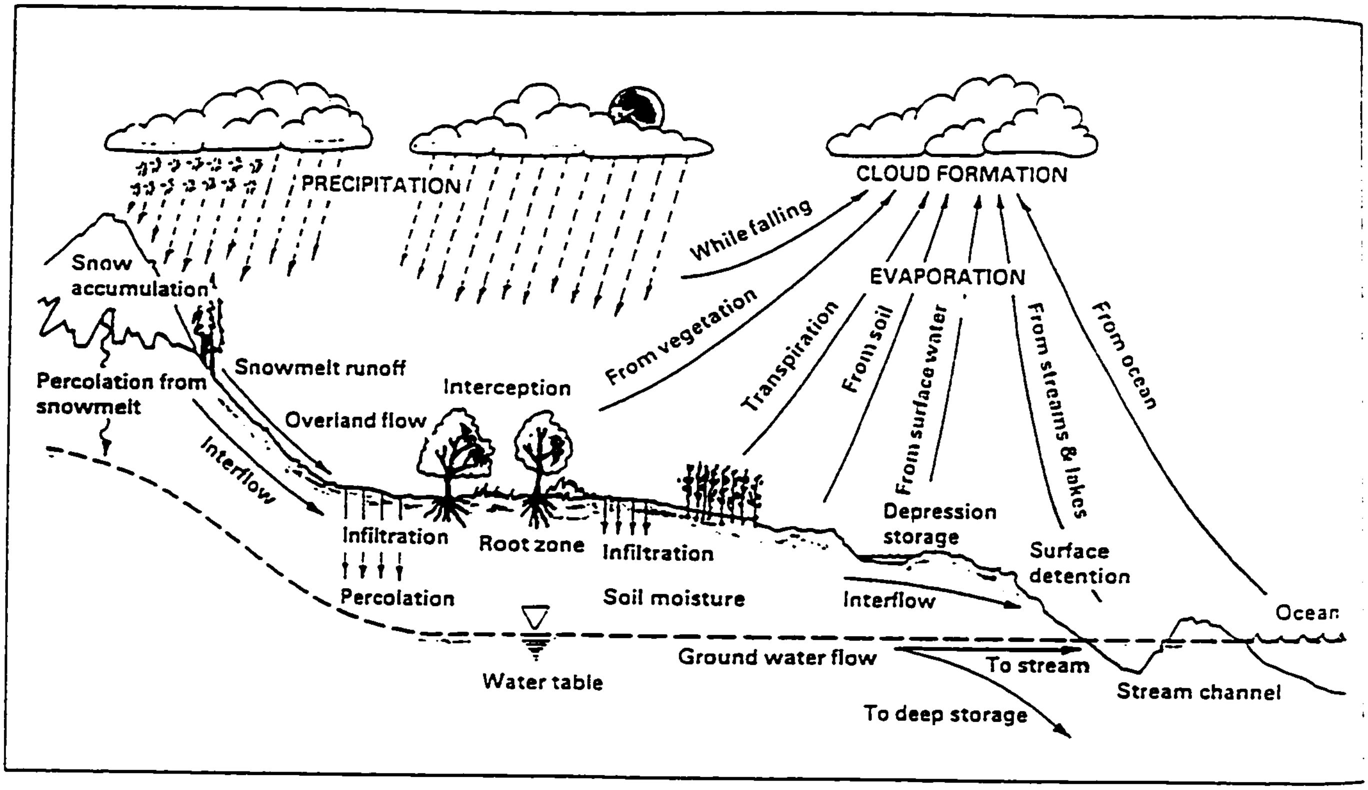


FIGURE 42: Hydrologic cycle and its major components (after Falkland, 1991)

Soil and bedrock components influence the storage capacity and flow rates for groundwater on the Islands.

To relate the hydrologic cycle to groundwater systems, a groundwater system consists of rainfall recharge percolating into the subsurface, reaching the water table and flowing through the soil or bedrock toward discharge points. The rate at which groundwater flows is a function of climatic factors, such as precipitation and evapotranspiration, and geological factors including porosity and permeability.

The hydrograph and precipitation data presented in Figure 43 illustrate the close relationship between climatic factors and groundwater recharge. There is a short time delay between precipitation and groundwater recharge. The relationship also shows that groundwater recharge occurs mainly during the wet winter months.

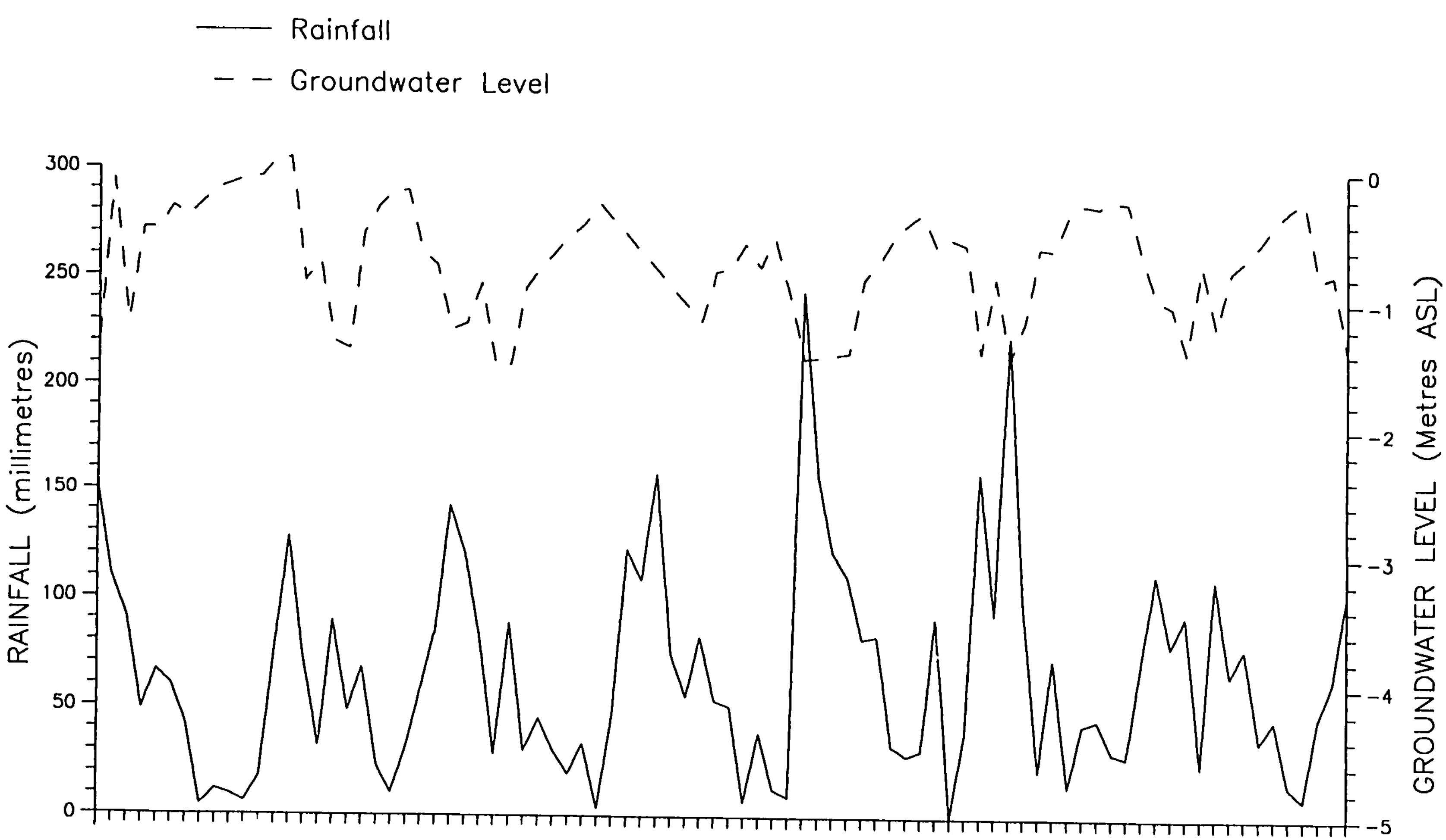


FIGURE 43: Relationship between precipitation and groundwater recharge (Groundwater levels courtesy of B.C. Environment, Groundwater Division)

7.0 GROUNDWATER ISSUES ON NORTH AND SOUTH PENDER ISLANDS

" Continuation of a hands-off policy on ground water quality will only encourage procrastination. " (Haimes, 1980, p107)

A questionnaire prepared and distributed in February 1991 by the local Trustees of North and South Pender Islands received a 28% mail response, which can be considered a good response, indicating the importance of water issues on the Islands. A copy of the questionnaire is presented in Appendix B. The results of the questionnaire are summarised in Table 11. Questions 6, 11, 15, and 22 were considered to be the most relevant to this study and were analysed in an attempt to qualitatively determine the groundwater concerns of Pender Island residents. The results indicate a keen interest in groundwater issues on the Islands. In general, the respondents from Trincomali and Magic Lake Estates, which have community water systems, were much more concerned about future water supply than residents of the remainder of the North Pender Island. Clearly 77% of the respondents from these two communities were concerned as compared to 55% for the remainder of the Island.

TABLE 11: Summary of Pender Islands Groundwater Questionnaire

Question #		RESPONDENTS FROM TRINCOMALI	RESPONDENTS FROM MAGIC LAKE	RESPONDENTS FROM REMAINDER OF ISLAND
6	drilled wells surface wells cisterns community systems	0 of 12 0 of 12 4 of 12 12 of 12	0 of 96 0 of 96 3 of 96 96 of 96	75 of 89 32 of 89 24 of 89 0 of 89
11	good fair poor	11 of 12 1 of 12 0 of 12	68 of 96 27 of 96 1 of 96	64 of 89 1 of 89 3 of 89
15	system failed	0 of 12	4 of 96	20 of 89
22	concerned about supply	11 of 12	83 of 96	50 of 89
	• future supply • conservation • future development • contamination	11 of 12 4 of 12 6 of 12 ----	83 of 96 35 of 96 30 of 96 14 of 96	33 of 89 13 of 89 12 of 89 12 of 89

The disparities between the communities of Trincomali and Magic Lake Estates and the remainder of North Pender Island are evident throughout responses to all questions. For residents outside these communities whose water supply system had failed in the past, 70% of respondents had not acquired cisterns as a means of supplementing their water supply. In addition for residents who had experienced water supply failure in the past, 90% were concerned about future water supplies even though a majority had done little to improve their supply. The remaining 10% were equally split between indifference and no concern which could possibly be explained by their acquisition of cisterns to supplement supply.

A further indication of the importance of water issues on the Gulf Islands is a study conducted by B.C. Environment (1993b) entitled "Stewardship of the Water" which included a section on groundwater management. Hornby Island and North and South Pender Islands were selected for additional research regarding the necessity of groundwater management and legislation. The selection of the Gulf Islands for these studies cannot be overlooked in emphasising the immediacy of groundwater issues.

In addition during the past several years, there have been a number of reported forums on North and South Pender Islands at which groundwater issues have been raised. The issues can be subdivided into water availability, water quality, education, and water management. There is significant overlap of groundwater issues between these subdivisions, which will be briefly discussed in the following section. A list of the groundwater issues is presented in Table 12.

TABLE 12: Groundwater Issues On North and South Pender Islands *

- Water Management
  - Lack of data for decision making
  - Conservation and misuse of water
  - Regulation of water well drilling, construction and abandonment
  - Regulating groundwater use
  - Assessment and monitoring
  - Regulation of land use practices in and around wells
  - Protection of groundwater quality and environmentally sensitive recharge and discharge areas

- Water Availability
  - Well interference
  - Withdrawals exceeding natural replenishment
  - Poor well yields
  - High well development

- Water Quality
  - Deteriorating water quality
  - Salt water intrusions
  - Impacts of sewage disposal
  - Groundwater contamination

- Education

* Table 12 was compiled from the following sources Groundwater Management: The Pender Island Project, 1994; Stewardship of Water, 1993; Pender Island Trustees Questionnaire, 1993; Stewardship of the Water Consolidation Update, 1994; The Hornby Island Groundwater Pilot Project, 1994; These Islands of Ours...Framing Our Common Future, 1992.

7.1 Water Management

In general, there is a great deal of information available regarding groundwater on the Gulf Islands. Unfortunately the data are widely dispersed, not available in a comprehensive database and do not include the most recent information. During the research for this project, water well data were only available in the B.C. Environment database for wells drilled up to and including part of 1989. There has been substantial development on the Islands during the interval 1989 to present representing perhaps the best data set. Before a resource can be adequately managed, it must be understood. Wolden and Erichsen (1990, p333) state that reliable geological data are a precondition for the responsible management of natural resources.

Geological mapping of the Gulf Islands is not adequate for the requirements of local hydrogeological investigations. Most of the work to date was conducted as part of very large scale regional studies. The most comprehensive geologic work performed in the area (England, 1989) is rarely referenced.

B.C. Environment (1993b, p9 and 1994c, p23) expressed the need for assessment and the monitoring of groundwater resources of the Islands. The assessment is directly related to the lack of data which is easily accessible. At present, there is no requirement for monitoring of water wells. There is also no requirement to submit any groundwater information resulting in a significant variation in the quality of reports ultimately submitted to B.C. Environment, Groundwater Division (B.C. Environment, 1993b, p9). Monitoring of groundwater resources should play an integral role in the development of future community plans. Monitoring wells located in areas with existing groundwater quality problems, areas of groundwater discharge and recharge, and background wells will provide a base line for information on groundwater quantity and quality. Monitoring requirements are useful since the effects of groundwater depletion and degradation of water quality are slow to manifest themselves, do not affect all well users equally or simultaneously, and may delay remedial action until it is too late (Templer, 1988, p230).

A monitoring program would provide a means of determining the cumulative impact of long term water withdrawals on the Islands. Kohut (1994, personal communication) indicated that there seemed to generally be a decline in water quality over the past 10-15 years on the Gulf Islands. This correlates with a period of rapid population growth and subsequent growth in groundwater and septic system usage on the Islands. From a health perspective, it is also important to test water quality for each water well on the Islands on an annual basis (B.C. Environment, 1994, p23).

In addition to a current database, comprehensive legislation is imperative for the management of groundwater resources. The present lack of groundwater legislation has resulted in an ad hoc development of the groundwater resources of the Islands. Legislation by itself will not result in reasonable management of a resource since there is also the necessity of the stakeholders involved to buy into the entire process. B.C. Environment (1993b, p8) expressed concerns regarding the lack of legislation to regulate such issues as water well drilling, construction and abandonment, groundwater use, and groundwater development. A Groundwater Pilot Project on Hornby Island (B.C. Environment, 1994, p51) indicated a desire to have legislation to empower a local Water Board to manage and protect the groundwater resources of the Island. In order to be effective, members of such a board would require access to highly trained professionals to provide the scientific basis and guidance necessary.

Conservation and misuse of water were highlighted as areas of concerns by Island residents (The Pender Island Pilot Project, 1994). The questionnaire distributed by local trustees also indicted that there was considerable concern over conservation of groundwater resources. Conservation can be viewed in several different perspectives including an ecosystem approach and the prudent and efficient use by humans. It should be noted, however, that conservation although it is a necessary part of any solution will not solve the problem of water availability. It is simply a means of extending a limited water supply. From a human consumption perspective, it makes intuitive sense that the less water utilized at any given time then the longer the resource will last. This requires that each individual take responsibility for their actions. Trincomali is the only district on the Pender Islands which uses peer pressure to persuade residents to take responsibility for their actions (Section 9.0). The residents of Magic Lake voted, by a large majority (252 to 87), in favour of the use of water meters (Pender Post, 1994) representing a large step forward in acceptance of ownership of water issues. Water meters have been successful in Trincomali in locating leaks in the system and should result in a more efficient water system in Magic Lake through improved leak protection.

The ecosystem perspective of groundwater conservation has not been reviewed in any reasonable manner to date although there has been mention of an ecosystem approach in the stewardship of water in British Columbia.

As a part of the Pender Island Pilot Project, a recommendation was made for the designation of Groundwater Management Areas (GMA) in regions experiencing groundwater problems. The basic difficulty posed by this approach is that it is reactive rather than pro-active so that the start of a potentially long bureaucratic process does not take place until there is a problem. In regions with a finite source of potable water, the aquifers may suffer irrepairable damage prior to any action being taken. A more reasonable approach would be to provide an assessment of areas such as the Gulf Islands which have groundwater problems and move as quickly as possible to designate them as

Groundwater Management Areas. Once again, there is the need for base data upon which to make decisions.

7.2 Water Availability

A common theme at public forums has been the availability of an adequate water supply. Increasing population and pressure for additional development have resulted in water supply being viewed as a determinant of carrying capacity of the Islands (Dovetail Consulting, 1992, p28). It is clearly understood by some residents that there is a finite water supply which will not only impact human habitation but also the Island ecosystem itself. Other residents have not grasped the limited nature of the water supply. Section 4.0 indicated that population increases on North and South Pender Islands have been relatively high over the past several decades. There is still a demand for property on the Islands. Potential purchasers of property are often warned about the need to ensure that there is a sufficient water supply prior to acquiring any property (Ince, 1993, p178).

Water availability is a recurring issue on the Islands partially as a response to seasonal scarcity of water. The results of the questionnaire distributed by the North and South Pender Trustees in 1993 indicated that the water supply of a number of Island residents had failed in the past and that residents have had to purchase water to ensure an adequate supply. Approximately 13% of the respondents to the questionnaire had their water supply fail in the past. Many of the respondents (70%) were also concerned about their future water supply further emphasizing the importance of this issue. Many of the concerns regarding future supply were centred around groundwater contamination, increased development and conservation.

The climatic data presented in Section 5.0 provides information indicating that severe droughts have occurred on the Islands during the recent past (Table 6). Given the present population of the Islands compared to the low populations during previous drought years, it can be anticipated that when a severe drought recurs on the Islands the impacts will be more critical.

