GROUNDWATER STORAGE AND MOVEMENT

AT

A SITE IN BEVERLY SWAMP

By

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ABSTRACT

Soil samples of peat and hydrologic data were collected from a site in Beverly Swamp, Ontario, from June to September of 1984. The data was analyzed to determine how groundwater storage and movement responded to fluctuations in the water table.

During periods of a lowering water table, groundwater flow was upward and storage capacity increased. The vertical water flow in the peat,which was the dominant direction of flow, was very small and decreased as water levels declined. In periods of recharge the water table rose quickly, groundwater flowed downward and storage capacity was reduced significantly. Vertical water movement increased as the water table rose but remained very small.

It is concluded that groundwater flow in the peat is very small and insignificant while antecedent moisture levels and rainfall amounts are the more important factors in controlling the short term storage capacity of the swamp.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The Beverly Swamp represents one of the four kinds of wetlands that exist in Canada. This swamp is a forested wetland that is seasonally or semi-permanently covered with slowly moving or standing water (Woo and Valverde, 1981). It is an area that supports a variety of plants ranging from coniferous and deciduous trees to tall shrubs, ferns, mosses, grasses, and herbs (Valverde, 1978). The surface soil is decomposed peat which is periodically flooded and remains relatively wet because of a high water table (Munro, 1984).

Groundwater storage and movement in a wetland is a topic that has not received much investigation. However, a good understanding of this topic can have some useful application to the flood control of streams which pass or have their headwaters in a wetland. Knowledge of the subsurface hydrology in peat would also be helpful in determining the extent of contamination and retrieval of toxic materials that might have spilled into a wetland area.

This field study was undertaken to determine the movement and storage of water in different natural summer conditions for a site in the Beverly Swamp adjacent to the Spencer Creek.

1.2 Previous Research

Only a few studies have examined the storage and flow of water in peat soil. Boelter (1964, 1965) studied the physical properties of peat and the hydraulic conductivities for some wetlands in Minnesota, U.S.A. The relationship of the summer moisture content of the peat and the position of the water table were investigated by Munro (1984). Woo and Valverde (1981) studied the regulatory role of the swamp runoff as governed by the changing groundwater storage capacity and the interaction between streamflow and groundwater.

Groundwater flow in peat was examined in a two part paper on "Peat Hydrology in the Hula Basin, Israel" by Neuman and Dasberg (1977). Bay (1967, 1969) studied the water storage, runoff, and factors influencing soil moisture for several bogs in north-central Minnesota, U.S.A.

1.3 Research Objectives

The goals of this study are:

1) to determine the hydraulic properties of the peat;
2) to investigate the pattern of vertical groundwater flow during periods of recharge and discharge; and
3) to determine the storage capacity and how it is affected by changes in the groundwater level and groundwater movement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Groundwater storage and movement in peat depends to a large extent on the physical properties of peat, the antecedent moisture content, the duration and intensity of water inputs (including rainfall and snowmelt), and losses from the wetland. In the proposed study, only the summer conditions are considered.

2.2 Properties of Peat

The physical properties of peat are extremely important in determining how much water is stored and how fast water will move through it (Bay, 1967). Boelter (1965) suggested that several properties of peat should be examined including its porosity, specific yield, specific retention, hydraulic conductivity, and degree of decomposition.

Porosity is the ratio of the volume of voids to the total volume of the soil mass in a column. Part of the water in peat is retained by surface tension in these void spaces and this water is referred to as the specific retention (Johnston, 1967). A small volume of water in the soil will drain by gravity. This ratio of the volume of water that a saturated soil will yield to gravity to the total volume of soil is the specific yield. It is the quantity of water in saturated peat that is free to flow vertically or laterally (Johnston, 1967).

Boelter (1965) stated that hydraulic conductivity of peat soil horizons is one of the more important physical properties that affect the hydrology of a bog. Hydraulic conductivity (K) is a factor of proportionality with the dimension of length divided by time (velocity) and is a property of the soil or rock material (Bouwer, 1978). This value varies considerably with the type of peat and the depth of the peat horizon (Boelter, 1965).

The rate of water movement in a bog will depend largely on the type of peat material in the organic soil profile. Denser decomposed peat retains water in small pores. Bogs made up of such peat are not easily drained and water moves through them very slowly (Boelter, 1965).

2.3 Peat Hydrology

The subsurface flow of water in a swamp involves two basic components: 1) vertical water movement, and 2) lateral movement to or from the stream (Appendix A).

Investigation of subsurface flow regime can be based largely on the interpretation of hydraulic head measurements in piezometers and observation wells under various natural conditions (Neuman and Dasberg, 1977). Using a piezometer nest one can determine the vertical gradient of water flow. Hydraulic gradients which prevail in saturated peats are such that water has a tendency to flow upward due to possible excess pore pressure (Neuman and Dasberg, 1977). In their work in the Hula Basin, Neuman and Dasberg showed that heavy rainstorms and flood events brought about a temporary reversal of the vertical water flow.

The lateral component in the Beverly Swamp is small as determined by Smith (1984). Woo and Valverde (1981) indicated that, for a site adjacent to the stream, there was a small lateral exchange of groundwater with streamflow because of the distinct stream channel which locally increases the hydraulic gradient and thus permits more rapid flow of water to the stream.

Two basic water level regimes exist in a bog area -- effluence and influence. Influent regime refers to a stream section which often imposes its level on the adjacent water table while effluence occurs occasionally during a large rainfall input which causes the swamp's water table to become higher than the stream (Woo and Valverde, 1981). This effluent regime would also bring about the recharging of the unsaturated zone in the peat as mentioned earlier by Neuman et al. (1977).

Any discussion of subsurface flow must involve the rate of specific discharge of water. This measurement of water flow has the dimensions of a velocity (md^{-1}) or flux and is sometimes known as the Darcy velocity or Darcy flux (Freeze and Cherry, 1979). If the hydraulic conductivities at each point are known, then Darcy's Law can be used to determine the specific discharge (v).

$$v = -K \frac{dh}{dl} \qquad (2.1)$$

where K is the hydraulic conductivity and $\frac{dh}{dl}$ is the hydraulic gradient (Freeze and Cherry, 1979).

2.4 Soil-Moisture Relationships

Within a soil column there can exist a saturated zone in which all the voids are filled with water and an unsaturated zone which voids are only partially filled with water: the rest of the pore space is taken up by air (Freeze and Cherry, 1979). The unsaturated zone is important because the moisture content within this zone is likely to affect the response of streams (Munro, 1984) and the water table to rainfall inputs. When volumetric soil moisture content (θ) values are low, there exists a greater potential to store water. When water table levels are high, then there is a greater runoff from the swamp as there is little storage capacity in the peat (Bay, 1969).

The water balance equation for a column of peat in a perched aquifer is:

$$\Delta S = P - E + \Delta F \qquad (2.2)$$

where ΔS is the change in storage in the peat layer, P is the rainfall, E is the evaporation, and ΔF is the gain or loss of water due to inflows or outflows through the sides of the column (Munro, 1984; Woo and Valverde, 1981).

The physical properties of peat, the water table, and the hydrometeorologic factors are conditions which influence the soil moisture relationships (Bay, 1967). The physical properties of peat in the zone of water table fluctuation are extremely important because they determine how much water is stored and how fast the water will move through it. Hydrometeorologic factors, such as rainfall amount and intensity, and seasonal variations in evaporation, will influence soil moisture content in the peat (Bay, 1967).

CHAPTER 3

STUDY AREA AND FIELD METHODS

3.1 The Study Area

Beverly Swamp is located in southern Ontario (43° 22' N, 80° 7' W) approximately 25 km northwest of the city of Hamilton. This wetland, with an average elevation of 268 m occupies an area of about 20 km^2 in the upper part of the Spencer Creek basin (Fig. 3.1).

The drumlins, terminal moraines, and till plain found in the swamp area are a direct result of the Wisconsin glaciation and the swamp is the remains of a shallow post-glacial lake (Chapman and Putnam, 1966). The two bedrock depressions of dolomite, which the swamp occupies, were infilled with clastic sediments to an average thickness of 5 m (Woo and Valverde, 1981). A layer of marl 0.5 to 1 m thick occurs throughout the swamp at a depth of 1 m. The impervious marl permits a perched water table to be maintained in the surface peat layer (Fig. 3.2). The peat, which is described as black friable organic debris (Valverde, 1978), is in an advanced state of decomposition and fits the sapric classification as outlined by Boelter in 1965 (Munro, 1982).

The peat is not homogeneous vertically. The colour ranges from black at the surface to brown at the marl, and the peat contains many wood inclusions as observed in pit excavations made to a depth of 1 m. The transition layer from organic to marl contains many shells indicating the lacustrine origin of the area (Valverde, 1978).

This wetland lies in a humid continental climatic region (Brown

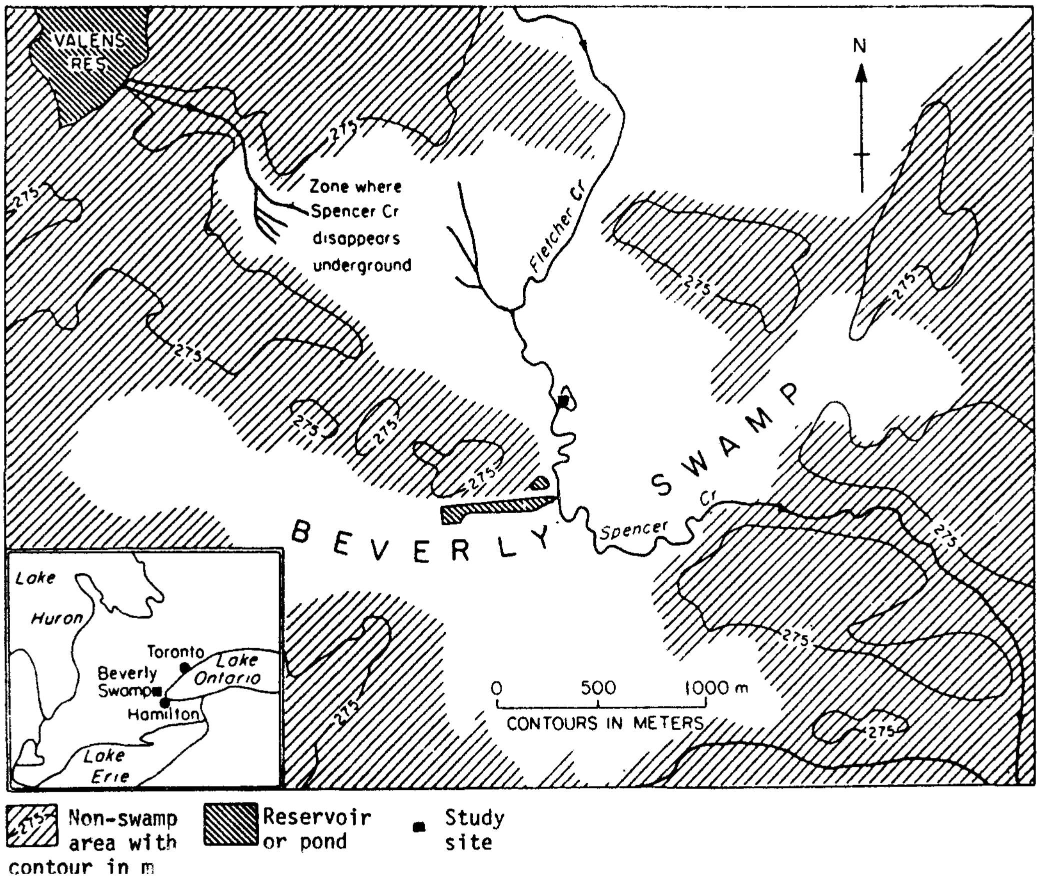


Figure 3.1 Location of study site.

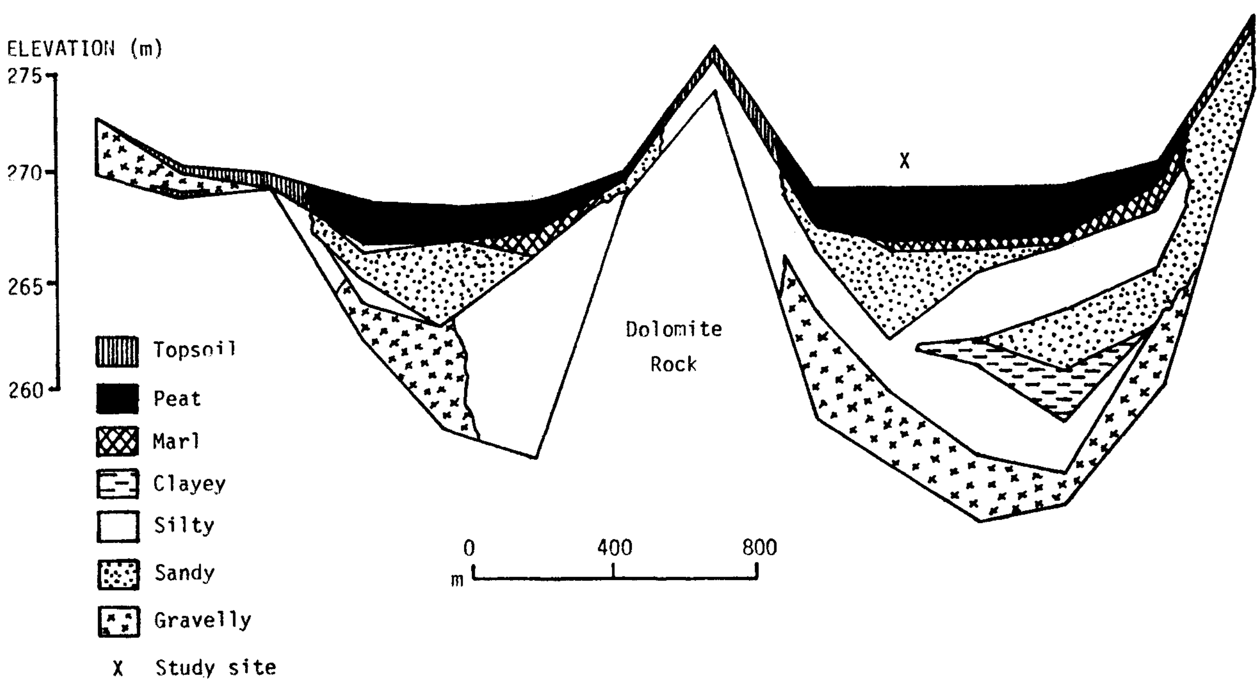


Figure 3.2 A cross-section of Beverly Swamp showing the surficial deposits (after Woo, 1979).

et al., 1968) and thus experiences January and July mean temperatures of -6°C and 21°C respectively. The average annual precipitation is 840 mm and the annual average evaporation is between 554 and 752 mm (Woo and Valverde, 1981).

