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GROUNDWATER SECTION

BC Environment

ASSESSMENT OF GROUNDWATER AVAILABILITY AND QUALITY

GALIANO ISLAND, BRITISH COLUMBIA

by

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Groundwater Section
Water Management Branch
Environment and Resource Management Department
Ministry of Environment, Lands and Parks
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ASSESSMENT OF GROUNDWATER AVAILABILITY AND QUALITY
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A.P. Kohut, P. Eng. and by D.A. Johanson , P. Geo.

Executive Summary

Groundwater is found primarily in open fractures in the Cretaceous bedrock formations of Galiano Island where it is a critical resource for meeting domestic water supply requirements. The entire island can be considered part of a fractured and interconnected bedrock aquifer system in which variations in productivity and water quality occur spatially within the groundwater system. The bedrock aquifer system on Galiano has been classified as a moderately developed and moderately vulnerable II B aquifer, with a ranking value of 14.

Twenty one groundwater regions have been defined on Galiano Island for describing and comparing groundwater conditions in various parts of the island. Areas of regional groundwater recharge and discharge have been delineated at a 1 : 12,000 map scale in each of the regions.

Well densities are highest in the Cain Peninsula, South Galiano, Georgeson Bay and North Galiano-Spanish Hills regions. These same areas are subject to localized problems of well interference, extraction exceeding availability during periods of high demand, deterioration in water quality and risks to contamination from surface sources of pollution. In a number of instances groundwater water quality has been impacted by salt water intrusion. Other water quality problems observed locally include elevated levels of: iron, manganese, fluoride, hydrogen sulphide and coliform bacteria.

Total estimated fresh groundwater reserves on the island, replenishable on an annual basis, range from 78 to 780 million Igals (0.35 to 3.5 million m^3). Full utilization of the estimated groundwater reserves in any one region is unlikely to be feasible without problems occurring. Current groundwater demand on the island based on 1991 population figures, including visitors, is estimated at 40 million Igals (0.18 million m^3) per year. Demand could approach 90 million Igals (0.41 million m^3) by the year 2040. While overall groundwater reserves exceed current demand, the demand is not uniform and is concentrated in the more densely populated areas of the island. In some groundwater regions, estimated available supply does not meet the estimated demand.

The judicious management of groundwater recharge areas will be critical to sustaining groundwater availability and quality in all of the groundwater regions of Galiano Island. Application of appropriate groundwater management measures within those areas currently experiencing quantity

and quality problems will be equally as important. Regions where the adoption of groundwater management measures is critically needed are: Cain Peninsula, Gossip Island, Wise Island, and parts of the North Galiano-Spanish Hills, Finlay Lake, South Galiano and Georgeson Bay regions. Groundwater discharge areas (wetlands), at intermediate elevations on the island may also act in part as recharge areas for regions downslope and warrant special management consideration. Given the high costs involved in acquiring definitive groundwater information and the scientific uncertainty in predicting groundwater availability in bedrock terrains, the precautionary principle should be adopted in selecting appropriate groundwater management measures for the Island. Based on the results of this study and groundwater studies elsewhere in the Gulf Islands, a number of recommendations are made to assist in achieving a sustained and healthy groundwater resource for island residents. Recommendations include:

- developing an on-going program for public education, awareness and conservation of groundwater for Galiano Island residents and visitors;
- examining available regulatory and non-regulatory options for groundwater management and protection;
- developing a preliminary groundwater management plan for Galiano Island based on the "precautionary principle" and linked to the Official Community Plan;
- developing individual protection plans for community well and spring sources;
- undertaking feasibility studies of alternate sources of water supply such as community wells and surface water storage reservoirs for high population density areas;
- examining existing groundwater information in more detail and conducting further field surveys in critical areas;
- undertaking research on effects of land use activities such as logging and road building on groundwater supplies and quality in bedrock terrains;
- developing guidelines for land use activities in critical recharge and discharge areas;
- promoting existing guidelines for well construction, testing and abandonment and the submission of groundwater information for inclusion in the groundwater database;
- updating the groundwater database and information system on a regular basis;
- establishing and maintaining a regional network of observation wells in key areas.

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1. Introduction

In 1994, the Minister of Environment, Lands and Parks authorized the Groundwater Section of the Hydrology Branch to undertake a groundwater assessment of Galiano Island to provide scientifically based information on groundwater resources to assist the Galiano Island Local Trust Committee in future land use planning initiatives and implementation of the Official Community Plan. The study was requested by the Islands Trust in reponse to the declining quality and quantity of groundwater on the Gulf Islands generally and on Galiano Island in particular, at a time when planning was underway for the future of 60 percent of the island's area, previously undeveloped land. As a first step, the Ministry supported an initial project undertaken by Don Harrison of Capilano College during the summer of 1994 to update the 1983 report prepared by Mordaunt and Hodge on the groundwater conditions of the island. Following this work, a Groundwater Study Advisory Committee was established including representatives from the community, the Groundwater Section, Galiano Island Local Trust Committee, Capital Regional District (Health Protection and Environment) and the Islands Trust. The Groundwater Study Advisory Committee provided advice to ministry staff and assisted in planning the specific scope, nature, deliverables and timing of the groundwater assessment. The committee met frequently during the course of the study, provided valuable input in setting study objectives, reviewed progress and contributed local knowledge to the project.

The prime objective of the study was to provide an up-to-date status report on the groundwater conditions of Galiano Island including information on known occurrence, availability, degree of water use, and water quality. This report augments Harrison's, 1994 report and provides additional information particularly on groundwater recharge-discharge relationships and groundwater quality. The report also provides recommendations for groundwater management and protection to assist in future land and water use planning.

This assessment has included a review and examination of all available water well records, water quality data, aerial photographs, previous hydrogeologic reports, soil and geology maps and observation well data. A limited number of field chemistry tests were conducted at selected well sites and water level readings were taken on a number of observation wells monitored during the course of the project. Much of the data obtained during this study was entered into a Geographical Information System (GIS) using ARC/INFO™ software and is available in electronic format.

2. Acknowledgments

The authors wish to acknowledge the valuable input and contributions made to the study by the members of the Groundwater Study Advisory Committee whose names are listed below.

Elisabeth Bosher, Galiano Island Trustee
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Debbie Holmes, Galiano Island Trustee
Kim Fowler, Islands Trust
Ming Yang, Capital Regional District, Health Protection and Environment
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Jack Ford
Kenneth Hardy
Frank Hillier
Rose Longini
Laurene Stefanyk
Gary Thomas

In addition, several staff members of the Ministry provided valuable technical assistance to the project including the following:

Fred Chwojka, Groundwater Section
Greg Blaney, Acting Head, G.I.S. Unit
Dennis Besler, G.I.S. Unit
Gary Lucas, G.I.S. Unit
John Revoy, Analyst, Data Systems
Bruce Mackenzie, G.I.S. Support, Systems Services Branch
Julia Roberts and Leah Bannister, Co-op Students
Bernard Schubert, Manager, Surveys Section
Gordie Roberts, Surveys Section
Mike Pronk, Surveys Section

Barbara Dashwood of the Islands Trust provided digital mapping information on lot boundaries and other features which were incorporated into the Geographic Information System. This assessment has benefited greatly from the considerable work that was carried out previously by members of the Galiano Conservancy Association in updating, verifying and summarizing available well record and water quality data for the island. The authors also appreciate the constructive comments and suggestions received on drafts of the report from the members of the Groundwater Study Advisory Committee, staff of the Groundwater Section and M. Holden, graduate student at Rutgers University.

3. Location, Topography and Drainage

Galiano Island, one of the southern Gulf Islands, is located in the Strait of Georgia between the mainland and Vancouver Island, in the southwest corner of British Columbia (Figure 1). The Island is approximately 5800 hectares (14,000 acres) in area and approximately 26.5 kilometres (16.5 miles) in length (Mordaunt and Hodge, 1983).

The topography of Galiano Island (Figure 2) is dominated by northwest-southeast trending elongate ridges and valleys which reflect the underlying bedrock structure and stratigraphy, and the activity of erosional agents (Carter, 1976). The highest points of land approximately 300 metres in height occur on Mount Galiano and Sutil Mountain at the southern end of Galiano Island. At over 240 metres, Bodega Ridge is the highest point of land in the northern portion of the island. North of Montague Harbour, a series of linear ridges with steep southwest facing cliffs form the back-bone of the island and the northeast facing slopes of these ridges are moderate to gentle (Harrison, 1994), reflecting the direction of dip of the underlying sedimentary bedrock.

The surface drainage is controlled by distinct ridges and valleys over most of the island. Harrison (1994) notes that linear depressions parallel to the geologic strike, or gullies at a high angle to the geologic strike are responsible for controlling the surface orientation of most streams. Often the depressions between ridges are infilled with organic debris, clays, and silts forming small wetlands, and bogs. Many of these valleys are poorly drained and locally swampy. Depending upon their relative elevation and surrounding land features these wetlands may be important as either zones of groundwater recharge, groundwater discharge or transitional discharge-recharge areas. These areas are discussed further in Section 10.

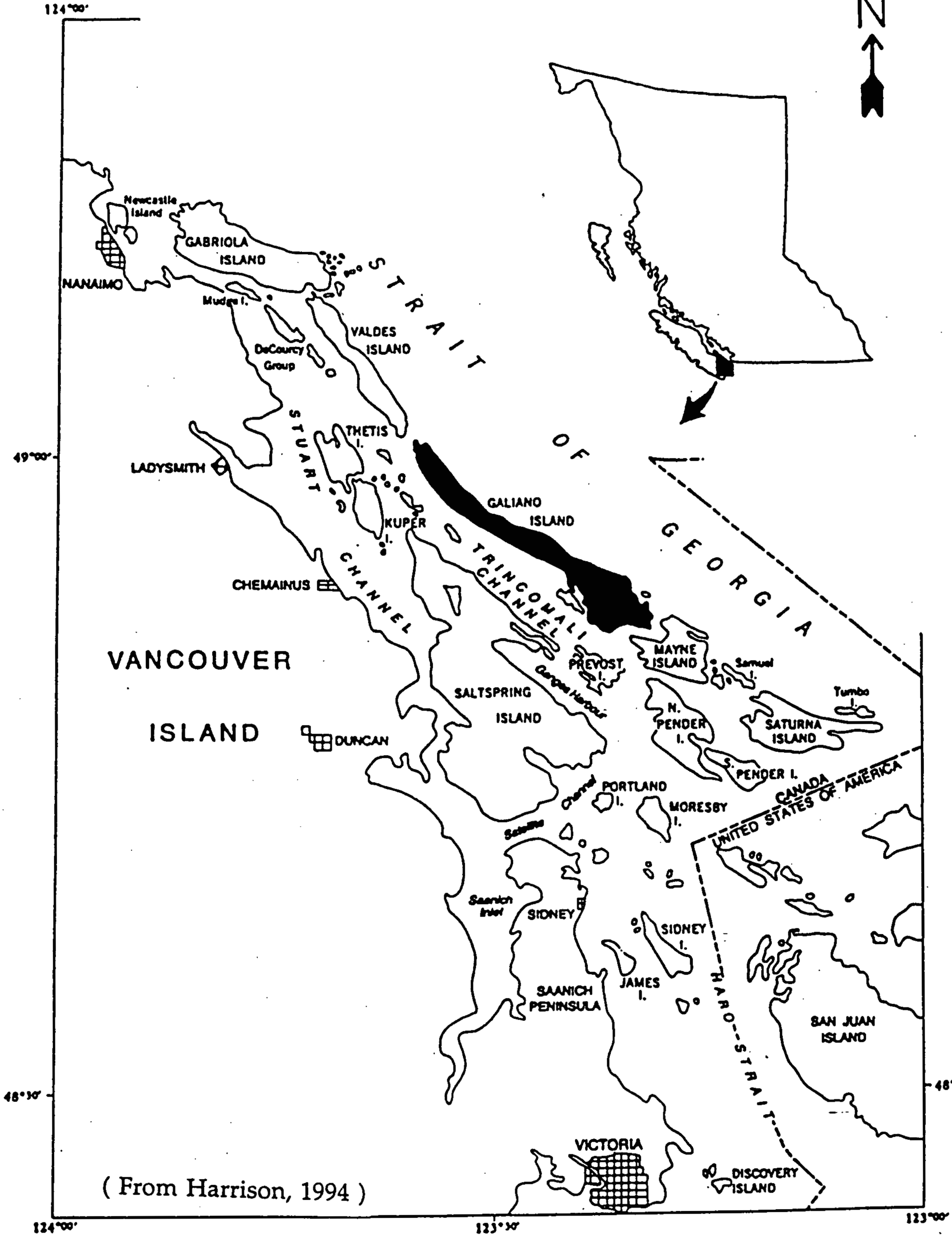
4. Climate

The climate of the Gulf Islands is somewhat unique for the southern portion of British Columbia. The area is located between two prominent mountain ranges (Vancouver Island Mountains and the Coast Range Mountains). The climate is partly continental intermontane and hence high temperature extremes with low precipitation may be expected (Dakin, 1975). The coastal waters tend to moderate the low winter temperatures and cool the summer highs.

The climate of Galiano Island is characterized by cool dry summers and humid mild winters. Based on records from 1951 to 1980, Environment Canada (198_), reports the average annual precipitation for a station on Galiano Island as 33.7 inches (856 mm). Over 90% of this total annual precipitation falls as rain with over 60% of the total falling during the period from November to February.

Location Map

Galiano Island, B.C.



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Ministry of Environment, Lands and Parks
Water Management Branch

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SCALE : AS SHOWN	DATE	PRODUCED BY:
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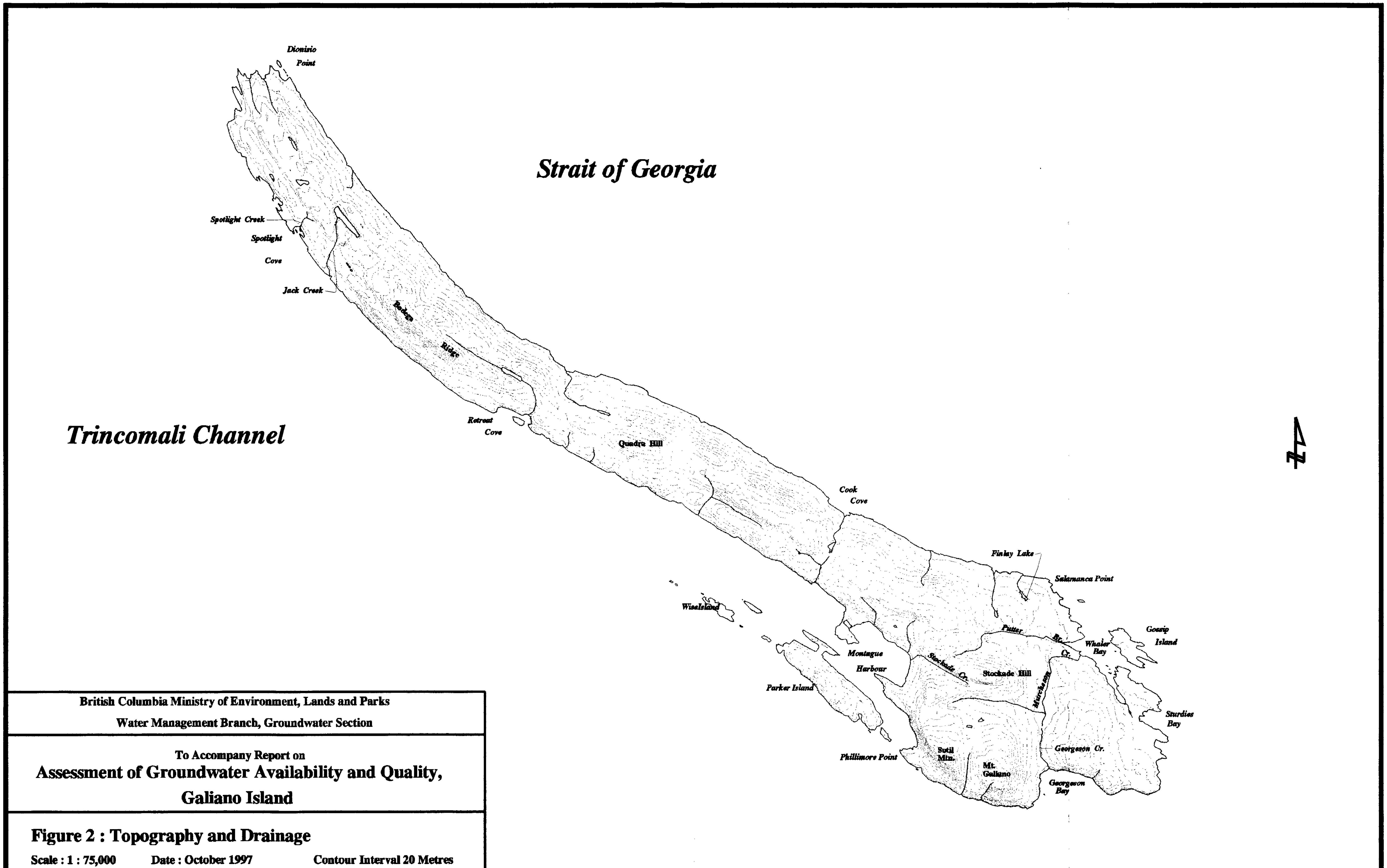

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Figure 2 : Topography and Drainage

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

On Galiano Island, the low annual precipitation together with a high number of sunshine hours are the principal meteorological influences causing annual extreme moisture deficits from May to early October. These drought effects are most extreme in wind swept areas, on sites with shallow soils, and on sunparched south, southeast and especially southwest facing slopes (Chilton, 1975).

5. Bedrock and Structural Geology

The bedrock deposits found on Galiano have been described and interpreted by several authors including: Henderson and Vigrass (1962), Halstead (1967), Muller and Jeletzky (1970), Carter (1976), and Mustard (1994). Mordaunt and Hodge (1983) and Harrison (1994) have described some of the findings of these authors and the major geologic characteristics of the island are summarized below.

Galiano Island is made up of sedimentary clastic rocks belonging to the Nanaimo Group of Late Cretaceous age (Muller and Jeletzky, 1970). Four geologic formations are recognized on Galiano Island, from oldest to youngest namely; the Northumberland Formation, the Geoffrey Formation, the Spray Formation and the Gabriola Formation. The distribution of these formations, their lithologies and structural features are shown in Figure 3. Halstead (1967) describes the sedimentary rocks of the Gulf Islands as follows: "The sandstones and conglomerates consist of angular to sub-angular fragments closely packed and well cemented with calcareous and ferruginous cements. The shales consist chiefly of dark grey, concentrically weathered carbonaceous, ferruginous and in places calcareous fine sandy shales with a great number of thin interbeds of brownish grey fine-grained sandstones."

The resistant sandstones and conglomerates of the Geoffrey Formation and Gabriola Formation form northwest-southeast trending ridges and cuestas whereas the less resistant mudstones of the Northumberland Formation, Spray Formation, and mudstone interbeds of the Gabriola Formation form longitudinal valleys and coastal lows (Carter, 1976). The Gabriola Formation is the most extensive geologic formation on Galiano Island, its principal lithology being sandstone. It underlies the southwest one-third and all of the north end of Galiano Island as a series of parallel northwest-trending ridges and valleys broken by northeast-trending faults and fracture systems (Carter, 1976). Erosion of the mudstone interbeds has produced pocket beaches along the northwest coast (Carter, 1976). In the south central part of the island, the Spray Formation underlies lowlands commonly poorly drained and swampy. The best exposures of the Spray Formation are at Sturdies Bay and Montague Harbour where erosion of the mudstone provides protected harbours (Carter, 1976). The Spray Formation forms a valley between these harbours.

Faulting believed to be related to late Cretaceous and Tertiary differential uplift of Vancouver Island and the simultaneous depression of the Georgia Basin has affected most of the rocks in the region (Muller and Jeletzky , 1970). Major longitudinal reverse faults trending parallel to the margins of the Georgia Basin and subsidiary reverse faults striking northeasterly have been mapped in the area. Carter (1976) summarized Galiano Island as structurally simple, consisting of strata that form a homocline dipping northeast. The fault system trends N. 20° East and consists of steeply dipping normal faults. He noted the fracture system consists of a set trending N. 24° East with dips near vertical and a set trending N. 45° West dipping 80° southwest which is ubiquitous but has little topographic expression. Mustard (1994) reports that the major northwest-trending faults are northeast dipping, thrust faults. Other numerous and widely distributed structural lineaments probably reflecting bedding planes and joint systems are readily observed on air photographs of the island. Outcrops of sandstone units often exhibit closely-spaced joints normal to bedding planes. It is most likely that the joint systems owe their origin to the post-Tertiary faulting, tilting and uplift that has affected the region. Isostatic rebound following glacial unloading and stress relief may have resulted in further development of bedrock fractures. Open fractures in the bedrock are important as they constitute the major zones for groundwater storage and movement.

6. Surficial Geology

With the melting of the ice during the last glaciation, various unconsolidated materials including a compact till were deposited. A thin cover of glacial till is found over most of the interior areas and glacial striations at Gray Peninsula attest to part of the topographic configuration of the island being modified by glacial erosion (Carter, 1976). Terrain mapping of the island at 1:20,000 scale has been completed by Pattison (1979). Fluvial materials were deposited or transported by meltwater to either low areas in a marine environment or to regions above marine influence (Mordaunt and Hodge, 1983). The unconsolidated deposits are generally thin, and therefore have limited groundwater potential. The thicker sections are found in topographic troughs.

Colluvial deposits are generally found on the backslope or gentle sloping side of bedrock cuesta. Most of the valley areas are characterized by either coarse colluvial material originating and transported from nearby rocky uplands or fine textured sediments deposited under former marine conditions. Marine deposits are found as high as 80 metres above sea level (Mordaunt and Hodge, 1983).

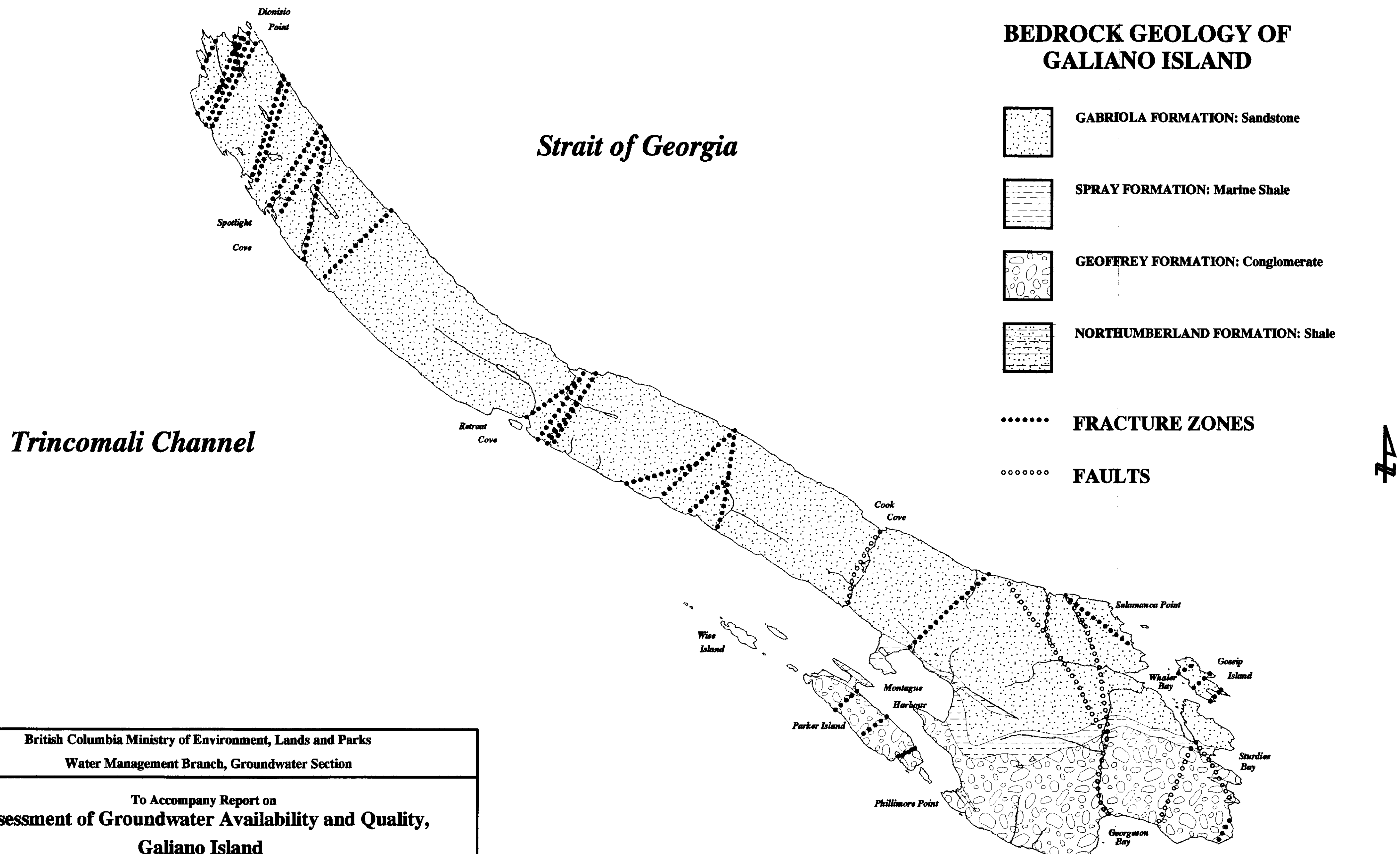

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Figure 3 : Geology

Scale : 1 : 75,000 Date : October 1997

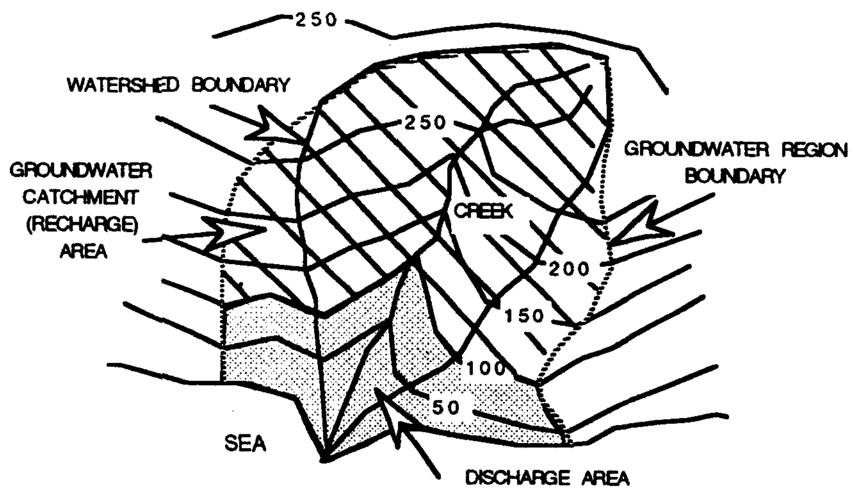
Bedrock Lithology and Structure after :
Foweraker (1973), Carter (1976) and Muller (1980).

7. Groundwater Regions

In 1983, Mordaunt and Hodge outlined 23 groundwater regions on Galiano Island based primarily on drainage, topographic features and degree of groundwater development. At the time, a distinction was made between the more heavily developed areas of the southeastern extension of the island where 14 regions were outlined and the lesser developed regions of the northwestern extension of the island where only 9 regions were outlined. In 1994, Harrison maintained the same names and configurations of the regions outlined by Mordaunt and Hodge (1983) to provide an effective comparison of the regions during the intervening 11 year period. In recent years, as groundwater development has been accelerated along the east coast of the northwestern extension of the island, consideration needed to be given to dividing some of the larger groundwater regions into smaller areas for examination. While the term groundwater region has been used synonymously with the term watershed in previous reports, further clarification on the definition and significance of a groundwater region is warranted.

For purposes of this report, the concept of a groundwater region has been further defined and the groundwater regions for the island have been re-examined and revised where appropriate. A *groundwater region* in this report is defined as a physiographic, water catchment area for groundwater encompassing all or a portion of one or more drainage basins, wherein the groundwater regime is described. While defining groundwater regions on the island provides an effective means for describing and comparing groundwater conditions in various parts of the island, it should be recognized that these regions are not entirely hydrologically isolated units. Extensive groundwater extraction in one groundwater region for example could ultimately affect groundwater in an adjacent region.

The boundaries of a groundwater region are determined in part by topographic (height of land) features, surface drainage characteristics and known geological conditions. Subsurface inter-connectivity of groundwater regimes between regions may exist in some instances. A groundwater region may include one or more *aquifers*, (water-bearing formations), watersheds or portions of an aquifer or watershed. An *aquifer* may be further defined as a subsurface layer or zone of permeable rock or soil that permits the passage of water. A *watershed* for a surface water feature is defined as the catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water. A watershed can be wholly contained within another watershed. The relationship between a groundwater region and a watershed is shown diagrammatically in Figure 4.



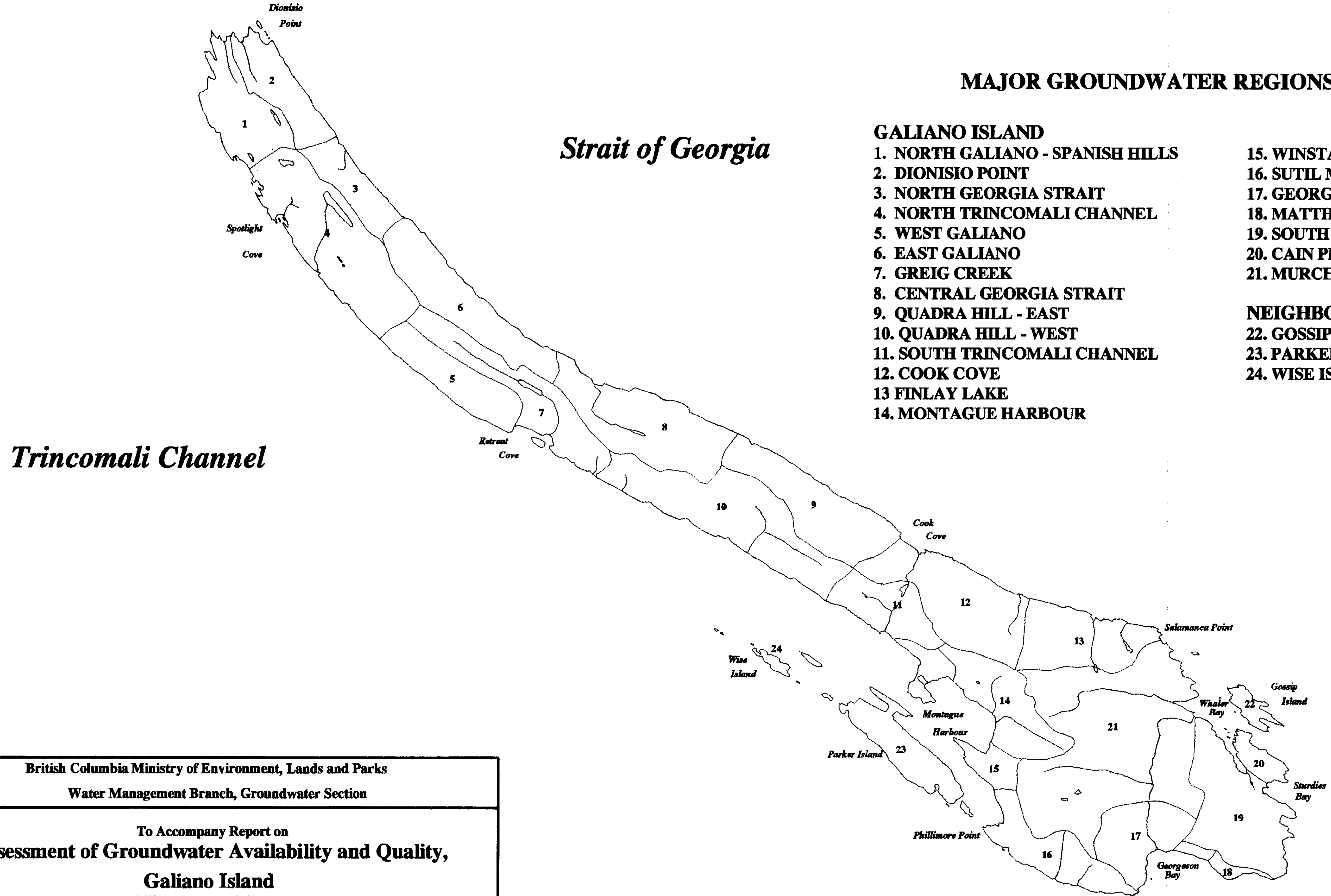
(PLAN VIEW)

Figure 4. Relationship between groundwater region and watershed, showing groundwater recharge and discharge areas (plan).

In outlining the revised groundwater regions on Galiano Island, the following information was utilized in interpreting and setting the boundaries of the groundwater regions:

- topographic features (ground elevation and slope) and surface drainage features observed on 1: 12,000 scale mapping (25 foot (7.6m) contour interval) and 1: 12,000 scale air photographs;
- known geologic conditions including structural features;
- the relative size of the land areas under consideration;
- the degree of uniformity within an area (e.g. topographic slope, geology);
- available groundwater level information from wells and springs, inferred hydraulic gradients and probable directions of groundwater flow.

In this report, the degree of groundwater development was not used as a prime criterion to define a groundwater region. The revised major groundwater regions for Galiano Island are shown in Figure 5. Additional groundwater regions were established along the northeast coast of the island and some previously defined smaller regions surrounding Sturdies Bay and Montague Harbour were combined resulting in a total of 21 major groundwater regions. A major revision was made to the Georgeson Bay Region which was reduced in size since much of the surface drainage from Murcheson Creek flows northerly and not towards Georgeson Bay. Groundwater regions were also outlined for Gossip, Parker and Wise Islands. A comparison between the regions outlined in this report and those outlined by Mordaunt and Hodge (1983) and Harrison (1994) is provided in Table 1.



MAJOR GROUNDWATER REGIONS

GALIANO ISLAND

1. NORTH GALIANO - SPANISH HILLS
2. DIONISIO POINT
3. NORTH GEORGIA STRAIT
4. NORTH TRINCOMALI CHANNEL
5. WEST GALIANO
6. EAST GALIANO
7. GREIG CREEK
8. CENTRAL GEORGIA STRAIT
9. QUADRA HILL - EAST
10. QUADRA HILL - WEST
11. SOUTH TRINCOMALI CHANNEL
12. COOK COVE
13 FINLAY LAKE
14. MONTAGUE HARBOUR
15. WINSTANLEY POINT
16. SUTIL MOUNTAIN
17. GEORGESON BAY
18. MATTHEWS POINT
19. SOUTH GALIANO
20. CAIN PENINSULA
21. MURCHISON - WHALER BAY

NEIGHBOURING ISLANDS

22. GOSSIP ISLAND
23. PARKER ISLAND
24. WISE ISLAND

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Figure 5 : Groundwater Regions

Scale : 1 : 75,000 Date : October 1997

TABLE 1. Groundwater Regions for Galiano Island and Neighbouring Islands.