FIGURE 44: Example of cistern collection system, North Pender Island

There are several areas of North Pender Island which have a relatively high density of water wells. These include Port Washington and Hope Bay. Both of these areas have anomalously high concentrations of iron and chlorides in the water. In the absence of any baseline data, it is difficult to ascertain if these high concentrations are a function of well density, a cumulative impact of well development, or local geology. However, as mentioned previously a relationship between well density and water quality problems has been observed on other Gulf Islands (B.C. Environment, 1993e, p9.50). Vonhoff (1985, p17) discusses the relationship between groundwater flow and fractures or faults in low permeability and porosity rocks such as occur on the Pender Islands (Section 6.4). High well development in regions of faulting or fracturing can lead to cigar shaped or linear cones of depression which can be interpreted from geologic mapping. Areas of high well development are also prone to well interference. As development on the Islands continues, it will be important to assess impact of new water wells on existing wells.

It is important that residents, potential future residents, politicians and tourists be educated as to the issue of water quality. B.C. Environment (1993e, p9.47) have published average yields of water wells on the Islands, although the average yield is strongly influenced by a few high yielding water wells. A more realistic representation of well yield is the median which for North and South Pender Islands is less than 1.5 gal/minute. In rural Alberta, some residents have cisterns which are filled from groundwater. The pumps on the wells are electronically controlled so that they only pump for several minutes at a time. The interval between pump times is variable depending on the flow rates of the well. This provides the capability to provide a more sustainable water supply during times of limited supply with a net result of less drawdown of the water table.

7.3 Water Quality

An earlier North Pender Island water study (Mordaunt, 1981) identified concentrations of dissolved minerals such as iron, chlorides and sulphides as impacting water quality. Chloride concentrations related to salt water intrusions were considered to be the most important indicator of water quality (Mordaunt, 1981, p18). Hope Bay, Davidson Bay, Colston Cove and the northwest tip of South Pender Island and the adjoining peninsula on North Pender Island have been delineated as areas having in excess of 300 mg/l chlorides (Figure 45). The anomalously high chloride levels in these areas is an indication of salt water intrusion. Each of these areas should be monitored on a regular basis to determine the location of the freshwater/salt water contact. Given that there is already a problem of salt water intrusion in these areas, it would be prudent to evaluate the development plans for these areas to ensure that additional demands on the groundwater supply do not enhance the landward movement of the fresh water/salt water interface. A cost effective means of monitoring the progression of the interface would be to measure the conductivity of the water in the wells. Figure 46 illustrates the relationship between total dissolved solids and conductivity. By utilizing this relationship in a monitoring program, it would be possible to identify increases in total dissolved solids and the direction and rate of landward migration of the interface.

LEGEND

> 2000 μmhos/cm

1500 to 2000 μmhos/cm

1000 to 1500 μmhos/cm

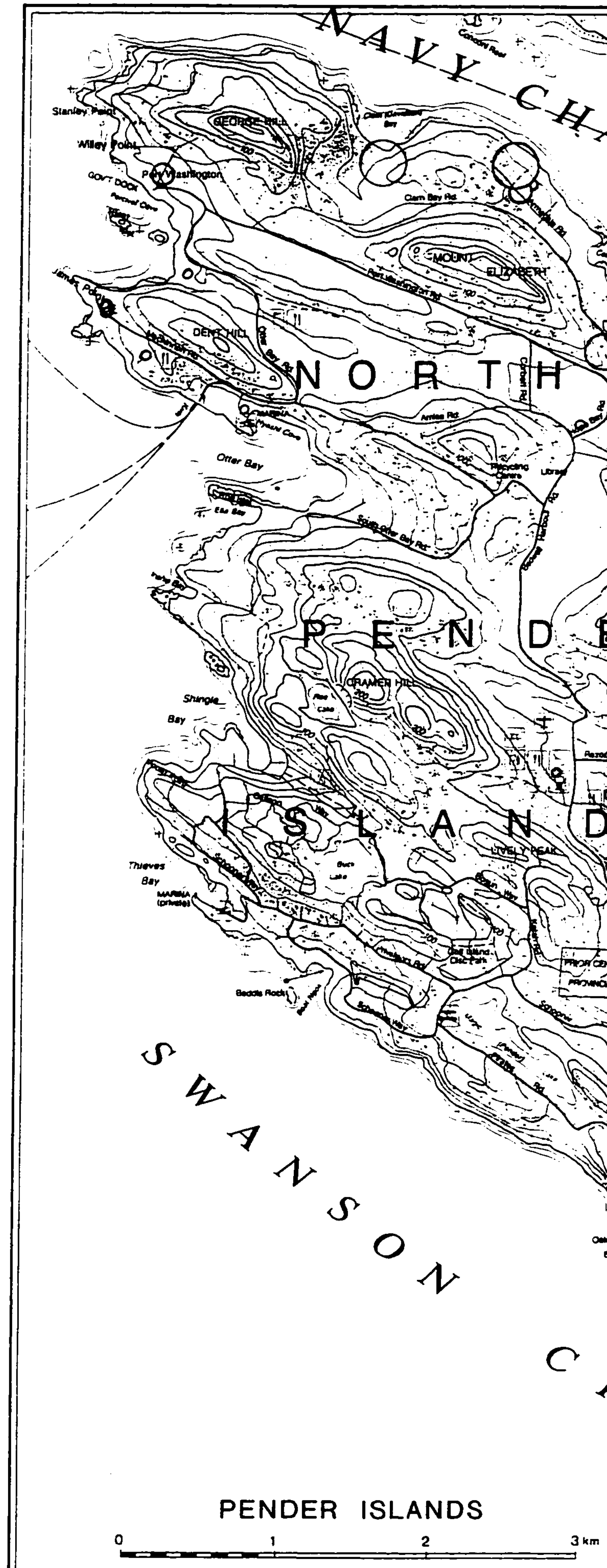


FIGURE 45:

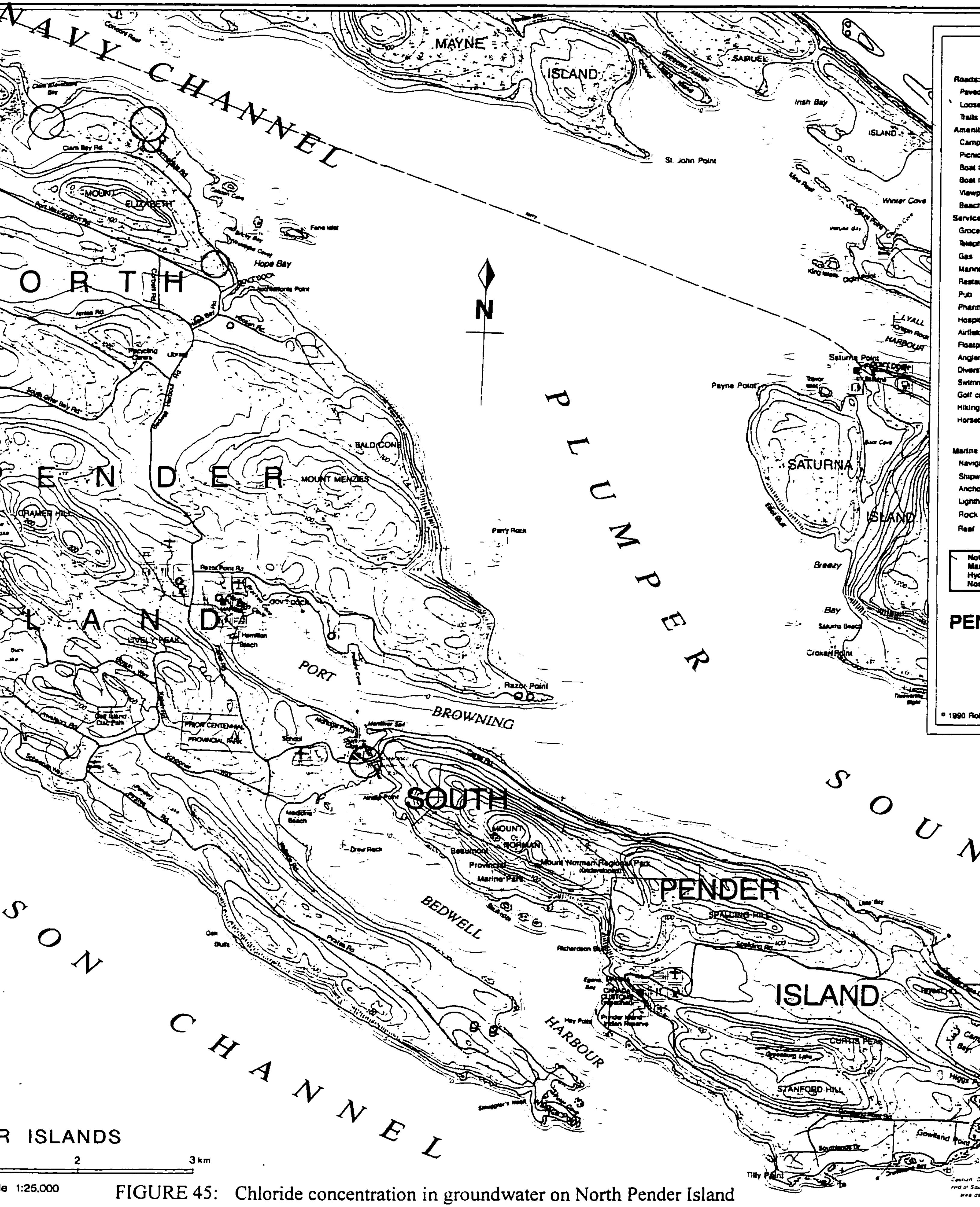
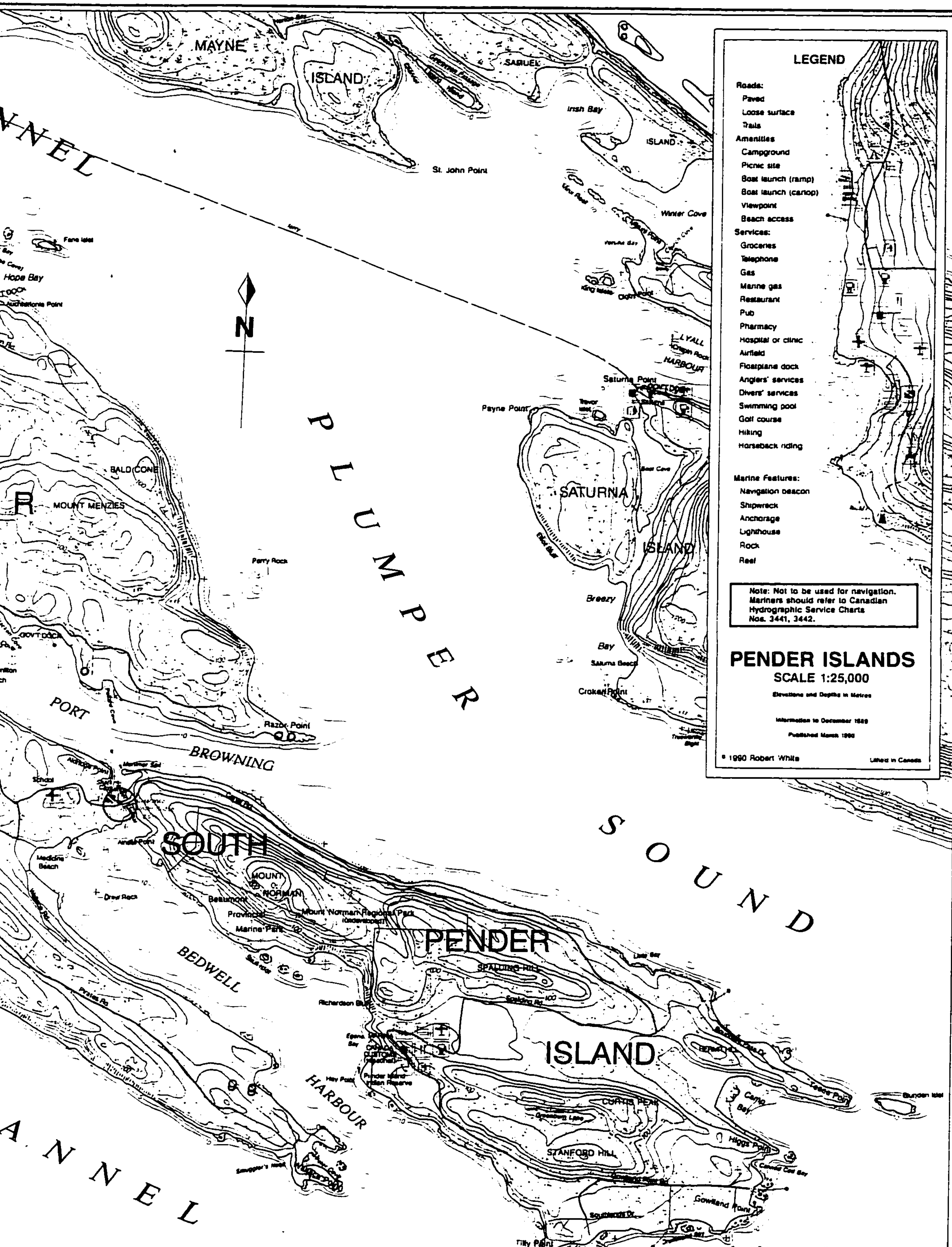


FIGURE 45: Chloride concentration in groundwater on North Pender Island



hloride concentration in groundwater on North Pender Island

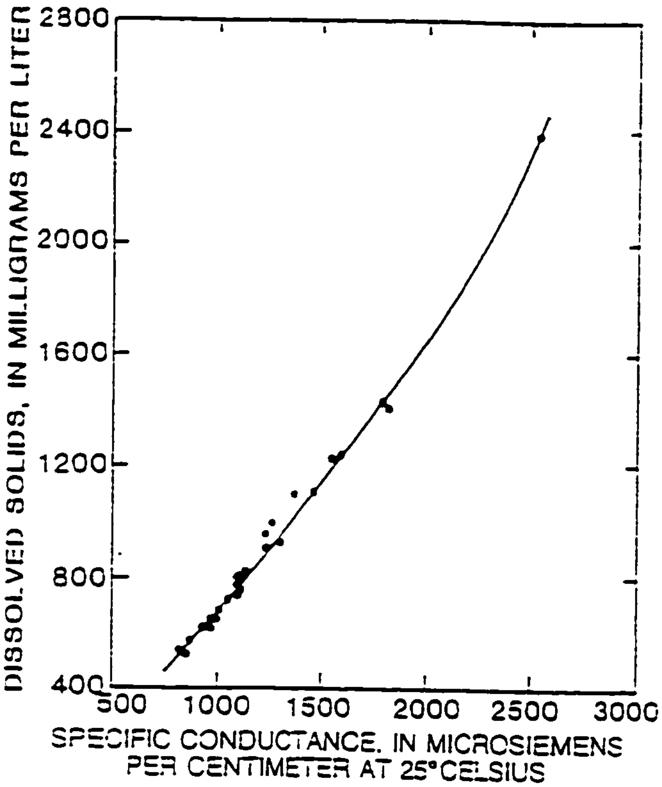


FIGURE 46: Relation between conductance and total dissolved solids (after W. Scott Keys, 1989)

A map illustrating areas of anomalous iron concentrations is presented in Figure 47. Areas denoted on the map have iron levels exceeding the recommended drinking water standards set by the B.C. Ministry of Health. Previous studies in the Gulf Islands have noted an association between water quality and high density development (B.C. Environment, 1993e, pp.50)

A comparison of the bedrock and structural geology (Figure 28) and the areas having water quality problems (Figures 45 and 47) offers some possible insights into the problems. The areas possessing water quality problems appear to be concentrated along the coast. These areas are considered to be desirable from a development perspective and as a result there has been high development in many areas. In addition, water quality problems seem to have been accentuated by local geology. Faulting occurs in close proximity to the following areas having water quality problems: **Hope Bay**, **Davidson Bay**, **Grimmer Bay**, and **Irene Bay**. Salt water intrusions are also more prevalent on small narrow peninsulas as may expected at **Stanley Point**, **James Point** and **Razor Point**. Similar relationships have been observed on other Gulf Islands (Dakin *et al.*, 1983). Figure 28 illustrates that there are a number of faults which do not appear to be conduits for groundwater flow. This indicates that each fault should be investigated to determine its hydrogeologic characteristics since faults may just as easily be barriers to groundwater flow as conduits (A. Kohut, 1995, personal

