Chapter 4: CLIMATE

4.1 Introduction

Meko and Graybill (1995) state that effective planning for use of water resources requires accurate information on hydrologic variability induced by climatic variations. North and South Pender Islands are located in the Mesothermal Biogeoclimatic Zone, which represents the driest mesothermal zone within British Columbia, as described by Krajina (1969). The climate of North and South Pender Islands is determined in large part by their geographic location, areal extent, topography, and proximity to continental and larger island land masses. The climate is west coast summer dry, with dry, warm summers and cool, wet winters (Eis and Craigdallie, 1980). For North and South Pender Islands, the average seasonal distribution of precipitation is 10.5% in summer, 41% in the fall, 34.6% in the winter, and 13.9% in the spring. The Davidson Current typically brings warm water from the south to the northeast Pacific Ocean during the winter months; heat and moisture are transferred into the air, culminating in increased precipitation (B.C. Integrated Land Management Bureau, 2007).

Climatic variability is beyond the control of the residents of North and South Pender Islands and as a result, there should be a strong emphasis placed on understanding climatic controls in the effective management of water resources**.** Figure 4.1 presents a simple conceptual model of the relationship between climate and groundwater resources. It illustrates that groundwater management requires an understanding of current and proposed land uses in addition to climate.

Precipitation plays a primary role in the groundwater resource assessment of small island environments (SOPAC, 1998), as it is often the only source of fresh water inputs to the water balance equation (Falkland, 1991). In addition to the supply side, evapotranspiration represents potentially the largest loss of moisture from the system. These two parameters are described by Falkland (1991) as the most important influences on freshwater resources on small islands.

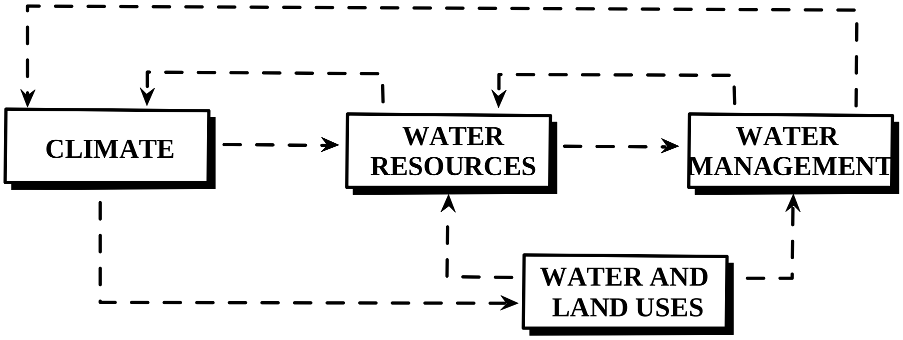

Figure 4.1: Relationship between climate and groundwater resource management (after da Cunha, 1989).

This chapter provides information on the climate of North and South Pender Islands and discusses the relationship between climate and water resources with an emphasis on groundwater resources. Groundwater resources are not always available when and where needed, nor do they always possess the necessary water quality. The groundwater resources of an island represent a snapshot of subsurface conditions at a given time.

4.2 Climatic Variables

The climatic variables discussed in this chapter are precipitation, temperature and evapotranspiration.

4.2.1 Precipitation

Precipitation records for North and South Pender Islands span the period of 1925 to present with only minor gaps in the data. At present, precipitation data are collected at Port Washington, North Pender Island and Trincomali, North Pender Island.

Figure 4.2 presents the annual precipitation records from 1925 to 2002. The data have been organized from March to February to reflect the ecological growth patterns rather than the typical calendar year. The data indicate the unpredictable nature of precipitation, in that there are neither distinct patterns in wet versus dry years, nor distinct patterns in precipitation levels. The range of annual precipitation is from 400 to 1152 mm and the variability can be approximately +/- 50% of the annual average. The standard deviation is 19% as a percentage of the average annual precipitation. The lack of a consistent level of annual precipitation adds to the difficulties of groundwater resource management on small islands. Table 4.1 shows the basic statistical data for precipitation for the time period of 1925 to 2002.

