LONG AND SHORT TERM TRENDS AND FLUCTUATIONS OF GROUNDWATER LEVELS AT THREE SITES IN NOVA SCOTIA

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ABSTRACT

Groundwater is an essential resource in Nova Scotia, and is used by over half of the province's population for domestic purposes. In order to manage this resource effectively, it is important to understand if and how groundwater levels are changing over time and, if possible, to determine the cause of these changes. In an attempt to advance this understanding, this report analyses the long and short term trends and fluctuations of groundwater levels at three sites in Nova Scotia. Data from monitoring wells at Lawrencetown, Halifax County and Durham, Pictou County suggests that slight increases in groundwater levels are occurring over the long term, in conjunction with slight increases in total precipitation. Seasonal trends are also apparent at these two sites, as well as at a third site on McNabs Island, Halifax County. Tidal effect is very apparent on groundwater levels at the Lawrencetown site, which is located approximately 150 feet (50 metres) from the shoreline of the Cole Harbour Estuary. Tidal effect was not found at the Durham site, likely due to its distance from the shoreline, nor was it found at the McNabs Island site, due to its elevation above sea level. Temperature is inversely related to groundwater level changes at all three sites. Barometric pressure is inversely related to groundwater level changes, but was found to have little effect on water levels at the Lawrencetown and Durham sites.

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Chapter 1: Introduction

1.1 Thesis Statement and Scope

The purpose of this study is to analyse the long term and short term trends and fluctuations of groundwater levels at selected sites in Nova Scotia. This is an important topic since groundwater is a vital resource, used throughout the province for industrial, domestic and agricultural purposes. In order to effectively manage this resource, it is necessary to know whether or not groundwater levels are generally increasing or decreasing over time, and what factors are affecting these levels over both the short and the long term. Factors considered include: climatic effects, seasonal/diurnal effects, external loading effects and anthropogenic effects that may be present.

This study focuses on data from three sites located in differing physiographic and hydrogeologic settings: Lawrencetown, Halifax County; McNabs Island, Halifax County; and Durham, Pictou County (Figure 1). Long term data (15-20 years) are studied at the Lawrencetown and Durham sites, while short term data (6 months) are studied at the McNabs Island site. It is hoped that this variety in settings and time factors provides a preliminary look at the behaviour of Nova Scotia's groundwater levels. Further discussion on site selection is included in Chapter 3.

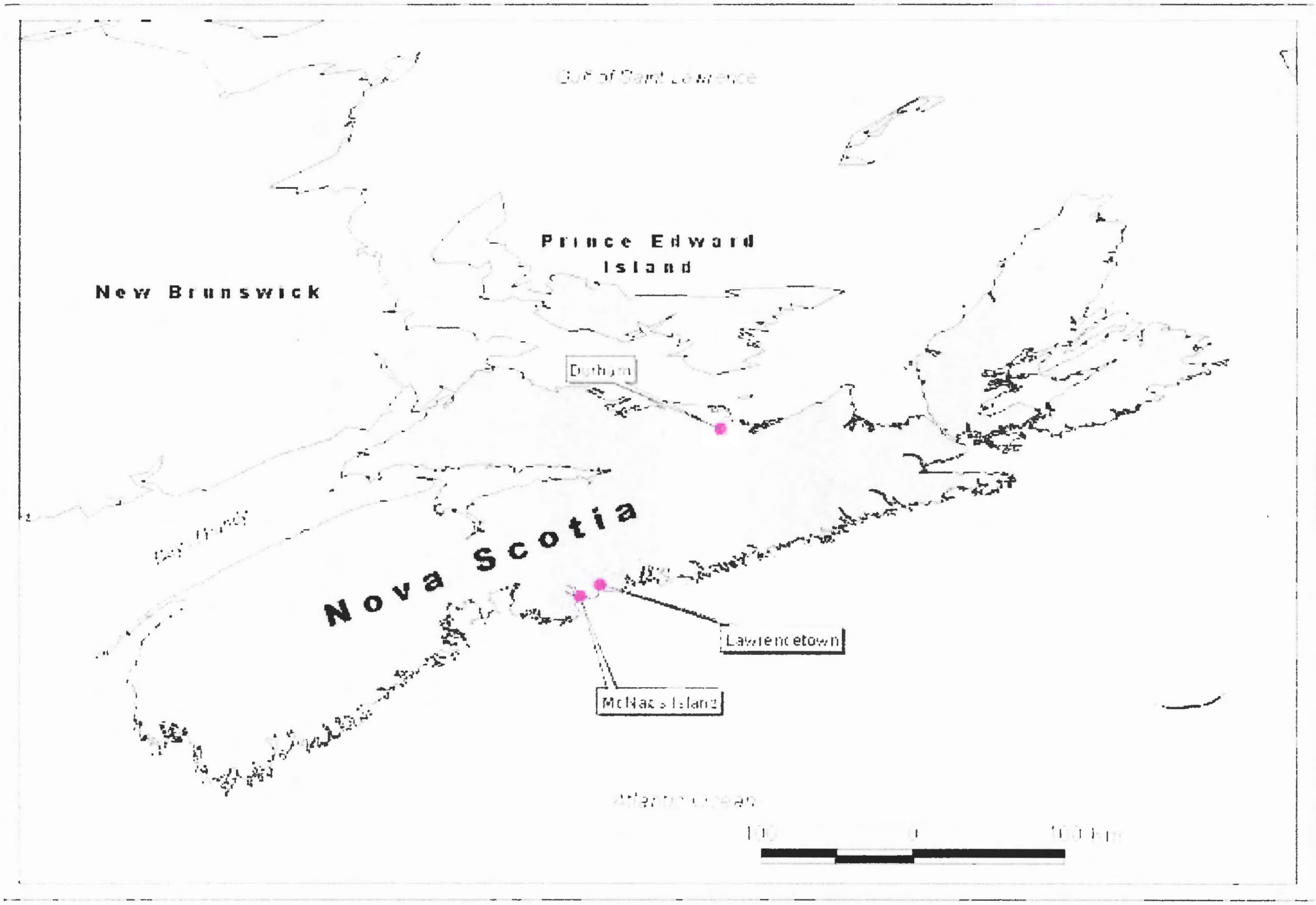


Figure 1 - Site Location Map

1.2 Importance

In 1991, Atlantic Canada used a total of 3175 million cubic metres of water for thermal power, manufacturing, municipal uses, agriculture and mining. In 1993, 55% of Nova Scotians depended on groundwater for domestic uses (www.ec.gc.ca/water/index.htm). Evidently, groundwater is a very important resource so managing it properly and protecting it is in our own best interests.

Groundwater levels reflect a number of factors such as changes in loading on the aquifer skeleton, climatic factors, changes in storage resulting from differences in supply and withdrawal, and long term changes in storage. Understanding the magnitude and effect of these factors is important because it enables us to determine how both nature and humanity are impacting the groundwater levels, therefore improving our ability to manage and protect our groundwater.

1.3 Physiographic Setting

Both the Lawrencetown and the McNabs Island well sites (Figure 1) are located in the Southern Upland, a physiographic region that is part of an erosional plain now composed primarily of granites, slates and greywackes (Roland, 1982) (Figure 2). The Lawrencetown study area (Figure 1) is located east of the city of Dartmouth, along the Atlantic coast where the Little Salmon River drains into the Cole Harbour estuary. The general area is hilly (Cross, 1980). The McNabs Island study area is located on McNabs Island at the mouth of Halifax Harbour (Figure 1). The island is hilly to rolling, with a low-lying area near the centre that consists of a pond and a salt-water marsh.

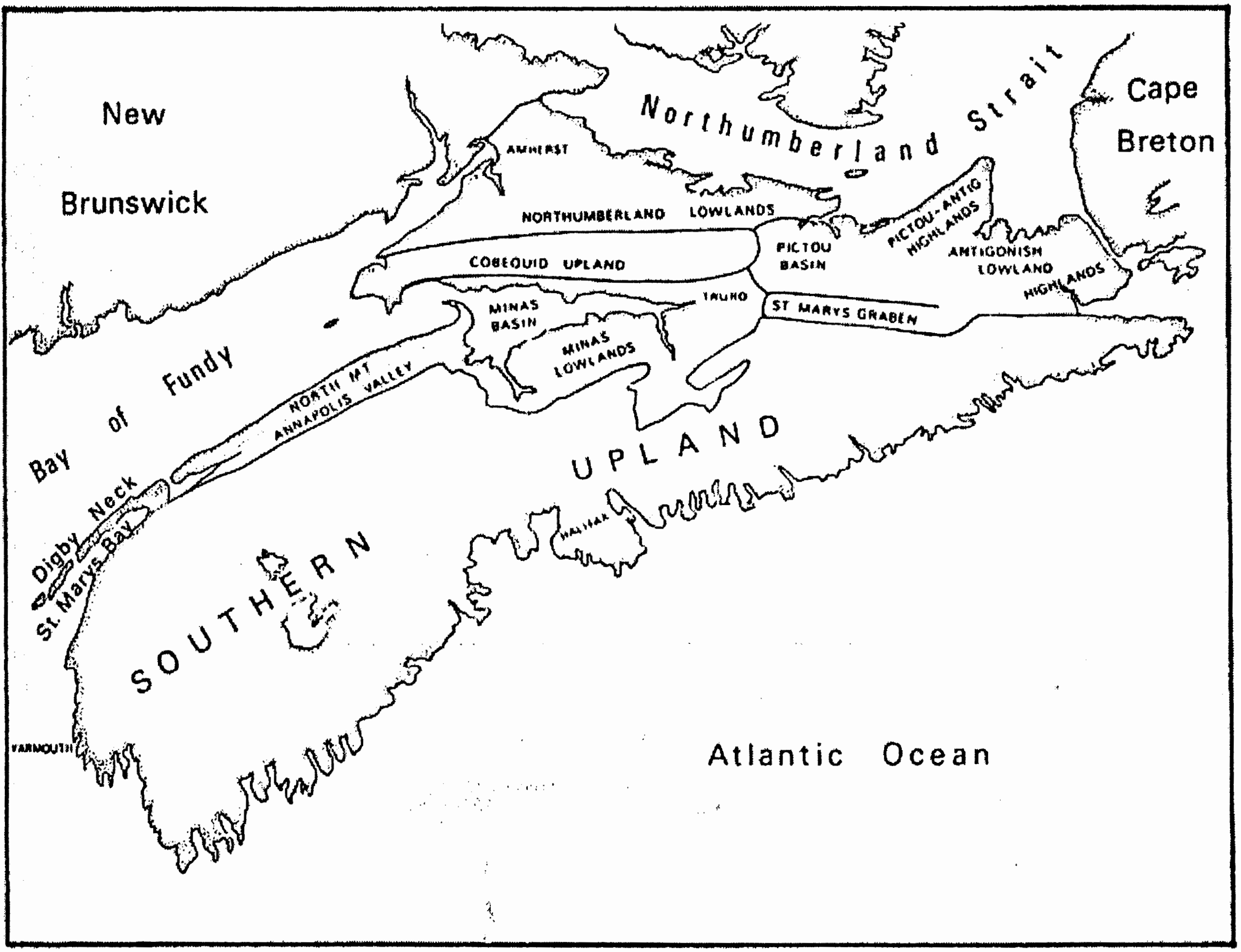


Figure 2 - Physiographic Setting of Nova Scotia (Roland, 1982)

The Durham well site is located in the Pictou Basin in Northern Nova Scotia (Figure 2). The study area lies near the West River, which drains into Pictou Harbour and the Northumberland Strait. The general area is low-lying, bordered by the Cobequid Uplands and the Pictou-Antigonish Uplands (Roland, 1986).

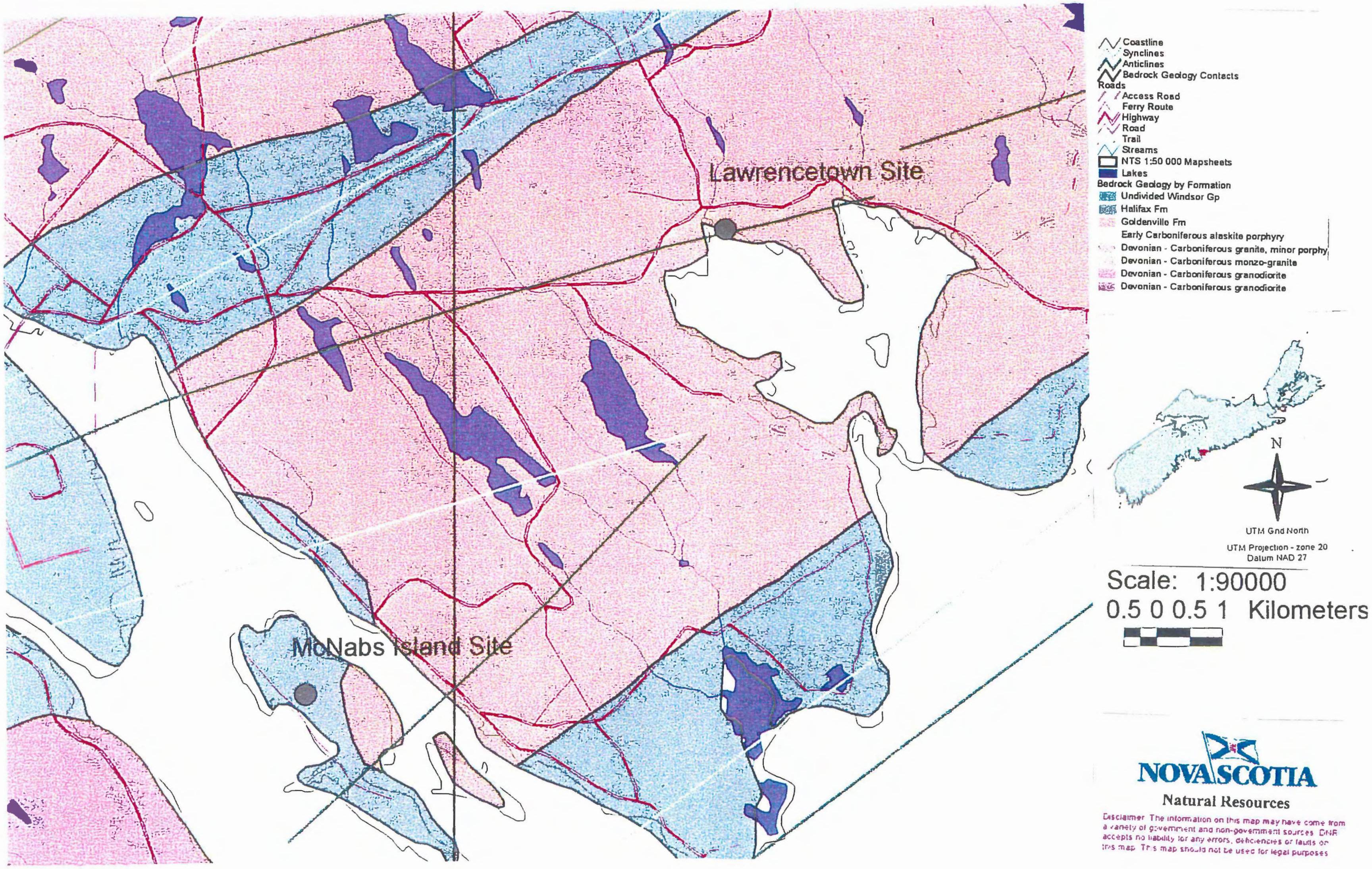
1.4 Hydrogeologic Setting

1.4.1 Bedrock Geology

The Lawrencetown and McNabs Island study sites are underlain by the Lower Ordovician Meguma Group (GSC 1906, Sheet no. 53). The Lawrencetown site is located in the Goldenville Formation (Figure 3) which consists primarily of quartzofeldspathic greywacke; however, drill chips from the 1977 drilling program revealed that the greywacke is interbedded with black to dark grey slate, as well as minor quartz and calcite stringers (Cross, 1980). Bedding strikes east-northeast and dips southeast at 48° and the site is situated near the axis of an anticline. A northwest-trending fault lies west of the study site (GSC 1906, Sheet no. 53). Major fractures strike mainly northeast and northwest and are steeply dipping. Groundwater movement in this rock type is controlled primarily by fracturing.

The McNabs Island site is located in the slates of the Halifax Formation but near a contact with the coarser greywacke of the overlying Goldenville Formation (Figure 3). The Halifax Formation is characterised by thinly laminated greenish-grey or bluish-black slates that weather to a rusty brown due to the high levels of iron sulphides. The northeast-trending axis of an anticline runs through the centre of McNabs Island.

Figure 3 - Bedrock Geology of the Lawrencetown & McNabs Island Sites



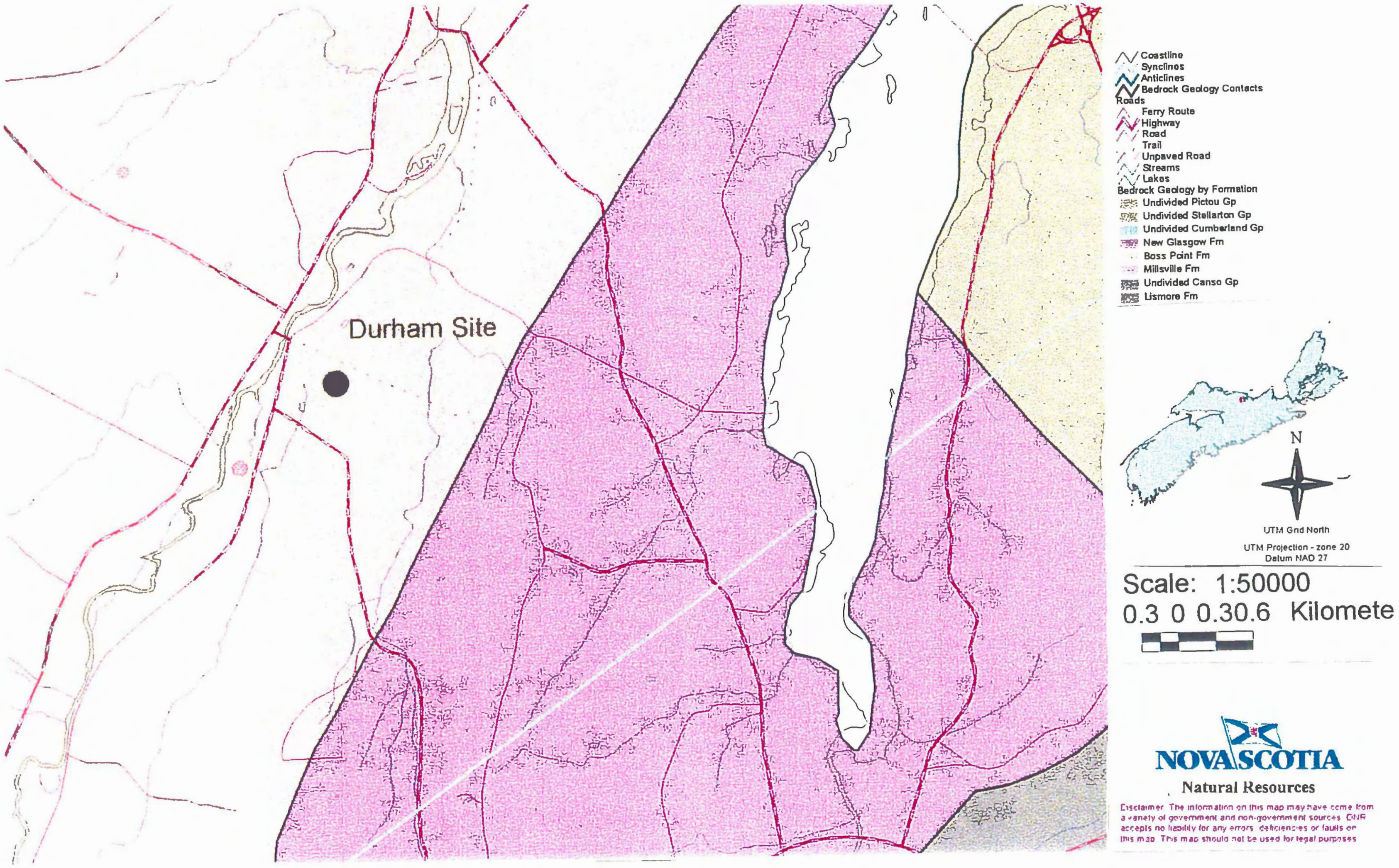
The Durham study site is situated within the Boss Point Formation, the upper unit of the Pennsylvanian Riversdale Group (Figure 4). The Boss Point Formation is made up of grey and red siltstones, sandstones and conglomerates. Groundwater movement in this sedimentary environment is likely controlled by both intergranular permeability and fracture permeability.

1.4.2 Surficial Geology

The surficial material at the Lawrencetown site consists of quartzite till from Pleistocene glacial deposition (Figure 5). The till is a bluish-greenish-grey, loose and cobbly silt-sand till that sometimes contains red clay inclusions. The matrix is generally sand ~80%, silt ~15 % and clay ~5%. Clasts consist of >85% quartzite which are derived from the local bedrock. Till thickness varies, but regionally averages 3m (Stea et al, 1979, Sheet No.3). At the site, till thickness is 2m based on the test hole logs. Large, quartzite (greywacke) boulders, which reflect the local bedrock geology, are found about the site (Cross, 1980). The surficial material at the McNabs Island site is composed of Lawrencetown till which occurs as both ground moraine and drumlins (Figure 5). This till is made up of red clay which grades to a brown, compact sand-silt till with matrix sand ~50%, silt ~35% and clay~15%. Till thickness averages 8m in ground moraine and 25m in drumlins (Stea et al, 1979, Sheet No.3).

The surficial geology at the Durham site is silty/sandy till which occurs as ground moraine (Figure 6).

Figure 4 - Bedrock Geology of the Durham Site



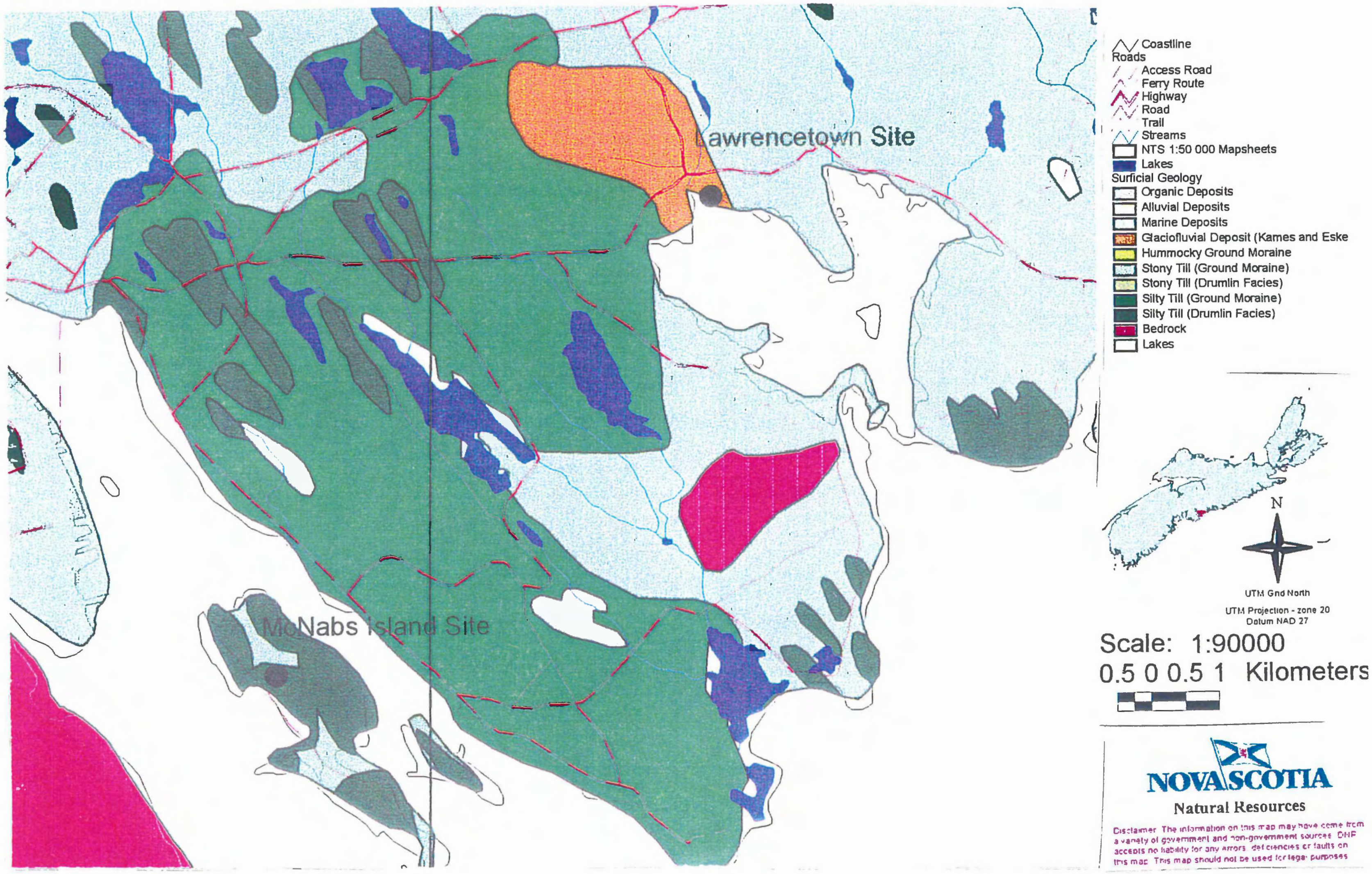
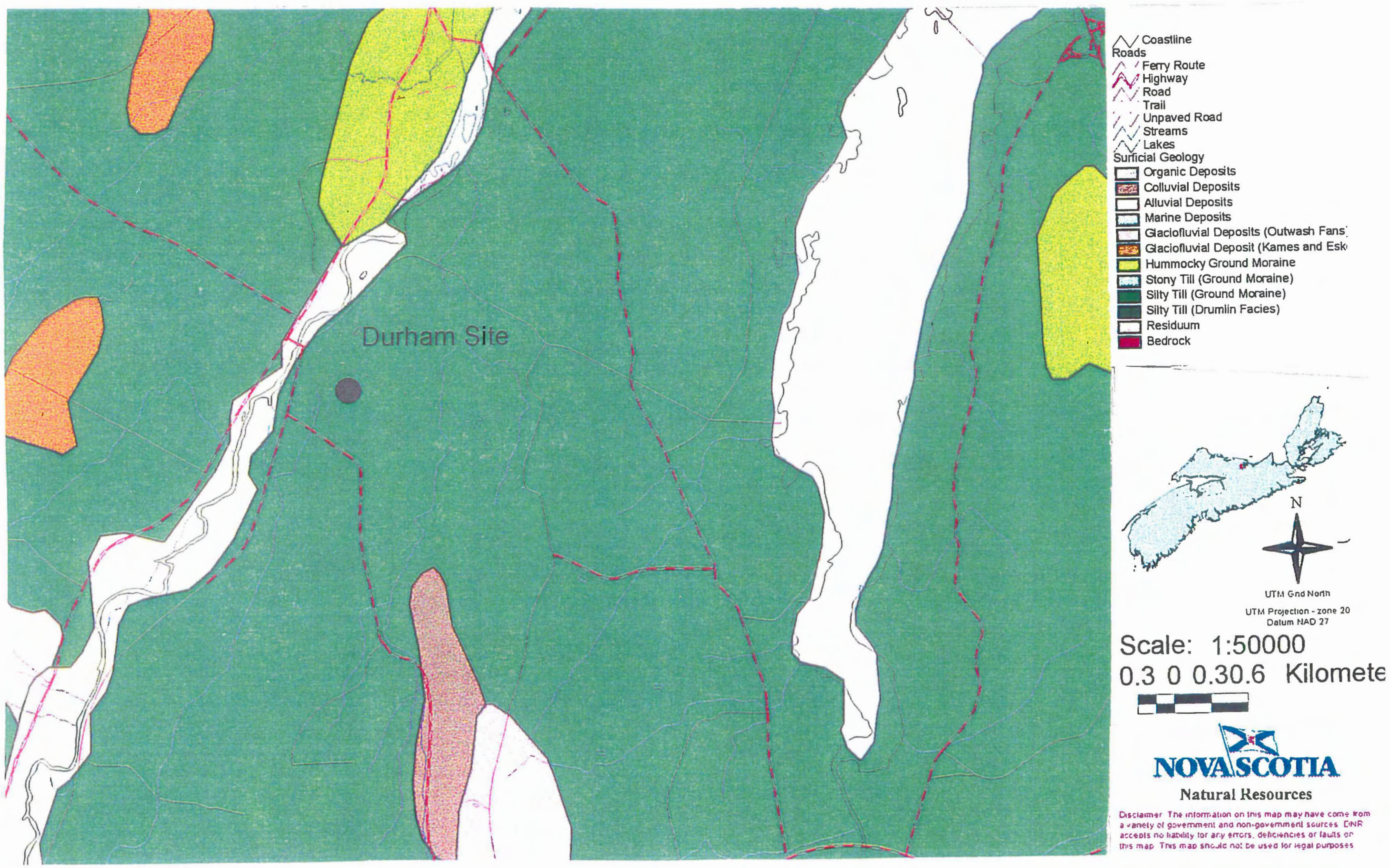


Figure 5 - Surficial Geology of the Lawrencetown & McNabs Island Sites

Figure 6 - Surficial Geology of the Durham Site



1.4.3 Well Data

Wells at the Lawrencetown and Durham sites are both drilled wells that are a part of the Department of the Environment's Observation Well Network, and each is located on private property. The Lawrencetown well is located near a residence on the shoreline of the Cole Harbour Estuary, and the Durham well is located on a farm. The well on McNabs Island is referred to as the 'teahouse well' because it is located near the Island Teahouse. This stone-lined, dug well is no longer in use due to poor water quality. Monitoring equipment was only installed temporarily at this site. Specific well data and lithologic logs are included below, in Table 1 and Table 2 respectively.

The data and logs are given in feet, as this is the prevailing unit in use by the water well community. Metric equivalents are given where considered important.

Table 1 - Well Data

Lawrencetown			McNabs Is			Durham	
Depth	174 ft		Depth	16.4 ft		Depth	247 ft
Diameter	6 in		Diameter	4 feet		Diameter	6 in
Casing	145 ft		Casing	N/A		Casing	N/A
Datum Point	6 ft ASL		Datum Point	N/A		Datum Point	60 ft ASL

Note: 1 inch = 2.54 cm, 1 foot = 0.3048 m
ASL = Above Sea Level

Table 2 - Lithologic Logs

Lawrencetown

Log (ft):

0 - 5	sand & gravel
5 - 12	boulders & broken bedrock
12 - 45	grey quartzite
45 - 102	greenish grey quartzite & quartz stringers
102 - 120	same as 45-102, but increase in slaty interbeds
120 - 152	greenish grey quartzite
152 - 165	dark grey & black slate & quartz veins
165 - 174	greenish grey quartzite & slaty quartizte, minor quartz stringers

Durham

Log (ft):

0 - 20	sandy till
20 - 22	grey sandstone
22 - 32	red shale
32 - 48	grey & red sandstone
48 - 56	grey oil shale
56 - 74	grey sandstone & shale
74 - 90	grey sandstone
90 - 100	red & grey sandstone & shale
100 - 135	coarse grey sandstone
135 - 150	red shale
150 - 165	fine red sandstone
165 - 180	grey shale
180 - 210	coarse red sandstone
210 - 228	grey sandstone & red shale
228 - 247	grey sandstone

Results for pump tests at Lawrencetown and Durham, which are available from internal Nova Scotia Department of the Environment (NSDOE) files, are summarized in Tables 3 (Lawrencetown) and 4 (Durham). A drawdown plot using the Jacob method (Fetter, 1994, p.224-229) shows results for both sites in Figure 7. At Lawrencetown, drawdown decreased steadily to ~80 minutes, and then showed a rising trend for the remainder of the test. The rise occurred because the pump stopped for about 4 minutes, and problems with the generator meant that a pumping rate of only 3 gallons per minute (gpm) could be maintained. At Durham, drawdown at the later stages of the test decreased steadily to ~180 minutes. This was followed by a rising trend due to a decrease in pumping rate from 10 gpm to 7.5 gpm. Calculated transmissivities were ~180 gallons per day per foot (gpd/ft) (2.7 m^2/d) for Lawrencetown, and ~ 400 gpd/ft (2.7 m^2/d) for Durham.

Safe yields based on transmissivities and available long term drawdowns are shown in Tables 3 and 4. Since safe yield is based on very short term data for both tests, values must be considered with caution. Tests were not long enough for boundary conditions to be determined and equilibrium was not reached in either case.

