Chapter 7: LAND USE AND GROUNDWATER BASINS: NORTH AND SOUTH PENDER ISLANDS

7.1 Introduction

This chapter describes the current land use on North and South Pender Islands and provides current population and estimated future population levels given the existing regulations concerning lot size and land use. North and South Pender Islands are then sub-divided into groundwater basins. Estimates of the groundwater resources are presented for each groundwater basin. The groundwater basins and their resources are related back to the climate, current watersheds, geology, and geophysics discussed in previous chapters. The groundwater basins and their resources are then used as an introduction to the governance of the resources.

7.2 Land Use

7.2.1 North Pender Island

North Pender Island has an area of 2,728 hectares. It has the highest population density of any of the Outer Gulf Islands at 0.51 persons/hectare (Islands Trust, 2005). There are a number of federal, provincial, and regional parks located on North Pender Island, including:

- Roes Island National Park Reserve
- Prior Centennial Provincial Park
- Community Parks (Magic Lake, Harbour Hills, Stanley Point, Hope Bay, Bald Cone, Medicine Beach, Pirates Road, Bedwell Harbour)

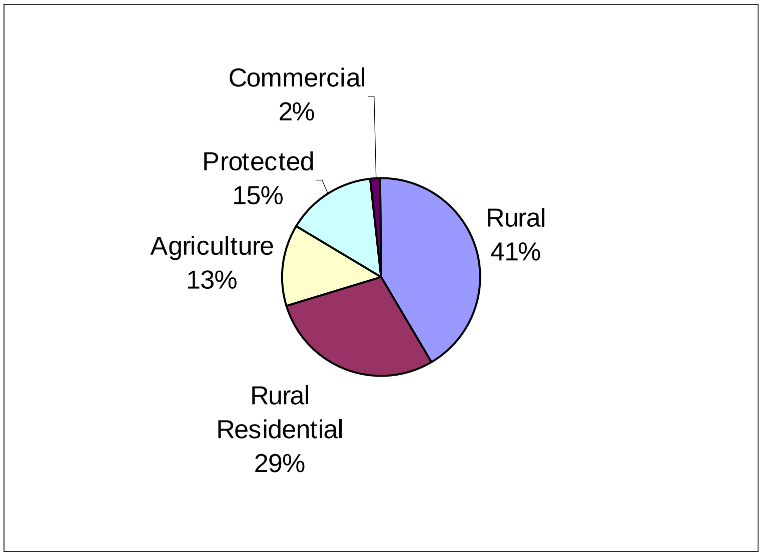

Figure 7.1: Land-use, North Pender Island (Islands Trust, 2003)

Figure 7.1 presents the distribution of land-use activities on North Pender Island. The majority of the land is classified as either rural or rural residential. The community plans for the island list 2101 lots, with a projected total population of approximately 4200 persons at full lot development (Islands Trust, 2003). The permanent resident population, as of the 2001 census, was listed as 1776 (Islands Trust, 2005).

The population density varies greatly on the island from an almost urban population density in Magic Lake Estates to relatively large agricultural tracts of land. Previous investigations have discovered decreased water quality in the vicinity of faulting and along the coast on North Pender Island (Mordaunt, 1981). Journeay *et al.* (2004) have noted areas of high risk for groundwater contamination in the vicinity of Hope Bay, along Dent Hill, in Port Washington, along Razor Point Road, to the west of Roe Lake, adjacent to Brackett Cove, in the vicinity of Medicine Beach, in the Municipal Improvement District of Trincomali, and adjacent to Shark Cove. Some of these areas have already encountered decreased water quality (Mordaunt, 1981; Henderson, 1998).

According to Islands Trusts (2005), a number of lots have potential for further subdivision. Some of these lots occur within areas of high risk of groundwater vulnerability mapped by Journeay *et al.* (2004).

The combined protected (parkland), agricultural reserve, and forest reserve lands on North Pender Island comprise 28% of the landmass. This portion of the island is currently unavailable for residential development.

7.2.2 South Pender Island

South Pender Island is one of the least developed islands of the Outer Gulf Islands. South Pender Island is approximately 934 hectares, of which parks (Federal, Provincial, and Regional) comprise approximately 25% (South Pender Island Local Trust Committee, 2004) of the total landmass. Additionally, there are several small community parks encompassing an additional 1.5% of the landmass of the island. The amount of parkland limits the quantity of land currently available for development (Table 7.1).