LEGEND

>4.0 mg/l

2.0 4.0 mg/l

1.0 to 2.0 mg/l

0.3 to 1.0 mg/l

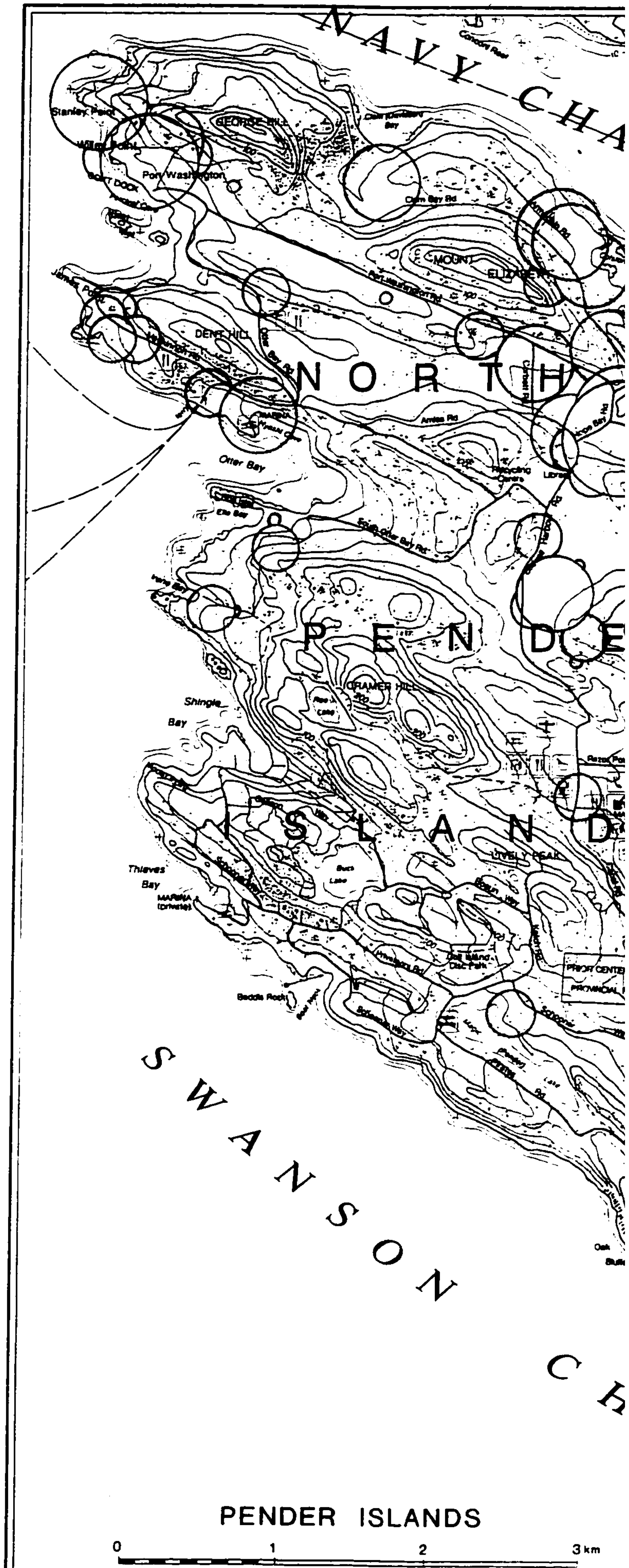


FIGURE 4

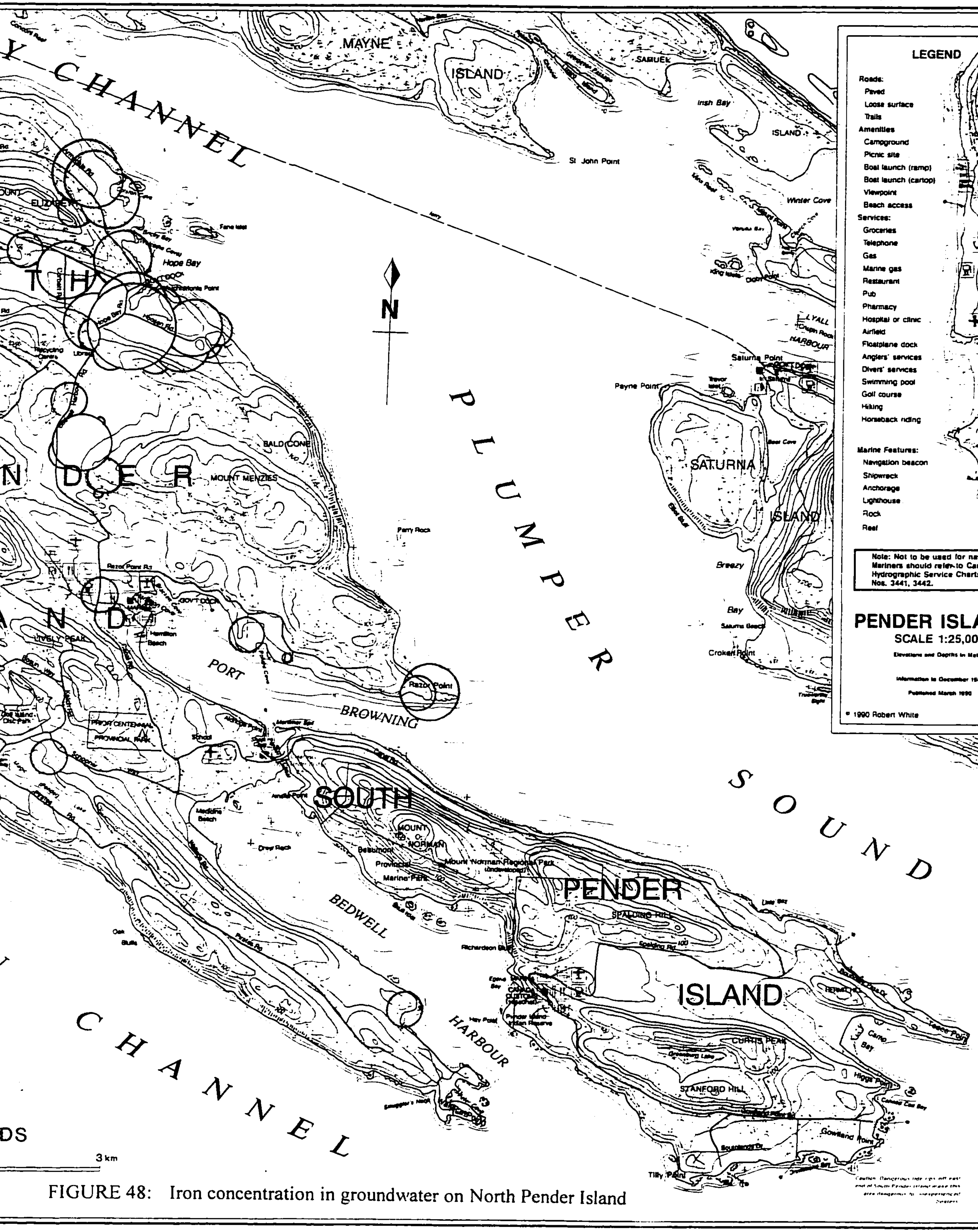
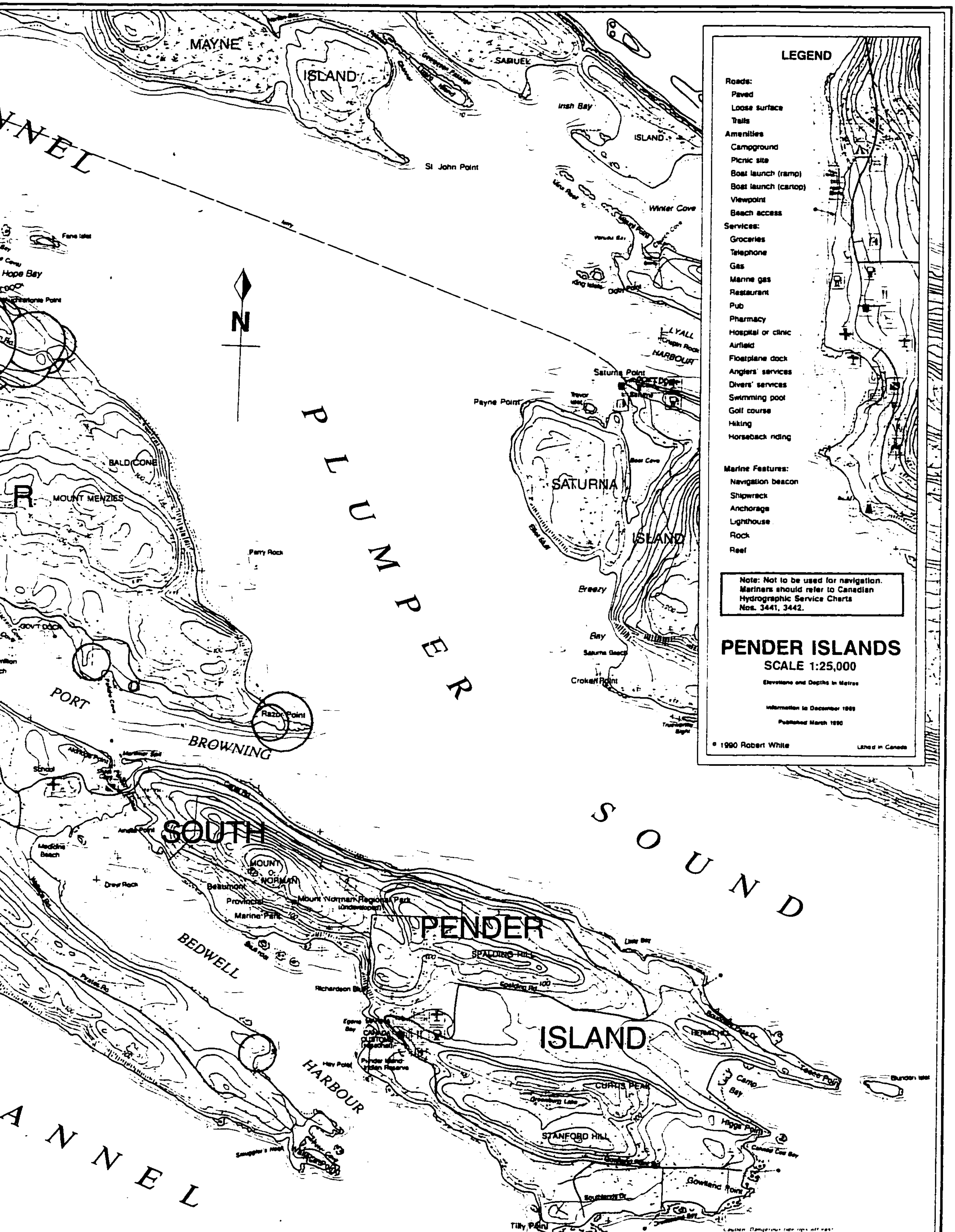


FIGURE 48: Iron concentration in groundwater on North Pender Island



Iron concentration in groundwater on North Pender Island

communication). A more comprehensive understanding of the faults and fracture patterns would provide more complete knowledge of the groundwater potential of the various groundwater basins.

A comprehensive geologic mapping program would define areas prone to water quality problems by identifying areas with increased secondary porosity and permeability. This information could then be utilized in the planning process to develop reasonable water management programs. This would enable a pro-active approach to preserving and maintaining reasonable water quality in these areas if they have not already been developed. If development has already taken place, it may be possible to develop water supply systems which will have minimal impact on water quality.

It is difficult to quantify the impacts of septic tanks and fields on groundwater quality on the Islands since no testing has been conducted. There are some general statements which can help to identify areas which have a greater potential for increased levels of E-coli bacteria. The geology and hydrogeology should be the basis for the selection of the type of septic system employed. All septic systems should be located as far as possible from known fault locations which would increase porosity and permeability since the higher secondary porosity and permeability enables a much more rapid groundwater flow causing potential for contamination of downslope water wells. In general, septic systems should be located downslope of water wells. The distance between septic systems and water wells should be controlled by local geologic conditions.

In terms of groundwater contamination, there is always the potential for chemical or oil spills. The only service station located on the Islands is now utilizing above ground fuel storage tanks thereby greatly reducing the likelihood of a fuel leak going unnoticed and contaminating the water supply of residents in close proximity to this site. Given the lack of industrial activity on the Islands, many of the concerns regarding chemical spills can be rectified by existing regulations regarding the transportation of dangerous goods and strong enforcement of these regulations.

There have been incidents recorded where contamination has resulted from poor well construction practices (B.C. Environment, 1993b, p5, and Roberts, 1994, personal communication). An enforceable code of practice as prepared in Britain (British Standard BS6316, 1992) could be developed to regulate the drilling, construction and test pumping of water wells.

7.4 Education

Public awareness is critical if groundwater issues are to move to the forefront of the political process. The research programs conducted by B.C. Environment, Groundwater Division into groundwater management are evidence of the importance of education. The Hornby Island Groundwater Pilot Project (B.C.Environment, 1994c, p22) recommends that publishing groundwater conditions in local newspapers would provide a means of maintaining a high level of public awareness. It also recommended that education of local residents regarding conservation, impacts of individuals actions on groundwater, and importance of groundwater protection be undertaken on the Gulf Islands (B.C. Environment, 1994c, p23). Public forums on the Islands have also established groundwater protection as an important focal point for education (Dovetail, 1992, p20). Dovetail (1992, p28) indicates that education on the sensitive nature of Island ecosystems would play an integral role in maintaining a quality environment for present and future generations of Island residents and visitors. The Pender Island Conservancy Association has prepared a brochure describing the Island ecosystem while stressing the limited nature of the water supply.

The draft report on Groundwater Management: The Pender Islands Pilot Project (B.C. Environment, 1994) places an emphasis on increasing awareness of water usage, the water cycle and conservation while promoting positive ethics and water issues. Recommendations for achieving these goals included allowing community groundwater groups to spearhead educational programs, inform visitors of the water limitations, and create a flexible legal framework.

8.0 LEGAL AND INSTITUTIONAL FRAMEWORK

> " Policy formation and implementation of groundwater protection is constrained by multiple actors and a diffusion of responsibility. The result has been considerable fragmentation and a lack of coherence and unity in groundwater protection policy. " (Kenski, 1990, p60)

Any groundwater management must be reviewed within the existing political and administrative framework (Lloyd, 1994, p35). Water law often overlaps other fields of law such as environmental law, natural resources law, property law, tort law and land use law (Goldfarb, 1988, p9). As such, there is a resulting fragmentation within the legal framework. Templer (1988, p227) refers to previous works which attribute water resource management problems to the large number of laws constraining its use and the multiplicity of agencies, often lacking coordination, dealing with various aspects of its use. Legislation, when adequately drafted, can be utilized to assist in the formatting and regulation of groundwater resource policy. Many problems, in the management of groundwater resources, have arisen in the past due to non-recognition of problems resulting from inadequate or nonexistent legislation (Falkland, 1991, p255).

Water law development in North America has evolved in such a manner that surface water legislation generally preceded groundwater legislation. This is certainly the case in British Columbia where there is no groundwater legislation at present (B.C. Environment, 1993b, p6). In fact, British Columbia represents the only portion of North America without groundwater legislation. The delay in development of groundwater legislation is partially a result of the fact that groundwater management is more difficult to develop and implement than surface water management since groundwater is an unseen commodity theoretically available to any surface owner who has the means to sink a well (Blomquist, 1991, p103).

Groundwater is viewed as a common pool resource which simply means that one pumper's rights must be defined with respect to all other pumpers' rights (Tarlock, 1985, p1751). Groundwater differs from other common pool resources such as hydrocarbons in that it is a renewable resource if extracted in a reasonable manner. This requires that someone take responsibility for determining who may use the resource, at what rate and under what conditions (Tarlock, 1985, p1751).

This section describes the current legal and administrative framework governing water resources in the Gulf Islands. The historical development of the legal framework will be outlined followed by a brief description of the various Acts which have an impact on water resources. A discussion regarding the problems associated with water resource legislation in general and more specifically its impact on the Gulf Islands is presented. It is important to bear in mind that the legal system is based on the principle of precedence (looking backwards rather than forward). In other words, the system is reactive in nature not proactive. Given the reactive nature of the legal system, it is important to also review the institutional framework governing water resources. Scott (1992, p346) states "courts may re-interpret private rights, and governments may pass new Water Acts, but the exercise of accepted rights may stay stubbornly on a course that is determined as much by custom, belief, technology and preferences as by formal law".

8.1 Historical Overview

Early water law in British Columbia was developed in response to shortcomings in the existing riparian rights under English common law which were not effective in dealing with the water requirements for the mining and agricultural sectors. A brief historical overview of water legislation in British Columbia is presented in Table 13.

TABLE 13: Historical Overview of Water Legislation

DATE	LEGISLATION AND SYNOPSIS
1859	Colonial Proclamation dealing with water rights .
	Gold Fields Act - B.C. Gold Commissioner given power to grant exclusive rights to use of specific quantities of water for mining.
1865	Land Ordinance Act - provided that every person living on and actually cultivating lands might divert any unoccupied water from a stream upon receiving written authority of the stipendiary magistrate of the district.

1871	Water rights had to be secured by means of a water record.
1892	Water Privileges Act - declared right to use and flow of all water in any stream vested in the Crown.
1897	Water Clauses Consolidation Act - confirmed necessity to make reasonable use of water for the purpose for which it was granted; continued vesting rights to use and flow of water in the province.
1909	Water Act - all water resources are vested in the provincial Crown but provides that rights to their use may be issued in form of water licenses; set up Board of Investigation to hear claims of all persons holding or claiming to hold water records or other water rights, to determine the priorities of the claimants, to lay down terms upon which new licenses should be granted and to cancel old records.
1960	Water Act amended making it applicable to groundwater in any part or parts of the province on a day proclaimed by provincial government. No such date has been proclaimed as of December, 1996.
1992	Water Amendment Act - enabled the formulation of regulations regarding environmentally sensitive engineering standards for water related construction includes; provisions detailing the regulatory powers of engineers, including the Comptroller of Water Rights and the Regional Water Managers, as well as the enforcement options, including prosecution or license suspension or cancellation.

In 1859, Governor Douglas proclaimed the Gold Fields Act under which the British Columbia Gold Commissioner was granted the power to grant exclusive rights to the use of specific quantities of water for mining purposes (Cail, 1974, p111). This legislation was based on similar existing legislation in California, Australia and New Zealand.

In 1892, legislation was passed which stipulated that the Crown provincial had the sole right to use all water in the province and that private rights could be obtained only through compliance with the legislation (Campbell, 1972, p4). Under this legislation, domestic water uses were exempted. In 1897, the Water Clauses Consolidation Act was passed which further emphasized the ownership of water resources by the Crown (Scott, 1992, p356). This was the first act in British Columbia which dealt exclusively with water. The Act also exempted the use of water for domestic purposes.

There is very little mention of groundwater in any of the water resources legislation in British Columbia. As a result, groundwater issues are dealt with under English common law. Specifically the English Rule or Right of Capture is often referred to in groundwater cases. Simply put, it states that if a water well was drilled the owner of the well is entitled to take out as much groundwater as desired without regard for the rights of others who may also have wells and whose wells might be affected by the pumping of a particular well (Lucas, 1981, p12). The early English courts had the perception that groundwater percolated through the ground in a random manner with little or no connection to surface water. Groundwater was considered to be part of the soil and exclusive rights to extraction were assigned to the overlying landowner (Tarlock, 1985, p1752). Under the English Rule, no consideration was given to the impact of unlimited extraction by a property owner. The traditional legal concepts of ownership and property rights do not adequately cover groundwater due to its mobility and as such a different legal framework is necessary to unambiguously outline property rights and rules of liability (Templer, 1988, p227).