The Beverly Swamp is covered by dense vegetation. Species of trees vary throughout the swamp with deciduous tree (red maple -- *Acer rubrum*, birch -- *Betula papyrifera*, aspen -- *Populas tremuloides*, silver maple -- *Acer saccharinum*, speckled alder -- *Alnus rugosa*) making up 80% of the forest cover and cedars (*Thuja accidentalis*) and tamarac (*Larix laricina*) accounting for the rest (Munro, 1984).

The swamp is flooded for 8 months of the year with the summer period experiencing water tables that fall below the surface of the peat. Spencer Creek and its tributary, Fletcher Creek, drain the swamp (Fig. 3.1). At Valens, just northwest of the swamp, Spencer Creek has been dammed for flow regulation and recreational purposes. A constant low flow is maintained from the dam during summer. Snowmelt in spring and a lowering of the Valens reservoir in the fall flood the swamp. The marl beneath the peat maintains a perched water table close to the soil surface but the water table may drop below the peat layer in very dry summers (Woo, 1978).

The study site is located at the centre of the swamp near the confluence of the Spencer Creek and a tributary (Fig. 3.1). The site is quite flat with small depressions and mounds with an elevation ranging from 267.6 m to 268.4 m (Smith, 1984). The peat is 1.16 to 1.35 m deep as was determined by two boreholes drilled in 1984. Beneath a layer of marl at 1.70 to 1.65 m there is a layer of sand.

The study site adjacent to the creek is covered with hardwood trees (mainly aspen) with a bush (red oiser -- Cornus stolonifera) dominating the edge of the clearing and the banks of the creek. Tall grasses grow in the clearing in summer.

3.2 Field Methods

Field work was done between June and September, 1984 during a period when the swamp experienced its lowest annual water table. The site was visited twice each week on a regular basis, and at shorter intervals when it rained. A few additional visits were made during October and November to observe the flooded condition.

At the study site adjacent to the creek,instruments and recorders were set up to measure groundwater level, stream level, hydraulic head (piezometers), and precipitation input (Fig. 3.3). The array of piezometers and wells drilled to various depths at the site are shown in Appendix A.

3.2.1 Water Level Data

A Luepold-Stevens Type F water level recorder was used to record the water table changes at observation well WC. Manual observations of groundwater levels were taken twice a week throughout the summer period at wells WL1, M1, and M2. All wells were one metre deep and reinforced by ABS plastic pipes with many 10 mm diameter holes drilled into the pipe to allow groundwater to flow into the wells. WC and WL1 were 0.15 m in diameter while M1 and M2 were 0.05 m. An electronic sensing device attached to a measuring tape was lowered manually to

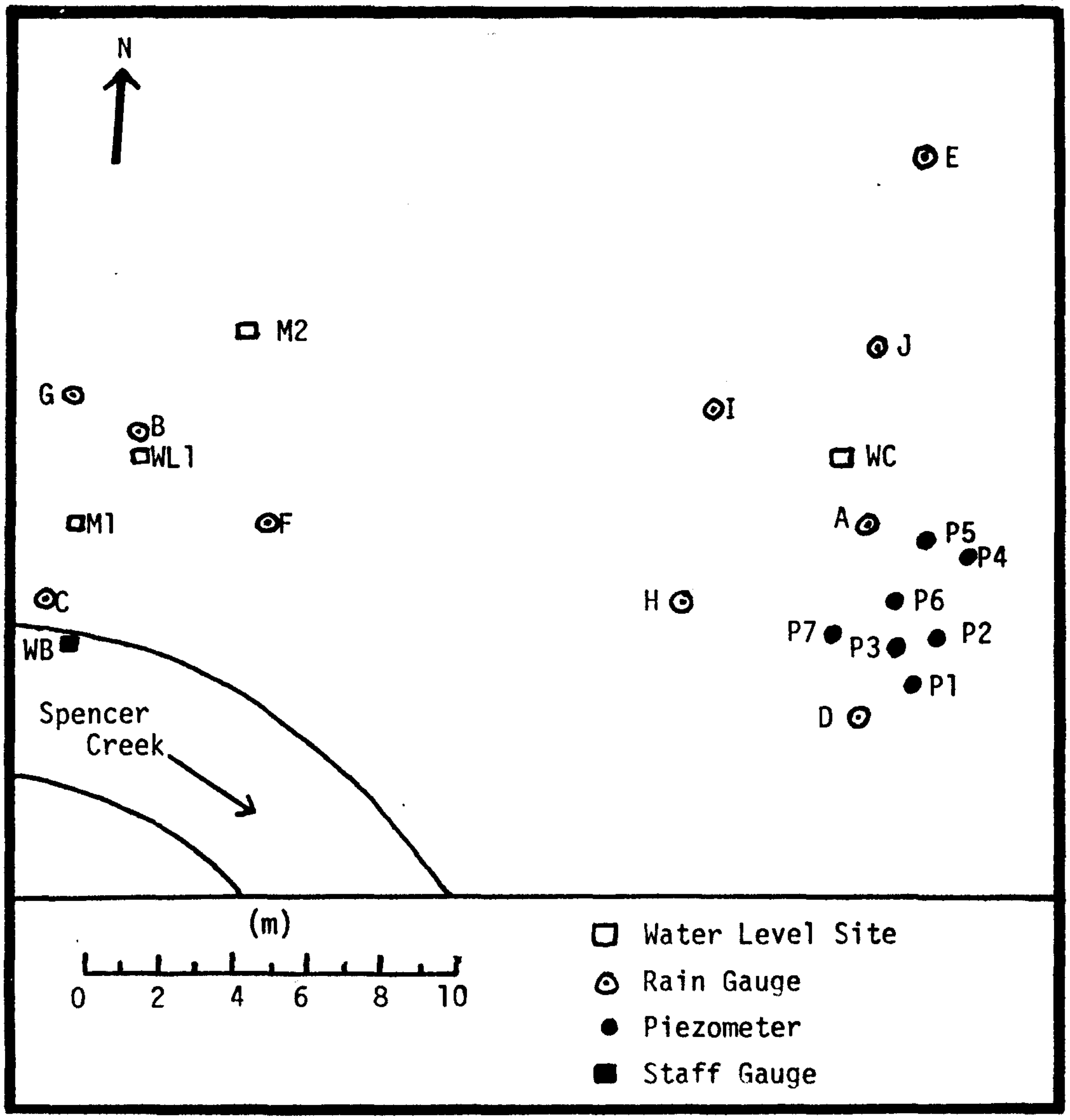


Figure 3.3 The study site and the location of instruments.

measure levels in WL1, M1, and M2 (Appendix A). When the sensor reached the water table, a buzzer sounded and the depth was read on the measuring tape at the point where it crossed the top of the piezometer.

A staff gauge placed in the creek provided data on the water level of the stream.

3.2.2 Precipitation Data

Valens Conservation Area (1 km northwest of Beverly Swamp) operates an official precipitation station using a Belfort weighing type of rain gauge to record rainfall. This station provided rainfall data for the present study. In addition, at the site in Beverly Swamp, rainfall was collected weekly in 1010 ml tin cans with plastic funnels taped to the top. Ten of these rain gauges at 0.75 m above the ground were placed at various locations throughout the study area. These values were averaged to determine the throughfall.

Daily rainfall was also measured at a site in Dundas, 17 km from the swamp. Data from Valens and from Dundas illustrate the spatial variation during the study period.

3.2.3 Soil Data

In the summer of 1984, 35 samples of peat were collected from pits dug near WC. Peat was extracted from 5 different levels, each sample being 14 cm in length. The samples were taken at average depths of 10, 30, 50, 70, and 90 cm. Large pits were dug for the deeper samples to minimize the compression of the soil. Samples were placed in tin cans with a volume of 1010 cm^3 and sealed immediately with lids before being transported back to the laboratory for analysis. Large samples were taken in order to reduce compression and to allow for a more accurate determination of specific yield (Johnston, 1967).

a) Soil Moisture. Each sample was weighed immediately upon arrival at the laboratory. Samples were then dried in an oven at 75°C to 80°C for 48 hours and then weighed again.

The volumetric soil moisture (θ) was calculated as:

$$\theta = \frac{Ww - Wd}{V} \tag{3.1}$$

where Ww is the weight of the wet sample, Wd is the weight of the dry sample, and V is the volume of sample (1010 cm^3).

b) Specific Yield. Specific yield was obtained following the laboratory procedure described by Johnston (1967). Field samples were saturated in the laboratory for 24 hours and allowed to drain for 48 hours before being weighed. The drained water was also weighed and its volume was measured in a graduated cylinder.

$$Sy = \frac{Vd}{V} \tag{3.2}$$

where Sy is the specific yield, Vd is the volume of water drained by gravity, and V is the volume of peat sample.

Specific retention (Sr) is the ratio of water retained against gravity compared with the volume of the sample.

$$Sr = \frac{Vr}{V} \tag{3.3}$$

where Vr is the volume of water retained in the sample, and V is the volume of the peat sample.

Porosity (θ) of the sample can be determined by:

$$\theta = Sy + Sr \quad (3.4)$$

c) Organic and Mineral Content. A set of dried soil samples were burned to determine the changes in the organic content in a column of peat down to the marl. Samples were weighed before and after being burned at 325°C for 3 hours. The percentage of organic matter was determined by:

$$Om = \frac{Wb}{Wd} \times 100\% \quad (3.5)$$

where Om is the per cent of organic matter, Wb is the weight of the burned peat, and Wd is the weight of the dried peat.

d) Bulk Density. The bulk density of each sample was measured using the oven dry weight (Wd) and the volume of the wet field sample (Ww).

3.2.4 Piezometric Measurements

In order to study vertical movement of groundwater, a nest of piezometers was installed on an undisturbed plot in a open area of the study site near WC (Fig. 3.3). A total of seven piezometers were installed at depths of 0.25, 0.50, 0.75, 1.0, 1.5, 2.5, and 3.0 m below the soil surface. Four piezometers were installed in different layers in the peat, one was positioned in the marl, and the remaining two were placed in sandy material.

An auger hole was drilled to the prescribed depth and a 0.25 m ABS plastic pipe was placed into the hole with a sock covering the bottom of the pipe to prevent clogging by sediments in the groundwater. The lower 10 cm of the pipe was perforated. The top of each piezometer was capped so that rainfall would not enter the pipe.

Investigation of the vertical flow is based on the interpretation of the hydraulic head measurements in the piezometers. Hydraulic head levels were established by measuring the distance of the water level from the top of each pipe using an electronic sensor with a buzzer which was attached to a measuring tape (Appendix A).

Hydraulic head measurements are an indication of fluid potential in which water flows from higher values to lower values (Freeze and Cherry, 1979). Piezometers were placed in the peat as well as the marl and sand to determine if the perched water table can be distinguished from the water table beneath the confining cap of the marl.

3.2.5 Hydraulic Conductivity

Hydraulic conductivity (K) was determined by measuring the recovery time of piezometers in peat after water is pumped from the wells. The Hvorslev piezometer test (Appendix A) was then used to determine the basic time lag (T_o) from the equation with the initial condition, $h = H_o$ at $t = 0$ (Freeze and Cherry, 1979).

$$\frac{H - h}{H - H_o} = e^{-t/T_o} \qquad (3.6)$$

where t is time, H is height of water surface, H is water level before draining.

Hydraulic conductivity was then calculated by the equation:

$$K = \frac{r^2 \ln (L/R)}{2 L T_o} \qquad (3.7)$$

where L is the length and R is the radius of the piezometer intake, while r is the radius at the top of the piezometer.

CHAPTER 4

FIELD RESULTS

4.1 Introduction

Chapter Four describes the results of field observation obtained in the study period from June to September, 1984.

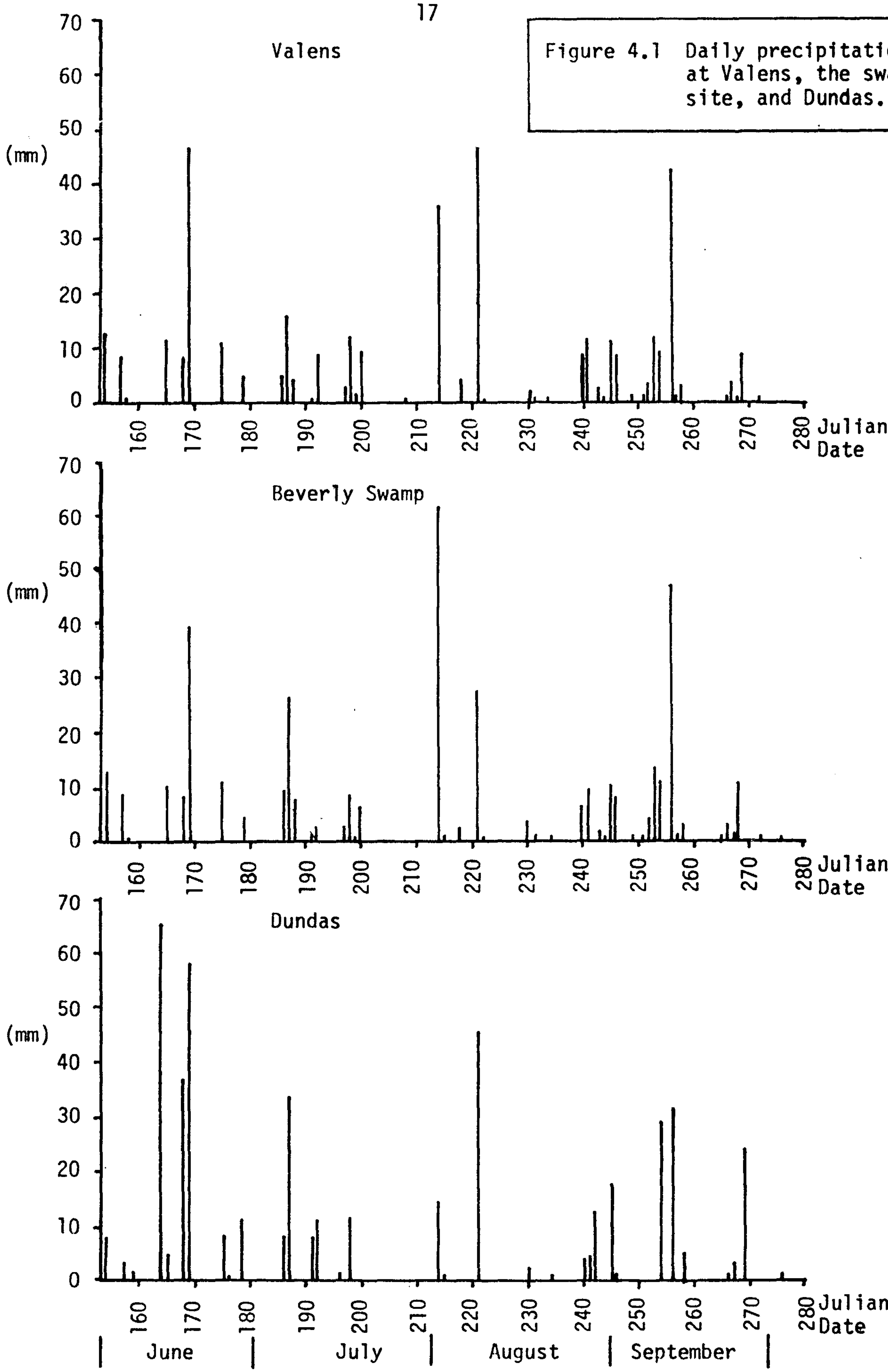
4.2 Precipitation

The daily total precipitation for the study site, for Valens, and Dundas are shown in Figure 4.1 During the study period there were five major storm events at the swamp with rainfall exceeding 25 mm. One major storm occurred in each of the months of June, July, and September. August had two such storm events and they occurred seven days apart. The driest month was July (Table 4.1).