Table 7.1: National, Provincial, and Regional Parks on South Pender Island

PARK	AREA
Beaumont Provincial Marine Park	58 hectares (143 acres)
Mount Norman Regional Park	101 hectares (250 acres)
Greenburn Lake National Park Reserve	118.4 hectares (293 acres)
Canal Road	
Mortimer Spit	
Gowland Point	
Ainslie Road	
Spalding Road	

Currently, there are 281 residential lots, with 43 of these lots having the potential for subdivision into an additional 191 residential lots (Islands Trust, 2002). The majority of the residential lots are located along the coastline. This choice of location has implications from a water quality perspective, as there is a greater potential for salt water intrusions (Journeay *et al.,* 2004). Of the portion of the island available for development, lot sizes vary, as they depend upon ocean frontage. Lots possessing ocean frontage must be a minimum of 0.4 hectares in size, while lots without ocean frontage must be a minimum of 0.8 hectares. The permanent resident population, as of the 2001 census, was 159 (Islands Trust, 2002). Agricultural reserve lands and forestry reserve lands comprise 17.5% and 8% respectively of the island (Figure 7.2). In light of the current land use, 52% of the island is presently dedicated to parks, agricultural reserve, and forest reserve, which would not be available for future development.

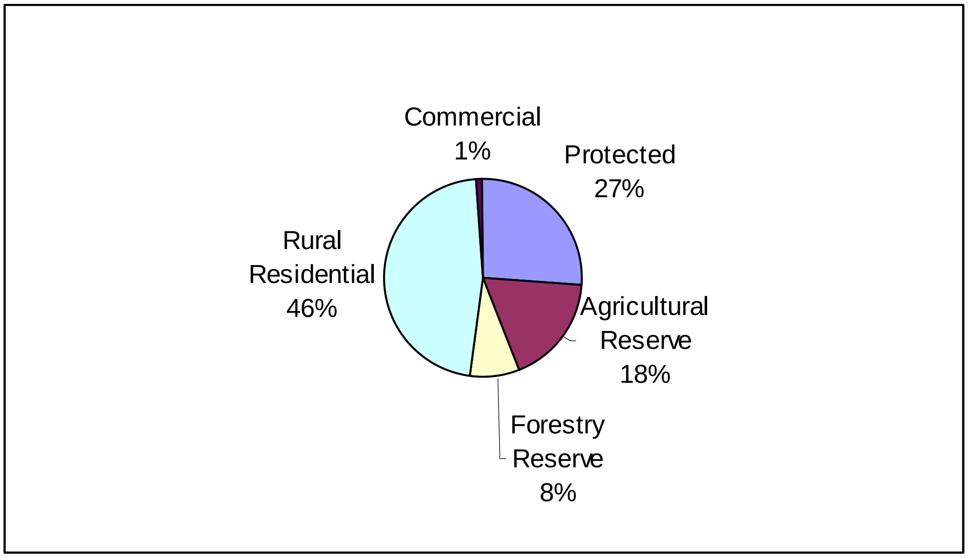

Figure 7.2: Land Use on South Pender Island (Islands Trust, 2002)

7.3 Groundwater Basins

A groundwater basin has been defined by the Department of Water Resources for California (2007) as an area underlain by permeable materials capable of furnishing a significant supply of groundwater to wells or storing a significant amount of water. For this study, groundwater basins have been delineated on the following basis:

- Topography –topography plays a role in surface runoff, recharge and discharge of groundwater, soil cover, vegetation cover, and in the occurrence of a perched water table.
- Surficial Geology – the soil type and thickness play a role in surface runoff and percolation of rainfall for groundwater recharge.

- Bedrock Geology – the contacts of bedrock formations have been found to provide reasonable production for water wells. The steep dip of the bedrock in some locations may influence groundwater movement. Depth to bedrock is also an important parameter as surface runoff is enhanced in areas having little or no soil cover.
- Faults – secondary porosity and permeability are increased at fault locations. Faults can act as barriers to groundwater movement as they represent preferred flow paths.
- Geophysical Interpretations – the results of time domain electromagnetic soundings since they provide a basis for estimating the depth to saline water on the island. Geophysical investigations also identified the depth to bedrock, bedrock heterogeneity, and presence of a perched water table.
- Surface watersheds

The boundaries of groundwater basins are not fixed and are subject to movement over time due to variations in extraction rates from water wells and land use. The actual boundaries of one aquifer may not coincide with those of another aquifer. A groundwater basin may contain more than one aquifer with the aquifers occurring at different depths. For North and South Pender Islands, there appear to be generally two aquifers. The first aquifer occurs within the soils overlying bedrock. This aquifer tends to be restricted to the low-lying areas of the islands where there is soil cover. This is represented by a perched water table and sand and gravel layers. The second aquifer occurs at depth within the bedrock and varies significantly across the islands with changing bedrock lithology and structural geological features.

It is not possible to calculate a water budget on a groundwater basin level due to a lack of information on water consumption. Estimates can however be made regarding the volume of water available for groundwater recharge in each groundwater basin. The Municipal Improvement District of Trincomali is the only portion of the case study area that accurately monitors groundwater extraction for human consumption. A water balance for Trincomali is presented in Section 8.2.4.3. There are other factors that limit the ability to undertake water budget calculations including the lack of information on the secondary porosity and permeability within the host material, lack of information on population density in each groundwater basin, lack of information on alternative water sources, and the difficulty in estimating environmental water requirements in each basin.