Table 3 - Lawrencetown Pump Test Summary

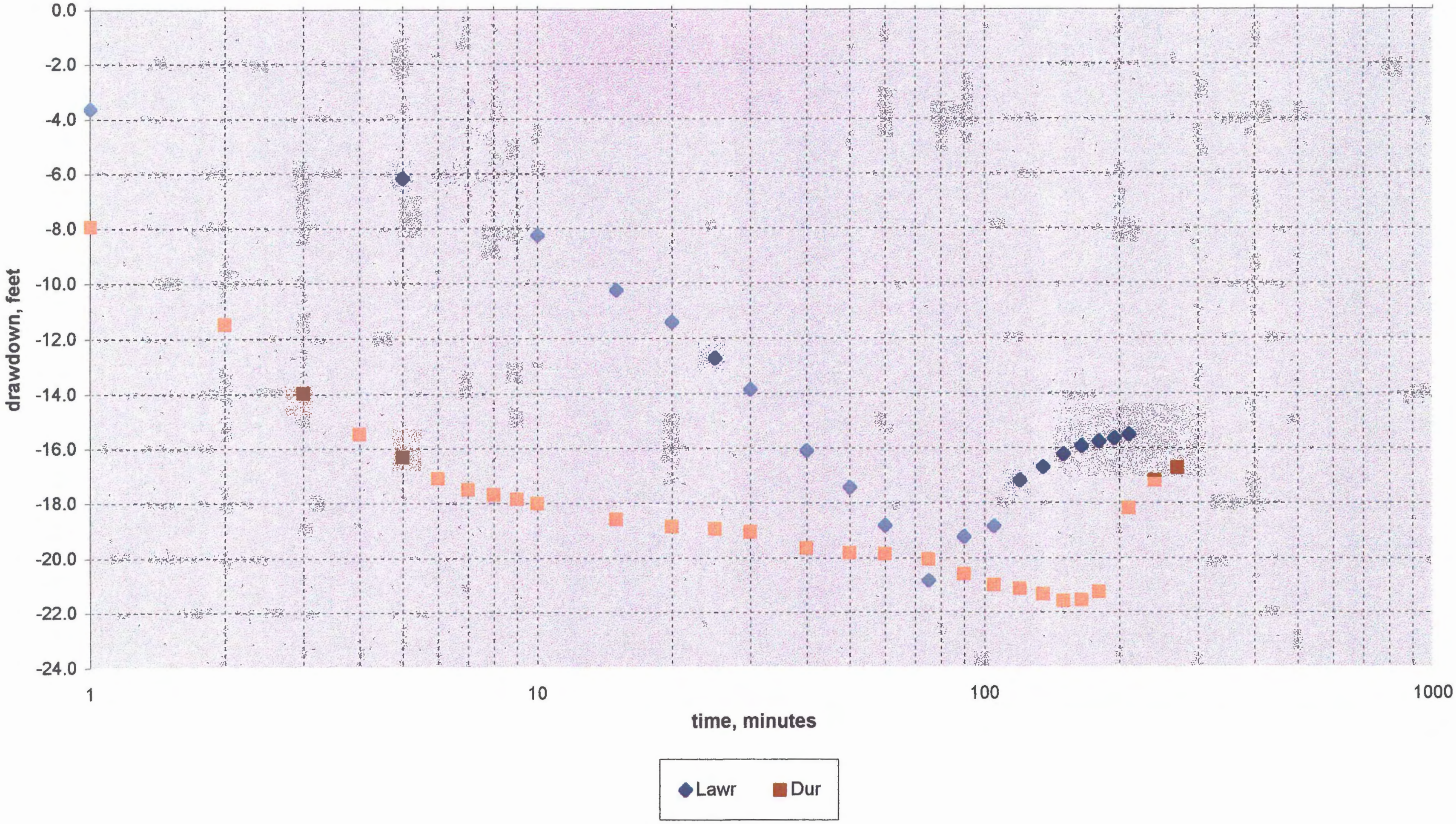
	Lawrencetown
Pumping Rate	10 gpm
Pump Setting	140 ft
Available Drawdown	136 ft during test 121 ft assumed long term
Max Recorded Drawdown (pumping well)	20.84 ft 17% of long term available
Safe Continuous Yield	8 gpm

Table 4 - Durham Pump Test Summary

	Durham
Pumping Rate	10 gpm
Pump Setting	138 ft
Available Drawdown	127 ft during test 112 ft assumed long term
Max Recorded Drawdown (pumping well)	21.58 ft 19% of long term available
Safe Continuous Yield	10 gpm

Note: 1 foot = 0.3048 m, 1 gallon per minute (gpm) = 4.54 litres per minute (Lpm)

Figure 7 - Short Term Pump Tests for Lawrencetown & Durham



Chapter 2 : Groundwater Level Fluctuations

2.1 Measurement

There are two different types of devices used for the measurement of water levels in this study. They are chart recorders and data loggers.

2.1.1 Chart Recorders

A Stevens Type F Recorder Model 68 (Figure 8) is currently used to measure water levels at the Durham site and was used to measure water levels at the Lawrencetown site up until October, 1999. This instrument is a mechanical device that records water level with respect to time. The Type F recorder operates using a float assembly that rises and falls with the water level. The movement of the float turns a drum at a proportional rate and a timer-controlled marker moves across a chart that is fitted to the drum (Figure 9). A continuous record of the water level in the well is recorded on the F-1 type chart. Measurements are made in feet or metres and the charts must be changed every 30 days. This instrument is capable of recording water level to an accuracy of 0.002 feet if the proper weight is employed.

The Type F recorder is very effective; however, some malfunctions are known to occur. For example, the pen may freeze or run out of ink. The float may be disturbed by debris that has fallen into the well or it may catch on the sides of a well casing that is no longer smooth due to scaling or corrosion. The recorder is placed outside of the well and is therefore exposed to vandalism. Any of these problems can result in missing data.

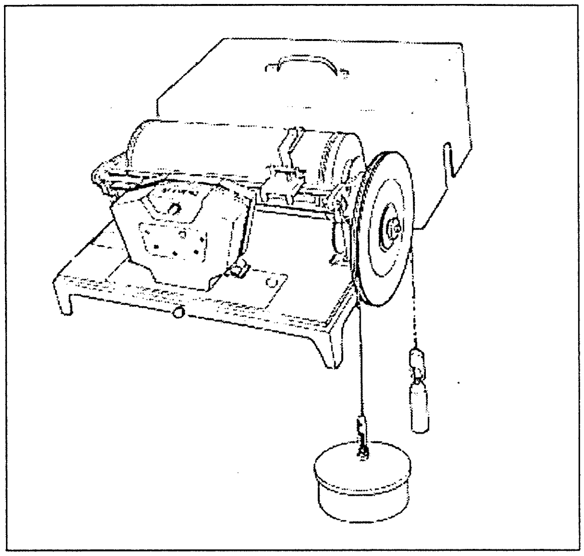


Figure 8 - Stevens Type F Water Level Recorder

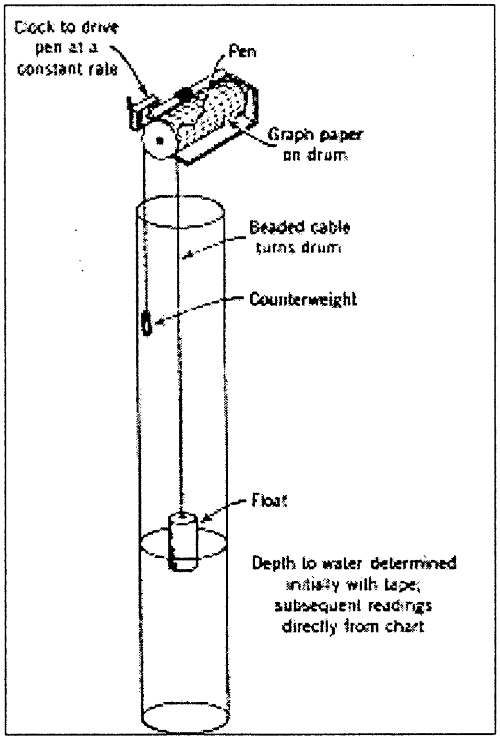


Figure 9 - Mechancially Actuated Drum Recorder

2.1.2 Data Loggers

Since October of 1998, a data logger measures water level at the Lawrencetown site and from November 9, 1989 to May 2, 1999 a data logger was used to measure water level at the McNabs Island site. Data loggers are recording systems that measure water level and store the data in digital format until it is downloaded to a laptop computer. A pressure transducer is placed in the well below the water level, at a depth that exceeds anticipated seasonal fluctuations. The pressure of the water column above the transducer is measured and can be converted to either the height of water from a set point, such as the top of the well casing, or to the hydraulic head above a specific datum, such as mean sea level. A Datapod DPX-WL system (Figure 10) is employed at the Lawrencetown site. This recording system receives hourly data from a pressure transducer and stores up to 6000 readings. The sensor has an accuracy of 0.1% linearity and 0.2% overall. A VEMCO Minilog 8-bit Temperature and Depth Logger (Figure 11) was used at the McNabs Island site. This recording system received hourly data from a pressure transducer and can store up to 8128 readings with a depth resolution of 0.1m. Water temperature was also recorded by this system.

While data loggers are subject to malfunctions like any man-made device, they do have some advantages over chart recorders. Data loggers are placed inside the well and data is collected directly from the device in digital format. They are not as vulnerable to weather and vandalism as chart recorders.

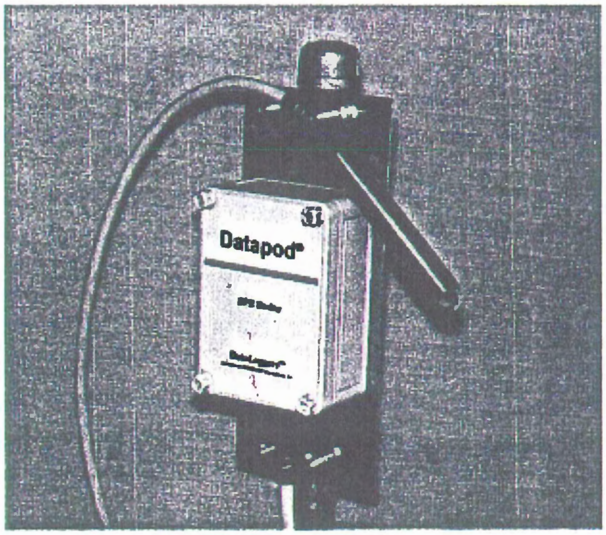


Figure 10 - Datapod DPX-WL System

Figure 11 - VEMCO Minilog 8-bit Temperature & Depth Recorder

2.2 Factors Affecting Groundwater Levels

2.2.1 Climatic Effects

Nova Scotia experiences an average annual rainfall of 1600 mm in the Cape Breton highlands, 1500 mm along the southern coast of the mainland and 1000 mm along the north shore of the mainland on the Northumberland Strait (www.ns.ec.gc.ca/climate/ns.html). Some of this precipitation may be intercepted by vegetation, or evaporate. It may also reach the ground where it runs off into streams and lakes, collects in puddles, flows across the ground in a thin sheet, or infiltrates the soil. The amount of water that can infiltrate the soil is finite and this is called the infiltration capacity. Infiltration capacity varies with soil type and with the moisture content of the soil. In dry soil, capillary forces draw water down into the soil because of tension created by surface effects between the water and the soil particles. The infiltration capacity in dry soil is high and as soil becomes moister, the capillary forces lessen and the infiltration capacity lowers. The equilibrium infiltration capacity is reached when the infiltration capacity is constant. If this equilibrium infiltration capacity is greater than the precipitation rate, then all of the water that reaches the ground will be absorbed into the soil (Fetter, 1994, p.47-49). Precipitation can therefore cause increases in groundwater levels because it can cause increases in storage.

Temperature affects groundwater levels because it determines the form of precipitation as well as the rate of evapotranspiration. The form of precipitation can affect how quickly recharge occurs. If precipitation falls as rain, recharge is relatively fast compared to snow. However, if precipitation falls as snow, and temperatures remain low, snow and ice accumulate and will not enter the groundwater system until they melt. This can cause a delay in recharge of the order of days to weeks. Frozen ground conditions may also limit recharge from rain, although some active infiltration will still occur in areas such as Halifax, where temperatures frequently fluctuate around 0°C.

Evapotranspiration is a mechanism for the mass transfer of water to the atmosphere by both free air evaporation and by the movement of water by plants from the ground to the atmosphere. This climatic effect plays a larger role during the warmer summer months (Fetter, 1994, p.32). While it can be measured using a lysimeter, it was not taken into account for the purposes of this study due to limited data.

2.2.2 Seasonal/Diurnal Effects

Nova Scotia has relatively distinct seasonal conditions that tend to impact groundwater levels. In late spring, snow that has accumulated over the winter melts, causing an increase in groundwater levels. In summer precipitation amounts are lower, evapotranspiration increases and pumping for irrigation purposes increases. For these reasons water levels tend to decrease and a recessional trend is observed throughout the summer. In late fall, precipitation increases, especially during the hurricane season, evapotranspiration decreases, and groundwater levels rise once again.

Diurnal variations may affect groundwater levels due to the differences in evapotranspiration during the day and night. If the water table is unconfined and close to the surface, decreases in water levels may occur due to the amount of water transferred out of the ground by plants and by evaporation. Maximum loss from the water table occurs when temperatures are highest, near midday (Todd, 1959, p.157). At night plants transfer little or no water and the levels rebound (Kruseman and de Ridder, 1994). Diurnal fluctuations become insignificant during the winter months when most plants are dormant (Todd, 1959, p.157).

2.2.3 External Loading Effects

External loading effects produce fluctuations in groundwater levels because they cause hydrostatic pressure changes in confined aquifers with elastic properties. The most common loading effects are changes in atmospheric pressure and changes in levels of bodies of water, such as oceans, lakes and rivers. Loading and unloading essentially deform the aquifer, causing changes in porosity, storage and groundwater levels. (Domenico and Schwartz, 1990, p.126).

Two types of changes in atmospheric pressure can affect water levels in groundwater: the rise and fall of the barometric pressure and gusts of wind.

Barometric pressure changes on unconfined aquifers are transferred directly to the aquifer and no water level fluctuation occurs in the well (Todd, 1959, p. 160). Wells in confined aquifers may experience significant fluctuations in water levels due to changes in barometric pressure. As air pressure rises, it pushes on the surface of the water in the well. Because the aquifer is elastic, and water is relatively incompressible, the water compensates by moving further into the aquifer and the water level in the well drops. The inverse also occurs - as the barometer falls, the water level rises (Davis et al., 1966, p.57). The barometric efficiency of an aquifer is the "measure of the competence of the overlying confined beds to resist pressure changes" (Todd, 1959, p.161). This means high values of barometric efficiency relate to thick, impermeable confining strata and low values relate to thinly confined aquifers. These values generally range from 20% to 75% (Todd, 1959, p.161).

The barometric efficiency (BE) can be calculated by using the following equation: $BE = (S_w \ / \ S_b) * 100$; where S_w is the change in water level and due to the change in barometric pressure S_b (US Dept. of the Interior, 1995). Values for S_w and for S_b must be in the same units, therefore barometric pressure must be converted to units of length. This can be done using a conversion table.

Storativity "is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head" (Fetter, 1994, p.116). The aquifer skeleton expands and contracts due to changes in pressure created by the head changes in a saturated zone. This is elasticity (Fetter, 1994, p.116). The compression of the aquifer skeleton due to a drop in head reduces effective porosity, expelling water and decreasing storage (Watson, 1995). According to Fetter, "specific storage is the amount of water per unit volume of a saturated formation that is stored or expelled from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head" (Fetter, 1994, p.116). The barometric efficiency can be related to storativity (S), specific storage (S_s), gravitational constant (g), density of the water (ρ_w), compressibility of the water (β), compressibility of the aquifer skeleton (α), the porosity (n), and the aquifer thickness (b) by a series of equations:

$$S = S_s b \qquad (1) \quad \text{(Fetter, 1994)}$$

$$S_s = \rho_w g (\alpha + n\beta) \qquad (2) \quad \text{(Fetter, 1994)}$$

$$BE = \frac{n\beta}{\alpha + n\beta} \qquad (3)$$

$$BE = \frac{\rho_w g n\beta}{S_s} \qquad (4)$$

$$BE = \frac{\rho_w g n\beta b}{S} \qquad (5)$$

Strong winds gusting over the top of the well may cause minor, short term fluctuations in water levels. Low pressure is created in the well as the high-speed air passes over it, resulting in a rise in water level. As the gust of wind ebbs, the atmospheric pressure increases again and the water level lowers (Todd, 1959, p.162).

For a small province Nova Scotia has a relatively long coastline, all of it exposed to tides. This means that many coastal aquifers experience daily loading and unloading due to high and low tides. As the ocean level rises during a high or flood tide, a greater load is placed on the aquifer forcing the groundwater levels to rise. The reverse is true during ebb tide. This effect is magnified during storms when onshore winds cause temporary sea level rise (Davis et al., 1966, p.57) or "piling up" of the water, especially during spring high tides. This effect lessens with distance from the coast (Fetter, 1994, p.376). Tidal efficiency (TE) of the aquifer is "the ratio of piezometric level amplitude to tidal amplitude" (Todd, 1959, p.165) and it can also be related to specific storage (S_s), gravity (g), density of the water

(ρ_w), compressibility of the water (β), compressibility of the aquifer skeleton (α) and the porosity (n) by the equations:

$$TE = \frac{\alpha}{\alpha + n\beta} \qquad (6)$$

$$TE = \frac{\rho_w g \alpha}{S_s} \qquad (7)$$

Tidal efficiency can also be related to barometric efficiency by the equation:

$$TE = 1 - BE \quad \text{(Todd, 1959, p.165)} \qquad (8)$$

Tidal efficiency and barometric efficiency are constant for a given aquifer since the compressibility of water (β) is constant at a constant temperature, and compressibility of the aquifer skeleton (α) and porosity (n) are properties of the aquifer materials. Values for the compressibility of the aquifer skeleton (α) differ for different earth material and are available from Table 5.

Table 5 - Vertical Compressibility Coefficients (α) of Various Earth Materials

Vertical compressibility (α)

Material	**ft^2/lb**	**m^2/N**	**bars^{-1}**
Plastic clay	1x10e-4 to 1.25x10e-5	2x10e-6 to 2.6x10e-7	2.12x10e-1 to 2.65x10e-2
Stiff clay	1.25x10e-5 to 6.25x10e-6	2.6x10e-7 to 1.3x10e-7	2.65x10e-2 to 1.29x10e-2
Medium-hard clay	6.25x10e-6 to 3.3x10e-6	1.3x10e-7 to 6.9x10e-8	1.29x10e-2 to 7.05x10e-3
Loose sand	5x10e-6 to 2.5x10e-6	1x10e-7 to 5.2x10e-8	1.06x10e-2 to 5.3x10e-3
Dense sand	1x10e-6 to 6.25x10e-7	2x10e-8 to 1.3x10e-8	2.12x10e-3 to 1.32x10e-3
Dense, sandy gravel	5x10e-7 to 2.5x10e-7	1x10e-8 to 5.2x10e-9	1.06x10e-3 to 5.3x10e-4
Rock, fissured	3.3x10e-7 to 1.6x10e-8	6.9x10e-10 to 3.3x10e-10	7.05x10e-4 to 3.24x10e-5
Rock, sound	less than 1.6x10e-8	less than 3.3x10e-10	less than 3.24x10e-5
Water at 25°C (β)	2.3x10e-8	4.8x10e-10	5x10e-5

(Domenico and Schwartz, 1990, p. 111)

2.2.4 Anthropogenic Effects

Water is pumped from wells for domestic, municipal, industrial and agricultural purposes. These requirements increase during the summer months, especially because of irrigation. While most natural changes produce gradual changes in groundwater levels, anthropogenic effects may be more rapid. Rapid fluctuations of groundwater levels through vertical distances are primarily in response to water removal from an aquifer by pumping (Davis et al., 1966, p.56). The decrease of water level, or drawdown, occurs around the well and causes a cone of depression to form. The amount of drawdown and the effect on water level that occurs with pumping depends on pumping rate, recharge rate, and aquifer properties. If pumping of water from a coastal aquifer produces a cone of depression that is too deep, salt-water encroachment may result.

The injection of water/fluid into the ground is not as common as pumping, but it is done for a variety of reasons, and may also affect groundwater levels. For instance, wastewater may be injected into isolated aquifers for disposal, or water may be injected into an aquifer as artificial recharge in an attempt to manage groundwater levels. Injection has the opposite effect on groundwater levels to pumping. Instead of lowering the water levels, it increases them (Fetter, 1994, p.197).

2.2.5 Other Effects

Some other effects that may cause groundwater fluctuations are earth tides, earthquakes and external loading by nearby trains. These effects will not be considered in this study, but are mentioned for interest's sake.

In regions that are far inland, small fluctuations in groundwater have been found to correspond with the cycles of the moon. These fluctuations are due to earth tides, which occur due to the attraction of the earth's crust towards the moon (Todd, 1959, p.168-169). These effects are generally small (< 0.1 foot amplitude) and will not significantly affect the results of this study due to other larger effects arising from proximity to the coast.

Earthquakes also have an effect on groundwater. As the earthquake waves propagate through the ground, aquifers expand and contract, causing fluctuations in the groundwater levels. This may have many effects, such as the sudden rising and falling of water in wells or the cessation or production of springs (Todd, 1959, p.170-171). While this is not of major concern in Nova Scotia, the possibility exists.

Wells located near passing trains may experience fluctuations due to changes in external load. Because of the elastic properties of an aquifer, the weight of the train causes a load change, compresses the aquifer skeleton and causes hydrostatic pressure to increases as the train approaches or stops nearby. Water level in the affected well nearby rises due to the compression of the aquifer skeleton. The reverse is true when the load is removed, as the train starts up and moves away. Hydrostatic pressure decreases after the train passes and the water level in the well falls below its normal level. After the initial decrease, the pressure recovers, fluctuating back and forth until the normal value is reached (Todd, 1959, p.169-170). There are no railway lines near the sites selected for this study.

Chapter 3: Site Selection & Methodology

This study focuses on sites that were selected for a variety of reasons, and while there are only three sites due to the limited scope of this report, it is hoped that together they offer some indication of the trends and fluctuations of groundwater in Nova Scotia.

3.1 Site 1 - Lawrencetown - Halifax County

The Lawrencetown site was selected to be representative of a crystalline rock environment on the Atlantic shore. Long term data is available from the Department of the Environment for this site, and the site is easily accessible from Halifax. Its proximity to the ocean (150 ft or 50 m) allows the study of tidal effects on groundwater levels.

3.2 Site 2 - McNabs Island - Halifax County

The McNabs Island site was selected because it provides an opportunity to study variations in shallow groundwater levels in a glacial till environment. The surficial geology and dug well at the McNabs Island site contrast the bedrock geology and drilled wells of the Lawrencetown and Durham sites. Short term records were made available by Gavin Manson of the Bedford Institute of Oceanography.

3.3 Site 3 - Durham - Pictou County

The Durham site was selected because it is representative of a sedimentary rock environment on the Northumberland shore. The site is geologically and geographically different from the Lawrencetown site. Long term data was available from Nova Scotia Department of the Environment. Tidal affects are not noticeable here since the site is located approximately 3.5 km inland, and the site is located on a farm.

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3.4 Data Processing and Manipulation

3.4.1 Water Level Data

Most data for the Lawrencetown site and all data for the Durham site were collected from the Nova Scotia Department of the Environment in the form of drum recorder charts. For the purpose of this thesis, an attempt to digitize this data was made; however, software limitations necessitated manual digitizing. Daily maximum and minimum readings were therefore manually extracted from the charts and then entered into a spreadsheet. Once the data was in digital format, the numbers could be manipulated and daily, monthly and yearly averages were tabulated and graphed. These numbers represent distance from the top of the well casing to the water surface in feet (1 foot = 0.3048 m). All water level data for Lawrencetown and Durham were recorded in feet, and due to the large amounts of data, conversions to metric were not made. The remaining data for the Lawrencetown site (October, 1998 to January, 2000) were collected from the Nova Scotia Department of the Environment in digital format with hourly readings, also in feet. These hourly readings were averaged to obtain daily, monthly and yearly averages.

Hourly water level data for the McNabs Island site were obtained in digital format from a study conducted by Gavin Manson of the Bedford Institute of Oceanography. Water level readings are in metres for this well.

3.4.2 Tidal Data

A tide gauge was installed by the Canadian Hydrographic Service in the Cole Harbour Estuary near the Lawrencetown site between December 9, 1999 and January 10, 2000. This tidal data set, compared to the Halifax Harbour tidal data set obtained from the Bedford Institute of Oceanography, enables the calculation of the time lag and amplitude attenuation of tides in the Cole Harbour Estuary. Tidal cycles between December 26 to 29, 1999 were studied for this purpose (Figure 12). Table 6 shows the amplitude ratio of Halifax Harbour tidal cycles to the Cole Harbour estuary tidal cycles as 0.60. Table 7 shows the time lag in the estuary as 1 hour 55 minutes at peaks and 2 hours and 53 minutes at troughs.

With this Cole Harbour estuary tidal data, it is now possible to correct Halifax Harbour tidal data, which is readily available, and correlate the Lawrencetown well data and estuary tidal data for longer periods of time. In order to compare water level fluctuations to tidal fluctuations, a period of relatively stable water level is required. Tidal cycles then have to be phase shifted to match tidal peaks and troughs with water level peaks and troughs (Figure 13). Comparisons can now be made, including the ratio of tidal amplitude to water level amplitude, in order to determine tidal efficiency of the aquifer.

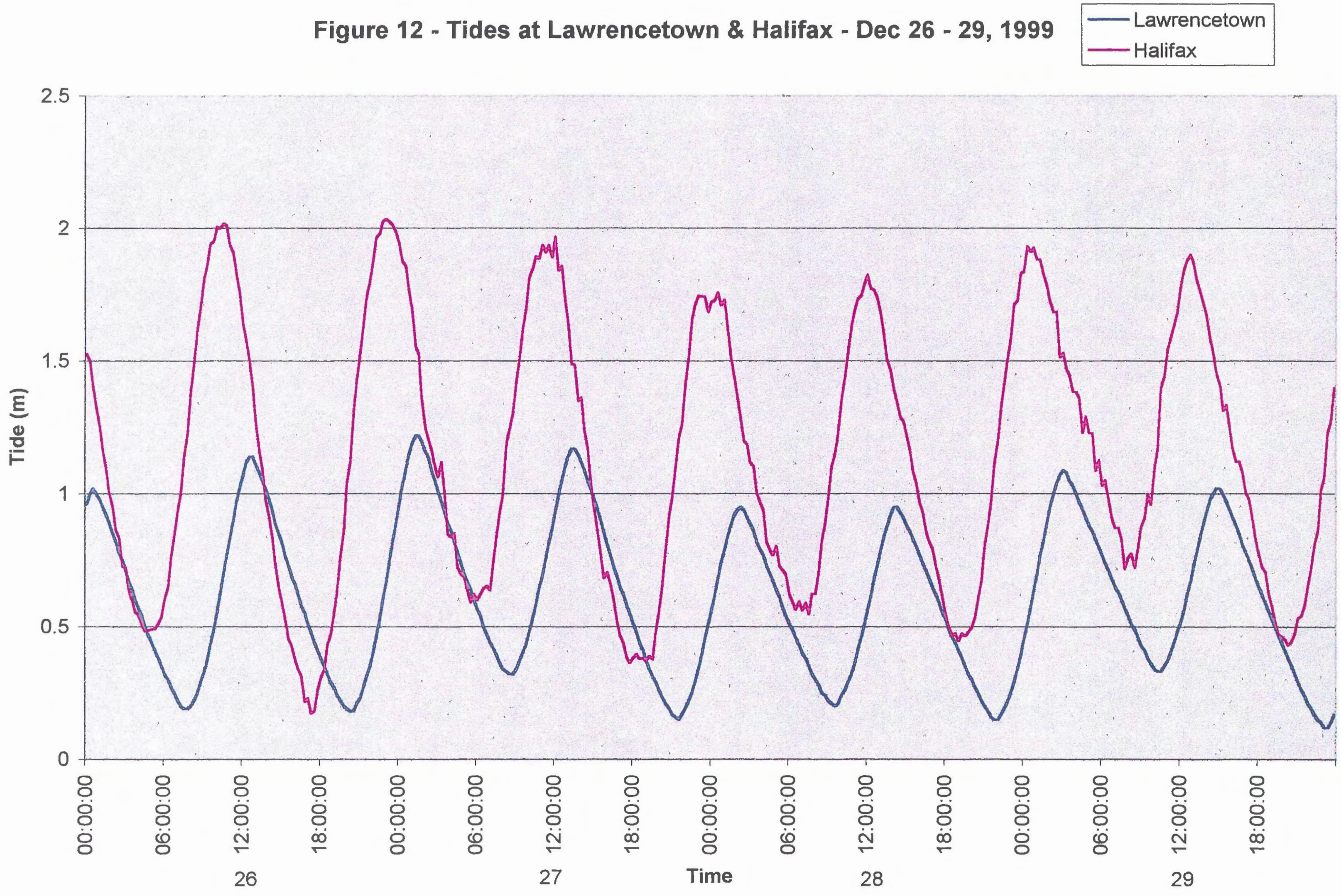


Figure 12 - Tides at Lawrencetown & Halifax - Dec 26 - 29, 1999

Table 6 - Amplitude Ratio of Halifax Tides to Lawrencetown Tides

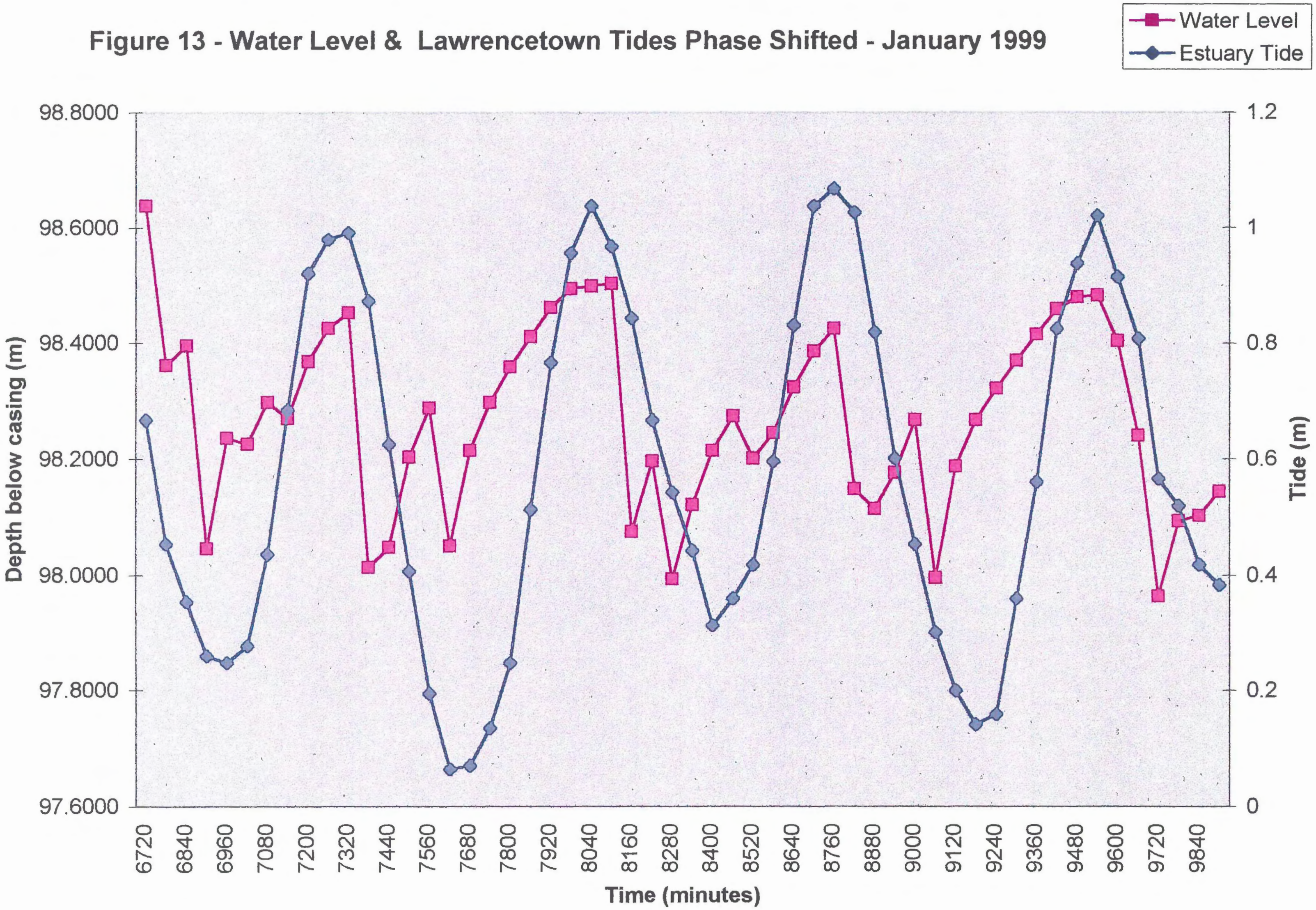
Peak -H	Trough - H	Amp - H	Peak - L	Trough - L	Amp - L
2.011	0.484	1.53	1.14	0.19	0.95
2.025	0.175	1.85	1.22	0.18	1.04
1.969	0.593	1.38	1.17	0.32	0.85
1.759	0.364	1.40	0.95	0.15	0.8
1.825	0.547	1.28	0.95	0.2	0.75
1.932	0.466	1.47	1.09	0.15	0.94
1.901	0.719	1.18	1.02	0.33	0.69
Average	Amp H	= 1.44	Average	Amp L	= 0.86

Ratio
0.60

Table 7 - Time Lag of Lawrencetown Tides Compared to Halifax Tides

	Time Lag	
Peaks	1:45	
	2:00	
	1:15	
	1:45	
	2:00	
	2:45	
	2:00	Avg P 1:55
Troughs	3:00	
	3:00	
	3:00	
	4:00	
	2:00	
	2:15	
	3:00	Avg T 2:53
Avg total	2:24	

Figure 13 - Water Level & Lawrencetown Tides Phase Shifted - January 1999



3.4.3 Climatic Data

Climatic data was purchased from Environment Canada in digital format, including precipitation, temperature, and barometric pressure. Yearly and daily average of total precipitation data were graphed and compared to yearly and daily average water levels for Lawrencetown and Durham. Daily averages of total precipitation data were graphed and compared to daily average water levels for McNabs Island. Daily average temperatures were graphed and compared to daily average water levels at all three sites. Hourly barometric pressure data was compared to hourly water level data at the Lawrencetown and McNabs Island sites. This comparison included the ratio of barometric pressure change to water level change in order to determine barometric efficiency of the aquifer. At the Durham site, hourly water level data was not available and barometric efficiency was therefore not considered.

3.4.4 Missing Data

Missing water level data from the chart recorders occurred for a number of reasons. Some data are missing due to equipment malfunctions such as the pen running out of ink or sticking; the float becoming caught up on the side of the well; the tape slipping off of the pulley; the clock stopping; or the tape falling off into the well. Other problems causing missing data included high humidity, causing the pen to blur or the chart to slip on the drum; high winds, causing the building to blow over and exposing the equipment; and low temperatures, causing the water to freeze. A large amount of data were missed because charts were not changed within the proper time period. Vandalism at the Lawrencetown site also resulted in missing data. Dr. Wade Blanchard, a Statistical Consultant at the Dalhousie University Math Department was consulted on how best to deal statistically with missing data. Due to the scope of the problem, it was suggested that an assessment of correlation be made visually from graphed data. As a result, water level data, tidal data and climatic data were graphed and visually correlated. It should be noted that correlation coefficients have been included on graphs containing long term data; however, the these correlation coefficients are not all considered significant and analyses were made visually only, not mathematically.

The data logger at the Lawrencetown site appears to have been producing anomalous data since May 1999. Any data after this time is considered unusable. The manufacturer is currently examining the data logger. Until this study, it was not known that there was a problem with the instrument.