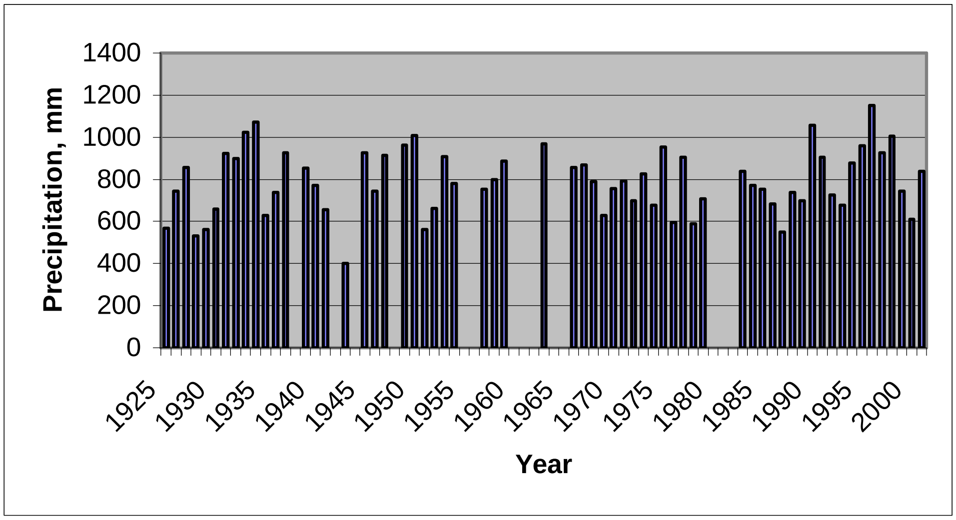

Figure 4.2: Annual precipitation, North Pender Island, 1925 – 2002.

Table 4.1: Basic Statistical Data for Annual Precipitation, North Pender Island

Average Rainfall	791 mm
Median Rainfall	790 mm
Standard Deviation	151 mm
Range in Annual Rainfall	400 – 1152 mm

Figure 4.3 presents the average monthly precipitation for North and South Pender Islands. There is a clear seasonal trend to the precipitation; November, December and January are generally wet months, while June, July, August, and September are dry months. A comparison of the average monthly precipitation for wet (October to March) and dry (April to September) periods indicates that 75% of the average annual rainfall occurs between October and March. The seasonal nature

of precipitation distribution is significant since during the dry months, the population of the islands triples, due to the influx of tourists, placing increased demands on water supply when there is the least potential for replenishing that supply (Agriculture Canada, 1988). The projected population growth for the surrounding urban areas will likely increase the number of tourists and water demand (B.C. Ministry of Management Services, 2005).