7.3.1 North Pender Island

As will be discussed in Section 8.2.4, there are several community water supply systems in place on North Pender Island. By far the largest is Magic Lake Estates, which relies on surface water from Buck Lake to meet the water requirements of the subdivision. It is anticipated that at full build out, surface water will also be required from Magic Lake and Roe Lake to meet the needs of the community. Two smaller community water supply systems are located in Trincomali and Razor Point. These systems rely on groundwater to meet the communities' water needs. With the exception of two individual desalination systems on the island, the remainder of the residents rely on individual water wells to supply potable water (Islands Trust, 2003).

The island has been subdivided into twelve groundwater basins (Figure 7.3). Integration of the geophysical data, geological mapping, climatic records and groundwater wells within each groundwater basin provides useful information regarding the occurrence of groundwater that information can then be easily incorporated into community plans.

The best-producing water wells on North Pender Island are defined as having production rates of 15 gal/min or more and have been located on the groundwater basin map (Figure 7.3). One-third of the best producing water wells occur near known faults. An additional six water wells located on the south side of Dent Hill form a near-linear pattern but appear to be more related to the Galiano/Northumberland Formation contact.

Insert Figure 7.3

Table 7.2: Storage capacity of North Pender Island groundwater basins*

Groundwater Basin	Area	Bedrock Formations	Primary Porosity	Zones of Secondary Porosity	Storage Capacity (cu. m)	Estimated Extractable Resources (litres)
NP-I	2.68 sq. km	DeCourcy	3.9 %	Yes	10,489,440	313,854,886
NP-II	2.2 sq. km	DeCourcy, Cedar	4.3 %	Yes	9,456,940	282,701,820
NP-III	3.36 sq. km	DeCourcy, Galiano, Northumberland, Mayne	3.9 %	Yes	13,103,565	391,837,275
NP-IV	3.37 sq. km	DeCourcy, Galiano, Northumberland, Cedar	4.3 %	Yes	14,479,065	432,968,930
NP-V	0.84 sq. km	DeCourcy, Galiano, Northumberland	3.9 %	Yes	3,272,320	97,852,510
NP-VI	0.88 sq. km	Galiano	3.9 %	Yes	3,431,390	102,609,200
NP-VII	5.21 sq. km	DeCourcy, Galiano, Northumberland	5.6 %	Yes	29,162,135	872,038,210
NP-VIII	2.2 sq. km	DeCourcy, Galiano, Northumberland, Cedar	5.6 %	Yes	12,316,020	368,287,175
NP-IX	0.67 sq. km	DeCourcy, Galiano, Northumberland	3.9%	Yes	2,609,585	78,034,620
NP-X	1.18 sq. km	Extension, Pender, Protection, Cedar, DeCourcy	4.0%	Yes	4,717,585	141,070,415
NP-XI	3.39 sq. km	Extension, Pender, Protection, Cedar, DeCourcy	4.0%	Yes	13,557,125	405,400,065
NP-XII	1.36 sq. km	Extension		Yes	5,302,270	158,554,310

*Extractable resources assumed to be 3% of storage capacity based on primary porosity; freshwater column assumed to be 100 metres in thickness.

The information presented in Table 7.2 is only an estimate of the storage capacity for each groundwater basin. The quantity of potable water available for human consumption is more closely related to a mixture of the extractable resources and the groundwater recharge on an annual basis. If the volume of water extracted exceeds the recharge then groundwater mining will occur.

7.3.1.1 Groundwater Basin NP-I

Groundwater basin NP-I occurs along the northernmost portion of North Pender Island (Figure 7.3). The basin includes Georges Hill, which provides significant topographic relief to assist in groundwater recharge. The groundwater basin is bounded to the north and east by Navy Channel, to the west by Swanson Channel, and to the south by groundwater basin NP-II. Bedrock in the basin comprises DeCourcy Formation sandstone in the vicinity of Georges Hill, and Cedar Formation shale along the north coast. Dip of the bedrock varies from approximately 23° to 55° to the south. There is a northeast-southwest trending fault extending from Clam Bay to Port Washington. The soil cover has variable thickness. Typically, the topographic highs have only a thin veneer of soil, if it is present at all, while there can be significant soil cover in the low-lying areas.

Ten of the top producing water wells occur within this basin. Four of the wells have been drilled in the Cedar Formation and the remaining wells are in the DeCourcy Formation. Five of the good producing wells are located close to the contact of the Cedar and DeCourcy Formations. The depth to the water-bearing zone is similar in some of the wells. Mordaunt (1981) found that several water wells in this basin had anomalously high chlorides and iron. It is likely that high chlorides represent saline water intrusions. Water quality should be a concern since four of the top producing water wells are located adjacent to the coastline.