Due to problems with equipment, measurements from the Halifax tide gauge could not be obtained for the entire month that the tide gauge was installed at the Lawrencetown site. There are therefore only three weeks of overlapping data from which tidal calculations could be made, that is from December 20, 1999 to January 10, 2000.

Chapter 4: Discussion of Results

4.1 Lawrencetown

Figure 14 suggests that water levels from 1978 to 1989 at the Lawrencetown site were rising slightly. This data projected to 1999 fits the average calculated from the data logger. However, missing data throughout the 1990s and anomalous readings by the data logger, which has been in use since 1998, make it implausible to reach conclusions about water levels over the past 10 years.

Figure 15 and Appendix I indicate that a seasonal trend is present, with the lowest water levels occurring in the late summer/ fall, between August and October. This corresponds with the typical water year of the Maritime Provinces, assumed to run from October 1 to September 30, with the lowest water levels at the start and at the end of the year. An exception occurred in 1999 due to data logger malfunction that produced anomalous peaks starting in May.

Figure 16 generally suggests a correlation between water level and precipitation. Both show slight, overall increases from 1978 to 1989, and both increase/decrease over the same time period. An exception occurs in 1980 to 1981 when water levels are especially low. In order to show this direct relationship on a smaller scale, one year was selected for study. Daily averages of water levels and daily averages of total precipitation for 1983 were plotted together in Figure 17 to demonstrate that water level increases with precipitation within a relatively short time period. Decreases in water levels are apparent during times of little/no precipitation. This indicates that recharge occurs quickly at the Lawrencetown site.

Figure 14 - Yearly Average of Water Level at Lawrencetown

Gaps in graph indicate missing or unusable data

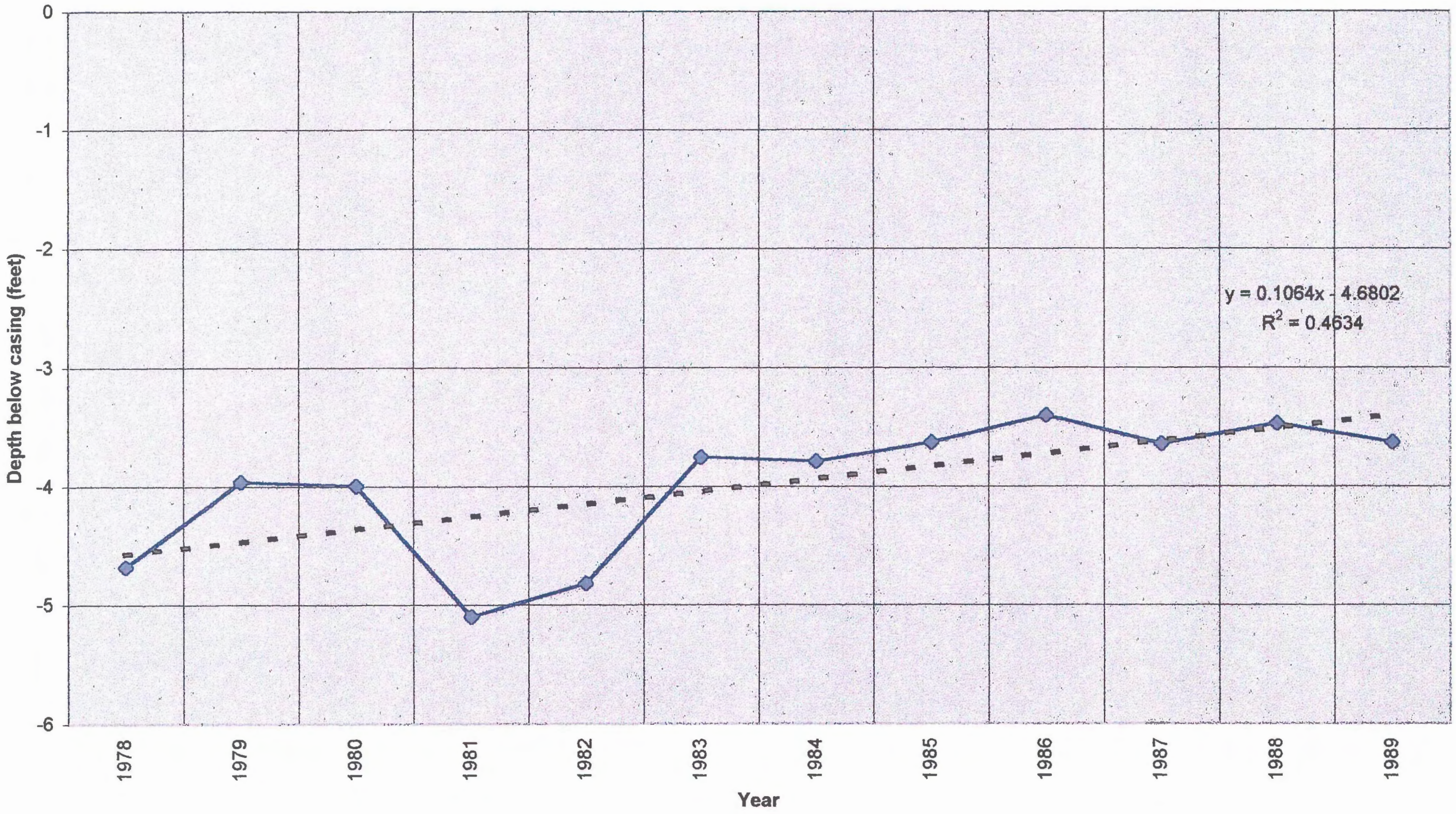
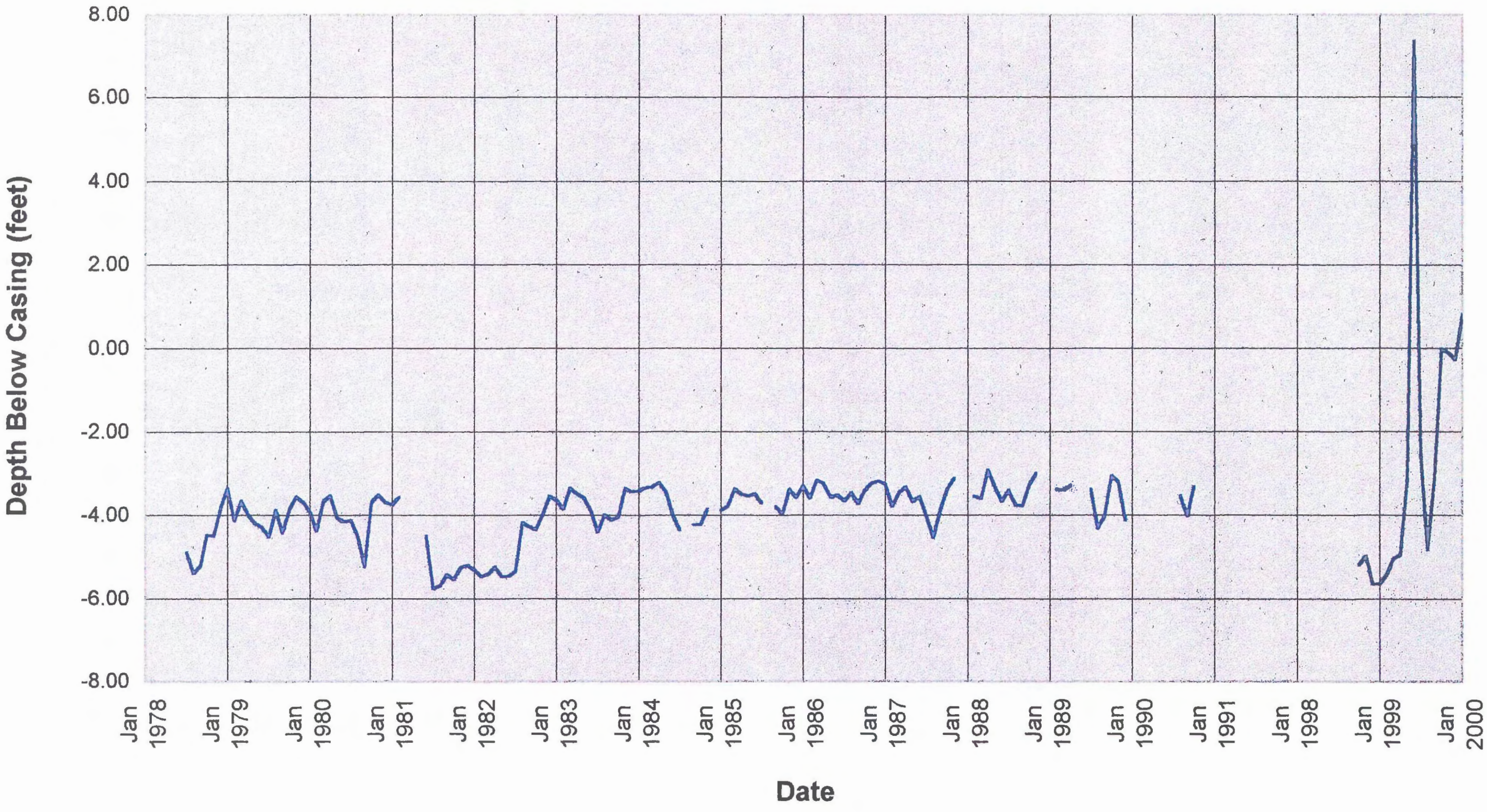


Figure 15 - Monthly Average of Water Level at Lawrencetown

Gaps in graph indicate missing or unusable data



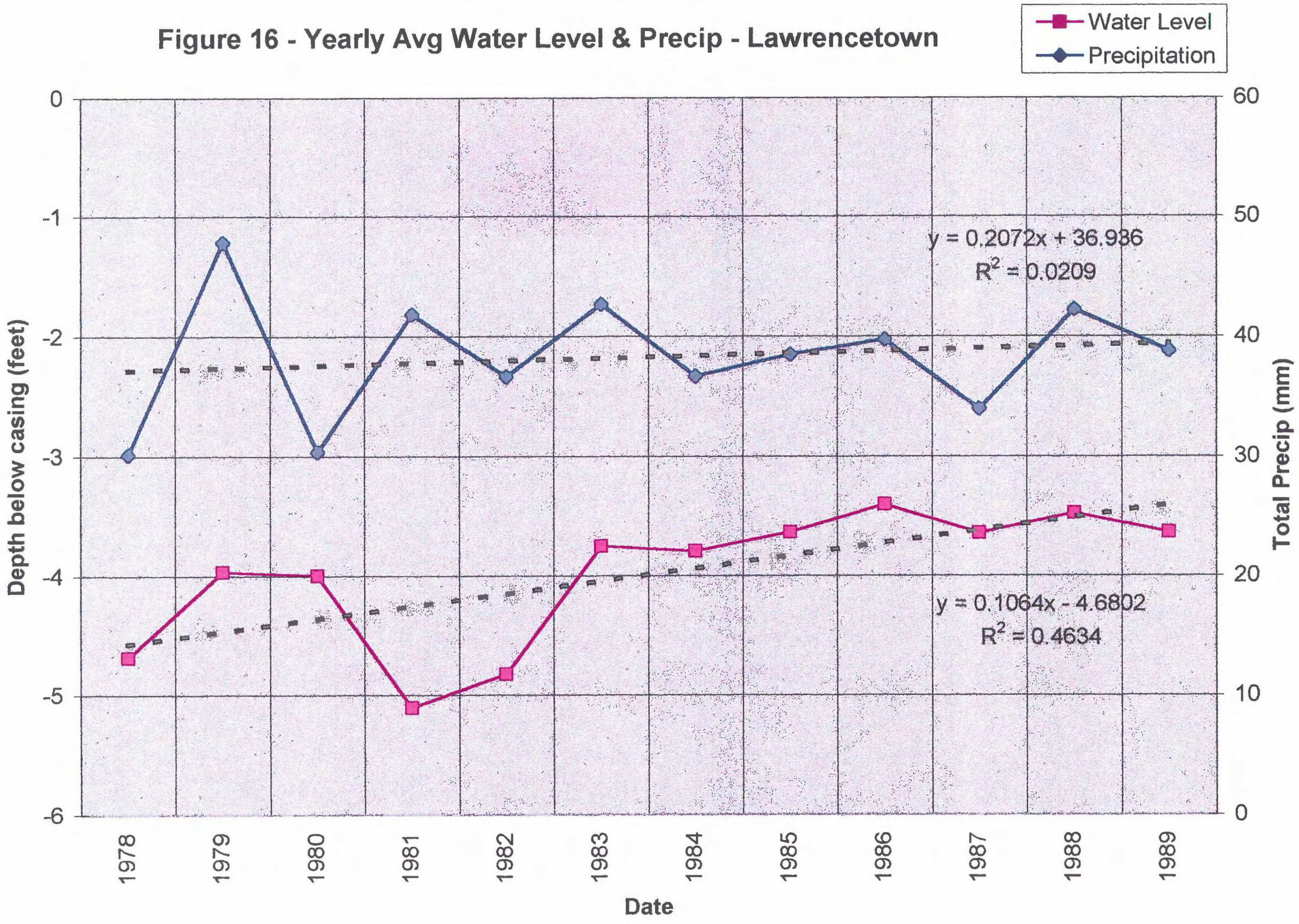
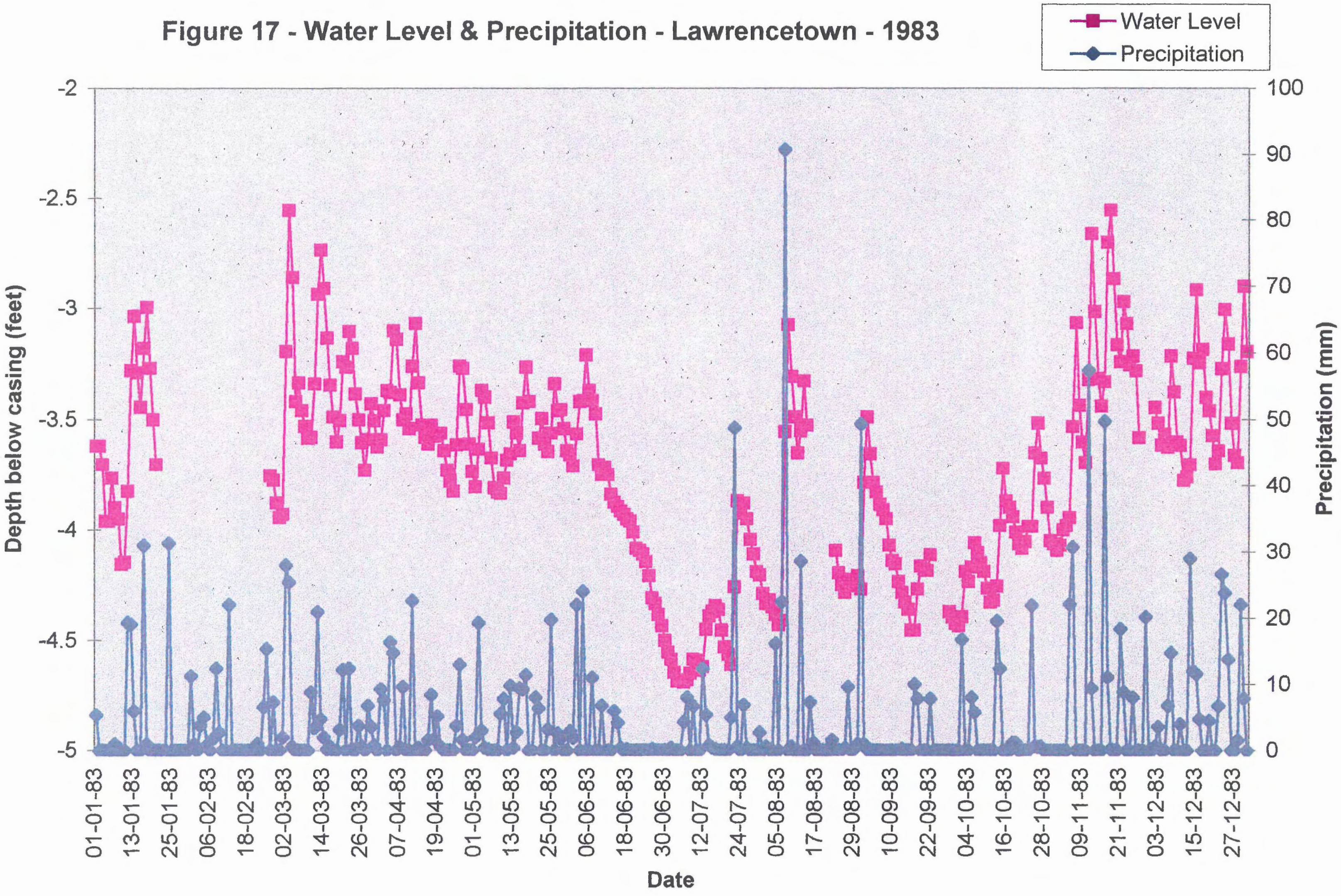


Figure 16 - Yearly Avg Water Level & Precip - Lawrencetown

Figure 17 - Water Level & Precipitation - Lawrencetown - 1983



Temperature appears to have an inverse relationship with water levels at Lawrencetown (Figure 18). As temperatures rise over the summer months, water levels decrease. This effect may be due to the increase in evapotranspiration and the decrease in precipitation during the warmer months. Conversely, as temperatures fall, water levels increase. This effect may be due to the decrease of evapotranspiration and increase of precipitation in the colder months.

Barometric pressure does not have a large effect on water levels at Lawrencetown. Hourly water levels and hourly barometric pressure readings plotted in Figure 19 indicate little or no correlation. This is supported by the low barometric efficiency, calculated as 0.13 (Figure 20). Also water levels corrected for barometric pressure show very little change (Figure 21). The fact that this effect is minimal at Lawrencetown may be due to the fact that the coefficient of vertical compressibility of the aquifer skeleton is relatively low for fissured rock (Table 5).

The water levels at the Lawrencetown site are heavily influenced by tides. Figure 22 shows that water levels fluctuate in a cyclical pattern associated with tidal cycles. As the tides flood the Cole Harbour estuary, the rise in sea level increases the external loading on the aquifer. This compresses the aquifer skeleton and forces the groundwater upwards. As the tide ebbs, the load on the aquifer decreases and the groundwater levels fall. The tidal efficiency at Lawrencetown was found to be 0.75 (Figure 23) and water levels corrected for tidal effect are not completely without tidal influence (Figure 22). The reasons for this are not fully understood. However, load transmission effects are such that the shapes of the

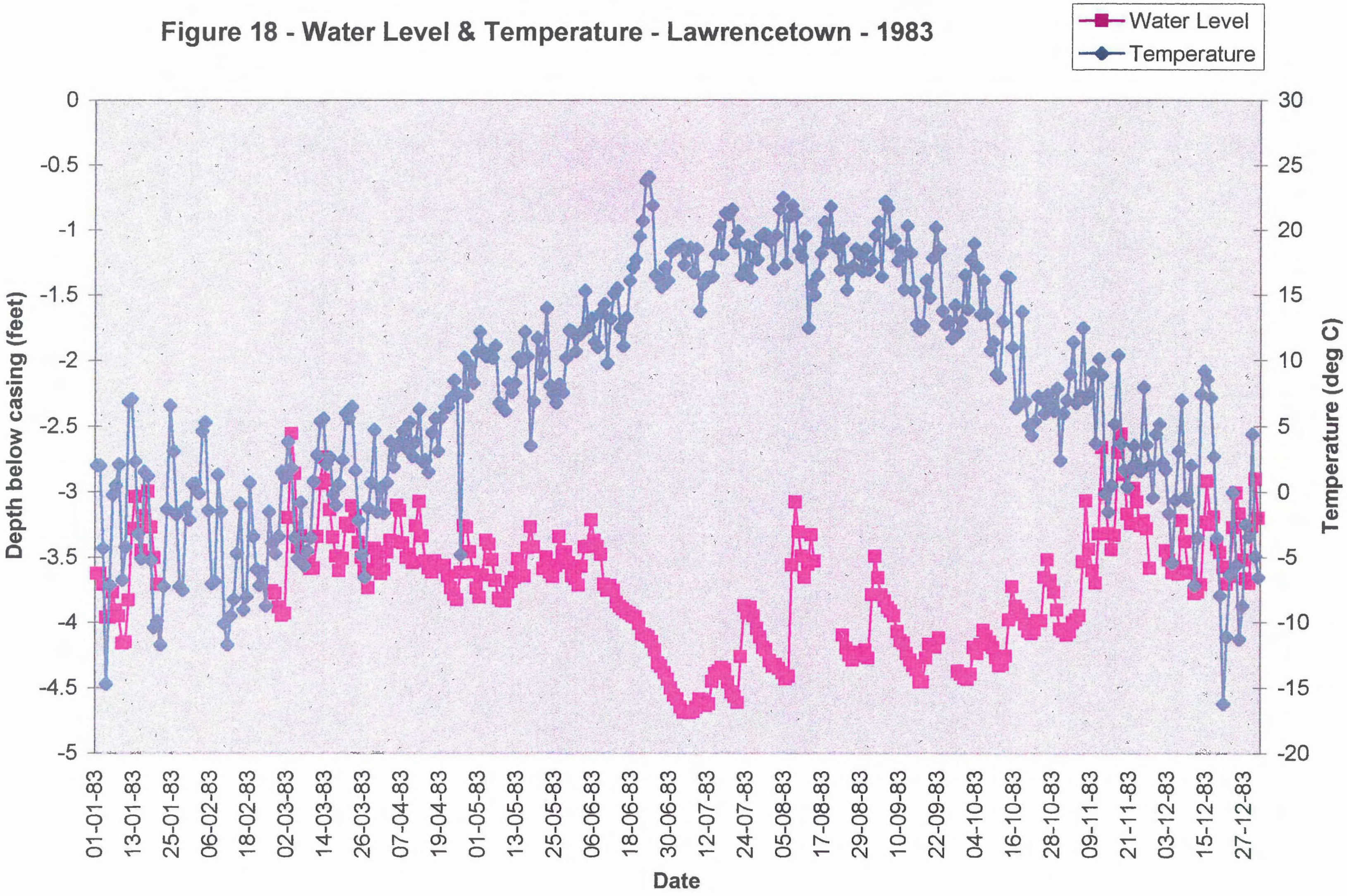


Figure 18 - Water Level & Temperature - Lawrencetown - 1983

Figure 19 - Hourly Water Level & Pressure - Lawrencetown Jan 1, 1999

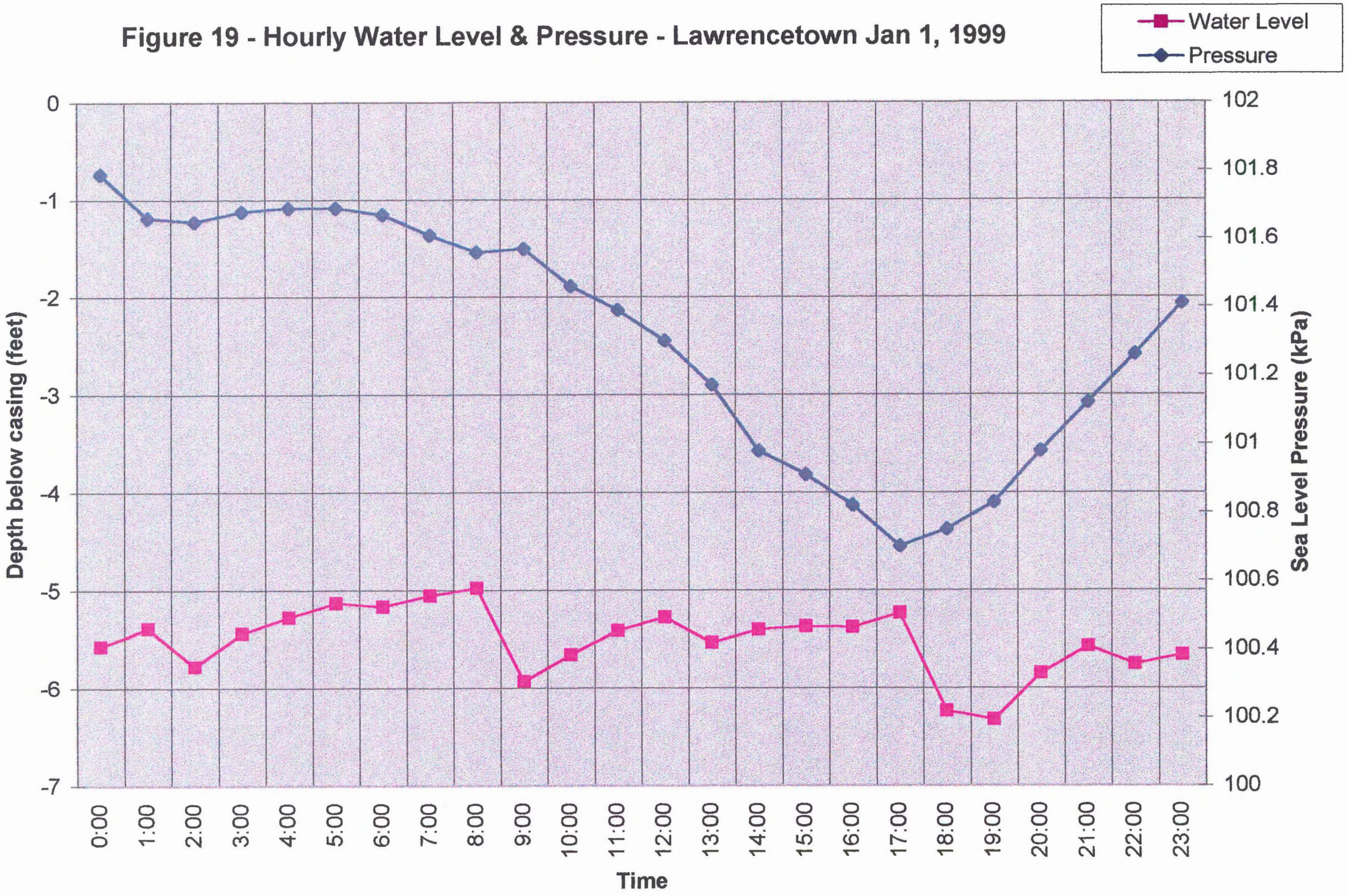


Figure 20 - Barometric Efficiency

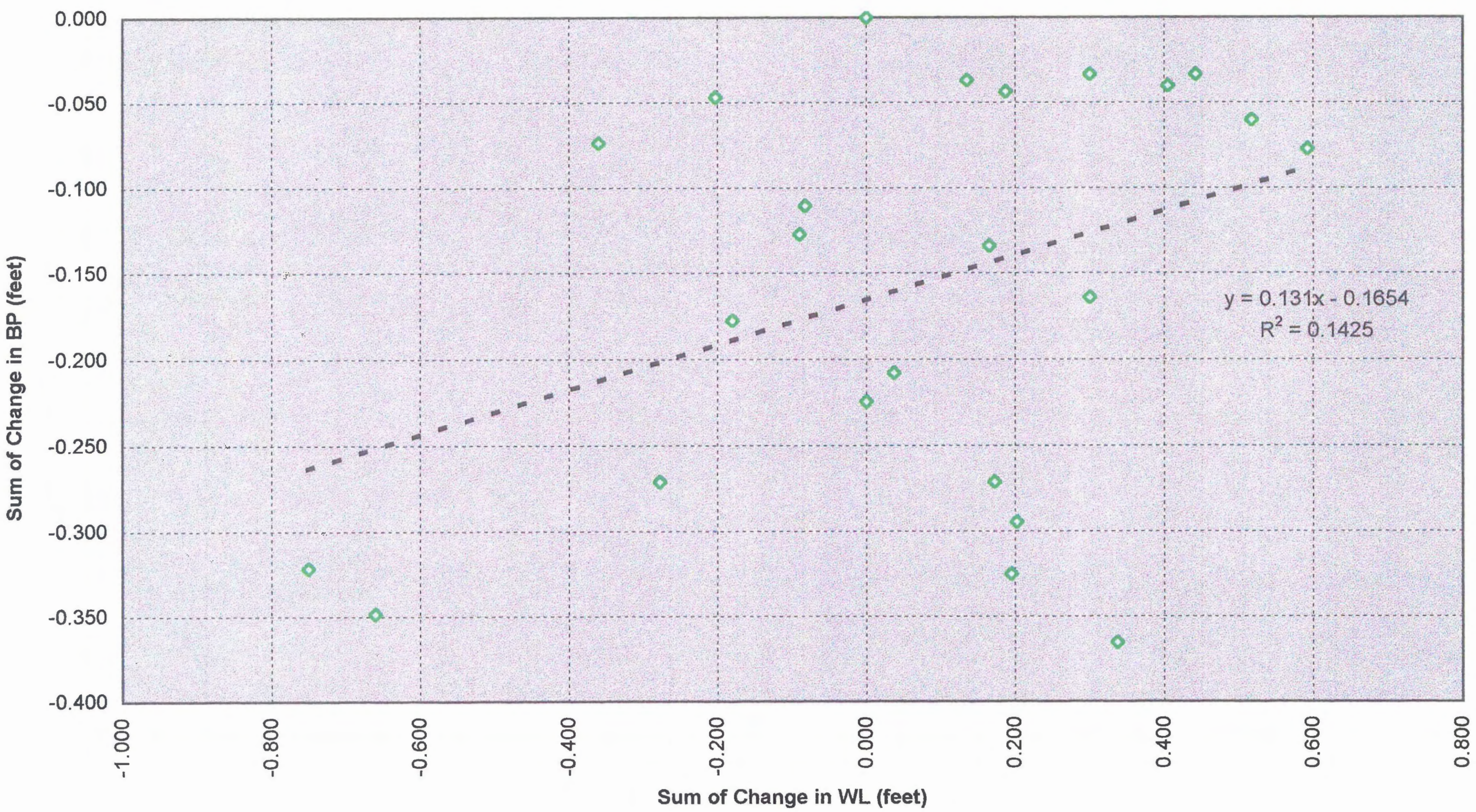
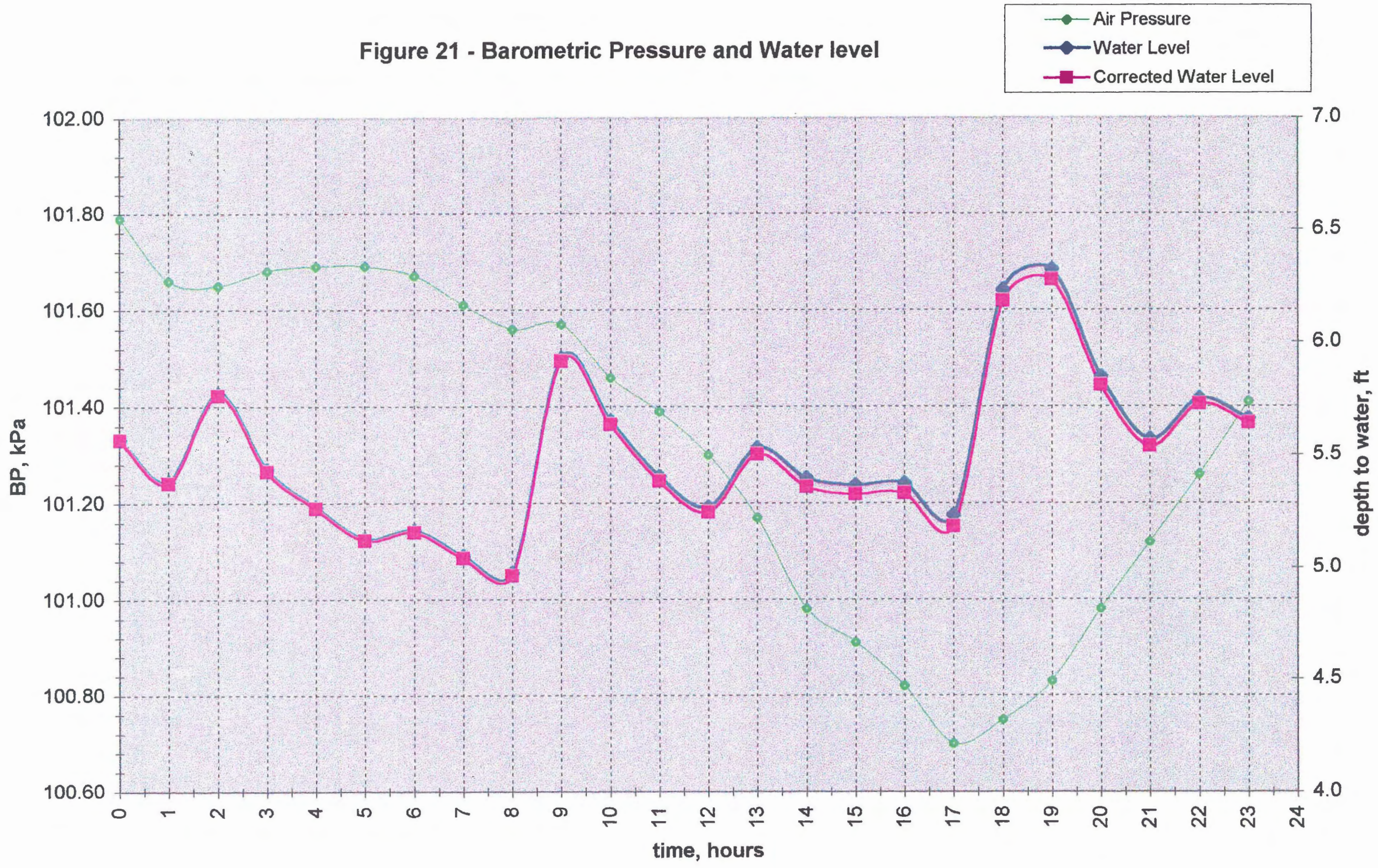