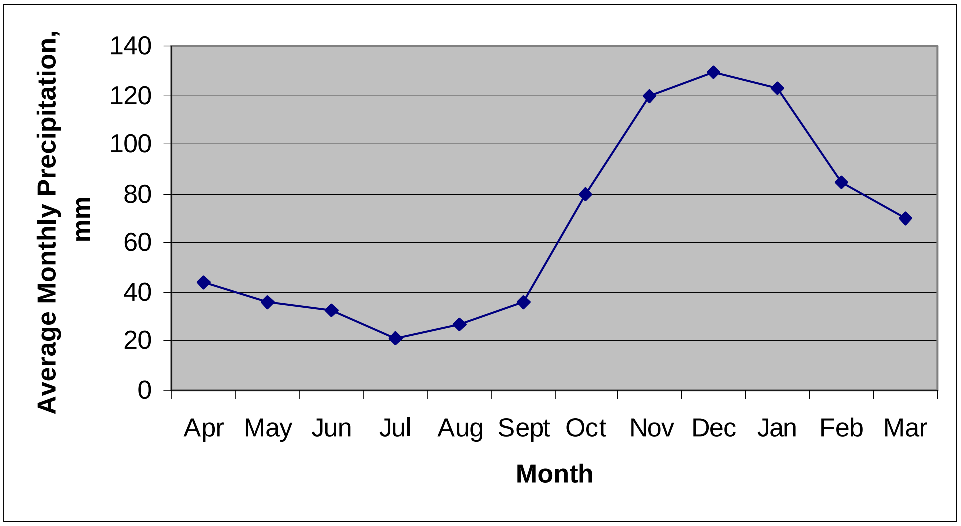

Figure 4.3: Average monthly precipitation, North Pender Island

As Dracup *et al.* (1980) state, the study of droughts has been seriously neglected and this is particularly true for small islands. Many national agencies, such as the U.S. Weather Bureau, have set up websites in recent years to provide information on droughts. The problem for many small islands is that the financial resources are not available for ongoing in-depth drought investigations. This is unfortunate, since droughts should be closely tied to security of water supply issues. Koshida (1991) defines droughts as prolonged periods of abnormally dry weather, producing a moisture shortage that affects crops and forests, and reduces water resources to a degree, thus creating serious environmental, economic or social problems. Droughts are generally determined after they have occurred making any response to a drought reactive.

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

40% represent drought emergency. Drought conditions on North and South Pender Island have occurred during the recent past (Table 4.2). As noted in Henderson (1998), the most severe drought conditions on record occurred between August 1942 and September 1944, when population on the islands was low. The lack of significant human demand on water resources during that period would have resulted in a rapid replenishment of groundwater resources once the drought conditions ended and normal rainfall levels had resumed. A more recent drought, between June and November 2002, had a significant impact on the water resources. Population levels were significantly higher than during the 1940s drought, so there was increased demand on the groundwater resources. Hydrographs, from observation wells located on North Pender Island, indicated a significant increase in the depth to the water table during late 2002. There are no similar increases in depth to the water table occurring within the time frame of record keeping for these wells for other drought periods.

Research in other jurisdictions having longer periods of records has found that average rainfall has actually increased locally since 1900 versus the time frame of 1800-1900 (Lamb, 1988; Frederikson, 1992; Stoddart and Walsh, 1992). This variation indicates the inherent dangers of using the past to predict the future when it comes to climate. This is particularly true for North and South Pender Islands, where it is only in the very recent past that climatic records have been available. A questionnaire distributed to residents of North Pender Island in 1990 by the local trustees indicated that 20 of the 89 respondents reliant upon water wells have experienced their wells running dry towards the end of the summer in the past (Henderson, 1998). The lack of water late in the summer season could be due to a number of factors including: too shallow wells, overpumping, and/or lack of rainfall (drought).

There is no discernable trend to the drought periods on the islands, except that they occur predominantly during the summer months. The 1960s represent the only decade since 1925 that did not experience drought conditions (Table 4.2). The droughts may be most severe when they extend into the wetter winter months, since it is then that groundwater recharge occurs on the islands. Due to the 2002 drought, the reservoir for Magic Lake Estates on North Pender Island was reduced to 50% of normal levels prior to the peak summer water consumption season of

2003 (Island Tides, 2003). This reduction provides an indication that drought conditions impact surface storage as well as groundwater recharge (Figure 4.4).

Table 4.2: Periods of Drought on North and South Pender Islands (adapted from Henderson, 1998)

Year	**Months of Below 60% Normal Precipitation**
1925	May, June, July, September, October, November
1926	May, June, August, October, January, February
1928	September, October, November, January
1929	July, August, September, November, December
1935	April, May, June
1942	August, September, October, January, February
1943	June, September, November, December, January, February, March
1944	April, May, June, July, August, September
1952	May, July, August, September, October, November
1956	April, May, July, November
1978	June, July, October, December, January, March
1985	July, August, September, November, December
1987	June, July, August, September, October, February
1993	August, September, October
1994	July, August
1995	May, September
1996	June, July
1998	April, August, September, October
1999	May, September
2000	April, August, February
2002	June, July, August, September, October, November

Figure 4.4: Signage showing Buck Lake water levels in Magic Lake Estates, North Pender Island.