Table 4.1 Monthly Rainfall (in mm) for 3 Sites

	Valens	Beverly Swamp	Dundas
June	100.9	91.5	197.7
July	61.8	63.6	69.9
August	114.0	114.3	82.1
September	106.1	114.3	128.2
Totals	382.8	383.7	477.9

Figure 4.1 Daily precipitation at Valens, the swamp site, and Dundas.



4.3 Hydrologic Conditions

4.3.1 Water Levels

Water levels in the swamp fluctuated in response to many large storm inputs (Fig. 4.2). The water table dropped below the ground surface in early June as evaporation increased. The groundwater level reached a summer low of 0.38 m below the ground surface on August 1 at the WC well.

4.3.2 Hydraulic Heads

Hydraulic heads for all piezometers decreased in periods of no precipitation (discharge) and increased rapidly with large storm inputs (recharge) (Fig. 4.3).

4.3.3 Hydraulic Conductivity

Hydraulic conductivity for piezometers P1 to P4 decreased with depth in the peat (Fig. 4.4) as well as with a declining water table.

Hydraulic conductivity ranged from 0.01×10^{-2} md^{-1} for the peat layer at the one metre depth to 20.78×10^{-2} md^{-1} for the 25 m depth. In his research on hydraulic conductivity of peat, Boelter (1965) determined values of 0.96×10^{-2} md^{-1} for well decomposed peat and 48.21×10^{-2} md^{-1} for moderately well decomposed woody peat. These values compare favourably with data obtained in the surface layer of peat in Beverly Swamp.

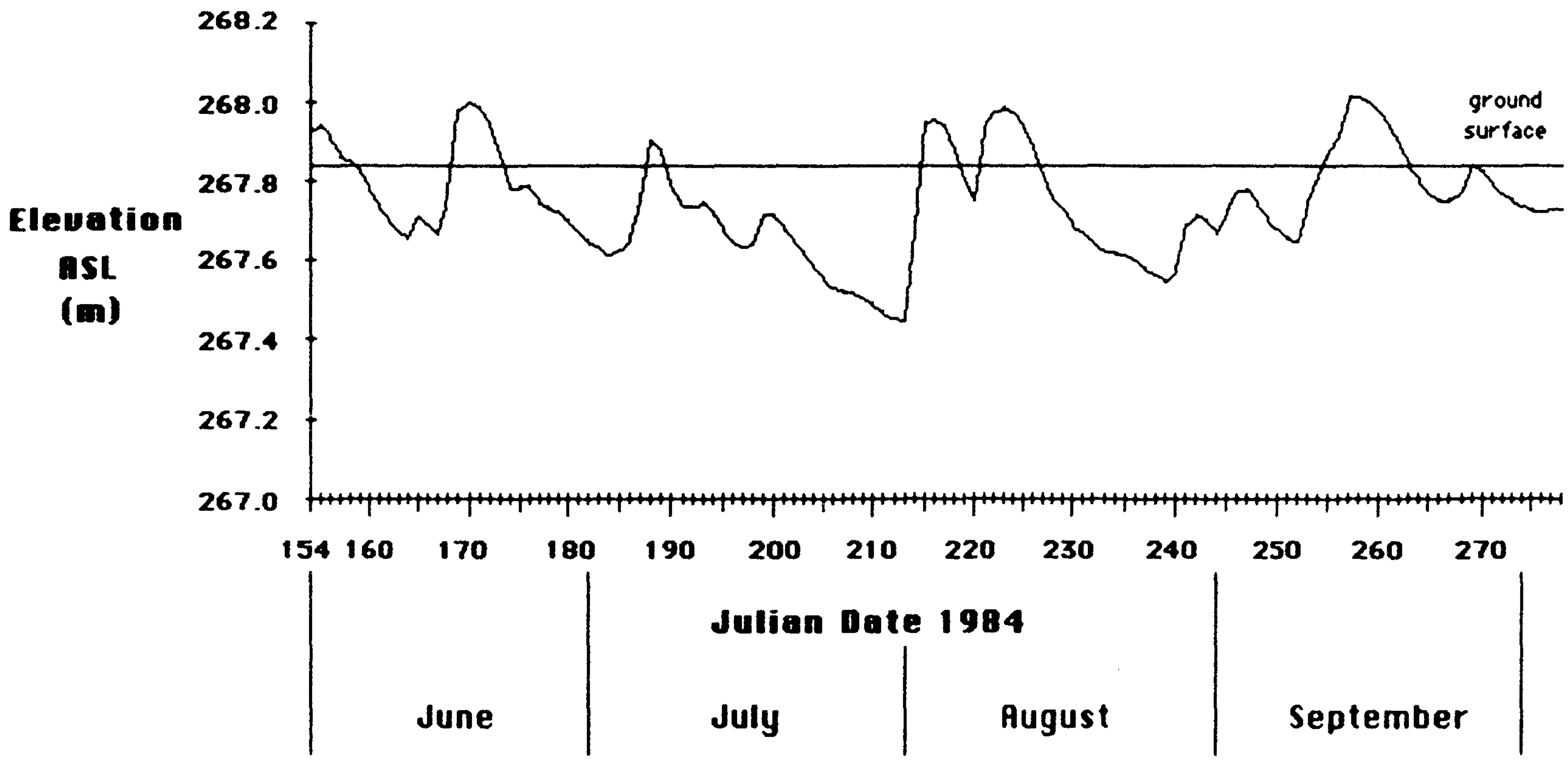


Figure 4.2 Daily mean water level at observation well WC.

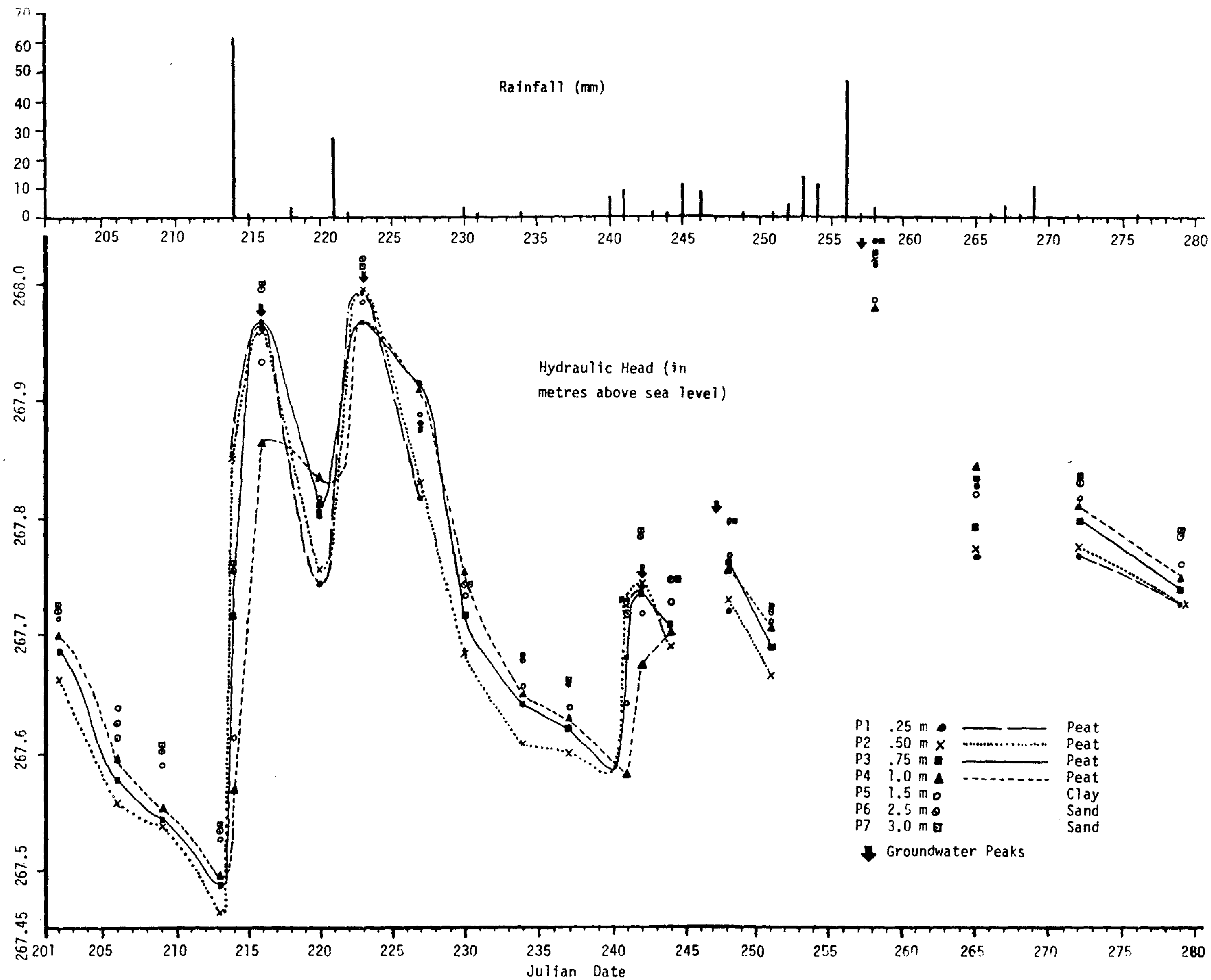


Figure 4.3 Hydraulic head values for piezometers in metres above sea level and rainfall in mm.

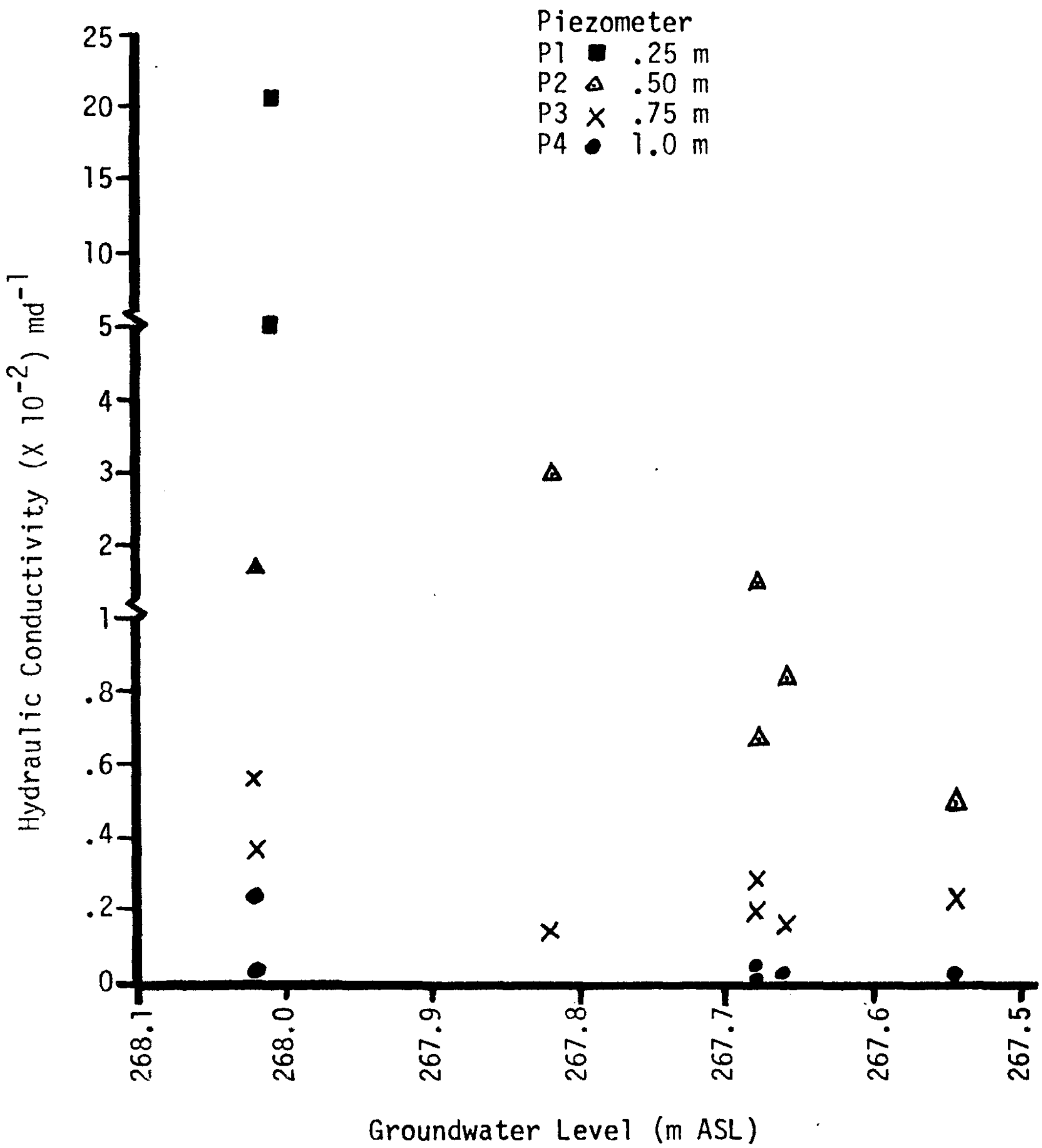


Figure 4.4 Hydraulic Conductivity and Groundwater Level

4.4 Soil Characteristics

4.4.1 Soil Moisture

The volumetric moisture content (θ) of peat decreased as the water table declined (Appendix A). Moisture content for the top layer of peat (0.03 to 0.17 m) ranged from near 80% for high water levels to near 60% when the water table fell to 0.32 m below the surface. The second sample layer (0.23 to 0.37 m) remained saturated for most of the study period. Values for this layer began to decrease toward the 70% range as the water table lowered to 0.30 m and part of the sample level was unsaturated. The third sample layer (0.43 to 0.56 m) remained saturated throughout the summer study period and moisture content showed a slight decrease as water levels dropped to the summer minimum.