MAJOR GROUNDWATER REGIONS (Johanson and Kohut, 1996)	AREA of REGION (hectares)	(acres)	MAJOR GROUNDWATER REGIONS Mordaunt and Hodge (1983), Harrison (1994)	AREA of REGION (hectares)	(acres)
GALIANO ISLAND					
1. NORTH GALIANO-SPANISH HILLS	224	552	1. NORTH GALIANO	229	566
2. DIONISIO POINT	178	440	2. SPANISH HILLS	181	446
3. NORTH GEORGIA STRAIT	136	337	3. GEORGIA STRAIT	1307	3229
4. NORTH TRINCOMALI CHANNEL	473	1170	4. TRINCOMALI CHANNEL	338	834
5. WEST GALIANO	200	493	5. RETREAT COVE	189	468
6. EAST GALIANO	303	748	6. GREIG CREEK	238	589
7. GREIG CREEK	282	698	7. QUADRA HILL	381	941
8. CENTRAL GEORGIA STRAIT	371	918	8. SOUTH TRINCOMALI CHANNEL	262	646
9. QUADRA HILL-EAST	308	762	9. MONTAGUE HARBOUR	190	202
10. QUADRA HILL-WEST	454	1122	10. MONTAGUE HARBOUR PARK	82	838
11. SOUTH TRINCOMALI CHANNEL	169	417	11. COOK COVE	339	666
12. COOK COVE	366	905	12. FINLAY LAKE	270	469
13. FINLAY LAKE	253	625	13. TWISS POINT	497	1228
14. MONTAGUE HARBOUR	291	720	14. SOUTHWIND DRIVE	67	166
15. WINSTANLEY POINT	64	158	15. PAYNE BAY	68	168
16. SUTIL MOUNTAIN	203	500	16. GEORGESON BAY	634	1565
17. GEORGESON BAY	194	480	17. SUTIL MOUNTAIN	153	377
18. MATTHEWS POINT	36	90	18. CAIN PENINSULA	10	24
19. SOUTH GALIANO	340	841	19. GULF ROAD (DRIVE)	35	87
20. CAIN PENINSULA	52	128	20. WHALER BAY	79	196
21. MURCHISON-WHALER BAY	916	2264	21. STURDIES POINT	74	182
			22. SCOONES POINT	213	526
			23. MATTHEWS POINT	40	99
Total Area Determined: (by ARC/INFO™ calculation)	5815	14369	Total Area Determined: (by planimeter)	5876	14512
NEIGHBOURING ISLANDS					
22. GOSSIP ISLAND	35	87			
23. PARKER ISLAND	165	409			
24. WISE ISLAND	13	32			
Total Area Determined:	214	529			

8. Water Well Record Information

Information contained in water well records is perhaps the most important source of available data on the groundwater conditions on the island. The total number of wells and spring sources in existence on Galiano and its neighbouring islands is, however, not known precisely. Submission of well records is not mandatory in British Columbia and available records are generally submitted voluntarily by well drilling contractors or obtained through well surveys of local residents. In recent years, members of the Galiano Conservancy Association have undertaken considerable work in collecting and up-dating well record information for the island to make it readily available for analysis. As of August 1996, the Groundwater Section had 828 records of wells (both drilled and dug), including 32 springs on file in the computerized WELL Database System with their locations plotted on 1 : 5,000 scale well location maps for the area. These well and spring locations are shown on Figure 6 (in pocket). Records also exist for an additional 62 wells although the precise locations of these have not been determined for plotting on the well location maps.

Figure 7, shows the density of existing well and spring sources in each of the groundwater regions under four categories varying from very low (less than one well per 20 acres) to very high (more than one well per two acres). Locally within each region, particularly along the coastal areas, well densities may greatly exceed the overall density for the region. Well density is indicative of the degree of groundwater development in each of the regions and a probable indicator of the degree of groundwater use which is discussed in Section 11. Well densities are highest in the Cain Peninsula, South Galiano, Georgeson Bay and North Galiano-Spanish Hills regions (Table 2). Areas of high well density are often associated with groundwater problems including ; failing well yields and deterioration in water quality. This is discussed further in Sections 13.1 and 13.2.

9. Hydrogeology

9.1 Aquifer Conditions

Evidence obtained during well drilling and well testing, indicates that the dominant factor governing groundwater availability in the bedrock is secondary porosity due to structurally controlled fracturing while primary or intergranular porosity is generally of minor importance. *Porosity* is an index of how much groundwater can be stored in a saturated medium and is usually expressed as a percentage of the bulk volume of the material (Driscoll, 1986). Representative porosity values for sedimentary rocks such as shales and sandstones are reported to range from 0 to 10 and 5 to 30 percent respectively (Freeze and Cherry, 1979). The majority of drilled wells completed since 1970

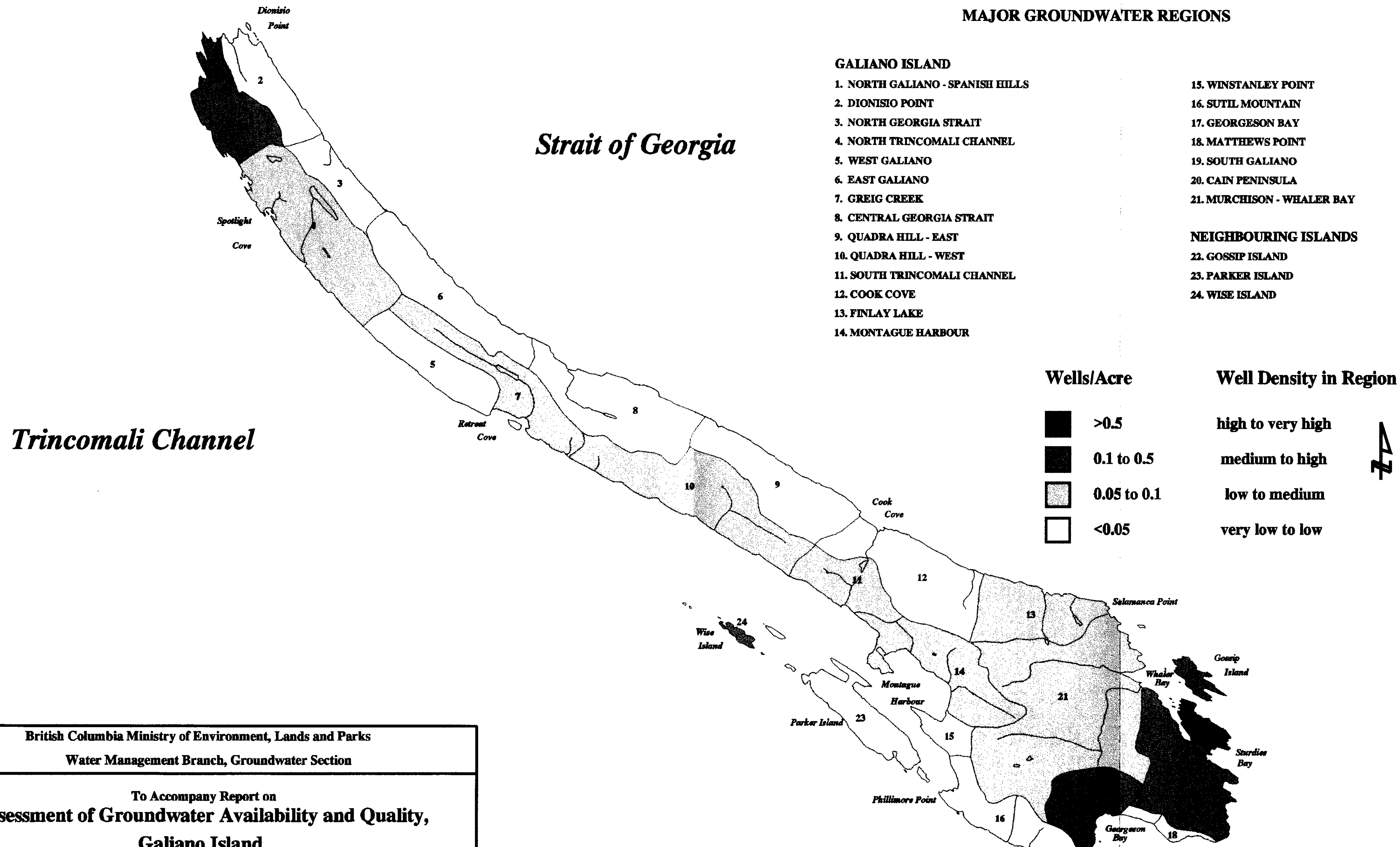

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Figure 7 : Well Density

Scale : 1 : 75,000 **Date : October 1997**

TABLE 2. Groundwater Regions for Galiano Island and Neighbouring Islands Sorted According to Well Density.

MAJOR GROUNDWATER REGIONS	AREA of REGION (hectares)	(acres)	NUMBER of REPORTED WELLS (including Springs)	WELL DENSITY Wells/Hectare	WELL DENSITY Wells/Acre
GALIANO ISLAND					
20. CAIN PENINSULA	52	128	92	1.769	0.716
19. SOUTH GALIANO	340	841	183	0.538	0.218
17. GEORGESON BAY	194	480	50	0.257	0.104
1. NORTH GALIANO-SPANISH HILLS	224	552	56	0.251	0.101
4. NORTH TRINCOMALI CHANNEL	473	1170	90	0.190	0.077
14. MONTAGUE HARBOUR	291	720	49	0.168	0.068
21. MURCHISON-WHALER BAY	916	2264	143	0.156	0.063
7. GREIG CREEK	282	698	42	0.149	0.060
11. SOUTH TRINCOMALI CHANNEL	169	417	22	0.130	0.053
13. FINLAY LAKE	253	625	32	0.126	0.051
10. QUADRA HILL-WEST	454	1122	51	0.112	0.045
5. WEST GALIANO	200	493	18	0.090	0.036
18. MATTHEWS POINT	36	90	2	0.055	0.022
6. EAST GALIANO	303	748	14	0.046	0.019
12. COOK COVE	366	905	15	0.041	0.017
16. SUTIL MOUNTAIN	203	500	8	0.040	0.016
3. NORTH GEORGIA STRAIT	136	337	5	0.037	0.015
2. DIONISIO POINT	178	440	5	0.028	0.011
8. CENTRAL GEORGIA STRAIT	371	918	7	0.019	0.008
15. WINSTANLEY POINT	64	158	1	0.016	0.006
9. QUADRA HILL-EAST	308	762	2	0.006	0.003
Totals:	5815	14369	887		
NEIGHBOURING ISLANDS					
22. GOSSIP ISLAND	35	87	17	0.480	0.194
24. WISE ISLAND	13	32	4	0.305	0.123
23. PARKER ISLAND	165	409	5	0.030	0.012
Totals:	214	529	26		

Well Density in Region	Wells/Acre
high to very high	>0.5
medium to high	0.1 to 0.5
low to medium	0.05 to 0.1
very low to low	< 0.05

Note: The number of reported wells, includes sources for which locations are known and are contained in the WELL Database System plus known wells where precise locations descriptions have not been determined.

have been drilled by the air rotary method. This method enables well drillers to identify the depth and approximate yield and water quality of individual major water-producing fracture zones. In most instances the bedrock wells are unlined except for a shallow steel surface casing completed in overburden materials. Where unlined, the wells may interconnect deep and shallow groundwater flow systems. Bedding plane partings and geologic contacts between different rock types also constitute important water-producing zones or aquifers. Well drillers, utilizing air rotary drilling techniques, report distinct water-producing fracture zones being encountered when wells are drilled. The widespread distribution of fracturing in the bedrock appears to be more important than individual major fault zones in governing the regional availability and movement of groundwater. Major faults may play an important hydrogeologic role locally, either as preferred conduits or as relative barriers to groundwater flow. Halstead (1967) reports, "The sedimentary rocks are characterized by low porosity and permeabilities near zero; thus movement of water is confined to structures such as bedding planes, faults and joints". As such, no unique aquifers have been identified. Rather , the entire island can be considered part of a fractured and interconnected bedrock aquifer system in which variations in productivity and water quality are found spatially within the groundwater system.

Groundwater is also found locally in unconsolidated deposits of sand and gravel, overlying the bedrock in a number of areas on the island. Groundwater in these deposits occurs in the pore spaces between sand and gravel particles and may occupy up to 25 percent of the deposit by volume. The small and localized extent of these aquifers limits their extensive use. Shallow, large diameter dug wells are normally constructed in the unconsolidated deposits and in wetland areas where groundwater comes to the surface in springs or seepages. Locations of these sources are shown in Figure 6. These sources can be relatively productive but in some cases may be adversely affected during periods of drought. Water quality can be subject to degradation from nearby surface sources of pollution and they can invariably have poor bacteriological quality.

Based on the aquifer classification system developed by Kreye et al (1994), the bedrock aquifer system on Galiano has been classified as a moderately developed and moderately vulnerable II B aquifer, with a ranking value of 14 out of 21. The criteria used for this classification and ranking is shown in Appendix I.

9.2 Hydrologic Cycle

A portion of the precipitation falling on Galiano infiltrates into the soil, replenishes the soil moisture or is used by plants and returned to the atmosphere by transpiration through the hydrologic cycle (Figure 8). Water that infiltrates below the root zone travels downwards until it reaches a level at which all of the openings or voids in the subsurface materials are filled with water. This zone is known as the *zone of saturation.* Water in this zone is referred to as *groundwater* . The upper surface of the zone of saturation, if not confined by a low permeability formation is called the *water table.* When an overlying impermeable formation confines the water in the zone of saturation under a pressure greater than atmospheric pressure, the ground water is under artesian pressure. Not all water from wells that penetrate artesian formations flows above the surface of the land. For a well to be artesian, the water in the well must stand above the top of the aquifer.

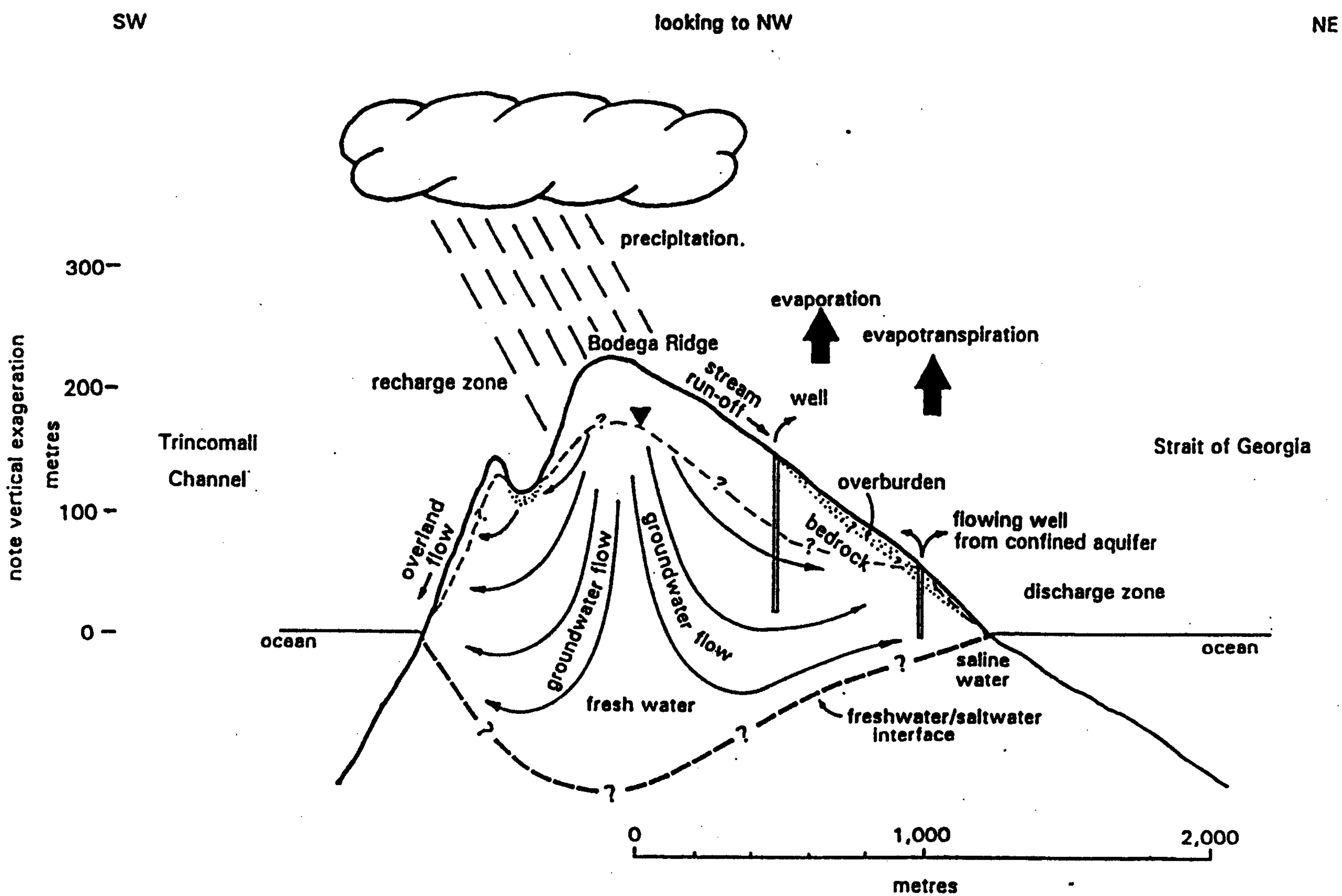
9.3 Water Levels and Groundwater Flow

Due to variations in geologic materials and surface topography, the water table occasionally intersects the surface of the ground or the bed of a stream, lake, or ocean. As a result, ground water moves to these locations and out of the aquifer. Ground water is continually moving within the aquifer even though the movement may be very slow. The water table or artesian pressure surface, slopes from areas of recharge to areas of discharge. The pressure differences represented by these gradients cause the flow of ground water within the aquifer. At any point the slope is a reflection of the rate of flow and resistance to movement of water through the saturated formation. Seasonal variations in the supply of water to the underground reservoir cause considerable changes in the elevation and slope of the water table and artesian pressure level.

Figure 8 depicts a simplified representation of the probable groundwater situation that occurs on Galiano Island wherein a freshwater lens of groundwater occurs within the bedrock underlying the island. The freshwater lens overlies saltwater and is thickest under the topographic highs where the groundwater is being replenished through infiltration of precipitation. The freshwater lens is thinnest along the coastal areas. Well depths range from 1.5 m (5 feet) to 207 m (680 feet). Confined and unconfined aquifer conditions exist with reported non-pumping water levels ranging from flowing to 82 m (268 feet) below the ground surface. Figure 9 illustrates groundwater levels in wells reflecting the topography in cross sections through the southern portion of Galiano Island. A similar situation exists in the central and northern parts of the island as shown in Figure 10. Locations of the cross sections are depicted in Figure 6.

Galiano Island North

(Schematic Cross Section and Hydrologic Cycle)



(From Harrison, 1994)

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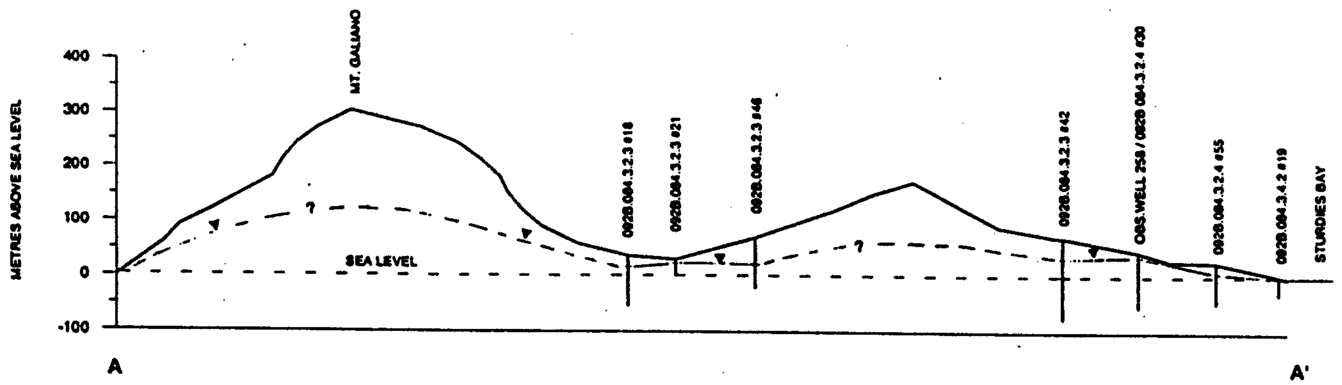

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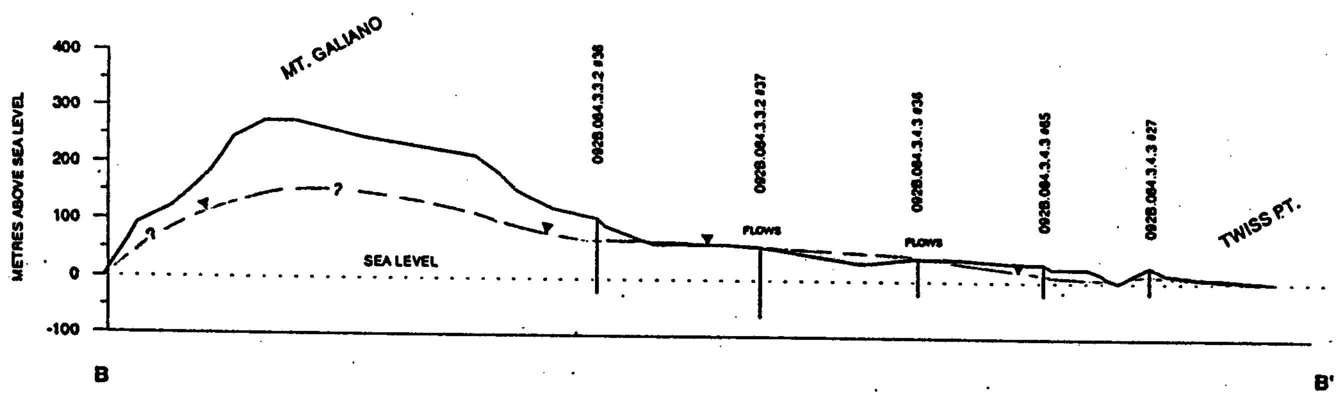

CROSS - SECTION B - B′

WATER LEVEL

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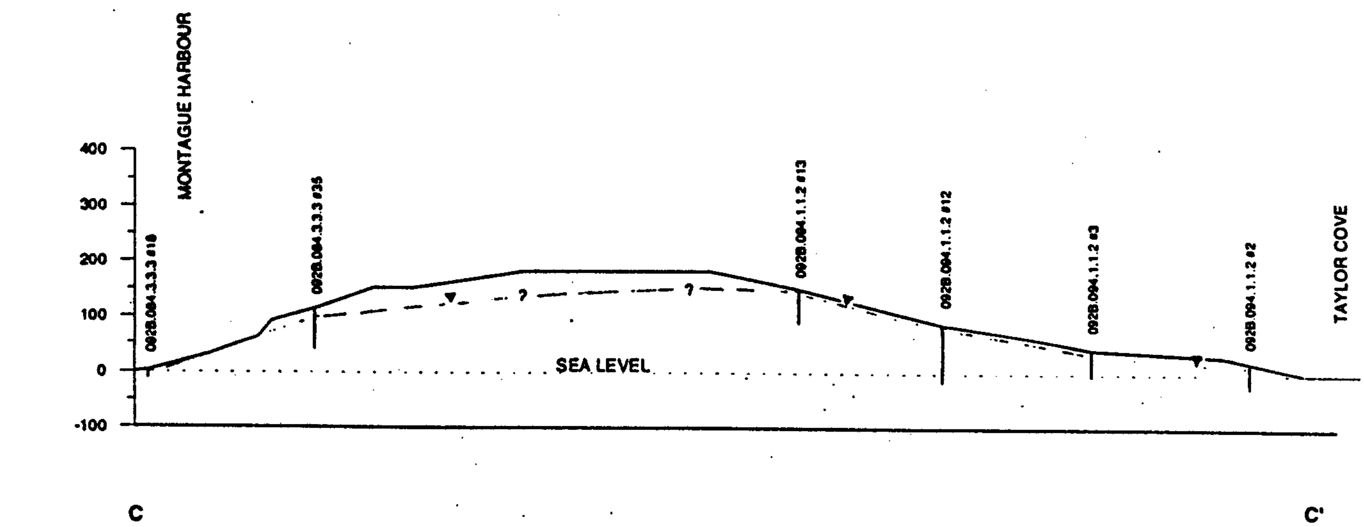

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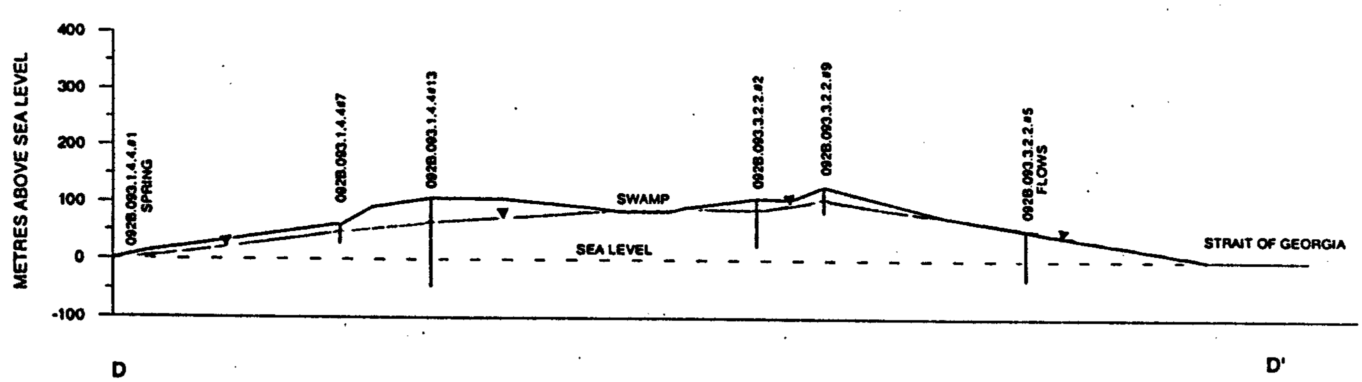
WATER LEVEL



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WATER LEVEL

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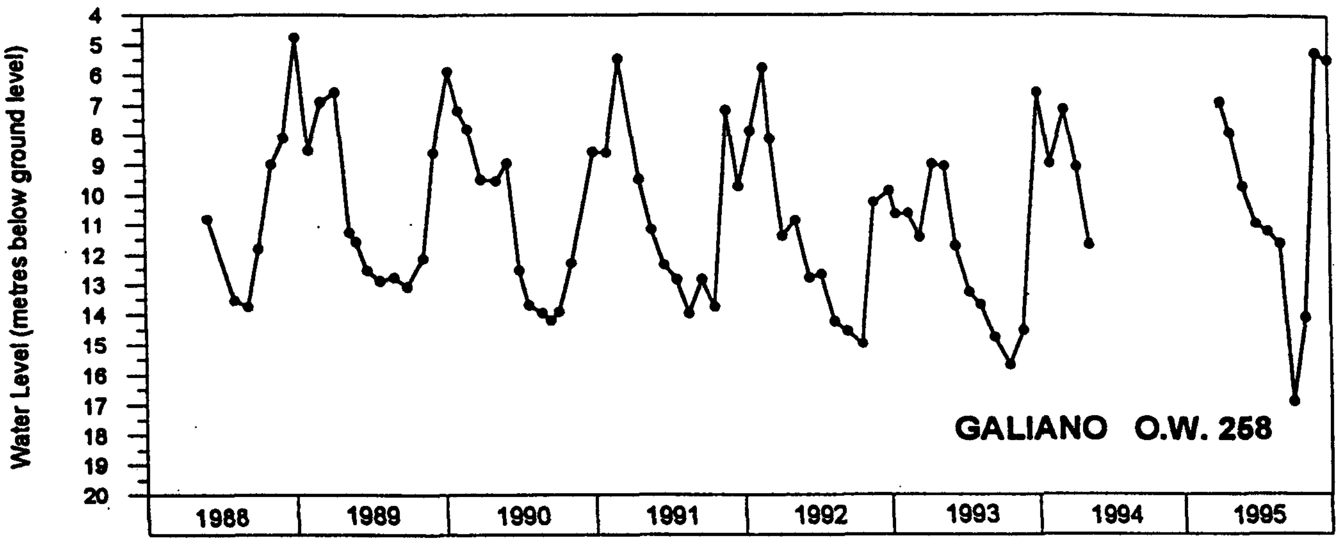
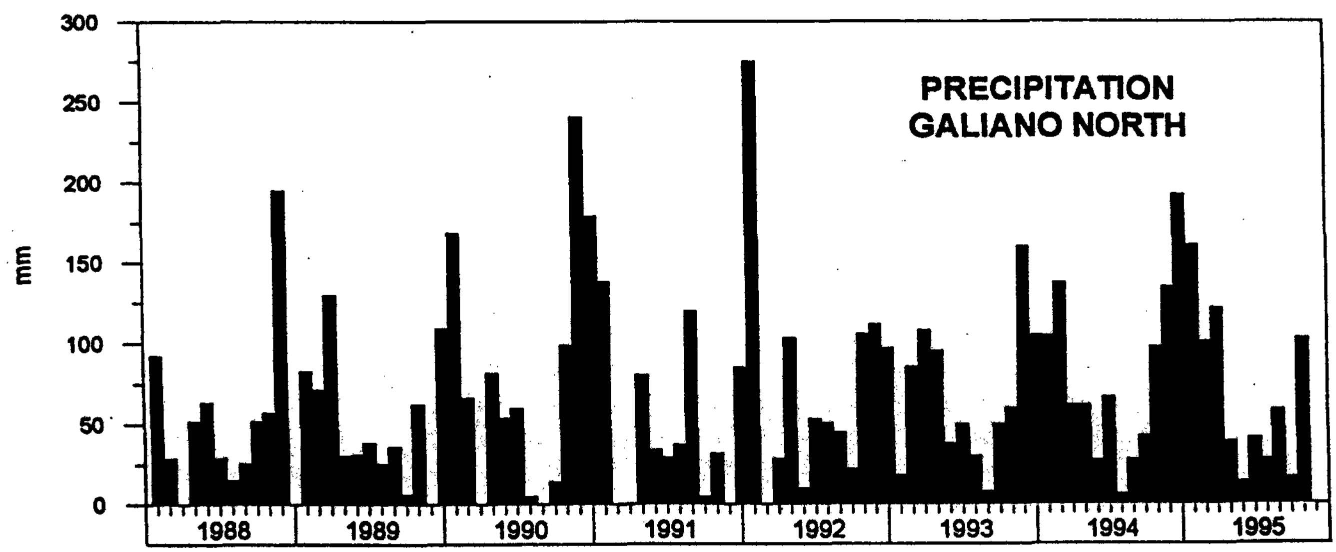
Data from numerous bedrock observation wells in the region (Kohut et al, 1984) indicate groundwater levels respond cyclically on a seasonal basis to climatic variations. Groundwater recharge occurs as water levels rise in response to fall and winter precipitation. Water levels decline during the dry summer and early fall months reaching a seasonal minimum between October and December. Long term (10-year) hydrograph records (Kohut et al, 1984) show a similar seasonal response in wells completed in different areas, in different rock types and different depths in various positions in groundwater flow systems. This suggests that there is significant hydraulic continuity within the fractured flow systems regionally. Figure 11 shows groundwater levels recorded in Observation Well 258 from 1988 to 1995. While levels appear to recover each year with recharge, there also appears to be an overall lowering of levels during the summer months. This seasonal lowering may be due to increased water demands in the South Galiano Region where the well is located. Other temporary observation wells established for this project show similar seasonal fluctuations (Figures 12, 13 and 14). Wells 326 and 327 located on the southern part of the island show an overall lowering during 1995 and 1996 (Figure 12). Observation wells 1 to 8 situated in less densely populated regions reflect seasonal recharge but do not show overall lowering during this same time period. Locations of the observation wells monitored are shown in Figure 6. Figure 15 shows reported water levels in wells in terms of elevation above sea level and inferred directions of ground water flow normal to the slope of the contoured water level surface. The significance of these water levels to groundwater recharge are discussed further in section 10.

9.4 Well Yields

Most well yields are estimated by drilling contractors and these are not as accurate as yields determined from long duration pumping tests. Generally speaking initial yield estimates tend to be more optimistic than yields confirmed by long-term pumping tests. However, the data does show relative variation in yields occurring aerially. Most of the wells produce from the fractured bedrock and were drilled for domestic supply. As such, the data is usually showing the water bearing ability of the initial fractures encountered. Often larger capacity wells could be constructed by further deepening.