No geophysical investigations were undertaken within NP-I. On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-I has a storage capacity of 10.5×10^6 m^3 and extractable resources of 31.3×10^7 litres.

7.3.1.2 Groundwater Basin NP-II

Groundwater basin NP-II is bounded to the north by groundwater basin NP-I, to the west by Swanson Channel, to the south by groundwater basin NP-IV and to the east by groundwater basin NP-III. Bedrock in the area consists of DeCourcy Formation sandstone, Northumberland Formation shale, and Galiano Formation sandstone. The Northumberland Formation shale underlies the low-lying areas within the basin, while the topographic highs are made up of more resistant sandstone. Dip of the bedrock varies from approximately 30° to 52°. As is typically the case, the surficial materials are generally only a thin veneer, where present at all, on the topographic highs but may attain thicknesses of up to 25 metres in low-lying areas.

No geophysical investigations were undertaken in this groundwater basin.

Nine of the best producing water wells are located within this basin. Four of the best producing wells are located close to known faults. There is generally insufficient data in the water well records to make a comparison of the depths of the water-bearing zones in this basin.

Mordaunt (1981) found that water wells in the vicinity of Port Washington had anomalously high levels of chlorides and iron. Only one of the best producing wells is located adjacent to the coastline.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-II has a storage capacity of 9.4×10^6 m^3 and extractable resources of 28.2×10^7 litres.

7.3.1.3 Groundwater Basin NP-III

This basin is bounded by Navy Channel to the north, groundwater basins NP-II and NP-IV to the west, groundwater basin NP-V to the east and groundwater basin NP-VII to the south. It is predominantly underlain by DeCourcy Formation sandstone, Northumberland Formation shale, Galiano Formation sandstone, and Mayne Formation shale. The bedrock dips between 13° and

27°. On the basis of field observations and geophysical interpretations, there is limited soil cover. Bedrock was exposed along most of the existing roadways and much of the shoreline.

There are two southwest-northeast trending faults. None of the best producing water wells are located within this groundwater basin. Mordaunt (1981) found that water wells in the vicinity of Hope Bay had anomalously high levels of chlorides and iron.

Geophysical investigations were conducted adjacent to Hoosen Road, Hope Bay, along Corbett Road, and at the Community Hall. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2. On the basis of the time domain electromagnetic sounding data, brackish water is anticipated at a depth of approximately 125 m in the low-lying area adjacent to Hoosen Road. With the use of the Ghyben-Hertzberg relationship, this translates to the potable water table occurring at 2.85 m above sea level.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-III has a storage capacity of 13.1 x 10^6 m^3 and extractable resources of 39.2 x 10^7 litres.

7.3.1.4 Groundwater Basin NP-IV

Groundwater basin NP-IV is bounded to the north by groundwater basin NP-II, to the east by groundwater basins NP-III and NP-VII, to the west by Swanson Channel, and to the south by groundwater basin NP-VI. The Allison Fault is located within this basin. Five of the best producing wells on the island is located within this groundwater basin. The presence of faulting within the bedrock likely results in zones of increased secondary porosity and permeability, since two of the best producing wells are located close to the fault near Ella Bay.

Bedrock comprises sandstone of the Galiano Formation, and shale of the Mayne Formation. The topographic highs comprise the more resistant sandstone, while the topographic lows are underlain by the less resistant shale units. The dip of the bedrock ranges from 24° to 82°. The topographic highs generally have little or no overburden cover, while the overburden cover can achieve thicknesses of up to 20 metres in the low-lying areas.

Geophysical investigations in this groundwater basin were conducted along McKinnon Road, adjacent to Otter Bay, and at Roes Islet. A time domain electromagnetic sounding located approximately 30 metres east of the breakwall at Roes Islet indicates saline water at a depth of 57 metres. On the basis of the geologic section developed by Henderson (1998), the saline water occurs within DeCourcy Formation sandstones underlying the Northumberland Formation shale. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2.

Three of the best producing wells occur along the south side of Dent Hill. There is no known fault in this area that would account for the general linear trend of these wells. On the basis of information from the water well database, it appears that several of these wells are producing from fractures at depths of between 10 and 20 metres. This corresponds well to the anticipated depth to the contact between the Galiano Formation sandstone and the underlying Northumberland Formation shale (Henderson, 1998). There are two possible scenarios: 1) the Northumberland shale acts as an impermeable horizon, with the result that there is a perched water table within the overlying sandstone; or 2) there is an increase in secondary porosity and permeability close to the stratigraphic boundary. Regardless, the stratigraphic boundary may represent the optimal drilling depth for groundwater wells.

