Final Report

on

Hydrological Investigations Wood Buffalo National Park 1985 to 1990

TR91-06WB

Prepared for:

Parks Canada, Wood Buffalo National Park
Fort Smith, NWT

by:

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MANAGEMENT PERSPECTIVE

The project described herein was initiated by the National Hydrology Research Institute (NHRI) in 1985. However, NHRI involvement in the Pine Point area, south of Great Slave Lake, dates back to early 1976, when Pine Point Mines requested that NHRI join them in a joint research project aimed at understanding ground water flow in the Pine Point, Great Slave Lake Region. The initial reason for undertaking the study was to assist Pine Point Mines in better designing dewatering systems for the open pit operations. In 1983, an unpublished report was prepared by Dr. K. U. Weyer, entitled: "Salt Dissolution, Karst Geology, Glacial Events and Groundwater Flow in the Pine Point Region" . That report stated that ground water flow in the Pine Point-Great Slave Lake area was via highly karstified (and hence highly permeable) aquifers, which are interconnected regionally. A further conclusion of the report was that there is no significant permeability impedance between the Pine Point Barrier complex being dewatered, and the extensively karstified formations underlying Wood Buffalo National Park. These conclusions were of great interest to the Canadian Parks Service, the Environmental Protection Service of Environment Canada, and the Government of the Northwest Territories. The implications of Dr. Weyer's findings were discussed extensively during the Northwest Territories Water Board Technical Advisory Committee meetings of 1985.

As a result of the report and its conclusions, a further study was commissioned. Geological Testing Consultants Ltd (GTC) of Ottawa was retained by NHRI to model the regional ground water flow, using available hydrogeological data obtained from Pine Point Mines (in the vicinity of the reef complex), and other sources. The main conclusion of the GTC report was that the model-predicted effects of dewatering beyond the reef were insignificant. The model indicated that recharge to dewatering operations from Great Slave Lake was nil. Clearly, there was a difference of opinion between the authors of the two reports.

The Wood Buffalo National Park Study described in this report was initiated at the request of the Canadian Parks Service and the Environmental Protection Service in 1985. The overall aim of the project was initially to monitor the impact of Pine Point dewatering operations on wetlands in the Park, with particular attention to the whooping Crane nesting grounds. A program of shallow drilling was undertaken in 1985. Since that time, the main activities associated with the study have been the monitoring of surface- and ground water levels at three sites in the Park, remote sensing to delineate areas of ground water recharge, and sampling to determine the hydrochemistry of surface waters at the three study sites.

Pine point ceased operations in 1987. However, the Canadian Parks Service at Fort Smith remained interested in the long term viability of the wetlands, and for this reason, it was decided to continue the monitoring work begun in 1985.

ABSTRACT

The extensive wetlands of northeastern Wood Buffalo National Park are the breeding ground for the world's only migratory population of whooping cranes (Grus americana). During the seventies, the commissioning of Pine Point Mines, near the south shore of Great Slave Lake, north of the Park necessitated open pit dewatering, which was seen as a possible threat to the existence of the wetlands, owing to a postulated lowering of regional ground water levels. It is generally agreed that a decline of water levels in the wetlands might affect the availability of food, possibly enhance the accessibility of the nesting sites to predators, or have other deleterious effects on the Whooping Crane. Therefore, the Canadian Parks Service has been justifiably interested in the viability of the wetlands.

With the cessation of dewatering from Pine Point in 1987, this interest remained, particularly in light of recent concerns about climatic change.

Ground water research in the Park was undertaken in 1985, with the completion of 14 shallow piezometers, two observation wells, and nine staff gauges to record the depth to the water table and the level of local ponds. Since that time, yearly sampling of surface waters, staff gauge measurements, and ground water level measurements have continued. The Department of Indian and Northern Affairs has provided routine measurement of discharge from two major springs in and near the Park. In addition, a remote sensing study, using both aerial photography, and satellite imagery was implemented.

The data collected from 1985 to 1990 show a strong trend toward lower mean annual water levels in the wetland areas studied. Seepage measurements made at three pond sites in 1985 indicate that much of the topography in the Park near the foot of the Caribou Mountains is discharge karst. This conclusion is strengthened by the observation of thick marl deposits on the bottom of many of the shallow ponds in the central and northern part of the Park. The contribution of large volumes of ground water to the wetlands from a regional ground water flow system probably originating in the Caribou Mountains would tend to stabilize the wetlands against short term decreases in annual precipitation. However, although the yearly fluctuations seen in both the ponds and shallow piezometers indicate that the wetland study sites benefit from ground water discharge, ground water seepage of itself does not appear to be adequate to maintain the ponds during periods of drier weather.