The monthly precipitation statistics presented in Table 4.3 also illustrate the unpredictable distribution. The range of precipitation for each month is very large. A review of the per cent of recorded precipitation data for each month indicates that during the summer months of July and August, there are drought conditions every second summer, on average. This figure decreases to every third spring and fall and every fourth winter. This is significant, since as stated previously the winter months are when the groundwater supplies are replenished on the island. These statistics are also important from a planning perspective, in that they indicate that drier than normal conditions can be anticipated for all months but with a greater frequency of occurrence for the dry summer months.

Table 4.3: Monthly precipitation statistics (based on period 1925-2002)

Month	**Average Precipitation, mm**	**Monthly Precipitation Range, mm**
April	44	5 – 100
May	36	8 – 113
June	32	0 – 134
July	21	0 – 101
August	27	0 – 112
September	36	0.5 – 94
October	80	15 – 187
November	120	26 – 249
December	130	11 – 268
January	123	22 – 295
February	85	13 –189
March	70	7 – 136

Major precipitation events can occur during much shorter intervals than are generally recorded. The intensity and duration of any precipitation event are important influences on the volume of water that percolates into the ground to recharge aquifers (American Society of Civil Engineers, 1996). Surface runoff is directly related to the intensity, duration and frequency of precipitation as well as the soil moisture conditions at the time of the precipitation event (Brooks *et al.*, 1997). Solley *et al.* (1998) provide a water relation of 25.4 millimetres (1 inch) of rain equalling approximately 25 million litres of water per square kilometre. In view of the average annual precipitation of 803 mm for North and South Pender Islands, this translates into 813 million litres of water per square kilometre, which is a significant volume of water. On the basis of these calculations, there should be no shortage of water resources on the islands, and a water resource assessment would be a waste of both time and resources. It is, however, important to refer back to the water balance equation. Its variables indicate that a large portion of precipitation does not contribute to groundwater recharge; instead, water is lost to evapotranspiration, surface runoff, interception and is impacted by the soil moisture content at the commencement of a precipitation event.

4.2.2 Temperature

Temperature is not directly related to the water balance equation but it is a controlling factor for evapotranspiration and additionally, temperature impacts the type and distribution of vegetation. Vegetation, in turn, influences surface runoff, interception of precipitation, and evapotranspiration. Woodward (1987) suggests that vegetation is influenced by the minimum daily temperatures and the physiological ability of the plant to survive low temperatures.

Temperature records for North Pender Island are only available from 1971 to 1994. Figure 4.5 presents the average annual temperature for North Pender Island for this period. The average annual temperature ranges from 8.7^0C to 11.2^0C. Given the short duration of the temperature records, it is difficult to make any inferences on the average annual temperature.