This portion of the basin has the potential for additional development of 55 visitor accommodation units (Island Tides, 2005). The availability of groundwater resources with no impact on neighbouring properties should be a determining factor in the decision-making process regarding the increased density of visitor accommodation in this area. The shallow depth of occurrence of the groundwater is significant to the consideration of groundwater recharge and water quality issues. It will be imperative to locate any septic fields and tanks so as to avoid the potential for contamination of the aquifer for all residents. Any additional visitor accommodations located along the coastline can potentially increase the likelihood of saline intrusions due to overpumping of the aquifer. On the opposite side of Otter Bay, saline water was mapped at a depth of 57 metres, which places a base to the potable groundwater resources. Pump tests or packer tests and drawdown tests should be mandatory for any additional development. Further development of the groundwater resources in this area should require review by a qualified hydrogeologist to minimize risk of saline intrusion and to fully evaluate the influence of pumping on neighbouring wells.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-IV has a storage capacity of 14.5 x 10^6 m^3 and extractable resources of 43.3 x 10^7 litres.

7.3.1.5 Groundwater Basin NP-V

Groundwater basin NP-V represents a relatively small area the northern portion of Bald Cone. The basin is bounded to the north and east by Plumper Sound, to the west by groundwater basin NP-III, and to the south by groundwater basin NP-VII. The bedrock within the basin consists of Galiano Formation sandstone along the coast line, Northumberland shale and DeCourcy Formation sandstone. The dip of the bedrock ranges from 15 to 55°. The Allison Fault is located within this basin. The topographic highs comprise the more resistant sandstone, while the topographic lows are underlain by the less resistive shale. The topographic highs generally have little or no overburden cover, while the overburden cover can achieve thicknesses of up to 20 metres in the low-lying areas.

Five of the best producing water wells are located within this basin. Three of these water wells are located north of Bald Cone in the Galiano Formation and the other two wells are located adjacent to the Allison Fault. No geophysical survey lines were located within this groundwater basin.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-V has a storage capacity of 3.3 x 10^6 m^3 and extractable resources of 9.8 x 10^7 litres.

7.3.1.6 Groundwater Basin NP-VI

Groundwater basin NP-VI is bounded to the north groundwater basin NP-IV, to the south by groundwater basin NP-VIII, to the east by groundwater basin NP-VII and to the west by Swanson Channel. The basin encircles Roe Lake. Bedrock is sandstone of the DeCourcy Formation with dips ranging from 50 to 60°. The Pender Fault crosses this groundwater basin.

None of the best water producing wells is located within this basin. No geophysical survey lines were located within this groundwater basin.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-VI has a storage capacity of 3.4 x 10^6 m^3 and extractable resources of 10.3 x 10^7 litres.

7.3.1.7 Groundwater Basin NP-VII

Groundwater basin NP-VII is bounded to the west by groundwater basins NP-IV, NP-VI, and NP-VIII, to the north by groundwater basins NP-III and NP-V, to the east by a groundwater basin NP-V, and to the south groundwater basin NP-XI. The bedrock comprises DeCourcy Formation sandstone, Northumberland Formation shale, Galiano Formation sandstone, and Cedar Formation shale. The bedrock dips are relatively steep, ranging from 40 to 87^0. The Allison and Pender Faults cross the basin as do two southwest-northeast trending faults. Several springs have been mapped close to the Allison Fault (Henderson, 1998).

Geophysical investigations were undertaken along Razor Point Road to the east of Brackett Cove, along Razor Point Road to the northeast of Pollard Cove, and at the Allison Farm. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2. in this basin.

Twelve of the best producing water wells are located in this basin with one adjacent to the Pender Fault, three adjacent to the Allison Fault and two close to the fault extending from

Bedwell Harbour to Port Browning. The Razor Point community water well is located within this groundwater basin system.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-VII has a storage capacity of 29.2 x 10^6 m^3 and extractable resources of 87.2 x 10^7 litres.

7.3.1.8 Groundwater Basin NP-VIII

Groundwater basin NP-VIII is bounded to the east groundwater basin NP-VIII, to the north groundwater basins NP-VI and NP-VII, to the west by Shingle Bay, and to the south by groundwater basins NPIX, NP-X, and NP-XI. The bedrock in this basin consists of DeCourcy Formation sandstone, Cedar Formation shale, and Protection Formation sandstone. The bedrock dips are range between 48 and 89^0.

The topographic highs comprise the more resistant sandstones, while the topographic lows are underlain by the less resistive shale units. The topographic highs generally have little or no overburden cover, while the overburden cover can achieve thicknesses of up to 20 metres in the low-lying areas.

Buck Lake is encircled by this basin. Geophysical investigations were conducted along Irene Bay Road and Shingle Bay Road. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-VIII has a storage capacity of 12.3 x 10^6 m^3 and extractable resources of 36.8 x 10^7 litres.

7.3.1.9 Groundwater Basin NP-IX

Groundwater basin NP-IX is bounded to the east by groundwater basins NP-X and NP-XII, to the north by groundwater basin NP-VIII, and to the east south by Swanson Channel. The bedrock in the basin consists of Pender Formation shale and Extension Formation conglomerate. The bedrock dip ranges from 56 to 74^0.