The saturated soil moisture or porosity (θp) ranged from 80 to 85% (Table 4.2). Munro (1982, 1984) found θp values to be close to 83% for the peat in Beverly Swamp. He also observed that the values remained uniform for his samples.

The available storage capacity or deficit of the unsaturated peat is defined as saturated soil moisture less the field moisture content (Munro, 1984). The values of $\theta p - \theta$ represent the average for each soil sample and were multiplied by the thickness of the unsaturated soil column they represented. The total deficit for a column involving two layers was simply achieved by adding the deficit for each sample. Soil moisture deficit (Sd) when plotted against the water level (Fig. 4.5) shows an increasing amount of water storage capacity as the water level falls. The results of regression analysis produces the following

Table 4.2 Properties of Soil Layers for Beverly Swamp Study Site

Average Depth of Soil Sample (m)	No. of Samples	% Volume of Soil Sample				Bulk Density $g\ cm^{-3}$	Volumetric % of Dried Soil Sample	
		Moisture Content	Specific Yield	Retention	Porosity		Organic Matter	Mineral Content
.10	9	71	5	74	80	0.29	75	25
.30	7	76	4	76	80	0.31	76	24
.50	6	78	2	78	80	0.35	64	36
.70	5	83	2	82	84	0.28	73	27
.90	4	84	3	82	85	0.28	55	45

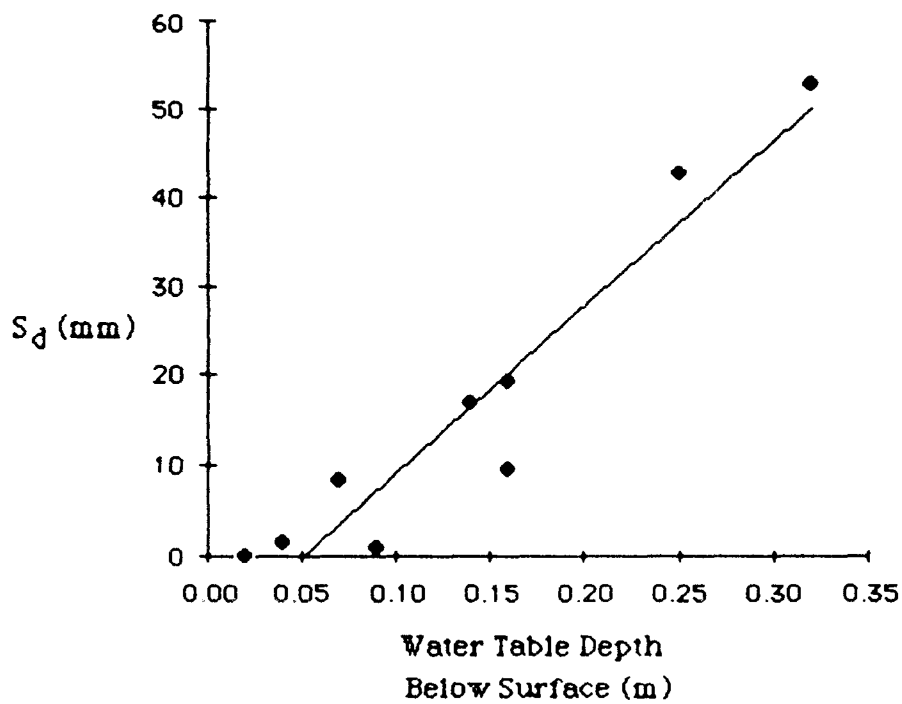


Figure 4.5 Regression of soil moisture deficit (Sd) against water table depth below the surface for the summer of 1984.

equation:

$$Sd = -8.5 + 18.3x \qquad (4.1)$$

where Sd is the storage deficit, -8.5 is the intercept (mm), 18.3 is the slope, and x is the groundwater level in m below the surface. The correlation coefficient and standard deviation for the regression are 0.95 and 18.9 mm respectively. These results are similar to Munro's (1984) regression of soil moisture deficit against water table depth for the summer of 1978.

4.4.2 Specific Yield and Retention

Specific yield (Table 4.2) was low and ranged from 2 to 5%. These results are similar to Smith's (1984), whose values ranged from 0.2 to 3.2% and Valverde's (1978), whose values varied from 5 to 7%. Both of these studies were in Beverly Swamp. This data is also close to the 10% obtained by Boelter (1965) for decomposed peat. Specific yield was generally greater at the surface and decreased somewhat with depth. The specific retention of all peat layers was high and increased with depth. Smith (1984) observed the same trend with depth but her percentages were smaller.

4.4.3 Bulk Density

Bulk Density values were found to be generally uniform with depth. Both Smith (1984) and Munro (1984) observed the same pattern for Beverly Swamp peat. Munro's bulk density values were lower and ranged from 0.18 to 0.22 g cm^{-3} while Smith's and the present study averaged 0.29 and 0.30 g cm^{-3} respectively. Boelter (1969) indicated that sapric peats had densities $\gtrsim$ 0.20 g cm^{-3}.

CHAPTER 5

WATER MOVEMENT AND STORAGE IN THE PEAT

5.1 Introduction

In this chapter the raw data presented in Chapter 4 will be interpreted to show how groundwater moves and is stored in relationship to water levels, storm inputs, hydraulic gradients, and storage capacity.

5.2 Vertical and Lateral Water Movement

In this section the hydraulic head (Appendix A) and the hydraulic gradient (Table 5.1) for the piezometers were used to determine the vertical flow of groundwater. The lateral flow was determined using the gradient between the recording well at WC and the staff gauge in the stream (Table 5.2). Changes observed in the gradients and hydraulic heads will be discussed for periods of discharge (falling water table), recharge (rising water table), and peak groundwater levels in the swamp. Vertical and lateral groundwater fluxes (Tables 5.1 and 5.2) will also be compared to the different groundwater levels and storm inputs.

During periods when the water table decreased for a week or more, the hydraulic head values for the piezometers in peat increased with depth which indicated an upwelling of water (Figs. 5.1a and 5.1c) from the deeper layer of peat (Neuman and Dasberg, 1977). Values for the piezometers in clay and sand remained higher than those in peat with the pressure in the sand (regional groundwater) being the highest.

The vertical hydrualic gradients for these drying periods are

Table 5.1

Vertical Hydraulic Gradients and Fluxes for Piezometers in Peat

Julian Date	Vertical Hydraulic Gradients (dh/dl)			Estimated Vertical Groundwater Flux (mmd^{-1})		
	0.25-0.5*	0.5-0.75*	0.75-1.0*	0.25-0.5*	0.5-0.75*	0.75-1.0*
July						
199	+0.02	+0.06	+0.06	+1.44	+0.51	+0.22
202		-0.09	-0.05		-0.77	-0.18
206		-0.08	-0.07		-0.68	-0.25
209		-0.02	-0.04		-0.17	-0.14
August						
213		-0.09	-0.03		-0.77	-0.11
214	0.00	+0.54	+0.59	0.00	+4.68	+2.12
216	+0.02	-0.03	+0.41	+1.44	-2.55	-1.48
220	-0.05	-0.22	-0.09	-3.60	-1.87	-0.32
223	0.00	+0.11	0.00	0.00	+0.94	0.00
227	-0.05	-0.33	+0.01	-3.60	-2.81	+0.04
230		-0.14	-0.15		-1.19	-0.54
234		-0.10	-0.03		-0.85	-0.11
237		-0.09	-0.03		-0.77	-0.11
241	+0.02	+0.18	+0.40	+1.44	+1.53	+1.44
242	-0.01	+0.02	+0.25	-0.72	+0.17	+0.90
September						
244		-0.08	+0.02		-0.68	+0.07
248	-0.04	-0.13	+0.02	-2.88	-1.11	+0.07
251		-0.10	-0.07		-0.85	-0.25
258	0.00	-0.03	+0.22	0.00	-0.26	+0.79
265	-0.02	-0.08	-0.21	-1.44	-0.68	-0.76
272	-0.01	-0.10	-0.05	-0.72	-0.85	-0.18

+ indicates downward flow   * depth of peat in metres
- indicates upward flow

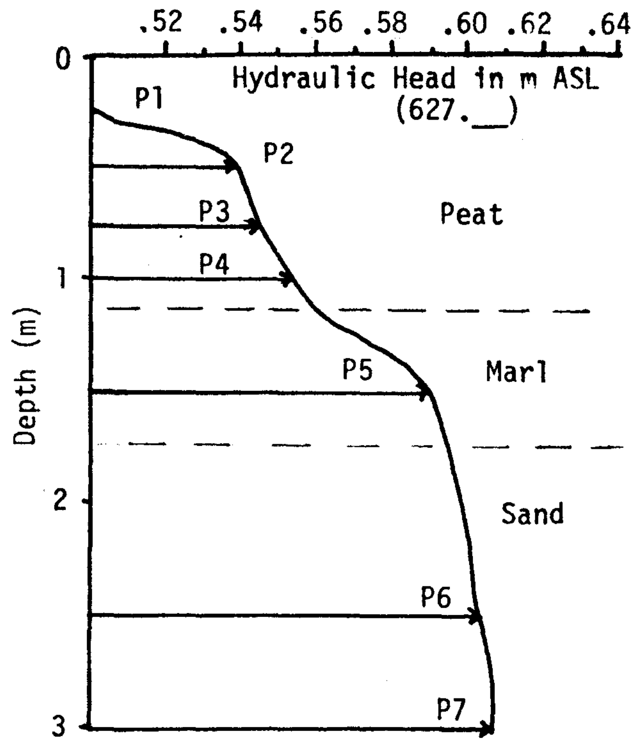
Table 5.2 Lateral Hydraulic Gradients for Water Table

Julian Date	Date	Lateral Hydraulic Gradient (dh/dl)	Depth of Water Table (cm)	Estimated Lateral Groundwater Flux (mm d^{-1})	Notes on Water Table Movement and Storm Characteristics
199	July 18	-.0015	-14.0	+0.20	Peak Water Level
202	July 21	+.0010	-18.1	-0.13	Falling Water Table (Discharge)
206	July 25	-.0010	-29.0	+0.01	Falling Water Table
209	July 28	-.0025	-32.1	+0.04	Falling Water Table
213	Aug. 1	-.0045	-38.5	+0.06	Falling Water Table
214	Aug. 2	-.0020	+ 0.4	+0.26	Storm 61 mm, Swamp Floods in 18 Hours
216	Aug. 4	-.0015	+12.3	+0.20	Peak Water Level
220	Aug. 8	+.0015	- 8.5	-0.20	Falling Water Table
223	Aug. 11	+.0010	+15.0	+0.13	Peak Water Level, Storm 27 mm on 221
227	Aug. 15	.0000	- 2.0	0.00	Falling Water Table
230	Aug. 18	+.0015	-16.2	-0.13	Falling Water Table
234	Aug. 22	+.0005	-22.5	-0.07	Falling Water Table
237	Aug. 25	-.0010	-24.8	+0.13	Falling Water Table
241	Aug. 29	-.0025	-13.2	+0.33	Storm, About 20 mm Over Two Days
242	Aug. 30	-.0010	-11.4	+0.13	Peak Water Level
244	Sept. 1	+.0005	-16.3	-0.07	Falling Water Table, Two Days After Peak
248	Sept. 5	+.0005	-12.1	-0.07	Falling Water Table, Two Days After Peak
251	Sept. 8	+.0010	-17.9	-0.13	Falling Water Table
258	Sept. 15	-.0010	+17.5	+0.13	Peak Water Level, Two Days After Storm
265	Sept. 22	.0000	- 7.0	0.00	Falling Water Table for One Week
272	Sept. 29	.0000	- 7.0	0.00	Falling Water Table, Three Days After Rainfall

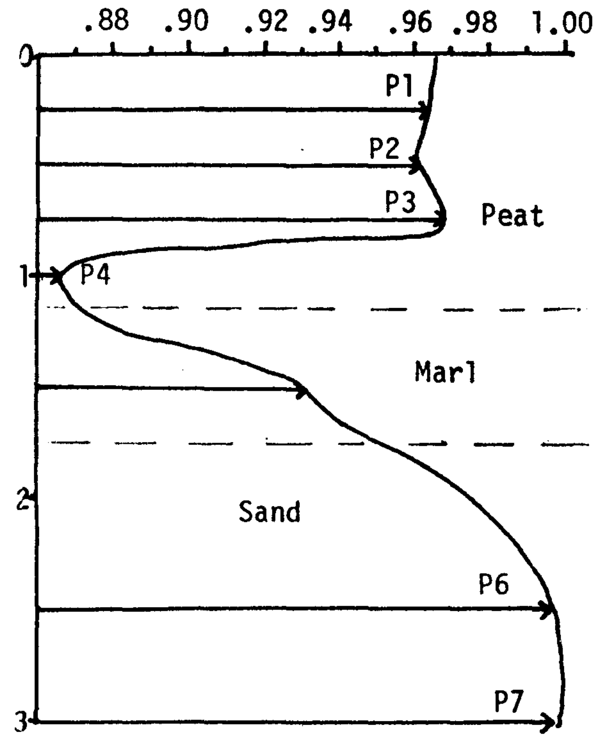
(a) Depth of Water Table
- indicates depth below ground surface
+ indicates water level above ground

(b) Groundwater Fluxes
+ denotes flow landward from stream
- denotes flow to the stream from the land

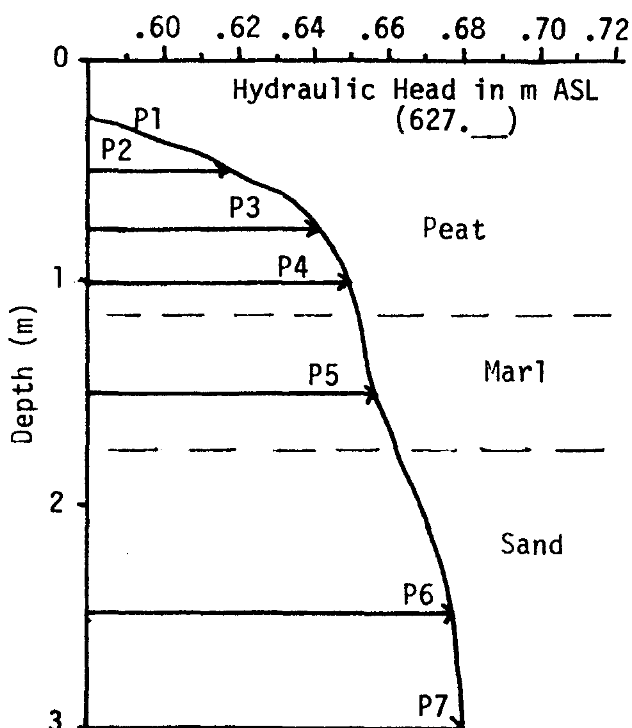
Figure 5.1 Examples of cross-sections of hydraulic head values for different water level regions.