Figure 21 - Barometric Pressure and Water level



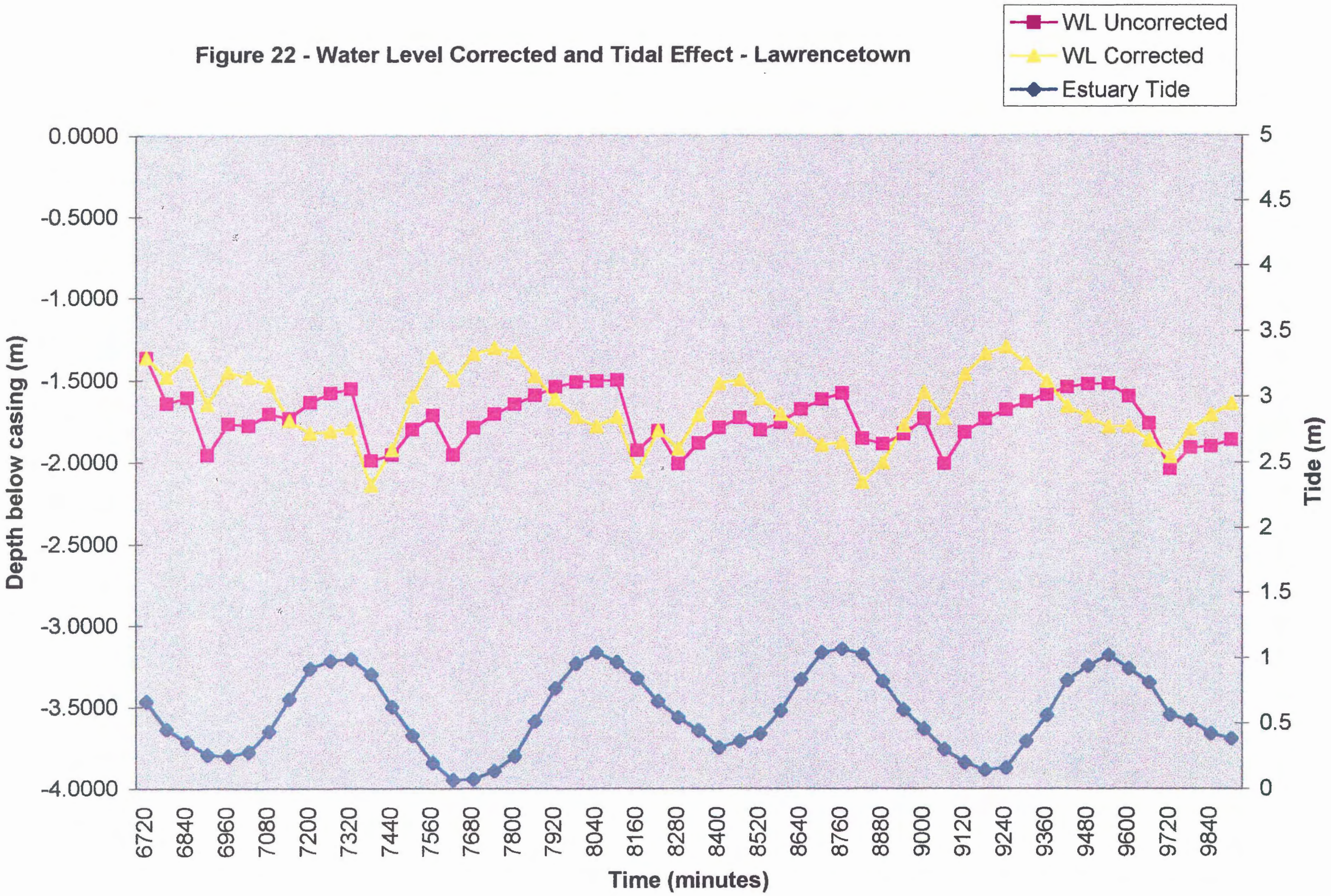
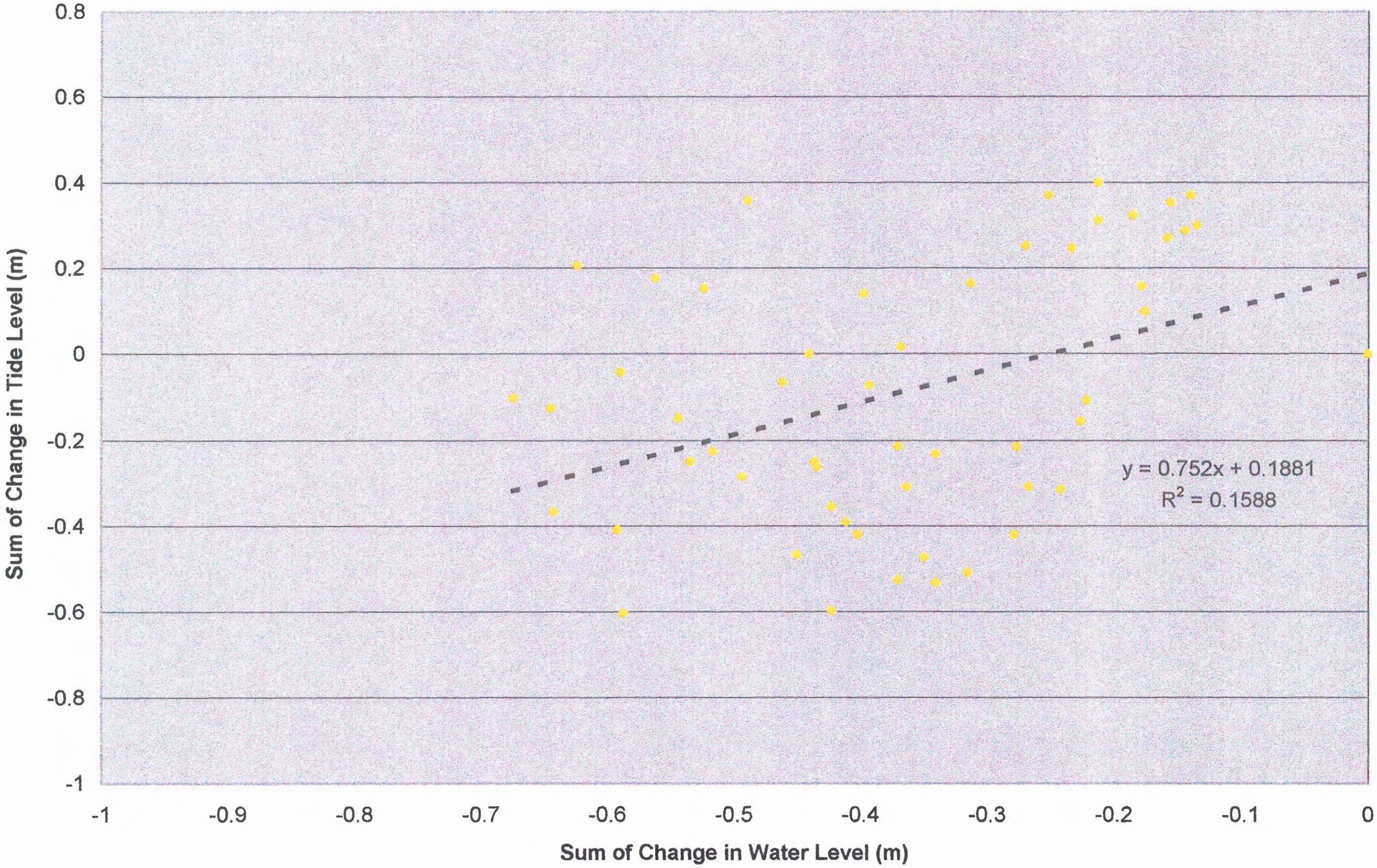


Figure 22 - Water Level Corrected and Tidal Effect - Lawrencetown

Figure 23 - Tidal Efficiency



water level curves are not exactly the same as the shapes of the tidal curves, and also secondary peaks are present in the water level data. These effects produce low correlation coefficients in both the barometric and tidal efficiency determinations.

Theoretically, the sum of the tidal efficiency and the barometric efficiency should be 1. In this case 0.75 + 0.13 only add up to 0.88 due to data scatter.

The equations discussed in Section 2.2.3 can be used to relate storativity to barometric efficiency.

By rearranging Equation (5), storativity can be calculated:

$$(5)\qquad BE = \frac{\rho_w gn\beta b}{S} \quad \text{and} \quad S = \frac{\rho_w gn\beta b}{BE} \quad \text{and if}$$

$\rho_w = 1000\ g/m^3$
$g = 9.8\ m/s^2$
$n = 0.05$ (fractured bedrock)
$\beta = 4.8*10e\text{-}10\ m^2/N$
$b = 8.8\ m$
$BE = 0.13$

$$\text{then}\qquad S = (1000\ kg/m^3)(9.8\ m/s^2)(0.05)(4.8*10e\text{-}10)(8.8m)/0.13 = 1.6*10e\text{-}5$$

This value (1.6*10e-5) is within the order of magnitude for storativity in confined aquifers (e10-3 to e10-5). It is also within the range of storativity values calculated from pump tests by the Nova Scotia Department of the Environment, which found the following values in the Meguma Group in Halifax County: 3.0*10e-4, 3*10e-6, and 8.5*10e-5, and from granites: 5*10e-4 and 5*10e-5.

The compressibility can be determined by using the results from Equation (5) and by rearranging Equations (1) and (2).

(1) $S = S_s b$ (2) $S_s = \rho_w g (\alpha + n\beta)$

multiply both sides of (2) by b: $S_s b = S = \rho_w gb(\alpha + n\beta)$

substitute (1) into (2) $(\alpha + n\beta) = \frac{S}{\rho_w gb}$

$$\alpha = \frac{S}{\rho_w gb} - n\beta$$

$$\alpha = \frac{1.6*10e\text{-}5}{(9.8\ m/s^2)(1000\ kg/m^3)(8.8m)} - (0.05)(4.8*10e\text{-}10m\ ^2/N)$$

$$\alpha = 1.6*10e\text{-}10\ m^2/N$$

This value for aquifer compressibility (1.6*10e-10 m^2/N) is within the order of magnitude for fissured rock, according to Table 5 on page 25.

Equations discussed in Section 2.2.3 can be used to relate storativity to tidal efficiency. Storativity can be calculated by rearranging Equation (7) and substituting Equation (1):

(7) $TE = \frac{\rho_w g\, \alpha}{S_s}$ and $S_s = \frac{\rho_w g\, \alpha}{TE}$ and if

$\rho_w = 1000\ kg/m^3$
$g = 9.8\ m/s^2$
$\alpha = 1.6*10e\text{-}10\ m^2/N$
$TE = 0.75$

then $S_s = (1000\ kg/m^3)(9.8\ m/s^2)(1.6*10e\text{-}10\ m^2/N) / 0.75 = 2.1*e10\text{-}6\ m^{-1}$

substitute (1) $S = (2.1*e10\text{-}6\ m^{-1})(8.8m) = 1.8*e\text{-}5$

The values for storativity calculated by tidal efficiency (1.8*e-5) and barometric efficiency (1.6*10e-5) are essentially the same within the uncertainties.

4.2 McNabs Island

Over the monitoring period of approximately six months, the water level at McNabs Island appeared to increase slightly overall (Figure 24). The increase from November to January is consistent with the 'fall rise', or the expected seasonal trend for this period in the water year. Because the monitoring period does not include the time of year when low levels typically occur, there are no major trends indicating a decrease in water levels. Daily averages of water levels in Figure 25 show that levels fluctuated often, increasing and decreasing by 20 cm to 30 cm every few days. The reason for these fluctuations is not known. It is known that pumping did not occur at the well during the monitoring period because it is out of use due to poor water quality.

Water levels do not correlate well with precipitation at the McNabs Island site (Figure 26). According to Manson (1999), this lack of correlation is due to a delay in precipitation entering the groundwater flow and reaching the monitoring well, and also due to delayed runoff when precipitation fell as snow.

Water levels generally have an inverse relationship with temperature at the McNabs Island Site (Figure 27). As previously discussed in Section 4.1, temperatures fall and water levels increase.

Tidal fluctuations do not correlate with water level fluctuations at the McNabs Island site (Figure 28). Tidal effect was not expected at this site because the well is topographically considerably above sea level elevation and is constructed in surficial materials.

Figure 24 - Monthly Average Water Level - McNabs Island - Nov 98 to May 99

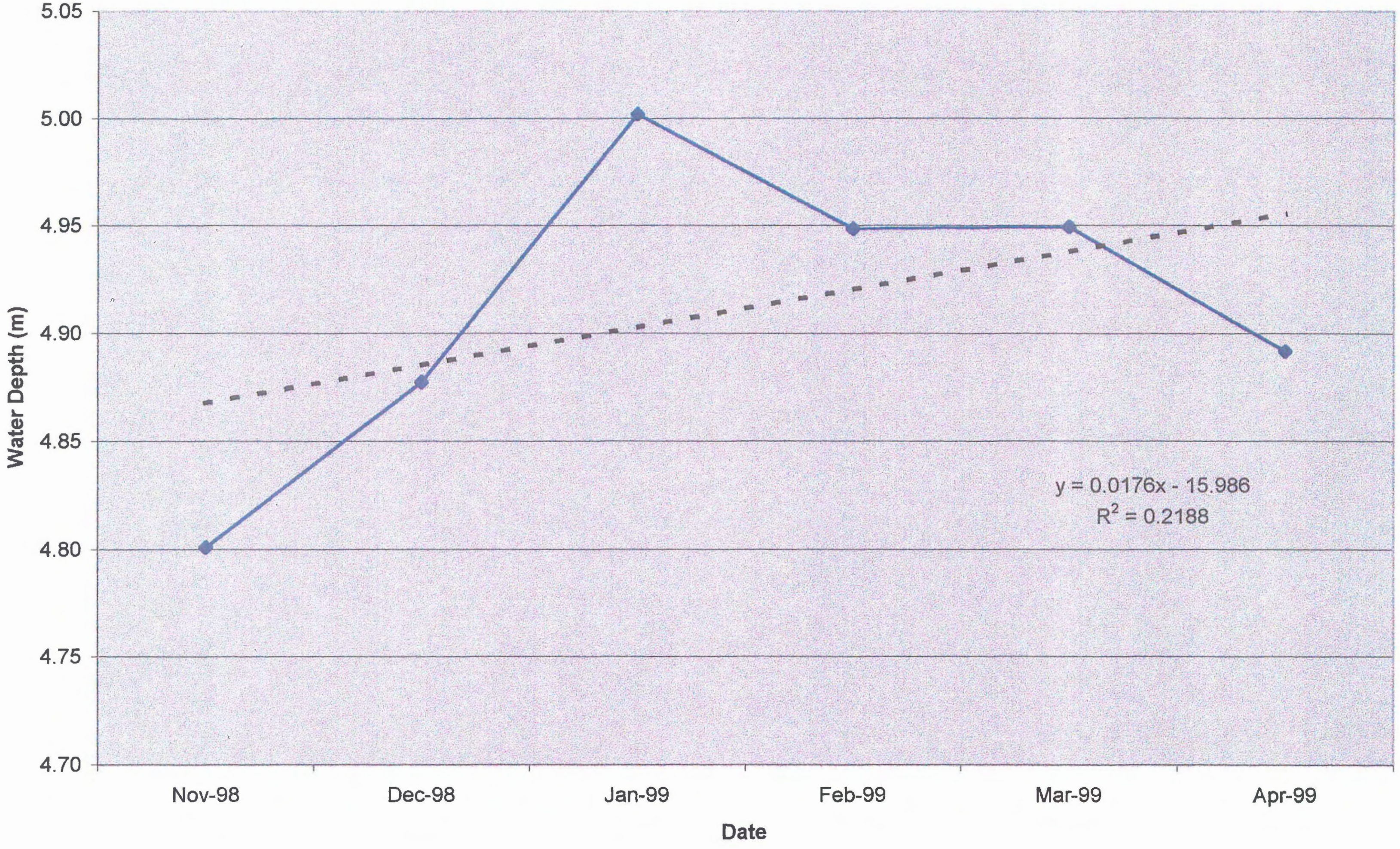
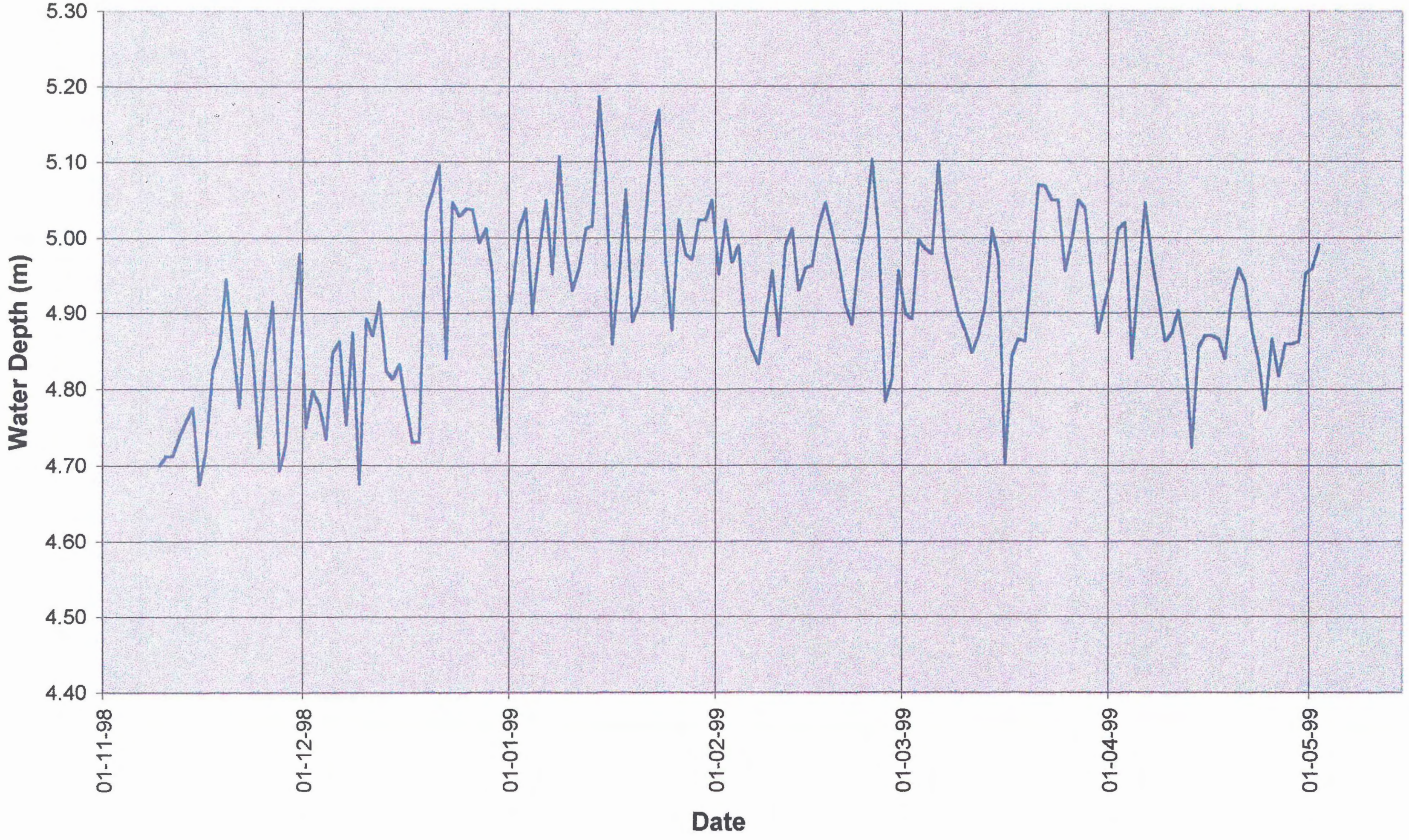


Figure 25 - Daily Average Water Level - McNabs Island - Nov 9, 1998 to May 2, 1999



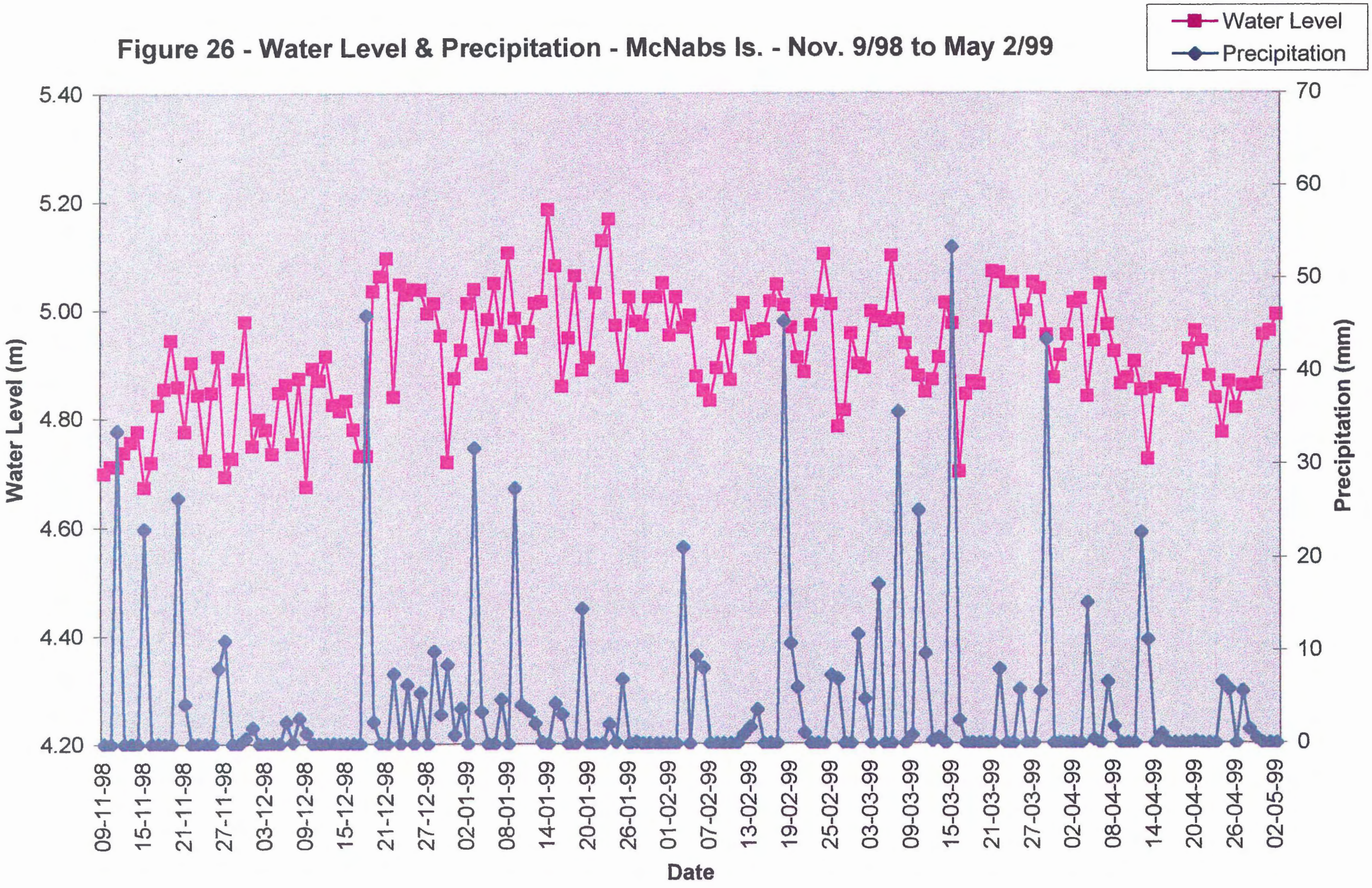
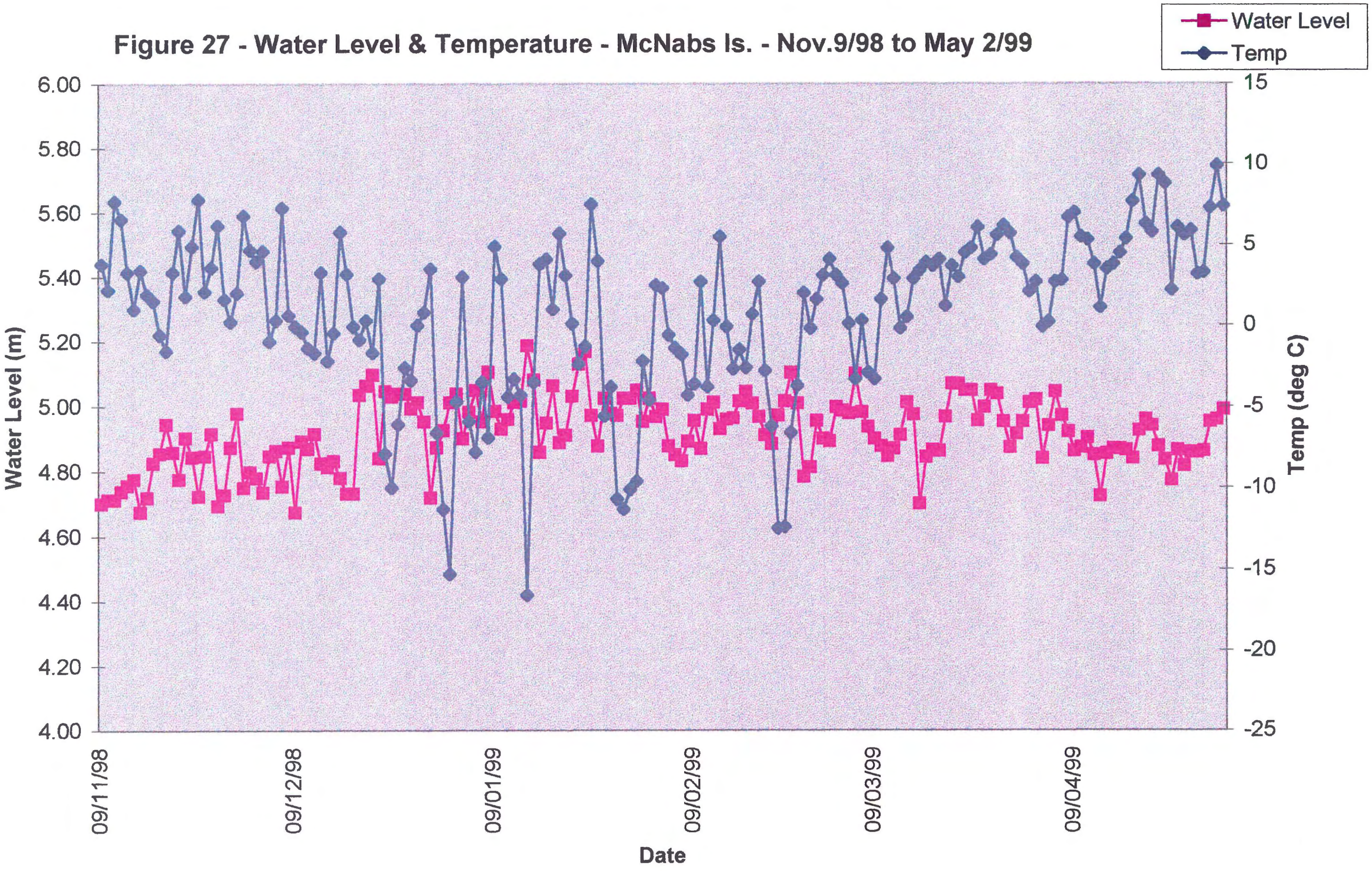


Figure 26 - Water Level & Precipitation - McNabs Is. - Nov. 9/98 to May 2/99

Figure 27 - Water Level & Temperature - McNabs Is. - Nov.9/98 to May 2/99



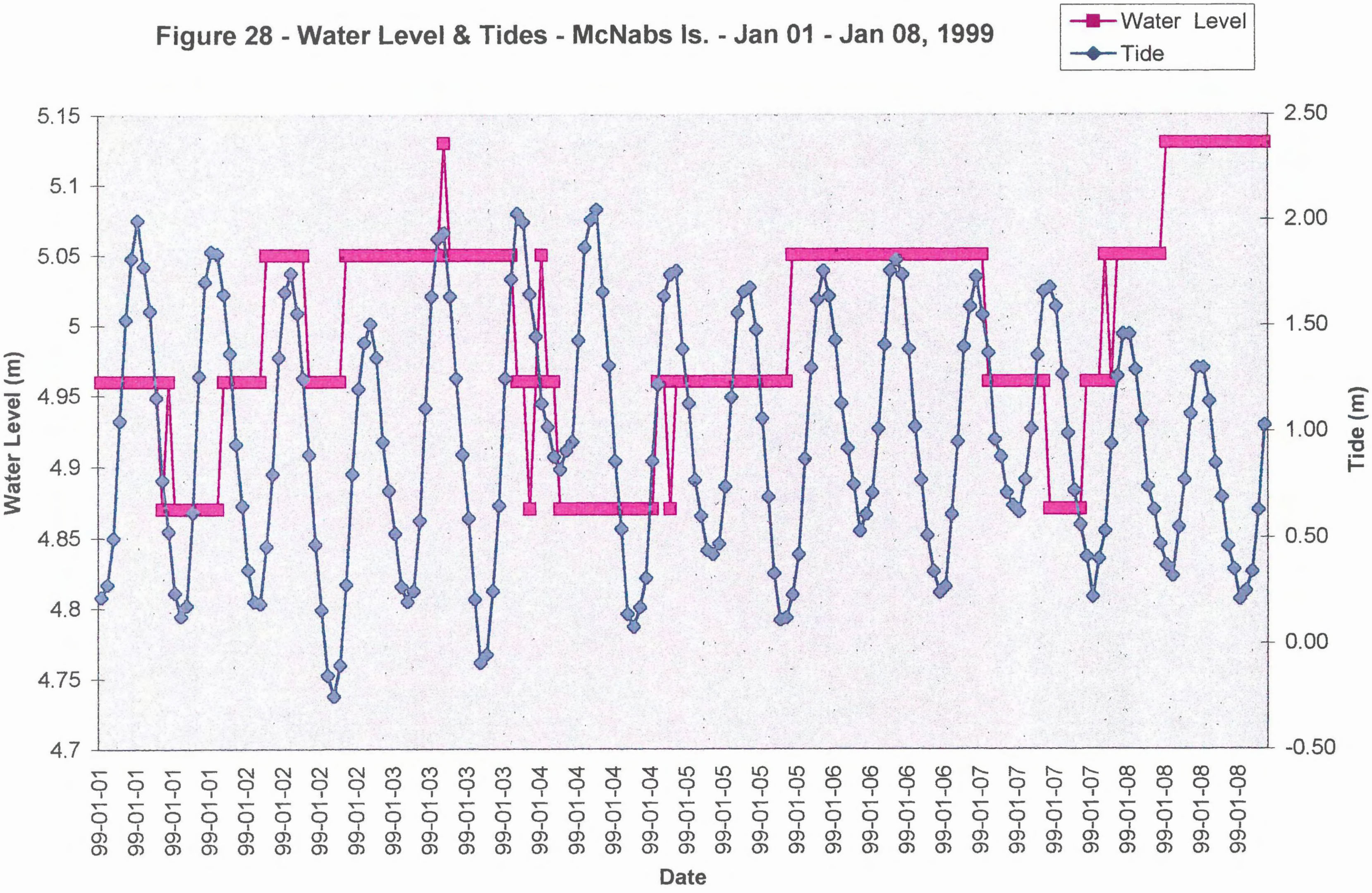


Figure 28 - Water Level & Tides - McNabs Is. - Jan 01 - Jan 08, 1999

4.3 Durham

At the Durham site, water levels from 1984 to 1999 appear to be rising slightly overall (Figure 29). The yearly averages reveal a trend of rising and falling on an annual scale. Between 1987 and 1999, levels alternately rose for one or two years and then fell for one year (Figure 29).

Figure 30 and Appendix II reveal a distinct seasonal trend at the Durham site. Water levels gradually decrease over the summer months, with lowest levels occurring between September and October. Levels increase more rapidly than they decreased and stay relatively high throughout the winter and spring. The monthly averages of water levels between 1984 and 1999 also indicate that there is often a secondary period of low water levels in the early spring. This behaviour is particularly noticeable in years 1984, 1987, 1988, 1989, and 1993-1997.

Figure 31 suggests a correlation between water level and precipitation over the long term. Daily average water levels plotted with daily total precipitation for1987 indicate that water levels do fluctuate with precipitation in general terms (Figure 32), but they do not respond as quickly as those seen at the Lawrencetown site earlier (Figure 17). The small amounts of precipitation during the summer months correlate with a steady, gradual decrease in water levels, while the large amounts of precipitation in the late fall (September to October) correlate with a steady increase in water levels (Figure 32).