Figure 16 was prepared showing ranges of well yields and overlaid with the bedrock geology map. No obvious correlation appears to exist between well yields and the fracture zones and faults shown or the bedrock geology. However, the location for the highest known producing bedrock well on Galiano Island was selected by Thurber Consultants Ltd. (1990) from previously mapped fault zones on air photos and on the ground investigation. It is drilled to a depth of 122 metres (400 ft) on District Lot 85, mid-island east of Spotlight Cove. It encountered water-bearing fractured sandstone from 21 to





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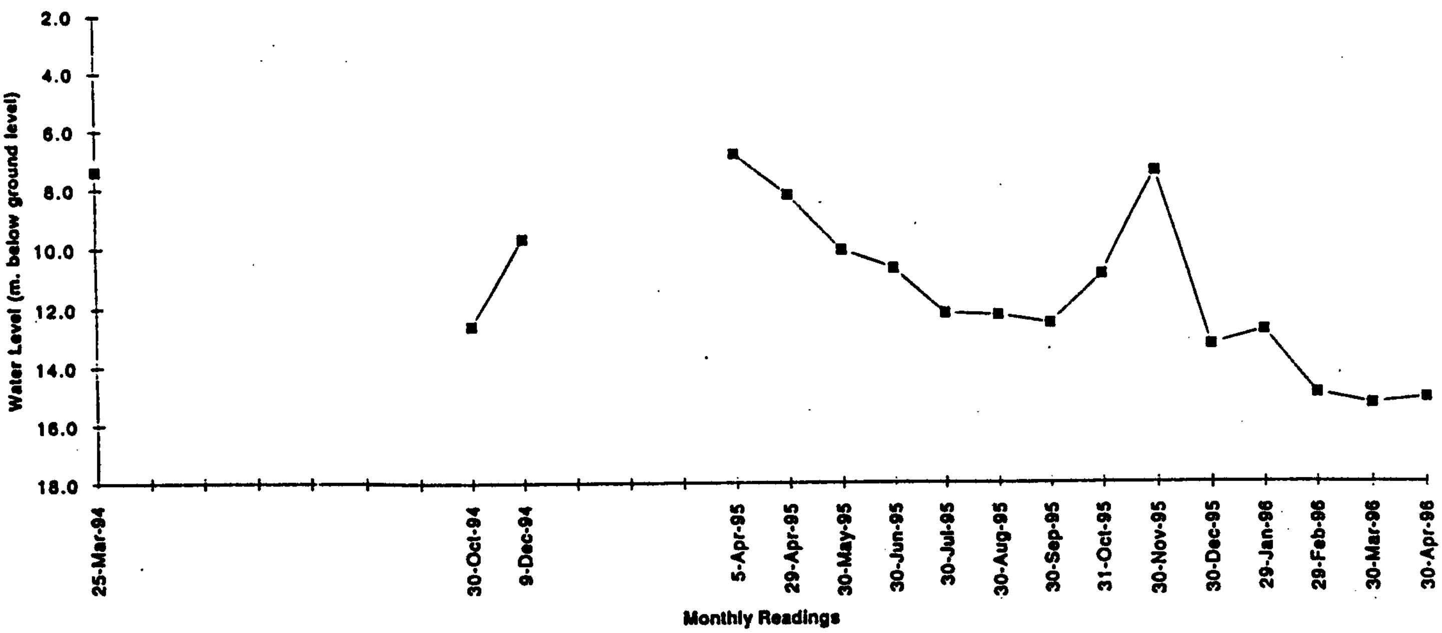
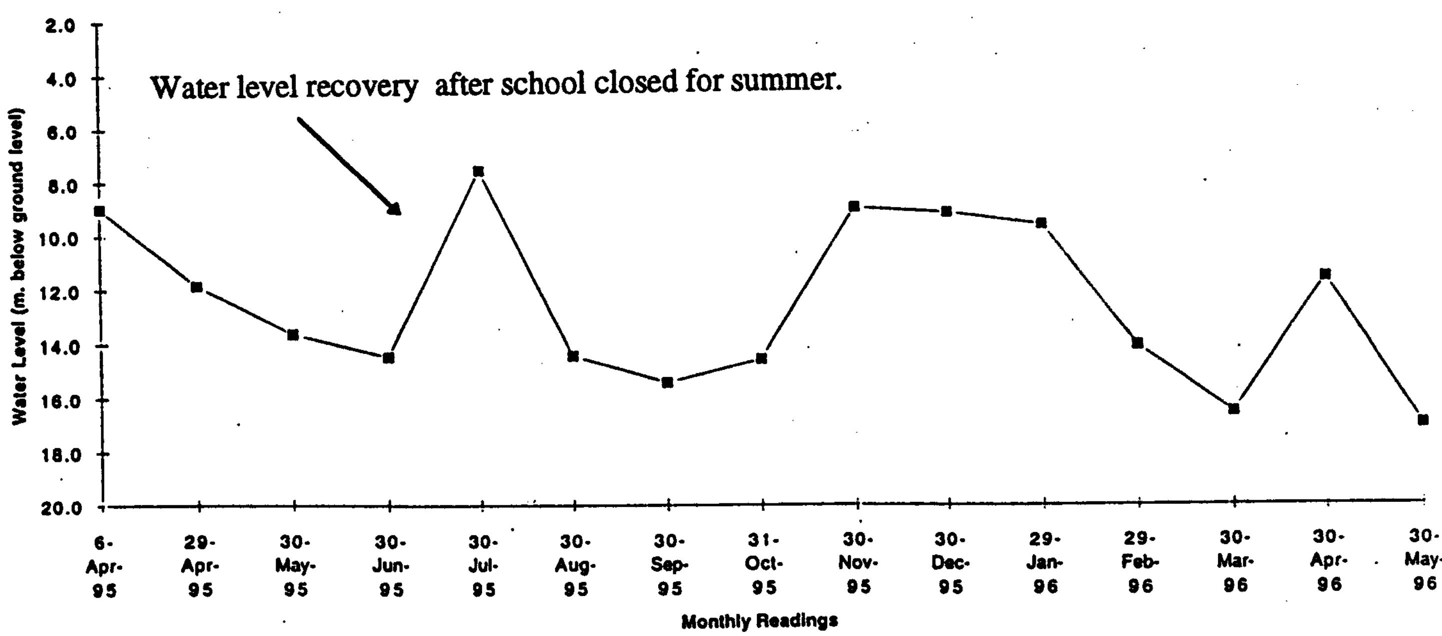
Hydrograph of Observation Well No. 326 Sturdies Bay Galiano Island, B.C.



Hydrograph of Observation Well No. 327 Whaler Bay Galiano Island, B.C.



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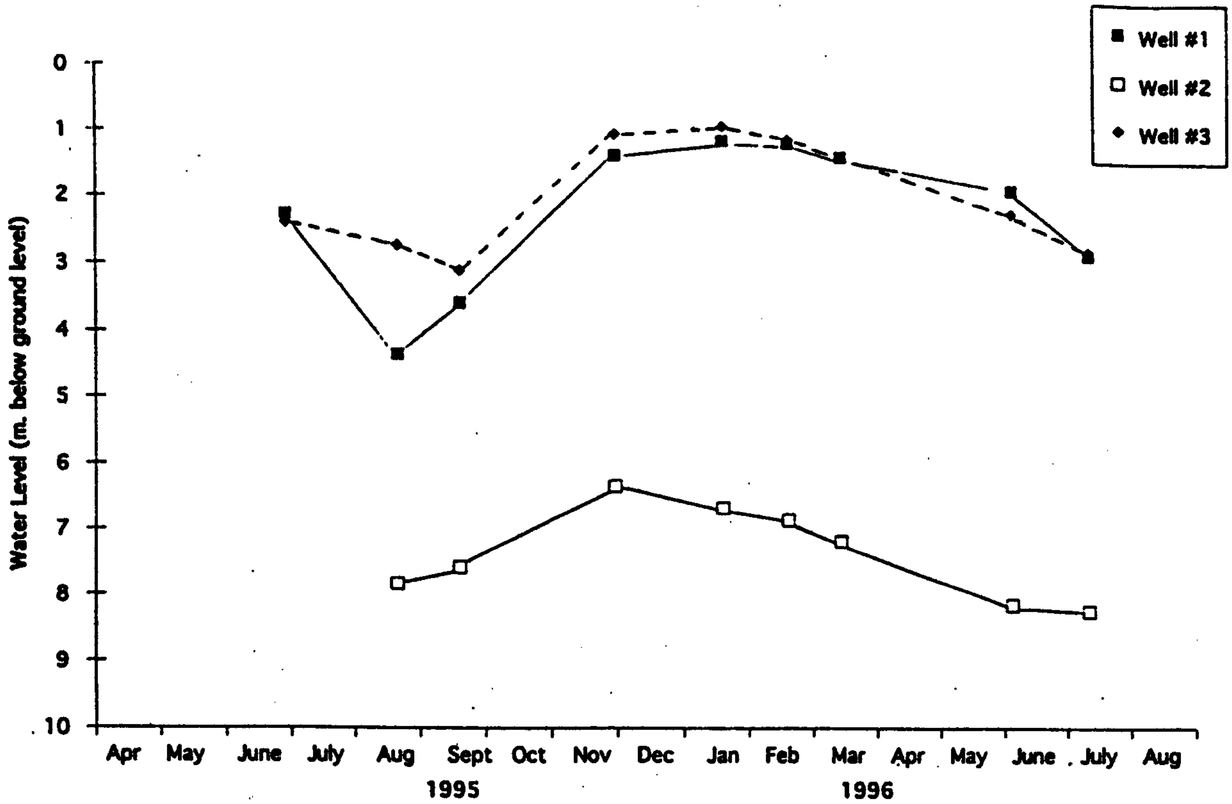
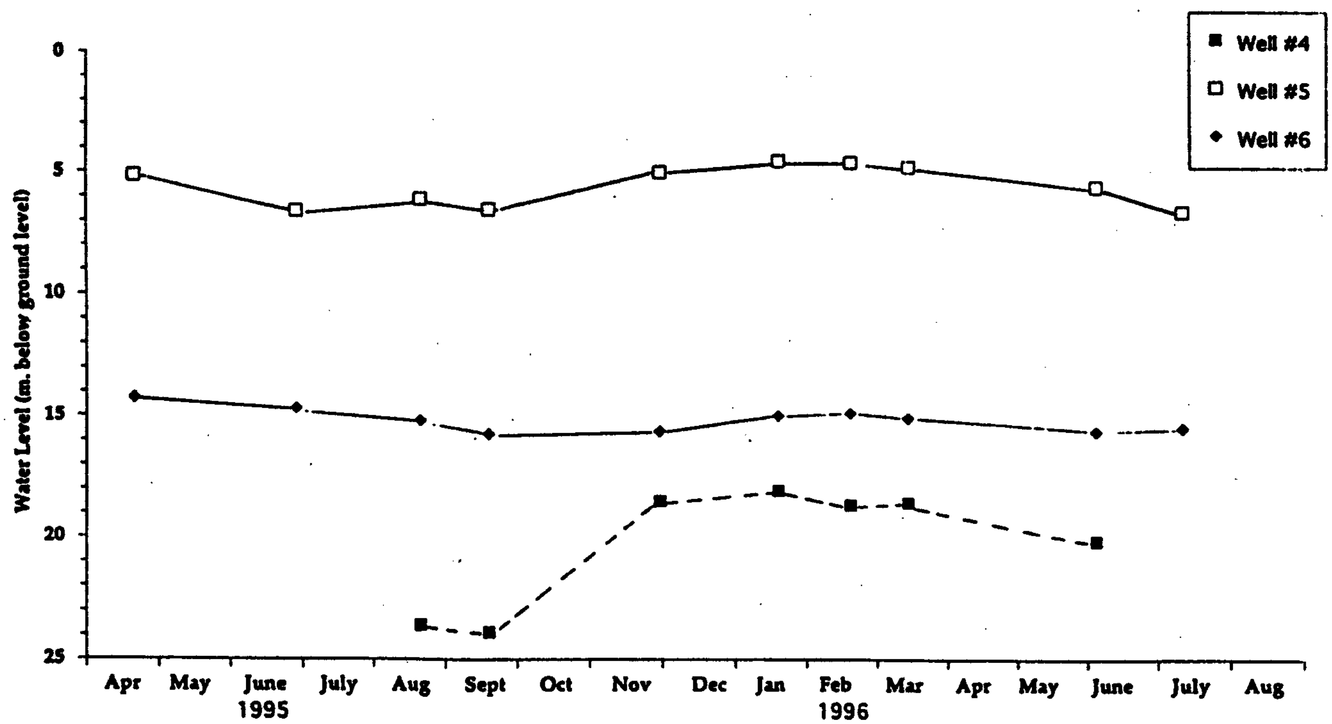
Hydrographs of Observation Wells #1, #2, and #3 Galiano Island, B.C.



Hydrographs of Observation Wells #4, #5 and #6 Galiano Island, B.C.



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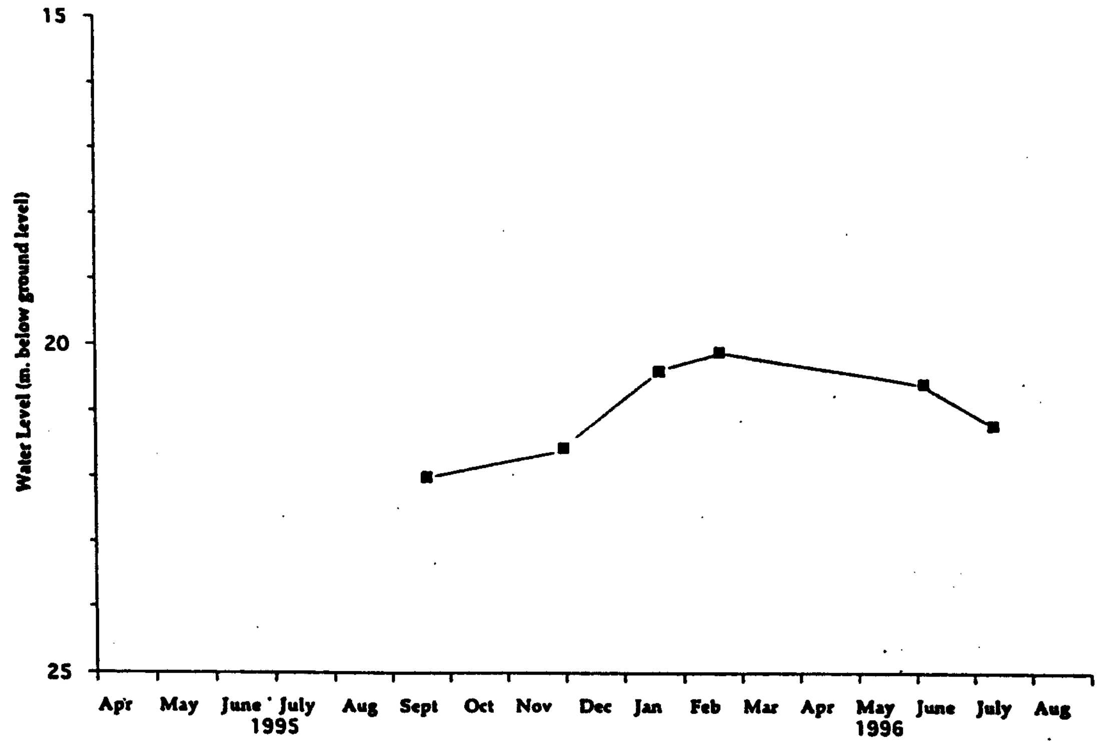
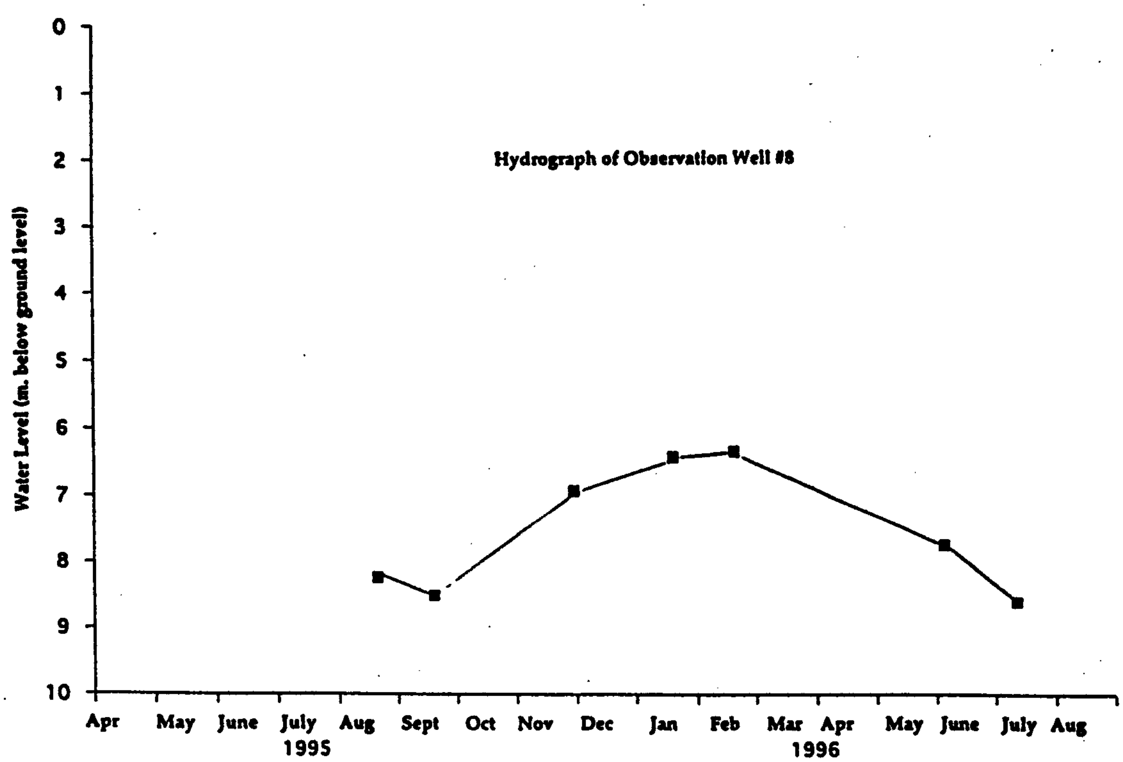
Hydrograph of #7 Observation Well.





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122 metres (69 to 400 ft). On the analysis of the 72 hour pumping test results, the consultant estimated the sustained yield of this well at 900 litres/minute (200 Igpm), subject to confirmation by further testing. Further detailed studies of yield and structural geology data may define a pattern of association. Some 677 estimated yield values indicated the following:

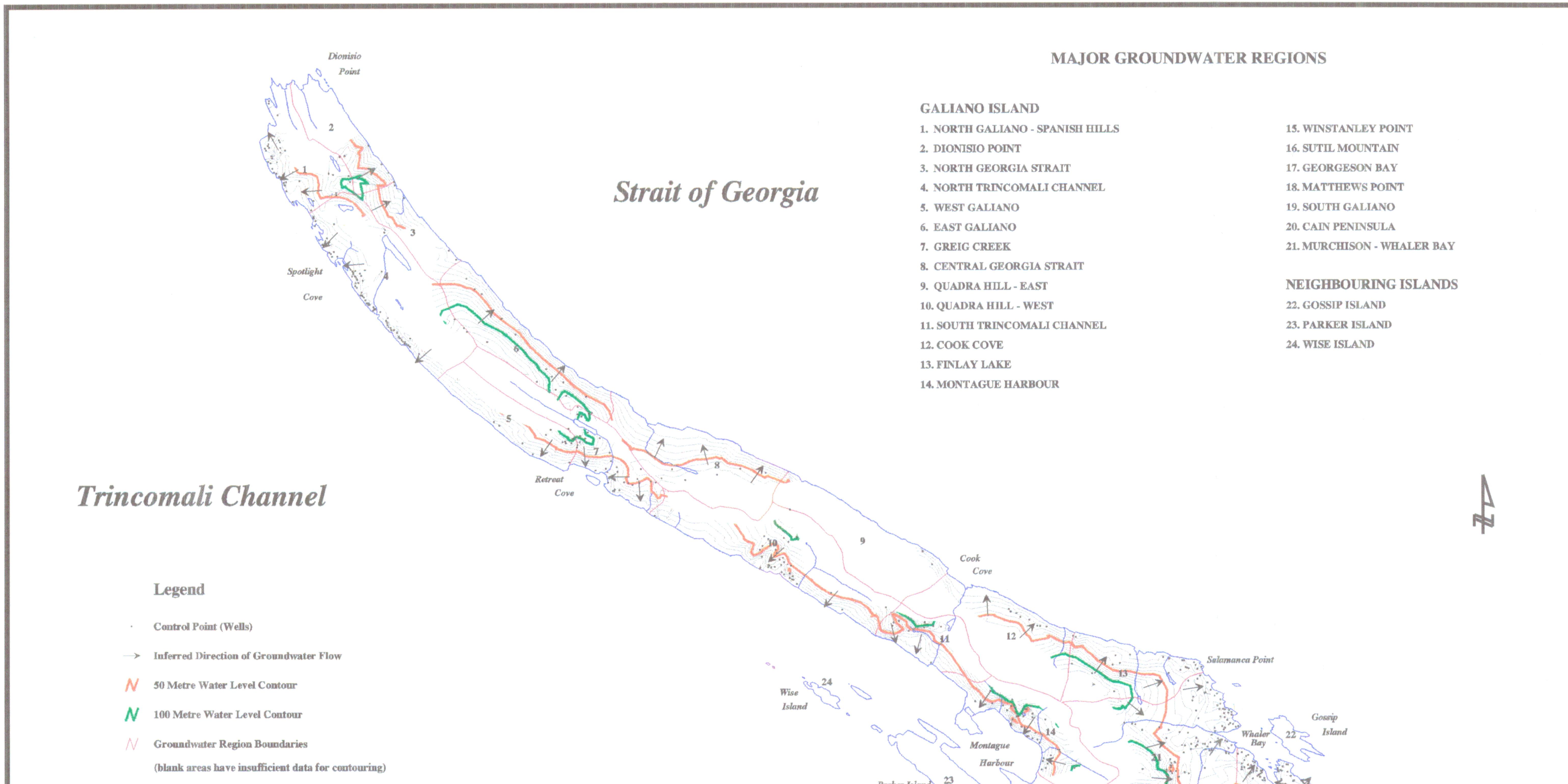
27% have a yield of 1.0 gpm or less
62% have a yield of less than 5.0 gpm
80% have a yield less than 10 gpm
94% have a yield less than 25 gpm

Two wells were rated to yield from 100 to less than 200 gpm. They are both close to one another on District Lot 85. The lower yielding well produces from water bearing gravels, whereas the higher yield well produces from fractured sandstone. They are also in proximity to a lake which could possibly have hydraulic connection.

Figure 17 shows the probability of obtaining a particular well yield based on the reported yield estimates. For example the probability of obtaining a well yield greater than 0.016 L/s (0.25 USgpm) is 80 percent while the probability of obtaining a well yield greater than 0.4 L/s (6.3 USgpm) is only 30 percent. Long term pumping tests of bedrock wells, carried out in some case for several days, provide important information on the productivity of wells and the ease at which water is able to move through the fractured bedrock formations. Pumping test results provide an indication of the apparent aquifer *transmissivity* which is a measure of the quantity of water which can move through a unit thickness of aquifer under a unit hydraulic gradient. Data from 68 pumping tests (Appendix II, Figure 1) carried out on bedrock wells on Galiano Island, indicate a median aquifer transmissivity value of approximately 1.9×10^{-7} m^2/s with values ranging from 6.0×10^{-4} to 1.4×10^{-8} m^2/s. The *hydraulic conductivity* of an aquifer is equal to the transmissivity divided by the saturated aquifer thickness and is a measure of the quantity of water which can move through a unit area of aquifer under a unit hydraulic gradient. Based on an aquifer thickness of 10 metres for example, the median hydraulic conductivity would be 1.9×10^{-8} m/s. Groundwater discharge or the quantity of flow through a cross sectional area of aquifer can be determined by Darcy's Law which may be expressed as follows:

$Q = KIA$ where Q = flow in m^3/s
K = hydraulic conductivity in m/s
I = hydraulic gradient (dimensionless)
A = area through which the flow takes place in m^2

Further discussion of groundwater flow is provided in section 11.1 on groundwater recharge potential.



British Columbia Ministry of Environment, Lands and Parks
Water Management Branch, Groundwater Section

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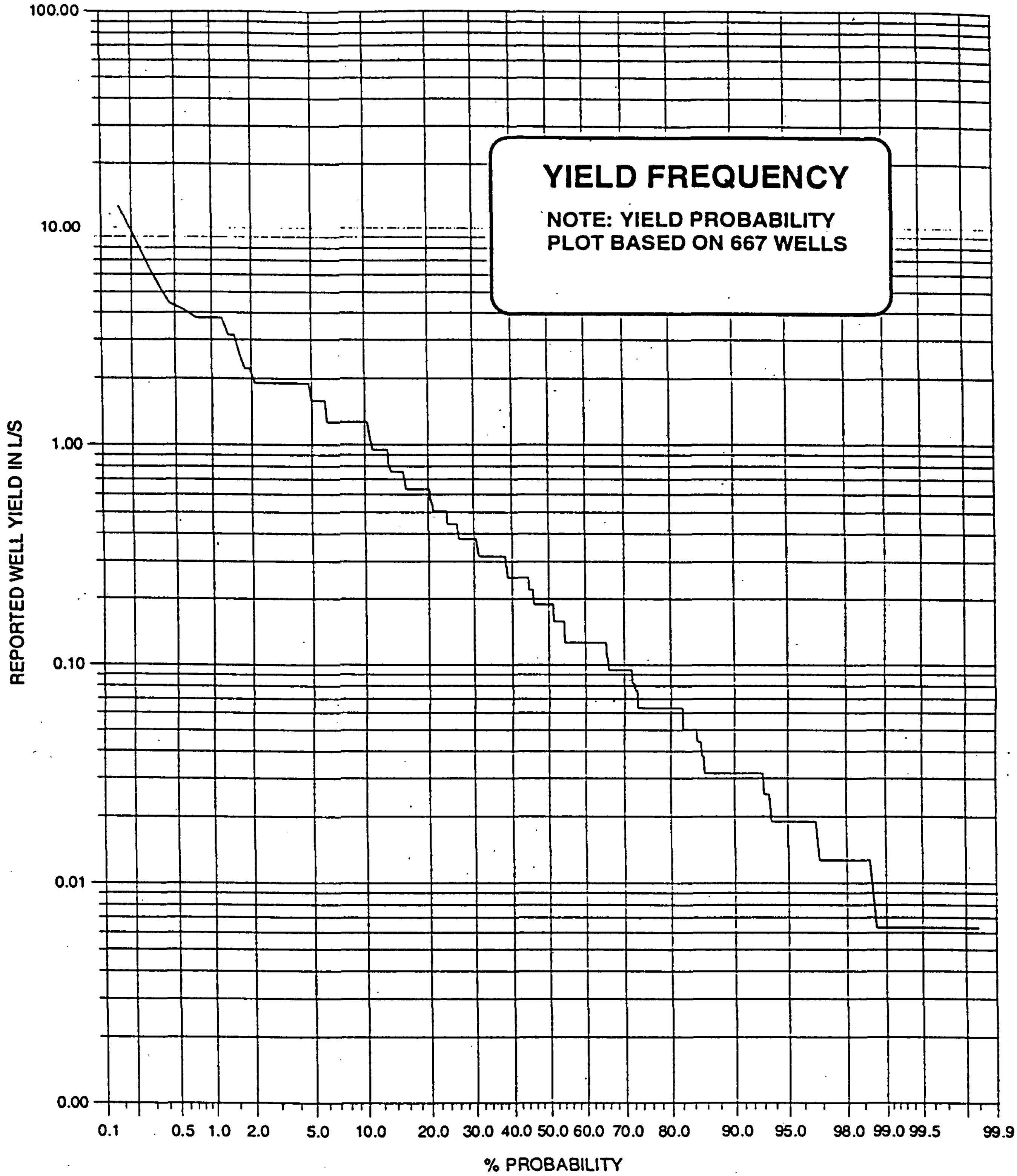
Figure 15: Water Levels and Groundwater Flow Directions

Scale : 1 : 75,000 Date : October 1997 Water Level Contour Interval 10 metres



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10. Groundwater Recharge and Discharge Areas

Within a groundwater region, groundwater is replenished from the infiltration of precipitation and surface runoff in the higher elevation areas . Groundwater moves through the subsurface under the influence of gravity towards the lower reaches of the groundwater region where it discharges in the form of springs or comes close to the ground surface. Areas where groundwater is replenished and is moving downward are termed *groundwater recharge areas.* Areas where groundwater is moving upwards and discharging to the surface in springs and wetlands are termed *groundwater discharge areas.*

Regionally, areas of groundwater recharge and discharge have been recognized in the sedimentary bedrock terrain in the Gulf Islands (Foweraker, 1974; Dakin et al, 1983). Water level information obtained from wells on Galiano Island and similar environs on other Gulf Islands provides evidence that groundwater level elevations tend to mirror the land surface. Groundwater mounds are found underlying the topographically higher areas of the island and upper reaches of the groundwater regions. This mounding effect results in the downward movement of groundwater from the topographically higher areas towards topographically lower areas. The relationship between recharge and discharge areas in the groundwater region is depicted in plan in Figure 4 and in cross-section in Figures 8 and 18.

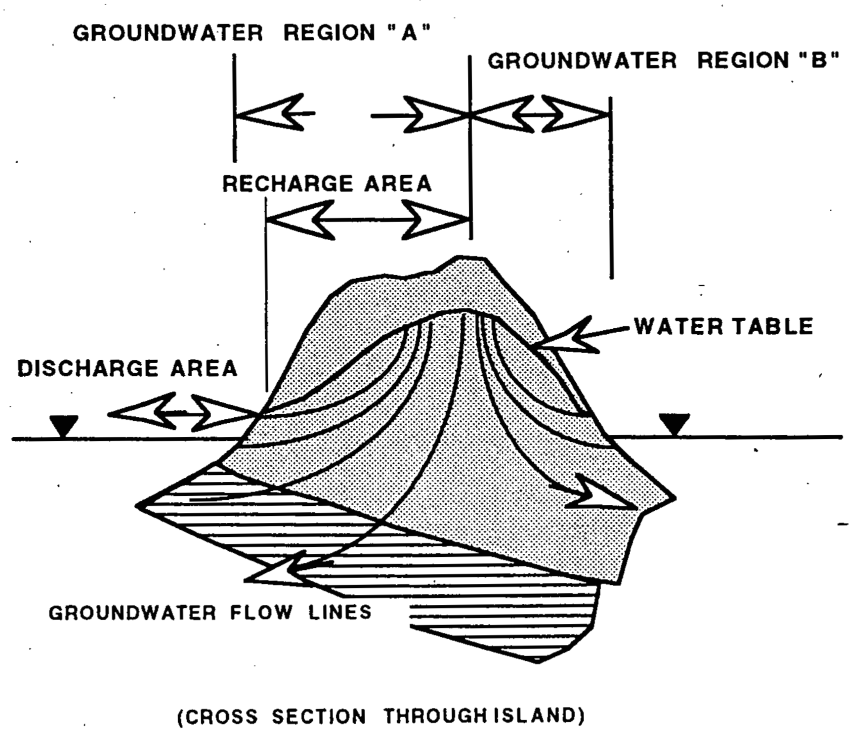


Figure 18. Relationship between groundwater region and groundwater recharge and discharge areas (cross section).

The demarcation point or boundary between a recharge and discharge area may be often be indicated by a change in topographic slope. The occurrence of flowing artesian wells, springs, wetlands and the presence of phreatophytic vegetation (water-loving plants) such as bulrushes and yellow arum (skunk cabbage) are generally good indicators of groundwater discharge conditions. Discharge areas mapped on Galiano include in part the vegetation units 9 (Red Alder - American skunk cabbage - common lady fern) and 10 (Wetland vegetation) mapped by Clement (1979). While site specific information on water levels may only be available in limited areas of the island, this information may be extrapolated to adjoining areas having a similar topographic setting. Variations in topography, soils, geologic materials and structural features may alter groundwater flow conditions and water level gradients resulting in localized areas of groundwater discharge.

Localized discharge areas located in the upper reaches of a groundwater region may also contribute to groundwater recharge for areas downslope. Depending upon the configuration of the surrounding topographic and water table gradients a local groundwater discharge area may also function in part as a recharge regime for areas downslope. This is depicted in Figure 19 where a wetland at an intermediate elevation receives groundwater discharge from areas upslope contributing to groundwater recharge downslope.

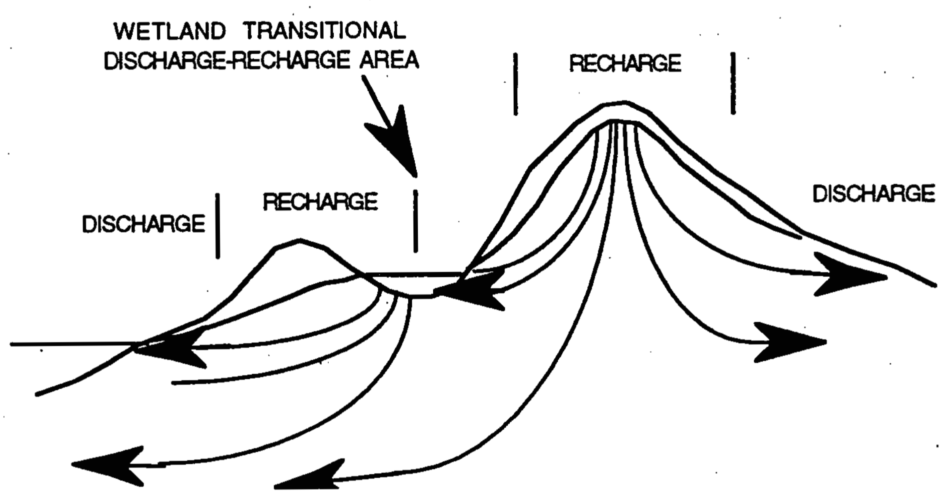


Figure 19. Example of transitional recharge-discharge area (cross section).

In outlining the extent of the groundwater recharge and discharge areas on Galiano Island (Figure 20), the following information was utilized for interpreting and setting the boundaries of the major recharge and discharge areas:

- topographic features (ground elevation and slope) and surface drainage features observed on 1: 12,000 scale mapping (25 foot (7.6m) contour interval) and 1: 12,000 scale air photographs;
- known geologic conditions including structural features;
- presence of flowing artesian wells, springs and wetlands;
- changes in topographic slope;
- available groundwater level information from wells and springs, inferred hydraulic gradients and probable directions of groundwater flow;
- presence of phreatophytic vegetation and changes in vegetation type and distribution.

As confirmatory information on water levels and groundwater gradients is not available everywhere on the island, the recharge and discharge areas delineated in Figure 20 have been termed probable recharge and discharge areas. In many cases groundwater found in the discharge areas in the lower reaches of the groundwater regions may be more mineralized as a result of long transport distances and extended residence time in the subsurface regime. The distribution of discharge areas in Figure 20 can be useful as a guide for indicating areas of more mineralized groundwater and flowing artesian conditions. In terms of groundwater and surface water quality protection, intensive land use activities (e.g. animal feedlots, high density subdivisions (< 10 acre lots), which can pose a risk to water quality should be discouraged in the recharge areas unless adequate safeguards are also put in place to reduce the risk of any contaminants being introduced to the groundwater regime. Safeguards for example could include provisions such as minimum lot sizes and special containment or treatment facilities for potential contaminants. Quality concerns and groundwater protection measures are discussed further in section 13. The judicious management of groundwater recharge areas will be critical to sustaining groundwater availability and quality in all of the groundwater regions of Galiano Island.