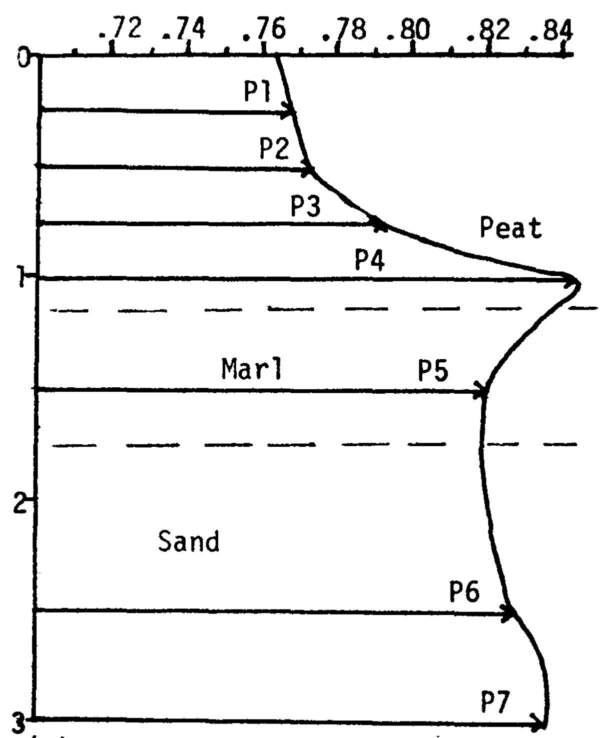
(a) Declining water table (Julian date 209)



(b) Recharging (Julian date 216)



(c) Declining water table (Julian date 234)



(d) One week after major storm (Julian date 265) small and range from zero to 0.15 while the lateral gradient ranged from zero to 0.0045. The water table gradient during the late July drying period sloped away from the stream (influence) and this gradient increased as the groundwater levels dropped to 0.39 m below ground surface. During the second drying period, in late August, the lateral gradient sloped toward the stream (effluence) and ranged from zero to 0.002 and eventually reached its lowest level before the next storm event. The vertical gradient is up to 100 times greater than the lateral gradient so the dominant direction of water flow at the study site is vertical.

During the periods of rainfall such as the storm on August 2, the hydraulic head values rose rapidly in the top 0.5 m of the peat (as the water infiltrated the soil). The vertical gradients from the 0.25 to the 0.5 m depth were very small or zero (Table 5.1) indicating the quick passage of water through this layer of peat. The gradients for the two deeper layers of peat (0.5 to 0.75 m and 0.75 to 1.0 m) were much steeper than the surface layer and five to six times greater than what they were during the drying period. The positive gradients indicated a reversal in the vertical flow as water moved downward into the peat (Fig. 5.1b). The layer of peat below 0.5 m responded slowly to rain inputs in comparison to the surface layer.

During the storm and 48 hours after, when the water level in the swamp peaked at 0.12 m above the ground surface at the site, the lateral gradients remained very small (-0.0020). The negative value indicated that water was moving landward from the stream.

During the period when water level peaked, the vertical hydraulic head values for the piezometer in clay were lower than the head values for the sand indicating that the confined aquifer in the sand was capped by the impervious marl (Fig. 5.1b). The piezometers in the sand had higher values than any other indicating that water reaches the regional groundwater system very quickly.

The vertical hydraulic gradient during peak water levels was very small for the two surface layers (0.25 to 0.50 m and 0.50 to 0.75 m) ranging from +0.2 to -0.2 while gradients for the deeper peat layer (0.75 to 1.0 m) are much higher with the flow still downward (+0.41 to +0.25). This pattern was repeated after storms in August and September (Julian dates 242 and 258). However, after the second August storm (Julian date 223), this pattern was not observed even though water levels were similar. Instead the 0.50 to 0.75 m layer had the highest vertical gradient (+0.11) while the deeper peat layer had a zero gradient. The closeness of the two early August storms (Fig. 4.1) and an increase in antecedent moisture from the first storm may have contributed to this condition.

Figure 5.1d shows that the hydraulic head pressure was the highest for piezometer P4 seven days after 47.1 mm of rain fell in a September 13th storm (Julian date 256). This situation occurred for two other large storms (Julian dates 214 and 221). In these cases the pattern was observed four and seven days respectively after the rainfall. As mentioned earlier, vertical groundwater movement is very slow in the deeper peat. Therefore, hydraulic pressure increases and decreases slowly compared to the other layers of peat. This pattern illustrates, again, the independence of the groundwater regime in the peat compared to the groundwater below the clay.

The groundwater flux (v), which has the dimension of a velocity, was calculated using Darcy's law (Equation 2.1). To find the estimated groundwater flux the gradients were multiplied by the average hydraulic conductivities. The average vertical conductivities of 0.072 md^{-1}, 0.0009 md^{-1}, and 0.0002 md^{-1} were calculated for the following depths -- 0.25 to 0.5 m, 0.5 to 0.75 m, and 0.75 to 1.0 m. The average horizontal conductivity for water level depths from the ground surface to 0.25 was 0.130 while 0.014 was used for water levels below 0.25 m. Tables 5.1 and 5.2 show the results of these calculations for varying groundwater conditions.

During periods of discharge, the vertical fluxes were upward and decreased with depth. Values were less than 1 mm per day for all layers. The lateral flux was less than 0.2 mm d^{-1} and this very small flow was toward the stream for water tables above the 0.24 m depth and landward when the water table was below 0.24 m.

During the two storms in which data was collected (Julian dates 214 and 241), the vertical water movement was downward with fluxes greater than 1 mm d^{-1}. The largest flux of 4.7 mm d^{-1} was calculated for the first storm. Also, during that storm the flux for the 0.25 to 0.5 m layer of peat was zero indicating that water moved rapidly downward filling up the pores in the surface peat and thereby reducing the gradient to zero. Water also moved at a greater rate in the deeper peats during the storms (Table 5.1).

The lateral flux also had its highest values during the rainfall. Flow was landward with fluxes of 0.3 mm d^{-1} which is more than three times the flux during a falling water table.

Peak water levels usually occurred between 24 and 48 hours after the storm. Vertical flow for this high water level period varied from zero to 2.6 mm d^{-1} and the direction of water movement also varied. When the swamp was flooded the 0.25 to 0.5 m layer of peat had a zero flux for two events and an upward movement of 1.44 mm d^{-1} for another. During peak groundwater levels in which the swamp was not flooded, water was flowing downward through the column of peat on Julian date 199 while in the second case (Julian date 242) water was flowing downward from 0.5 to 1.0 m and upward in the 0.25 to 0.5 m layer of peat.

The fluxes for the deeper peat layer also varied during peak water levels as shown by the highest rates of water movement for the peat column during Julian dates 242 and 258. However, for other peak periods, flow rates were higher in other levels in the peat. The changing conditions may be a result of varying intensities of rainfall and antecedent moisture levels in the soil.

Lateral water movement during peak water levels had decreased by nearly half from the rates calculated for the rainfall period and continued to flow landward from the stream.

Vertical and lateral groundwater flow, with peak values of 4.7 mm d^{-1} and 0.3 mm d^{-1} respectively, indicate a very small amount of groundwater being transported through the peat during changes in the water table. Water moved upward in the peat except during recharge while lateral flow maintained an influent regime except during a period of falling water levels when the water table was near the surface.

5.3 Water Storage in the Peat

Using the regression equation of soil moisture deficit against water table depth, the daily storage deficit was calculated in mm (Fig. 5.2 and Appendix A). The maximum storage deficit of 63.2 mm was reached when the water level reached its lowest level of 0.39 m below the ground surface. This occurred in late July and early August after a couple of weeks of little or no rain and high evaporation rates.

The 61.3 mm of rain from the storm of less than 18 hours on August 2 (Julian date 214) very quickly filled up the available storage capacity of the peat and flooded the swamp. The storage capacity decreased as the groundwater level rose and the vertical water movement reversed and flowed downward.

Six days after the initial input the water level fell to 0.09 m below the surface and storage deficit increased to about 8 mm. However, the second storm of August which deposited 27 mm of rain in one hour flooded the swamp. Even though it had only 4/10 the input of the previous storm it was able to flood the swamp by 0.02 m more than the previous event. The increased antecent moisture in the soil as a result of the first storm allowed a smaller input to raise the groundwater levels very quickly. The swamp had a very small capacity at the beginning of the storm to store any water, thus most of the water entering the swamp by rainfall or by streamflow would be discharged to the outlet.

Following the second major storm of August (Julian date 221), the soil moisture deficit increased as groundwater levels receded and vertical flow returned to a small upward flow. As the groundwater level reached its lowest point of 0.29 m in August (Julian date 239) so did

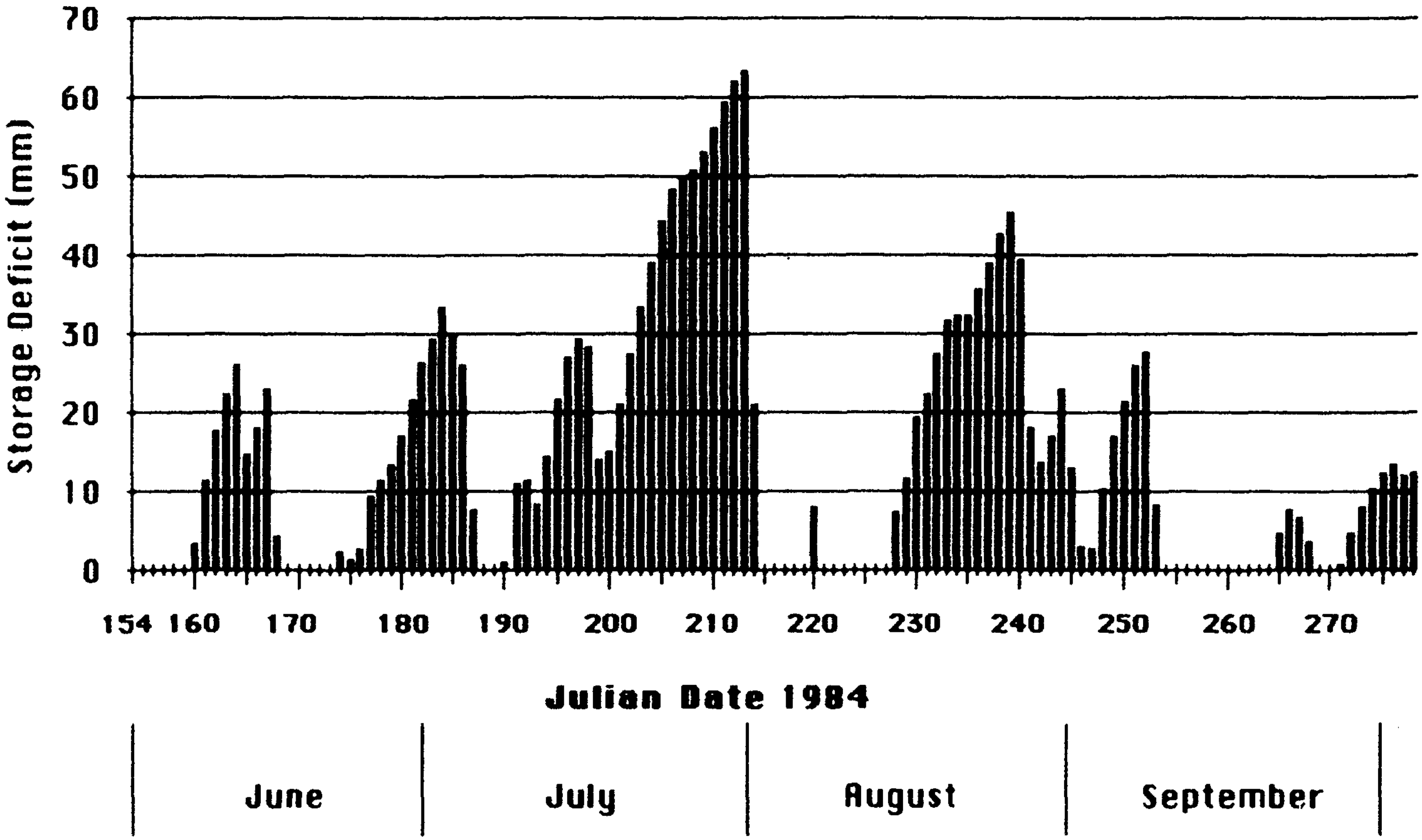


Figure 5.2 Daily storage deficit for the study site as calculated by the regression equation (4.1).

the storage deficit at 45.3 mm.

A total of 15.7 mm of rain fell in two days in late August and filled two thirds of the available storage as the soil moisture deficit decreased from 39.8 to 13.6 mm. However, the groundwater level rose only about half way to the ground surface from 0.26 to 0.12 m.

Rainfall input of less than 2 mm at the end of August did not raise the groundwater level or decrease the deficit. Water levels continued to fall and deficits increased until 18 mm or rain reduced the deficit from 23.0 to 2.6 mm.

In early September storage capacity increased steadily for 7 days until about 30 mm of rain fell over a period of 3 days and slowly filled the available storage and the swamp flooded. Two days following the last rainfall a single storm deposited 47 mm of rain (Julian date 256). The storage capacity was already zero so the additional rainfall raised the level of the flooded swamp to its highest level for the study period (17.5 cm above the ground surface). During this peak water level, water flowed toward the land from the stream. The direction of the water flow from the stream was controlled by the topography and vegetation (Woo and Valverde, 1981), and since the storage capacity was already zero, the large rainfall and additional water from the stream would have to flow toward the outlet of the swamp.

During this study period the swamp was flooded five times. In three of these cases the swamp was able to store some of the rainfall. In the first storm (Julian date 169), 46 mm or rain fell. At that time the storage capacity was at 23 mm. Approximately half of the rainfall would have been stored by the swamp.

In the second event (Julian date 187), the storage deficit was 30 mm, so most of the 36 mm of rain would have been stored. In both of these rainfalls the swamp flooded after the storage capacity was filled. The second storm, however, had a lower flood level than the first because of the swamp's capacity to absorb most of the rainfall.

The third storm on Julian date 214 has already been discussed. The fact that the swamp, with 63.2 mm of storage, was able to store most of the 61.3 mm of rainfall was not mentioned. However, the swamp flooded as water from the stream flowed toward the site at peak water level.

In the two other cases, the storage was already at or near zero (Julian dates 221 and 256) so runoff would not have been attenuated by the swamp.

The swamp was able to store some rainfall and flood waters but only in the short term.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Groundwater storage and movement at a site in Beverly Swamp was monitored from June to September, 1984.