In the case of the Gulf Islands, the English Rule is basically fair if all users, of a particular aquifer, use roughly equal technologies for their domestic water supply. Since little or no record of groundwater usage is available, and there are no guidelines for available technology, it is not possible to determine the equitability of the English Rule.

Control and ownership of water resources is vested in the provinces, under the Constitution Act (s 109) (Thompson, 1991, p432). The provinces have the legislative authority to make laws governing the management of natural resources including water (s 92 (5)).

8.2 Water Related Legislation

Given the many and varied uses of water in our daily lives, water is implicated in many pieces of legislation. Table 14 presents a partial list of areas of legislation which may have an impact on water resources.

TABLE 14: Partial List of Provincial Legislation Impacting Water Resources

- Environmental Management Act
- Environment and Land Use Act
- Fire Services Act
- Forest Act
- Health Act
- Highway Act
- Islands Trust Act
- Land Act
- Municipal Act
- Pesticide Act
- Waste Management Act
- Water Act

8.2.1 Water Act

The Water Act represents a recipe for the issuance of water licenses. The Act deals only with surface water although in 1960 a provision was made for the extension of the Water Act to groundwater. The extension to groundwater has never been proclaimed by the legislature. Campbell (1972, p16) states:

> " evidently no serious conflicts have yet arisen by virtue of groundwater use and the act will likely be proclaimed to apply to this source only when material interference with surface water rights result from groundwater withdrawal. "

The Water Act basically regulates the allocation of surface water in British Columbia. Allocation is based on prior appropriation or the first in time, first in right legal doctrine. The Act defines the priority among water users, who can hold a water license, and its duration (Day and Affum, 1990, p7).

British Columbia represents the only province in Canada and the only area in North America which does not have some form of groundwater legislation. Given that there are regions of British Columbia such as the Gulf Islands which are heavily reliant on groundwater for domestic water supply, it would seem that some form of legislation is necessary to protect and manage this resource. Representatives of Islands Trust have been interested in the development of groundwater legislation for some time but to no avail (Islands Trust, 1993).

The Water Act makes no provision for anticipating potential problems or planning to mitigate these potential problems. B.C. Environment (1993e) claims, and rightly so, that the Water Act has served the province well but that it is limited in its ability to accommodate comprehensive stewardship of water. It is recommended that regulation of groundwater and procedures to integrate groundwater and surface water be incorporated in any new policies and legislation.

8.2.2 Islands Trust Act

As stated in the Islands Trust Act S.B.C. 1989 c.68 s.3,

> " the object of the trust is to preserve and protect the trust area and its unique amenities and environment for the benefit of the residents of the trust area and of the Province generally, in cooperation with municipalities, regional districts, improvement districts, other persons and organizations and the government of the Province. "

Under Bylaw No. 17 (Islands Trust, 1994, p13), the Islands Trust Council has stated several objectives regarding the freshwater resources of the Gulf Islands including: a self-sufficiency of freshwater supplies, support for water conservation measures, encouragement for the efficient use of freshwater resources, encouragement for development of legislation to protect the sustainability and quality of groundwater on the Gulf Islands, and use of the community plans and regulatory bylaws to ensure that neither density nor intensity of land use is increased in areas with a known water quantity or quality problem, maintain water quality, and consider existing, anticipated and seasonal demands for water (Islands Trust, 1994, p13). The fact that there is a comprehensive statement regarding water supply in the bylaws is to be commended. Unfortunately, the bylaw is not enforceable and represents a reactive approach since it is in effect for areas having known water quantity and quality problems. It would be more beneficial for residents of the Gulf Islands if there were proactive measures in place to reduce the potential for development of water quantity and quality problems.

The Islands Trust Policy Statement (Islands Trust, 1994, p7) presents an ecosystem approach to preservation and protection of the islands. If water management on the Gulf Islands is to be successful, such an approach is mandatory. Unfortunately, there is no direction as to how to implement an ecosystem approach to meet the Trust's mandate of preserving and protecting the Trust Area. In order to have a sustainable water supply on the Gulf Islands, it is necessary to have basic information regarding climatic controls on water supply, geology which controls the distribution of the water supply and human population which can be supported by this water supply. This type of information should be compiled and integrated with historical and socio-economic factors to form the basis of the community plan. Water supply forms an integral part of an ecosystem approach and can be utilised as a means of determining how much development should occur if the Islands Trust is going to live up to their mandate of preservation and protection for future generations.

The Islands Trust Policy Statement has little muscle when it comes to dealing with issues, water and otherwise, on the Gulf Islands. The Ministry of Energy, Mines and Petroleum Resources recently approved a permit for a gravel operation on North Pender Island with little or no regard for the Islands Trust Policy Statement which discourages extraction of granular materials on the Islands (Island Tides, 1995a). The concepts and policies put forward by the Islands Trust Policy Statement represent a significant step toward sustainability but they must be enforceable. There is a necessity for cooperation with a number of other government agencies which have the legal authority over water resources to enable the concepts and policies to be put into practice. Within the time frame of development on the Gulf Islands, there is little time that can be allotted to enable the necessary cooperation since it has already been shown that the population of the Pender Islands may reach a projected maximum by 2008 (Section 4.0).

8.2.3 Health Act

The Health Act has an impact on the approval of waterworks systems and sewerage plans and systems by providing officials to investigate, regulate and control such systems. Concerns regarding the quality of water from a public health perspective arose in 1888 when the Health Act covered sanitary requirements regarding water supply and human waste disposal (Rueggeberg and Dorcey, 1992, p204).

The Health Act provides a framework for the investigation, regulation and control of septic tanks, waterworks systems, and sewage disposal systems to ensure that human health is safeguarded. The Sewage Disposal Regulation requires a permit and compliance with the permit conditions for the construction, installation, repair, or alteration of a sewage disposal system (B.C. Environment, 1994, p32).

The guidelines for Canadian drinking water quality have been included in Appendix B. The drinking water quality standards are not legally enforceable in British Columbia (Freeze *et al.*, 1993, p5.12). The chemicals and physical parameters which are most relevant to the Pender Islands are chlorides, iron, and turbidity which have only aesthetic objectives within the guidelines. There is, however, the possibility that well concentrations well above the aesthetic objective for drinking water may pose a potential health hazard. Grover and Zussman (1985, piii) believe that constant monitoring of water quality is required to minimize the risks of waterborne disease.

8.2.4 Land Act

The Land Act administers and disposes of Crown land which for North and South Pender Islands represents a very small percentage of the total area.

8.2.5 Municipal Act

As the example of Trincomali illustrated, the Municipal Act enables a community to be incorporated as an improvement district to ensure that a viable water supply is available to all residents. Under the Municipal Act sections 944, 945, 928, and 949(2), the South Pender Island Trust Committee is empowered to adopt community plans. The purpose of the plan is to provide a framework for planning future development on the Island. As was the case with the Islands Trust Act, Bylaw No. 28 (South Pender Island Trust Committee, 1990) lists a number of community objectives which indicate a will to preserve and protect the Island ecosystem. The basic science required to make informed decisions has, however, not been undertaken. The community plan includes low density development, number of residents per parcel of land, water supply watersheds, road standards, water supply, sewage disposal, and community water and sewer systems. Each of these issues requires some knowledge regarding the water resources available on the Island. There should be distinctly different planning legislation for groundwater recharge versus discharge areas.

In addition, Bylaw No. 28 encourages water conservation, proof of water supply, certification of well tests, and compliance with the Health and Waste Management Acts regarding the disposal of sewage. There is, however, nothing in the Bylaw which enables enforcement. Bylaw No. 218 for North Pender Island makes similar suggestions but is no more enforceable (North Pender Island Trust Committee, 1991) than Bylaw No. 28. It should be a simple matter to amend these bylaws to include an enforcement provision but this is not always the case.

In order for the community plans to be effective, there is also a requirement for cooperation with many other government agencies. As mentioned above, disposal of sewage alone requires cooperation between the Health Department, Municipal Affairs and Ministry of the Environment, Waste Management Division. This situation creates fragmentation in the administration of regulations.

8.2.6 Waste Management Act

The waste management act states that it is not permissable to introduce wastes into the environment without a permit (Freeze *et al.*, 1993, p5.13). This includes septic wastes for which the act makes little mention of groundwater other than to state that siting should take into account hydrogeological considerations.

8.3 Institutional Framework

The consortium of Acts listed in Table 14 which influence the regulation of groundwater within British Columbia indicates that many government agencies have some responsibility for groundwater quality and quantity. Islands Trust has a mandate to preserve and protect the Gulf Islands but in order to meet their mandate they require the cooperation of many other government agencies. A 1994 amendment to the Islands Trust Act (33(s8.1)) actually attempts to legislate coordination between agencies. Unfortunately, coordination will only be successful if there is the will to cooperate between agencies as well as the appropriate funding levels. The Groundwater Division of B.C. Environment, which represents the technical expertise regarding groundwater resources, has been asked on numerous occasions for advice regarding groundwater issues on the Islands by Islands Trust but due to other commitments and funding restraints may not always be able to respond in a timely manner. Table 15 lists the government agencies with involvement in groundwater.

TABLE 15: Government Agencies Involved In Groundwater Management

- Islands Trust
- Capital Regional District
- Ministry of Environment, Lands and Parks
- Ministry of Health
- Ministry of Forests
- Ministry of Transportation and Highways
- Ministry of Municipal Affairs
- Ministry of Small Business, Tourism and Culture
- Ministry of Agriculture, Fisheries and Food

The distribution of responsibility between such a wide group of government agencies ultimately results in fragmentation with its inherent inefficiencies. Pucci (1994, p984) stated that planning and control by agencies requires highly concentrated decision making, complicated lines of authority, consistency, and large overhead costs and response times which result in many undertakings failing to impact the planning process due to lack of enthusiastic support.

At present, final approval for subdivisions on the Gulf Islands is provided by an Approving Officer from the Ministry of Transportation and Highways' (MOTH). The Approving Officer has given approval for projects in the past without ever viewing the property while illustrating a lack of familiarity with the Official Community Plan (Island Tides, 1995b). Currently both the CRD and Islands Trust are interested in taking over responsibility for the Approving Officer.

9.0 DESCRIPTION OF WATER PRACTICES FOR EXISTING DEVELOPMENTS

9.1 Trincomali Improvement District

The Trincomali subdivision was established in 1968 by a developer who had the foresight to realize that water supply may be a problem. The developer established the Pender Utilities Ltd. which was responsible for the installation of the original water system in Trincomali consisting of six wells with diesel pumps. The water was pumped up to two 45,450 litre tanks at the top of the hill at the entrance to Trincomali to form a gravity feed system. For a connection fee and a water use fee of $200.00/year, connections were made to individual lots. After a period of time, some diesel contamination was discovered in several wells. One of the wells also had a reputation for being brackish particularly during the summer months. The contaminated wells were replaced by alternate wells and the diesel pumps were replaced by electric pumps to reduce the potential for contamination.

As population growth occurred, the water system became inadequate to meet the water needs of the community particularly during the dry summer months (J. Roberts, personal communication, 1994). In 1978, some of the properties, which are located at higher elevations in Trincomali, were without water for 60 days (Roberts, personal communication, 1994). In 1980,the Capital Regional District (CRD) would have taken over the operation of the system at an initial cost to the district of $60,000 plus $600/property.

In 1982, the Trincomali Property Owners' Association met to consider three water supply and management options. These included:

1. a continuation of the existing Pender Utilities system
2. responsibility of water supply transferred to the CRD
3. formation of an Improvement District to manage the Trincomali water system

The members of the Property Owners' Association voted for the formation of the Trincomali Improvement District. On February 28, 1983, the letter patents forming the Trincomali Improvement District were issued. The Improvement District's purpose was outlined to be ".... the acquisition, maintenance, and operation of works for waterworks purposes and all matters incidental thereto." Subsequently, five trustees were elected to enable the holding of the first Annual General Meeting in August 1983.

Along with the Improvement District status, there is a set of powers outlined in Section 827 of the B.C. Municipal Act which include:

1. levy parcel taxes
2. tax sale of lands when parcel taxes unpaid for more than two years
3. levy water tolls for properties using the water system
4. authority to cut off water service if tolls are unpaid or if a user makes irresponsible use of districts limited water supply

All of the bylaws passed by the elected trustees must be approved by the B.C. Ministry of Municipal Affairs before they can be enforced.

Since its inception, the Trincomali Improvement District has established parcel taxes, and water tolls as well as some other charges. The Parcel Taxes are designed to cover the costs of capital expenditures required for system improvements. Parcel Taxes are levied on all properties in the district regardless of whether or not they utilize the water system. An example of the capital expenditures was the cost of establishing a new reservoir in 1988. Property owners, in the district, were given the option of paying a lump sum of $1,550 or paying a parcel tax of $188/year for a twenty year period. All of the lump sum payments and parcel taxes were set aside to cover the costs of the reservoir construction. The reservoir has a capacity of 1.36 million litres and was designed by a resident civil engineer (Figure 48).

The water tolls are only levied on properties which utilize the water system. The water toll has been $190/year since 1990 which is less than the rate charged by Pender Utilities Ltd. prior to the formation of the Improvement District. Funds received from the water toll are used to cover the operating and maintenance costs of the system. The operating costs for the system are approximately $15,000/year which includes $1,000 set aside for future maintenance expenses.

FIGURE 48: Trincomali water reservoir, North Pender Island

Some of the other charges include:

1. a water connection fee of $500 for connection to the system
2. a turn-off fee of $25 if property owner requests that water service be suspended
3. a turn-on fee of $25 if property owner requests that water service be restored or water service has been suspended for non-payment of water tolls.

The trustees of the Trincomali Improvement District distribute literature regarding the water supply situation in the district to all new residents indicating that the trustees have a reasonable understanding of water issues for their portion of North Pender Island. The literature represents an attempt to educate new property owners about the limited supply of water and the necessity for water conservation. They also ensure that each new property owner is aware of Bylaw 11 which states:

> " Water is to be used sparingly for essential domestic purposes only. Hot tubs must be of the recycling type and may be filled only between December and May. No water is available for filling swimming pools, holding ponds, cisterns or dug-outs. No watering of gardens or lawns or washing of cars, boats or patios with water direct from the system is permitted. Bath and wash water should be saved for these purposes and for serious gardeners, rain water should be collected in cisterns or barrels. "

As of April 15, 1994, there were 79 out of 104 property owners connected to the system and metered. The meters were installed by a group of volunteers at a cost of approximately $150/meter. The CRD would have charged between $450 and $480 to install the meters (J. Roberts, personal communication, 1994). The installation of water meters enabled the detection of leaks present in the system such as leaky faucets and running toilets. The water meters are read on a monthly basis during the wet season and on a two week interval between July and October (dry season). The average daily consumption recorded per household is posted on the Trincomali notice board for households using more than 180 litres (40 gallons)/day. An example of the posted water meter readings is shown in Table 16. The trustees have found that the approach of relying on peer pressure through the posting of water use, in conjunction with the educational efforts, has been an effective deterrent to excessive water consumption (J. Roberts, personal communication, 1994).

TABLE 16: Water Meter Readings in Trincomali (late winter 1994)

ROLL	PLAN	LOT	LAST NAME	MARCH (gal./day)	FEB. (gal./day)	DEC. - JAN. (gal./day)
302	21432	B	Phippen	110	32	93
57	17910	62	Patching	89	68	76
116	23332	16	Paterson	87	90	81
4	17910	4	Rea	85	66	70
61	17910	66	Ross/Vye	81	57	64
35	17910	39	Bollen	69	101	109
9	17910	9	Hodgkinson	64	72	75
112	23332	12	Martens	64	40	61
119	23332	19	Libby	62	63	64
34	17910	38	Hughes	61	53	50
401	1084	12	Folk	60	44	31
102	23332	2	Schneider	57	74	58
52	17910	57	Friesen	53	49	53
23	17910	25	Swain	52	6	7
22	17910	24	Harper	52	24	38
26	17910	30	Lane	49	42	53
10	17910	10	Thorsteinson	6	44	42
38	17910	42	Martin	45	43	45
125	23332	25	Kent	43		

Residents, who maintain high rates of consumption for several metering periods, will be visited by several of the trustees to bring to the attention of the property owner their excessive water consumption or to determine the reason behind the high water consumption during this metering period. Continued excessive use of water may result in the discontinuation of water services from the system.

The district has established what they envision as reasonable water use rates for essential domestic purposes (Table 17). These rates are substantially lower than water use rates in other areas of North America. The trustees state that "experience over several years with metered water connections shows that these amounts of water are quite adequate if care is taken to avoid unnecessary use" (J. Roberts, personal communication, 1994) (Table 18).

TABLE 17: Recommended Reasonable Water Use For Essential Domestic Purposes

270 to 320 litres (60 to 70 gallons)/day for a 2 person household
410 to 500 litres (90 to 110 gallons)/day for a 4 person household
635 to 725 litres (140 to 160 gallons)/day for a 6 person household

TABLE 18: List of Unnecessary Uses of Water

1. flushing toilet after each use
2. washing under a running tap
3. long showers
4. use of clothes washers and dish washers with small loads
5. any running of hoses

At present, the district is trying to maintain an accounting balance for water in the reservoir. The district has developed a strict approach to doling out the scarce water supplies in the Trincomali area. It appears that they have little room for other approaches. An additional concern to property owners should now be maintenance of water quality. It is important to obtain an alternate water supply to reduce the impact of contamination of one of their existing wells. Since all properties have septic fields, the likelihood of contamination is a real concern. Of equal importance is the prospect of saline intrusions given the location of Trincomali on the tip of a narrow peninsula and the history of brackish water in wells in the past.

The municipal district of Trincomali is taking a proactive approach to water management by preparing plans to build additional storage capacity to ensure water supply once the Trincomali area is fully developed (G. Ravenscroft, personal communication, 1996).