11. Water Supply and Demand

11.1 Groundwater Recharge Potential

The availability of groundwater on Galiano Island is dictated primarily by the geographic (area and topography of land surface) and hydrologic characteristics (permeability and storage coefficient) of the bedrock formations and rate of groundwater recharge from infiltration of precipitation and surface runoff. Groundwater recharge rates are difficult to determine directly. They may be estimated from water balance equations but there is often considerable uncertainty associated with determining the accuracy of the hydrologic components needed to solve the equations. In a given year, some 11 billion Igals of water falls on the island in the form of rain and snow (based on annual precipitation of 856 mm). Most of this amount either runs off the land or is evaporated, utilized by vegetation and transpired while a small percentage is available for groundwater recharge. Halstead, (1967) estimated that 2 inches (50mm) or 6 percent of the annual precipitation may be available for groundwater recharge. Based on studies of Mayne Island, Foweraker (1974) estimated that 1 inch (25mm) of precipitation or 3 percent may be available but concluded that on an annual basis, storage and permeability and not precipitation appear to be the limiting factors controlling groundwater availability on the Gulf Islands. Other investigations in the Gulf Islands and east coast of Vancouver Island including: Piteau Associates (1994a), Piteau Associates (1994b) and Hardy BBT Ltd. (1991), have estimated that from 6 to 12 percent of the annual precipitation may be available for groundwater recharge. The effect of long-term climate change on groundwater recharge has not been assessed.

Seasonal water level fluctuations in observation wells also provide an indication of the timing, duration and degree of groundwater recharge but reliable estimates of bedrock porosity are required to convert the observed water level changes to equivalent recharge quantities. Hodge (1995) in examining fluctuations in groundwater levels in bedrock observation wells on Saltspring Island utilized a porosity value of 0.01 percent and estimated recharge amounts ranging from 1.0 to 43.2 mm (0.045 to 1.7 inches) or 0.1 to 4 percent of the average annual precipitation at the community of Ganges for the 1951 to 1977 period of record.

Another approach which can be utilized to estimate recharge quantities is by examining representative groundwater flow systems on the island and calculating the probable quantities of groundwater likely moving through the flow systems based on estimates of: hydraulic conductivity, hydraulic gradient and flow area utilizing Darcy's Law, as discussed previously in Section 9.4. As an example, an analysis was carried out by examining the groundwater flow system in the North Georgia Strait Region where flow conditions are likely to be relatively uniform. Results of the analysis are provided in Appendix III. Figure 1 (Appendix III) illustrates the probable flow system with the hydraulic gradient approximating the topographic slope. Figure 2 (Appendix III) shows theoretical discharge quantities in Igals per minute plotted against hydraulic conductivity values in m/s for different thickness of aquifer. Figure 2 indicates for example that in order to accommodate an equivalent recharge rate of 10 percent of the annual precipitation, the hydraulic conductivity would need to be a minimum of 5×10^{-7} m/s, with flow taking place through 30 metres of saturated aquifer thickness. Available data on aquifer transmissivity as discussed previously in section 9.4, however, indicates the median hydraulic conductivity is probably an order of magnitude less, which would suggest aquifer recharge must be less than 10 percent, perhaps less than 5 percent. It appears, based on known transmissivity data, the bedrock aquifers as a whole on Galiano do not appear physically capable of transmitting quantities of flow equivalent to recharge rates as high as 10 percent of the annual precipitation. This does not negate the possibility, however, of there being some localized zones of more permeable bedrock strata in some areas. To date, only a very small percentage of wells have encountered such zones.

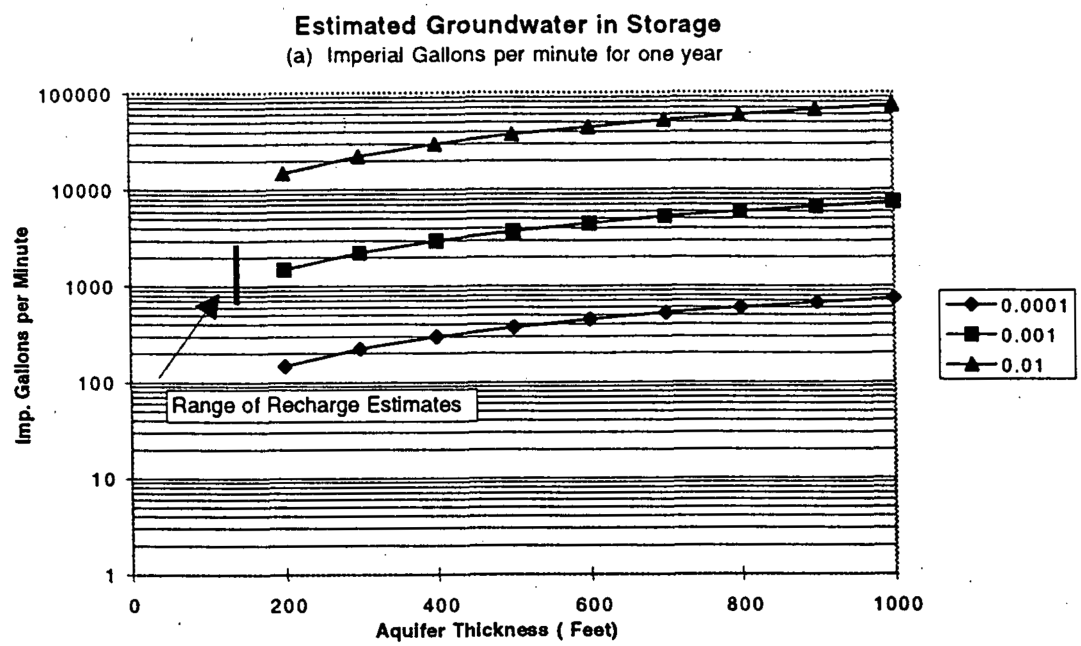
11.2 Groundwater Storage in the Bedrock

While porosity indicates the volume of water an aquifer can hold, it does not indicate how much the aquifer will yield. The *storage coefficient* of an aquifer represents the volume of water released from storage, per unit of aquifer storage area per unit change in pressure head. For unconfined conditions, the storage coefficient of the aquifer is equivalent to the *specific yield* , where the specific yield is the quantity of water that a unit volume of an unconfined aquifer will give by drainage under the force of gravity. The amount of water that a unit volume of aquifer retains after gravity drainage is called its *specific retention.* Specific yield and specific retention are related to aquifer porosity as follows:

Aquifer Porosity (%) = Specific Yield(%) + Specific Retention(%)

For confined aquifers, storage coefficients are much lower than unconfined aquifers as water is released primarily by compression of the aquifer and expansion of the water when pumped. Pressure in the aquifer is reduced but the aquifer is not dewatered. From extensive pumping tests of wells, Moncur (1974) found that a storage coefficient of 10^{-4} approximates the storage value of the sedimentary bedrock on Mayne Island. A low storage coefficient indicates confined groundwater conditions and or very low specific yield values under unconfined conditions. It is possible that actual groundwater conditions in the bedrock varies between confined and unconfined conditions depending upon fracture depths and their orientation and position within groundwater flow systems.

Previous studies by Mordaunt and Hodge (1983) and Harrison (1994) have estimated the groundwater supplies in storage and recoverable in each region utilizing a conceptual aquifer model based on a water-bearing thickness of 200 feet and storage coefficient of 0.01 percent (1×10^{-4}). For the entire island their figures indicate that 7.8×10^7 imperial gallons may be available in the groundwater regime and replenishable on an annual basis. This figure is equivalent to 0.71 percent or 0. 24 inches (6 mm) of the average annual precipitation of 33.7 inches (856 mm). While this figure could be considered a conservative estimate, it is probably within an order of magnitude of the total fresh groundwater reserves which may be replenishable on an annual basis (i.e. from 7.8×10^7 to 7.8×10^8 imperial gallons). Figure 21 shows the amount of groundwater in storage expressed in; (a) Imperial gallons per minute for one year and, (b) the equivalent yield in millions of Imperial gallons per year, for storage coefficients ranging from



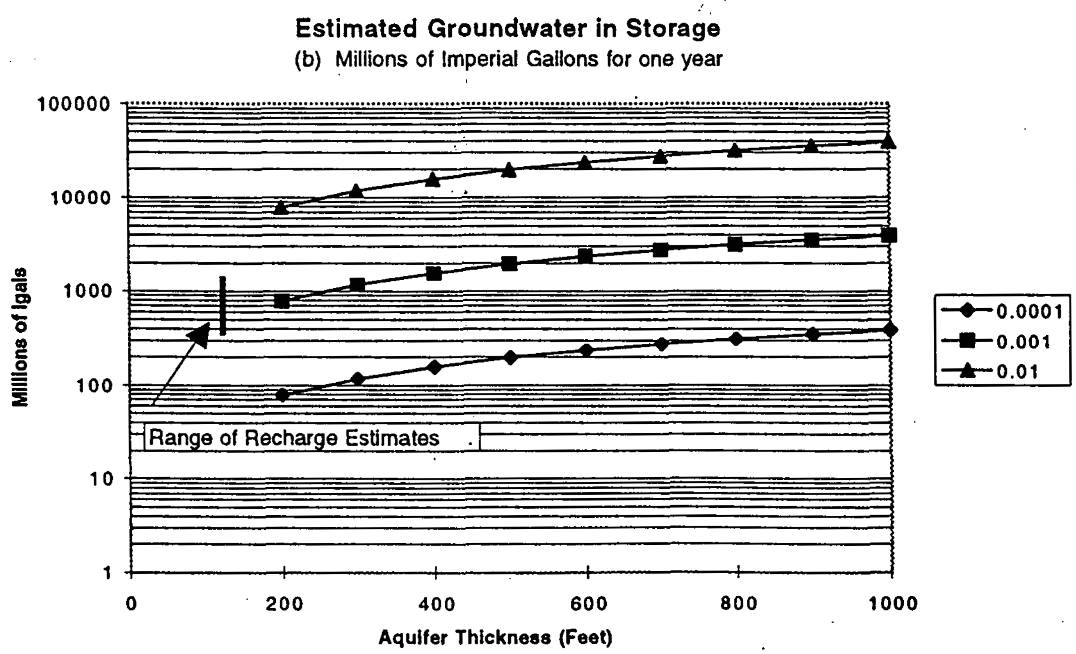


Figure 21. Estimated groundwater in storage for varying aquifer thicknesses and storage coefficients.

10^{-4} to 10^{-2} and aquifer thickness up to 1000 feet. Recharge estimates based on infiltration of 3 to 12 % of the annual precipitation are also illustrated for comparison. It is evident from Figure 21 that the storage coefficient of the bedrock is a limiting factor and would need to exceed 10^{-4} by up to an order of magnitude to enable infiltration of any significant percentage of the precipitation (i.e. > 3 %).

11.3 Groundwater Demand

Groundwater from bedrock wells is an important source of water supply for individual domestic use, community water systems and for small mixed farming operations on the island. Groundwater demand and existing groundwater use are difficult to determine accurately but may be estimated utilizing a number of different approaches. Previous studies by Mordaunt and Hodge (1983) and Harrison (1994) have estimated groundwater use in each region by multiplying the number of existing wells by assumed usage figures in the range of 200 to 500 Igals per day per well for 100 days. For 1994 this translates to a usage of 16 million Igals over 100 days, based on 200 Igals per day per well or 58 million Igals a year. While this approach provides an indication of demand, these figures may not accurately reflect actual use for a number of reasons. The number of wells in existence and in actual use is not known precisely. Only a few wells are equipped with flow meters that monitor actual consumption and use varies seasonally. Many wells are not in active use or may be used very sparingly due to poor yields and water quality problems. The degree to which groundwater is used for non-drinking water purposes such as garden watering is not known. Water from some wells may also be shared and a few larger capacity wells provide drinking water for groups of residents. For the most part, permanent residents are very conscientious in using water and are aware of measures for conserving water. Harrison (1994) concluded that an estimated daily water usage figure of 200 Imp. gallons per day is likely representative of actual water consumption in most Galiano homes. While average daily use may be a few hundred gallons per household, larger quantities of water, for example 500 gpd, may be required to meet peak demand periods and the requirements for new subdivision purposes. In some community water systems, Harrison (1994), reports usage figures ranging from 125 gpd per household during winter months and 255 gpd per household during peak usage in summer months. In the Montague Improvement District, where usage figures have been recorded through metering, figures range from 35,000 gallons per month in winter to 86,000 gallons per month in summer, for 29 households (Harrison, 1994). This translates into 40 gallons per day per household (average) in winter to 100 gallons per day per household (average) in summer. Groundwater demand within regions, moreover, is not distributed uniformly but is concentrated along waterfront areas and along interior valleys where subdivision density is high.

Population figures may also be used to indicate domestic water use demand. Based on 1991 Statistics Canada data showing a resident population of 905 persons and 420 private households suggests an annual demand of 31 million Igals, based on 200 Igpd per household. With the usual influx of visitors to the island during the summer months demand might be expected to increase a further 30 percent to about 40 million Igals per year, assuming the population temporarily doubles for four months each year. With a continuing population increase (Figure 22) similar to the past 30 years, demand including visitor use could approach 90 million Igals by the year 2040.

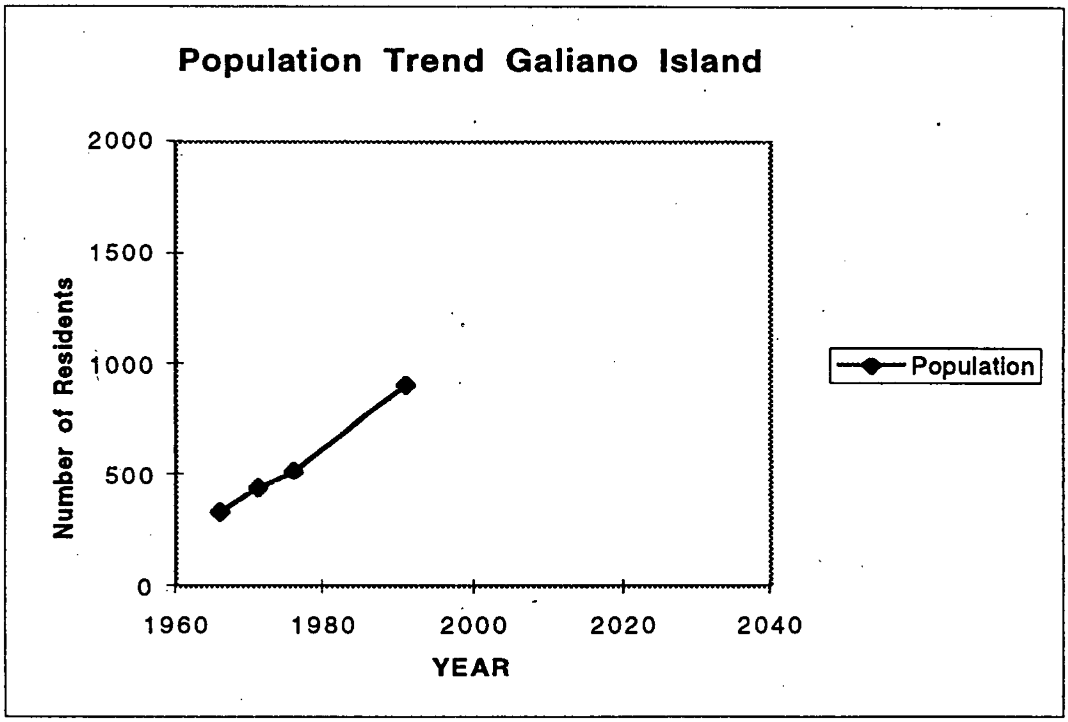


Figure 22. Population trend for Galiano Island.

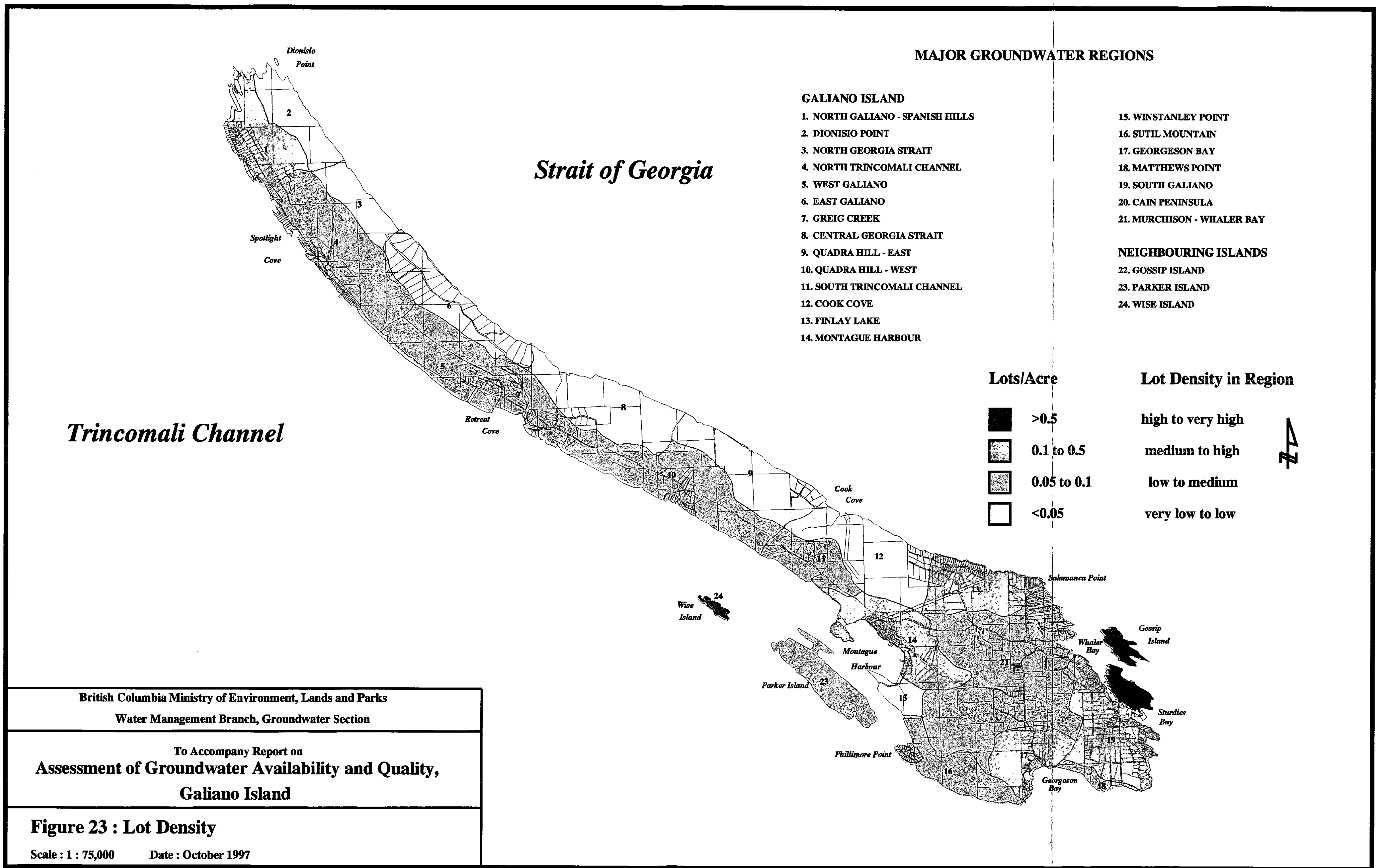
A further indication of groundwater demand can be obtained by examining lot densities on the island (Table 3). Figure 23 shows the distribution of lots as of 1995 and provides an indication of lot density in each of the groundwater regions. For the most part the regions with the greatest lot densities, conform to those areas with the greater number of wells. Lot densities , however, for several regions exceed current well densities by a factor of 50 percent or more (Table 4) indicating that further groundwater development is most likely to occur in these areas. Well densities have the potential to increase significantly in Regions 1 and 14 (North Galiano-Spanish Hills and Montague Harbour) where well densities are relatively high already. While well densities on Wise Island and Gossip Island range from medium to high. These could increase significantly if wells were to be constructed on existing lots. Based on an estimated 1143 lots currently being available on

TABLE 3. Groundwater Regions for Galiano Island and Neighbouring Islands Sorted According to Lot Density.

MAJOR GROUNDWATER REGIONS	AREA of REGION (hectares)	(acres)	ESTIMATED NUMBER OF LOTS	LOT DENSITY Lots/Hectare	LOT DENSITY Lots/Acre
GALIANO ISLAND					
20. CAIN PENINSULA	52	128	85	1.635	0.662
19. SOUTH GALIANO	340	841	195	0.573	0.232
1. NORTH GALIANO-SPANISH HILLS	224	552	105	0.470	0.190
13. FINLAY LAKE	253	625	85	0.336	0.136
17. GEORGESON BAY	194	480	60	0.309	0.125
14. MONTAGUE HARBOUR	291	720	80	0.275	0.111
4. NORTH TRINCOMALI CHANNEL	473	1170	100	0.211	0.086
16. SUTIL MOUNTAIN	203	500	40	0.198	0.080
21. MURCHISON-WHALER BAY	916	2264	150	0.164	0.066
7. GREIG CREEK	282	698	45	0.159	0.065
18. MATTHEWS POINT	36	90	5	0.137	0.056
5. WEST GALIANO	200	493	24	0.120	0.049
10. QUADRA HILL-WEST	454	1122	54	0.119	0.048
11. SOUTH TRINCOMALI CHANNEL	169	417	20	0.118	0.048
6. EAST GALIANO	303	748	31	0.102	0.041
12. COOK COVE	366	905	28	0.076	0.031
15. WINSTANLEY POINT	64	158	3	0.047	0.019
9. QUADRA HILL-EAST	308	762	13	0.042	0.017
8. CENTRAL GEORGIA STRAIT	371	918	15	0.040	0.016
2. DIONISIO POINT	178	440	3	0.017	0.007
3. NORTH GEORGIA STRAIT	136	337	2	0.015	0.006
Totals:	5815	14369	1143		
NEIGHBOURING ISLANDS					
24. WISE ISLAND	13	32	50	3.814	1.543
22. GOSSIP ISLAND	35	87	69	1.949	0.789
23. PARKER ISLAND	165	409	36	0.218	0.088
Totals:	214	529	155		

Lot Density in Region	Lots/Acre
high to very high	>0.5
medium to high	0.1 to 0.5
low to medium	0.05 to 0.1
very low to low	< 0.05

Note: The number of lots in each region has been estimated on the basis of available cadastral mapping. Some lots may transect the boundaries of groundwater regions.



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Water Management Branch, Groundwater Section

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Figure 23 : Lot Density

Scale : 1 : 75,000 Date : October 1997

TABLE 4. Comparison of Lot and Well Densities with Estimates of Water Storage and Demand for Galiano and Neighbouring Islands.

MAJOR GROUNDWATER REGIONS	AREA of REGION (hectares)	(acres)	ESTIMATED NUMBER OF LOTS	LOT DENSITY Lots/Acre	WELL DENSITY Wells/Acre	LOT DENSITY / WELL DENSITY	ESTIMATED WATER STORAGE Igals/year	ESTIMATED DEMAND Igals/year	DEMAND/ STORAGE
GALIANO ISLAND									
20. CAIN PENINSULA	52	128	85	0.662	0.716	0.924	6.98E+06	6.21E+06	0.89
19. SOUTH GALIANO	340	841	195	0.232	0.218	1.066	4.57E+07	1.42E+07	0.31
1. NORTH GALIANO-SPANISH HILLS	224	552	105	0.190	0.104	1.825	3.00E+07	7.67E+06	0.26
13. FINLAY LAKE	253	625	85	0.136	0.051	2.656	3.39E+07	6.21E+06	0.18
17. GEORGESON BAY	194	480	60	0.125	0.104	1.200	2.61E+07	4.38E+06	0.17
14. MONTAGUE HARBOUR	291	720	80	0.111	0.068	1.633	3.91E+07	5.84E+06	0.15
4. NORTH TRINCOMALI CHANNEL	473	1170	100	0.086	0.077	1.111	6.35E+07	7.30E+06	0.11
16. SUTIL MOUNTAIN	203	500	40	0.080	0.016	4.999	2.72E+07	2.92E+06	0.11
21. MURCHISON-WHALER BAY	916	2264	150	0.066	0.063	1.049	1.23E+08	1.10E+07	0.09
7. GREIG CREEK	282	698	45	0.065	0.060	1.071	3.79E+07	3.29E+06	0.09
18. MATTHEWS POINT	36	90	5	0.056	0.022	2.500	4.88E+06	3.65E+05	0.07
5. WEST GALIANO	200	493	24	0.049	0.036	1.333	2.68E+07	1.75E+06	0.07
10. QUADRA HILL-WEST	454	1122	54	0.048	0.045	1.059	6.09E+07	3.94E+06	0.06
11. SOUTH TRINCOMALI CHANNEL	169	417	20	0.048	0.053	0.909	2.27E+07	1.46E+06	0.06
6. EAST GALIANO	303	748	31	0.041	0.017	2.499	4.06E+07	2.26E+06	0.06
12. COOK COVE	366	905	28	0.031	0.016	1.935	4.91E+07	2.04E+06	0.04
15. WINSTANLEY POINT	64	158	3	0.019	0.015	1.278	8.59E+06	2.19E+05	0.03
9. QUADRA HILL-EAST	308	762	13	0.017	0.003	6.491	4.13E+07	9.49E+05	0.02
8. CENTRAL GEORGIA STRAIT	371	918	15	0.016	0.008	2.143	4.98E+07	1.10E+06	0.02
2. DIONISIO POINT	178	440	3	0.007	0.006	1.080	2.39E+07	2.19E+05	0.01
3. NORTH GEORGIA STRAIT	136	337	2	0.006	0.015	0.400	1.83E+07	1.46E+05	0.01
Totals:	5815	14369	1143				7.80E+08	8.34E+07	0.11
NEIGHBOURING ISLANDS									
24. WISE ISLAND	13	32	50	1.543	0.123	12.500	1.76E+06	3.65E+06	2.08
22. GOSSIP ISLAND	35	87	69	0.789	0.194	4.059	4.75E+06	5.04E+06	1.06
23. PARKER ISLAND	165	409	36	0.088	0.012	7.201	2.22E+07	2.63E+06	0.12
Totals:	214	529	155						

Well or Lot Density in Region	Number/Acre
high to very high	>0.5
medium to high	0.1 to 0.5
low to medium	0.05 to 0.1
very low to low	< 0.05

Notes: 1. Water storage calculated utilizing a storage coefficient of 0.001 and aquifer thickenss of 200 feet (61 metres).
2. Estimated demand based on 200 Igpd/lot.

Galiano and assuming one household per lot, potential groundwater demand could approach 108 million Igals per year, including visitor use. A comparison showing the ranges of groundwater storage, recharge and demand estimates for Galiano is depicted in Figure 24.

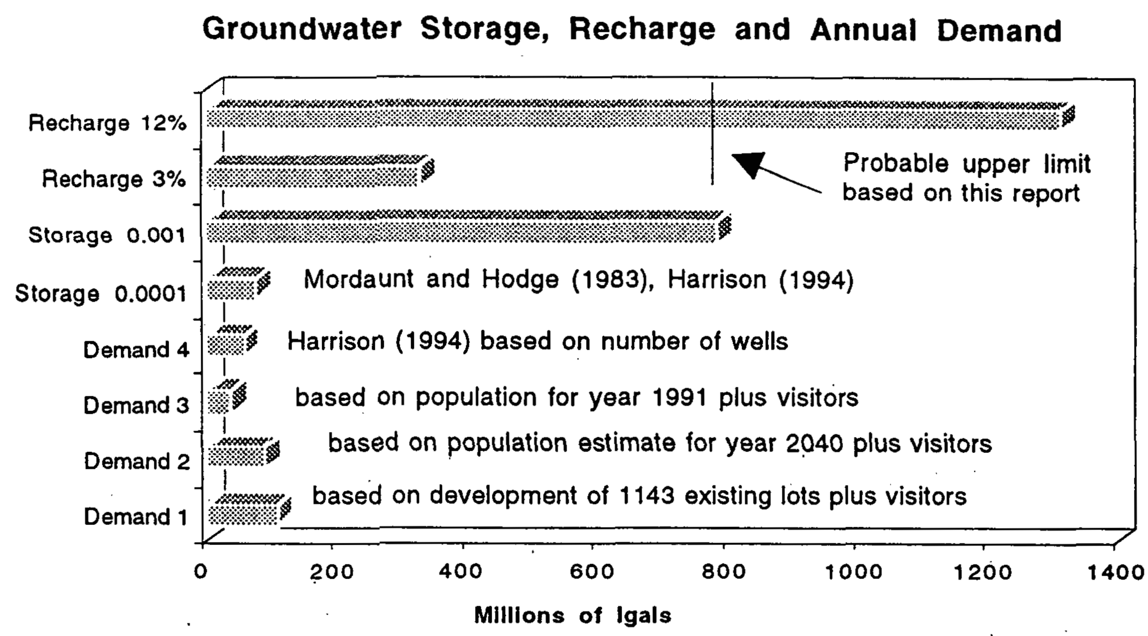

Figure 24. Comparison of groundwater storage, recharge and demand estimates.

For the island as a whole, Harrison (1994) estimated the ratio of demand to storage at 51.4 % (based on individual well usage at 500 Igals/day) with demand/storage ratios theoretically exceeding 100 % in some groundwater regions. Regions having elevated demand/storage ratios may be expected to show evidence of both water quantity (shortages during peak demand) and quality problems. Given the uneven distribution of wells on the island and their concentration in the coastal areas on small lots, it is unlikely except for the smaller groundwater regions such as Cain Peninsula, Gossip Island, Wise Island and parts of the North Galiano-Spanish Hills Region, Finlay Lake Region, South Galiano Region and Georgeson Bay Region that groundwater demand is approaching storage on an annual basis. Well distribution, density, spacing, depth, elevation and proximity to coastal areas are other critical factors which contribute to water quantity and quality problems on the island. The historic pattern of development on the island has been such that for the most part, the upper reaches of the groundwater regions have remained largely undeveloped. While additional groundwater supplies on the island may be available in the upland areas, managing where and how future wells are constructed will be especially important. Community wells for example, should not be precluded in recharge areas. Revised estimates in Table 4. Water availability figures shown are based on a storage coefficient of 0.001 and should be regarded as an upper limit for planning purposes. Full utilization of the estimated groundwater reserves in any one region is unlikely to be feasible without problems occurring. Careful monitoring of groundwater development, the degree of use and response of the groundwater regime is required to determine optimum limits of extraction.

11.4 Interaction of Surface Water and Groundwater

Over much of Galiano Island surface drainage is topographically controlled by distinct ridges and valleys. Many depressions at various elevations between these ridges and in the valleys are natural catchment areas which store water throughout the year (Harrison, 1994). These wetlands and bog areas are or potentially are very important aquifer recharge areas, especially during the extreme moisture deficit period from May to early October when groundwater levels are declining and high demand is occurring on the resource. Under natural conditions throughout much of the year they may be acting as groundwater discharge areas, but potentially they may play a dual role.

Surface water is an important water source on Galiano Island for domestic, stock watering, irrigation use and fire protection. Existing water licences on springs, creeks and lakes on the island have been delineated in the Official Community Plan (Galiano Island Local Trust Committee, 1995) and by Harrison (1994). A listing of active licences is shown in Table 5. Licences have been issued for up to 8.2 million gallons of water annually for domestic use and 48 million gallons (176 acre-feet) for irrigation purposes. Springs represent points of groundwater discharge and attest to the close relationship between groundwater and surface water features. As discussed in Section 10, some wetlands may also represent zones of groundwater discharge. While large surface flows occur in creeks during the winter months a critical factor for water availability is their flow during the summer months. Many of the more viable surface water sources such as Murcheson Creek, Putter Brook and Pirart Brook lie within groundwater discharge areas (Figure 20), wherein groundwater discharge probably assists in sustaining surface flows to some degree during the summer months.

Preliminary estimates (pers. comm. J. Ford, 1995) carried out on several of the major creeks on the island such as Murcheson Creek, Putter Brook and Jack Creek indicate that significant quantities of water (several 100 million Igals) may be available from these sources for community supply purposes. Feasibility studies including an examination of factors such as land acquisition, reservoir construction, environmental impacts, pipeline and water treatment costs would be necessary to determine the viability of using these sources for community water supply systems.

TABLE 5. Summary of Water Licences on Galiano Island, October 1996.

Source Name	Use Description and Quantity
Brammel Spring	1 licence for domestic 1000 gpd
Crabtree Swamp	1 licence for land improvement 0.4 AF
Dalrymple Spring	1 licence for domestic 500 gpd
Davidson Brook	1 licence for Irrigation 10 AF
Farrell Spring	1 licence for domestic 500 gpd
Finlay Brook	3 licences for domestic use 5500gpd
	4 licences for storage 6.25 AF
	1 licence for irrigation at 2 AF
Finlay Lake	1 licence for irrigation 0.25 AF
Fish Pond	1 licence for irrigation 30 AF
Fishbein Pond	1 licence for irrigation 30 AF
Galt Swamp	1 licence for fire protection and storage for 3 AF
Georgeson Creek	2 licences for domestic for 1000gpd
	1 licences for conservation-storage
Greig Creek	2 licences for domestic 1000 gpd
Grimmer Creek	2 licences for domestic use 1000 gpd
	1 licence for storage 0.33 AF
Jack Creek	1 licence for land improvement 0.2 AF
Lindsay Springs	1 licence for waterworks 3285000 gpy
McDowell Brook	1 licence for irrigation for 0.5 AF
	1 licence for land improvement for 10.5 AF
Morgan Creek	1 licence for domestic 500 gpd
Murcheson Creek	1 licence for domestic 2000gpd
	1 licence for domestic 4000 gpd, irrigation 80 AF
Pirart Brook	1 licence for irrigation 10.4 AF, stockwatering 400 gpd
	1 licence for storage 11 AF
Pochin Spring	1 licence for domestic 500 gpd
Pottinger Spring	1 licence for domestic 500 gpd
Putter Brook	1 licence for watering for 10 AF
	1 licence for land improvement for 0.4 AF
Robbins Spring	1 licence for domestic 500 gpd
Sater Spring	1 licence for domestic 500 gpd
Scarrow Spring	2 licence for domestic 1500 gpd
Spotlight Creek	1 licence for domestic 500 gpd
Stemo Spring	1 licence for domestic 150 gpd
Stockade Creek	1 licence for domestic 500 gpd
Trinco Spring	1 licence for waterworks 1095000 gpy
Tweeden Creek	1 licence for domestic 500 gpd

gpd= gallons per day
AF = acre-feet
gpy = gallons per year

12. Hydrochemistry

When precipitation infiltrates into the subsurface, many opportunities are presented for the introduction of mineral and organic substances, micro-organisms, and polluting substances. As surface water seeps downward into the soil and through the underlying deposits to the water table, most of the suspended particles are filtered out. This natural filtration may be partially effective in removing bacteria and other particulate materials; however, the dissolved chemical characteristics of the water may change and vary widely when it comes in contact with different geologic materials.