Storage capacity in the swamp increased as the water levels fell below the ground surface and as evaporation increased. Water levels remained close to the surface during the summer and the loss of water in storage was limited to the surface layer of peat.

This surface layer of peat is the most active as indicated by the higher specific yields, hydraulic conductivities, and groundwater fluxes. The deeper layer of peat has smaller specific yields and fluxes than the surface peat. Its hydraulic conductivities are almost zero. Therefore, the lower peat layer is not susceptible to storage change nor is it capable of allowing much water movement.

The storage capacity of the swamp is then dependent upon the lowering of the water table to allow the draining and evaporation of water from this surface layer. If the water table remains high then there is little storage capacity and greater runoff from the swamp will occur (Bay, 1969).

The swamp experienced short periods of available storage during the summer. However, several large storms completely filled this storage capacity and flooded the swamp. Therefore, as Bay (1967) concluded, wetlands have little storage capacity except in the short term. The swamp was able to absorb smaller rainfall inputs when the water levels had declined 0.15 m below the ground surface. When a second large rainfall event followed within a relatively short timespan, then the swamp is flooded rapidly because of a high antecedent moisture content.

Piezometric data indicated that the groundwater in the peat is perched on the marl and, therefore, subsurface flows in the peat layers are independent from the regional groundwater.

The vertical hydraulic gradients and fluxes in the peat reversed during large rainstorms or during floods allowing some downward movement of water. This recharge happens very quickly as water infiltrates the active surface zone and fills up the available storage space. The vertical gradients and fluxes are significantly higher during recharge than during discharge. The downward movement of groundwater lasts for only a few days and the gradients quickly resume their upward direction soon after the peak water levels.

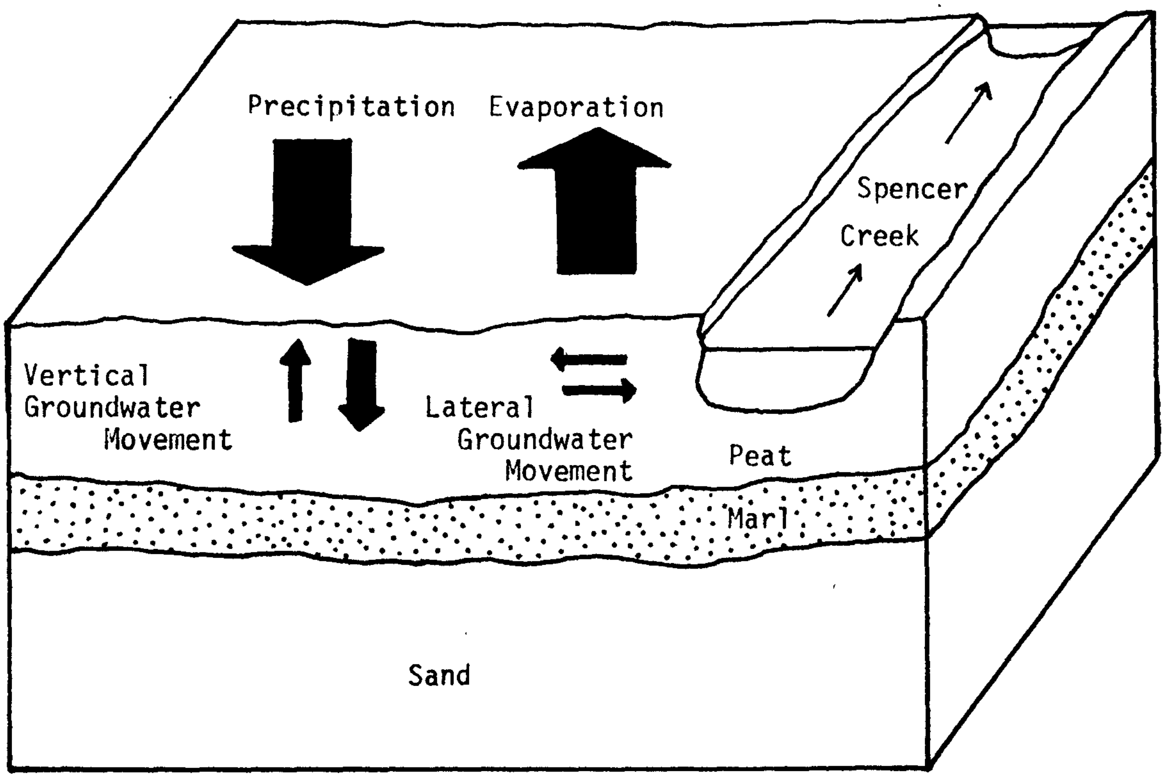
The vertical movement of water, although small, is the dominant direction of water flow in the peat during the summer. Lateral water movement to and from the stream is very small and is less important as indicated by the small gradients and fluxes that existed during the summer of 1984.

There is a downward flow during the recharging of the swamp, but for the rest of the summer, the flow is upward. As mentioned earlier the lateral gradient and fluxes are so small that water moved very slowly between the site and the stream.

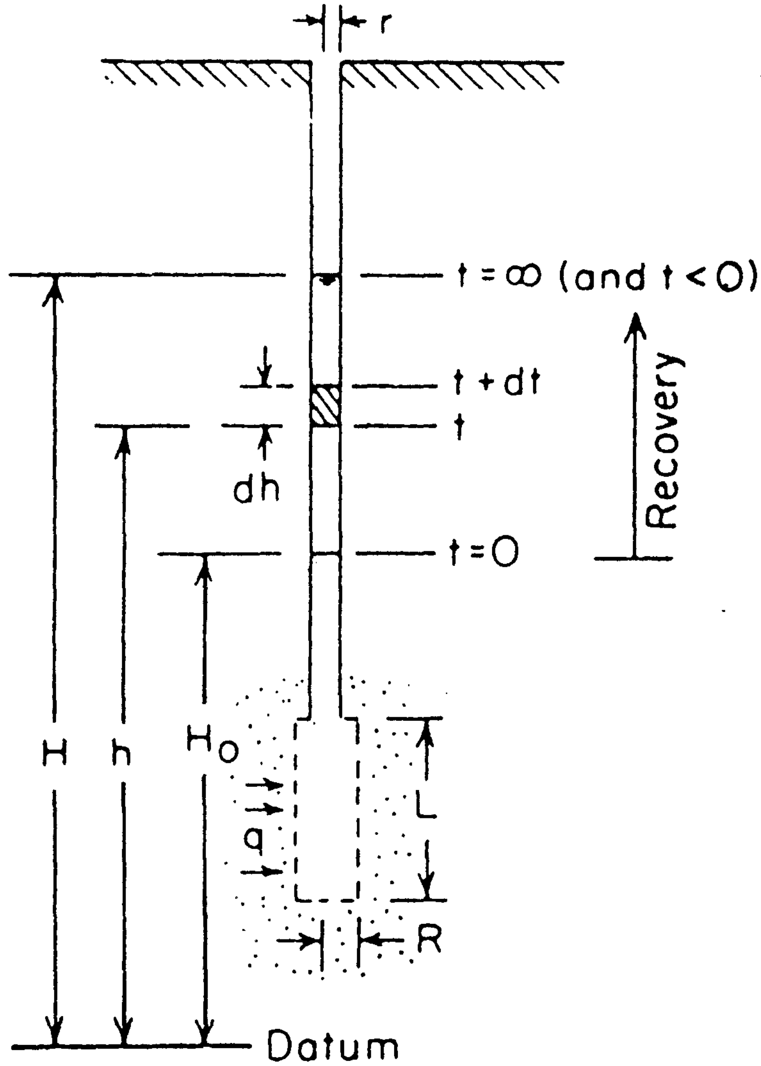
Therefore, groundwater flow in the peat is very small and does not play a major role in the storage capacity of the swamp. Rainfall amounts and antecedent moisture levels are more important factors in controlling the short term storage capacity of the bog.

This study spanned over only one season during which the water levels remained very high throughout the summer period. Further studies would be required to determine the groundwater storage and movement for summers when water levels are lower and storage capacities are higher.

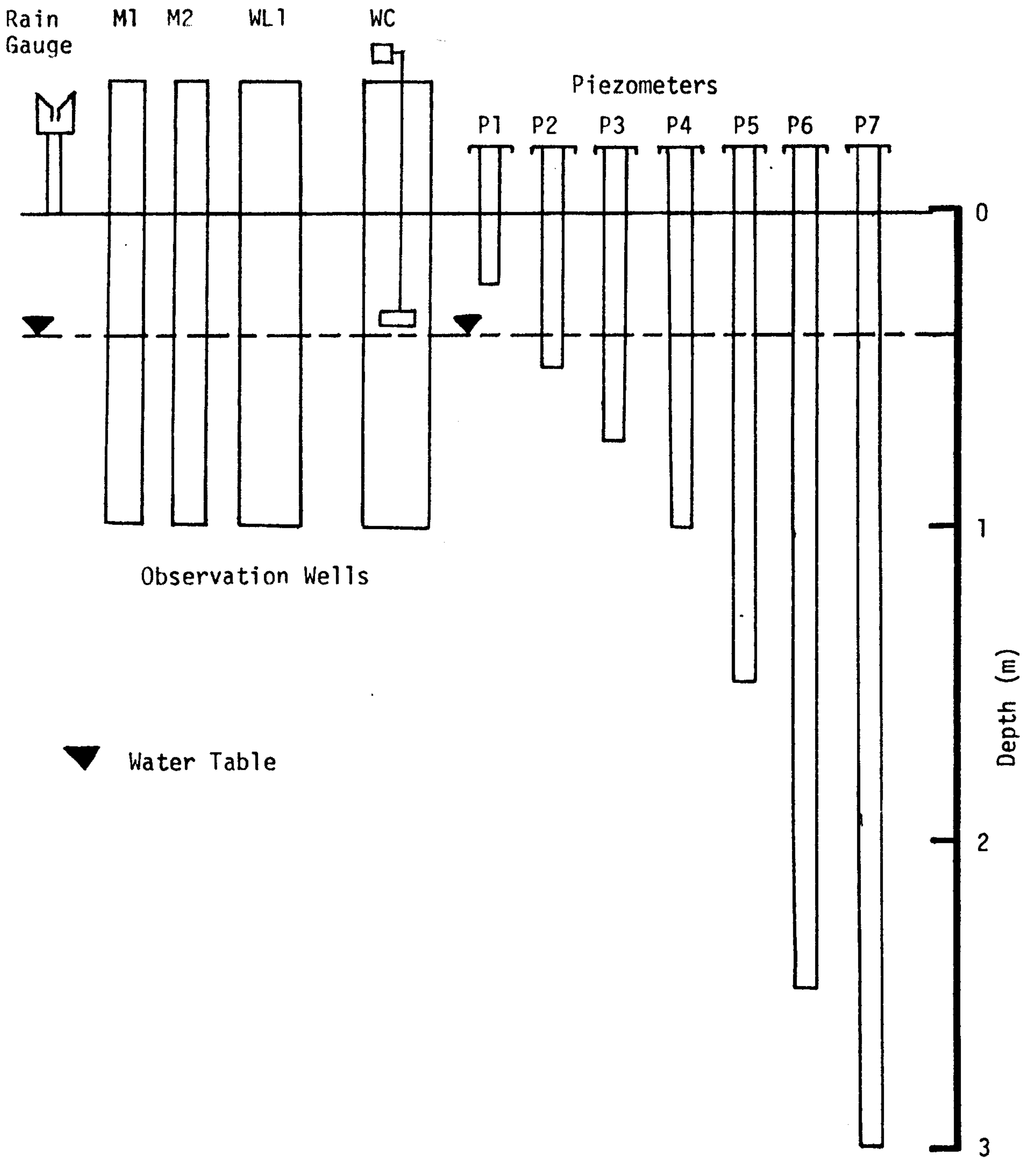
APPENDIX A



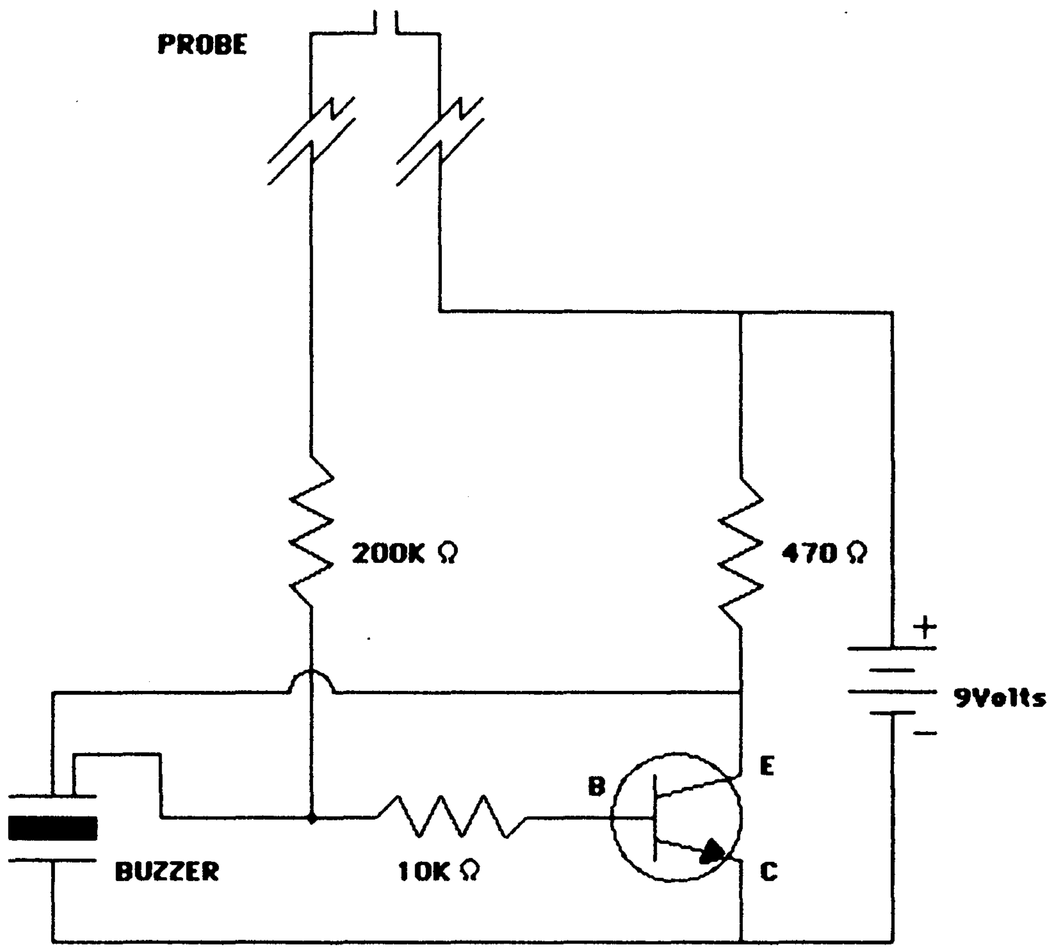
Groundwater inputs and losses for study site during the summer.