Figure 29 - Yearly Average of Water Level at Durham

Gaps in graph indicate lost or unusable data

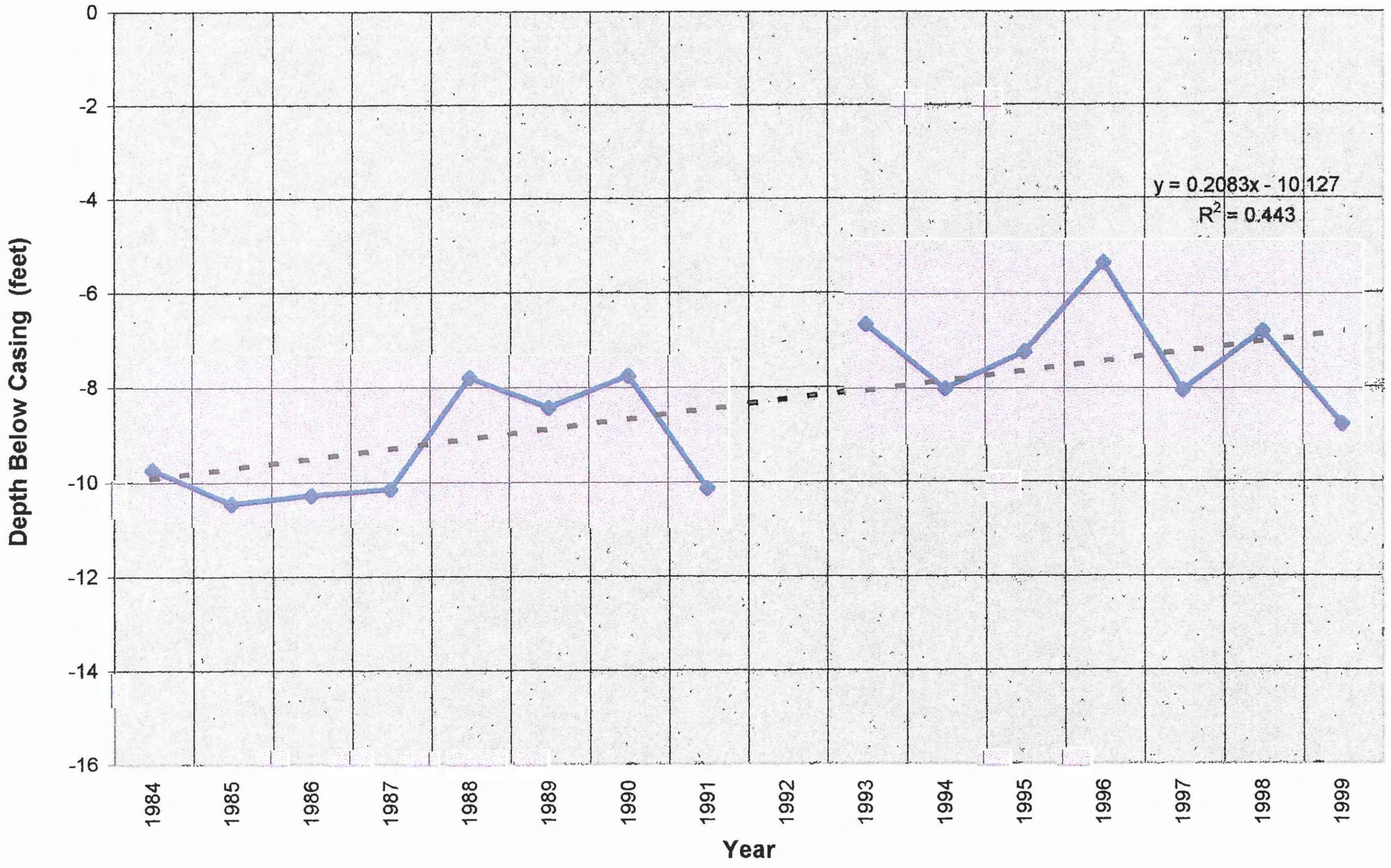
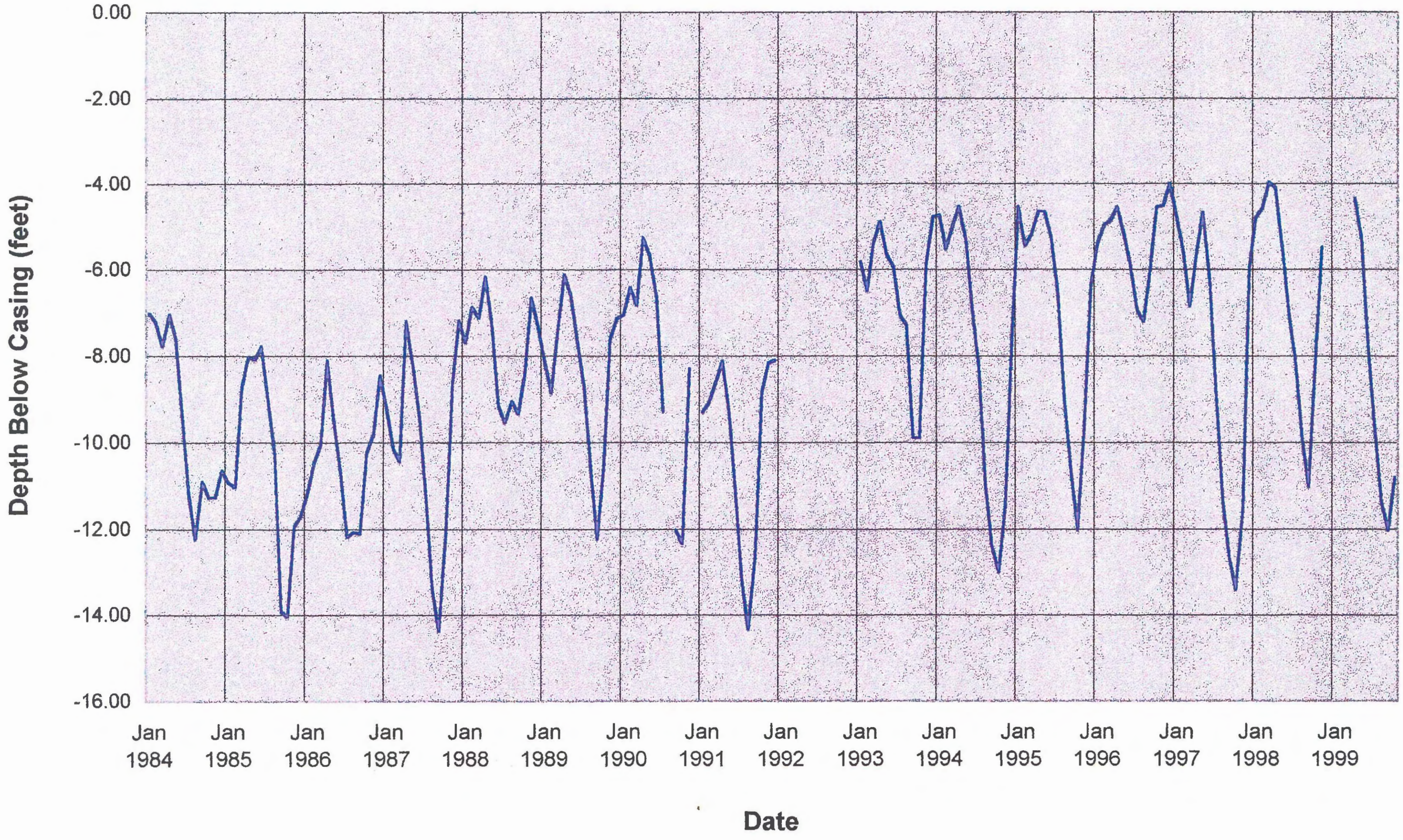


Figure 30 - Monthly Average of Water Level at Durham

Gaps in graph indicate lost or unusable data



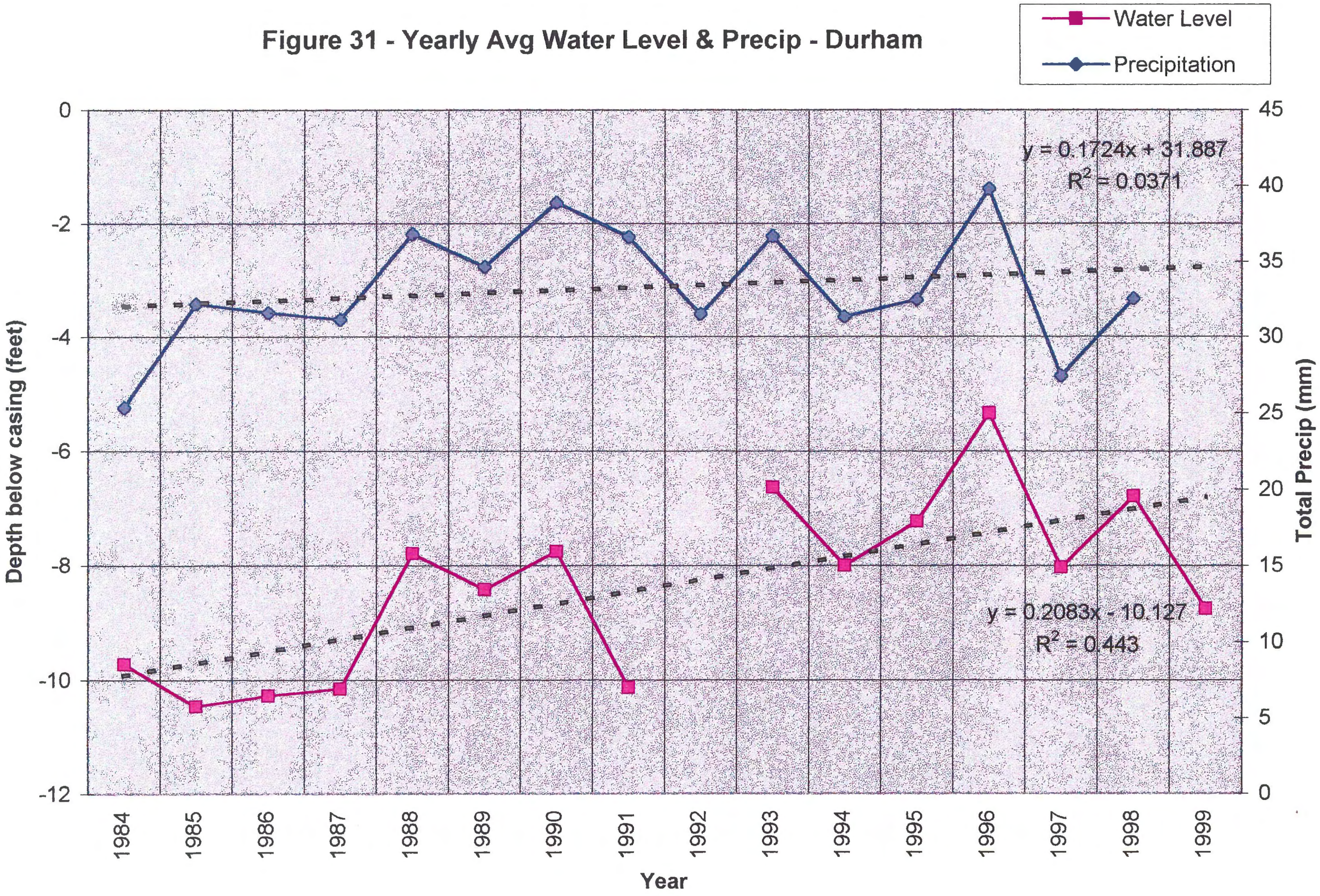


Figure 31 - Yearly Avg Water Level & Precip - Durham

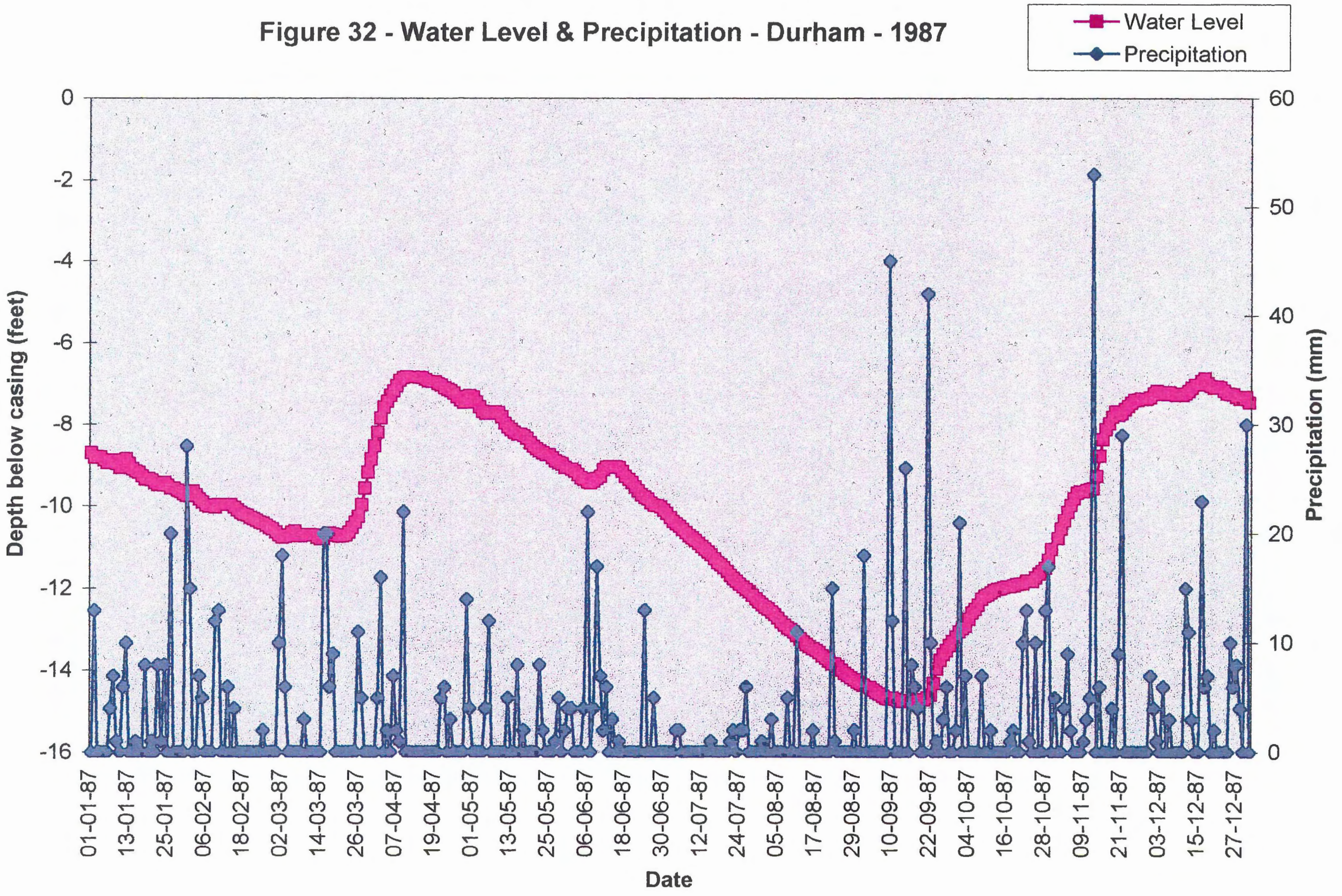


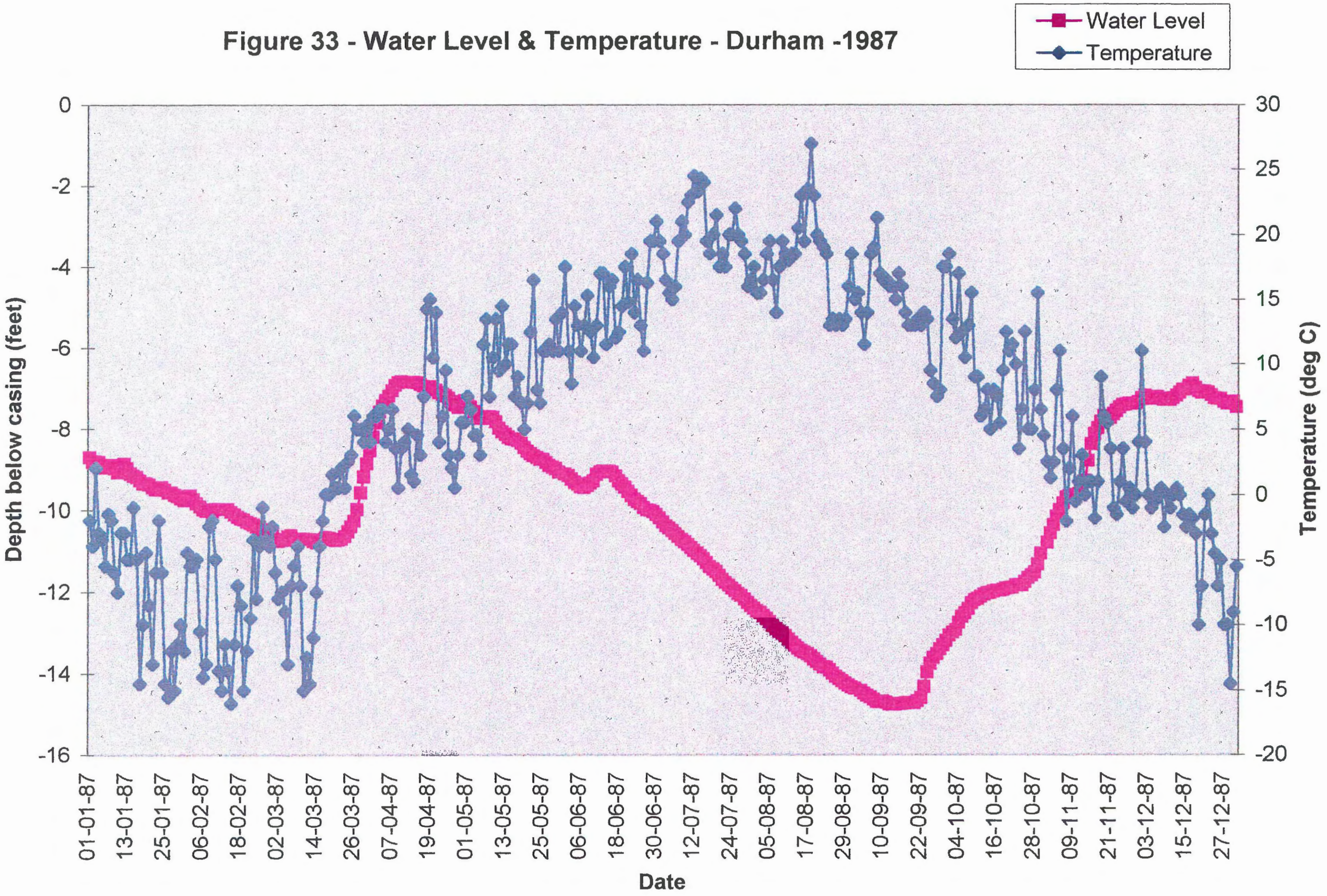
Figure 32 - Water Level & Precipitation - Durham - 1987

Daily average water levels plotted with daily average temperatures for 1987 reveal a negative correlation (Figure 33). As temperatures increase during the summer months, water levels decrease and as temperatures decrease during the winter months, water levels increase.

Figure 34 suggests that there may be a very small barometric effect at the Durham site. Daily averages of water level and barometric pressure for June 1994 show a negative correlation. When the barometer fell June 6-7 and June 21-22, the external loading on the aquifer skeleton decreased and water levels increased in response. Barometric efficiency was not calculated for this site because hourly water level data is not available.

Tidal effects were not present nor were they expected at this site due to the well's distance from the coast.

Figure 33 - Water Level & Temperature - Durham -1987



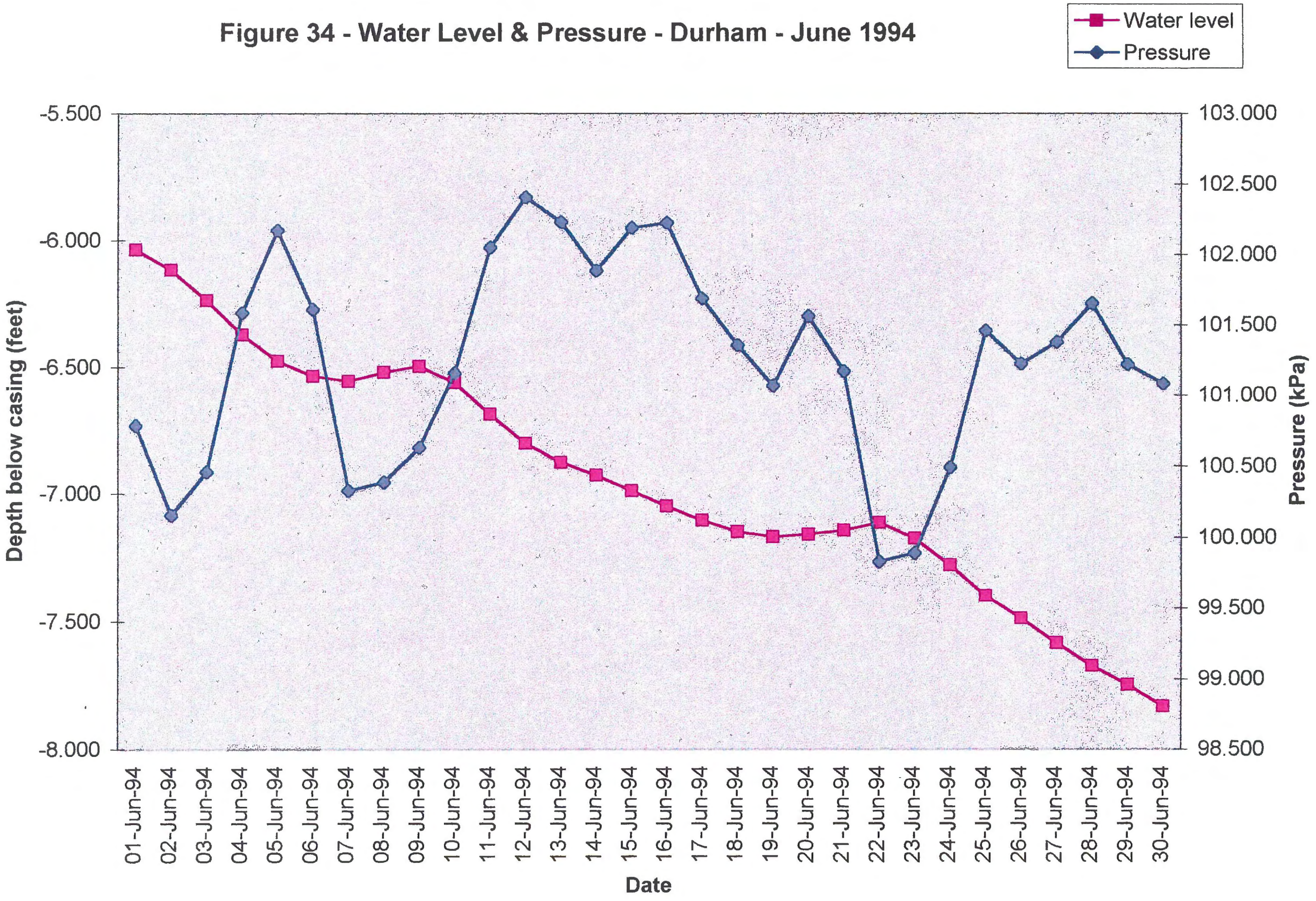


Figure 34 - Water Level & Pressure - Durham - June 1994

Chapter 5 : Conclusions, Recommendations, and Further Work

5.1 Conclusions

Overall trends measured during this pilot study suggest that groundwater levels are increasing slightly over the long term, an increase that is likely related to precipitation which is also increasing slightly over the long term. Seasonal trends exist at all three sites, and were especially evident in the water levels at the Durham site. Climatic effects had obvious correlation to groundwater fluctuations at the Lawrencetown site and at the Durham site, especially total precipitation. Tidal effects were prominent at the Lawrencetown site. However, tidal effects were not found on groundwater levels at the Durham site, likely due to its distance from the shoreline, or at the McNabs Island site, likely due to its elevation above sea level and the well construction in surficial material.

5.2 Recommendations

The NSDOE Observation Well Network is a valuable tool for monitoring groundwater levels; however personnel restrictions may be causing the loss of valuable data. Because data is collected roughly twice a year from a given site, problems with equipment may not be detected for substantial periods of time and valuable may be lost. At Lawrencetown, a malfunctioning/improperly calibrated data logger would have continued to gather poor data had an anomaly not been discovered during the course of this study. I would recommend improvements to the monitoring of the provincial observation well network. Data collection from a remote site would allow data to be verified more often than twice a year and reduce the amount of lost data in the event of a malfunction or problem. Water level records are more manageable in digital format so I recommend that existing data from chart recorders be digitized.

5.3 Further Work

There are many sites that have not been studied over the long term, in this manner. A province-wide study using all other wells in the network would provide a clearer picture of trends in groundwater levels in Nova Scotia. The fact that levels appear to be increasing introduces more questions, such as: Why are levels increasing? Does sea level rise play a role in coastal areas? Is the water quality changing and if so, in what way? All of these questions could be addressed in future studies.

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Websites

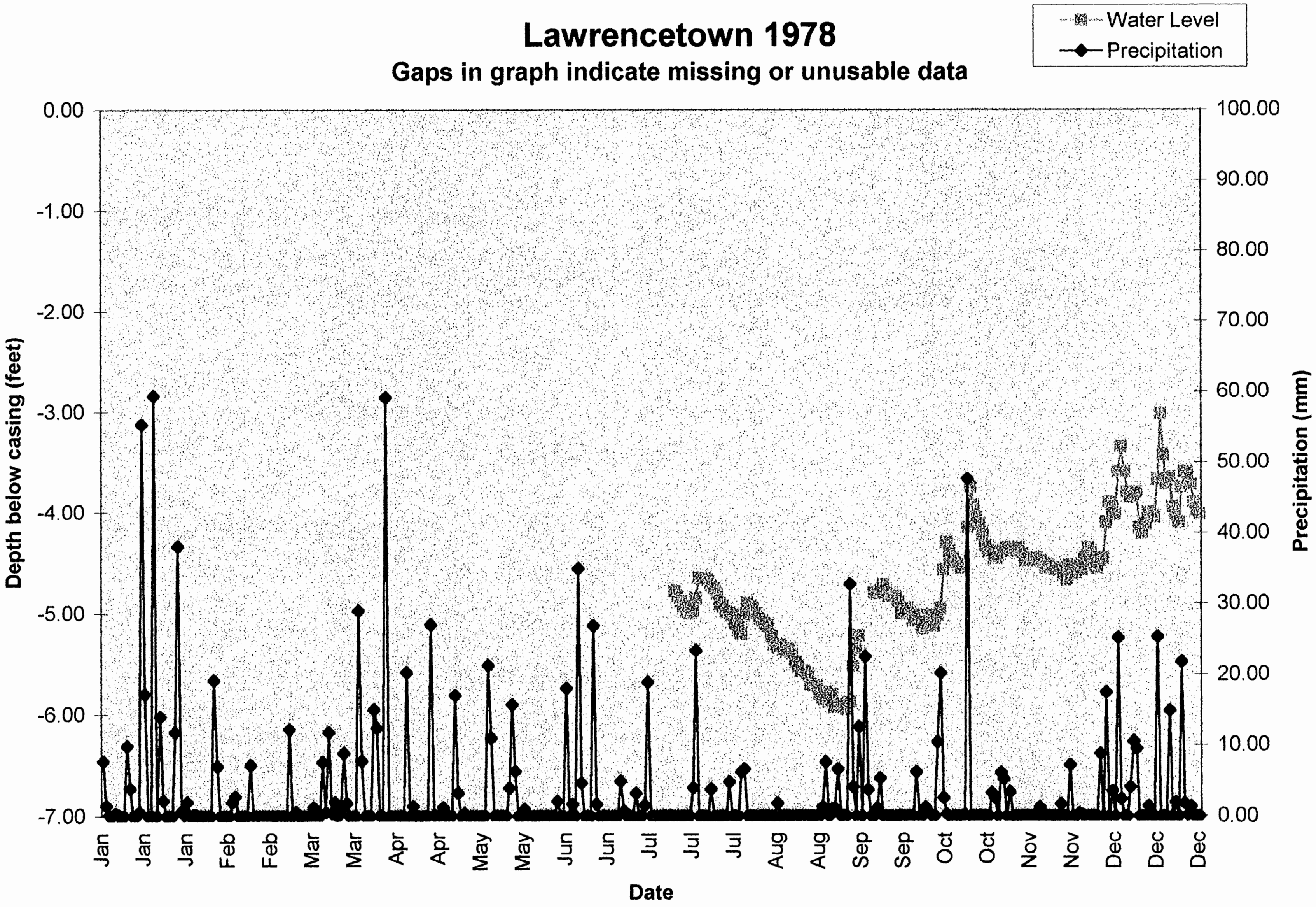
www.ec.gc.ca/climate/ns.html

www.ec.gc.ca/water/index/htm

Appendix I

Daily Average Water Level and Daily Total Precipitation

Lawrencetown - 1978-1990, 1998-2000


Lawrencetown 1978
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
0.00
-1.00
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-7.00
Precipitation (mm)
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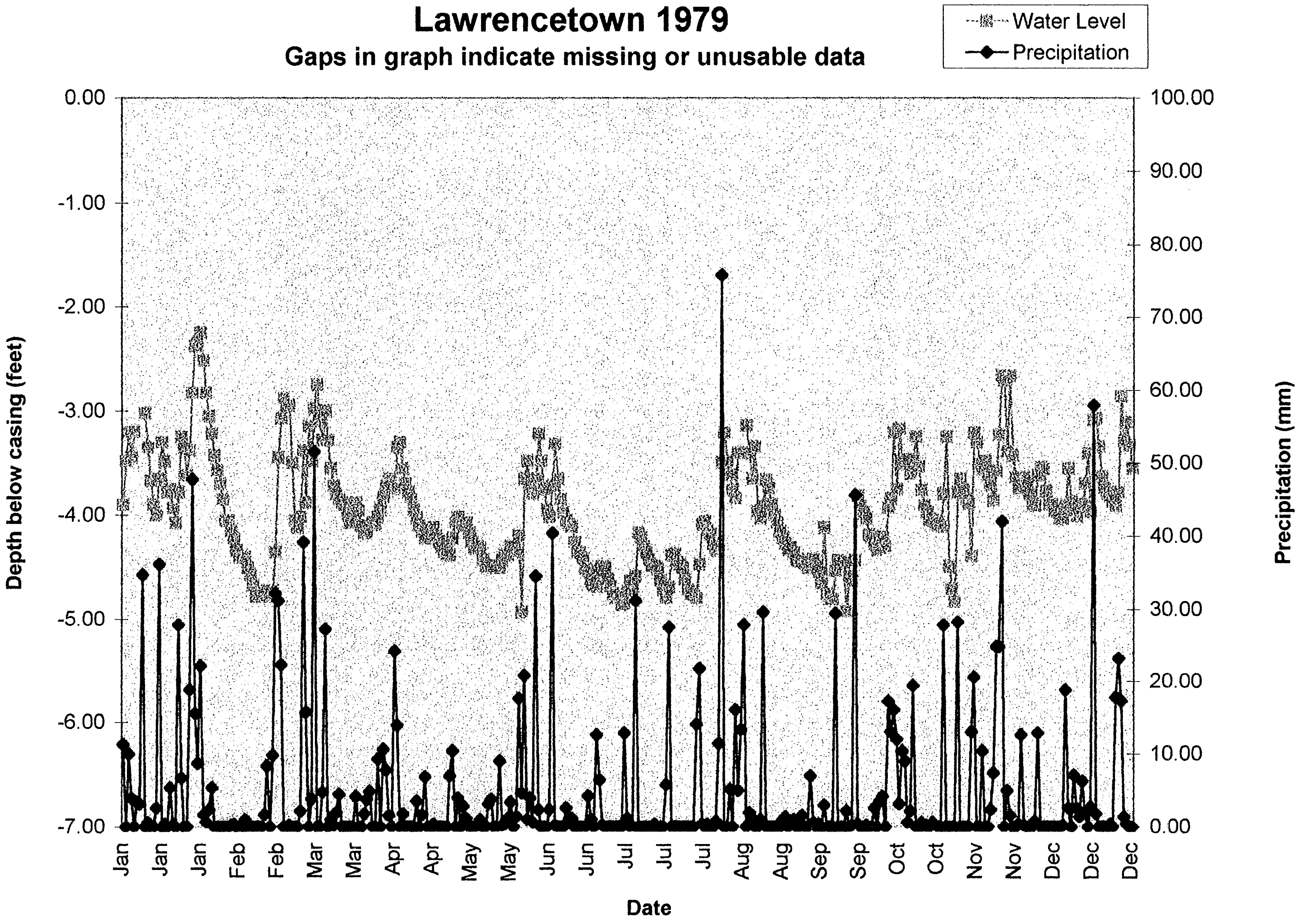
Lawrencetown 1979
Gaps in graph indicate missing or unusable data
Water Level
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Depth below casing (feet)
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-7.00
Precipitation (mm)
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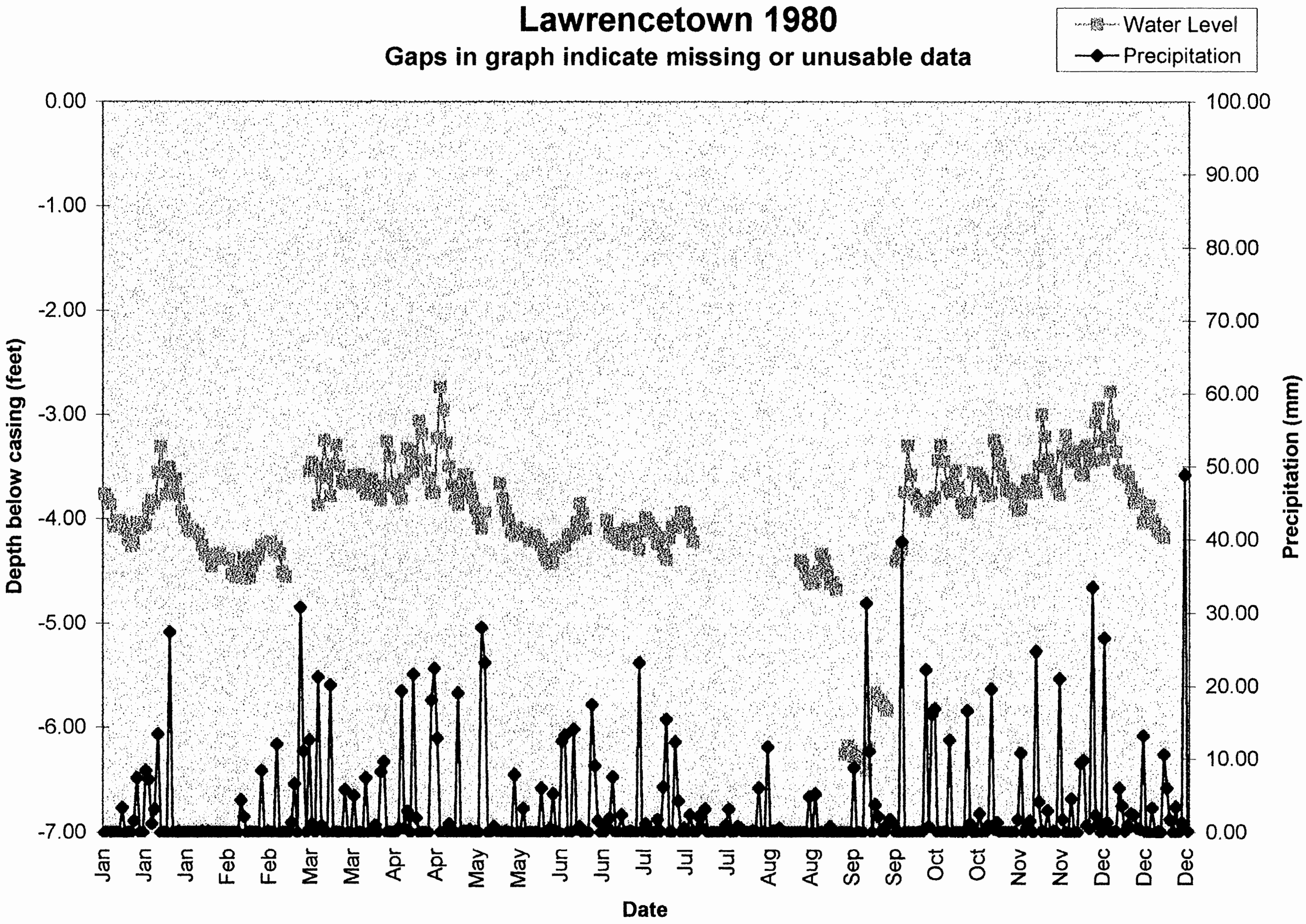
Lawrencetown 1980
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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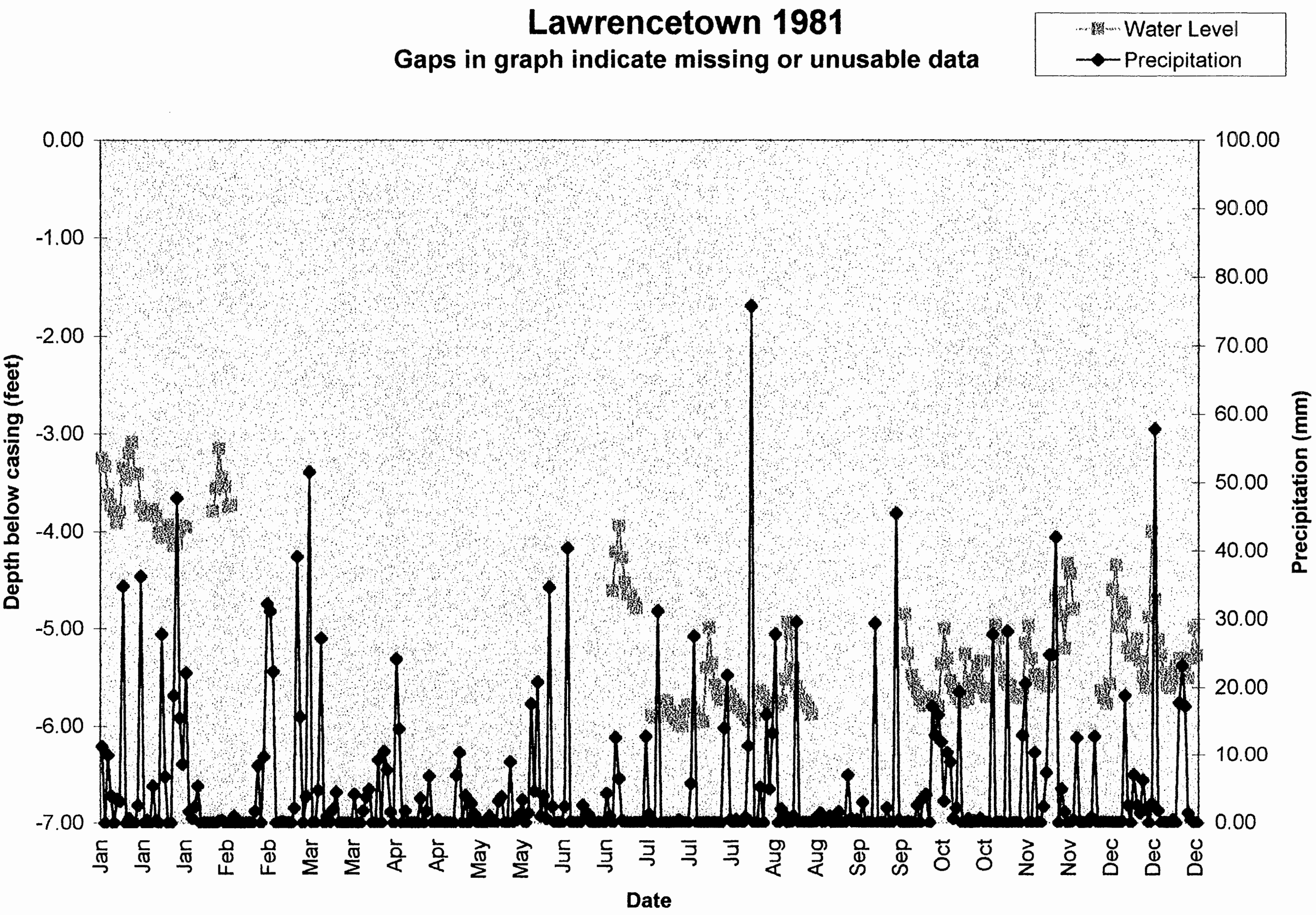
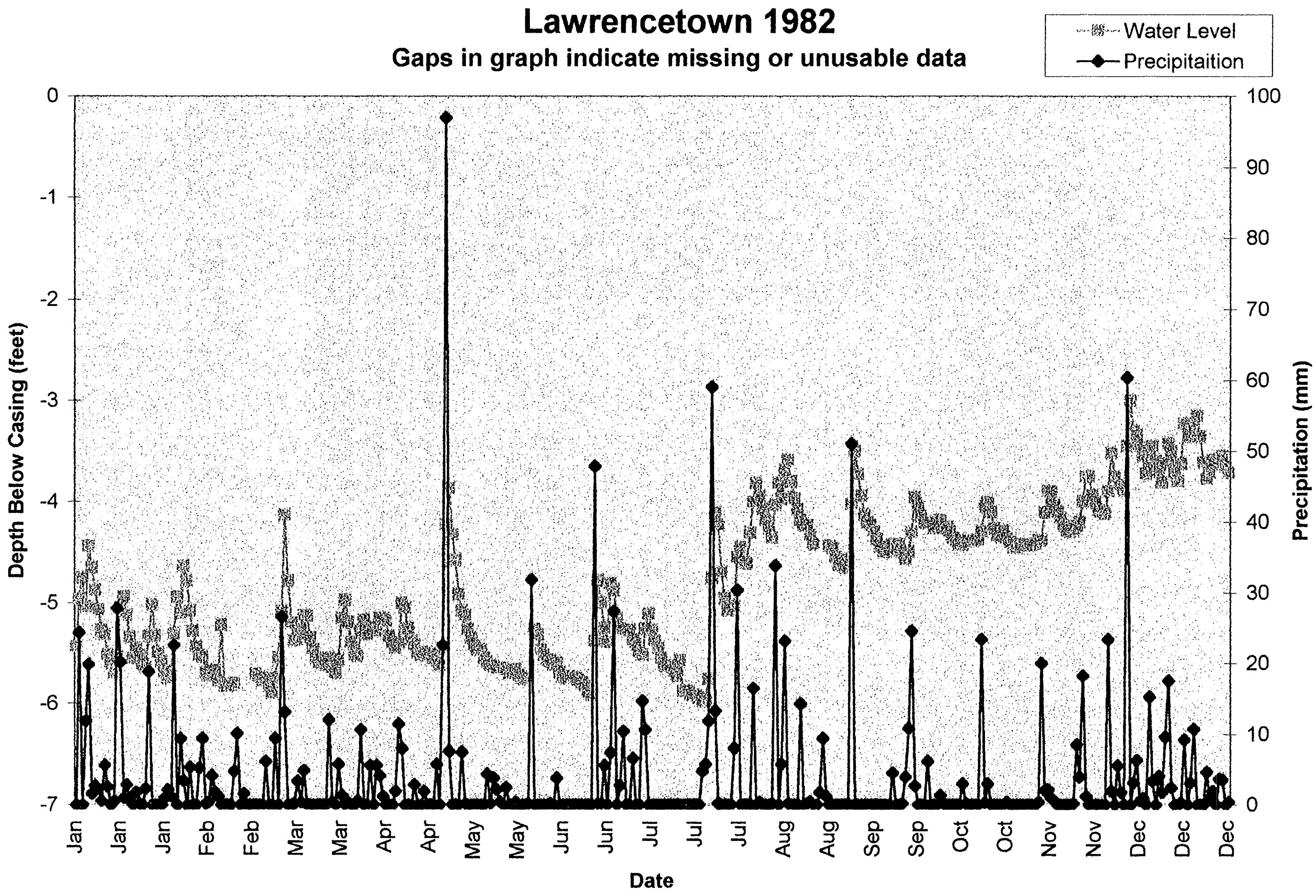