None of the best producing water wells are located within this groundwater basin. The groundwater basin is within Magic Lake Estates water system. No geophysical lines were surveyed within this groundwater basin.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-IX has a storage capacity of 2.6 x 10^6 m^3 and extractable resources of 7.8 x 10^7 litres.

7.3.1.10 Groundwater Basin NP-X

Groundwater basin NP-X is bounded to the west and south by Swanson Channel, to the north by the Pender Fault, and to the west by groundwater basin NP-XI. The bedrock in this basin consists of Extension Formation conglomerate, Pender Formation shale, and Protection Formation sandstone.

The basin encompasses Magic Lake and is located entirely within Magic Lake Estates. The Magic Lake Estates water supply system, managed by the Capital Regional District, is the major water provider for residents of the basin (see Section 8.2.4.1). No geophysical data were acquired in this basin during the field investigations for this research. None of the best producing water wells are located within this basin.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-X has a storage capacity of 4.7 x 10^6 m^3 and extractable resources of 14.1 x 10^7 litres.

7.3.1.11Groundwater Basin NP-XI

Groundwater basin NP-XI encompasses a portion of both Magic Lake Estates and the Municipal Improvement District of Trincomali. The basin is bounded to the west by groundwater basins NP-VIII, NP-X, and NP-XII, to the north by groundwater basin NP-VII, to the east by Bedwell Harbour, and to the south by groundwater basin NP-XII. As with groundwater basin NP-X, the Capital Regional District manages water supply within a portion of the basin (see Section 8.2.4.1). An intermittent stream provides drainage during the wet winter months in this basin.

The bedrock in the basin consists of DeCourcy Formation sandstone, Cedar Formation shale, Protection Formation sandstone, Pender Formation shale and Extension Formation conglomerate. Bedrock dips relatively steeply, ranging from 38° to 75°. A north-south trending fault occurs within the Improvement District of Trincomali. Geophysical investigations were undertaken at Medicine Beach within this basin. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2.

One of the best producing water wells is located in Extension Formation conglomerate. No geophysical investigations were undertaken in this region, due to the high degree of development and the lack of any significant length of straight roads along which to conduct the surveys.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-XI has a storage capacity of 13.6 x 10^6 m^3 and extractable resources of 40.5 x 10^7 litres.

7.3.1.12Groundwater Basin NP-XII

Groundwater basin NP-XII is located along the southwest shore of the island. It is bounded to the south by Swanson Channel, to the west by groundwater basin NP-IX, to the north by groundwater basins NP-X and NP-XI, and to the east by Peter Cove. The basin encompasses a portion of both Magic Lake Estates and the Municipal District of Trincomali.

Bedrock within the basin is comprised of Extension Formation conglomerate. Bedrock dips range from 38° to 52°. A north-south trending fault occurs within the Municipal Improvement District of Trincomali. Three of the best producing water wells are located within this basin. Two of the best producing water wells are located adjacent to the fault in the Municipal District of Trincomali. The water wells are also located close to the coastline so that saline intrusions should be a concern.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin NP-XII has a storage capacity of 5.3×10^6 m^3 and extractable resources of 15.8×10^7 litres.

7.3.2 South Pender Island

There are at present no community water supply systems in place on South Pender Island, although Poets Cove does have a water supply system, relying on withdrawals from Greenburn Lake to provide water for guests and owners of units (see Section 8.2.4.4). Water supply is otherwise based on individual water wells drilled by and for property owners; this drilling has essentially been conducted on an ad hoc basis. The best producing wells for South Pender Island are defined as having production rates of 10 gal/min or more and are located on groundwater basin map (Figure 7.2). Eight of the best producing wells are located along a fault.

There are four basic groundwater basins on South Pender Island (Figure 7.3, Table 7.3). On the basis of the intrinsic vulnerability map produced by Journeay *et al.* (2004), the only portions of South Pender Island that possess a greater than moderate intrinsic vulnerability are located along the coast line. Groundwater well data and structural mapping should be included to increase the rated vulnerability along the fault associated with the best producing water wells.

The information presented in Table 7.3 is only an estimate of the storage capacity for each groundwater basin. These figures do not represent the quantity of potable water available for human consumption.