The variables of Hvorslev's piezometer test which were used to calculate the basic time lag in Equation 3.6 and hydraulic conductivity in Equation 3.7 (after Freeze and Cherry, 1979).



Field instrumentation for the investigation of groundwater processes.



Schematic diagram of the electronic sensor used to measure water levels in wells and piezometers.

The following four pages indicate the average water levels for each two-hour period in the WC observation well from June to October, 1984. The graphs from the Leupold-Stevens Type F water level recorder were used to calculate these averages.

JULIAN DATE	TIME OF DAY (HOURS) 0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200
154	267.903	267.908	267.916	267.925	267.932	267.937	267.939	267.941	267.942	267.944	267.945	267.946
155	267.946	267.946	267.946	267.946	267.945	267.944	267.942	267.940	267.937	267.935	267.932	267.929
156	267.926	267.923	267.919	267.915	267.911	267.907	267.903	267.898	267.892	267.888	267.883	267.879
157	267.875	267.870	267.866	267.862	267.857	267.852	267.843	267.850	267.862	267.860	267.862	267.859
158	267.856	267.856	267.856	267.857	267.857	267.856	267.853	267.851	267.848	267.846	267.846	267.845
159	267.842	267.840	267.837	267.833	267.827	267.821	267.814	267.810	267.807	267.805	267.803	267.801
160	267.799	267.796	267.814	267.790	267.785	267.779	267.770	267.761	267.757	267.756	267.756	267.755
161	267.755	267.753	267.752	267.749	267.746	267.739	267.731	267.722	267.715	267.713	267.713	267.713
162	267.713	267.713	267.712	267.711	267.708	267.703	267.697	267.691	267.691	267.683	267.684	267.685
163	267.685	267.685	267.685	267.685	267.684	267.678	267.671	267.663	267.657	267.658	267.660	267.661
164	267.662	267.663	267.664	267.663	267.657	267.651	267.642	267.637	267.632	267.633	267.642	267.698
165	267.742	267.733	267.724	267.722	267.718	267.713	267.710	267.706	267.704	267.703	267.704	267.706
166	267.708	267.709	267.709	267.708	267.704	267.698	267.692	267.686	267.681	267.679	267.681	267.682
167	267.682	267.682	267.682	267.682	267.681	267.677	267.670	267.660	267.653	267.652	267.654	267.656
168	267.658	267.659	267.663	267.682	267.761	267.793	267.796	267.819	267.821	267.835	267.862	267.900
169	267.931	267.948	267.965	267.977	267.984	267.989	267.992	267.997	267.999	268.001	268.002	268.004
170	268.005	268.005	268.005	268.005	268.004	268.003	268.002	268.001	267.999	267.997	267.996	267.995
171	267.994	267.993	267.992	267.990	267.989	267.986	267.984	267.982	267.979	267.977	267.975	267.972
172	267.969	267.966	267.963	267.959	267.954	267.949	267.943	267.939	267.931	267.931	267.920	267.913
173	267.906	267.900	267.895	267.888	267.880	267.873	267.864	267.854	267.844	267.836	267.830	267.823
174	267.815	267.810	267.803	267.799	267.793	267.788	267.778	267.769	267.763	267.758	267.756	267.755
175	267.754	267.771	267.808	267.801	267.792	267.791	267.789	267.786	267.785	267.784	267.788	267.793
176	267.796	267.796	267.795	267.794	267.792	267.785	267.779	267.775	267.772	267.766	267.764	267.763
177	267.762	267.760	267.758	267.756	267.755	267.748	267.742	267.736	267.729	267.723	267.723	267.723
178	267.723	267.723	267.722	267.721	267.720	267.736	267.756	267.753	267.743	267.739	267.733	267.731
179	267.731	267.732	267.733	267.734	267.734	267.731	267.724	267.716	267.711	267.706	267.705	267.709
180	267.711	267.713	267.713	267.713	267.713	267.711	267.705	267.699	267.693	267.688	267.684	267.684
181	267.686	267.687	267.688	267.687	267.687	267.686	267.671	267.664	267.660	267.659	267.659	267.661
182	267.662	267.663	267.663	267.663	267.663	267.657	267.647	267.639	267.636	267.634	267.638	267.640
183	267.641	267.642	267.642	267.643	267.643	267.636	267.626	267.622	267.622	267.623	267.626	267.627

JULIAN DATE	TIME OF DAY (HOURS) 0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200
184	267.628	267.629	267.630	267.630	267.631	267.626	267.608	267.601	267.592	267.591	267.594	267.598
185	267.602	267.604	267.630	267.630	267.629	267.626	267.611	267.600	267.657	267.658	267.657	267.655
186	267.658	267.654	267.653	267.653	267.653	267.651	267.642	267.633	267.625	267.666	267.667	267.666
187	267.665	267.664	267.664	267.664	267.691	267.801	267.802	267.792	267.798	267.802	267.837	267.844
188	267.868	267.891	267.903	267.908	267.912	267.913	267.914	267.913	267.912	267.911	267.908	267.936
189	267.901	267.898	267.893	267.891	267.881	267.876	267.867	267.861	267.853	267.848	267.841	267.836
190	267.826	267.819	267.811	267.806	267.799	267.798	267.782	267.773	267.765	267.761	267.758	267.755
191	267.752	267.749	267.746	267.744	267.742	267.740	267.738	267.734	267.732	267.729	267.728	267.727
192	267.725	267.738	267.746	267.740	267.737	267.736	267.733	267.741	267.741	267.732	267.737	267.743
193	267.750	267.761	267.759	267.761	267.763	267.755	267.746	267.741	267.738	267.736	267.736	267.737
194	267.737	267.737	267.735	267.733	267.731	267.723	267.714	267.706	267.697	267.693	267.693	267.693
195	267.693	267.693	267.692	267.692	267.691	267.686	267.676	267.665	267.656	267.652	267.651	267.651
196	267.652	267.653	267.653	267.653	267.652	267.651	267.646	267.639	267.636	267.635	267.639	267.642
197	267.643	267.646	267.644	267.644	267.642	267.635	267.628	267.623	267.619	267.616	267.619	267.620
198	267.622	267.623	267.624	267.625	267.625	267.619	267.612	267.616	267.617	267.666	267.716	267.712
199	267.705	267.701	267.698	267.697	267.696	267.720	267.751	267.741	267.731	267.724	267.724	267.725
200	267.728	267.729	267.731	267.732	267.730	267.721	267.710	267.702	267.696	267.693	267.694	267.695
201	267.695	267.695	267.695	267.694	267.693	267.686	267.677	267.669	267.663	267.659	267.658	267.659
202	267.660	267.660	267.660	267.660	267.660	267.651	267.642	267.635	267.630	267.627	267.627	267.627
203	267.628	267.628	267.628	267.628	267.628	267.624	267.613	267.604	267.593	267.591	267.593	267.594
204	267.596	267.598	267.600	267.601	267.600	267.593	267.582	267.571	267.563	267.560	267.560	267.562
205	267.565	267.566	267.567	267.568	267.569	267.562	267.553	267.544	267.536	267.531	267.530	267.532
206	267.535	267.538	267.540	267.542	267.547	267.541	267.531	267.524	267.518	267.513	267.514	267.516
207	267.520	267.522	267.524	267.526	267.529	267.528	267.523	267.518	267.513	267.513	267.515	267.518
208	267.520	267.523	267.526	267.528	267.530	267.529	267.524	267.516	267.508	267.504	267.505	267.508
209	267.510	267.513	267.516	267.519	267.520	267.517	267.506	267.499	267.493	267.490	267.489	267.490
210	267.492	267.495	267.499	267.500	267.502	267.500	267.488	267.482	267.477	267.473	267.471	267.472
211	267.473	267.474	267.476	267.477	267.477	267.477	267.474	267.469	267.463	267.460	267.457	267.457
212	267.458	267.459	267.460	267.461	267.464	267.468	267.458	267.454	267.449	267.447	267.444	267.444
213	267.444	267.446	267.447	267.449	267.451	267.456	267.455	267.453	267.448	267.446	267.445	267.444

JULIAN DATE	TIME OF DAY (HOURS) 0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200
214	267.449	267.471	267.581	267.696	267.682	267.672	267.656	267.645	267.732	267.831	267.849	267.882
215	267.916	267.930	267.938	267.945	267.949	267.953	267.956	267.959	267.960	267.963	267.965	267.966
216	267.966	267.966	267.936	267.965	267.965	267.962	267.961	267.958	267.956	267.955	267.954	267.952
217	267.950	267.949	267.948	267.947	267.945	267.942	267.939	267.936	267.933	267.929	267.925	267.922
218	267.917	267.913	267.909	267.901	267.894	267.887	267.878	267.869	267.863	267.856	267.848	267.841
219	267.836	267.830	267.825	267.820	267.813	267.808	267.799	267.792	267.783	267.779	267.775	267.773
220	267.769	267.766	267.763	267.759	267.756	267.753	267.745	267.736	267.731	267.727	267.725	267.785
221	267.846	267.859	267.886	267.921	267.936	267.946	267.954	267.959	267.962	267.965	267.969	267.971
222	267.973	267.930	267.977	267.979	267.980	267.982	267.983	267.984	267.985	267.987	267.988	267.989
223	267.989	267.990	267.991	267.991	267.991	267.991	267.990	267.990	267.989	267.989	267.988	267.987
224	267.986	267.985	267.984	267.982	267.980	267.978	267.974	267.972	267.969	267.966	267.963	267.959
225	267.956	267.953	267.949	267.947	267.942	267.939	267.933	267.929	267.923	267.920	267.916	267.912
226	267.908	267.904	267.899	267.894	267.891	267.888	267.879	267.873	267.869	267.863	267.858	267.852
227	267.846	267.841	267.836	267.831	267.828	267.821	267.810	267.801	267.793	267.790	267.788	267.784
228	267.780	267.778	267.774	267.771	267.767	267.763	267.755	267.746	267.739	267.735	267.734	267.733
229	267.731	267.729	267.928	267.726	267.724	267.719	267.713	267.704	267.699	267.695	267.694	267.693
230	267.693	267.692	267.691	267.690	267.689	267.687	267.682	267.677	267.674	267.686	267.695	267.693
231	267.690	267.688	267.686	267.684	267.683	267.679	267.673	267.665	267.660	267.657	267.655	267.655
232	267.655	267.655	267.655	267.655	267.655	267.651	267.644	267.638	267.633	267.632	267.632	267.632
233	267.633	267.633	267.633	267.633	267.633	267.630	267.622	267.614	267.610	267.607	267.607	267.608
234	267.608	267.609	267.610	267.612	267.613	267.613	267.615	267.615	267.623	267.633	267.633	267.632
235	267.632	267.632	267.632	267.631	267.626	267.619	267.612	267.608	267.606	267.606	267.608	267.608
236	267.610	267.610	267.612	267.613	267.614	267.608	267.598	267.592	267.586	267.583	267.583	267.585
237	267.587	267.589	267.590	267.592	267.593	267.589	267.581	267.574	267.566	267.563	267.562	267.563
238	267.567	267.569	267.571	267.573	267.574	267.572	267.565	267.558	267.551	267.546	267.545	267.545
239	267.548	267.550	267.553	267.555	267.556	267.558	267.551	267.545	267.539	267.536	267.535	267.535
240	267.536	267.539	267.543	267.547	267.549	267.554	267.563	267.595	267.623	267.626	267.626	267.626
241	267.625	267.668	267.715	267.713	267.711	267.708	267.705	267.704	267.702	267.699	267.700	267.703
242	267.706	267.708	267.709	267.711	267.726	267.736	267.736	267.732	267.723	267.720	267.719	267.719
243	267.719	267.718	267.718	267.717	267.715	267.709	267.701	267.692	267.685	267.680	267.679	267.679
244	267.679	267.679	267.679	267.679	267.678	267.678	267.673	267.665	267.657	267.653	267.654	267.656
245	267.657	267.663	267.703	267.752	267.748	267.740	267.734	267.726	267.719	267.716	267.746	267.774