Lawrencetown 1981

Gaps in graph indicate missing or unusable data


Lawrencetown 1982
Gaps in graph indicate missing or unusable data
Water Level
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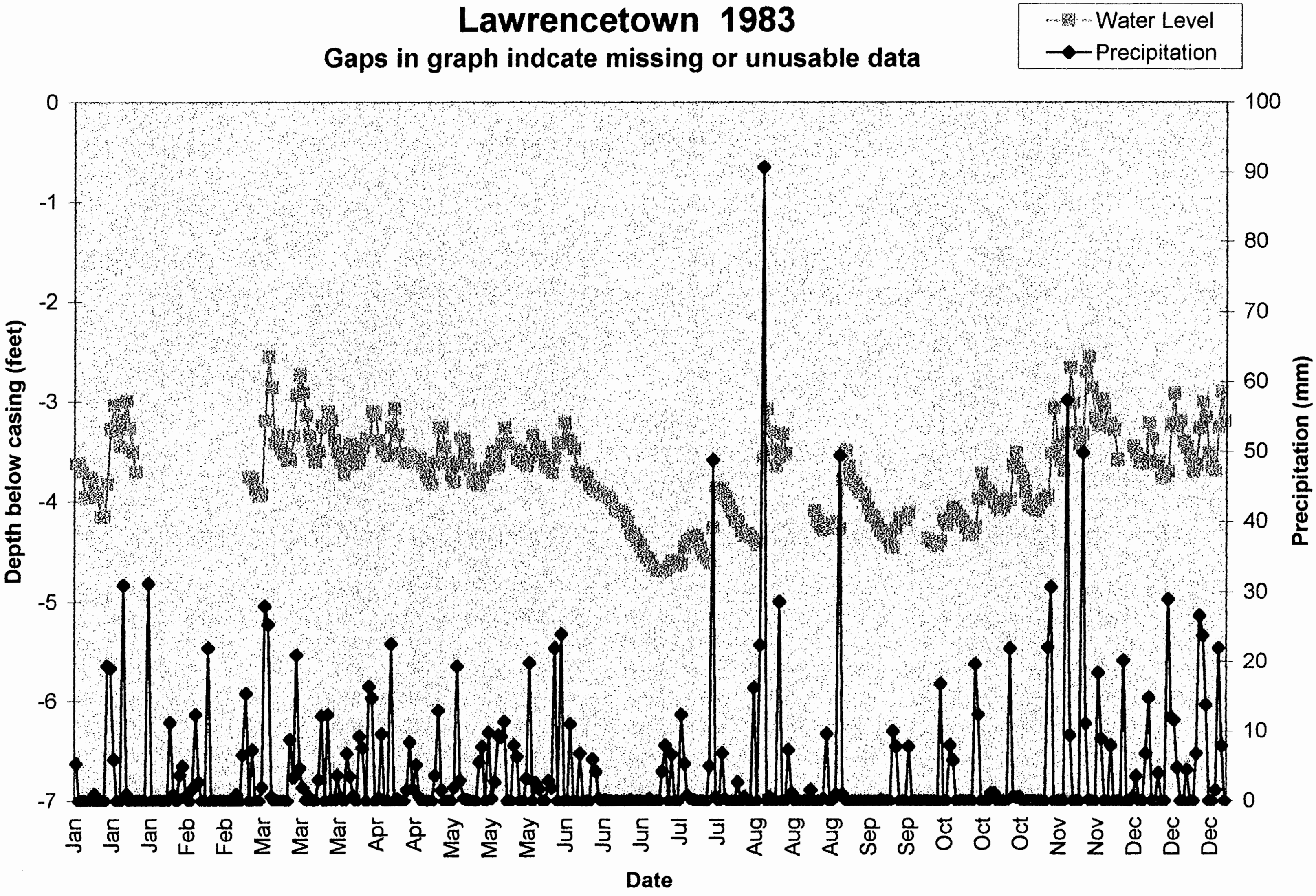

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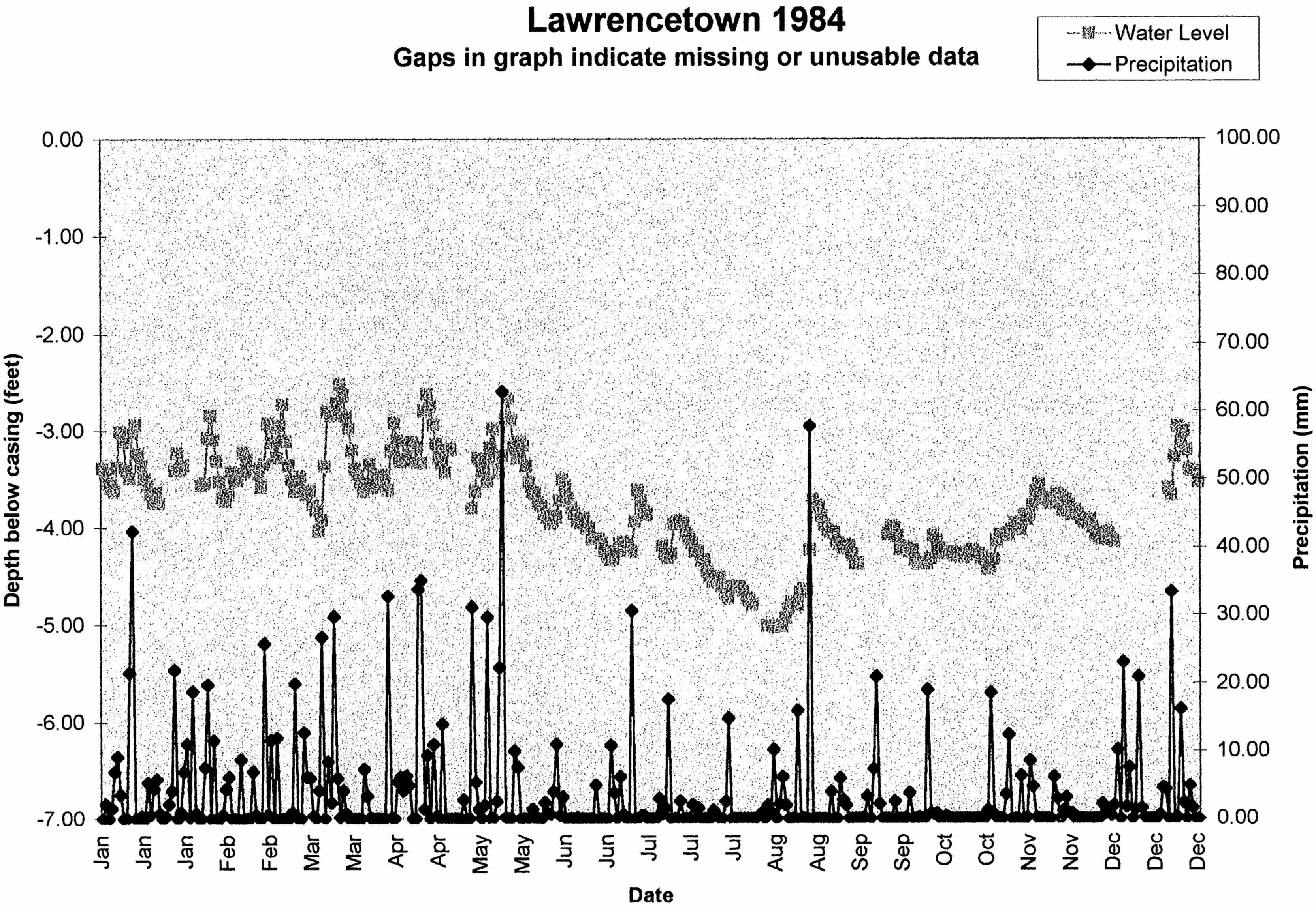
Lawrencetown 1984
Gaps in graph indicate missing or unusable data
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Depth below casing (feet)
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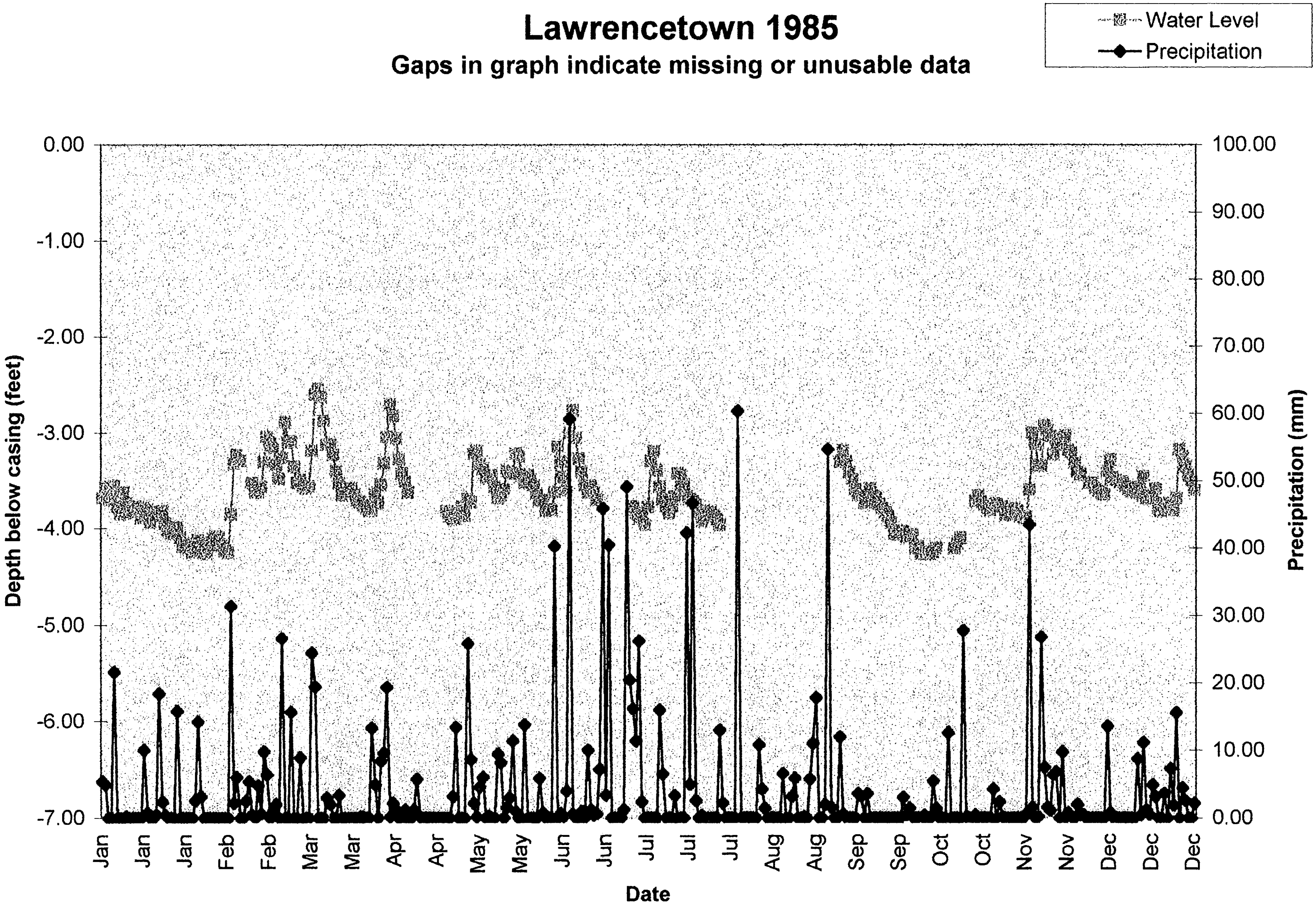
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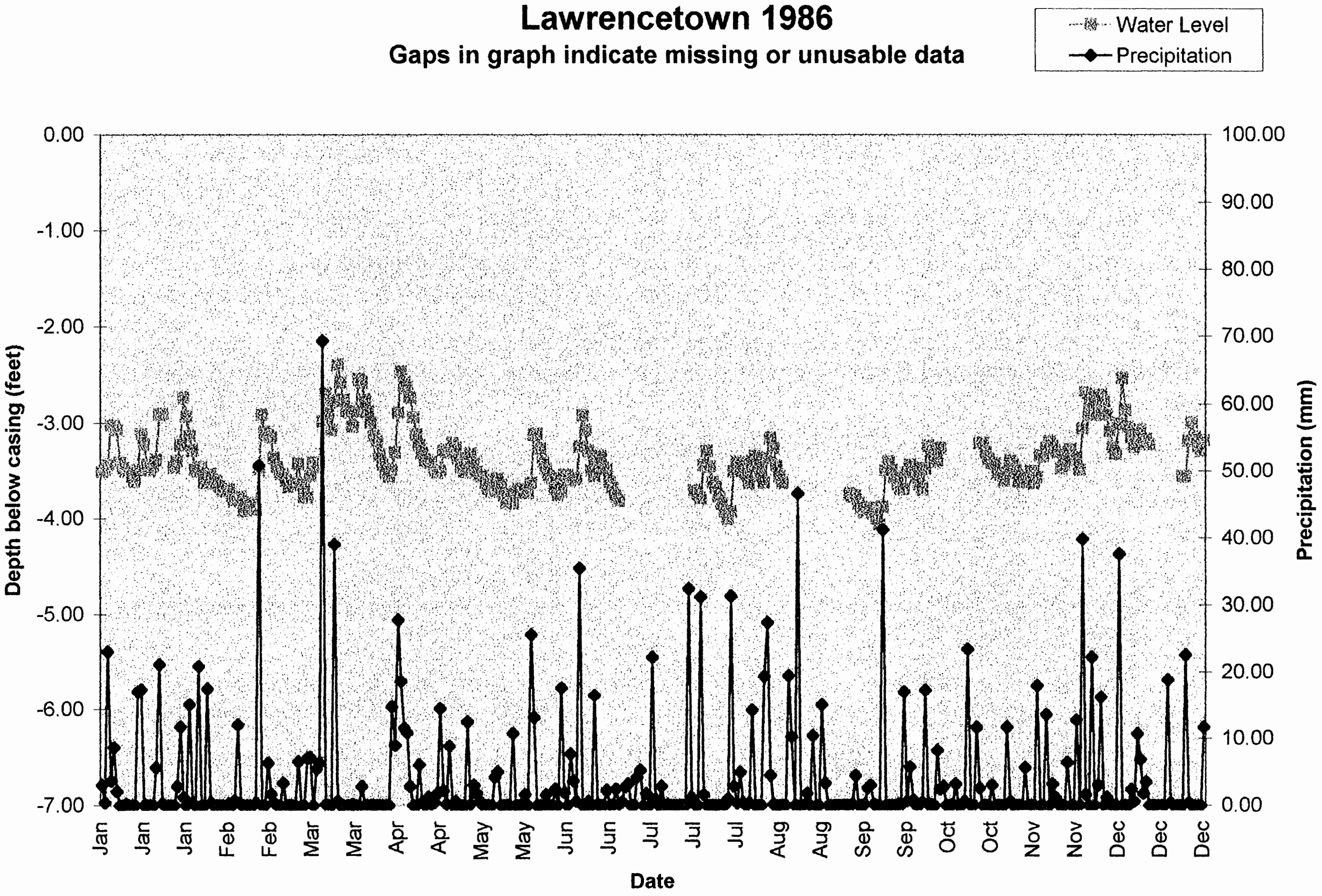