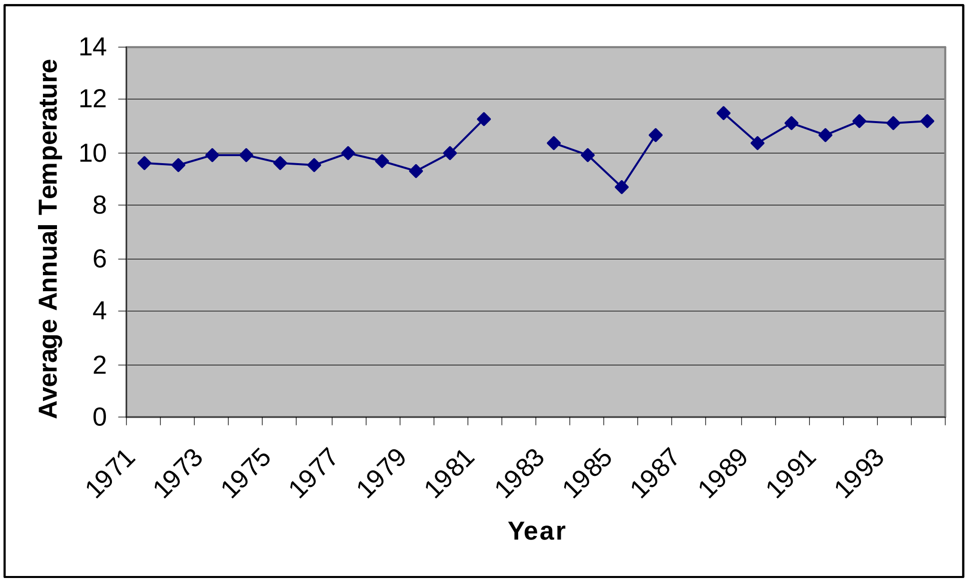

Figure 4.5: Average annual temperature, 1971-1994, North Pender Island (Henderson, 1998)

The temperature records are useful in illustrating the seasonal variation in temperature on North Pender Island. Figure 4.6 presents the average monthly temperature for North Pender Island. The average monthly temperature ranges from a low of 4^0C in January to a high of 16.5^0C in July and August (Henderson, 1998). The warmest months occur during the driest part of the year. As will be discussed in Section 4.2.3, the warmest months also have significant evapotranspiration which can result in net moisture losses during the warm, dry summer months.

The mean daily temperatures for July and December are presented in Figure 4.7. The mean daily temperature is simply the average of the maximum and minimum temperatures recorded on a particular day. The variation in mean daily temperature is greater during December than in July for the period of record.

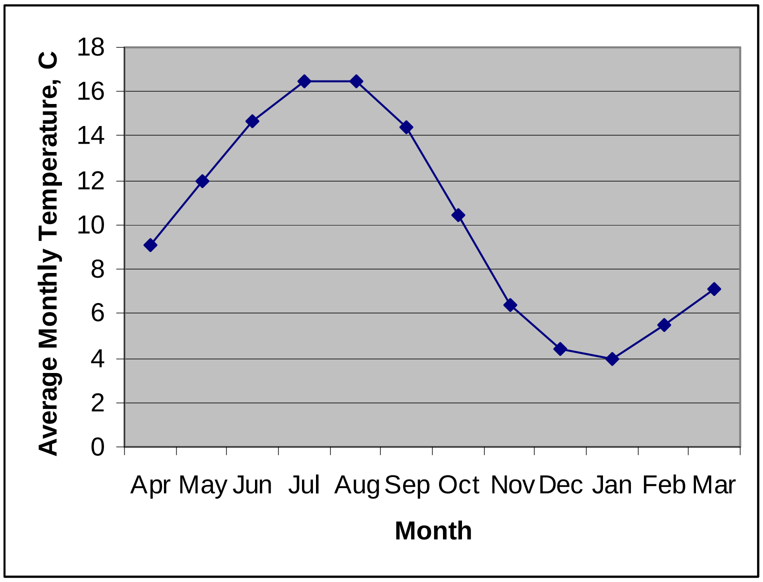

Figure 4.6: Average monthly temperature, 1971-1994, North Pender Island (Henderson, 1998)