9.2 Magic Lake Estates

The approach taken at Magic Lake Estates is drastically different from that taken by the residents of Trincomali. In the early 1960s, the Magic Lake Estates subdivision was approved with 1,243 lots giving the subdivision one of the largest population densities in the Gulf Islands. The average lot size in the development varies between one-third and one-half acre. The subdivision, along with similar subdivisions on other islands such as Hornby Island, ultimately led to the formation of Islands Trust which placed a ten acre lower limit on lot size in the Gulf Islands.

Gulf Industries Ltd. was formed to construct and operate a water supply system while Pender Holdings, a partnership of four companies, was formed to operate the sewer system for Magic Lake Estates. Magic Lake (Figure 49) is an artificial impoundment constructed in 1964 by Magic Lake Estates (Mordaunt, 1981, p63). Initially, Magic Lake was utilized as the source of potable water for the residents of Magic Lake Estates under a license granted to Gulf Industries Ltd. entitling the withdrawal of 454,600 litres/day (100,000 Igal/day) or 166 million litres/ year (36.5 mIgal/year). By the late 1970s, the water supply from Magic Lake ceased due to the reduction in water quality resulting from the location of septic fields adjacent to the lake and the subsequent increase in algal content (D. Ball, personal communication, 1994). A referendum was scheduled for the spring 1995 to determine whether residents are willing to incur a cost of $50/year to have a water treatment plant on Magic Lake.

FIGURE 49: Magic Lake, North Pender Island

Buck Lake, which is also an artificial impoundment constructed in 1967 by Pender Holdings (1967), replaced Magic Lake as the water supply for the community. Pender Holdings (1967) had been granted a license to withdraw 380,000 Igal/day (1.73 million litres/day) or 139.5 mIgal/year (634.2 million litres/year) from Buck Lake in 1969. To protect the water supply for the community, a reserve was placed on Roe Lake by an Order of Council (#3010) in November 1978 (Mordaunt, 1981, p66).

In 1980, the operation of the water supply and disposal system was taken over by the Capital Regional District (CRD) at the request of the residents of Magic Lake Estates. A committee of local residents makes recommendations to the CRD. Any decisions for expenditures on the system must be approved by the CRD environmental committee and the CRD Board.At present, Buck Lake represents the sole source of potable water for the community system. Figure 50 illustrates the dangerously low water levels in Buck Lake during the summer of 1994. The sign had shown low water levels in Buck Lake for the past year. On August 11, 1994, residents of Magic Lake Estates were advised against washing cars, driveways or watering lawns (Island Tides, 1994a).

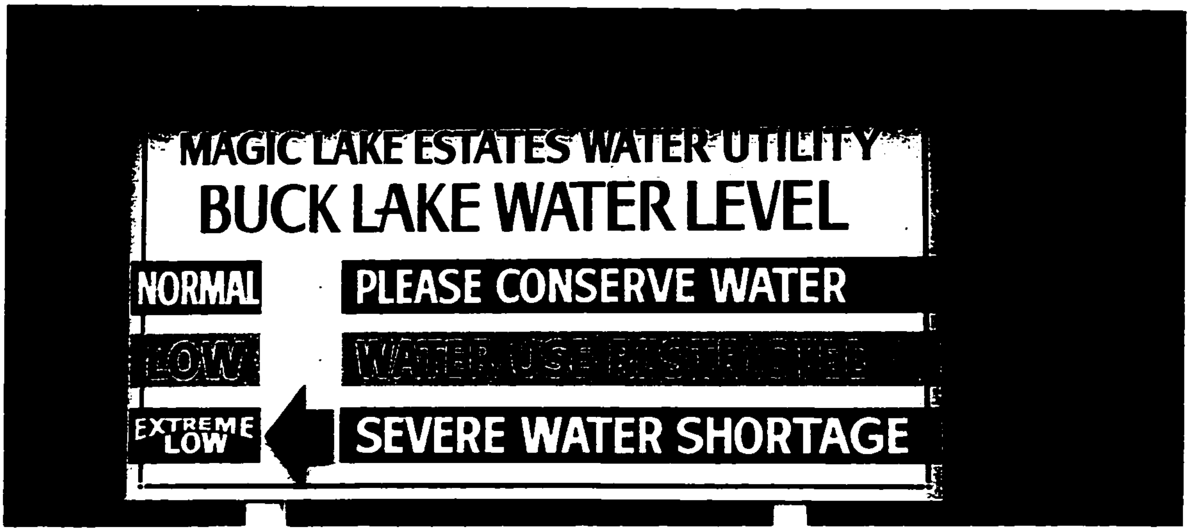


FIGURE 50: Sign in Magic Lake Estates indicating extremely low water levels in Buck Lake during August 1994.

Given that approximately 750 lots have been developed to date, there will almost certainly be a water supply problem as more lots become developed. Magic Lake and Roe Lake have been set aside as potential sources of water for the community system. Additional expenditures to improve the water quality from Magic Lake would be necessary before the water could be utilized. It is, however, projected that at full development there would not be sufficient water to meet the needs of the community (D. McFarland, personal communication, 1994).

The residents of Magic Lake Estates are levied parcel taxes of $129/year for water supply and $295/year for sewage. In addition, a user fee of $60/year for water supply and $101/year for the sewer system are levied. The total cost of the water supply system ($189) compares favourably with other systems on the Island such as Trincomali ($190).

During the summer of 1994, a groundwater well was drilled in close proximity to the fire station in an attempt to augment the water supply. The geologic interpretation of a fault at this site, which was the basis for the drill hole location, was in error and as a result no significant water was encountered.

Prior to drilling any additional groundwater wells, the community should ensure that the most recent reasonable geological interpretation for the Island is used.

Based on discussions with the CRD (J. McFarland, personal communication, 1994), the water consumption per household is estimated to average 818 litres/lot/day (180 Igal/lot/day) which is similar to rates utilized by urban dwellers. This rate tends to triple during the summer and peaks at about 2500 litres/lot/day (550 Igal/lot/day). Given that there are approximately 1.8 persons/household, consumption of water is 454 litres/person (100 Igal/person) which is 2.5 times the regulated consumption in Trincomali.

The community of Magic Lake lacks the educational literature such as that prepared by the Trincomali Improvement District to present to new residents. The current residents have until recently been in opposition to metering of water consumption. As of October, 1994, the residents of Magic Lake approved the implementation of water meters (Pender Post, 1994). Studies have shown that water meters have a tendency to reduce water consumption (Jordan, 1994). Water meters will, also, identify any major leaks in the system and enable a full water accounting system to be utilized to measure losses from the system. It was estimated that up to 15% of the water in the community system could be lost due to leaks (Island Tides, 1995b).

Recently these estimates have been revised to up to 45 % of the water supply may be lost as a result of leaks in the water supply system (Island Tides, 1996).

It is anticipated that the majority of the leaks occur at joints in the pipe (G. Hussey, personal communication, 1996) since leaks in the pipe itself generally result in the leaking section of pipe blowing itself apart. To replace the existing water supply system, it is estimated to cost approximately $100/metre (G. Hussey, personal communication, 1996) or about $2.5 million for the entire system.

In discussions with several residents of Magic Lake Estates, many stories exist of residents using water from the system to wash vehicles, residents leaving water running while they were off the Island in the winter to prevent pipes freezing, etc. (D. Ball, personal communication, 1994). It is imperative that the residents of this community become more attuned to the water availability situation in their community and work together to ensure a sustainable water supply.

A program should be established to encourage residents in the purchase and installation of water saving devices such as low flow toilets, low flow shower heads, etc.. By reducing the costs of conservation to residents, it is likely that more residents will actively participate in water conservation. An attempt was made to pass a bylaw imposing additional charges to homes which did not install low-flush toilets. This bylaw was opposed by a large number of residents and never proceeded (Islands Tide, 1994a). On a positive note however, Pender Lumber reported selling 300 low flush toilets during the bylaw controversy (Island Tides, 1994a).

At present, there are two sewage treatment plants which provide secondary treatment (aeration only). The capacity of the system is 172,748 litres (38,000 IGal) and it is currently operating at close to capacity. The treated fluids are discharged into the ocean. According to the residents committee, there is a potential sludge disposal problem developing in the system (D.Ball, personal communication, 1994). There is also a problem with the leakage of the effluent sewage system (Island Tides, 1996).

9.3 The Remainder of North and South Pender Islands

Although there are additional multiple water user systems on the Islands, the major water systems have been discussed in Sections 9.1 and 9.2. The majority of the remainder of island residents rely on water wells and septic fields for water supply and septic disposal. Up to 1986, there have been 550 recorded water wells on the Pender Islands. These wells include both drilled and dug wells; unfortunately the wells have proceeded on an *ad hoc* basis following the development of the Islands. **The community plans have provided a basis for the development of the remainder of the Islands but with little regard for groundwater resources.**

Of the wells drilled on the Islands, 45% have a flow rate of 4.546 litres/minute (1 gallon/minute) or less. The average flow rate is 17.82 litres/minute (3.92 gallons/minute). The median flow rate of 6.82 litres/minute (1.5 gallons/minute) is likely more representative of typical flow rates on the Islands. The flow rates of some water wells are not sufficient to provide a water supply sustainable particularly during the dry summer months.

Options available to residents have a price tag associated with them. It is possible to consider drilling additional water wells, using cisterns, or trucking water. The costs of these options are presented in Table 19. In addition, it should be noted that trucking water requires using a cistern and the drilling of addition water wells does not negate the use of cisterns.

TABLE 19: Costs Of Options For Increasing Water Availability

OPTIONS	COST
Additional water wells	\$36/metre
Trucked water	\$400/3,000 gallons
Cisterns	\$13,000/11,000 gallon tank

The *ad hoc* nature of the development brings the groundwater rights of individual property owners into question (Section 8.0). Some groundwater rights issues are well interference and contamination.

At least one individual and one corporate entity on the Pender Islands have desalination plants. Bedwell Harbour has an extensive desalination system in place and is currently lobbying for a revision to the zoning bylaws to increase density of development at their Bedwell Harbour location. In order for desalination to be an alternative source of water supply, there must be guidelines for the disposal of the salts extracted from the water. Simply returning the salt to the ocean can adversely impact the near shore environment creating additional problems at the expense of water supply. One of the difficulties with desalination is the expense involved in acquiring and maintaining a system.

Previous research by Mordaunt (1981, p21), indicated that areas of high density development on the remainder of the Islands generally corresponding to coastal areas are more prone to declining groundwater quality.

At present, there are no controls over the extraction of groundwater. The areas adjacent to the large development on North Pender Island may be adversely impacted by the decreased percolation of precipitation to recharge aquifers. This would be a response to the decrease in vegetative cover and increase in the infrastructure of roads and houses which result in increased surface runoff.

10.0 GROUNDWATER MANAGEMENT PLAN

> " Ecologically effective ecosystem management will require the development of a robust logic, rationale, and framework for addressing the inherent limitations of scientific understanding. It must incorporate a strategy for avoiding irreversible or large scale environmental mistakes that arise from social and political forces that tend to promote fragmented, uncritical, short-sighted, inflexible, and overly optimistic assessments of resource status, management capabilities, and the consequences of decisions and policies. " (Frissell and Bayles, 1996, p229)

It has already been established that an island ecosystem is very sensitive and subject to drastic changes as a result of human interference. The natural sensitivity of island ecosystems demands a pro-active approach to groundwater management rather than the norm of reactive management procedures. Dorcey (1987, p481) stated:

> " there is a deep concern throughout the nation about the state of the resource and a general lack of confidence in the existing approaches to management of water resources in Canada. "

An effective groundwater management plan should encompass the major issues impacting groundwater to provide a pro-active framework for sustainability. The objectives of any management plan should be clearly defined at the outset, a course of action should be developed, and there should be an adequate opportunity for monitoring the success of the implementation phase to ensure that the objectives are being achieved. Tate (1990, p4) stated that water management is the task of selecting specific actions from among a range of available alternatives.

After reviewing the available alternatives, this section describes a recipe for groundwater resource management in the Gulf Islands in both the short and long terms by reviewing water management, water availability, water quality, and education. Table 20 provides an overview of the proposed groundwater management plan.

TABLE 20: Summary Outline of Proposed Groundwater Management Plan

Water Management

- promote participation of stakeholders
- develop an up-to-date database
- select a management committee
- develop an enforceable legal framework
- reduce fragmentation in governance

Water Availability

- promote education of stakeholders
- develop an enforceable legal framework
- develop strong economic policies
- detailed geologic mapping
- control rate and location of development
- institute bylaws promoting rainwater catchment
- promote conservation and recycling

Water Quality

- develop an enforceable legal framework
- institute a water monitoring program
- develop enforceable well completion guidelines
- institute a short term moratorium on development

Education

- provide workshops on water resources management
- provide information packages for residents and tourists
- promote research and development

Prior to outlining the proposed groundwater management plan, it is worthwhile to put the plan in perspective by reviewing the extreme endpoints related to water on the Gulf Islands. At one endpoint, there are predictions of no shortage of water resulting in beliefs that no restrictions should be placed on development. Based on the research conducted to date, it is safe to conclude that water is a valued resource having a limited supply. Unrestricted development on the Islands would result in decreased water quality either through saline intrusions or other contamination, decreased groundwater recharge due to increased surface runoff, water shortages particularly in the late summer months, increased removal of the vegetative cover leading to changes in the water balance, and ultimately decreased property values and tax revenues based on the first four items. This represents an entirely reactive approach to water management with little regard for the preservation and protection of the Gulf Islands for current or future generations. In the long term with this approach, it will be necessary to develop an island-wide water distribution and sewage system.

At the other end of the spectrum, there are recommendations for a complete and immediate halt to development. This would not necessarily improve water quality in areas with existing water quality problems nor would it increase water supply. A long term moratorium on development would result in a maintenance of the status quo existing on the Islands but with changes to the legal and institutional framework, it would be possible to enforce measures to reduce water demand thereby indirectly increasing supply. **To have an entirely pro-active approach, the Islands could be treated as a National Park with strict guidelines covering removal of the vegetative cover and abstraction of groundwater, purchase by government of any lands for sale to preserve and protect greater portions of the Islands, and ban the use of desalination plants.** This approach will result in similar economic impacts as the other extreme with reduced tax revenues due to a slowly reducing population base. However by charging an annual fee for tourists to use the area and increased property values for the remaining residents, the decline in tax revenues may be offset by making the Islands a more desirable end point for visitors. Given the financial status of the federal and provincial governments, it is unlikely if the concept could ever be attained.

In reality, neither of these extreme positions is acceptable. The groundwater management plan presented in the following sections attempts to find the middle ground between these extreme positions. The steps which must be taken to ensure a sustainable water supply for the Islands will result in demands being placed on residents and to a lesser extent visitors to the Gulf Islands.

10.1 Water Management

The development of a reasonable water management scheme is reliant on the development of a legal framework, public involvement in decision making, and a reduction in institutional fragmentation. Water management should be based on sound scientific data. At present, decisions regarding development are being made without adequate information on the groundwater resources. Dorcey (1987, p499) lists the following questions as part of a management decision making process:

> " How well can management decisions be made with presently available information?
>
> How much better could decisions be made with improvements in the information available?
>
> How might information be improved through different types of research?
>
> What is the likelihood of improving information by different types of research?
>
> What are the costs of different types of research?
>
> How long will it take to improve information by different types of research? "

10.1.1 Legal Framework

The need for a legal framework has been recommended by several groups in the recent past including the Pender Islands Pilot Project Committee (1994). The following recommendations are suggested for inclusion in a legal framework for groundwater management in the Gulf Islands:

- requirement for a groundwater impact assessment prior to approval of any development and provision for refusing development or rigorous mitigation requirements if practicable when significant adverse impacts
- enforceable guidelines for well completion, legislation regarding well interference
- mandatory use of cisterns
- regulations for the disposal of highly saline waste from desalination
- protection of recharge areas
- guidelines for a regular water monitor program, and
- guidelines for emergency water supply
- demand water reduction requirements (low flow fixtures, water meters, consumption charges)

It will be impossible to manage the groundwater resources without enforceable legislation. There must be a well defined legal framework before any one government agency can bear responsibility for groundwater supply. The legal framework must address issues such as well interference since it has been illustrated that the Right of Capture in English common law is not an effective principle for sustainable groundwater development. **There are currently no guidelines encompassing hydraulic fracturing of wells, excessive pumping of water wells, completion of water wells, or disposal of by-products of desalination.**

A groundwater impact assessment program should be designed and enforced by B.C. Environment Groundwater Division in conjunction with Islands Trust. The overall mandate should be to ensure that no development which has a negative impact on groundwater supplies of existing residents is approved. An integral portion of the groundwater impact assessment should be the time of year when it is conducted. To observe the maximum impacts on adjacent properties to the proposed development, groundwater impact assessments should be conducted in the late summer or early fall.

Ensuring reasonable water quality should be a priority of any legislation. There is presently legislation defining the appropriate distance between septic systems and water wells. Unfortunately, safety of a groundwater source is dependent on good well construction and local geology which should be the prime reasons for determining safe separation distances rather than having a blanket policy which is expected to cover all situations which may arise. By having flexible legislation which would be based on site specific conditions, there would have to be an institution willing to take responsibility for providing approvals. Once again, it is recommended that B.C. Environment Groundwater Division in conjunction with Islands Trust would be the appropriate governing bodies.

It has been shown previously that there is a need for guidelines for well completion in the Gulf Islands. As Smoley (1992, p35) states, there is no safe distance between septic fields and water wells for a poorly completed well.

10.1.2 Public Participation

To be successful, a groundwater management plan requires public participation. Smutko and Danielson (1992, p185) state:

> " local citizens, by participating in the process of developing groundwater policy, can become more aware of the problems and possible solutions and are more willing to live with the consequences of policy decisions than when they are imposed from the outside ".

10.1.3 Ownership of Water Resource Issues

It is crucial that residents of the Gulf Islands must take ownership of water resources issues. Management of water resources should be by a committee of stakeholders including government representatives and local residents as recommended by B.C. Environment (1994, p29). The committee members should have attended workshops on water resource management as recommended in the previous section to ensure that all committee members have a basic knowledge of groundwater flow, areas of recharge and discharge, potential sources of contaminants, well interaction etc. which may be impacted by their management decisions. If local residents do not take ownership of water resource issues, it will likely result in government taking charge of the situation to react to public concerns related to water problems with the likelihood of increased costs to the stakeholders.