The nature of the rocks that form the earth's crust affects not only the quantity of water that may be recovered but also its quality characteristics. As surface water seeps downward to the water table, it dissolves portions of the minerals contained by soils and rocks. Ground water, therefore, usually contains more dissolved minerals than surface water.

Significant spatial and temporal groundwater quality variations occur at shallow depth (<150 m) within the fractured sedimentary bedrock of the Upper Cretaceous Nanaimo Group underlying the Gulf Islands. Natural groundwater is found to vary relative to sampling position within the groundwater flow systems. Recharge areas are generally characterized by low mineralized (low specific conductance), calcium and sodium-bicarbonate type groundwater while deeper portions of flow systems and discharge areas are dominated by brackish sodium-chloride type groundwater (Ministry of Environment, Lands and Parks, 1994).

During the period 1960 to present, a large number of chemical analyses have been acquired from various sources for Galiano island water wells and filed with the Groundwater Section in Victoria. The Galiano Conservancy Association assembled much of this chemistry data into an electronic spreadsheet. This spreadsheet was utilized and expanded for purposes of this report. The spreadsheet was checked against original data for accuracy and many additional analyses were added. Data was checked for reliability and some results were deleted from the spreadsheet. This could occur where the water had been treated or where the well had not been in use for an extended period. Some 562 water analyses on the final spreadsheet were loaded to an Oracle™ relational database to query and produce maps of various chemical parameters using ARC/INFO™ software as the geographic information system (GIS). This database was linked to the water well database so data could be accurately plotted to maps using each wells digitized location. Also, other parameters on each well could be used in querying the data (i.e. plot all chloride values in the database for only drilled bedrock wells).

12.1 Sampling Procedures and Analyses

The 562 water analyses compiled and loaded to the Oracle™ relational database were obtained from various sources. These included:

1. A number were obtained from reports submitted by groundwater consulting firms, especially in recent years with the developments occurring in the former MacMillan Bloedel Forestry Lands.

2. In the summer of 1973 the Groundwater Section carried out field sampling and tested the water samples with a Hach™ DR-EL Engineering Laboratory Kit.

3. In August 1980, chemical tests were carried out by the Groundwater Section in order to update and supplement information in areas with high chemical concentration problems (Mordaunt and Hodge, 1983).

4. From the early 1980's to 1994 many local people collected water samples and sent them for laboratory analyses under the British Columbia subsidized Water Quality Check Program. Copies of all this data was made available to the Groundwater Section.

5. In the summer of 1994 D. Harrison carried out field sampling with a field Hach™ water chemistry kit and a Beckman™ conductivity meter.

6. In the summer of 1995 field tests were carried out using a Hach water-chemistry kit and a Beckman™ conductivity meter. Fresh chemicals were used in all testing and the conductivity meter was calibrated with solutions obtained from the laboratory. Wells sampled were checked for use and that the water was not treated to insure accurate results.

As the analyses are obtained from a number of sources the quality of sampling would vary. Where it was obvious there was a problem with the sample due to factors such as sampling an unused well or the water was subject to in home treatment, the sample results were not used in this study.

12.2 Selected Physical and Chemical Parameters

12.2.1 Specific Conductance

Specific conductance or conductivity is a measure of water's ability to conduct an electrical current. This varies with the number of free ions or amount of dissolved constituents. The specific conductance is proportional to total dissolved solids and inversely proportional to temperature (Halstead, 1986). In general, specific conductance multiplied by a factor of 0.65 will give an estimate of the total dissolved solids in ground water. Total dissolved solids (TDS) of 1000 mg/L corresponds with a specific conductance of approximately 1600 μmhos/cm (micromhos per centimetre) at 25°C. Specific conductance generally has a direct correlation with the length of time water has been in the groundwater flow system. However, in an area undergoing salt water intrusion the specific conductivity would be elevated. It is therefore a good field measure to take in areas of suspected intrusion, especially in combination with chloride testing, and to generally map ground water flow systems. The recommended limit for specific conductance in drinking water is 1000 μmhos/cm.

Three maps displaying conductivity in a time series were produced to examine any pattern occurring with time. These are: Figure 25 showing conductivity data historically (1950 to 1974); Figure 26, historically to 1984 and Figure 27, historically to 1996. These basically show high conductivity readings occurring prior to 1974 along the east coast from south of Salamanca Point to south of Sturdies Bay and along the coast south and north of Spotlight Cove. By 1983 these two areas had additional high conductivity data, also a high reading was recorded near the shore at Georgeson Bay, near the coast south of Retreat Cove and on Wise Island. The high reading obtained inland from Georgeson Bay is for a dug well and would not be from seawater intrusion or deep brines. Harrison (1994) explained its occurrence as a result of surface run-off from a nearby industrial property. The third map (Figure 27) shows many more high conductivity readings being obtained in the two main problem areas. These suggest evidence of saltwater intrusion, which is also likely the case for the additional high readings obtained at Phillimore Point and Montague Harbour..However, the two recent high readings obtained for two deep drilled bedrock wells north to north-east of Retreat Cove on the west side of Galiano Island are not believed due to saltwater intrusion, or from a local surface source. These appear to be the result of saline water occurring at depth.

12.2.2 Chloride

The presence of high levels of chloride in groundwater can result from a number of conditions, such as: tapping groundwater that has been in the flow system a long enough time to evolve from a bicarbonate type water to a chloride type, or from water extracted from marine deposited sediments, containing residual salts, or from infiltration from surface sources, or from salt water intrusion caused by overpumping wells (Mordaunt and Hodge, 1983). The Canadian Water Guidelines (Health and Welfare Canada, 1989) set the maximum acceptable concentration (MAC) for chloride in drinking water at 250 mg/L.

Four maps in a time series were prepared and show the results of sampling and testing for chloride concentration in the groundwater. The first map (Figure 28) displays historic chloride data to 1974. This data shows a similar pattern as the conductivity data for that period. High chloride readings were obtained along the coast south of Salamanca Point to south of Sturdies Bay and in the Spotlight Cove area. Of the 103 samples analyzed for chloride, 84% contained less than 50 mg/L and 9% were above the MAC for chloride of 250 mg/L. The second map (Figure 29) displays the chloride data to 1984. Additional high chloride levels are shown in the general Whalers Bay to Sturdies Bay area. High level readings were also obtained along the coast at Georgeson Bay, Montague Harbour, and south of Retreat Cove. Of the 148 samples analyzed, 79% contained less than 50 mg/L chloride, while 12% were above the MAC of 250 mg/L. The third map (Figure 30) displays the chloride data historically to 1996. High level readings continue to be obtained in the Salamanca Point area south to Sturdies Bay. Additional high chloride levels are found at Phillimore Point, Montague Harbour, Wise Island, south of Spotlight Cove, Georgeson Bay, near the coast south-east of Retreat Cove, and north to north-east of Retreat Cove on the west side of Galiano Island. Of the 271 samples analyzed for chloride to 1996, 73% contained less than 50 mg/L chloride and 14% were above the MAC of 250 mg/L. The fourth map (Figure 31) shows only the recent chloride data obtained from 1984 to 1996. Areas of elevated chloride correspond with areas of elevated specific conductance.

12.2.3 Fluoride

In some areas water sources contain natural concentrations of fluoride. Where the concentrations approach optimal levels, beneficial health effects have been observed. However, fluoride concentrations in excess of 1.5 mg/L may produce dental fluorosis (tooth mottling) particularly among children ingesting these waters (British Columbia Ministry of Health, 1982). Kohut and Hodge (1985) reported fluoride concentrations up to 13.4 mg/L in bedrock wells at a number of locations in Cretaceous bedrock strata on the Gulf Islands and east coast of Vancouver Island. They surmised the high concentrations were associated with water-producing zones in shale and clay strata and may be attributed to the release of fluoride ion from fossiliferous marine shales containing fluorapatite, through dissolution and anion exchange processes under elevated pH conditions.

Figure 32 is a map showing the distribution of known fluoride concentrations in the study area. Of the 184 sample results known, 19 are equal to or greater than the health standard of 1.5 mg/L, with the highest concentration reported at 7.08 mg/L. All but one of these is completed in the Gabriola Formation and where a detailed drill log is available it describes shale layers occurring in the marine sandstone. All but two samples have pH levels exceeding 8.0. The two exceptions are reported as 7.8 and 7.9.

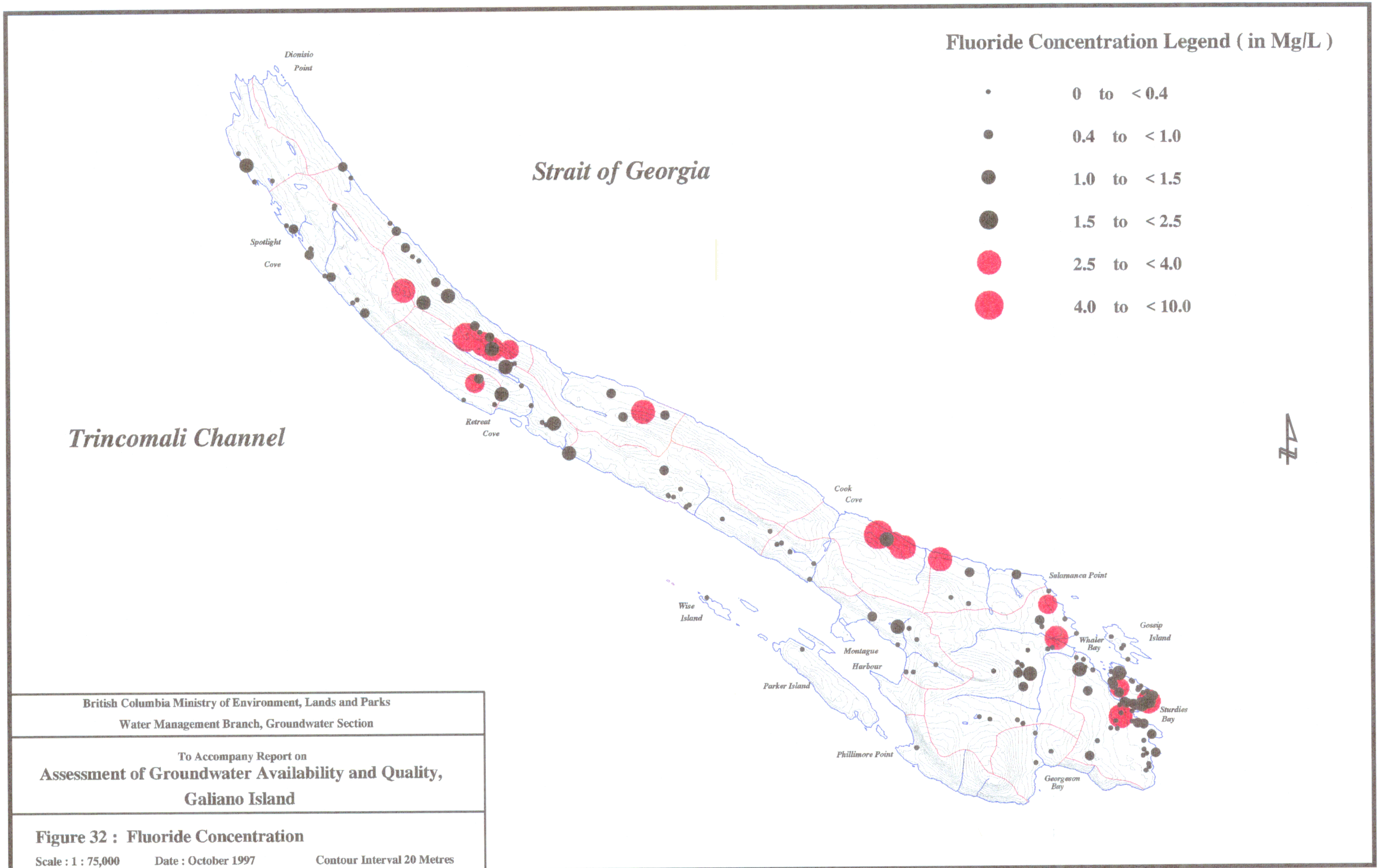

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Figure 32 : Fluoride Concentration

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

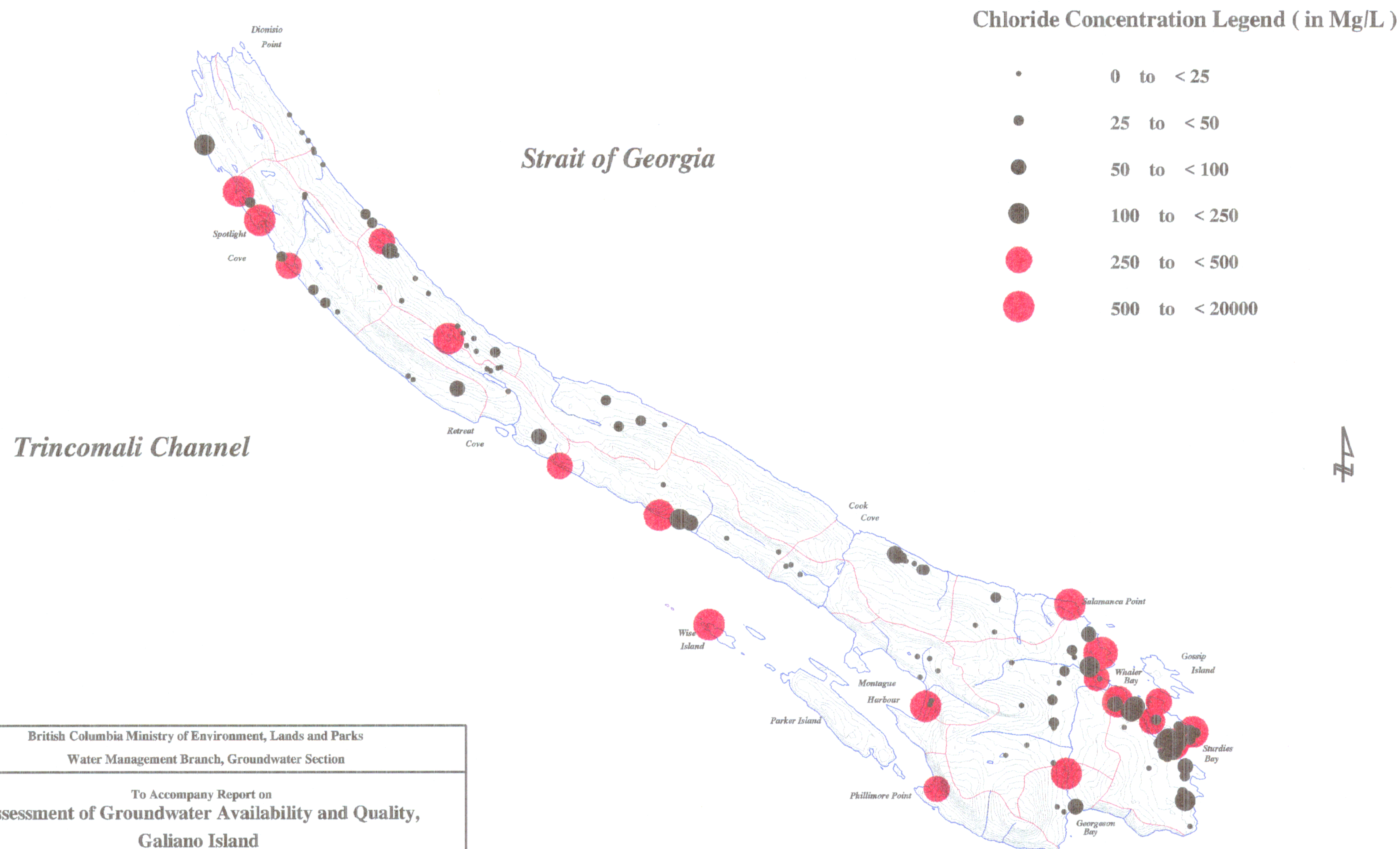

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Figure 31 : Chloride Data 1984 to 1996

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

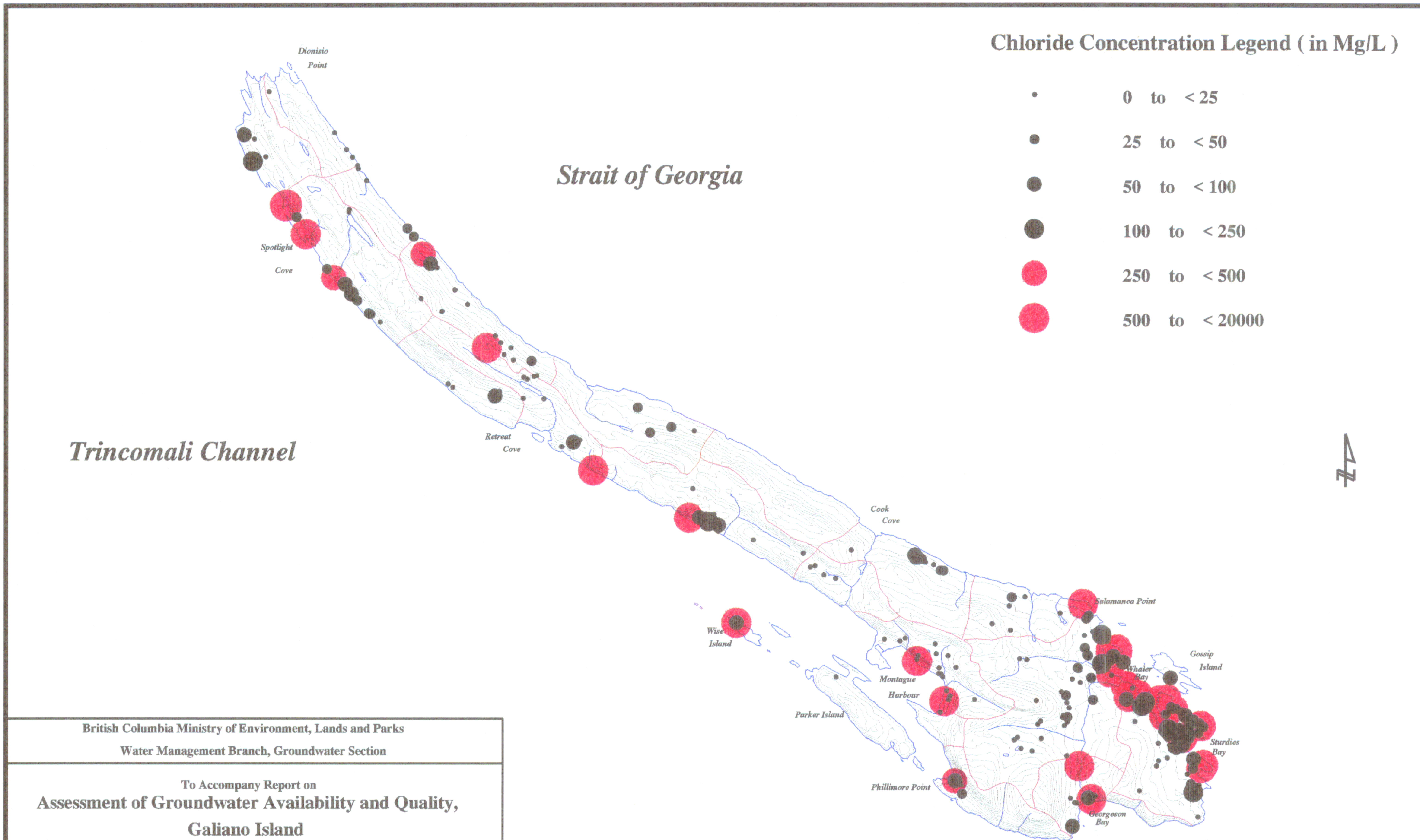

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Figure 30 : Chloride Data to 1996

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

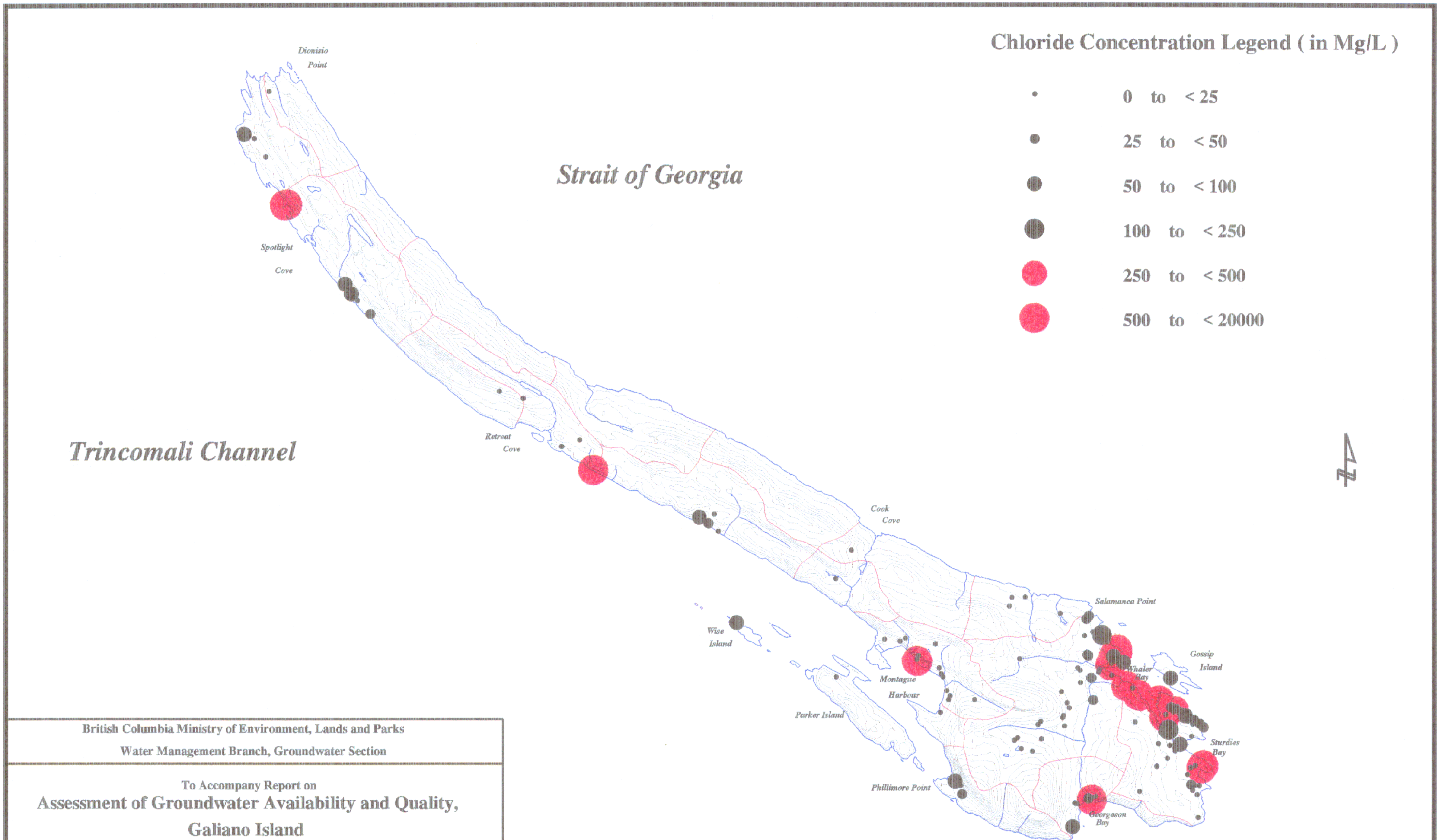

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Figure 29 : Chloride Data to 1984

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

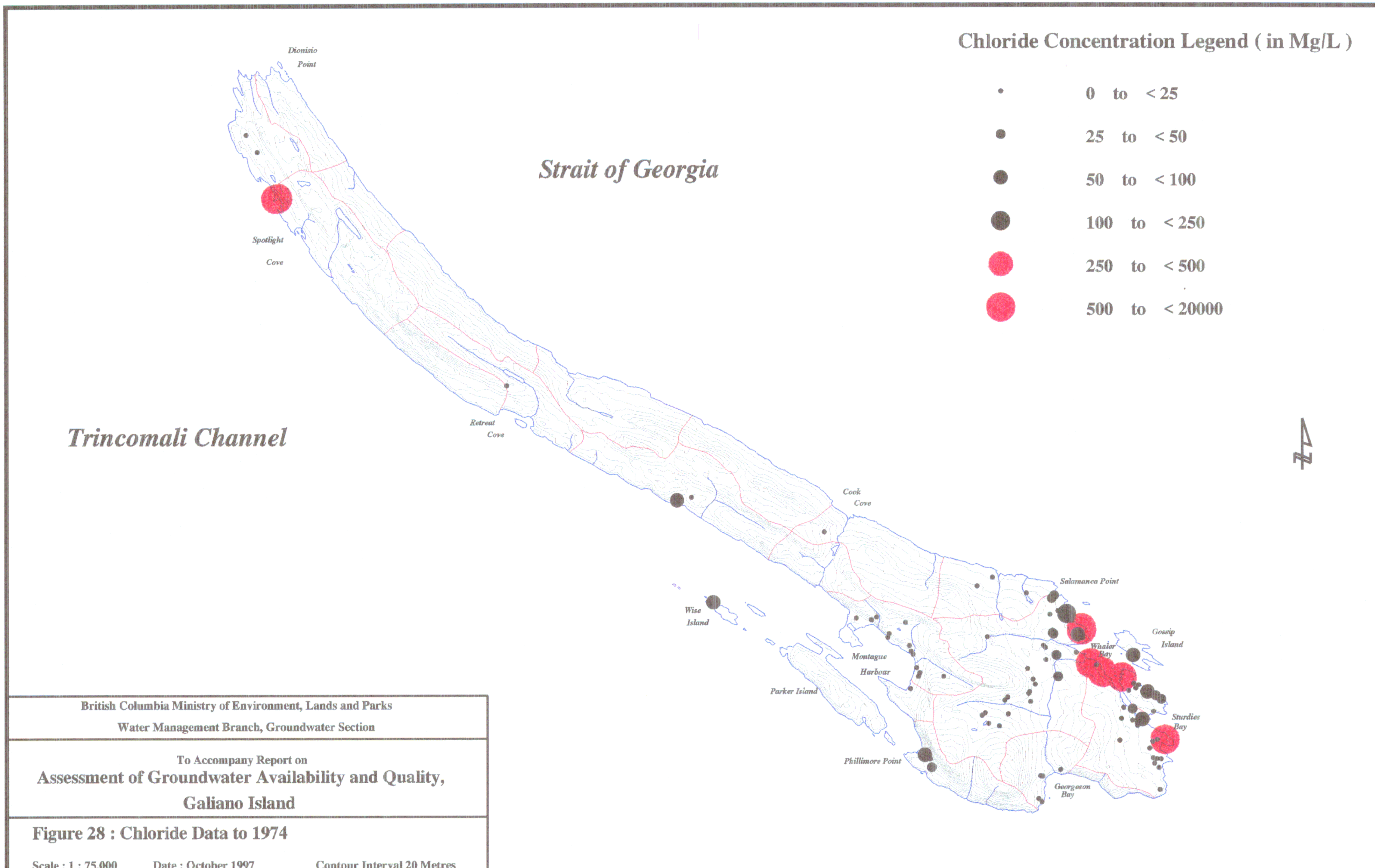

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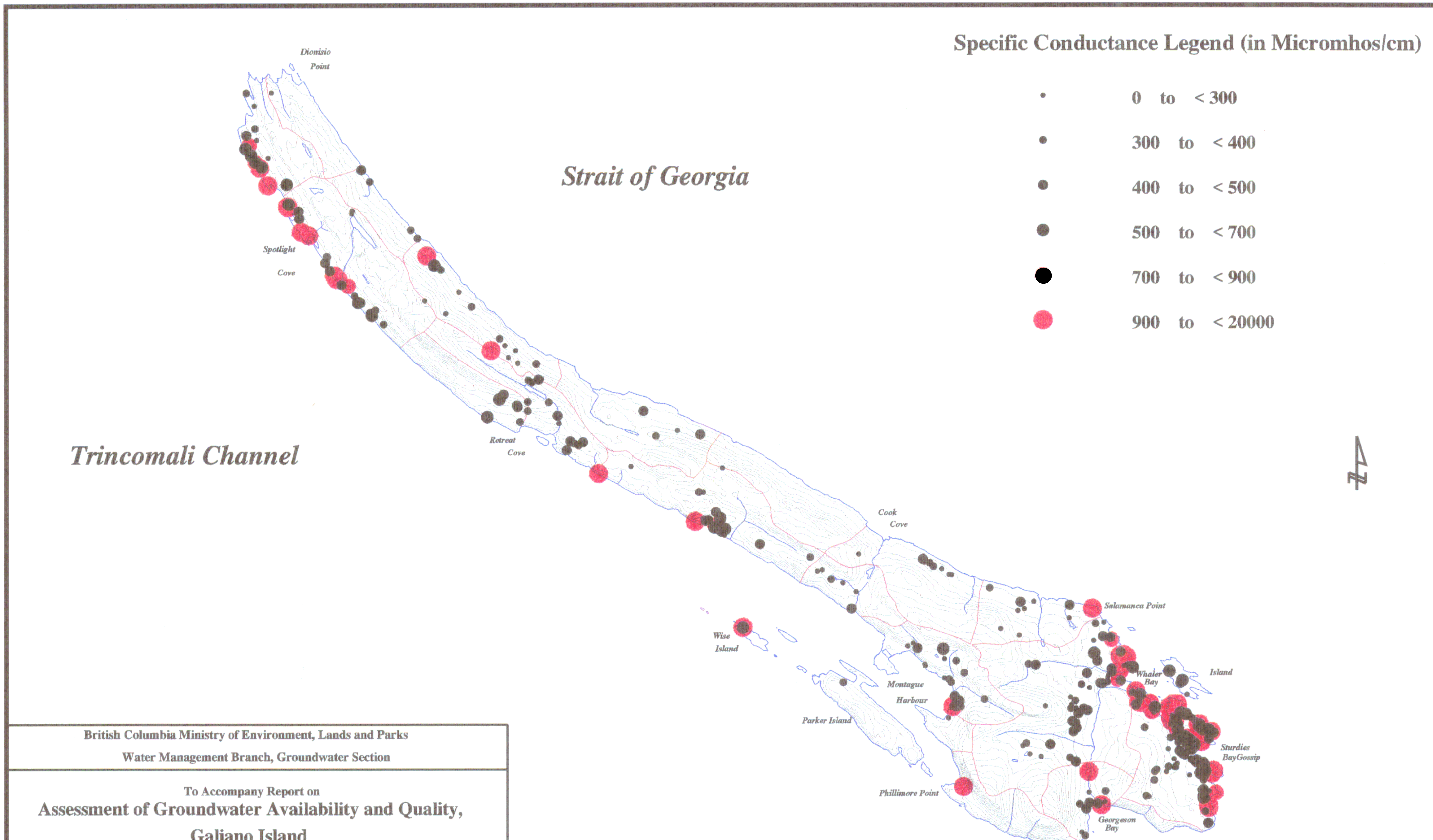
Figure 28 : Chloride Data to 1974

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres



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To Accompany Report on
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Figure 27 : Specific Conductance to 1996

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

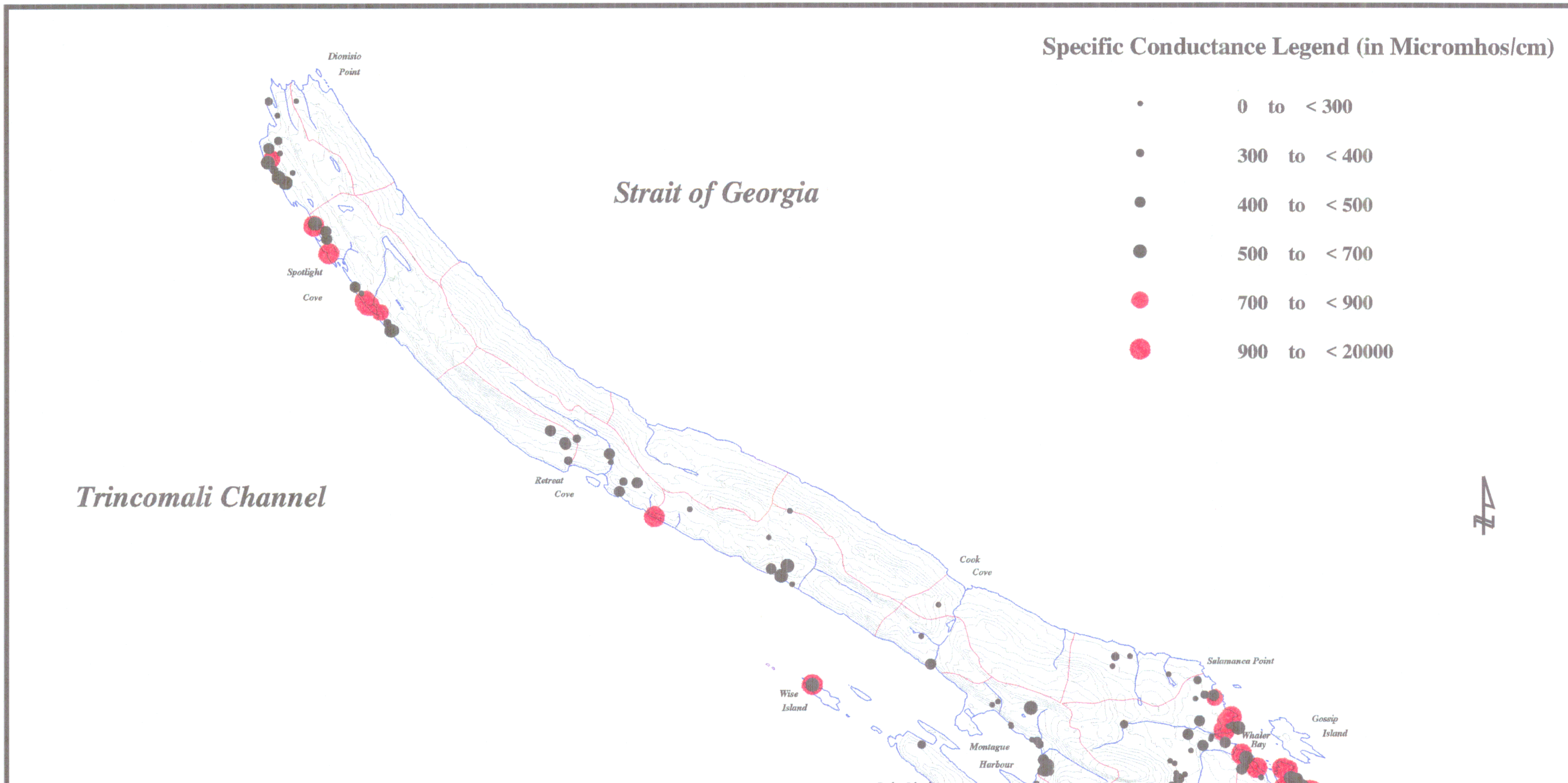

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Figure 26 : Specific Conductance to 1984

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

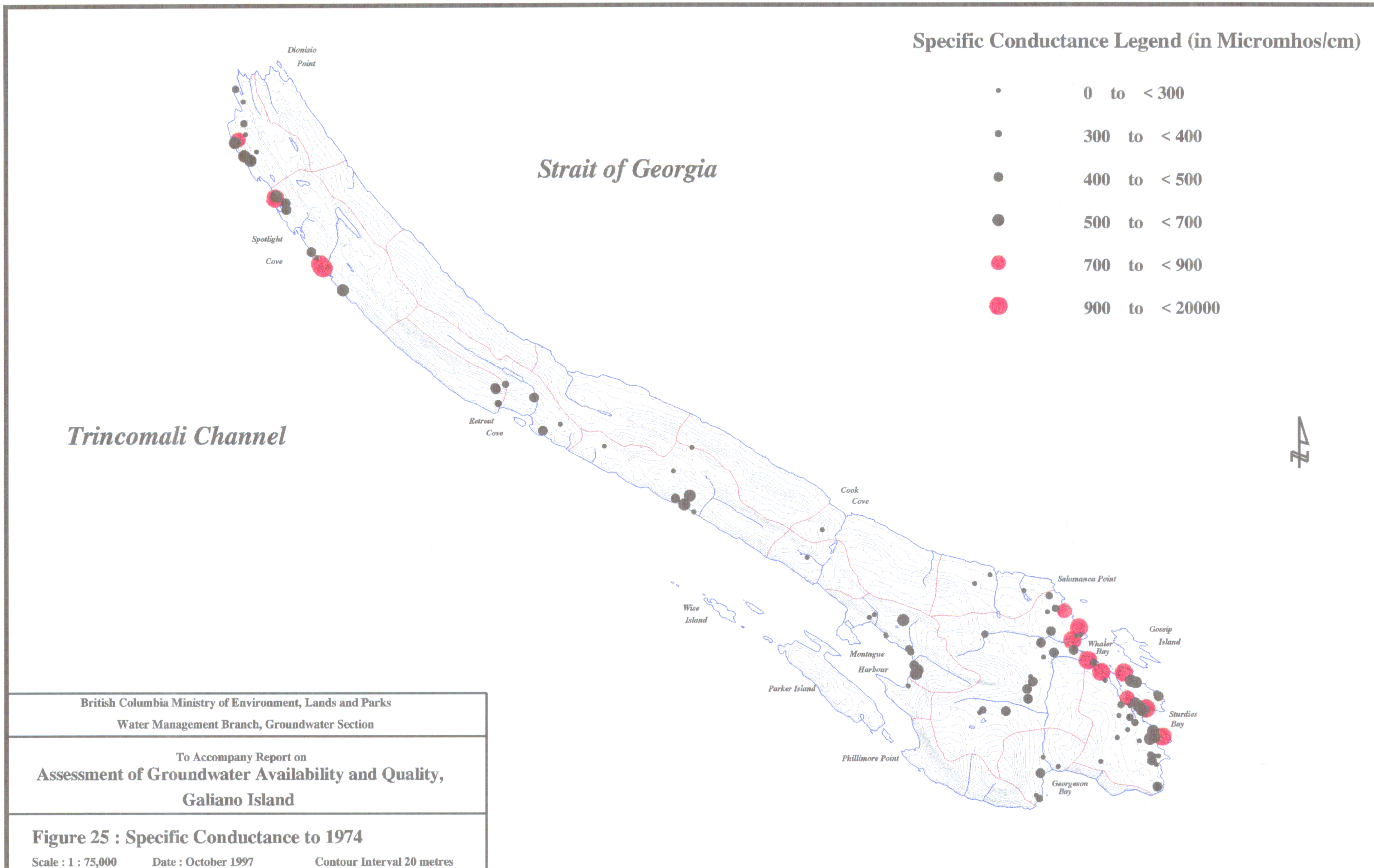

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Figure 25 : Specific Conductance to 1974

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 metres

12.2.4 Sodium and Potassium

Sodium is the most important member of the alkali metals and abundant of the group in natural waters. Essentially all waters contain some sodium, this may vary from minute amounts to very high concentrations found in connate waters. Sea water contains about 10,000 mg/L of sodium (Hem, 1959). For persons placed on a low-sodium diet because of heart, kidney, circulatory ailments or complications of pregnancy, the level of sodium in water is an important consideration.