Table 7.3: Storage capacity of South Pender Island groundwater basins*

Groundwater Basin	Area	Bedrock Formations	Primary Porosity	Zones of Secondary Porosity	Storage Capacity (cu.m.)	Estimated Extractable Resources (litres)
SP-I	2.8 sq. km	De Courcy	3.9 %	Yes	10,915,815	326,416,950
SP-II	3.5 sq. km	De Courcy, Cedar, Protection	3.7 %	Yes	12,938,530	386,902,155
SP-III	1.54 sq. km	Protection, Pender, Extension	4.4 %	No	6,776,355	202,634,065
SP-IV	1.6 sq. km	Extension	5.6 %	Yes	8,961,260	267,969,455

*Estimated extractable resources assumed to be 3% of storage capacity based on primary porosity; assumption that freshwater column is 100 metres in thickness

7.3.2.1 Groundwater Basin SP-I

Groundwater basin SP-I is bounded to the northwest by North Pender Island, to the north by Plumper Sound, and to the south by groundwater basin SP-II. The basin is separated from groundwater basin SP-II by the topographic highs of Mount Norman, Spalding Hill and Hermit Hill. A major fault (Pender Fault) is located adjacent to this basin and auxiliary faulting may be associated with the major fault possessing higher secondary porosity and permeability. The basin is bisected by a north south trending fault. An east-west trending fault is present within the basin and extends into groundwater basin SP-II. Bedrock consists of DeCourcy Formation sandstone having dips on the order of 86^0. The topography is also relatively steep with little or no soil cover over most of the basin.

Geophysical investigations were undertaken adjacent to Canal Road. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2. Two of the best water producing wells are located along the east-west trending fault within this basin. The proximity to the coast should be a concern from a water quality perspective as overpumping has the potential to result in saline intrusions.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin SP-I has a storage capacity of 10.9 x 10^6 m^3 and extractable resources of 32.6 x 10^7 litres.

7.3.2.2 Groundwater Basin SP-II

Groundwater basin SP-II (Figure 7.3) is bounded to the west by Bedwell Harbour, to the north by SP-I, and west by Plumper Sound and to the south by groundwater basin SP-III. The underlying bedrock comprises De Courcy Formation sandstone, Cedar Formation shale, and Protection Formation sandstone. The bedrock is dips from 74 to 88^0. There is a substantial soil cover in the valley associated with the presence of the Cedar Formation shale. Seven water wells producing 37.9 lpm (10 gpm) or more are located in this basin. Six of the water wells are located very close to one another occur in a development on Spalding Hill and form a linear trend indicating the possible presence of an east-west trending fault (Figure 7.3).

A geophysical investigation was undertaken adjacent to Spalding Road. The time domain electromagnetic sounding results indicate the presence of saline water at a depth of approximately 123 metres, which places a limit on the drilling depths for water wells in the low-lying areas of the basin. With the use of the Ghyben-Hertzberg relationship, this translates to the potable water table occurring at 3.06 m above sea level.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin SP-II has a storage capacity of 12.9 x 10^6 m^3 and extractable resources of 38.7 x 10^7 litres.

7.3.2.3 Groundwater Basin SP-III

Groundwater basin SP-III (Figure 7.3) surrounds Greenburn Lake; the only surface water body on South Pender Island. The lake receives runoff from Curtis Peak to the north and Stanford Hill to the south. There are several permits for extraction of water from the lake, including Poets

Cove located in groundwater basin SP-III. There is no metering system to monitor the actual volume of water extracted by any of the permit holders.

The underlying bedrock consists of Protection Formation sandstone, Pender Formation shale, and Extension Formation conglomerate. There is a fault of limited lateral extent mapped between Gowlland Point and Canned Cod Bay.

No water wells in the water well database with production rates of 37.9 lpm (10 gpm) or more are located within this basin. No geophysical investigations were undertaken in SP-III during the research for this dissertation. Depths to the water table and saline water were estimated on the basis of the geophysical results from SP-IV. The thickness of the geologic units encountered was based on geologic cross-sections prepared by Henderson (1998).

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin SP-III has a storage capacity of 6.8 x 10^6 m^3 and extractable resources of 20.2 x 10^7 litres.

7.3.2.4 Groundwater Basin SP-IV

Groundwater basin SP-IV (Figure 7.3) is located in the southern portion of the island. It is bounded to the north by Stanford Hill and to the east, west and south by Swanson Channel. The bedrock underlying the basin consists of Extension Formation conglomerate with low primary porosity and permeability. A fault has been mapped near Tilly Point and this fault continues through Bedwell Harbour to Port Browning. Dip of the bedrock varies from approximately 25° to 75°. There is one water well in the water well database with a production rate of 37.9 lpm (10 gpm) or more located within this basin.

Geophysical investigations were conducted along Southlands Drive and Higgs Road in this groundwater basin. The geophysical surveys conducted delineated a possible buried channel in the vicinity of Southlands Drive, which may represent a relatively good, shallow source of fresh water. A displacement in the seismic refraction data indicates the possible presence of a fault perpendicular to Higgs Road. Along the Higgs Road survey line, saline water is anticipated above the soil/bedrock interface close to Swanson Channel. The physical properties of the soil and bedrock at each survey location are presented in Table 6.2.