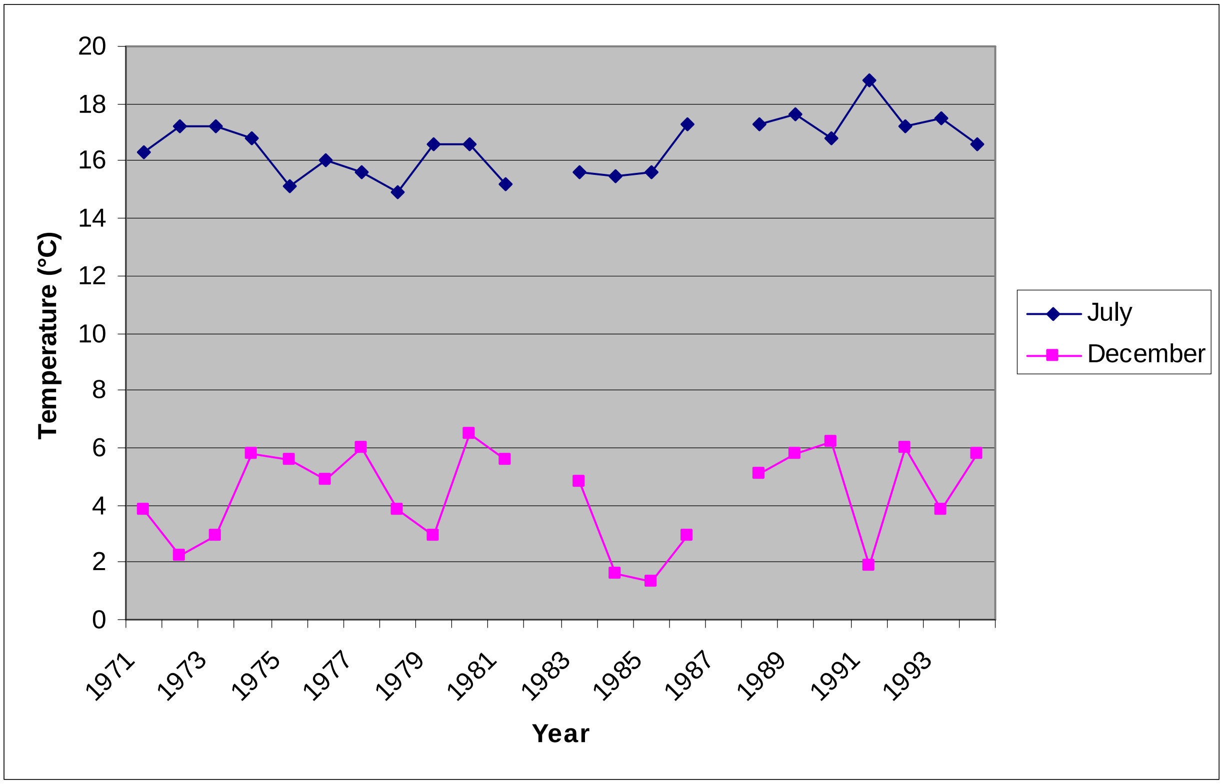

Figure 4.7: Average temperatures for July and December, 1971-1994, North Pender Island (Henderson, 1998)

4.2.3 Evapotranspiration

Evapotranspiration is defined by the American Society of Civil Engineers (1996) as the process by which water moves from the soil to the atmosphere. The Turc equation (equation 4.1), which is based on annual average temperature and precipitation, was used to calculate an estimate of evapotranspiration (Balek, 1989), given the lack of field data on actual evapotranspiration rates.

$$E_t = \frac{P}{(0.9 + (P/L)^2)^{1/2}} \quad \text{mm/yr} \qquad (4.1)$$

Where P is annual precipitation in mm

$$L = 300 + 25T + 0.05T^3 \qquad (4.2)$$

T is mean annual temperature in ^{0}C

E_t is total evapotranspiration in mm/year

As stated by Birkle *et al.* (1998), evapotranspiration is a complex and ambiguous component of the water balance equation, while the American Society of Civil Engineers (1996) points out that all methods of calculating evapotranspiration provide only estimates of the average evapotranspiration. Henderson (1998) found that for North and South Pender Islands on average 64% of the annual precipitation may be lost due to evapotranspiration. Estimates of evapotranspiration are presented in Figure 4.8 for North Pender Island. During the period 1971 to 1994, evapotranspiration is estimated to range from 425 mm/year to 645 mm/year. The range in evapotranspiration should, however be, compared to the annual precipitation. This ratio is referred to as the drying index and has an influence on the amount of precipitation that is lost to surface runoff. Figure 4.9 presents the drying index for North Pender Island for the years when temperature data are available. The drying index ranges from 53% to 72%. If we use the figure of 64% of precipitation lost to evaporation, then for an average annual rainfall, there would be 293 million litres of water per square kilometre available. This number would be further reduced by losses due to surface runoff, which can be significant due to the topography, thin soil cover and human impact (American Society of Civil Engineers, 1996).