Figure 33 is a map of Galiano, Gossip, Parker and Wise Islands and displays ranges of sodium results reported. Elevated levels of sodium occur near the coast and are likely due to saltwater intrusion, however, a few elevated levels are reported inland and are likely related to the presence of older more mineralized groundwater.

Potassium concentrations are low for the most part. The highest recorded concentration is 12 mg/L.

12.2.5 Calcium and Magnesium

Calcium and magnesium are the most common constituents found in natural waters. These elements contribute to the hardness of water and they are readily dissolved from many rocks and leached from the soils (Halstead, 1986). The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) in assessment of data decided there was no need to set a numerical guideline for either of these constituents.

Figure 34 is a map showing sample ranges for 241 tests for total calcium. Of these, 91% tested less than 50 mg/L calcium. Of the 5% testing 100 mg/L or higher, all except one was associated with high conductivity water and/or high chloride water. The exception was a sample from a spring at Phillimore Point which has low chloride but high sulphate content.

Figure 35 is a map displaying total magnesium ranges. Of the 223 total test results, 95% are in the range 0 to less than 20 mg/L total magnesium.

12.2.6 Hardness

The hardness of water is defined as the concentration of ions in the water which react with sodium soaps to produce insoluble residues. The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) has set no guideline for hardness. It states " Public acceptance of hardness varies considerably. Generally, hardness levels between 80 and 100 mg/L (as CaCO3) 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."

Figure 36 shows the distribution of 308 hardness values obtained was constructed. It was found that 71% of the test results showed the well water to have a hardness value of less than 100 mg/L, 90% were less than 200 mg/L and 10% were 200 mg/L or higher. Of the 32 test results recorded at 200 mg/L or higher, all but three are located relatively near the coast and correspond to the areas of high conductivity and high chloride groundwater.

12.2.7 Alkalinity

Carbonate (CO3) and bicarbonate (HCO3) alkalinity in water reflects its ability to neutralize acid. The presence of alkalinity does not imply that the water has a pH greater than 7, it merely indicates that ions are present which can neutralize acid. When groundwater is recharged by precipitation, bicarbonate ions are usually the first to enter solution. For this reason, a water sample which has a predominant bicarbonate value is commonly associated with the recharge end of the groundwater flow system. Carbonate ions seldom form a large percentage of the alkalinity ions (Heisterman, 1974).

Figure 37 is a map showing various categories of total alkalinity. Fifty-six percent of the test results fall in the 0 to less than 150 mg/L categories and ninety-two percent in the 0 to less than 225 mg/L. Only one sample was in excess of 500 mg/L bicarbonates, which is the acceptable limit (Halstead, 1986).

12.2.8 Hydrogen Ion (pH)

The relative hydrogen ion concentration (pH) in a water sample controls whether a solution will have acidic or basic properties. pH values range from 0 to 14, where 7 indicates neutral water, values less than 7, increasing acidity; and values greater than 7, increasing alkalinity. pH is an important indicator in groundwater because many chemical reactions are influenced by the degree of acidity or alkalinity (Heisterman, 1974). As an aesthetic objective the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) , recommend the pH should be within the range of 6.5 to 8.5.

The 384 test results for pH are shown on a map of the study area (Figure 38). The following calculations were prepared from the data:

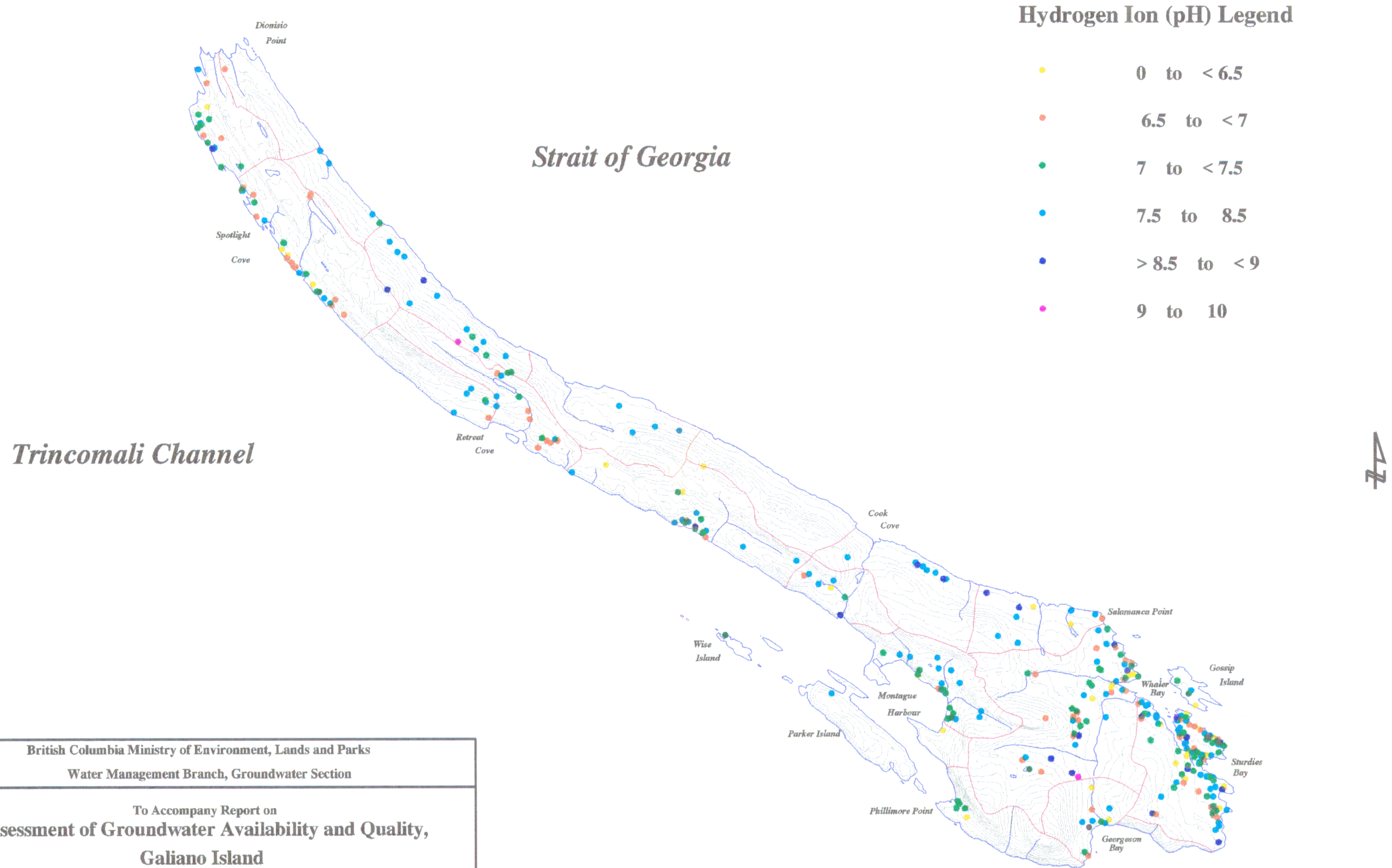

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Figure 38 : Hydrogen Ion (pH)

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

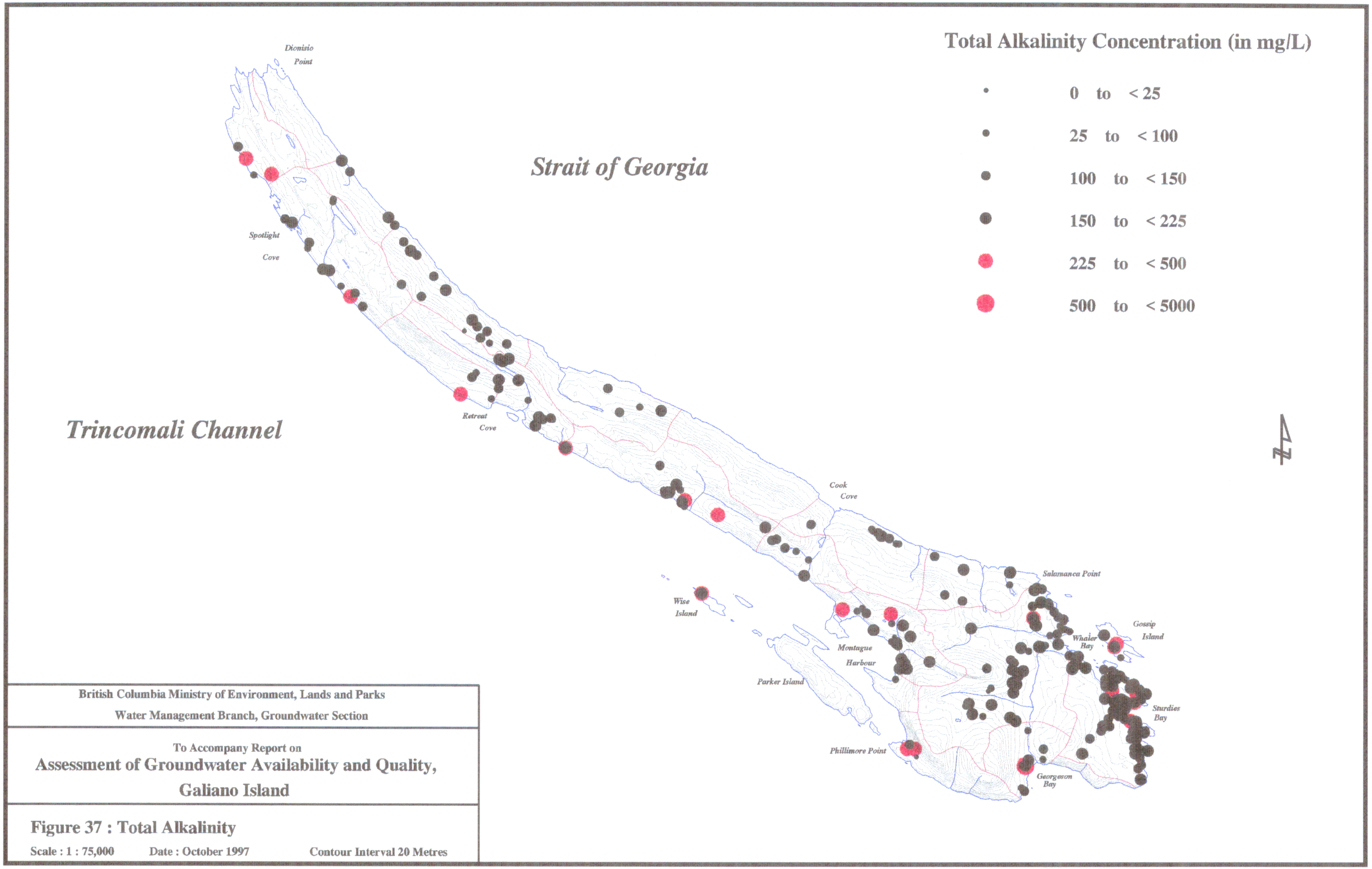

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Figure 37 : Total Alkalinity

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

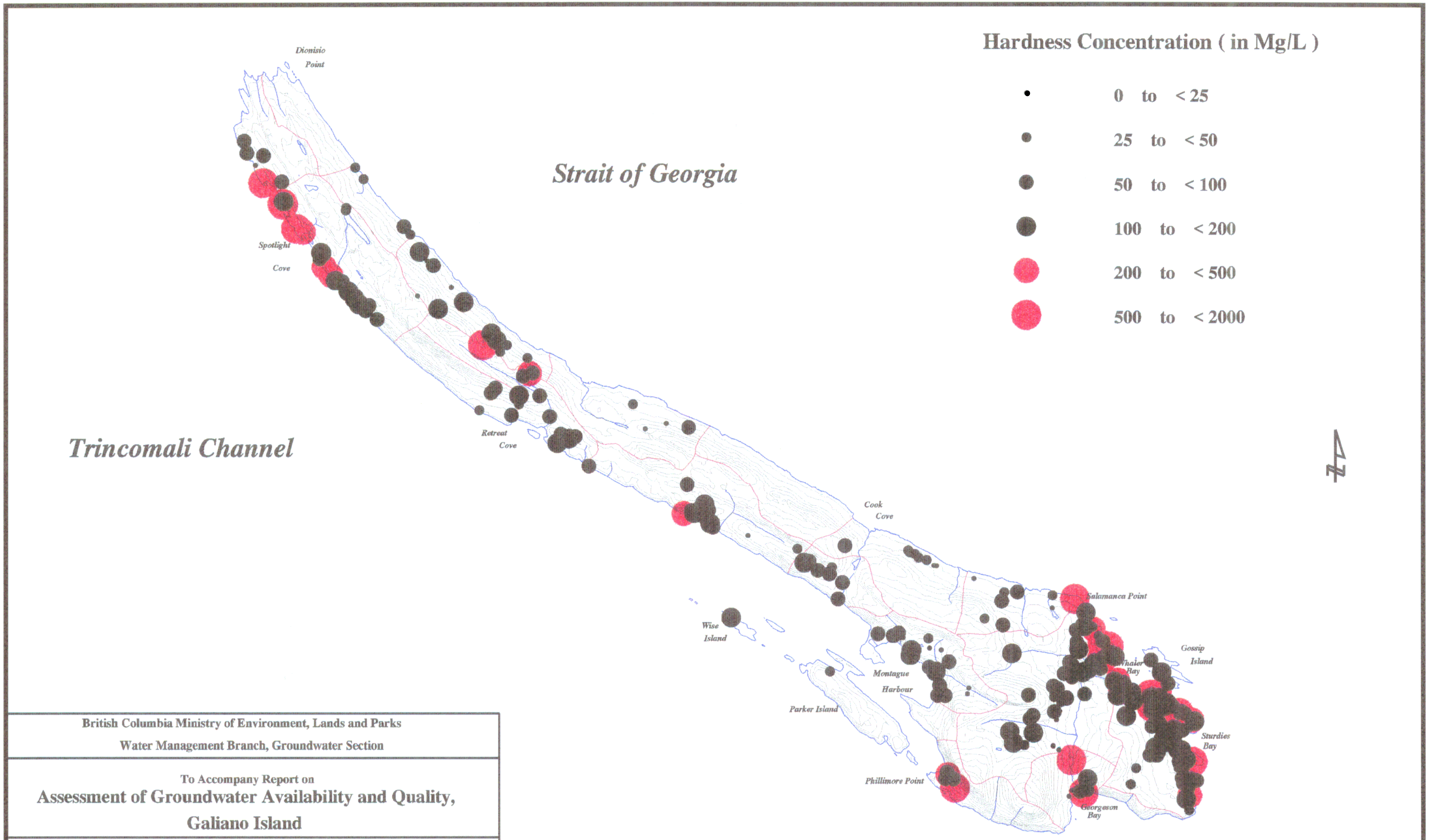

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Figure 36 : Hardness

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

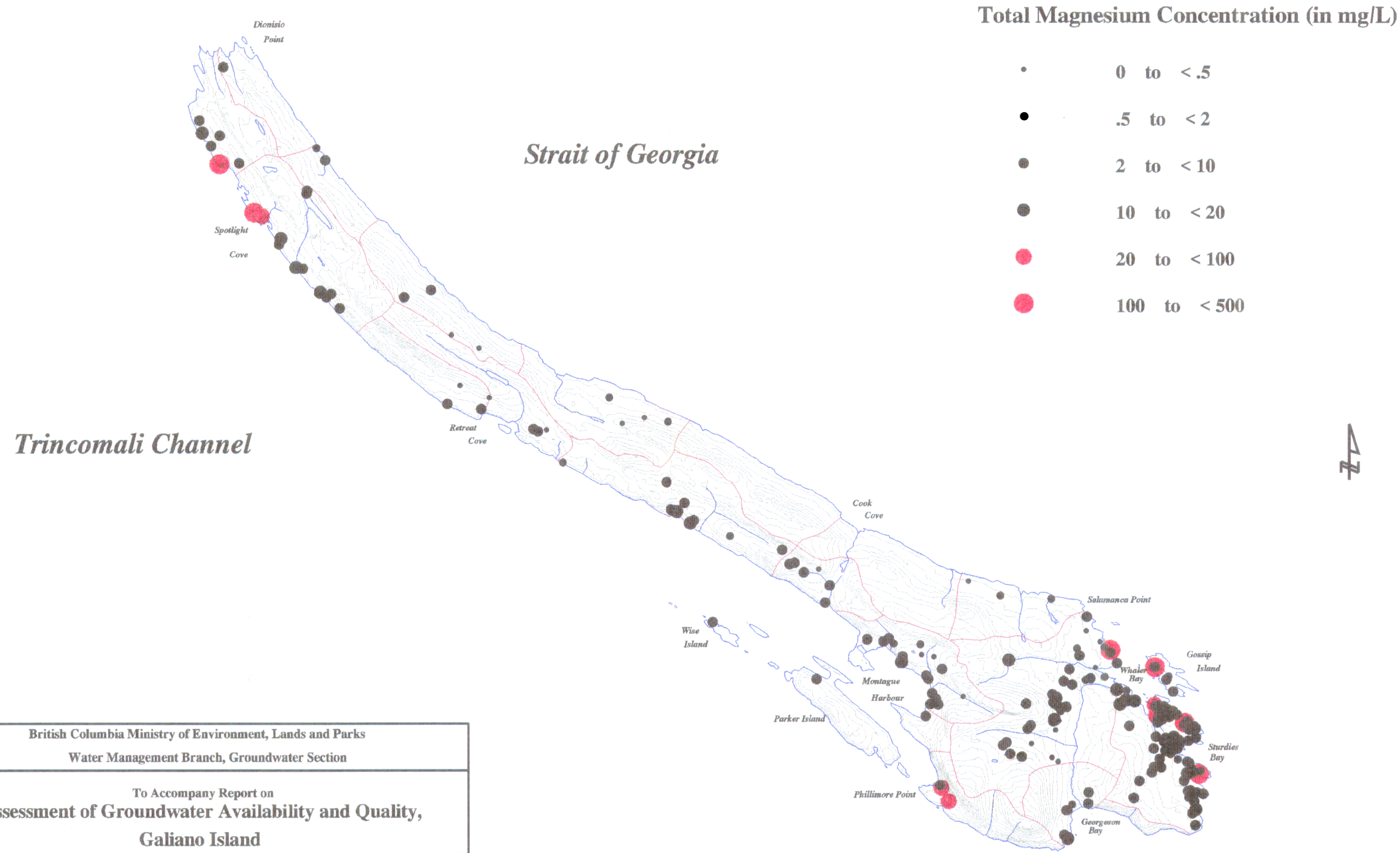

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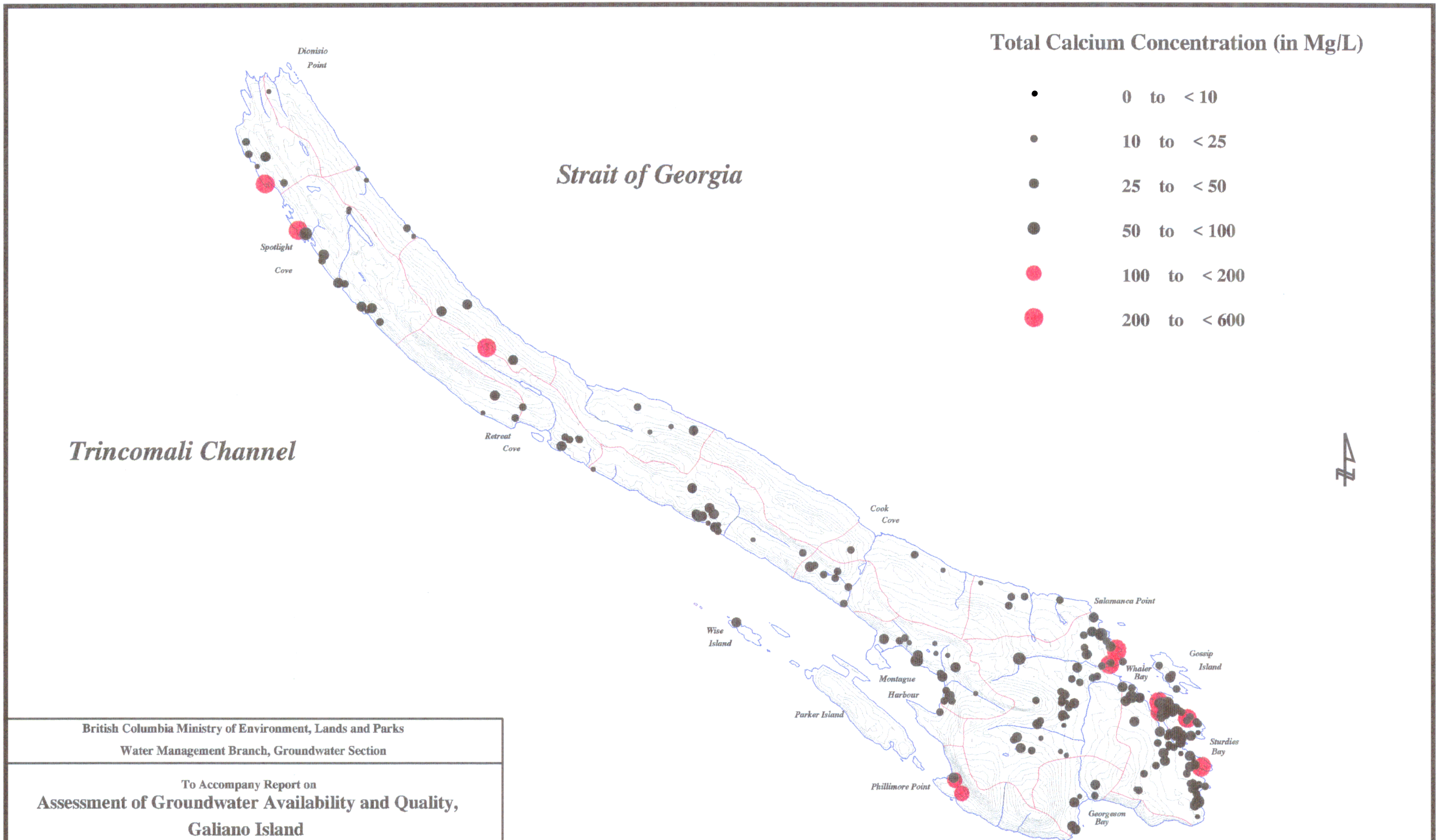
Figure 35 : Magnesium

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres



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To Accompany Report on
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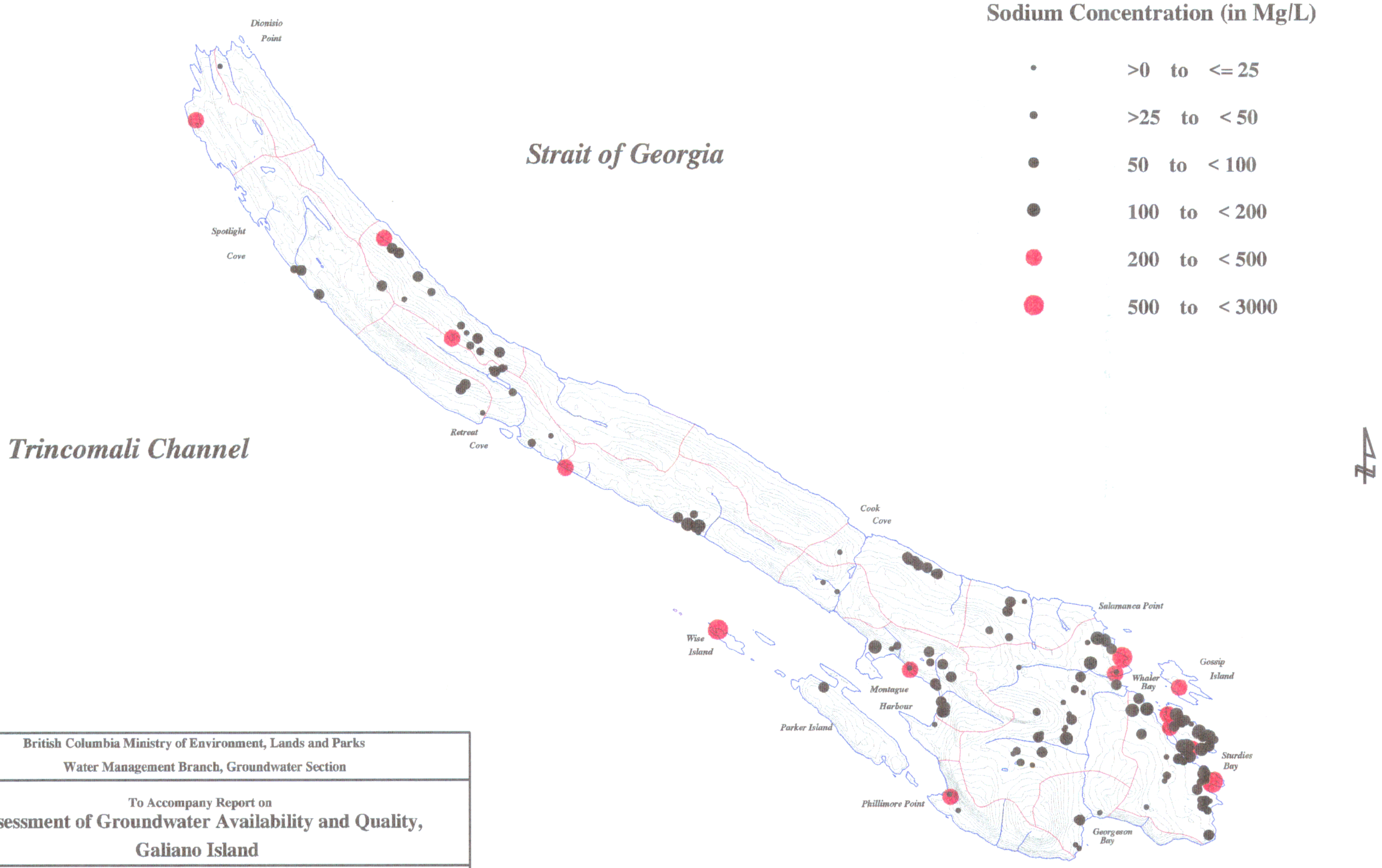
Figure 34 : Calcium

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres



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To Accompany Report on
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Figure 33 : Sodium

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

12% have a pH less than 6.5
81% have a pH from 6.5 to 8.5
7% have pH > 8.5 to 10.

The values ranged from as low as 5.5 to as high as 10.

12.2.9 Sulphate and Hydrogen Sulphide

Elevated concentrations of sulphate ion have only been reported in three instances in greater concentrations than 200 mg/L. Two of these are associated with high chloride content wells and very likely are not in use. The third is for a licensed spring at Phillimore Point. It was tested to contain 583 mg/L sulphate in the summer of 1973.

Figure 39 is a map displaying various known concentrations of sulphate in the groundwater. Of the 140 known tests for sulphate, 90% gave concentrations less than 50 mg/L. The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) , for aesthetic reasons has set ≤ 500 mg/L as an objective for sulphates. For drinking purposes, a preferred limit of 250 mg/L is proposed, however concentrations up to 500 mg/L are acceptable (Halstead, 1986).

Hydrogen sulphide (H_2S) which is often associated with sulphates can be detected readily by its characteristic rotten-egg odour. Concentrations less than 1 mg/L can cause severe corrosion. This amount can be detected by odour and taste (Driscoll, 1986). In the study area, the H_2S characteristic smell has been reported on a number of occasions. However, no actual measurements of concentrations are on file. The H_2S may result from anaerobic decay of organic material and bacterial reduction of sulphates and is often associated with shales and clays (Mordaunt and Hodge, 1983).

12.2.10 Nitrate

Nitrate can be a natural constituent but high concentrations often suggest a source of pollution, (Ministry of Environment, Lands and Parks, 1994). The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) maximum acceptable concentration for Nitrate ($N0_3$) is 45 mg/L or 10 mg/L if expressed as Nitrogen (N). Nitrate may cause methaemoglobinaemia in infants who have been given water or fed formulas prepared with water having high nitrates.

Figure 40 was prepared to display laboratory test results for NO_3 + NO_2. While field tests nitrate have been undertaken for nitrate (Harrison, 1994), these results are considered approximate only and need to be confirmed by laboratory analysis. It basically shows that few wells have elevated $NO_3 + NO_2$ concentrations. Of the four tests that showed $NO_3 + NO_2$ concentrations over 2 mg/L, two were for springs and one was for a 8 foot dug well. These three results were obtained in the 1970's. These results would suggest improper wellhead and spring intake construction and surface runoff contamination possibly contributing to pollution and not direct pollution of the aquifer.

In constructing the map (Figure 40) it was calculated that 1% of the total 172 analyses for $NO_3 + NO_2$ were above the MAC of 10 mg/L (expressed as Nitrogen) and 91% had less than 0.5 mg/L.

12.2.11 Iron

Iron is found in trace amounts in practically all sediments and sedimentary rocks. The iron content of water is important because small amounts seriously affect water's usefulness for some domestic and industrial purposes. The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989), for aesthetic reasons propose an objective of ≤ 0.3 mg/L because iron in water stains plumbing fixtures, stains clothes during laundering and clogs pipes. Beyond 1.0 mg/L the water has an objectionable bitter-sweet astringent taste (Halstead, 1986).

Most water problems that result from high iron content are associated with the sudden change in the state of the iron from ferrous (dissolved) to ferric (semisolid) iron. Ferric oxides and oxy-hydroxides come out of solution and coat surrounding surfaces (Driscoll, 1986). The water is clear when pumped, but on standing turns yellow and a reddish flocculent settles out. Water standing in a well that has been idle may have a higher iron content compared to the natural waters in the aquifer. In some cases this may be contributed from corrosion of the well casing. Therefore, when sampling a well, the pump should be operated long enough to remove all the stagnant water. This appears to be a problem with some of the water samples collected on Galiano Island.