The only hope for a pro-active approach to solving water problems is to have the direct involvement of all stakeholders. It is recommended that the management committee be composed of a representative of B.C. Environment (Groundwater Division), Islands Trust, a representative from one or two of the following groups: academia, consulting hydrogeologists, or water well drillers, and three representatives from the local community. This would result in no group having control which would necessitate consensus for the decision making process. It should be noted, however, that both consulting hydrogeologists and water well drillers have an economic vested interest in water management issues. In order to be successful, this approach requires a strong chairperson to lead the management committee.

The residents of Trincomali on North Pender Island have taken ownership of water issues for their community out of sheer necessity and have developed a successful water management program. These residents have had to make a number of sacrifices to attain success in resource management.

It may not be possible for the residents of North Pender Island to have an overall management plan due to the fragmentation of water development on the Island. There would have to be agreement between the CRD, Trincomali, Razor Point, and other residents to achieve success. This should not deter efforts to have a water management committee for those portions of the Island which have not organized. A possible means of incorporating the existing water groups into an overall water management committee would be to have two levels of management. The first would be responsible for overall water management for the island while the second may provide water management on individual groundwater basins (Figure 51). The second group could be comprised of three members of the community. Although South Pender Island does not have the same level of existing water management, residents could have a similar two-tiered system of water management.

It is important to have the cooperation of local trustees of Islands Trust but it is as important to ensure that they are not part of the management committee given their general concern for re-election.

10.1.4 Institutional Framework

For successful management in both the short and long term, it is imperative that one government agency be given overall responsibility for the governance of the Islands. It will be necessary for this agency to have the cooperation of other government agencies which have an interest in groundwater issues. It is suggested that Islands Trust would be the best agency to fulfill this role. It is recommended that planners from Islands Trust spend much more time on the Islands than is presently the case. In addition, staff of Islands Trust must identify areas in which they do not have sufficient expertise and seek to rectify the deficiency by utilising others who possess the required knowledge. The fragmentation of control over groundwater issues is a major drawback to management of the resource.

10.2 Water Availability

The potable groundwater available on the Gulf Islands has been shown to be limited by climatic variables, local geology, and population pressures. There are several options available to increase water availability including increased pumping, drilling additional wells, controlling water demand, conservation, and education.

The negative side effects of increasing the number of wells and pumping rates are much greater than any gains which may be achieved. Saline intrusions along the coastal areas of the Islands are an example of the negative side effects of overpumping an aquifer where water tables are low as is the case in the northeast portion of North Pender Island. Horizontal wells may offer an opportunity to increase production while at the same time reducing drawdown . Horizontal wells are currently being used in the oil industry to increase production while maintaining reservoir integrity. This is likely only a viable option for some of the improvement districts since costs of horizontal wells are approximately quadruple those of conventional wells. Horizontal wells would however result in less drawdown of the aquifer with increased productivity while decreasing the overall environmental impact.

10.2.1 Water Demand Management

A more reasonable alternative for stretching a limited resource is by controlling the demand for that resource. The Improvement District of Trincomali is an example of a region which has taken a proactive approach to controlling water demand (Section 9.1). In the case of groundwater, conservation methods will result in increased availability. As Postel (1985, p7) states: "only by managing water demand, rather than ceaselessly striving to meet it, is there hope for a truly secure and sustainable water future".

There are a number of alternatives in water demand management which can be utilised on the Gulf Islands including monetary incentives, water meters, retrofitting, recycling, public awareness programs, legal framework, and government economic policies. The residents of North Pender Island who are already part of an Improvement District have an opportunity to use monetary incentives as a means of controlling water demand. This simply involves the establishment of a pricing structure for the water which reflects its inherent value. Tate (1990, p5) states that "realistic water pricing is one of the most fundamental keys to water demand management and is central to many of its options".

Water pricing could be established in several ways. A system could be designed to provide some economic advantage to full time residents of the Island by having a lower rate during the wet winter season when aquifers are being recharged and demand is relatively low. The rates for water consumption during the drier portions of the year could be determined such that there is a sliding scale varying from a low price for a certain volume of water during the rainy season to a high price during the dry, peak use summer months. Such a pricing mechanism will also bridge the gap between residents and operators of tourist accommodations, since it follows a user pay principle and any water consumption above the basic minimum required for a resident would be charged at a higher rate. Pricing will not be an effective tool by itself since it has the potential to provide a system whereby water is available in relative abundance to only those who can afford it. When combined with other options however, pricing schemes can be very effective tools. It is estimated that water consumption can be reduced by simply having an effective pricing plan.

It may be prudent for proprietors of tourist accommodations to have water meters for each room. This would be a truly user pay system and would bring home to tourists the critical nature of water availability by incorporating their water consumption into their room charges.

For areas such as Magic Lake Estates, water availability can be dramatically increased simply by locating and repairing the leaks in the water supply system. When up to 45% of the water entering the system may be lost to leakage, the available resources can be almost doubled simply by proper maintenance and control of the current system. By ensuring that every resident in Magic Lake has a water meter and is a part of the water supply system, it is possible to implement full system accounting once the repairs to the system have been completed. Full system accounting would involve the determination of the water available to the system at any point in time and being able to account for its consumption. Such a system would enable an early detection of leaks. In the short term, repair or replacement of the current water supply system is imperative. In the long term, continued maintenance is essential to ensure that water is available to meet the daily needs of current and future residents.

10.2.2 Rate of Development

The rate of development will play an integral role in water availability. It is recommended that in the short term there is a moratorium on development until a thorough understanding of the groundwater resources can be ascertained. Once this study has been completed, development projects should be allowed to proceed but in a phased manner to ensure that sufficient water for each phase is available without impacting neighbouring water wells. This will allow for slow growth while at the same time limiting development in recharge areas. Under no circumstances should development be allowed in groundwater recharge areas. This is a recurrent theme in all papers reviewing groundwater management and although it is often stated in Islands Trust documents, it is generally not a consideration by planners in the approval of developments. This approach to development would have to be included in the community plans for each Island.

10.2.3 Local Geology and Hydrogeology

Another important parameter in the availability of groundwater resources is the local geology. Falkland (1991, p97) indicates that knowledge of the hydrogeology requires detailed mapping of local geology with special emphasis on factors controlling permeability distribution. In addition, the local geology controls the storage capacity of groundwater in the subsurface. It is of utmost urgency that the local structure be mapped in detail to enable the quantification of the storage capacity of each island. This study has provided the local stratigraphy but additional information is required to understand the factors controlling secondary porosity and permeability. Spinks and Wilson (1990, p484) are of the opinion that storage capacity is of the greatest importance in the short term management of an aquifer. The storage capacity in conjunction with the rate of withdrawal and recharge of the groundwater resources would enable a prediction of the carrying capacity of the Islands.

Figure 51 presents the groundwater basins for North and South Pender Islands. Recharge and discharge zones should be identified in each groundwater zone. This can be accomplished by preparing geologic cross-sections through the groundwater zone (Figures 37 - 40). This information is critical to the determination of lot size, location of sewage disposal systems, location of water wells and siting of island infrastructure (roads). Groundwater zones should be incorporated into the Community Development Plans with stringent limits placed on development in sensitive groundwater recharge areas.

10.2.4 Conservation

Conservation and recycling are the primary methods of increasing water availability at the household level. Short term increases in water availability level will in all likelihood not achieve significant success if on a voluntary basis. One of the major drawbacks to success is the implementation cost to residents. Government economic policies are necessary to promote the replacements of household water devices such as shower heads, toilets etc. with flow reducing devices. The cost of such devices will pay for themselves very quickly simply by reducing the energy requirements for water heating (Rocky Mountain Institute, 1991).

10.2.5 Scientific DataBase

There are a plethora of existing groundwater data available from existing water well logs; unfortunately, these data have not been updated into a database which would provide much needed

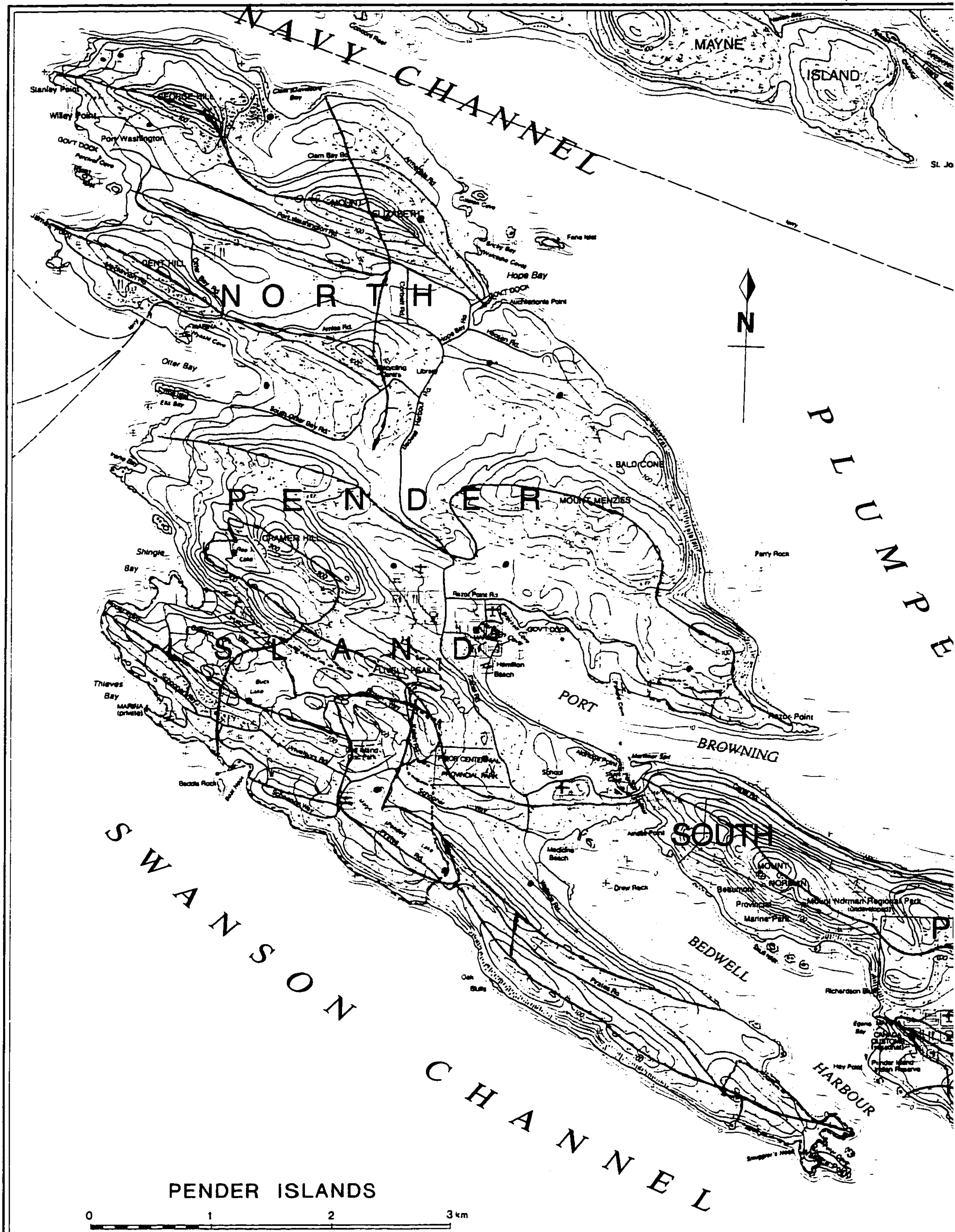
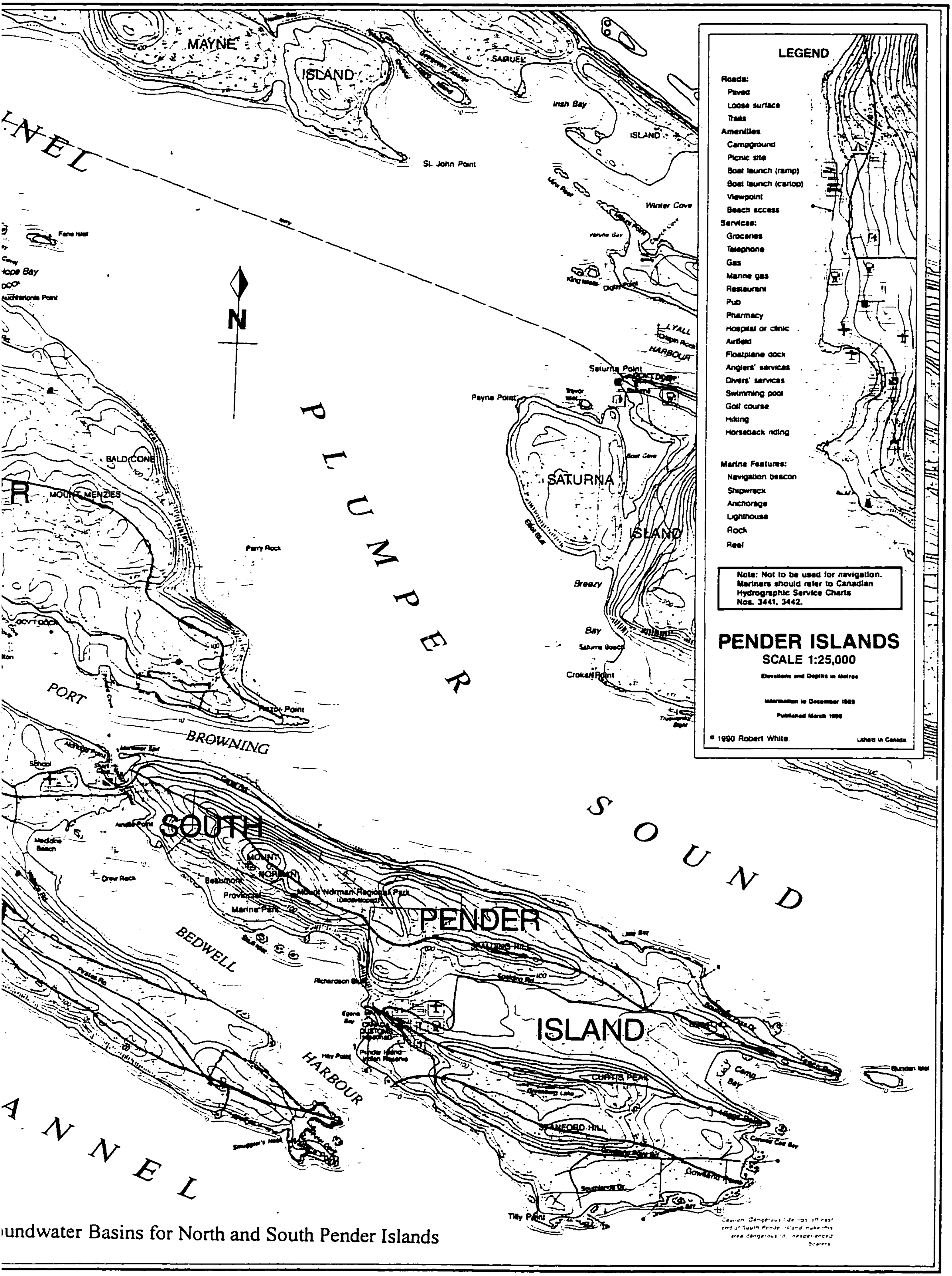


FIGURE 51: Groundwater Basins for North and South Pender Islands



undwater Basins for North and South Pender Islands

knowledge for decision making. For this study, data were available, from a database compiled by B.C. Environment Groundwater Division, up to and including water well logs to 1986. Data were unavailable from 1986 to present which likely represents the best data quality for any database for the islands. Any database should be user friendly to non-technical people as well as robust enough for the rigours of day to day use by water resource professionals (Goodrich and Phraner, 1991, p92). The water well locations in latitude and longitude should be included in the database as opposed to the present lot number with no indication of the exact location on the lot. The use of portable global positioning systems (GPS) should provide approximately 2 to 5 metre accuracy in a cost effective manner. The database should be compiled in conjunction with the geologic mapping to provide additional information regarding the specific stratigraphic unit which is acting as the aquifer for any given water well.

Geologic mapping could be accomplished in several ways including the development of close ties with post-secondary institutions (a groundwater study was recently conducted on Galiano Island by a student from Capilano College and studies have been conducted by students from the University of Calgary on North Pender Island), the secondment of a hydrogeologist from B.C. Environment Groundwater Division to Islands Trust, joint ventures with other government agencies (B.C. Energy, Mines and Petroleum Resources) or the utilization of qualified local residents (Dr. R. McWhae, North Pender Island).

10.2.6 Catchment Systems

Many islands throughout the world have building bylaws which require cisterns for rainwater catchment to supplement water supply. In many cases, the size of the cistern required is based on the dimensions of the roof of the structure. Similar bylaws should be put forward and enforced on the Gulf Islands since cisterns represent a very cost effective means of increasing water availability on a household level. Spinks and Wilson (1991, p484) are of the opinion that storage capacity is of the greatest importance in short term water management. There are residents on the Pender Islands who rely almost exclusively on water collected in cisterns as their sole water supply (P. Brown, personal communication, 1996). Financial assistance should be provided were necessary to support compliance with such a bylaw. A proposal for the use of cisterns to provide water for firefighting in new subdivisions was recently criticized since it was unclear who was responsible for their construction and maintenance (Island Tides, 1995b).

In addition, short term benefits that accrue from conservation and water catchment practices would be a long term advantage since the efficient use of water can lead to extended life of water well and septic systems (Rocky Mountain Institute, 1991, p11).

10.2.7 Hydraulic Fracturing

For residents dependent on water wells, a technique of inducing fractures in the well called hydraulic fracturing can be used to increase the short term production from a well. The technique has not been used extensively in groundwater drilling and there is little data available regarding the long term effects of hydraulic fracturing. Hydraulic fracturing may result in impacts to adjacent water wells which would necessitate legislation to ensure that one resident's gain in production is not at the expense of their neighbours' water supply.