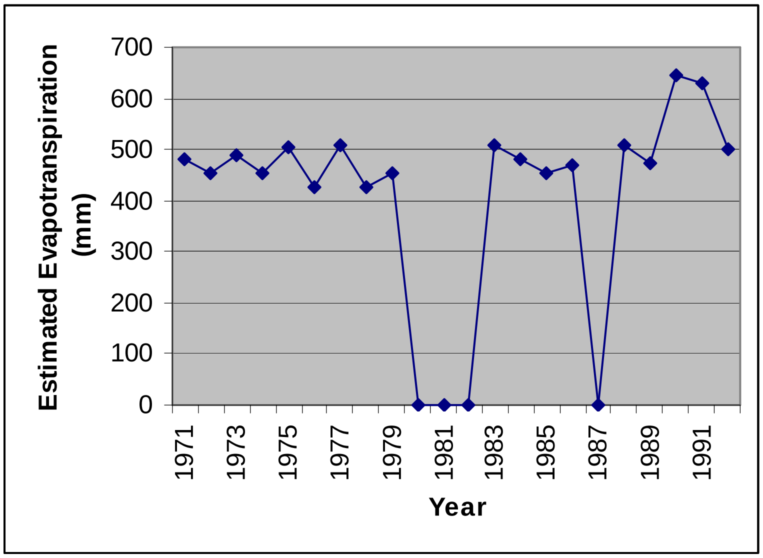

Figure 4.8: Estimated annual evapotranspiration, North Pender Island (Henderson, 1998) (no data for 1980 to 1982 and 1987)

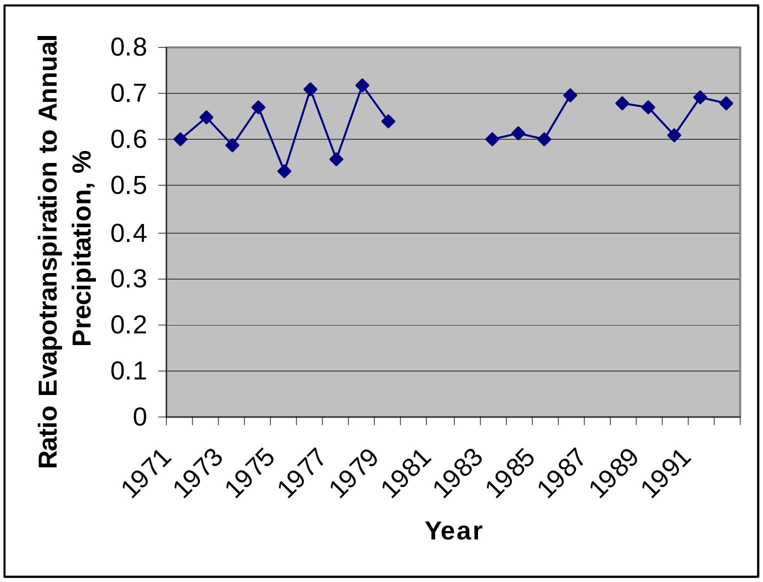

Figure 4.9: Drying index (ratio evapotranspiration to annual precipitation), North Pender Island (Henderson, 1998)

There is a strong interrelationship between near-surface geology, vegetation cover and evapotranspiration, adding to the difficulty of measurement. Milly (1994) points out that for areas having little or no soil cover, the rocks are often not capable of retaining water for subsequent evapotranspiration. When evapotranspiration is combined with other moisture losses for variables of the water balance equation, only a small percentage of the precipitation is available for replenishing water resources.