On the basis of the assumptions used to calculate both the storage capacity and the extractable resources, groundwater basin SP-IV has a storage capacity of 9.0×10^6 m^3 and extractable resources of 26.8×10^7 litres.

7.4 Summary

A phased approach was undertaken to estimate the groundwater resources of North and South Pender Islands. The islands were subdivided into groundwater basins on the basis of surface watersheds. A review of the porosity and permeability of the geologic units indicated that of the groundwater held in storage only a small percentage was actually available for human consumption. On the basis of porosity of the bedrock in each groundwater basin, the extractable yield was estimated, using climatic data and groundwater recharge so that the groundwater resources assessment for the islands can be estimated.

To estimate the groundwater storage capacity, it was necessary to use the information obtained on the geology of the islands from the field mapping and laboratory analysis to estimate the primary porosity of each bedrock unit. In the absence of any laboratory measurements for a bedrock unit, an estimate from the literature was used. It was not possible to calculate secondary porosity on the basis of the laboratory measurements, since no samples were obtained from the major fault zones. Because the secondary porosity is not included, the resulting storage capacity estimates are likely underestimated; the secondary porosity can be significantly larger than the primary porosity on a local scale. It is, however, likely that the faults have limited lateral dimension, which would reduce their groundwater storage capacity. The underestimation could be viewed as a built-in safety factor, in view of the annual variations in precipitation, which would result in the volume of water varying both temporally and spatially.

The calculation of primary porosity is based on relatively few surface samples of the sandstone bedrock units. It has been assumed that the porosities measured from these samples represent the average primary porosity for the bedrock unit.

In the determination of the groundwater resources, the strike, dip and measured thickness of the bedrock formations have been taken into consideration, as have the thickness of the soil cover and soil type. This information was obtained from field investigations as part of the research for this dissertation as well as from the existing literature. The dip of the bedrock units has an impact. Vertical water wells drilled into a steeply dipping horizon will remain within the same stratigraphic unit for most of their length, whereas in dipping strata, a number of geologic boundaries may be intersected. Water well records indicate that groundwater production occurs at fractures and at stratigraphic boundaries on the islands (www.gov.bc.ca/cgi-bin/env_exec/wwwapps/waterbot/ gwellout).

The bedrock formations show significant variation in rock type as observed from both geological and geophysical mapping. These rock type variations will have an impact on groundwater resources. A formation that is predominantly comprised of sandstone often has shale and siltstone horizons. These horizons appear laterally continuous but are generally too thin to be mapped by surface geophysical methods.

Knowledge of the depth of occurrence of saline groundwater based on the geophysical survey results, when combined with the hydrogeological properties of the bedrock units, provides an estimate of the thickness of stratigraphic units available for groundwater storage. To estimate the groundwater resources, approximations have been made regarding the surface runoff and evapotranspiration occurring on the island. These parameters are poorly defined but the approximations represent a conservative approach. The parameters will change both temporally and spatially, so that they represent only a brief point in time estimate. Henderson (1998) estimated that evapotranspiration could be as high as 65% of the total annual precipitation. Since the surface runoff can be as high as 30% in steep terrain (American Society of Civil Engineers, 1996) and additional losses occur due to groundwater discharge and human impacts, as little as 1.0% of the total annual rainfall may be available for groundwater recharge. A portion of this volume is required by the ecosystem, so that a safe yield may be reduced to 0.5% or, for the average annual precipitation, about 5 million litres per square kilometre, as calculated in Chapter 4.

It is possible to increase the permeability of water wells by hydrofracing at a given depth (Alliance Well Drilling, personal communication, 2008). According to water well drillers on the islands, this approach is not always successful in greatly enhancing water production but provides sufficient water for a residence.

The evaluation of groundwater resources on North and South Pender Islands enables a comparison of two adjacent islands representing opposite ends of the development spectrum for the Outer Gulf Islands. North Pender Island has the highest level of development of any of the Outer Gulf Islands and therefore has fewer remaining options for resource management while South Pender Island is one of the least developed.

The calculation of the extractable groundwater resources was based on the assumption that 3% of the storage capacity is available. The hydraulic conductivity of the stratigraphic units is relatively low and as a result the extractable groundwater resources are quite low. It is entirely possible that the use of 3% may be on the high side with actual extractable groundwater resources being 1% or less. The use of 3% in the calculations takes into account the secondary porosity and permeability.

There is an inherent danger to underestimating the groundwater resources in that community plans would be based on a reduced level of development. There is a similar danger to overestimating the groundwater resources as that may lead to overdevelopment of the islands and increased pressure placed on the extractable groundwater resources.

The following chapters provide an overview of the institutional framework and recommended approaches to change the current governance of groundwater resources on North and South Pender Islands. Chapter 4 indicated that changes in vegetative cover will impact surface runoff, evapotranspiration, and interception of precipitation so that changes to the governance of groundwater resources will be influenced by decisions impacting land use.