10.2.8 Long Term Solutions

If the proposed short term recommendations for groundwater management are not followed, it is inevitable that in the long term, there will be a need to either replace or supplement groundwater supplies. Options to augment groundwater resources in the future could include desalination, development of an island-wide distribution system, and importation.

10.2.8.1 Desalination

Desalination must be carefully considered as an option since it potentially solves a problem of water supply but at the expense of creating a waste disposal problem. Within any legal framework, controls must be placed on the use of desalination systems and disposal of highly saline by-products. Pier and Mesa (1991, p132) reported that desalination was technically an option for providing water supply but that power costs and problems with disposal of highly saline water are factors making desalination difficult to implement.

10.2.8.2 Island-Wide Distribution System

The development of an island-wide water supply system on North Pender Island would be an expensive proposition averaging in current dollars approximately $100/metre. Given the present fragmented state of water management on the Island, there is the potential for conflict between groups currently involved in effective water management and those taking an *ad hoc* approach. An island-wide distribution system would, however, enhance the viability of other means of increasing water availability such as a pipeline from Vancouver Island or water tankers delivering water during periods of water shortage.

All of the long term options are expensive requiring that residents pay either through a lump sum payment or an annual tax surcharge. It does not seem reasonable to force other residents of British Columbia to pay for the necessary water infrastructure on the Gulf Islands. An island-wide water distribution system would require water meters which would enable a number of user pay scenarios to be developed.

10.3 Water Quality

10.3.1 Water Monitoring

Water quality is closely related to water availability since as groundwater resources become depleted, there is a much greater tendency for water quality to decline. Saline intrusions in coastal areas and along fault lines are prime examples of this phenomenon. It is recommended that a groundwater monitoring program be established as part of the overall groundwater management plan. At present, there are no requirements for monitoring groundwater quality resulting in uncertainty as to whether the potable groundwater currently used by residents meets the Canadian Safe Drinking Water Standards.

There are a number of areas on North Pender Island which have been identified as having anomalously high levels of chlorides and iron. The chlorides are a result of saline intrusions indicative of overpumping of the aquifer. A monitoring program would enable the accurate delineation of the freshwater/saltwater interface. This information could play a role in the determination of levels of development along the coastline by indicating regions of overpumping. The monitoring program should be conducted during August when groundwater levels will be low due to the dry summer conditions resulting in possibly the worst case scenario for water quality.

It is recommended that the monitoring program include, as a minimum, measurement of depth to water table, salinity, iron concentration, nitrates and E-coli bacteria. Increased levels of nitrates and E-coli bacteria would be indicators of contamination from sewage disposal systems and indicative of major health concerns. The data acquired from a monitoring program should be included in a groundwater database for the Islands. It is also recommended that the testing program be conducted on an annual basis to enable management decisions to be made before a degradation of water quality becomes an irreparable problem.

There is very little information regarding the effects of continued annual drawdown of the water table on water quality. It is projected that there has generally been a decline in water quality over the past several decades (A. Kohut, personal communication, 1994). A monitoring program is needed to assist in determining the long term and cumulative effects of annual drawdown of the water table.

A monitoring program will require inter-agency cooperation since at present the Health Officer is responsible for septic systems, B.C. Environment Groundwater Division and Islands Trust would benefit from an improved database, and cooperation would be required from the Improvement Districts and Capital Regional District.

As part of an integrated approach to water management, a strong legal framework would be required for a successful water quality monitoring program. Pro-active approaches to protect groundwater resources, as discussed previously, are cost effective means of ensuring a sustainable supply. Legislation regarding contamination of groundwater resources must be enforceable and act as a deterrent.

10.3.2 Guidelines for Well Completion

One of the other water quality issues arising on the Gulf Islands is related to well completions. Many of the water wells are relatively old and have not been completed in a reasonable manner leading to increased turbidity and the potential for contamination from septic systems. During the rainy season, it is common to hear water from surface runoff flowing down poorly completed wells (A. Kohut, personal communications, 1995). It is recommended that drilling and well completion guidelines or standards be developed. B.C. Environment Groundwater Division personnel would represent the best resource available to prepare such guidelines. The guidelines must be enforceable if the problem of well completion is to be eliminated.

10.3.3 Moratorium on Development

As was the case with water availability, it is recommended that a moratorium on development occur to allow the collection of the necessary water quality information to make appropriate decisions regarding continued development. Once the data have been collected and analysed, it is recommended that development proceed on a gradual basis to ensure that water quality can be sustained within acceptable limits.

10.4 Education

The role of education in a water management program is difficult to quantify but it does play a significant role in reinforcing other aspects. The Rocky Mountain Institute (1991, p13) has discovered that:

> " costs of, and water savings from, educational programs and rate structure changes can be difficult to calculate. For example, new rate structures will reduce water use, but the response may vary from year to year depending on such factors as weather, consumer income brackets, awareness of ways to reduce water use, and consumers understanding of the relationship between water bills and the amount of water used. "

10.4.1 Education of Stakeholders

The education of stakeholders in the water management issues in the Gulf Islands should play a prominent role in any management plan. The stakeholders can be summarised as Island residents, planners for Islands Trust, B.C. Environment Groundwater Division, tourists, and elected officials. Research by Hamilton (1985, p319) has shown that there is generally a lack of knowledge regarding water consumption by the public and that with increasing knowledge of water use that there is a greater effort to conserve. Hoenig (1993, p274) stresses the importance of public involvement in conjunction with education. Education of stakeholders is a continuing process and should begin as soon as is practicable.

As mentioned previously, it is necessary to have an understanding of the water resources of the Islands in order to successfully manage the resource and develop sustainable community plans. To achieve this goal, it is recommended that water resources workshops be held in the Gulf Islands requiring mandatory attendance of Islands Trust planners. The workshop should stress the basic criteria for water resources assessment and develop a plan of activities for the upcoming year to solve any immediate concerns which may have arisen in the previous year. The presentations should be given by representatives of B.C. Environment Groundwater Division and selected researchers from post-secondary institutes and industry. The cost of the workshops could be recovered through the maintenance of sustainable water supply enabling enhanced land values rather than a decrease in tax revenue due to reduced land values resulting from declining water availability and quality.

To be successful, participation by local residents would be required. It would be difficult to make attendance mandatory but water management is such a critical issue that it may warrant unconventional methods to entice residents to attend. It is recommended that a tax surcharge be levied on residents who do not choose to attend the workshop, unless they have a prior engagement.. By educating Island residents about water resources issues, they will be better able to conserve and manage their own water resources. This could result in the deferral of capital expenditures for such costly infrastructure as an island-wide water supply system. This approach gives residents a choice of either attending the workshop or paying higher taxes. Hamilton (1985, p315) reflects on education campaigns being based on the premise that the more a group of individuals knows about a particular resource then the more inclined they are to conserve it.

Workshops must be held on a regular basis to provide feedback to the Island residents. It is recommended that workshops occur every second year. The workshops would double as a forum for residents to voice their concerns regarding water issues on their Island. The workshops have the potential to ultimately allow better management decisions and community plans prepared due to the two-way flow of information. A focal point for the workshops should be to educate the Island residents that there is a problem and that they must take ownership of the problem. If ownership is accepted then it may be possible to move away from the us versus them mentality which often exists between government agencies and local groups (Hoenig, 1993, p275). The population of the Pender Islands seem to be polarised in their views on water supply issues with almost as many claiming that water availability is not a problem as there are accepting that water supply is a key issue.

The population of the Islands increases drastically during the dry summer months creating a strain on the water supply. As such, attempts must be made to educate tourists as to the critical nature of water supply on the Islands. It is recommended that pamphlets outlining the water supply and waste disposal issues be made available at inns, lodges, bed & breakfasts, campgrounds and on the B.C.

Ferries to the Islands. The Islands Trust have prepared such a document but it does not have a wide distribution. In addition, prominent notices should be strategically located at all ferry terminals informing all passengers of water shortages, requesting cooperation of all residents and visitors, and outlining penalties for misuse of water resources.

Politicians can be a very difficult group to educate since they tend to react to the apparent crisis of the day. There is a need for political will from the onset of any water resources management plans in the Gulf Islands if the long term sustainability of the resource is to be achieved. This requires a pro-active approach which means identifying and addressing a problem before it becomes one which is the opposite of modern political approaches to problem solving. As Foster and Sewell (1983, p2) so rightly claim, the position of water resources on the issue-attention cycle will ultimately determine the political will to resolve any issues (Figure 52). To have groundwater issues maintain a high prominence, it is recommended that Island residents constantly maintain contact with their elected officials to keep the issue at the forefront of the political agenda. As noted in Island Tides (1994d), the Environment Minister stated that he would respond to public pressure for groundwater legislation.

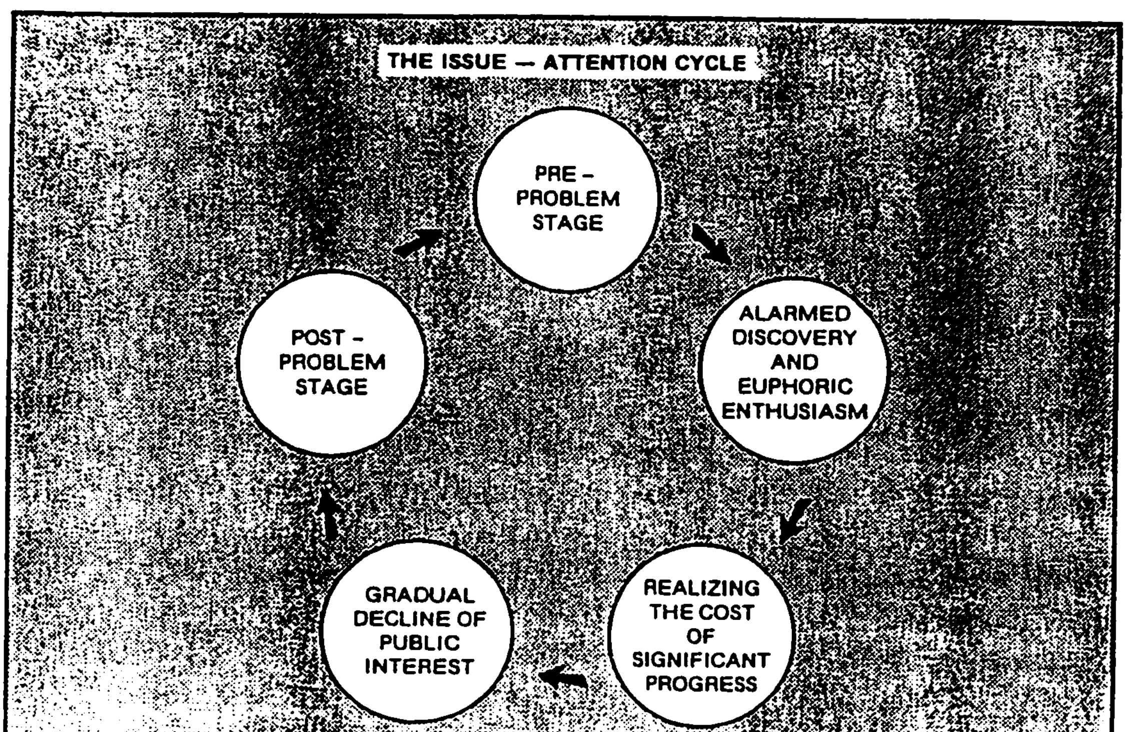


FIGURE 52: The Issue-Attention Cycle (after Foster and Sewell, 1983)

It is recommended that the local newspapers be encouraged to play a role in the education of Island residents. The Pender Islands have two newspapers which have done a credible job of presenting information regarding water resources issues impacting Island residents. The local newspapers have the potential to reach a wide range of Island residents and visitors. For example, Island Tides, with a circulation of 8,000, is distributed free of charge and available on B.C. Ferries providing ready access to information for tourists as well as local residents.

10.4.2 Research

To further enhance the learning process, it is recommended that Islands Trust and B.C. Environment develop close ties with post-secondary institutions. Students and instructors from these institutions may approach water issues from different perspectives enabling new directions to research and alternative strategies for water management. They also offer a reasonable cost labour pool for research activities.

One of the problems with utilising post-secondary institutions is the hefty price paid to cover administrative costs at the institution and the often slow response time. The establishment of a joint venture approach may enable government and post-secondary institutions to reduce the administrative expense and devote more energy and resources to completing research activities.

11.0 CONCLUSIONS

> " Development itself will only be achieved through the protection of the environment: without it, the fragility of environments, particularly in coastal basins, makes natural resources vulnerable; without it, landscapes and living conditions - the quality of life - the charm of the region - deteriorates to the cost of the populations and visitors alike. " (Kurtovich and Whyte, 1991, p115)

The groundwater management issues facing the Gulf Islands are not unique: rather they are common to many coastal environments. Scarce potable groundwater supplies will continue to provide a barrier to continued economic development and growth due to the physical limitations of island ecosystems (Miwa *et al.*, 1988, pxv).

The lack of a legal framework places British Columbia below many Third World nations in their ability to manage groundwater resources. A legal framework must be a cornerstone of any management plan.

In conjunction with a legal framework, it is imperative that Island residents accept ownership for the groundwater resources issues of their island ecosystem. With an appropriate database of scientific information (climate, geology, hydrogeology), and education, Island residents will be in a better position to make decisions which will impact the development of their island. Given the rate of population growth on the Pender Islands during the past 25 years, there is very little time to make the decisions which will maintain the quality of life now enjoyed by Island residents.

If the Island residents do not take a proactive approach to managing their groundwater resources, government will take control of the situation once groundwater supplies have been overdeveloped or contaminated (a reactive approach). Based on discussions with many Island residents, they are a very independent group who would no doubt prefer to manage their own destiny.

The success of any groundwater management program will require political will. Once again the Island residents will have to seize the day to ensure that the ground water issues maintain a high political profile. During the past year, the attempts by B.C. Environment Groundwater Division to prepare a legal framework for groundwater have been sidelined (Kohut, 1995, personal communication) and will likely only resurface if there is a demand for such legislation from concerned residents.

Along with political will, there is a need to simplify groundwater management for the Gulf Islands. There should be one government agency charged with the responsibility of overseeing the Gulf Islands. This agency must have the cooperation of other agencies to remove the stumbling block of a fragmented approach to management. The input of the Island residents would be crucial to the success of any management program.

The management requirements for groundwater resources on the Gulf Islands represents an almost circular argument which keeps returning to the needs stated above of a legal framework, education, political will, and a scientific database. Each of these needs is highly dependent on the others for the development of a successful groundwater management plan.

In the long term if no groundwater management plan is developed for the Gulf Islands, there is the likelihood that an island-wide water distribution and sewage systems will have to be developed at high cost. The water necessary to fill such a distribution system will probably have to come from either designated wells on the islands or off-island sources and transported via pipeline, tankers, or trucks to the island.

It cannot be overemphasized that the decisions regarding groundwater issues made within the next few years will impact not only the present residents of the Gulf Islands but also future generations of islanders as well. As Hare (1985, p4) states:

> " the problems are soluble if good water science is combined with sound political understanding. "

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13.0 PERSONAL COMMUNICATIONS

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APPENDIX A

Guidelines for Canadian Drinking Water Quality

Fifth Edition

Prepared by the
Federal-Provincial Subcommittee on Drinking Water
of the
Federal-Provincial Advisory Committee on Environmental
and Occupational Health

Published by authority of
the Minister of National Health and Welfare
1993

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Recommandations pour la qualité de l'eau potable au Canada, cinquième édition
1993

derivation of the guidelines, as well as the supporting documentation for each parameter, are published separately by the Department of National Health and Welfare.

Guidelines for some of the parameters included herein are more restrictive than those in the previous edition. It is recognized that not all drinking water supplies will be able to meet these more restrictive guidelines immediately and that priority given to meeting these new limits may be based on factors such as cost and the degree to which the drinking water supply exceeds the guideline value. However, it is recommended that all public and private drinking water supplies aim to reduce concentrations of these substances to below the specified values as soon as practicable.

The guidelines defined herein should not be regarded as implying that the quality of the drinking water may be degraded to the specified levels. Indeed, a continuous effort should be made to ensure drinking water is of the highest possible quality.

2. Explanation of Terms

2.1 Maximum Acceptable Concentration (MAC)

Maximum acceptable concentrations have been established for certain substances that are known or suspected to cause adverse effects on health. Each maximum acceptable concentration has been derived to safeguard health assuming lifelong consumption of drinking water containing the substance at that concentration. The use of drinking water for all usual domestic purposes, including personal hygiene, has been considered in the derivation of the guidelines wherever possible. However, water of higher quality may be required for some special purposes, including renal dialysis.

Drinking water that continually contains a substance at a level greater than its maximum acceptable concentration will contribute significantly to consumers' exposure to the substance and may, in some instances, induce deleterious effects on health. However, short-term excursions above the maximum acceptable concentration do not necessarily mean that the water constitutes an undue risk to health. The amount by which, and the period for which, the maximum acceptable concentration can be exceeded without posing a health risk must be assessed by taking into account the toxicity of the substance involved. When the maximum acceptable concentration for a substance is exceeded, however, the minimum action required is immediate resampling. If the maximum acceptable concentration continues to be exceeded, the local authority responsible for drinking water supplies should be consulted concerning appropriate corrective action.

2.2 Interim Maximum Acceptable Concentration (IMAC)

For those substances for which there are insufficient toxicological data to derive a maximum acceptable concentration with reasonable certainty, interim values have been recommended, taking into account the available health-related data, but employing a larger safety factor to compensate for the additional uncertainties involved. Interim maximum acceptable concentrations were also established for those substances for which estimated lifetime risks of cancer associated with the guideline (the lowest concentration in drinking water that is practicably achievable using available analytical or treatment methods) are greater than those deemed to be essentially negligible. Because of their nature, interim maximum acceptable concentrations will be reviewed periodically as new toxicological data and new methods of quantitation and treatment become available.