In 1986, a proposal was prepared by NHRI, which suggested that the monitoring of the three sites in the Park be continued until 1990, at which time sufficient data would have been gathered to allow some conclusions to be made with respect to visible trends in surface and ground water availability in the whooping crane nesting area.

This report is the final compilation of hydrologic and chemical data collected over 1985-1990 by Parks Canada, INAC, and IWD personnel, in Wood Buffalo National Park.

TABLE OF CONTENTS

FIGURES (at back of report)

LIST OF TABLES

INTRODUCTION

This report presents the results of a study carried out for Canadian Parks Service by the National Hydrology Research Institute (NHRI) and the Environmental Protection Service (EP), from 1986 to 1990, concerning the fate of wetlands in Wood Buffalo National Park. The study was begun in 1985.

PURPOSE

Wood Buffalo National Park is the nesting ground for the only migratory population of Whooping Cranes (Grus americana), which depend upon the extensive wetlands in the Park to provide suitable habitat. The original purpose of the study, was to see if the dewatering operations at Cominco's Pine Point Mine, which had been going on since 1971, was causing any detectable lowering of water levels in the wetlands within the Park.

Due to prohibitive ground water dewatering costs, Pine Point Mines suspended its operations in 1987. However, concerns about climate change and its possible effect on the wetlands which make up the Whooping Crane nesting grounds remained, and the study has continued.

REGIONAL SETTING

Wood Buffalo National Park is situated on the Alberta-Northwest Territories boundary (Figure 1). Geologically, it overlies the easternmost extent of the Palaeozoic sediments of the Western Canada Sedimentary Basin. The Slave River, which flows in a northeasterly direction along the eastern boundary of the Park, traces out the topographically low area where the Palaeozoic sedimentary rocks overlap the Proterozoic rocks of the Precambrian Shield.

It has been postulated that the great ground water discharge zone which occupies much of the low-lying area of the Park originates in the Western Canada Sedimentary Basin. The Basin, with its southwesterly dipping strata, is a vast ground water flow system, which is recharged in the Cordillera, and is thought to discharge along the Palaeozoic-Proterozoic contact in northeastern Alberta, northern Saskatchewan, and through the Interlake region of Manitoba. Lowland areas of Wood Buffalo National Park in fact show classical evidence of ground water discharge, the most notable being the development of extensive discharge karst topography, characterized by chemical precipitation of minerals dissolved in the upwelling ground waters, and extensive salt deposits along river valleys which focus discharge (eg. the Salt River). However, stratigraphic and hydrochemical evidence indicates that most of the discharging ground waters originate in a more localized (albeit very large) ground water flow system originating in the Caribou Mountains, the Birch Hills, and the Cameron Hills. These would tend to act as relatively local per turbations on the regional flow system, and could provide a very large flux of ground water to the wetlands and to the saline discharges along river valleys such as the Salt River. A detailed description of the area's hydrogeology is included in a report submitted to NHRI by Geologic Testing Consultants Ltd (GTC), of Ottawa (1983), and an unpublished report by K. U. Weyer (1983).

DATA COLLECTED

In 1985, the Sass, Klewi, and Sass-Klewi sites were selected by NHRI and Parks personnel, for the investigation of ground and surface water conditions (Figure 2). In 1986, in consultation with the Canadian Wildlife Service, the number of surface water study sites was expanded to include the Nyarling, Little Buffalo, and North Klewi sites.

The instrumentation at the first three sites included shallow piezometers (from less than a metre, to up to 3 metres in depth), and staff gauges in adjacent marl ponds, for the measurement of water levels in the ponds (Figure 3). Instrumentation at the three sites added in 1986 was restricted to staff gauges.

A diamond drill rig was retained in 1985 to drill two observation wells to bedrock along highway 5, to the south and west of the study areas (Figure 2). These wells, D1 and D2, were equipped with steel casing, and are used for the measurement of depth to ground water.

The work completed in 1985 included the use of seepage meters to measure the flux of ground water into the marl ponds at the three study sites. The investigators concluded that there is a significant measurable seepage flux of ground water into the marl ponds at the three sites. This data was included in the NHRI's interim report (Nobert and Barry, 1986). The detection of ground water discharge is in line with the presence of thick marl layers on the bottom of the ponds, and the observed calcite/gypsum saturation of the waters.

The field data collected over 1986 to 1990 include:

Surface water chemistry

Samples have been collected from the three field sites annually by Canadian Parks Service personnel, and analyzed by N.H.R.I.

Surface water gauge measurements

Gauge measurements at the six sites have been made each year by Canadian Parks Service personnel, to record water level variations in the marl ponds. The measurements were made during the spring, summer and fall. Sufficient readings were taken to allow reasonable confidence in graphing the data as a time series.