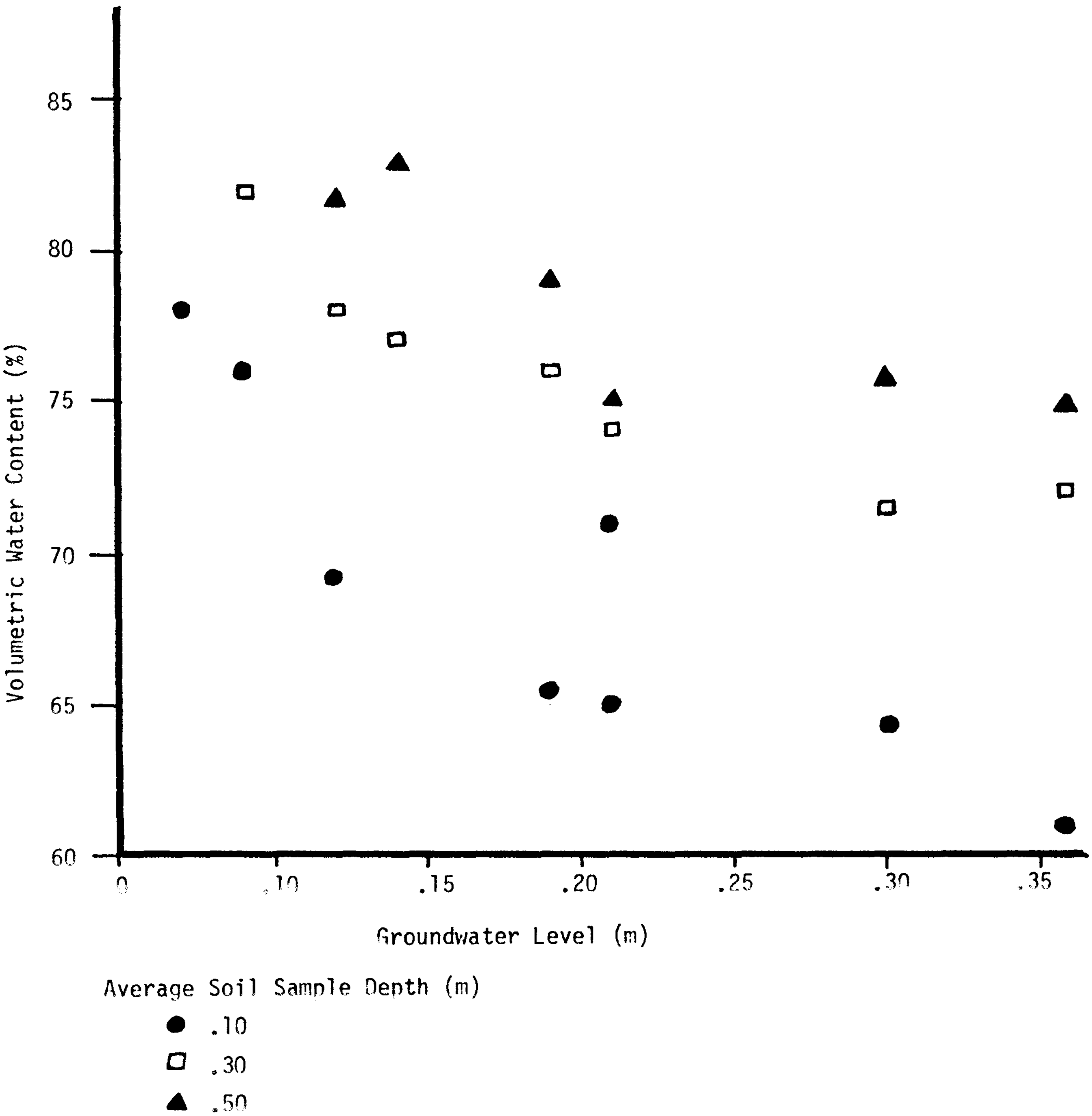
JULIAN DATE	TIME OF DAY (HOURS) 0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200
246	267.769	267.767	267.767	267.769	267.771	267.775	267.780	267.784	267.789	267.791	267.792	267.793
247	267.794	267.794	267.794	267.793	267.792	267.783	267.780	267.776	267.768	267.765	267.763	267.760
248	267.758	267.756	267.753	267.750	267.747	267.743	267.738	267.731	267.723	267.719	267.717	267.716
249	267.715	267.713	267.712	267.710	267.709	267.706	267.702	267.697	267.693	267.689	267.689	267.688
250	267.688	267.687	267.686	267.685	267.684	267.682	267.678	267.672	267.667	267.663	267.663	267.663
251	267.663	267.663	267.663	267.663	267.662	267.658	267.653	267.646	267.642	267.640	267.640	267.640
252	267.641	267.642	267.642	267.643	267.642	267.640	267.636	267.632	267.629	267.640	267.650	267.680
253	267.720	267.754	267.755	267.749	267.745	267.743	267.739	267.738	267.761	267.760	267.758	267.759
254	267.759	267.760	267.763	267.769	267.794	267.819	267.829	267.834	267.841	267.851	267.859	267.865
255	267.869	267.873	267.875	267.877	267.878	267.878	267.877	267.875	267.874	267.872	267.869	267.866
256	267.863	267.860	267.858	267.855	267.874	267.899	267.912	267.927	267.956	267.982	267.995	268.004
257	268.008	268.013	268.015	268.017	268.018	268.018	268.019	268.019	268.019	268.019	268.018	268.018
258	268.017	268.017	268.017	268.017	268.017	268.016	268.015	268.015	268.014	268.013	268.012	268.011
259	268.010	268.009	268.008	268.007	268.005	268.003	268.000	267.998	267.996	267.995	267.993	267.991
260	267.990	267.988	267.985	267.983	267.979	267.977	267.973	267.969	267.967	267.964	267.961	267.959
261	267.955	267.952	267.949	267.945	267.941	267.937	267.933	267.929	267.925	267.923	267.918	267.915
262	267.912	267.909	267.906	267.902	267.898	267.892	267.886	267.881	267.877	267.872	267.867	267.853
263	267.859	267.857	267.852	267.849	267.843	267.838	267.833	267.829	267.825	267.823	267.821	267.819
264	267.812	267.815	267.812	267.809	267.805	267.802	267.794	267.792	267.789	267.787	267.785	267.783
265	267.781	267.779	267.777	267.775	267.773	267.772	267.769	267.765	267.762	267.761	267.759	267.758
266	267.757	267.757	267.756	267.755	267.754	267.753	267.752	267.751	267.751	267.751	267.751	267.751
267	267.751	267.754	267.759	267.760	267.761	267.760	267.760	267.759	267.758	267.758	267.758	267.758
268	267.759	267.759	267.760	267.762	267.763	267.766	267.768	267.769	267.770	267.772	267.804	267.833
269	267.828	267.829	267.832	267.837	267.842	267.844	267.846	267.845	267.844	267.844	267.843	267.841
270	267.839	267.836	267.833	267.830	267.827	267.824	267.819	267.816	267.813	267.810	267.809	267.806
271	267.804	267.801	267.799	267.796	267.794	267.792	267.790	267.788	267.785	267.783	267.782	267.781
272	267.780	267.779	267.777	267.775	267.773	267.772	267.767	267.763	267.762	267.760	267.760	267.759
273	267.759	267.758	267.757	267.756	267.754	267.753	267.750	267.748	267.746	267.745	267.745	267.745
274	267.744	267.744	267.743	267.742	267.741	267.739	267.736	267.734	267.733	267.732	267.731	267.731
275	267.731	267.731	267.731	267.731	267.731	267.729	267.727	267.724	267.723	267.723	267.723	267.723
276	267.723	267.723	267.731	267.724	267.724	267.723	267.721	267.720	267.719	267.718	267.719	267.722
277	267.725	267.727	267.730	267.732	267.733	267.732	267.731	267.728	267.726	267.727	267.728	267.729
278	267.731	267.731	267.731	267.731	267.730	267.729	267.725	267.724	267.721	267.721	267.722	267.722

Groundwater Measurements (water level above sea level in m -- 26_.___)

Julian Date	Date	WC	M2	WL1	M1	Staff
153	June 2	7.929	7.938	7.934	7.925	7.947
160	June 9	7.784	7.793	7.781	7.770	7.771
167	June 16	7.679	7.699	7.688	7.674	7.672
174	June 23	7.786	7.788	7.780	7.767	7.772
181	June 30	7.685	7.693	7.691	7.675	7.671
190	July 9	7.798	7.797	7.785	7.781	7.779
196	July 15	7.651	7.678	7.665	7.654	7.631
199	July 18	7.701	7.715	7.706	7.703	7.727
202	July 21	7.660	7.678	7.669	7.655	7.637
206	July 25	7.551	7.588	7.575	7.570	7.569
209	July 28	7.520	7.563	7.552	7.547	7.574
213	August 1	7.456	7.502	7.493	7.488	7.546
214	August 2	7.845	7.858	7.853	7.855	7.886
216	August 4	7.964	7.973	7.972	7.968	7.987
220	August 8	7.756	7.758	7.746	7.740	7.727
223	August 11	7.991	8.007	7.999	7.995	8.011
227	August 15	7.828	7.828	7.821	7.813	7.824
230	August 18	7.679	7.696	7.686	7.676	7.651
234	August 22	7.616	7.640	7.627	7.620	7.609
237	August 25	7.593	7.623	7.612	7.604	7.608
241	August 29	7.709	7.721	7.713	7.705	7.757
242	August 30	7.727	7.749	7.740	7.730	7.749
244	Sept. 1	7.678	7.699	7.688	7.680	7.672
248	Sept. 5	7.720	7.736	7.723	7.719	7.711
251	Sept. 8	7.662	7.683	7.672	7.665	7.644
258	Sept. 15	8.016	8.029	8.024	8.020	8.032
265	Sept. 22	7.771	7.782	7.771	7.764	7.769
272	Sept. 29	7.771	7.784	7.775	7.765	7.774
279	October 6	7.721	7.743	7.731	7.721	7.722
286	October 13	7.794	7.811	7.802	7.794	7.804
293	October 20	7.841	7.862	7.854	7.847	7.862

Hydraulic Head for Piezometers in Metres above Sea Level (26_.___)

Piezometer Depth (m) Soil Type at Bottom of Piezometer		0.25 peat	0.50 peat	0.75 peat	1.0 peat	1.5 marl	2.5 sand	3.0 sand
Julian Date	Date							
199	July 18	7.701	7.697	7.682	7.674	7.641	7.755	7.759
202	July 21	dry	7.663	7.685	7.698	7.716	7.721	7.723
206	July 25	dry	7.558	7.577	7.594	7.639	7.625	7.613
209	July 28	dry	7.538	7.543	7.552	7.589	7.602	7.606
213	Aug. 1	dry	7.464	7.487	7.494	7.526	7.534	7.537
214	Aug. 2	7.853	7.852	7.716	7.569	7.614	7.755	7.759
216	Aug. 4	7.964	7.960	7.967	7.864	7.933	7.996	7.997
220	Aug. 8	7.744	7.756	7.812	7.835	7.817	7.808	7.804
223	Aug. 11	7.994	7.995	7.967	7.967	7.986	8.002	8.015
227	Aug. 15	7.818	7.830	7.912	7.910	7.889	7.880	7.879
230	Aug. 18	dry	7.683	7.717	7.754	7.734	7.742	7.741
234	Aug. 22	dry	7.617	7.641	7.649	7.656	7.677	7.679
237	Aug. 25	dry	7.599	7.621	7.628	7.638	7.658	7.660
241	Aug. 29	7.731	7.725	7.680	7.580	7.641	7.720	7.731
242	Aug. 30	7.740	7.742	7.736	7.673	7.719	7.784	7.788
244	Sept. 1	dry	7.689	7.708	7.702	7.727	7.748	7.748
248	Sept. 5	7.721	7.730	7.762	7.756	7.764	7.796	7.796
251	Sept. 8	dry	7.665	7.689	7.707	7.708	7.721	7.723
258	Sept. 15	8.019	8.020	8.027	7.972	7.983	8.047	8.035
265	Sept. 22	7.769	7.773	7.792	7.844	7.820	7.827	7.834
272	Sept. 29	7.773	7.775	7.799	7.811	7.815	7.830	7.833
279	Oct. 6	7.729	7.729	7.740	7.750	7.761	7.786	7.787
286	Oct. 13	7.802	7.802	7.810	7.814	7.829	7.851	7.853
293	Oct. 20	7.855	7.854	7.830	7.831	7.851	7.882	7.881



Water content of peat for various groundwater levels.

JULIAN DATE	DAILY MEAN WATER LEVEL (m) ASL	WATER TABLE DEPTH BELOW GROUND SURFACE (m)	STORAGE DEFICIT (mm)
154	267.932	-0.09	0
155	267.941	-0.10	0
156	267.904	-0.06	0
157	267.860	-0.02	0
158	267.852	-0.01	0
159	267.820	0.02	0
160	267.777	0.06	3.18
161	267.733	0.11	11.24
162	267.699	0.14	17.46
163	267.673	0.17	22.22
164	267.654	0.19	25.69
165	267.715	0.13	14.53
166	267.695	0.15	18.19
167	267.669	0.17	22.95
168	267.771	0.07	4.28
169	267.982	-0.14	0
170	268.001	-0.16	0
171	267.984	-0.14	0
172	267.945	-0.10	0
173	267.866	-0.03	0
174	267.782	0.06	2.27
175	267.787	0.05	1.35
176	267.781	0.06	2.45
177	267.743	0.10	9.41
178	267.733	0.11	11.24
179	267.722	0.12	13.25
180	267.702	0.14	16.91
181	267.675	0.17	21.85
182	267.650	0.19	26.43
183	267.633	0.21	29.54
184	267.613	0.23	33.20
185	267.630	0.21	30.08
186	267.652	0.19	26.06
187	267.752	0.09	7.76
188	267.907	-0.07	0
189	267.871	-0.03	0
190	267.788	0.05	1.17
191	267.738	0.10	10.32
192	267.737	0.10	10.50
193	267.749	0.09	8.31
194	267.716	0.13	14.35
195	267.675	0.17	21.85
196	267.646	0.20	27.16
197	267.632	0.21	29.72
198	267.640	0.20	28.25
199	267.718	0.12	13.98
200	267.713	0.13	14.90
201	267.679	0.16	21.12

JULIAN DATE	DAILY MEAN WATER LEVEL (m) ASL	WATER TABLE DEPTH BELOW GROUND SURFACE (m)	STORAGE DEFICIT (mm)
202	267.645	0.20	27.34
203	267.613	0.23	33.20
204	267.582	0.26	38.87
205	267.552	0.29	44.36
206	267.530	0.31	48.38
207	267.521	0.32	50.03
208	267.518	0.32	50.58
209	267.505	0.34	52.96
210	267.488	0.35	56.07
211	267.470	0.37	59.36
212	267.456	0.39	61.93
213	267.449	0.39	63.21
214	267.679	0.16	21.12
215	267.950	-0.11	0
216	267.958	-0.12	0
217	267.939	-0.10	0
218	267.881	-0.04	0
219	267.803	0.04	0
220	267.751	0.09	7.94
221	267.931	-0.09	0
222	267.978	-0.14	0
223	267.990	-0.15	0
224	267.975	-0.13	0
225	267.935	-0.09	0
226	267.882	-0.04	0
227	267.814	0.03	0
228	267.756	0.09	7.03
229	267.730	0.11	11.79
230	267.687	0.15	19.65
231	267.673	0.17	22.22
232	267.645	0.20	27.34
233	267.622	0.22	31.55
234	267.618	0.22	32.28
235	267.618	0.22	32.28
236	267.600	0.24	35.57
237	267.579	0.26	39.42
238	267.561	0.28	42.71
239	267.547	0.29	45.27
240	267.577	0.26	39.78
241	267.696	0.15	18.01
242	267.720	0.12	13.62
243	267.701	0.14	17.09
244	267.669	0.17	22.95
245	267.723	0.12	13.07
246	267.779	0.06	2.82
247	267.780	0.06	2.64
248	267.738	0.10	10.32
249	267.702	0.14	16.91
250	267.677	0.16	21.48

JULIAN DATE	DAILY MEAN WATER LEVEL (m) ASL	WATER TABLE DEPTH BELOW GROUND SURFACE (m)	STORAGE DEFICIT (mm)
251	267.653	0.19	25.88
252	267.643	0.20	27.71
253	267.748	0.09	8.49
254	267.812	0.03	0
255	267.874	-0.03	0
256	267.915	-0.07	0
257	268.017	-0.18	0
258	268.015	-0.17	0
259	268.001	-0.16	0
260	267.975	-0.13	0
261	267.935	-0.09	0
262	267.888	-0.05	0
263	267.837	0.00	0
264	267.799	0.04	0
265	267.769	0.07	4.65
266	267.753	0.09	7.58
267	267.758	0.08	6.66
268	267.774	0.07	3.73
269	267.840	0.00	0
270	267.822	0.02	0
271	267.791	0.05	0.62
272	267.769	0.07	4.65
273	267.751	0.09	7.94
274	267.738	0.10	10.32
275	267.727	0.11	12.33
276	267.722	0.12	13.25
277	267.729	0.11	11.97
278	267.727	0.11	12.33

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