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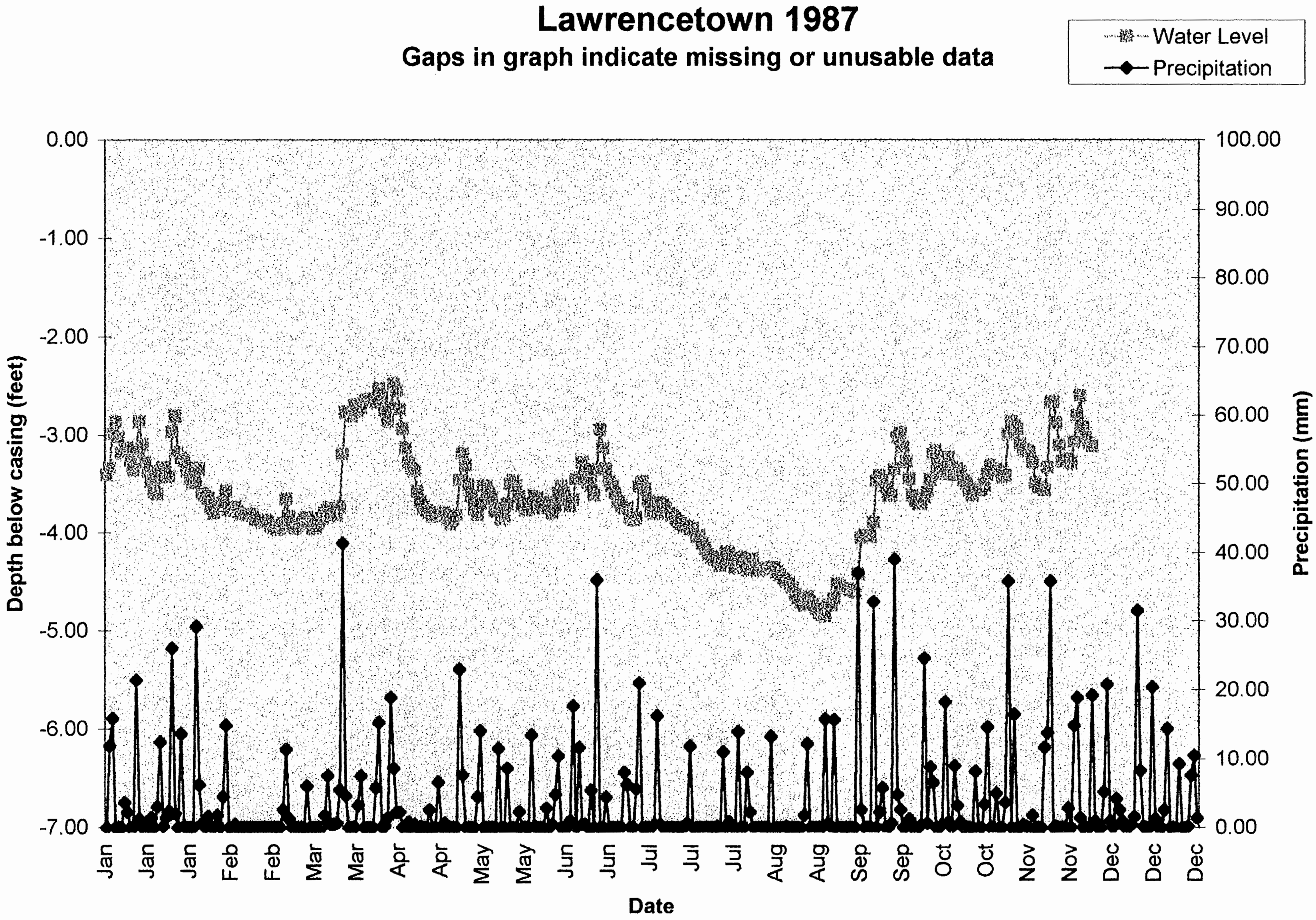
Lawrencetown 1987
Gaps in graph indicate missing or unusable data
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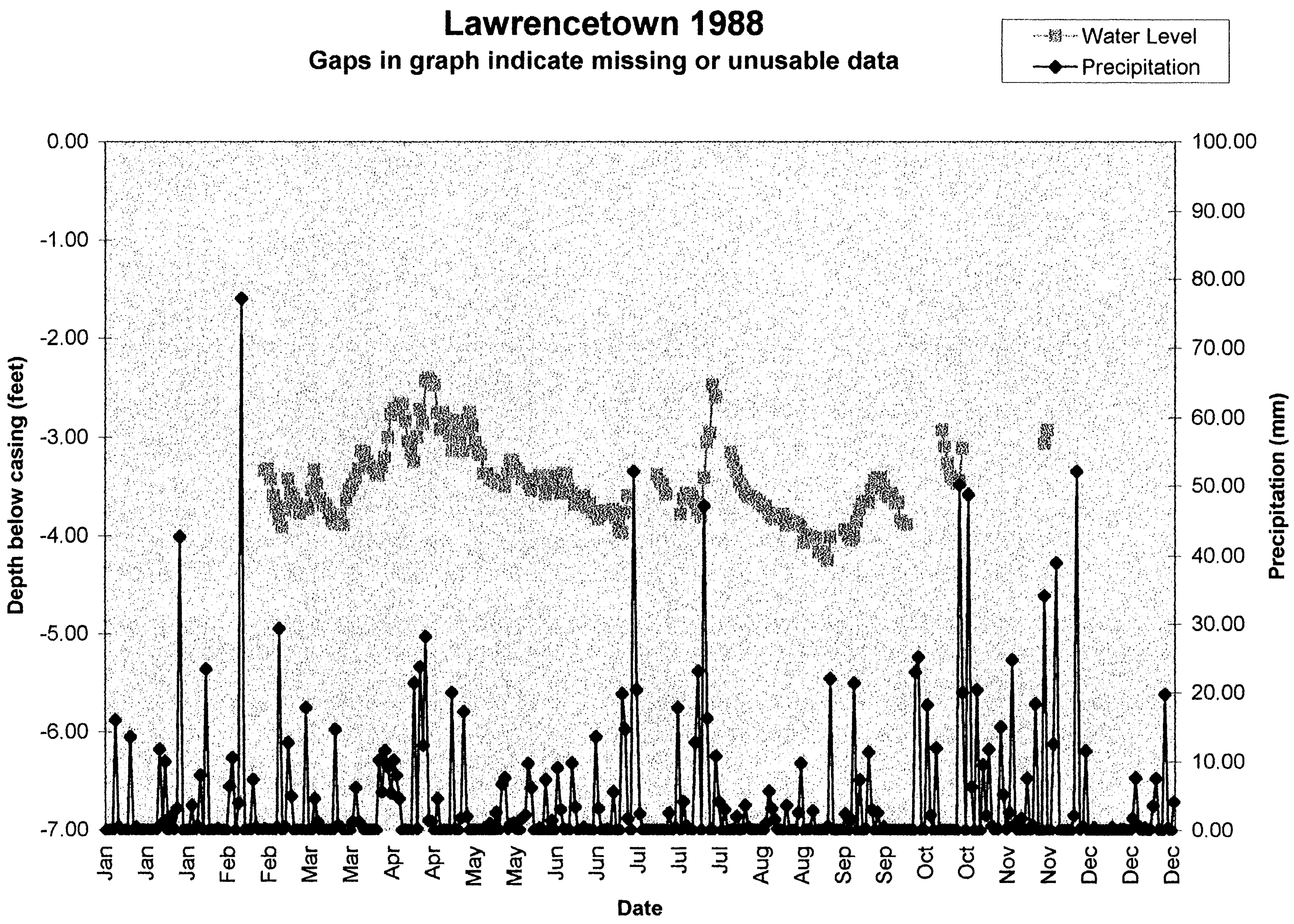
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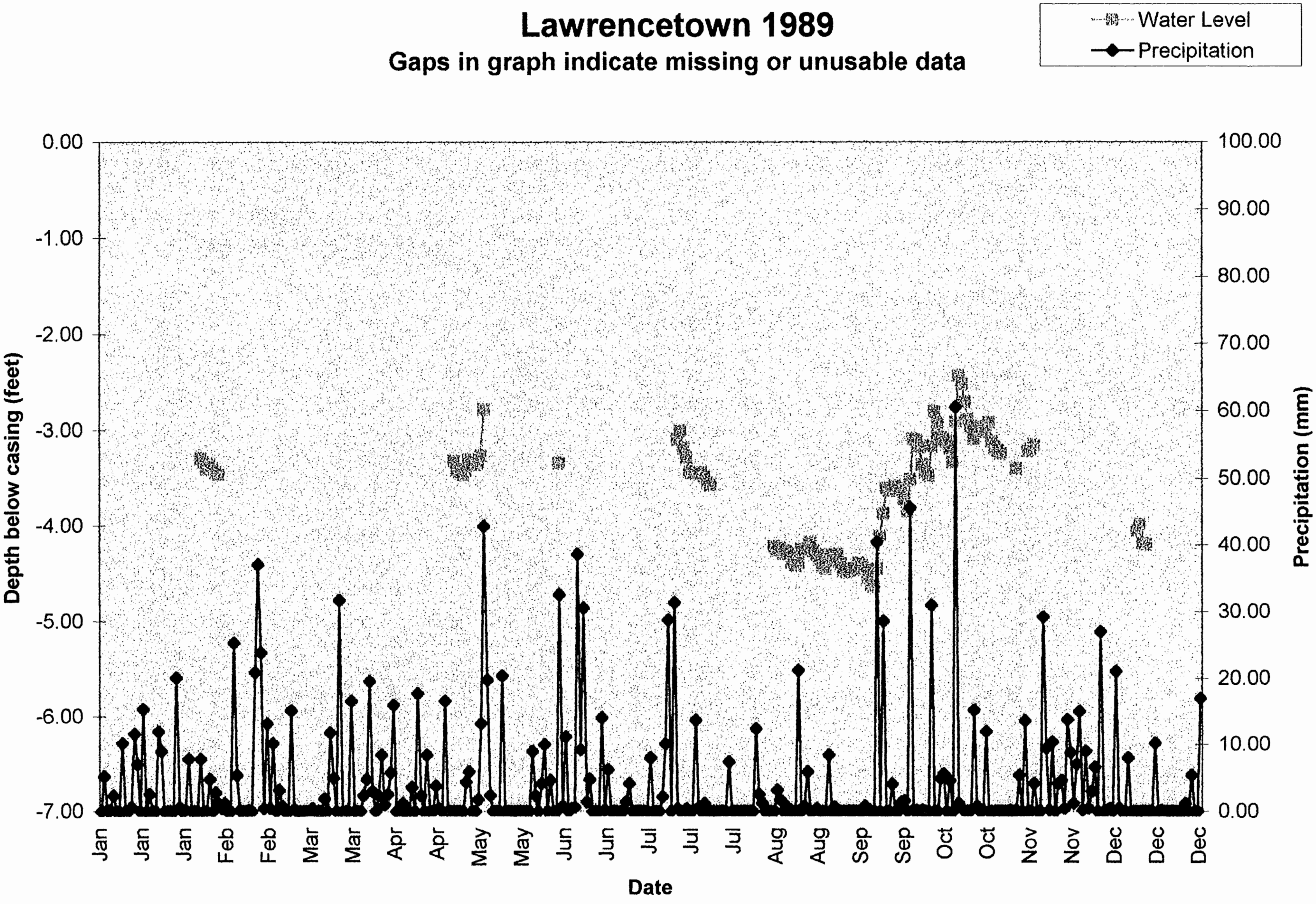
Lawrencetown 1989
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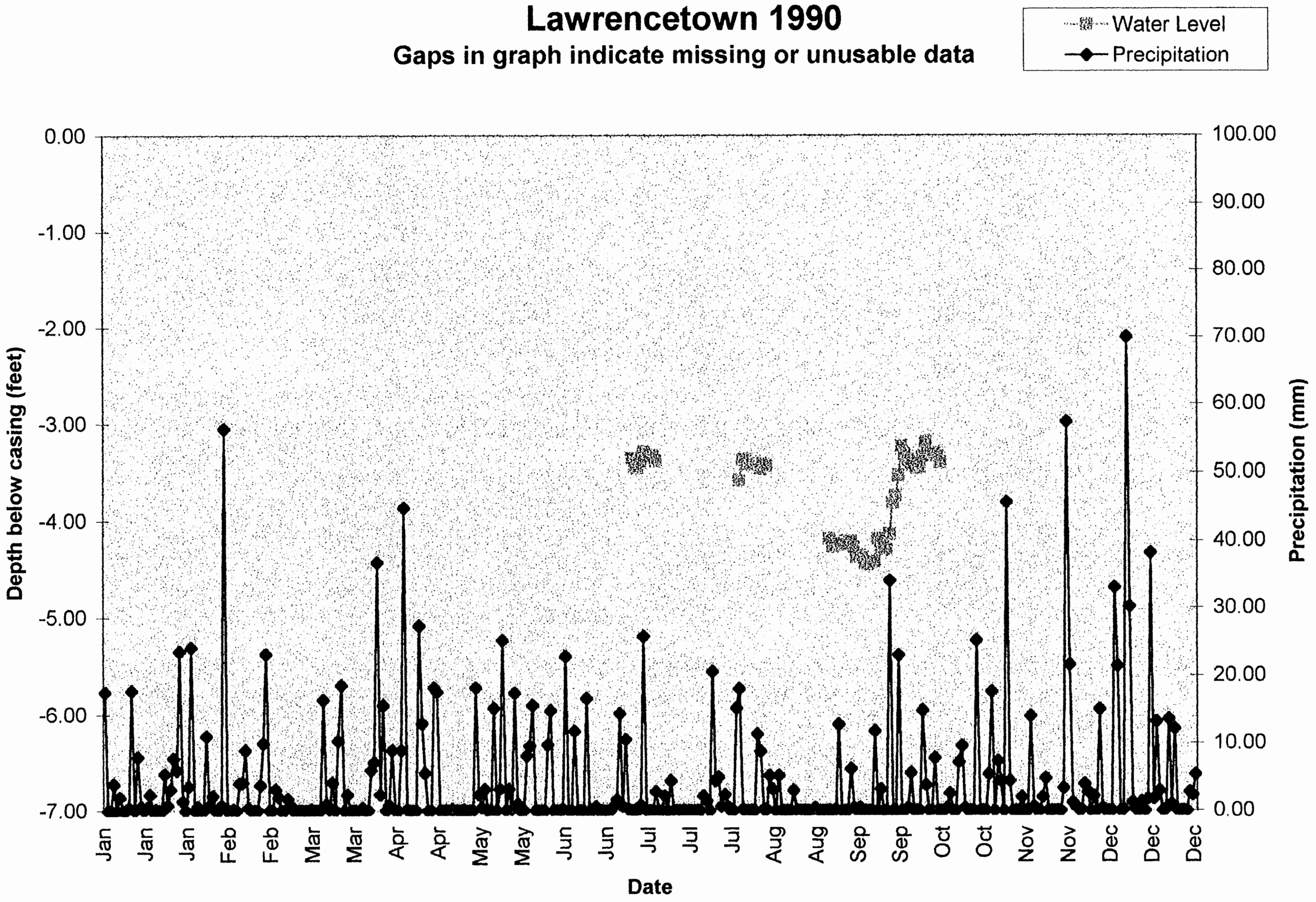
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Gaps in graph indicate missing or unusable data
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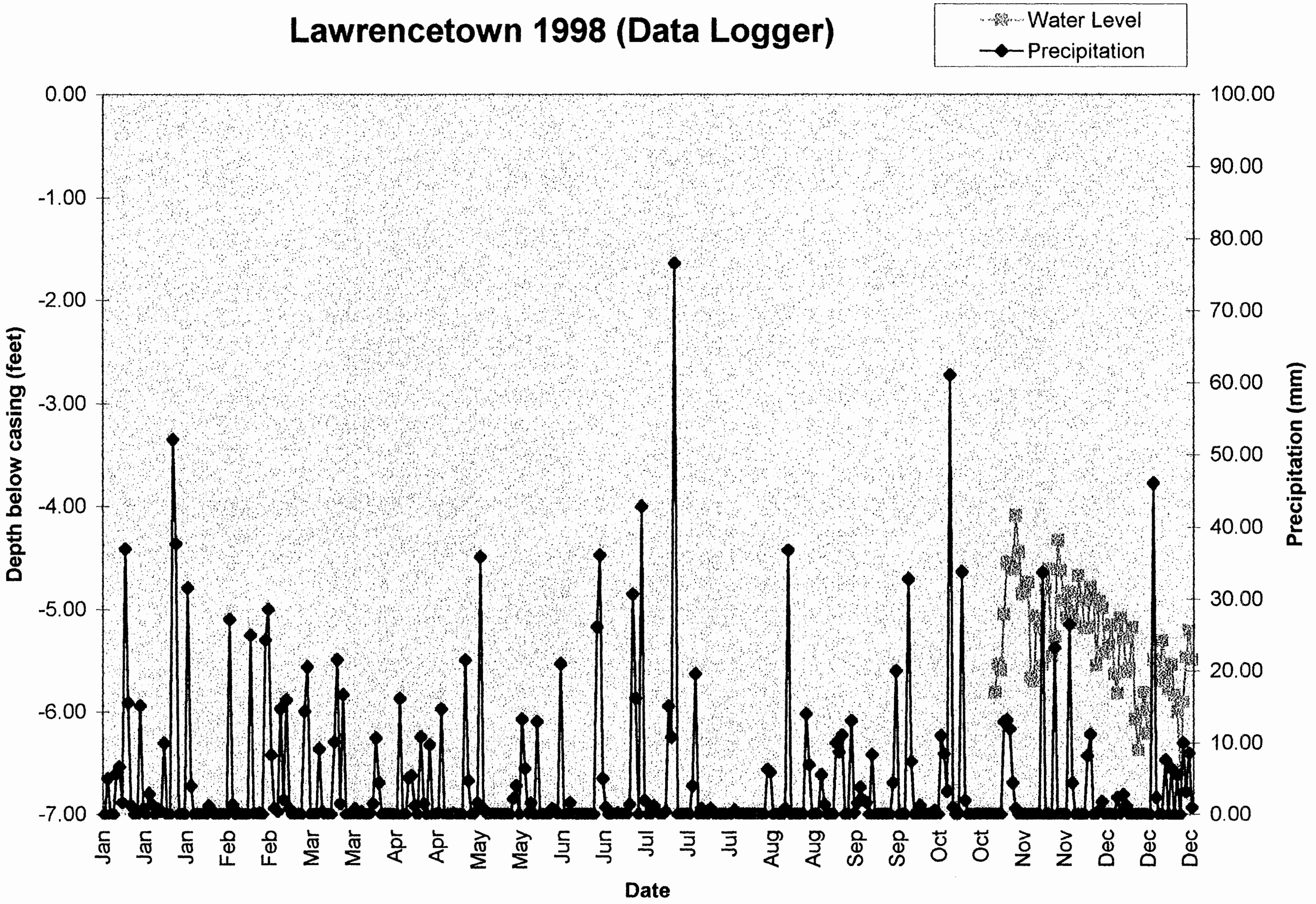
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Precipitation
Depth below casing (feet)
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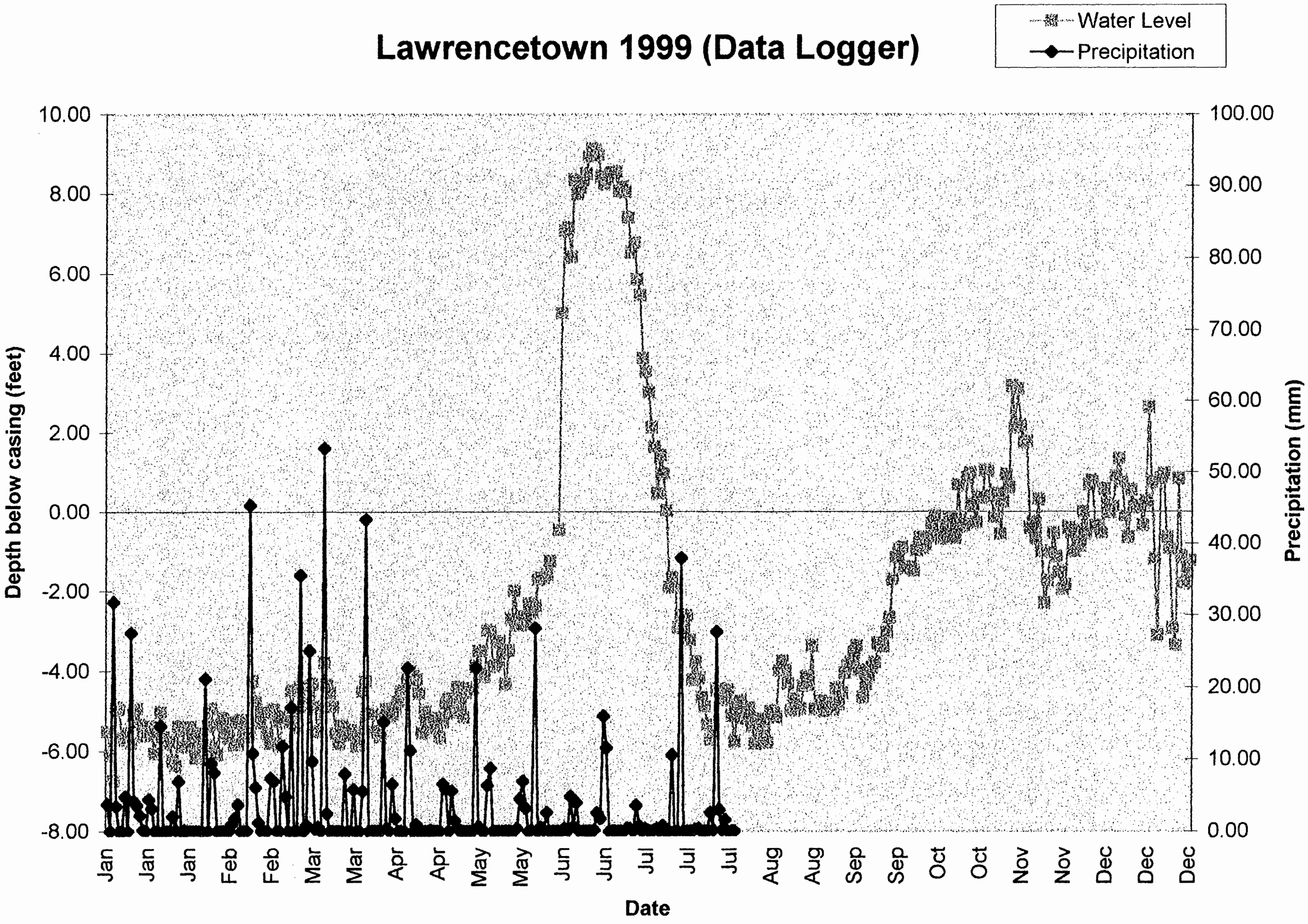
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Water Level
Precipitation
Depth below casing (feet)
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Precipitation (mm)
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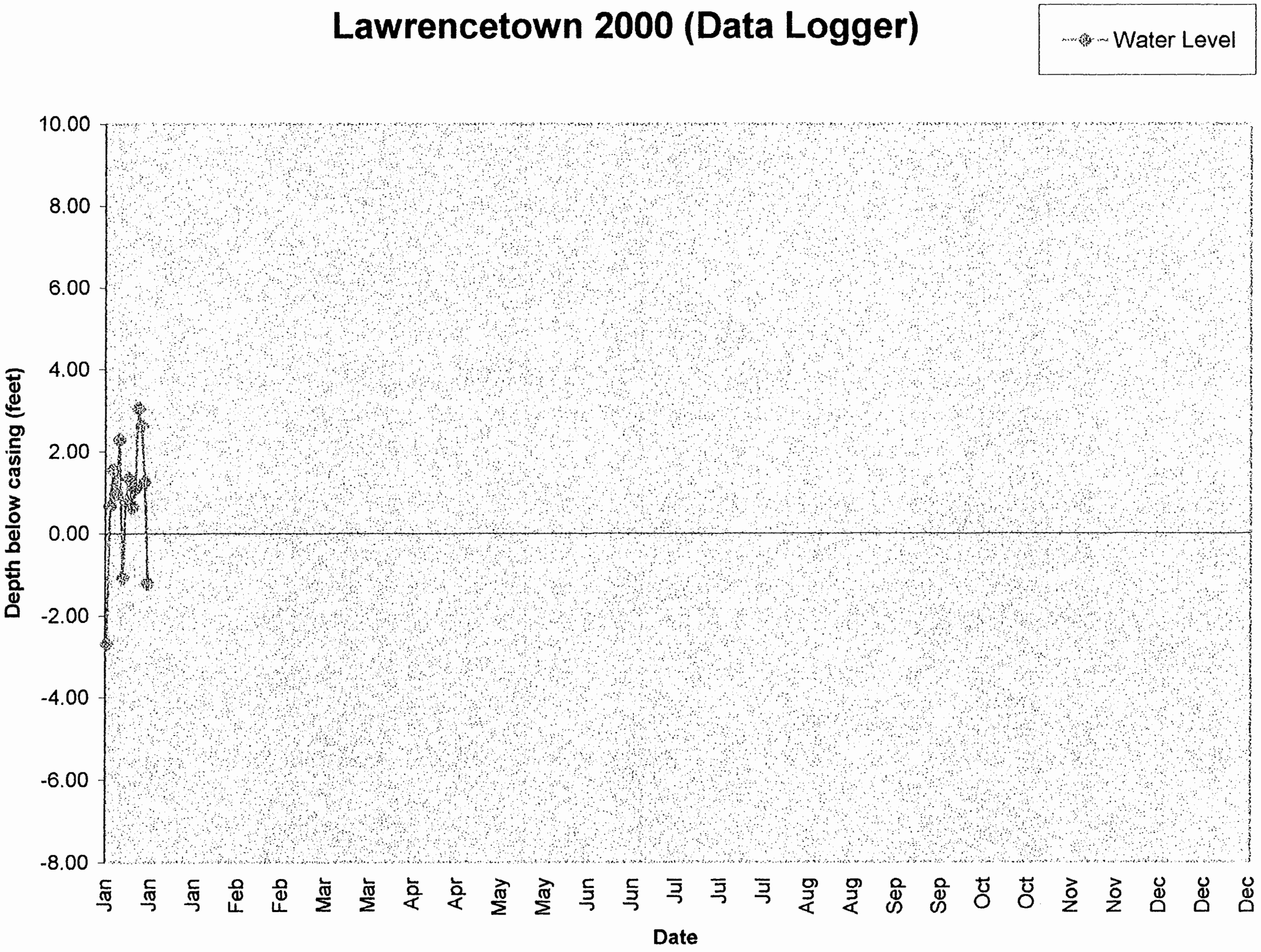
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Depth below casing (feet)
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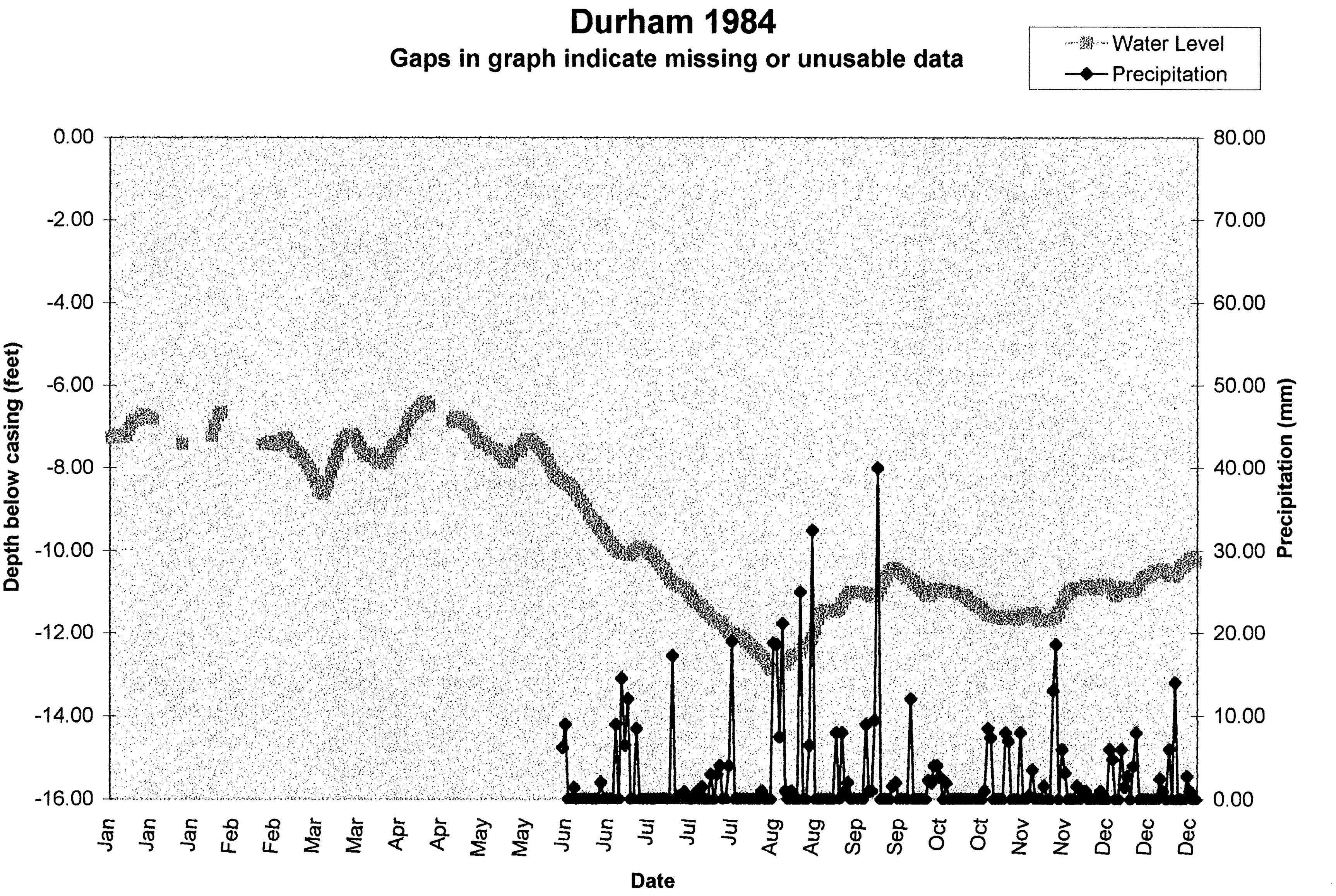
Appendix II

Daily Average Water Level and Daily Total Precipitation

Durham - 1984-1991, 1992-1999



Durham 1984
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
Precipitation (mm)
80.00
70.00
60.00
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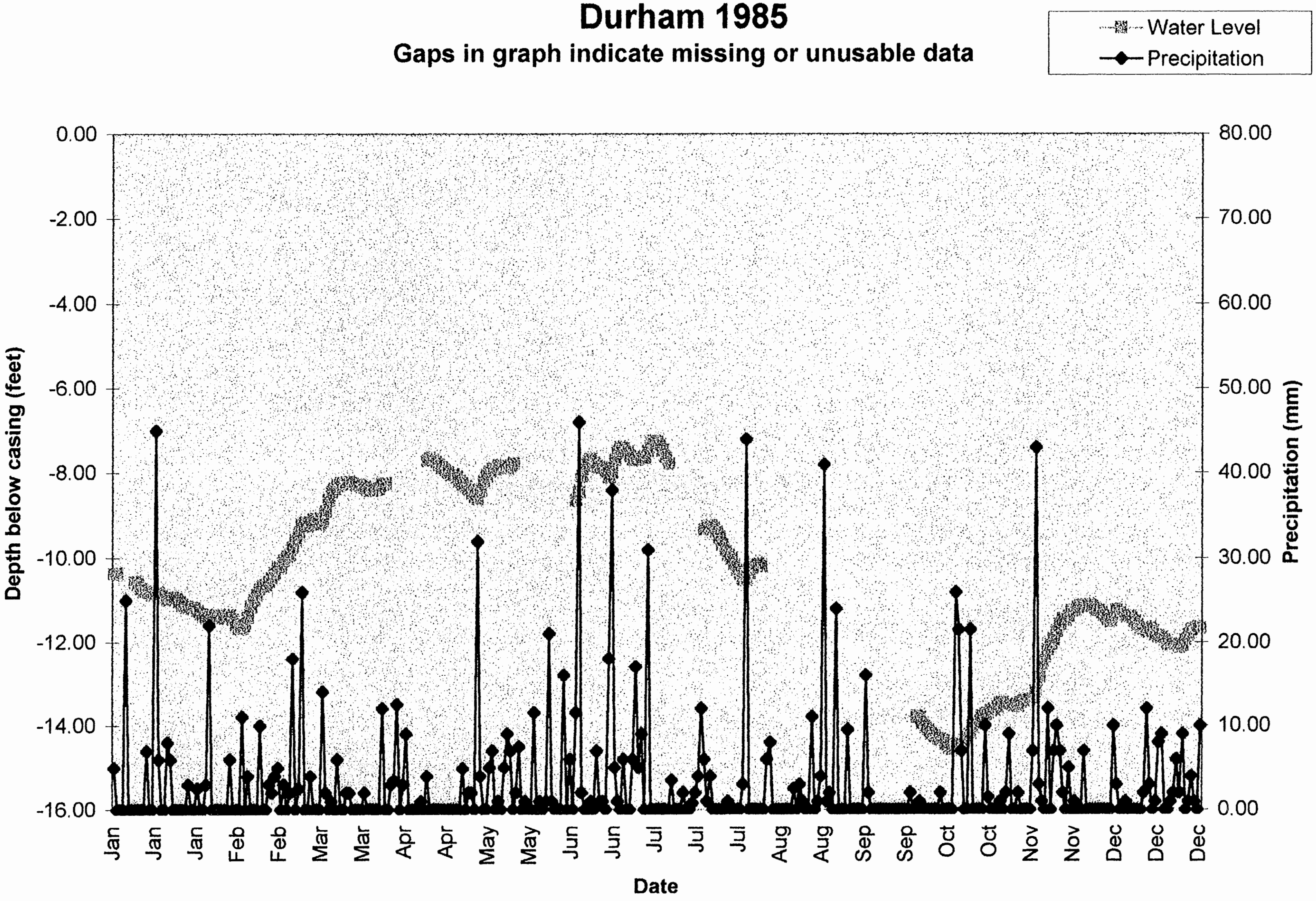

Durham 1985

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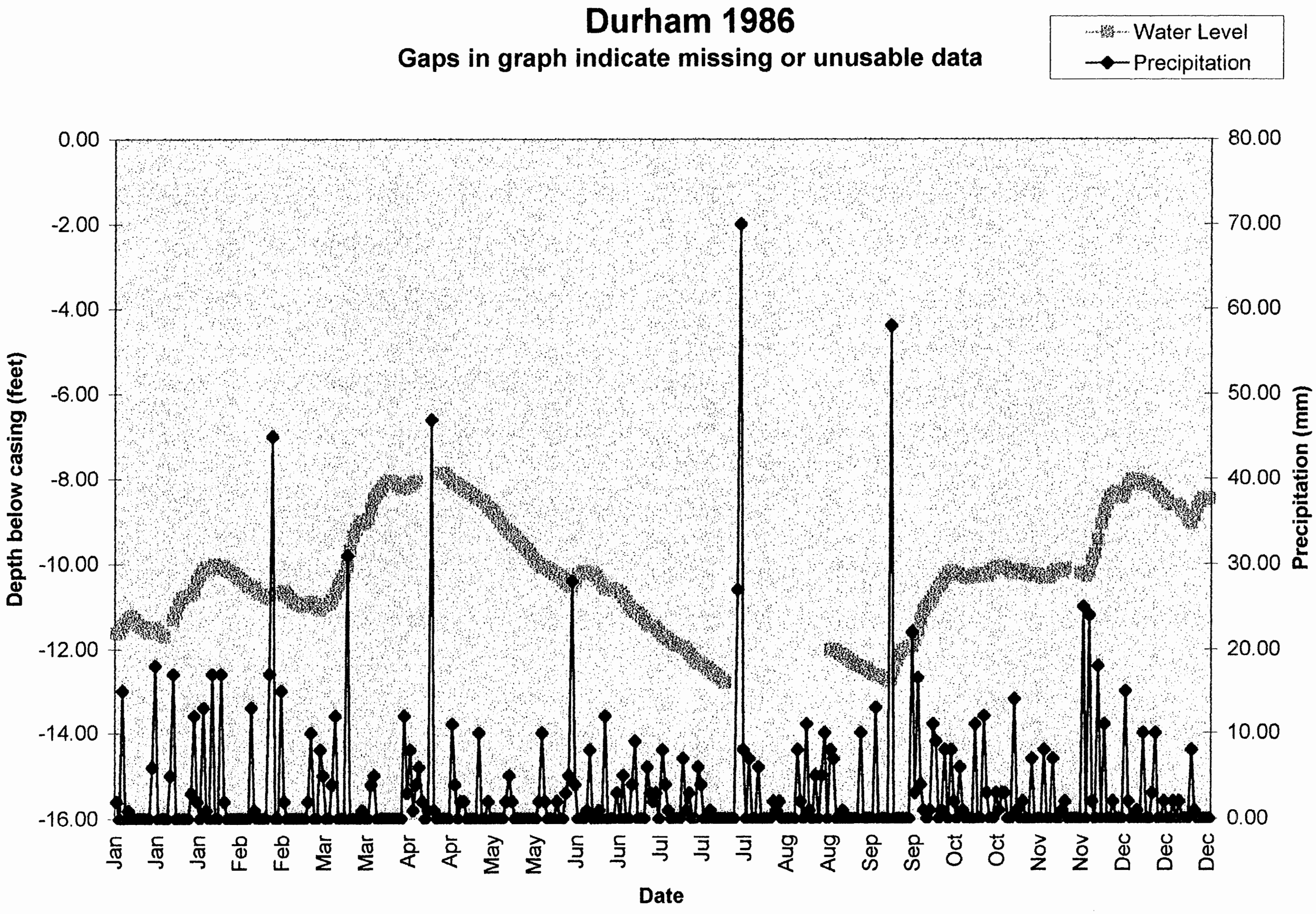
Durham 1986
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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Precipitation (mm)
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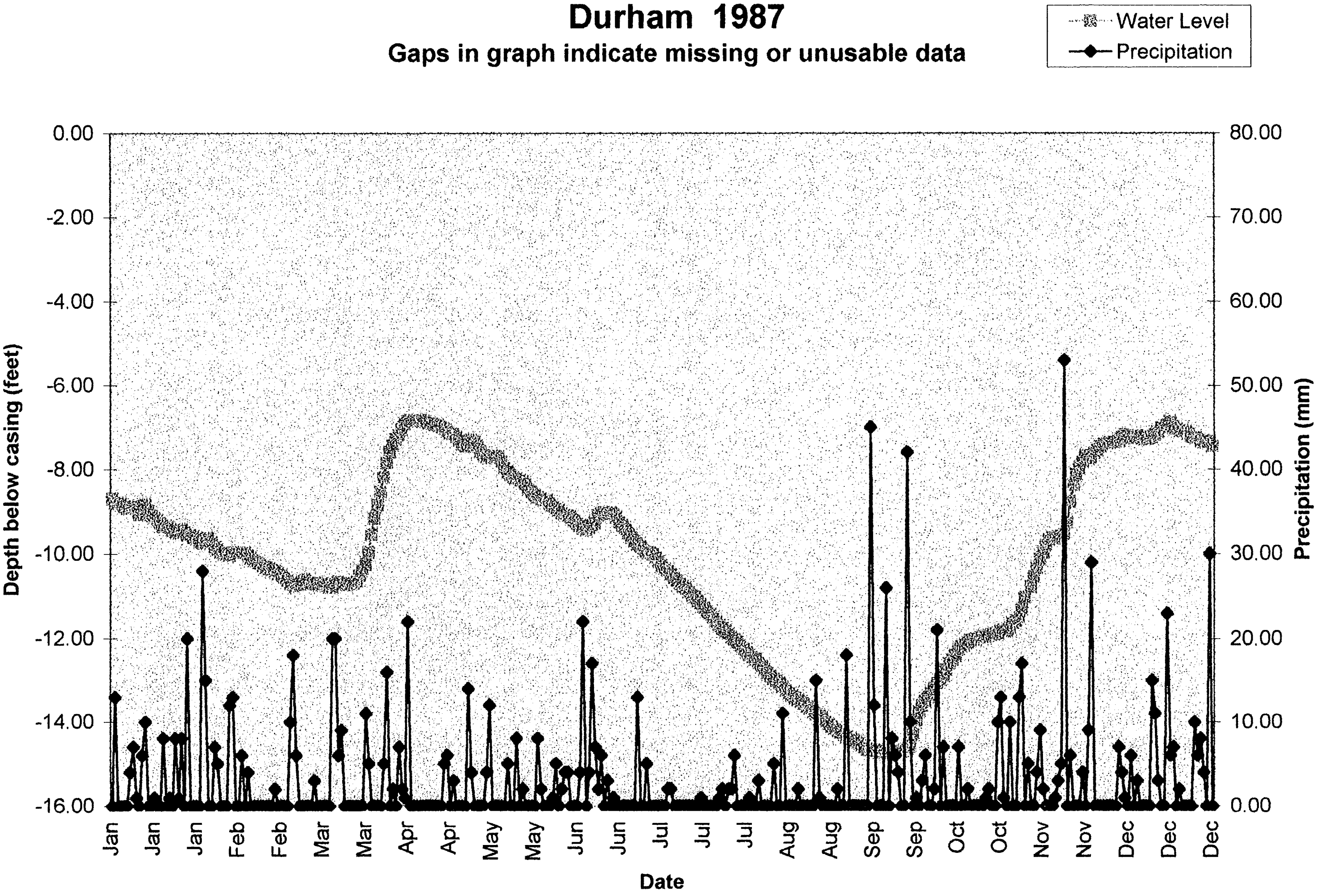
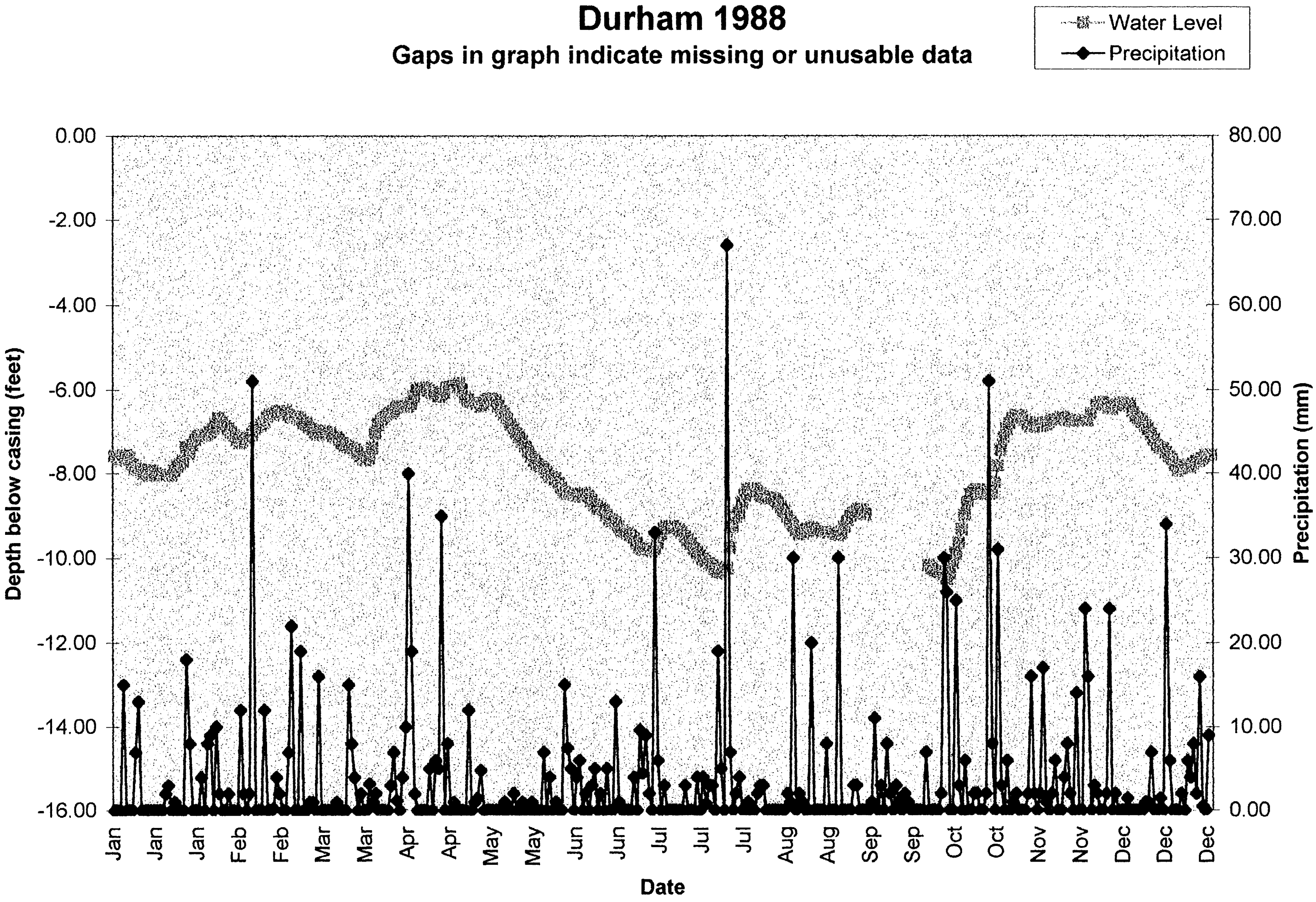
Durham 1987