2.3 Aesthetic Objective (AO)

Aesthetic objectives apply to certain substances or characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good quality water. For certain parameters, both aesthetic objectives and health-related guidelines (i.e., maximum acceptable concentrations) have been derived. Where only aesthetic objectives are specified, these values are below those considered to constitute a health hazard. However, if a concentration in drinking water is well above an aesthetic objective, there is a possibility of a health hazard.

3. Microbiological Characteristics

3.1 Coliform, Coliform Background and Heterotrophic Plate Counts

All drinking water supplies should be analyzed routinely for coliform bacteria and the general bacterial population. This general population can be estimated from either background colony counts on total coliform membrane filters or heterotrophic plate counts (HPC), as outlined in *Standard Methods for the Examination of Water and Wastewater.* Excessive concentrations of the general bacterial population can hinder the recovery of coliforms and thereby prevent the detection of a potential threat to public health.

The maximum acceptable concentration for total coliforms in drinking water is zero organisms detectable per 100 mL. Because coliforms are not uniformly distributed in water and are subject to considerable variation in enumeration, drinking water that fulfils the following conditions is considered to be in compliance with the total coliform maximum acceptable concentration:

1. No sample should contain more than 10 total coliform organisms per 100 mL, none of which should be fecal coliforms;
2. No consecutive sample from the same site should show the presence of total coliform organisms; and
3 For community drinking water supplies:
   a) not more than one sample from a set of samples taken from the community on a given day should show the presence of coliform organisms; and
   b) not more than 10% of the samples based on a minimum of 10 samples should show the presence of coliform organisms.

If any of the above criteria are exceeded, corrective action should be taken immediately, in consultation with the local authority responsible for drinking water supplies. The most common immediate actions include resampling, increasing disinfectant dosage, flushing water mains, using an alternative source of water and advising consumers to boil their drinking water.

If up to 10 total coliform organisms per 100 mL are detected from a single sample, or if the sample contains either more than 500 HPC colonies per millilitre or more than 200 background colonies on a total coliform membrane filter (i.e., overgrowth), the water should be resampled. If the presence of coliforms is reconfirmed (see 2, above), the cause should be determined and corrective action taken as appropriate. If there is a recurrence of unacceptable background or heterotrophic plate counts, the system should be inspected to determine the cause. If remedial action is deemed necessary, special sampling should continue until consecutive samples comply with the guidelines.

3.2 Viruses and Protozoa

Guidelines for viruses and protozoa are not proposed at this time. It is desirable, however, that no viruses or protozoa (e.g., *Giardia*) be detected. A water treatment system that provides effective filtration and disinfection and maintains an adequate disinfectant residual should produce water of an acceptable quality in this regard.

3.3 Sampling

The frequency of sampling depends upon the quality of the source water, the number of water sources, the past frequency of unsatisfactory samples, the adequacy of treatment and capacity of the treatment plant, the size and complexity of the distribution system, the practice of disinfection, and the size of the population served. The following is offered as a guide:

Population Served	Minimum No. of Samples per Month
up to 5 000	4
5 000 to 90 000	1 per 1 000 of population
more than 90 000	90 + (1 per 10 000 population)

3.4 Disinfection

Disinfection is the one step in water treatment specifically designed to destroy pathogenic organisms and thereby prevent waterborne diseases, which are the most common health risk associated with drinking water. Alone, disinfection is not always sufficient to produce a supply of adequately treated water. Other treatments may be necessary, depending upon the water source, to ensure the effectiveness of the disinfection process and to satisfy other criteria for good quality drinking water. The disinfecting agents commonly used in water treatment today include chlorine and its compounds.

3.5 Turbidity

An average maximum acceptable concentration for turbidity (i.e., 95% of the time) is 1 nephelometric turbidity unit (NTU) for water entering a distribution system. A maximum of 5 NTU may be permitted if it can be demonstrated that disinfection is not compromised by the use of this less stringent value. An aesthetic objective of 5 NTU has been set for the point of consumption.

The presence of turbidity can significantly affect both the microbiological quality of the drinking water and the ability to detect bacteria, viruses and protozoa. Waterborne bacteria, viruses and protozoa can be embedded in, or adhered to, particles in the raw water, or they can become trapped within floc formed during water treatment. Thus, turbid finished water can contain undesirable microorganisms that may not be detectable or that may be grossly underestimated by current detection methods.

More important, however, is the capacity of turbidity-causing material to interfere with the disinfection process. Depending upon the composition of this material, interference with disinfection can range from negligible to severe. It must also be noted that any sudden increase in the turbidity of the finished water indicates deteriorating quality of the raw water or loss of control in the water treatment processes.

4. Chemical and Physical Parameters

4.1 New, Revised and Reaffirmed Guidelines

New, revised and reaffirmed guidelines for chemical and physical parameters are presented in Table 1 as "proposed guidelines." If, after one year from date of publication of this edition, no evidence is presented proving the unsuitability of the proposed values, they will be adopted as guidelines.

Table 1
Proposed Guidelines for Chemical and Physical Parameters

Parameter	Proposed Guideline (mg/L)	Previous Guideline (mg/L)
arsenic	IMAC 0.025	MAC 0.05
barium	MAC 1.0	IMAC 1.0
boron	IMAC 5.0	MAC 5.0
copper	AO ≤ 1.0	AO ≤ 1.0
dichlorophenoxyacetic acid, 2,4- (2,4-D)	IMAC 0.1	MAC 0.1
dinoseb	MAC 0.01	None
nitrilotriacetic acid (NTA)	MAC 0.4	MAC 0.05

4.2 Summary of Guidelines

Guidelines for all chemical and physical parameters, including all new, revised and reaffirmed guidelines, are listed in Table 2.

Table 2
Summary of Guidelines for Chemical and Physical Parameters

Parameter	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
aldicarb	0.009		
aldrin + dieldrin	0.0007		
arsenic		0.025	
atrazine		0.06	
azinphos-methyl	0.02		
barium	1.0		
bendiocarb	0.04		
benzene	0.005		
benzo(a)pyrene	0.00001		
boron		5.0	
bromoxynil		0.005	
cadmium	0.005		
carbaryl	0.09		
carbofuran	0.09		
carbon tetrachloride	0.005		
chlordane	0.007		
chloride			≤250
chlorpyrifos	0.09		
chromium	0.05		
colour			≤15 TCU [1]
copper [2]			≤1.0
cyanazine		0.01	
cyanide	0.2		

Parameter	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
diazinon	0.02		
dicamba	0.12		
dichlorobenzene, 1,2- [3]	0.2		≤0.003
dichlorobenzene, 1,4- [3]	0.005		≤0.001
dichlorodiphenyltrichloroethane (DDT) + metabolites	0.03		
dichloroethane, 1,2-		0.005	
dichloromethane	0.05		
dichlorophenol, 2,4-	0.9		≤0.0003
dichlorophenoxyacetic acid, 2,4- (2,4-D)		0.1	
diclofop-methyl	0.009		
dimethoate		0.02	
dinoseb	0.01		
diquat	0.07		
diuron	0.15		
ethylbenzene			≤0.0024
fluoride [4]	1.5		
glyphosate		0.28	
heptachlor + heptachlor epoxide	0.003		
iron			≤0.3
lead [2,5]	0.01		
lindane	0.004		
malathion	0.19		
manganese			≤0.05
mercury	0.001		
methoxychlor	0.9		
metolachlor		0.05	

Parameter	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
metribuzin	0.08		
monochlorobenzene	0.08		≤0.03
nitrate [6]	45.0		
nitrilotriacetic acid (NTA)	0.4		
odour			Inoffensive
paraquat		0.01	
parathion	0.05		
pentachlorophenol	0.06		≤0.03
pH			6.5–8.5 [7]
phorate		0.002	
picloram		0.19	
selenium	0.01		
simazine		0.01	
sodium [8]			≤200
sulphate [9]			≤500
sulphide (as H_2S)			≤0.05
taste			Inoffensive
temephos		0.28	
temperature			≤15°C
terbufos		0.001	
tetrachlorophenol, 2,3,4,6-	0.1		≤0.001
toluene			≤0.024
total dissolved solids			≤500
triallate	0.23		
trichloroethylene	0.05		
trichlorophenol, 2,4,6-	0.005		≤0.002
trichlorophenoxyacetic acid, 2,4,5- (2,4,5-T)	0.28		≤0.02

Parameter	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
trifluralin		0.045	
trihalomethanes	0.35		
turbidity [10]	1 NTU [10]		≤5 NTU [2,10]
uranium	0.1		
xylenes (total)			≤0.3
zinc [2]			≤5.0

Notes:

1. TCU = true colour unit.
2. At the point of consumption.
3. In cases where total dichlorobenzenes are measured and concentrations exceed the most stringent value (0.005 mg/L), the concentrations of the individual isomers should be established.
4. It is recommended. however, that the concentration of fluoride be adjusted to 1.0 mg/L, which is the optimum level for the control of dental caries. Where the annual mean daily maximum temperature is less than 10°C, a concentration of 1.2 mg/L should be maintained.
5. Because lead is a component of many plumbing systems, first-drawn water may contain higher concentrations of lead than are found in running water after flushing. Faucets should therefore be thoroughly flushed before water is taken for consumption or analysis.
6. Equivalent to 10.0 mg/L nitrate as nitrogen. Where nitrate and nitrite are determined separately, levels of nitrite should not exceed 3.2 mg/L.
7. No units.
8. It is recommended that sodium be included in routine monitoring programs, as levels may be of interest to authorities who wish to prescribe sodium-restricted diets for their patients.
9. There may be a laxative effect in some individuals when sulphate levels exceed 500 mg/L.
10. See section 3.5; NTU = nephelometric turbidity unit.

4.3 Parameters without Guidelines

Since 1978, some chemical and physical parameters have been identified as not requiring a numerical guideline. Table 3 lists these parameters. The reasons for parameters having no numerical guideline include the following:

- currently available data indicate no health risk or aesthetic problem (e.g., calcium);
- data indicate the compound, which may be harmful, is not registered for use in Canada (e.g., 2,4,5-TP) or is not likely to occur in drinking water at levels that present a health risk (e.g., silver); or
- the parameter is composed of several compounds for which individual guidelines may be required (e.g., pesticides [total]).

Table 3
Parameters without Guidelines

Parameter	Parameter
ammonia	phenols
asbestos	phthalic acid esters (PAE)
calcium	polycyclic aromatic hydrocarbons (PAH) [2]
endrin	resin acids
gasoline	silver
hardness [1]	tannin
lignin	total organic carbon
magnesium	toxaphene
methyl-parathion	trichlorophenoxypropionic acid, 2,4,5- (2,4,5-TP)
mirex	
pesticides (total)	

Notes:

1. Public acceptance of hardness varies considerably. Generally, hardness levels between 80 and 100 mg/L (as $CaCO_3$) are considered acceptable; levels greater than 200 mg/L are considered poor but can be tolerated; those in excess of 500 mg/L are normally considered unacceptable. Where water is softened by sodium ion exchange, it is recommended that a separate, unsoftened supply be retained for culinary and drinking purposes.
2. Other than benzo(a)pyrene.

APPENDIX B

PENDER ISLANDS GROUNDWATER QUESTIONNAIRE

There is probably no issue of greater concern to residents of this community than that of water. There is ample evidence of shortage, especially after dry summer months, as well as concern about taste and quality, and residents have expressed doubt about how they might obtain adequate supplies of good drinking water in years to come.

By taking a few minutes to complete this form you will be helping yourselves and your community. Data sources will be confidential. Results will be summarised and made available to your local community planning processes and to the Water Management Division of the Ministry of Environment.

Leave the space blank if you don't know the answer. Fill out an additional form(s) if you have more than one source of supply. Your trustees will supply you with extra copies required.

1. Name (optional) ________________________________

2. Address or Area ________________________________

3. Legal description of property (from tax assessment notice).

   Lot __________ Plan __________ Section __________

4. Is property occupied: Full time ______________ Part time ______________

5. Do you carry on any type of home occupation?

   ____ Yes ____ No Details ________________________________

6. What is your source of water?

   Surface well ____________ Depth ______________

   Rate of flow (if known) g.p.m. ______________ Winter g.p.m. ____________ Summer

   Drilled well ______________ Depth ______________

   Rate of flow (if known) g.p.m. ______________ Winter g.p.m. ____________ Summer

   Cistern rain water ________________________________

   Community supply ________________________________

   Other________________________________

7. Do you drink this water? ___ Yes ___ No

8. How many in your household? ________________________________

9. Do you share a source of water? ___ Yes ___ No

10. If Yes, with how many households? ________________________________

11. How do you rate your supply (quantity)? ___ Good ___ Fair ___ Poor

12. Check (✓) if your water supply is:

   ___ Brackish
   ___ Discolored
   ___ Hard
   ___ Soft
   ___ Sulphurous
   ___ Salty
   ___ Visibly contaminated
   ___ Other ______________________

13. Do you ever have to leave your property to get water? ____ Yes ____ No

14. Have you ever had to purchase water? ____ Yes ____ No

15. Has your supply ever failed? ____ Yes ____ No

16. Over the past few years has your supply:

____ Increased ____ Decreased ____ Remained Constant

17. Have you ever had your well water tested? ________________________________

18. Are there any suspected or potential contaminants near your well? If so, describe.

____

19. What other purposes do you use water for apart from drinking and domestic use?
eg. ____ Garden ____ Irrigation ____ Swimming Pool Other ____________

20. How much water do you think you use each day? ____________________________

21. Are you satisfied with your present supply? ____ Yes ____ No

22. Are you worried about your future supply? ____ Yes ____ No

If Yes, what is your principal concern and do you have any suggestions.

____

23. Are you aware of any unused or abandoned wells on your property or elsewhere?

____

If so are they capped or sealed? ______________________________________

24. Do you have any other comments or information to offer about water supply?

____

____

____

____

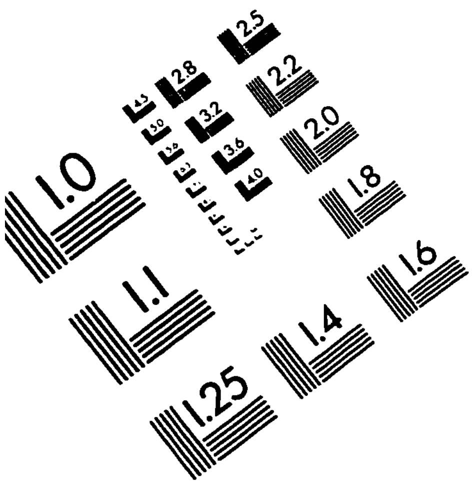
The Ministry of Environment estimates that each person uses about 80 gallons of water each day on average. Of that, about 30 gallons is flushed down the toilet, the rest goes for showers, laundry, dish-washing, cooking, drinking and sheer waste, eg. leaving the tap flowing while shaving or brushing your teeth.

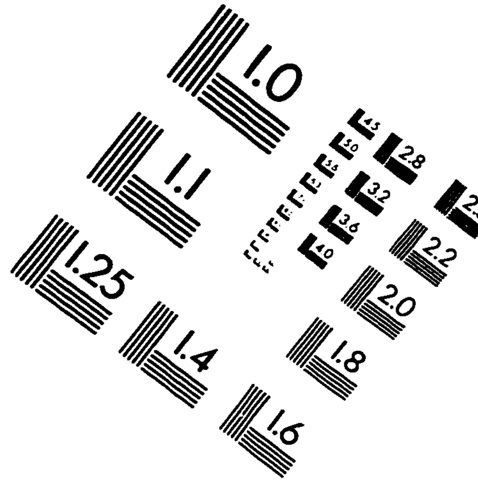
Please take the time to complete this form and return it by February 23, 1994 to your trustees by leaving it in the NRS community box at the Driftwood Centre, or at locations advertised, by mail or by delivering it personally. Thank you for your participation.

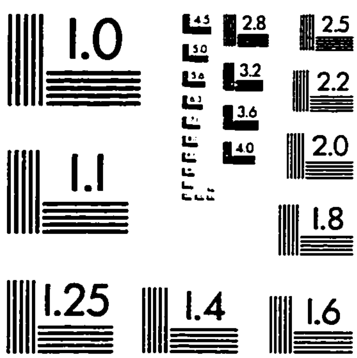
Bob Allison, North Pender Trustee
Joy Ridley, North Pender Trustee

Elaine Jacobson, South Pender Trustee
Catherine Milsum, South Pender Trustee

IMAGE EVALUATION TEST TARGET (QA-3)







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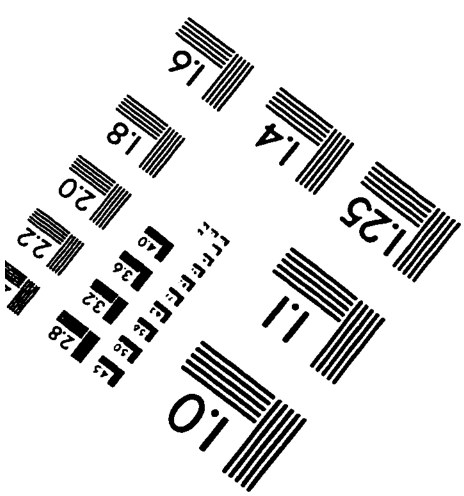

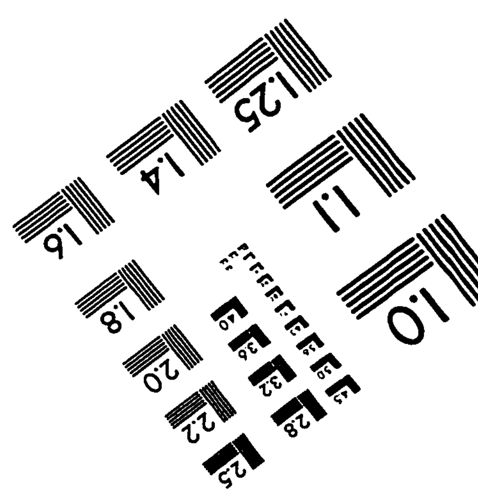

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