Ground water level measurements

Ground water depth measurements were continued in the 14 shallow piezometers drilled in 1985 in order to record variations in the depth to ground water at the Sass, Klewi, and Sass-Klewi Sites. More frequent readings were made in the two wells, D1 and D2 along Highway 5.

Spring discharge measurements

Discharge measurements were made on a time-of-visit basis at Angus Tower Spring within the Park, and Half-Way Spring, to the north (Figure 2).

Ground water chemistry

Water samples were collected from the two springs at time of visit, and analyzed by INAC. No sampling was done in the piezometers located at marl pond sites.

Existing data collected from other sources include:

River discharge data

These data were used to investigate any discernible trends toward greater or lesser flow in the rivers with time, and to compare any flow trends in large rivers draining significant areas of the northern Interior plains (such as the Slave), to smaller rivers (such as the Buffalo), draining areas within the Park.

Remote sensing

A contract for remote sensing work was let in 1988 to the Saskatchewan Research Council. The contractor was to use LANDSAT MSS and NOAA satellite imagery to identify areas of ground water discharge in the Park immediately to the east and northeast of the Caribou Mountains, where most of the discharge-related surface features are found.

Due to the lack of suitable ground truthing, the LANDSAT component of the study was not successful in generating an accurate classification of the area of interest. However, the NOAA image obtained does show a correspondence between the infrared energy emitted by the ground, and areas where ground water discharge features are seen on aerial photographs.

Aerial photography

A suite of air photos, covering the area to the north and east of the Caribou Mountains, was used to identify topography indicative of ground water discharge. The principal indicator is solution karst, infilled with marl, which is easily visible on aerial photographs. Under these conditions, large areas of the land surface are dotted with myriad white-bottomed ponds, which indicate the upwelling of ground water with attendant precipitation of calcium carbonate, gypsum, and other evaporites from a super saturated solution. These minerals are deposited, along with organic material and some clay, as marl, which gives the ponds their distinctive white-bottomed appearance.

LANDSAT Thematic Mapper imagery

False colour images were obtained, to assist in the delineation of ground water discharge areas.

DISCUSSION

Hydrometric Data

Slave River

Because of the large size and drainage area of the Slave River, its discharge record provides a better indication of major regional trends toward wetter or dryer conditions than data from smaller streams.

Figure 4 shows the instantaneous flow record for the Slave River from 1953 to 1990. The figure indicates that while there has been a very general tendency for flows to follow a somewhat sinusoidal pattern, with a period of about 10, there is no visible tendency for flows in the river to increase, or decrease over the long term. The relatively low flows periods (e.g. 1968, 1981) are ascribed to dry climatic conditions that year and the higher flows seen from 1972 to 1976 indicate wetter conditions. Annual minimum flows also vary from year to year, which means that the baseflow component, most in evidence during the winter months is also dependent upon the climatic cycle, but in a more subdued fashion. This evidence suggests that a significant amount of the ground water input to the river is from flow systems wherein the ground waters have a fairly short residence time. It follows that if all the baseflow to the river is supplied by the regional flow system discharging from the Western Canada Sedimentary Basin or the Caribou Mountains, then the year to year variation in minimum flows would not track the prevailing climatic trends. In comparison to precipitation, surface water, and bank storage inputs, the contribution to the river from large regional ground water flow systems is relatively constant, and masked behind ground water and surface water inputs which vary much more greatly over shorter periods. To quantify the contribution to the Slave River from the various inputs is beyond the scope of this project.

season, when precipitation, and other inputs do not keep up with evapotranspiration, and other losses. Water levels reach their low point in the late summer and fall, then begin rising again through the winter months, when evapotranspiration is nil, and ground water input continues. This water level rise is augmented in the spring when the snow melts, to begin the cycle anew.

There has been a very distinct decrease in water level elevation over the period 1985-1990 in all of the monitored ponds. This decline is likely due to a drop in precipitation over the period 1988-1990, which, if one takes the hydrometric data and continues it onward in time, is indicated as part of the 10-year cycle evi dent in the hydrometric data. In 1981, for instance, which the hydrometric data indicate to have been an extremely dry year, the marl ponds were also very low (E. Kuyt, pers. comm.).

Ground Water Levels

Figure 9 shows the elevation of ground water in 13 of the 14 shallow piezometers drilled in 1985 at the Sass, Klewi, and Sass-Klewi sites. Measurement data are included in Appendix B. Piezometer P11 remained dry or frozen for most of the period of record and is not included. Readings show a similar pattern of water level variation observed in the pond gauges. This indicates that the ponds are the surface expression of conditions in the shallow ground water zone. The ground water data show that there has been a very definite decline of ground water levels over the period of record (1985 to 1990). As described above for the staff gauge readings, this is due to a gradual decrease in precipitation in the area, in accordance with the observed data.