Figure 41 is a map showing various ranges of concentrations of total iron obtained in water analyses historically to present. Dissolved iron was seldom tested for. "Dissolved" iron is iron that is found in solution when the iron determination is made on a filtered sample at the laboratory. "Total" iron includes all the iron in solution and including that which has precipitated out in the sample bottle. The "dissolved" iron determination often is not representative of conditions existing in the sample at the time of collection, because oxidation of ferrous iron and precipitation of ferric hydroxide has often occurred prior to iron determination. "Total" iron values should represent more closely the actual concentration in the sample at the time of

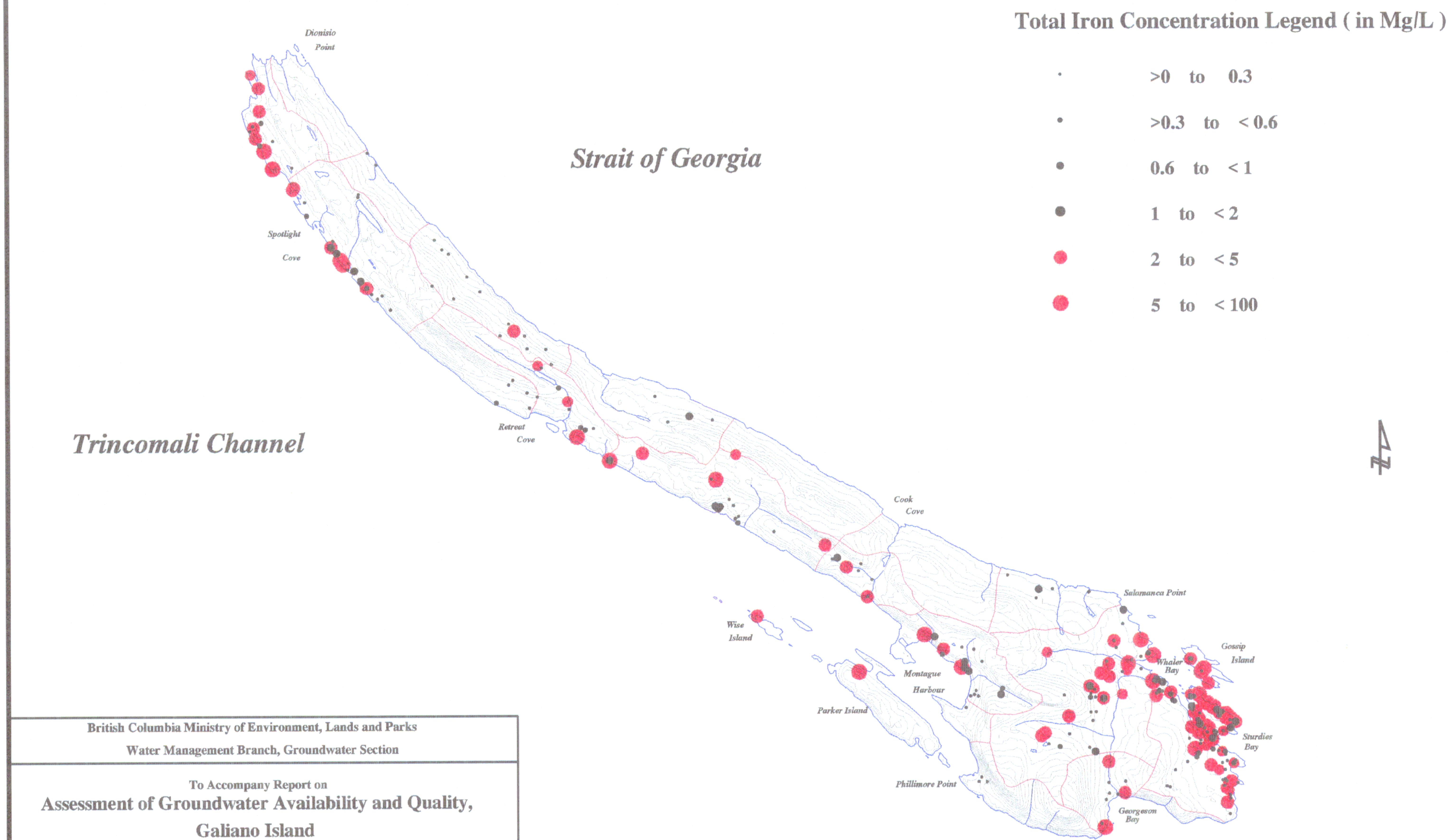

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Figure 41 : Total Iron

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

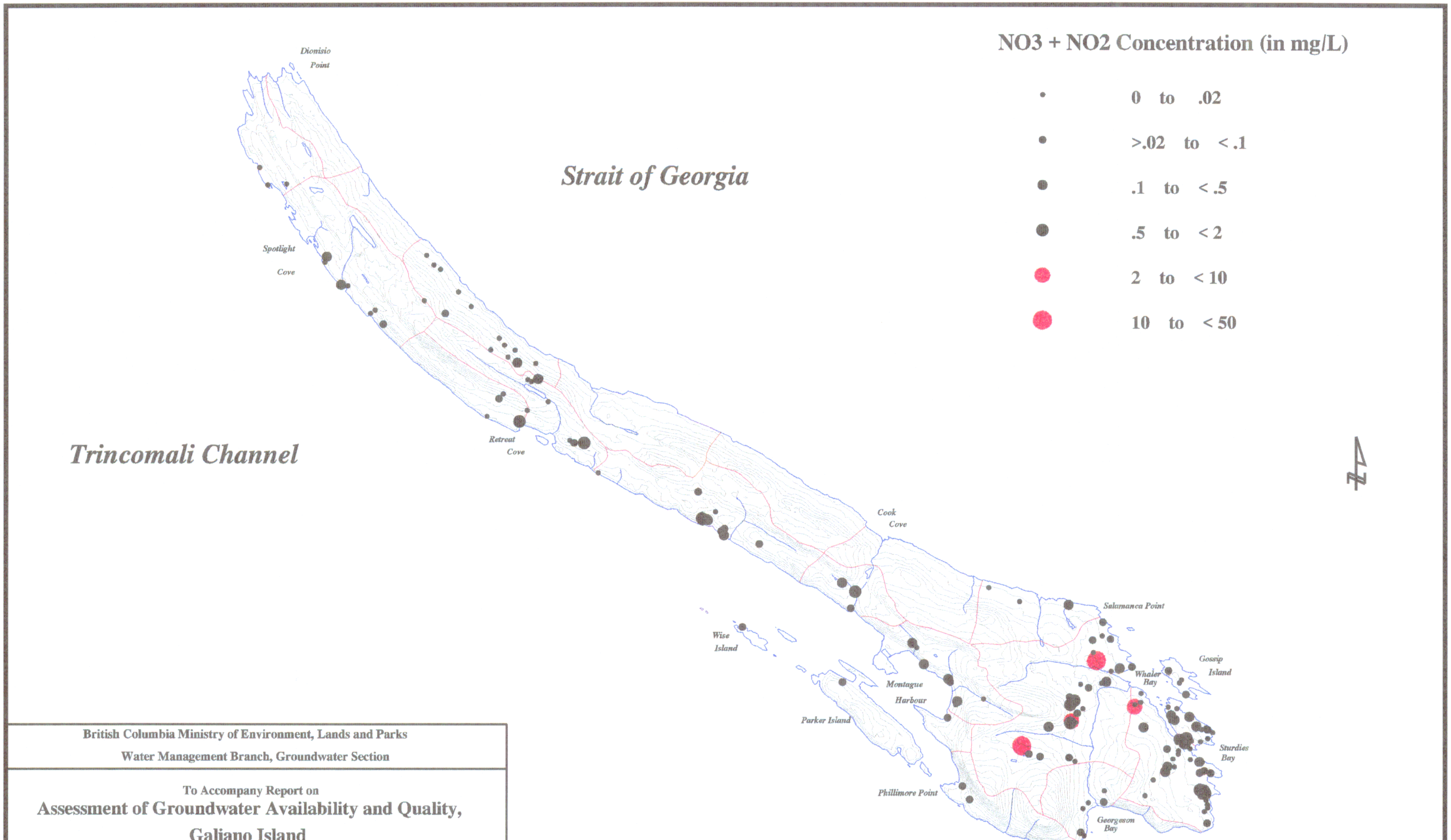

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Figure 40 : NO3 + NO2 Concentration

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

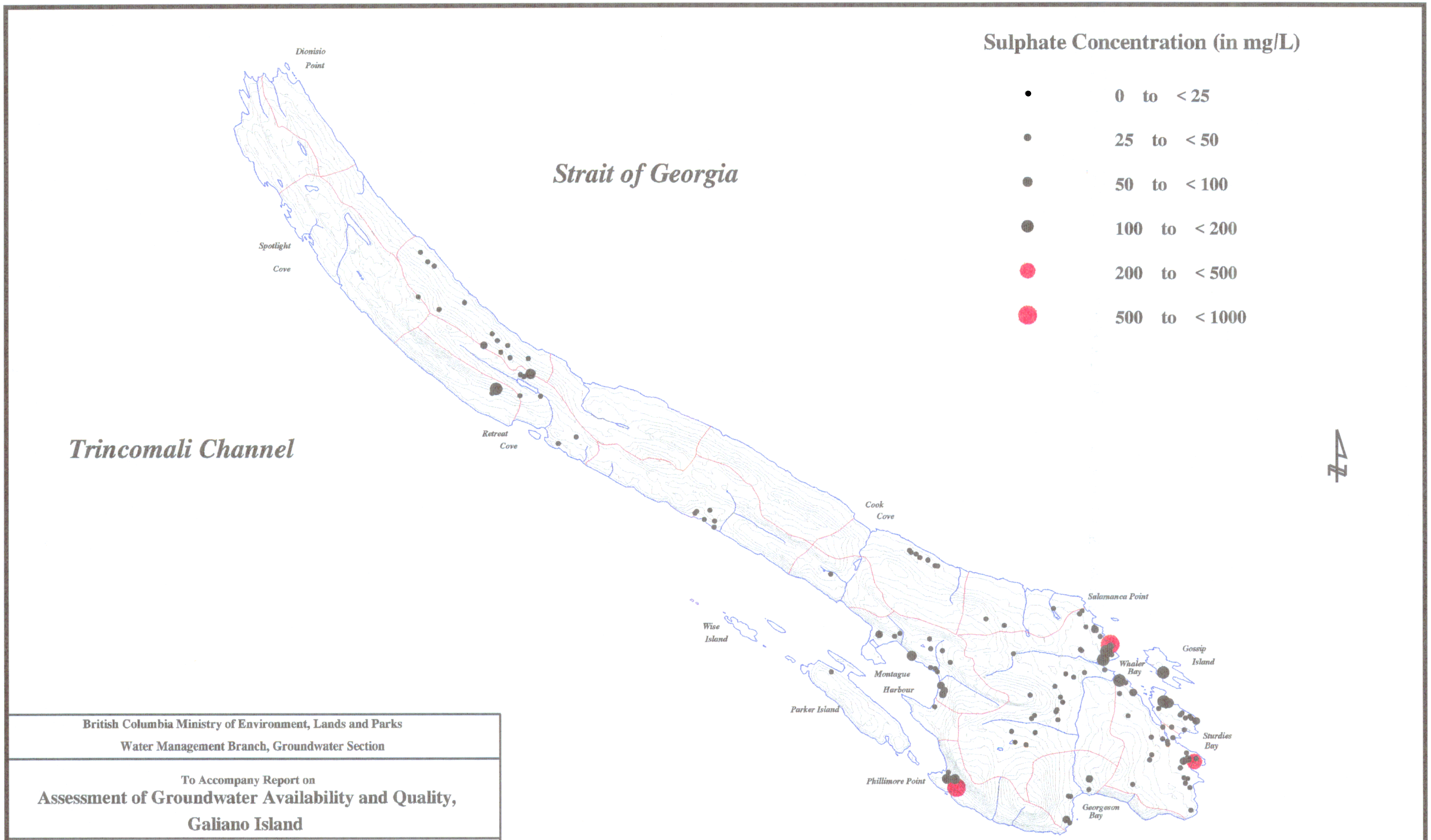

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Figure 39 : Sulphate

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

collection, but they will also include iron that was in suspension as well as what was in solution, unless the sample was filtered when it was collected (Hem, 1959).

In constructing the map (Figure 41) it was found that of the total 309 tests for total iron, 143 (or 46%) were ≤ 0.3 mg/L which is the maximum acceptable concentration proposed as an aesthetic objective in the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989). The rest were as follows:

31 (10%)	> 0.3 to < 0.6 mg/L
29 (9%)	0.6 to < 1.0 mg/L
35 (11%)	1.0 to <2.0 mg/ L
46 (15%)	2.0 to <5.0 mg/L
25 (8%)	5.0 to < 100 mg/L

The higher values of total iron appear to be rather scattered. Many of the high values occur in the Cain Peninsula - Sturdies Bay area, in the Whaler Bay area and along the coast in the north-west part of Galiano Island. High values are also reported on Gossip, Parker and Wise Island.

12.2.12 Manganese

Manganese is objectionable in water in the same way as iron. Stains caused by manganese are more objectionable and harder to remove than those of iron. Therefore the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) has proposed ≤ 0.05 mg/L as a maximum acceptable concentration for aesthetic reasons.

Figure 42 shows various ranges of total manganese concentrations. Of the 170 test results for total manganese, 91 (54%) are over the proposed objective of ≤ 0.05 mg/L. These are scattered over the map area, however, further study may determine grouping patterns.

12.2.13 Arsenic

Arsenic concentrations exceeding the interim maximum acceptable concentration of 0.025 mg/L (Health and Welfare Canada, 1993) have been reported for two bedrock wells on Galiano Island. One on Section 7 was tested as 0.090 mg/L and the other on District Lot 41 was tested as 0.060 mg/L. Origin of the arsenic is likely natural and caused by the presence of arsenic minerals in the bedrock.

12.2.14 Uranium

Uranium is present in trace amounts in most natural waters. On Galiano Island, of the 15 known samples for dissolved uranium, none exceed the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) maximum acceptable concentration of 0.1 mg/L.

12.2.15 Coliform Bacteria

Drinking water sources are normally tested for "indicator bacteria" (coliforms). Most indicator bacteria do not cause any health risk, but their presence may indicate the water has been contaminated and may contain harmful bacteria, viruses or parasites. A water analysis with positive identification of coliform bacteria implies a potential danger and a common treatment remedy is to sterilize the well by adding a chlorine agent (Halstead, 1986). Water treatment imposes additional costs, requires maintenance and can result in quality changes which may not be acceptable to all consumers.

There are two basic types of coliform bacteria that laboratories commonly test for namely: "total coliforms" and "faecal coliforms". Faecal coliforms grow only in the digestive systems of warm blooded animals, whereas total coliform bacteria include many bacteria which grow naturally in water, soil or digestive systems of animals (British Columbia Ministry of Health, 1995). If a well water sample contains faecal bacteria, disinfection is required to insure potability. No amount of faecal bacteria is acceptable.

Drinking water, by law in British Columbia public water systems should never have more than ten total coliform organisms in a 100 millilitre sample, and no more than ten percent of samples should have any coliform bacteria (British Columbia Ministry of Health, 1995).

Figure 43 is a map showing total coliforms results for well samples and was produced mainly from analyses for water samples submitted under the now discontinued Water Quality Check Program. Results of water analyses completed in recent years on newly drilled wells drilled in the undeveloped areas of the island are also incorporated in this map. Of the 183 total tests for total coliforms/per 100ml and on file with the Groundwater Section, the following results were obtained: 111 had less than 2.2, 10 were from 2.2 to less than 5.0, 16 were from 5.0 to less than 10, 22 were from 10 to less than 20, 17 were from 20 to less than 100 and 7 were from 100 to less than 3000. Very few specific tests for faecal coliform were performed. The results above must be carefully interpreted as many samples may have been contaminated during sampling, been in transit for a prolonged period or the well may have sat idle for a period of time. Disinfecting these wells may have brought many of them back to a bacteria free state. However, there have been some documented cases where despite repeated disinfection, total coliform testing continued to

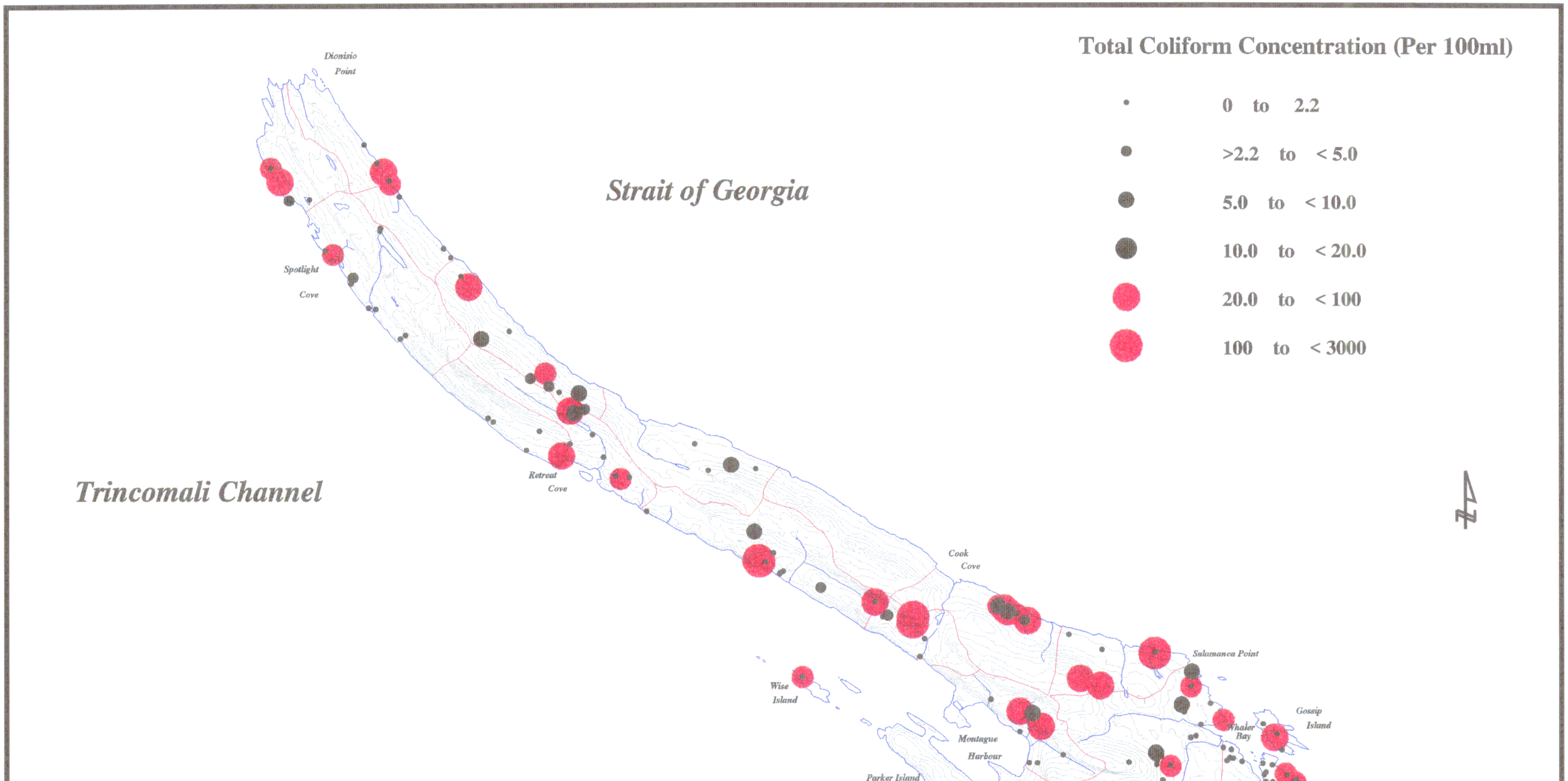

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Figure 43 : Total Coliform

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

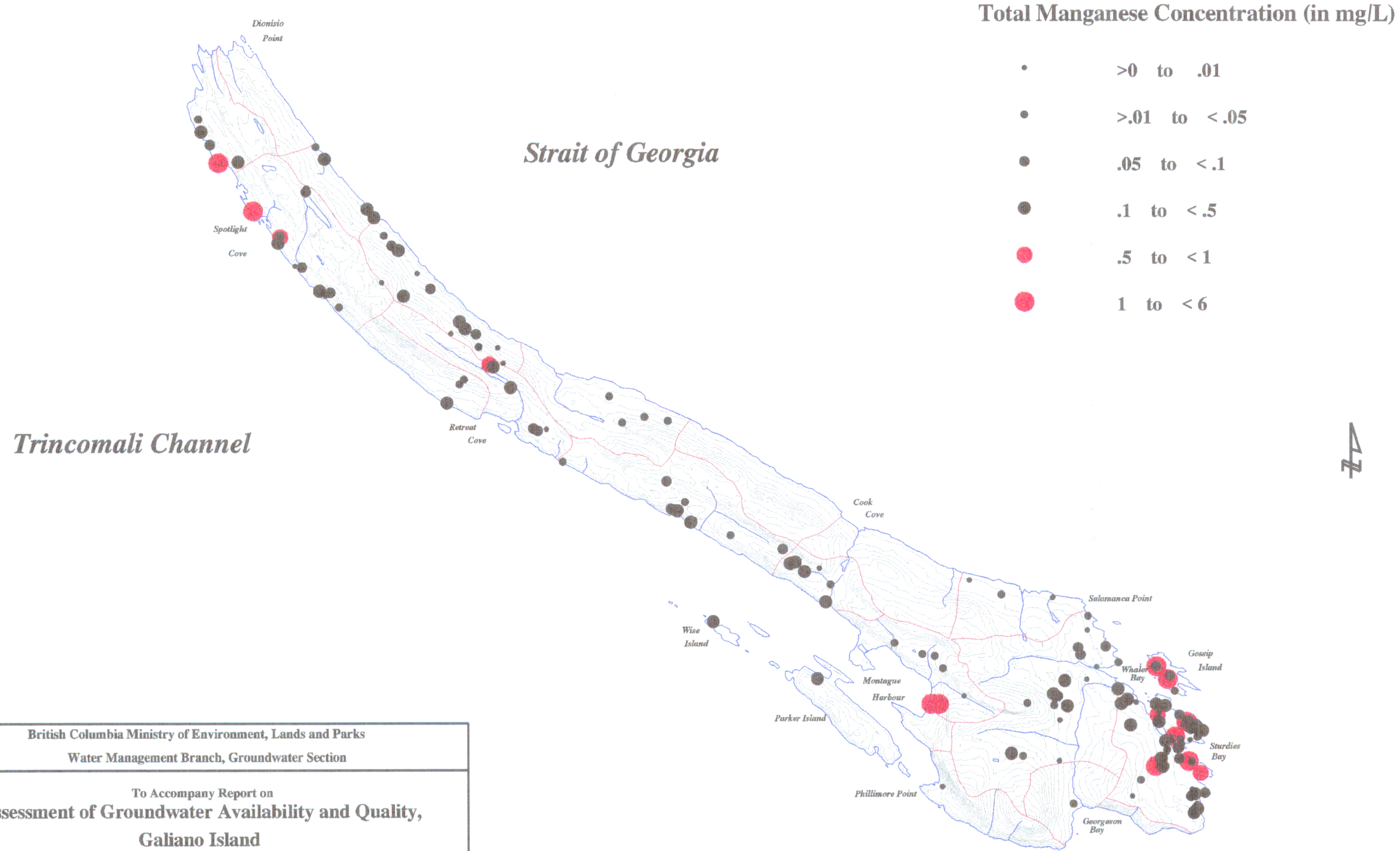

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Figure 42 : Total Manganese

Scale : 1 : 75,000 Date : October 1997 Contour Interval 20 Metres

show the presence of coliform bacteria. In some cases high bacteria counts have been attributed to naturally occurring bacteria in the aquifer connected to surface recharge waters. This water may be entering the aquifer through bedrock micro-fractures in contact with saturated overburden soil or stagnant pond water. Another source could be surface water leaking into the well around the casing which had not been adequately sealed in the bedrock. While the presence of total coliform bacteria is problematic, further studies would be necessary to isolate whether there are any specific areas where groundwater may be contaminated by faecal coliform bacteria.

13. Groundwater Management and Protection

13.1 Groundwater Concerns

Groundwater concerns on Galiano Island and its environs are similar to issues identified elsewhere in the Gulf Islands (e.g. Hornby Island Pilot Project Committee, 1994; Pender Islands Project Committee, 1994). A summary of common concerns and those specific to particular groundwater regions on Galiano are listed in Table 6. These concerns have been identified from various sources including; the Galiano Official Community Plan Bylaw No. 108. (Galiano Island Local Trust Committee, 1995), previous groundwater reports and the preceding text of this report. General descriptions of some of the various concerns are provided in Appendix II.

On Galiano Island there is a high degree of association among factors related to well density, lot density, deteriorating water quality, salt water intrusion, increasing water demands and poor well yields. Attention should be given to adopting management measures which address specific concerns in these regions and help prevent similar types of problems from occurring in regions currently not affected.

13.2 Management and Protection

There are a number of management and protection measures which could be considered to ensure the sustainability and quality of groundwater supplies on Galiano Island (Table 7). These include both regulatory and non-regulatory instruments. While groundwater has been confirmed as a crown resource in British Columbia under the *Water Act* and the *Water Protection Act*, the range of regulatory measures currently available for groundwater is severely restricted pending future provincial legislation. Groundwater development and use in British Columbia is currently unregulated except for restrictions on the bulk export of groundwater under the *Water Protection Act*. Also, under the regulations of the *Environmental Assessment Act*, environmental impact assessments may be required for large groundwater extractions greater than 75 L/s. Although some regulatory measures may be appropriate, it is likely that a combination of regulatory and

TABLE 6. Summary of groundwater concerns, Galiano Island and neighbouring islands.

Groundwater Concerns	Quantity	Quality	Health/Safety	Main Regions Affected
Groundwater Use	X	X	X	All
Provision and Maintenance of Public Drinking Water Sources	X	X	X	selected areas only
Salt Water Intrusion	X	X	X	1,4,6,10,13,14,16,17,19,20,21,22,24
Impacts of Land Use Practices	X	X	X	All
Impacts of Other Resource Extraction	X	X	X	All
Protection of Critical Recharge and Discharge Areas	X	X	X	All
Provision of Well Information	X	X	X	All
Currency, Availability and Limitations of Groundwater Information	X	X	X	All
Poor Well Construction Practices	X	X	X	All
Need for Water Well Construction Standards	X	X	X	All
Qualifications of Well Drillers and Pump Installers	X	X	X	All
Public Awareness of Groundwater Conditions	X	X	X	All
Need for Comprehensive Groundwater Management	X	X	X	All
Groundwater Monitoring	X	X	X	All
Groundwater Availability	X			All
Need for Water Conservation	X			All
Excessive Water Use Locally	X			All
Poor Well Yields	X			All
Well Interference/Decreasing Yield/Quality Changes	X	X		1,17,19,20,22,24
Sustainability of Fresh Water Supplies	X	X		All
Increasing Water Demands	X	X		All
Well Density	X	X		1,17,19,20,22,24
Groundwater Withdrawals Exceeding Natural Replenishment	X	X		1,17,19,20,22,24
Uncontrolled Flowing Artesian Wells	X		X	All
Improperly Abandoned Wells		X	X	All
Uncapped Wells		X	X	All
Poor Water Quality		X	X	1,4,6,10,13,14,16,17,19,20,21,22,24
Water Potability		X	X	All
Deteriorating Water Quality		X	X	1,4,6,10,13,14,16,17,19,20,21,22,24
Special Quality Concerns (Fluoride - Arsenic)		X	X	6,7,8,12,13,19,20,21- 11,20
Need for Well Water Quality Testing Services		X	X	All
Effects of Water Treatment		X	X	All
Effects of Waste Disposal		X	X	All
Areas of Groundwater Contamination		X	X	unknown
• Contamination from Septic Wastes		X	X	unknown
Need for Pollution Prevention		X	X	All
• Need for Well Head Protection		X	X	All
• Need for Aquifer Protection Measures		X	X	All

TABLE 7. Summary of regulatory and non-regulatory groundwater management measures.

REGULATORY MEASURES	CURRENT AVAILABILITY
Well Permitting:	
• License Groundwater Use	-
• Require Well Drilling Permits	-
• Require Well Testing Permits	-
• Require Well Registration	-
• Require Well Tagging	-
Qualifications of Operators:	
• Certify and Licence Well Drillers	-
• Certify and Licence Pump Installers and Testers	-
Standards:	
• Mandatory for Well Construction	-
• Mandatory for Well Capacity Testing	-
• Mandatory for Water Quality Testing	-
• Mandatory for Safe Well Closure	-
Reporting:	
• Mandatory Submission of Well Records	-
• Mandatory Monitoring of Quantity and Quality	-
Management Area Designation:	
• Groundwater Management Area (GWMA)	-
Planning:	
• GWMA Plan	√
• Land Use Zoning Plan	√
Mandatory Consultation:	
• Inter-agency	-
• Public	-
• Advisory Committees	-
Existing Regulations/ByLaws:	
• Subdivsion Approvals	√
• Buiding Permits	√
• Sewage Disposal	√

NON-REGULATORY MEASURES	CURRENT AVAILABILITY
Public Education and Awareness:	
• Groundwater Workshops	√
• Provision of Information Materials	√
Data Gathering:	
• Aquifer Classification and Inventory	√
• Aquifer Mapping	√
• Well Inventory and Database	√
• Field Surveys	√
• Observation Well Network	√
Voluntary Certification of Operators:	
• Well Drillers	√
• Pump Installers and Well Testers	-
Guidelines:	
• Well Construction	√
• Well Capacity Testing	√
• Water Quality Testing	√
• Well Closure	√
Reporting:	
• Voluntary Submission of Well Records	√
• Voluntary Monitoring of Quantity and Quality	√
• Voluntary Well Tagging	-
Advisory:	
• Referrals	√
• Partnerships	√
Conservation:	
• Water use	√
Planning and Protection:	
• Special Area plans	√
• Well Head Protection Plan	√
• Hazardous Waste Collection	√
• Contaminant Inventory	√
• Contingency Plans	√
• Spill Response Planning	√
• Adoption of Best Management Practices	√
• Land Acquisition	√
• Storm Water and Sewage Controls	√
• Facility Siting, Design and Operation	√
• Cluster Development	√
• Conservation Easements	√
• Purchase of Development Rights	√
Consultation:	
• Inter-agency co-operation	√
• Public forums	√
• Advisory Committees	√
• Protocol Agreements among Agencies	√

non-regulatory measures may ultimately prove most effective. In the interim, adoption of non-regulatory measures can assist in meeting some management and protection objectives. A key policy lever for promoting groundwater management on Galiano Island could include adoption of the precautionary principle (House of Commons, 1995). This principle implies that where an activity or substance poses a serious threat of harm to the environment or human health, precautionary measures would be taken even in the face of scientific uncertainty. Achieving an effective groundwater management plan for Galiano Island would require consultation among land owners, water users, local and provincial government agencies, representatives of the well drilling industry and other land resource based industries. Further information on general steps for developing a groundwater protection plan is provided in the 1995 Environment Canada publication entitled "Groundwater Quality Protection Practices". Groundwater protection planning is currently being considered by a number of communities in British Columbia where groundwater supplies are important (e.g. Township of Langley, City of Abbotsford, District of North Saanich and District of Central Saanich). Growth management planning and official community planning for example may provide opportunities to include integrated measures to safeguard groundwater supplies.

14. Conclusions

Groundwater found in the Cretaceous bedrock formations of Galiano Island is a critical resource for meeting the domestic water supply requirements of the island. Open fractures in the bedrock constitute the major zones for groundwater storage and movement. The entire island can be considered part of a fractured and interconnected bedrock aquifer system in which variations in productivity and water quality occur spatially within the groundwater system. The bedrock aquifer system on Galiano can be classified as a moderately developed and moderately vulnerable II B aquifer, with a ranking value of 14.

Twenty one groundwater regions have been defined on Galiano Island for describing and comparing groundwater conditions in various parts of the island. Areas of regional groundwater recharge and discharge have been delineated at 1 : 12,000 scale on the basis of topography, geology, drainage, groundwater levels and distribution of vegetation features.

As of August 1996, the Groundwater Section had 828 records of wells including 32 springs on file in the computerized WELL Database System with locations plotted on 1 : 5,000 scale well location maps for the area. Density of existing well and spring sources determined for each groundwater region ranges from very low (less than one well per 20 acres) to very high (more than one well per two acres). Well density is indicative of the degree of groundwater development in each region and a probable indicator of the degree of groundwater use. Well densities are highest in the Cain Peninsula, South Galiano, Georgeson Bay and North Galiano-Spanish Hills regions. Areas of high well density are often associated with groundwater problems including; failing well yields and deterioration in water quality.

The storage coefficient of the bedrock is a limiting factor governing groundwater availability and would need to approach 10^{-3} to enable infiltration of a significant percentage of the annual precipitation (i.e. > 3 percent). Total estimated fresh groundwater reserves on the island, which may be replenishable on an annual basis, range from 78 to 780 million Igals (0.35 to 3.5 million m^3). Careful monitoring of groundwater development, the degree of use and response of the groundwater regime is required to determine optimum limits of extraction. Current groundwater demand on the island based on 1991 population figures, including visitors, is estimated at 40 million Igals (0.18 million m^3) per year. Demand could approach 90 million Igals (0.41 million m^3) by the year 2040. While overall groundwater storage exceeds current demand, demand is not uniform and is concentrated in the more densely populated areas of the island. These same areas are subject to localized problems of well interference, extraction exceeding availability during periods of high demand, deterioration in water quality and risks to contamination from surface sources of pollution. In a number of instances groundwater water quality has been impacted by salt water intrusion resulting in increased dissolved mineralization including elevated levels of sodium and chloride. Other water quality problems observed locally include elevated levels of: iron, manganese, fluoride, hydrogen sulphide and coliform bacteria. These can be the result of both natural conditions and human factors.

The historic pattern of development on the island has been such that for the most part, the upper reaches of the groundwater regions have remained largely undeveloped. The judicious management of groundwater recharge areas will be critical to sustaining groundwater availability and quality in all of the groundwater regions of Galiano Island. Application of appropriate groundwater management measures within those areas currently experiencing quantity and quality problems will be equally as important. Regions where the adoption of groundwater management measures is critically needed are: Cain Peninsula, Gossip Island, Wise Island, and parts of the North Galiano-Spanish Hills, Finlay Lake, South Galiano and Georgeson Bay regions. Groundwater discharge areas (wetlands), at intermediate elevations on the island may also act in part as recharge areas for regions downslope and warrant special management consideration. Given the high costs involved in acquiring definitive groundwater information and the scientific uncertainty in predicting groundwater availability in bedrock terrains, adoption of the precautionary principle could assist in selecting appropriate groundwater management measures for the Island.