Gaps in graph indicate missing or unusable data





Durham 1988

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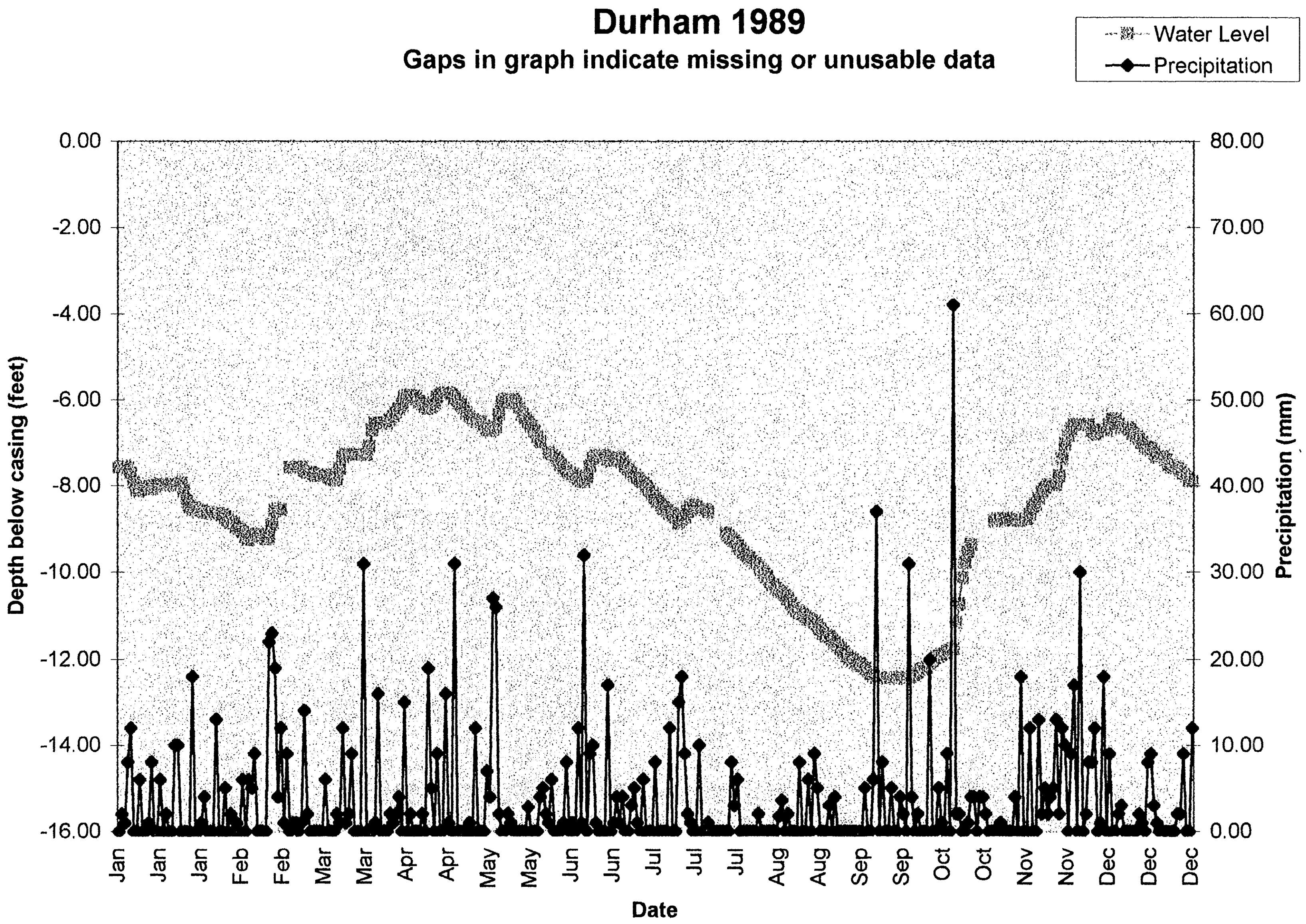
Durham 1989
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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Precipitation (mm)
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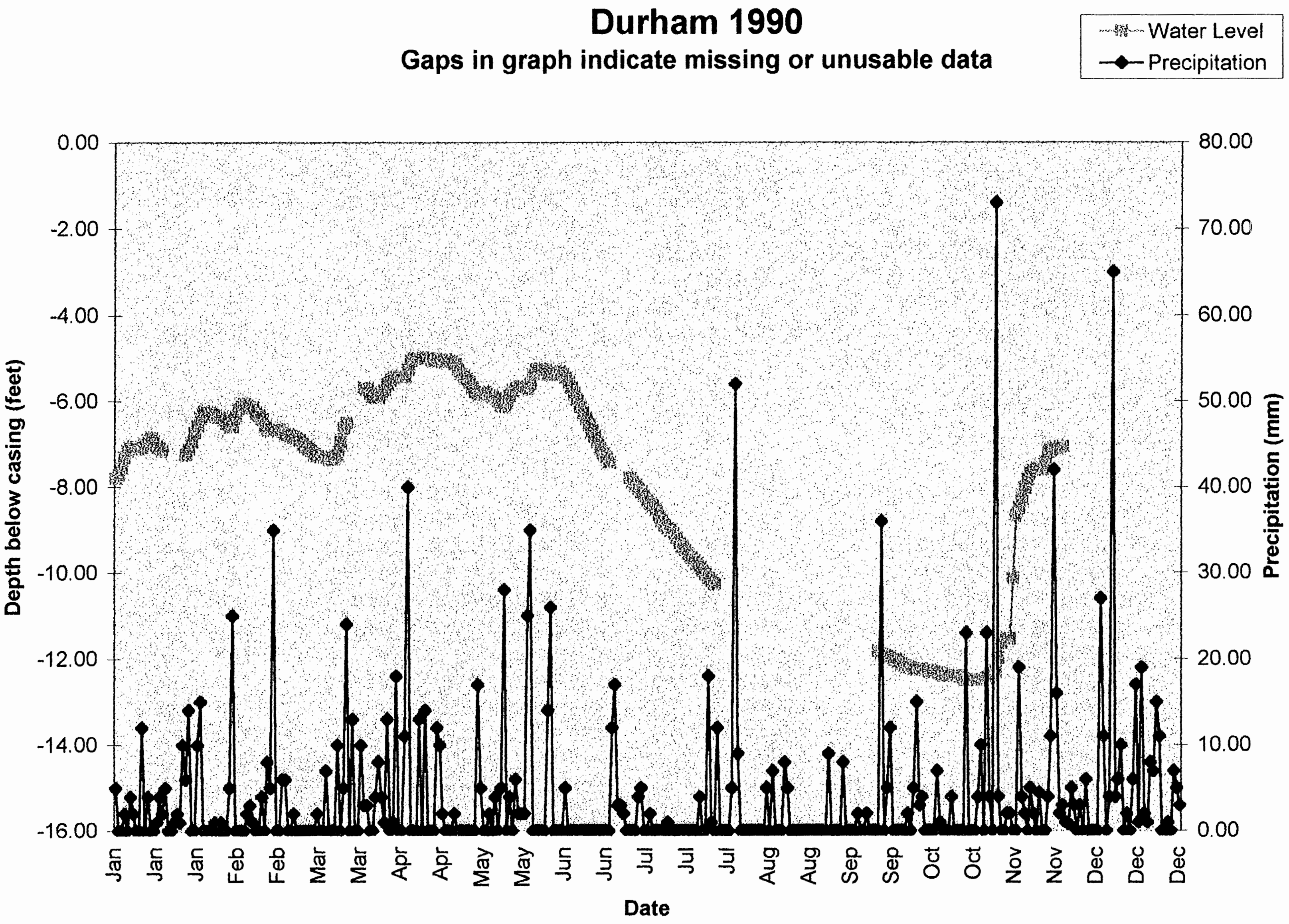
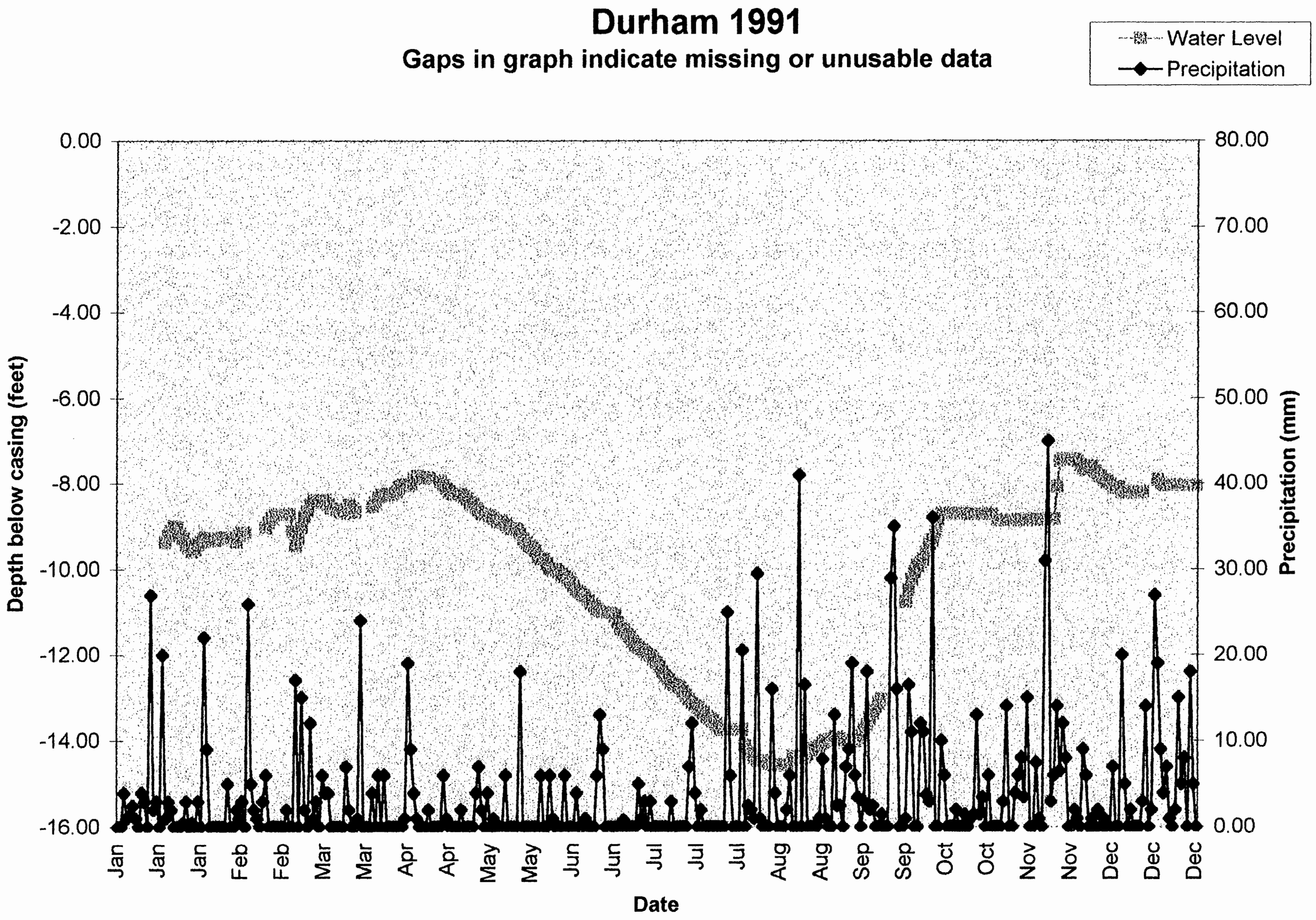


Durham 1990

Gaps in graph indicate missing or unusable data


Durham 1991
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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Precipitation (mm)
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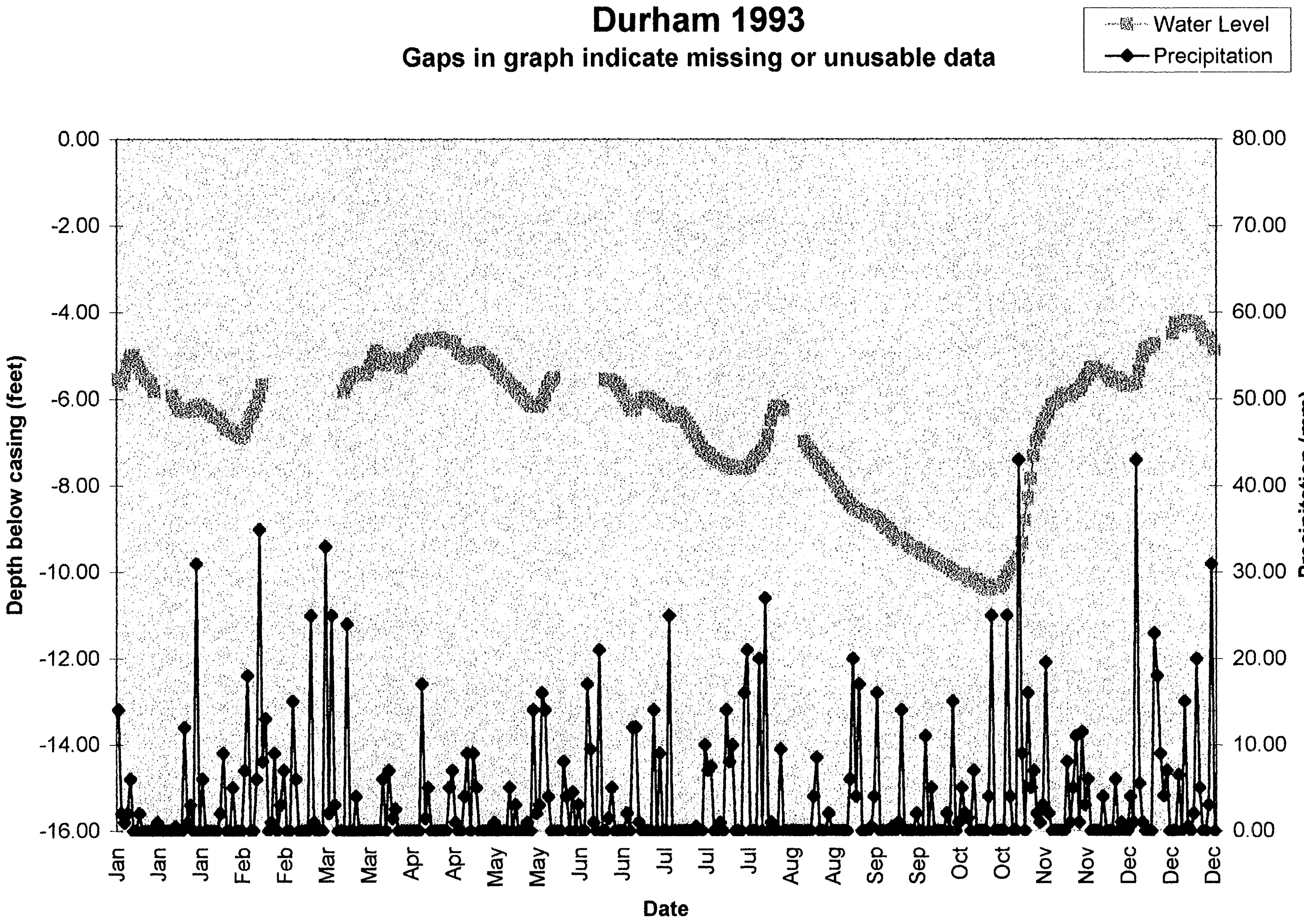
Durham 1993
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
0.00
-2.00
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Precipitation (mm)
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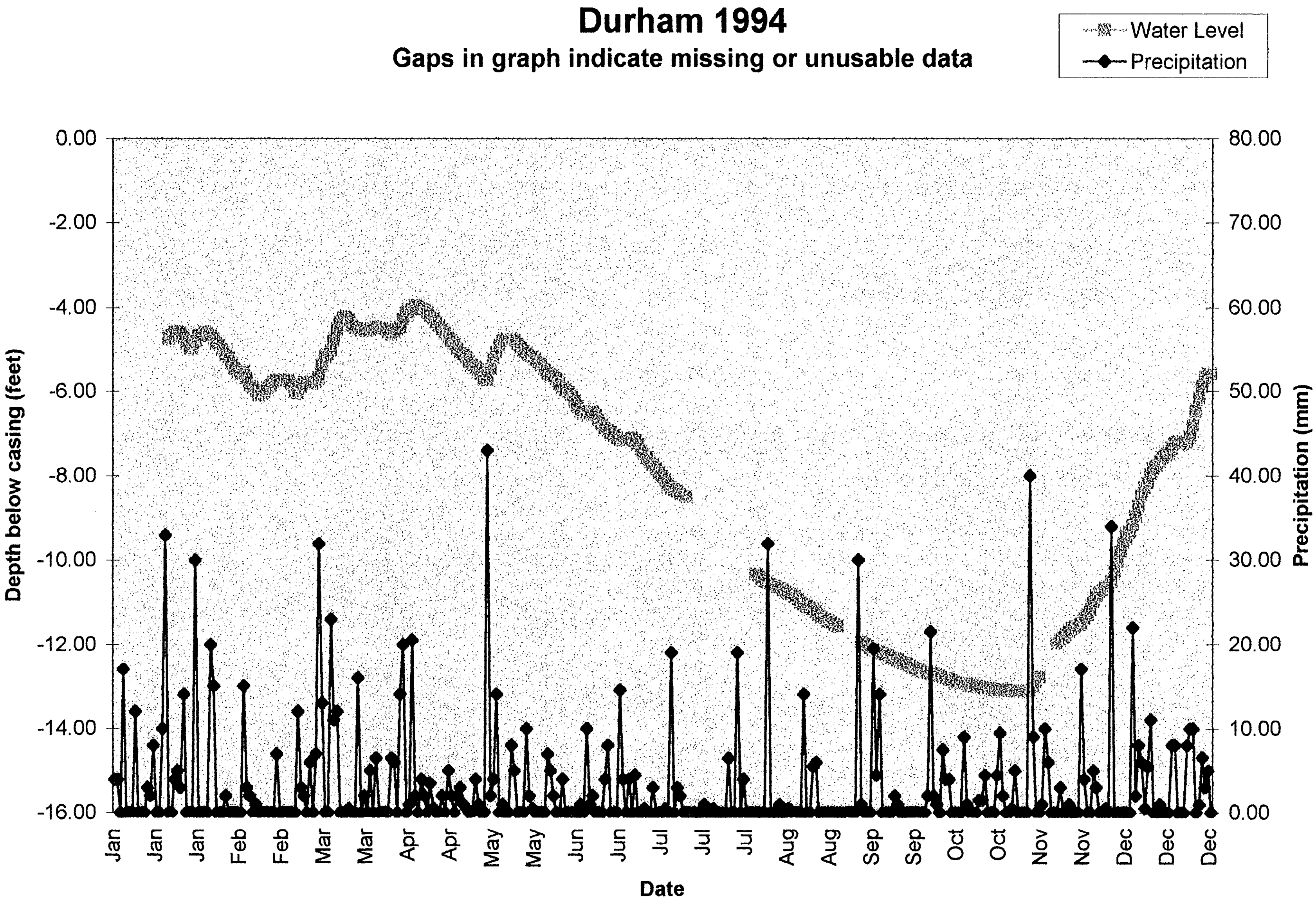
Durham 1994
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
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Precipitation (mm)
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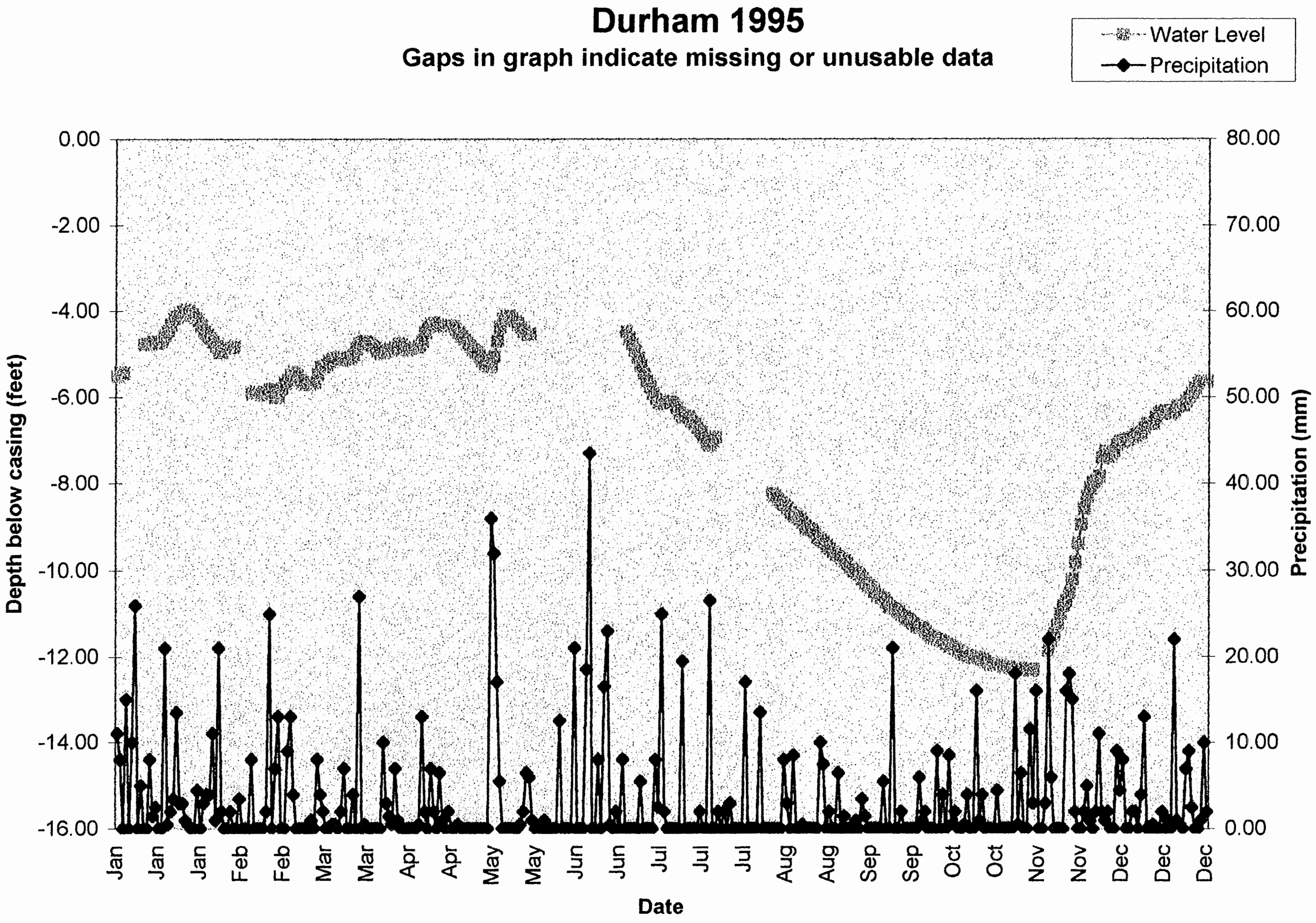
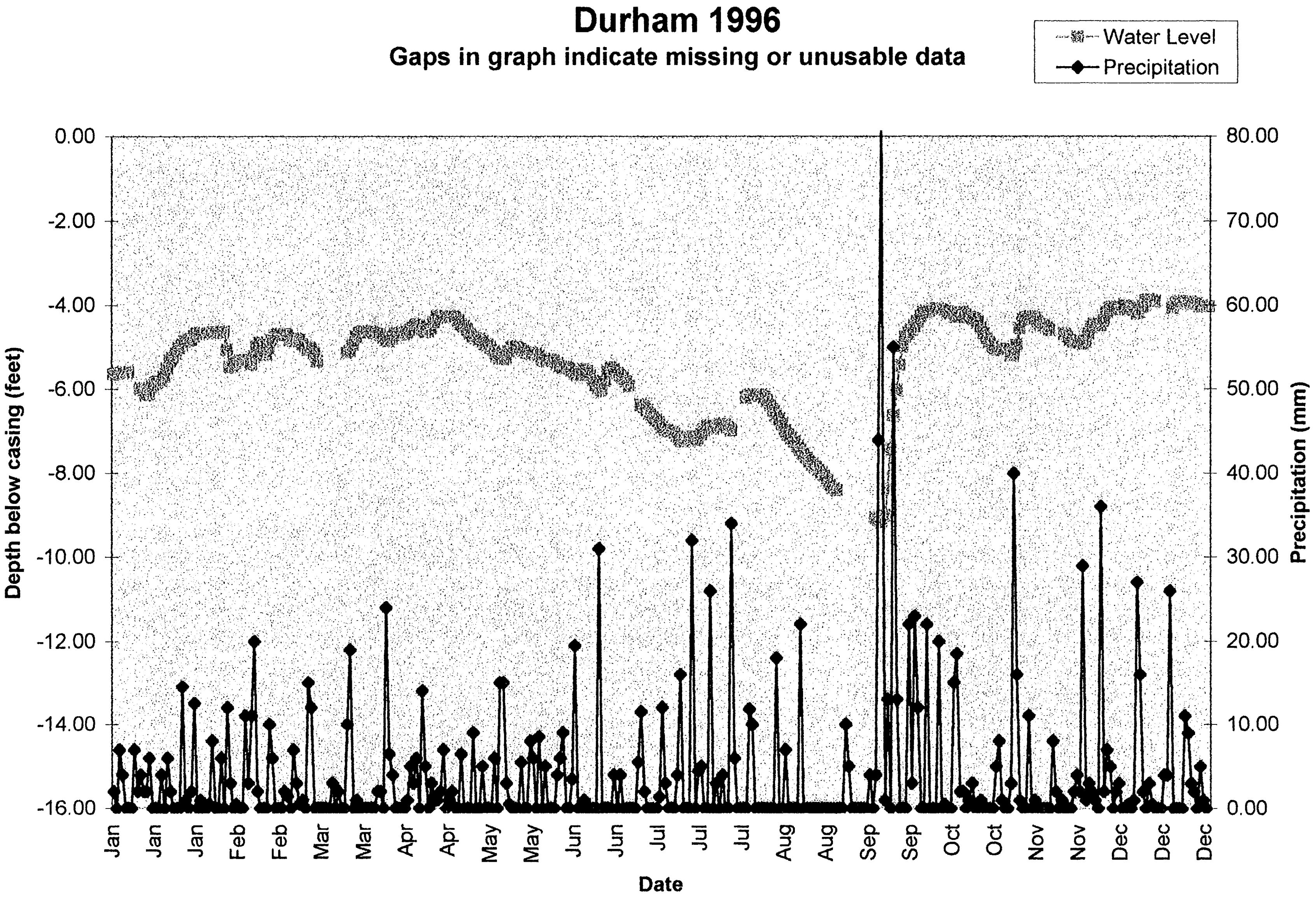
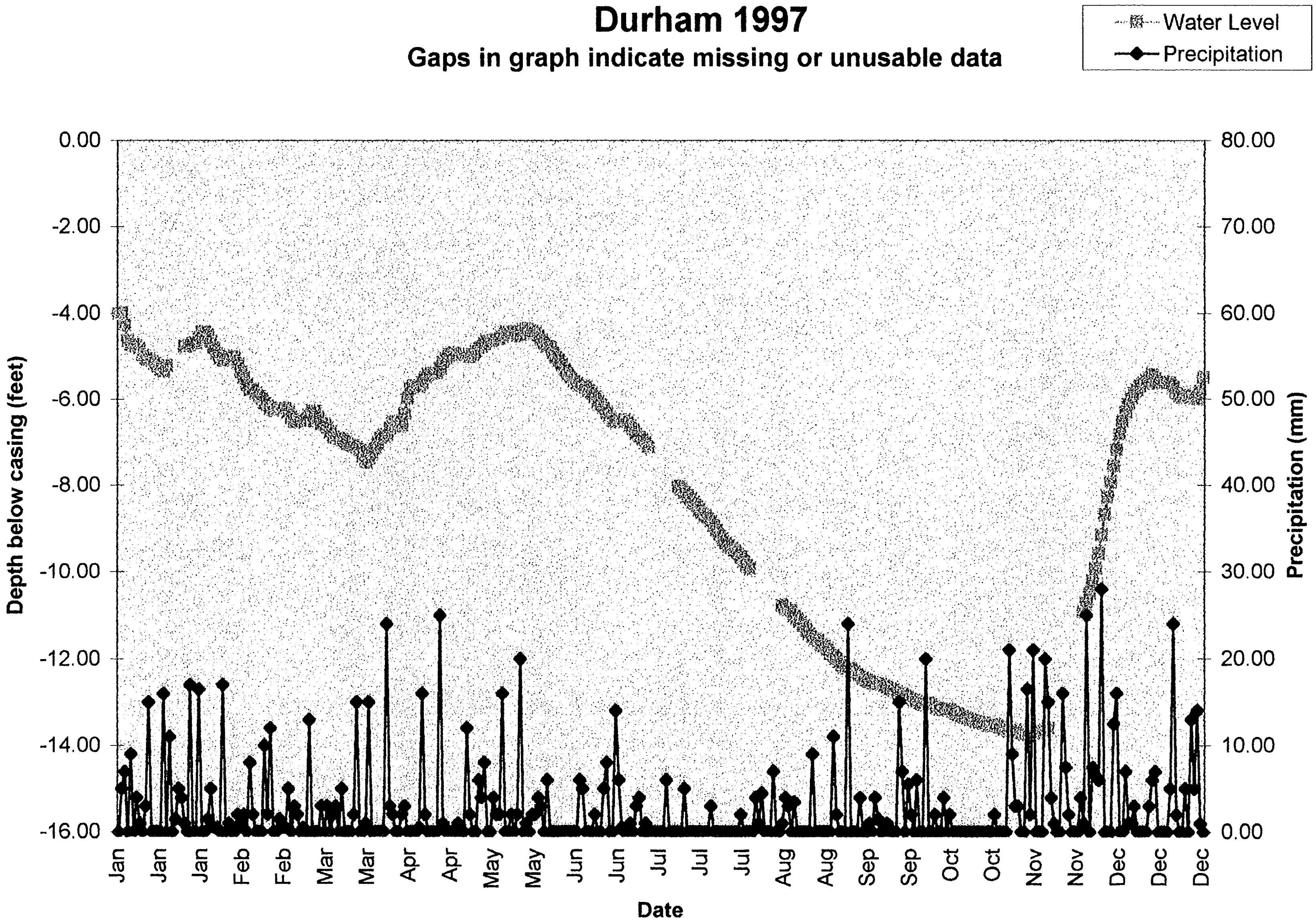


Durham 1995

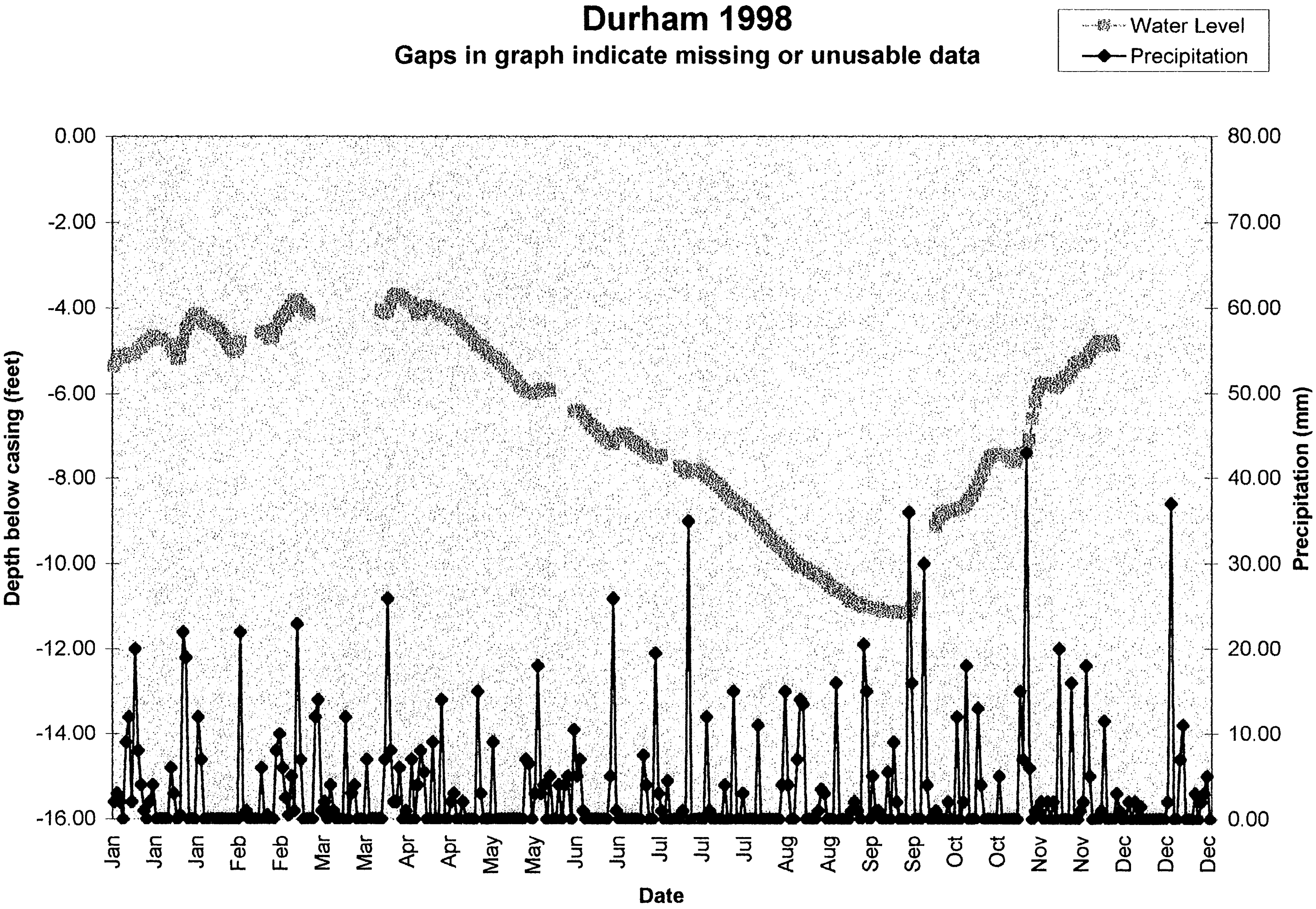
Gaps in graph indicate missing or unusable data


Durham 1996
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
Depth below casing (feet)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Precipitation (mm)
Jan
Jan
Jan
Feb
Feb
Mar
Mar
Apr
Apr
May
May
Jun
Jun
Jul
Jul
Jul
Aug
Aug
Sep
Sep
Oct
Oct
Nov
Nov
Dec
Dec
Dec
Date



Durham 1997

Gaps in graph indicate missing or unusable data



Durham 1998
Gaps in graph indicate missing or unusable data
Water Level
Precipitation
Depth below casing (feet)
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
Precipitation (mm)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Jan
Jan
Jan
Feb
Feb
Mar
Mar
Apr
Apr
May
May
Jun
Jun
Jul
Jul
Jul
Aug
Aug
Sep
Sep
Oct
Oct
Nov
Nov
Dec
Dec
Dec
Date

Durham 1999

Gaps in graph indicate missing or unusable data