4.2.4 Other Parameters of Water Balance Equation

The other parameters of the water balance equation (surface runoff, groundwater outflow, change in groundwater storage, change in soil moisture, water recharge/discharge due to human activity, interception, and communication with surrounding area) are all directly related to climate. Surface runoff refers to all waters, originating as precipitation, flowing freely on the surface of the earth either by overland sheet flow or by channel flow in rills, gullies, streams or rivers (American Society of Civil Engineers, 1996). Surface runoff is directly related to the intensity, duration and frequency of precipitation events and is also dependent upon the soil moisture conditions at the time of precipitation (Brookes *et al.*, 1997).

Three distinct physical processes explain surface runoff: 1) Hortonian overflow; 2) saturation overflow; and 3) overland flow due to surface crusting (ASCE, 1996). In Hortonian overflow, surface runoff occurs first as sheet flow and as it moves downslope becomes rill and/or gully flow prior to concentrating into streams. This type of flow occurs when the rainfall intensity exceeds the capacity of the soil to absorb water.

Saturation overflow is similar to Hortonian overland flow, but in this instance surface runoff occurs due to the soils having become saturated and therefore unable to absorb any more water. For overland flow due to surface crusting, the formation of a surface crust is influenced by climate, storm type, vegetation cover, soils and topographic relief.

Interception represents that portion of the precipitation caught by vegetation and evaporated back into the atmosphere both during and after the precipitation event. It is influenced by the form, density, and surface texture of the leaves and twigs of the vegetative cover as well as by the frequency, type, intensity and duration of the precipitation event. According to Falkland (1991), interception is a small percentage of the total precipitation during heavy rainfalls but could represent a significant proportion of a light rainfall.

Soil moisture is a measure of the water storage capacity of soils at any given time. It is directly related to the porosity of the soils. Once all of the available pore spaces are filled with water, the condition of maximum storage has been attained, resulting in surface runoff for any additional precipitation.

The force of gravity causes the downward draining of soil moisture resulting in groundwater recharge. Some of the soil moisture is held in place by capillary forces and does not migrate downward (American Society of Civil Engineers, 1996).

4.3 Relationship to Groundwater Resource Assessment

The water balance equation can be re-written using groundwater terminology as follows:

$$\text{Recharge} = \text{Discharge} + \text{Change in Storage} \qquad (4.3)$$

There may be as little as from 0.5% to 5% of the precipitation available to recharge groundwater aquifers. The lowest value would still translate into 4 million litres of water per square kilometre. If it is assumed that each resident uses 75 litres of water per day, and that the average lot size is one acre having two persons per residence, then the human requirements on an annual basis would be approximately 13.5 million litres of water per square kilometre. This simple calculation would indicate that at full build out there would be a groundwater deficit of 8.5 million litres per square kilometre assuming no other water sources. If we were to examine 1943, the driest year on record on North and South Pender Islands, the water available at an estimate of 0.5 % of the rainfall, would be 0.85 million litres per square kilometre before human consumption. There would be a deficit of 12.65 million litres per square kilometre after human consumption. These simple calculations indicate that the water supply is very sensitive to the actual losses by the variables listed in the water balance equation. These calculations would also be sensitive to the population density on the island but could be used to establish a reasonable level of population density, design community plans and perhaps restrict tourist numbers during the dry summer months particularly, during drought years.

Natural recharge on North and South Pender Islands comes from deep percolation of precipitation. Deep percolation is influenced by a number of factors, including the texture of near surface materials and their permeability, the vegetative cover, the frequency, intensity and volume of precipitation, topography, and temperature (American Society of Civil Engineers, 1996). When recharge is equal to discharge then groundwater conditions have achieved a steady state. Human activities such as water well withdrawals, change this equilibrium and can only be accounted for by increased recharge, decreased discharge, or some combination of these two. The components of equation 4.3 can only be fully understood in the context of the hydrogeological setting, as will be discussed in Chapters 5 and 6.