15. Recommendations

As the Official Community Plan (1995) for Galiano Island indicates, the preservation, protection and sustained supply of all fresh water resources including groundwater are vital to ensuring the health and well being of island residents and their island environment. Based on the results of this study and groundwater studies elsewhere in the Gulf Islands, the following recommendations are made to assist in achieving a sustained and healthy groundwater resource for island residents.

1. Develop an on-going program for public education, awareness and conservation of groundwater for Galiano Island residents and visitors. This could include workshops, brochures and notices for example on topics such as, how to use water wisely and well head protection.

2. Examine available regulatory and non-regulatory options for groundwater management and protection.

3. Develop a preliminary groundwater management plan for Galiano Island linked to the Official Community Plan. Given the inherent uncertainties associated with groundwater in fractured bedrock terrains, the "precautionary principle" should be followed as a basis for the plan.

4. Develop individual protection plans for community well and spring sources.

5. Undertake feasibility studies of alternate sources of water supply such as community wells and surface water storage reservoirs for high population density areas.

6. Examine existing groundwater information in more detail and conduct further field surveys in the Cain Peninsula, South Galiano, Georgeson Bay, and North Galiano-Spanish Hills regions to provide further information on the nature of the quantity and quality problems found in these areas. This should include site specific investigations of water quality problems such as salt water intrusion to determine controlling factors.

7. Undertake research on effects of land use activities such as logging and road building on groundwater supplies and quality in bedrock terrains.

8. Develop guidelines for land use activities in critical recharge and discharge areas.

9. Promote existing guidelines for well construction, testing and abandonment and the submission of groundwater information for inclusion in the groundwater database.

10. Update the groundwater database and information system for Galiano Island on a regular basis.

11. Establish and maintain a regional network of observation wells in key areas to monitor groundwater levels and groundwater quality on a continuing basis. Results from the network should be reported regularly.

While the securement of resources including: funding, technical advisory assistance and administrative assistance to implement the above recommendations are beyond the scope of this report, it may be possible through partnerships and cooperative arrangements to combine further initiatives with other related activities being carried out by various agencies on the island, on other Gulf Islands or elsewhere in the province.

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Appendix I. Aquifer Classification and Ranking, Galiano Island.

AQUIFER CLASSIFICATION WORK SHEET

AQUIFER LOCATION: Galiano Island.

REFERENCE NUMBER: 92B 13/14 and 92G 4

DESCRIPTIVE LOCATION: Galiano Island.

DESCRIPTIVE NAME: Galiano Island - Bedrock Aquifer System.

NTS MAP SHEET: 92B 13/14 and 92G 4

WELL RECORD MAP SHEETS: Groundwater Location Maps: BCGS Numbers: 92B.084.1.4, 2.1 2.2, 2.3, 2.4, 3.1, 3.2, 3.3, 3.4, 4.1 093.1.4, 2.2, 2.3, 2.4, 3.1, 3.2, 3.3, 3.4, 094.1.1, 92G.003.1.1.

CLASSIFICATION: IIB RANKING VALUE: 14

Aquifer System Size: Approximately 58 km^2.

Aquifer Boundaries: Geographic: Shoreline

Geologic Formation (overlying): Mainly Glacial Drift Materials less than 100 cm deep over Bedrock. Local areas of marine clay deposits, glaciofluvial deposits, and till, over 100 cm thick.

Geologic Formation (aquifer): Fractured Bedrock - Upper Cretaceous Nanaimo Group (i.e. sandstones, shales and conglomerate).

Confined/Unconfined/Bedrock: Bedrock - Sedimentary rock of upper Cretaceous age belonging to the Nanaimo Group.

Vulnerability: Moderate - Exposed bedrock to overburden thickness of 45.7 metres (150 ft).

Productivity: Yields range up to 15.15 L/s (200 gpm). Of the 677 reported yields, 27% yield less than 0.08 L/s (1.0 gpm), 94% yield less than 1.9 L/s (25 gpm). A few wells were reported dry.

Depth to Water: Flowing to 81.7 metres (268 feet) below ground level. Observation wells show water levels are influenced in areas by pumping interference.

Flow Direction: Regional groundwater level elevations estimated and contoured from land surface altitudes and historical water level measurements in wells. Generally form a subdued replica of the land surface. Groundwater flow directions inferred assuming the bedrock permeability is isotropic or uniform throughout.

Recharge: Infiltration of precipitation. May be local inter-relationship between surface water (i.e. lakes, creeks) and groundwater.

Domestic Well Density: Moderate domestic well density, clustered locally.

Users/Level of Use: Primarily domestic.

Reliance on Source: Conjunctive, Predominantly used for domestic purposes.

Quality Concerns: Local sea water intrusion near coastal areas. Elevated levels of fluoride, iron, and hydrogen sulphide locally.

Quantity Concerns: Overdeveloped in areas of the Island.

Notes:
References:

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AQUIFER CLASSIFICATION AND RANKING

AQUIFER LOCATION: Galiano Island

REFERENCE NUMBER: 92B 13/14 and 92G/4

CLASSIFICATION: II B **RANKING VALUE: 14**

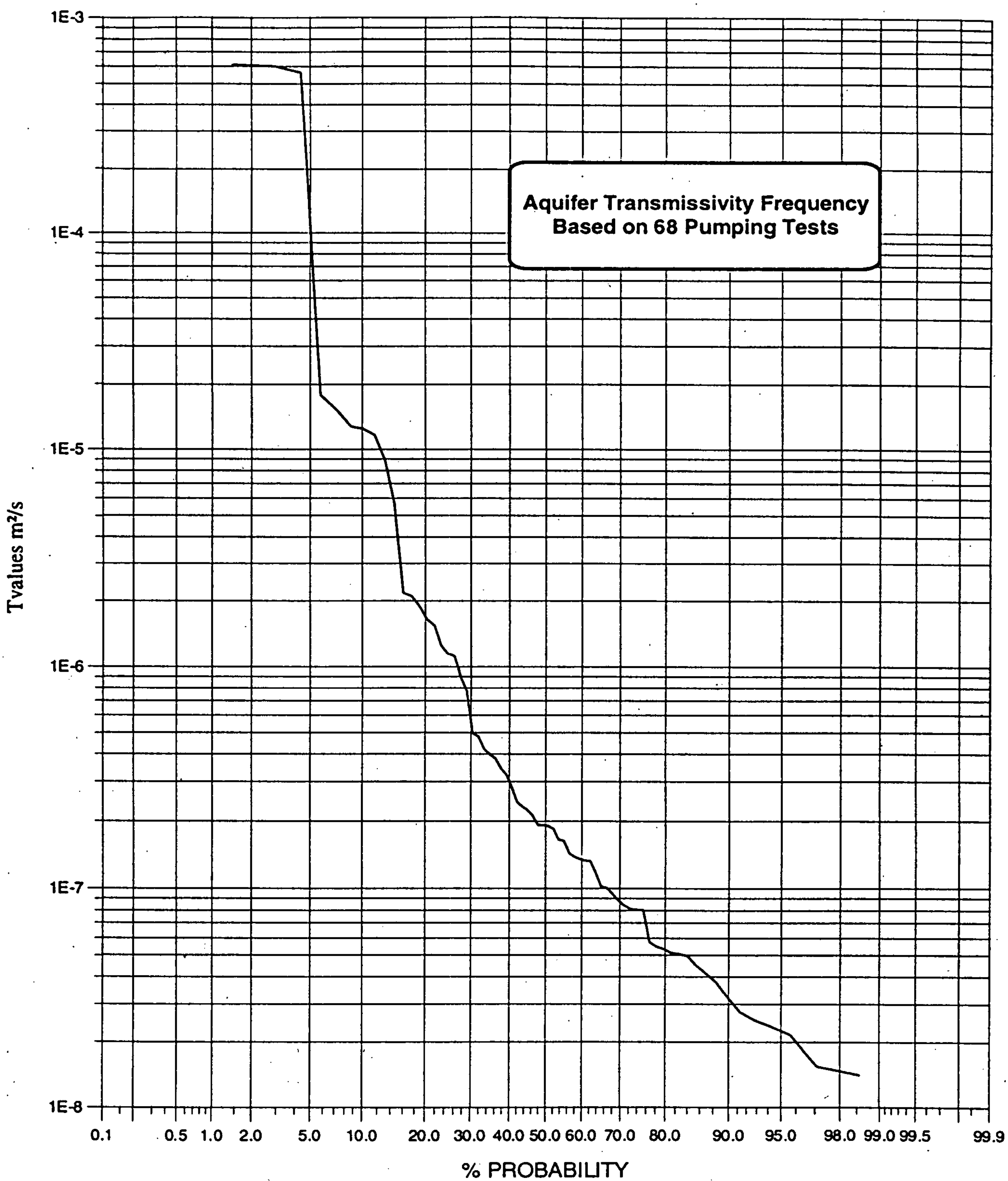
Classification Component:

Level of Development: **II** Moderate level of development. Moderate demand and low yields. Local areas highly developed.

Vulnerability: **B** Moderately vulnerability to contamination.

Ranking Component:

	Value	
Productivity:	1	
Vulnerability:	2	
Size:	3	
Demand:	2	
Type of Use:	2	
Quality Concerns:	2	
Quantity Concerns:	2	Total = **14**



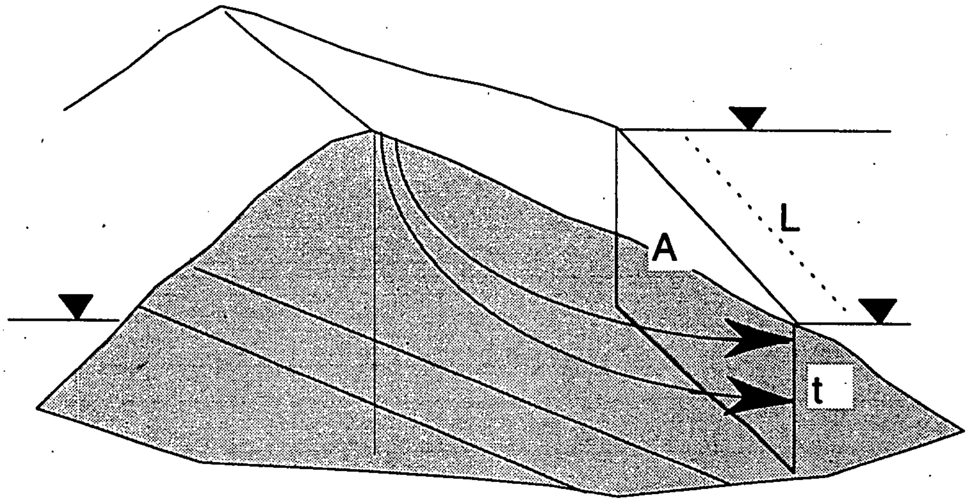
Province of British Columbia
Ministry of Environment, Lands and Parks
Water Management Branch

TO ACCOMPANY REPORT ON

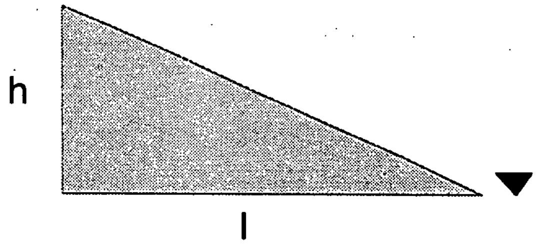
ASSESSMENT OF GROUNDWATER AVAILABILITY AND QUALITY GALIANO ISLAND, BRITISH COLUMBIA

SCALE :	AS SHOWN	DATE	PRODUCED BY:
			FILE NO: FIGURE: 1. Appendix II

NORTH GEORGIA STRAIT REGION



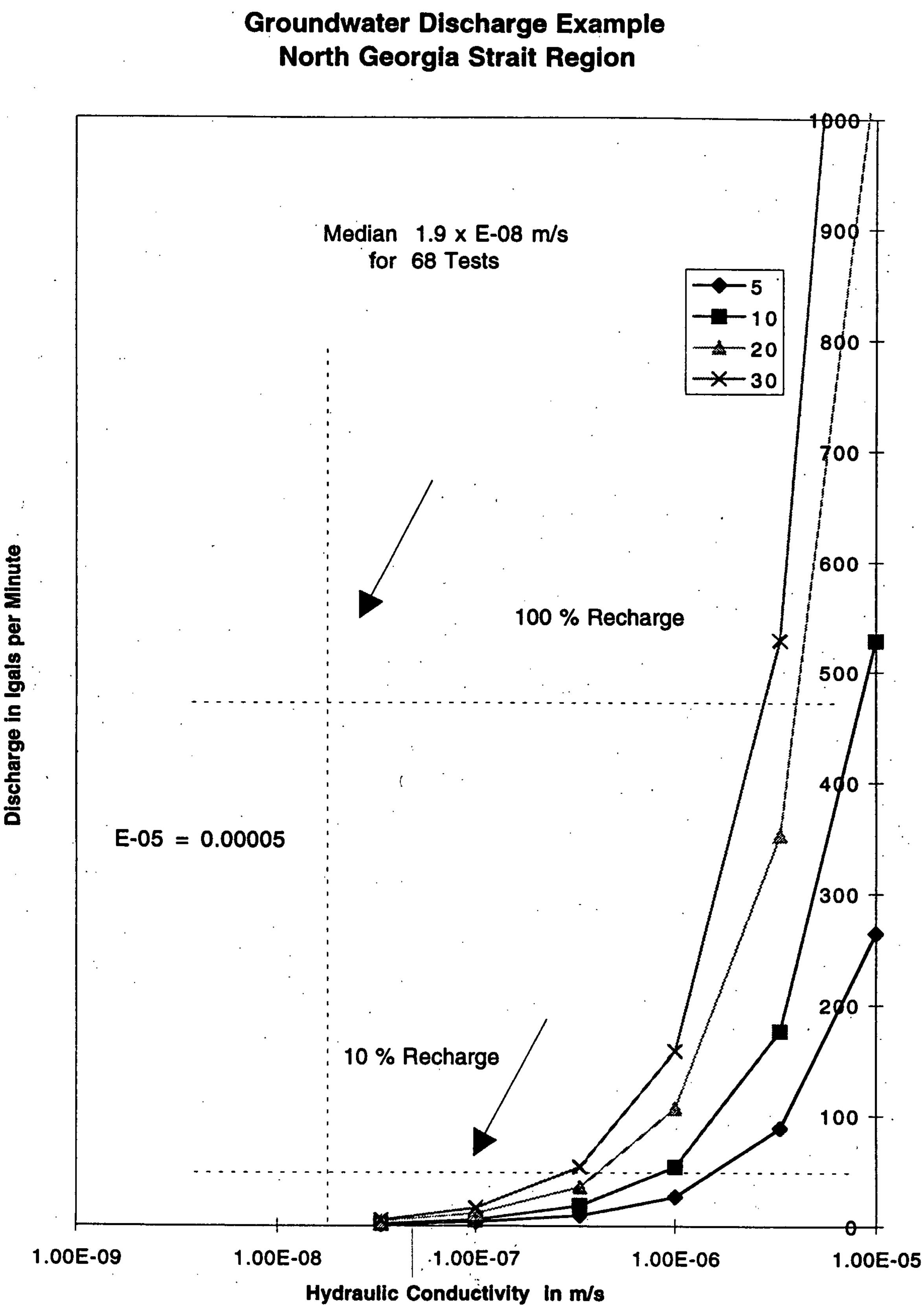
CROSS SECTION



$$Q = K\,I\,A$$

where
Q = discharge
K = hydraulic conductivity
A = area through which flow occurs (L x t)
t = thickness
I = hydraulic gradient = h / l = 0.2
L = 2000 m
h = 120 m
l = 600 m

Appendix III. Figure 1. Example illustrating groundwater flow system and discharge in the North Georgia Stait Region



Appendix III. Figure 2. Theoretical discharge quantities for values of hydraulic conductivity and aquifer thickness from 5 to 30 metres.

Appendix IV
Groundwater Concerns

Poor Well Yields

The majority of wells on the island are low yielding bedrock wells and in many cases only supply marginal amounts of water for domestic use. Due to this inherent characteristic, the performance of these wells are sensitive to changes in demand, use of neighbouring wells, seasons of the year and changes in water quality. Larger capacity wells where they exist are generally affected to a lesser degree by these factors.

Groundwater Withdrawals Exceeding Natural Replenishment

Where a significant number of wells have been constructed in an area there is concern that the combined use of the wells can exceed the annual replenishment rate in the area and that a groundwater "mining" situation exists. Regions where there is a high demand relative to groundwater availability would be expected to have more water quantity and quality problems than other regions on the island.

Well Interference

When wells in close proximity to one another are pumped they can lower the water level in adjacent wells. This effect is termed *well interference* and this results in reducing the capacity of each well. The magnitude of the effect depends to a large degree on the pumping rates and distance between the wells. One well withdrawing a large quantity of water can affect a number of neighbouring smaller capacity wells. In fractured bedrock conditions the effects are not necessarily symmetrical around the major-producing well but can extend significant distances along preferred directions in elongate zones away from the pumping well.

Uncontrolled Flowing Artesian Wells

Flowing wells which are not capped properly with a flow control valve, waste water and cause an overall lowering of the water table which depletes the aquifer and reduces the yield of neighbouring wells. These wells also contribute to well interference effects explained below. Some of these wells only flow during the winter months.

Improperly Abandoned Wells

Wells that are no longer being used and have not been sealed can contribute to groundwater contamination as these wells may become conduits for pollutants entering aquifers. Wells, especially larger diameter ones, that are not adequately capped also pose a safety hazard for people, particularly small children and also animals.

Poor Well Construction

Wells that are not completed with an adequate surface seal can contribute to groundwater contamination through the introduction of pollutants from the land surface particularly during periods of fall and winter runoff. Wells situated in low lying areas and close to nearby sources of contamination such as septic fields are particularly vulnerable. Guidelines and a draft code of practice for well construction for wells have been developed for British Columbia (Ministry of Environment, 1982; Ministry of Environment, 1994).

Poor Water Quality

Groundwater quality can fluctuate seasonally and with time due to a number of factors, some of which are caused be natural or induced by human activities such as well pumping and waste disposal practices. During periods of groundwater recharge groundwater quality in individual wells often improves significantly with the influx of fresher recharge waters (low in dissolved mineralization) and less groundwater use during this period. During the dry summer months with increased groundwater use, quality can deteriorate with increased dissolved minerals, elevated levels of hydrogen sulphide gas and dissolved iron being noted. Lowered water levels in dug wells during the summer months can also result in increased biological activity in the bottom of these wells and production of: hydrogen sulphide gas, algae and their decay products which cause odour and taste problems. Salt water intrusion is more prevalent during the summer months when water demand is high. Areas of high subdivision density where individual wells and septic installations are in close proximity often show deteriorating quality during the summer months. Presence of coliform bacteria in groundwater in these situations is problematic. Where septic installations are malfunctioning, groundwater quality problems can result, leading to elevated levels of faecal coliforms, phosphates and nitrates. Natural dissolved constituents such as fluoride for example can occur locally at concentrations exceeding drinking water guidelines.

Salt Water Intrusion

Where wells are situated in close proximity to the ocean, pumping from these wells will draw the fresh water-salt water interface landwards, resulting in deterioration of groundwater quality as evidenced by increased levels of dissolved minerals principally sodium and chloride. This effect is called *sea water encroachment or sea water intrusion.* At the same time groundwater can be drawn upwards from beneath the fresh water-salt water interface resulting in a condition known as *upconing.* Upconing can also occur in areas inland depending upon the depth of the well and position of the interface. Sea water encroachment and upconing are two types of *salt water intrusion* which occur in coastal areas.

Groundwater Contamination from Septic Wastes

Septic wastes pose a special problem for groundwater in situations where there is a high density of wells and septic fields in close proximity. Where these fields are malfunctioning as a result of poor soil conditions, high water table conditions or improper construction there is a concern that groundwater can be contaminated. Poorly constructed wells not having an adequate surface seal can also contribute to their contamination. Unauthorized disposal of septic wastes and grey water can also lead to groundwater contamination. Treatment of contaminated groundwater imposes additional costs. It can change the quality of drinking water and may be unacceptable for some consumers. Unauthorized construction of earth pit privies cause direct contamination to groundwater and only sealed concrete vaulted privies should be installed. In regions adjacent to foreshore areas, contaminated groundwater discharging to the ocean, can result in contamination of shellfish beds.

Impacts of Land Use Practices

Human activities in the vicinity of wells and in and around sensitive recharge and discharge areas can contribute to groundwater quality deterioration and reduce groundwater availability. Drainage works for example can intercept and divert runoff normally contributing to groundwater recharge in an area. Soil removal and paving of areas can lead to reduced groundwater recharge. Intensive applications of animal wastes to land in excess of crop requirements can lead to groundwater contamination. Abandoned landfills, sites of chemicals spills and inappropriate waste disposal practices can contribute to local instances of groundwater contamination. Galiano Landfill, for example, located in DL 17 was closed in 1991 and a landfill closure plan was approved 1992. Since the closure of the landfill, the Ministry of Environment has undertaken post-closure monitoring including sampling of metals , nutrients (nitrates, phosphates, etc.) and coliform bacteria (faecal, total) in various wells, ponds and drainages in the area. High density developments utilizing individual wells and septic installations on small lots can lead to contamination of groundwater and well interference problems. Intensive land clearing, logging and road building can lead to soil erosion and disturbance of the natural hydrologic regime of an area. There has, however, been little research carried out on the effects of logging and road building on groundwater supplies in fractured bedrock terrains.

Appendix V
Glossary of Terms

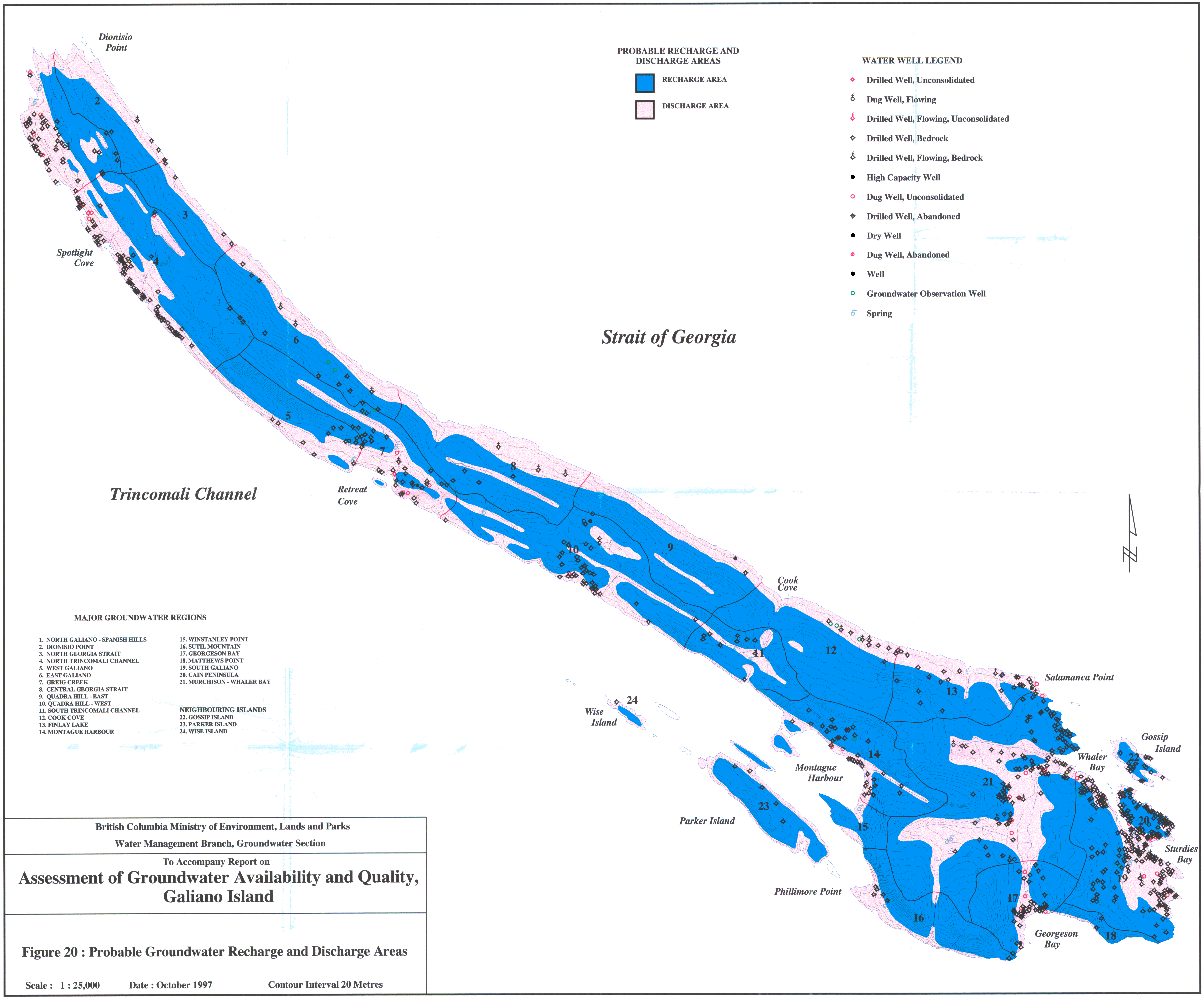
aquifer	a water-bearing geologic formation, subsurface layer or zone of permeable rock or soil that permits the passage of water
discharge area	an area where groundwater is moving upwards and discharging to the surface in springs and wetlands
groundwater	water occurring below the surface of the ground under saturated conditions
groundwater region	a physiographic, water catchment area for groundwater encompassing all or a portion of one or more drainage basins, wherein the groundwater regime is described
hydraulic conductivity	a measure of the quantity of water which can move through a unit area of aquifer under a unit hydraulic gradient, it is equal to the transmissivity divided by the aquifer thickness
permeability	a measure of the ability of an aquifer to transmit a fluid through a unit area of aquifer under a unit hydraulic gradient
porosity	the ratio of the void space in a rock to the total volume of rock and void space, expressed as a decimal fraction or percent
precautionary principle	ensures that a substance or activity posing a threat to the environment is prevented from adversely affecting the environment, even if there is no conclusive scientific proof linking that particular substance or activity to environmental damage
recharge area	an area where groundwater is replenished from infiltration and is moving downwards
storage coefficient	represents the volume of water released from storage, per unit of aquifer storage areas per unit change in pressure head

transmissivity — a measure of the quantity of water which can move through a unit thickness of aquifer under a unit hydraulic gradient, it is equal to the hydraulic conductivity times the aquifer thickness

watershed — the catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water. A watershed can be wholly contained within another watershed

water table — the upper surface of the zone of saturation where not confined by a low permeability formation

zone of saturation — zone in which all of the openings or voids in the subsurface materials are filled with water



British Columbia Ministry of Environment, Lands and Parks

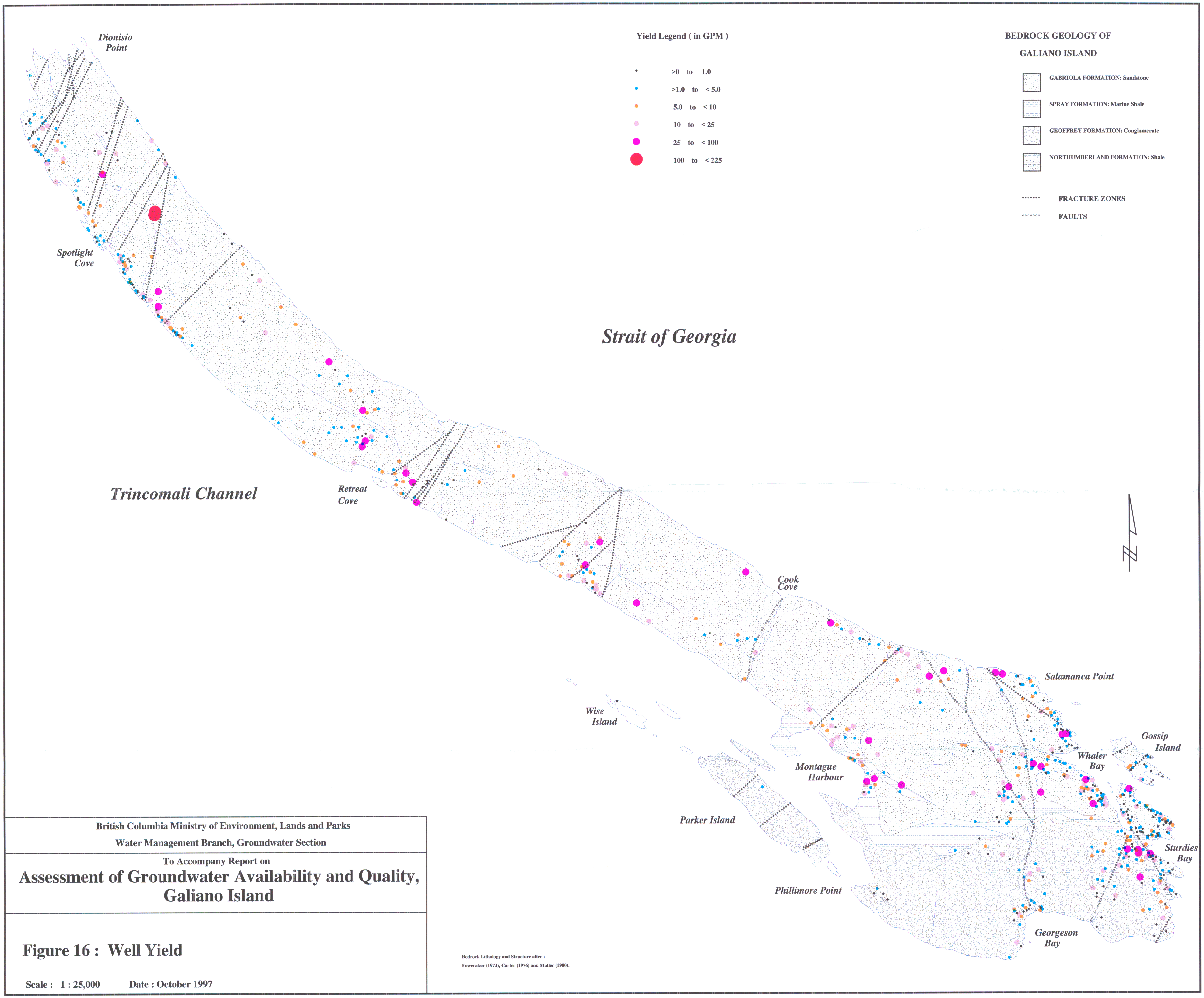
Water Management Branch, Groundwater Section

To Accompany Report on

Assessment of Groundwater Availability and Quality, Galiano Island

Figure 20 : Probable Groundwater Recharge and Discharge Areas

Scale : 1 : 25,000 | Date : October 1997 | Contour Interval 20 Metres



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To Accompany Report on

Assessment of Groundwater Availability and Quality, Galiano Island

Figure 16 : Well Yield

Scale : 1 : 25,000 Date : October 1997

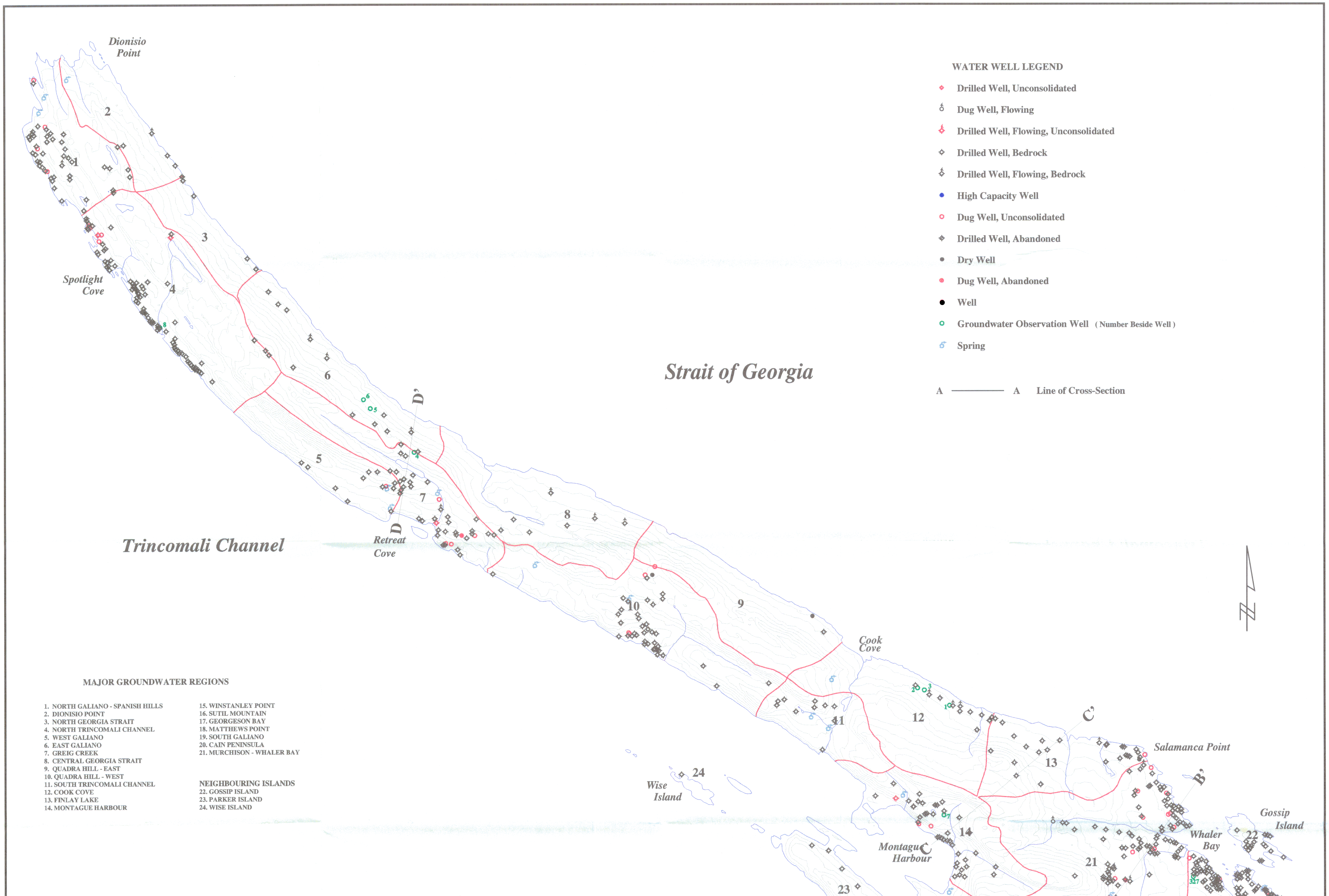

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Figure 6 : Well and Spring Locations

Scale : 1 : 25,000 Date : October 1997 Contour Interval 20 Metres