Water levels in observation wells D1 and D2 drilled along Highway 5 are graphed in Figure 10, and shown in Appendix C.. Well D2 shows a much greater annual water level fluctuation than D1. This is probably due to the geology of material overlying the water table at the two sites. It is probable that the storage capacity of overburden encountered at D1 is higher than that of the dense clayey sandy silt found at D2. Assuming that equivalent amounts of precipitation are received at the two well sites, this would explain the difference in the water level response between the two wells. The pattern of response is similar to that of the ponds and the shallow piezometers, but there are some significant differences. The two wells show a water level rise in the spring, as would be expected, when the water table rises in response to snowmelt. The water levels drop during the summer as expected, but unlike the shallow piezometers and the marl ponds, the levels continue to drop over the winter, because these sites are in a ground water recharge area. No rise in water level is observed until spring.

Water levels in the two bedrock wells likewise show a definite drop in water levels over the period of record. This drop in water levels is attributed to a reduction in precipitation during the period of observation.

Spring Discharge

Discharge data for the two springs are shown in Figure 11. Both show a fairly regular response to snowmelt and summer precipitation, with a delay of a couple months, resulting in a sudden increase in discharge rate toward the middle of the year. This shows that the springs receive much of their discharge water from local recharge, not from the regional ground water flow system. Over the period of record, there does not appear to be any long-term consistent trends in discharge rate, and this is probably due to local precipitation effects in the recharge areas, rather than any regional change in water balance.

Angus spring responds more regularly than Half-way spring, which did not respond at all to snowmelt or precipitation events in 1987, for instance. The reason for this is unknown, but could certainly be related to localized variations in precipitation, or differences in elevation of the two springs.

Precipitation

A plot of total annual precipitation for Fort Smith Airport and Hay River (stations 2202200 and 2202400, respectively) is shown in Figure 12. Data for these, and a number of other stations in the Pine Point/ Great Slave Lake Region are included in Appendix A. While these are data from only two stations, it is assumed that these records are nevertheless indicative of regional precipitation levels.

Significant low precipitation periods occurred in the mid- to late forties, 1959, 1969 through 1972, and in the late seventies/early eighties. The precipitation variations are reflected in river and lake levels. By association, the water levels in the marl ponds and in the shallow connected ground water zone seems to likewise be strongly dependent on precipitation. The occurrence of drought in the region therefore appears to have a strong effect on the water levels in the ponds, and ground water discharge is insufficient to maintain water levels without precipitation input.

Hydrochemistry

Table 1 summarizes the chemical analyses of waters from the Half-Way and Angus Tower springs and Table 2 shows the chemistry of the marl ponds. The data are also presented in Figures 13 and 14 as Piper trilinear diagrams, which show the relative contribution of various major ions to the total ionic strength of the solution.

The Piper diagrams show a greater scatter of data points for the marl ponds than for the springs. Most of the spring samples plot virtually on top of one another in the diagram, with the exception of two samples from the Angus, and one sample from the Half-way Spring. This is in line with the general observation

Table 1: Hydrochemical Analyses, Waters from Half-way and Angus Tower Springs
(mg/L, unless otherwise indicated)

Sample Location	Date	Temp (C)	pH	Cond (umho/cm)	TDS	Tot. Hard	Tot. Alk.	Ca	Mg	Na	K	Cl	SO4	S	HCO3
Angus	07-Jan-86		7	2800	2600	2000	260	660	92	27.3	1.73	40	355	0.005	316.9
Angus	28-Apr-86		7	2500	2600	1800	260	580	94	27	1.9	32	1500		316.9
Angus	11-May-86		6.94	2600	2570	1600	264	490	95	28	2.5	33	1300	6	321.8
Angus	28-May-86		7.1	2400	2500	1600	280	510	74	20	1.4	18	1400	13	341.3
Angus	30-Jun-86		7.1	3400	2500	1800	270	550	95	25.2	1.8	51	1300		329.1
Angus	30-Jul-86		7	2500	2600	260	260	570	86	28	2.4	26	1300		316.9
Angus	05-May-87		7	2700	2500	1700	260	530	92	27	2	33	1400	11	316.9
Angus	04-Jun-87		7.2	2600	2600	1500	260	460	85	27	2.2	44	1500	9.6	316.9
Angus	29-Jun-87	5	7.62	1500				554	188	27.3	2	36.	1300		
Angus	13-Aug-87		7	2600	2600	1700	270	530	95	32	2.3	47.	1500	11	329.1
Angus	03-Dec-87		7.1	2700	2500	1800	290	550	93	27	2.2	48	1600	9.7	353.5
Angus	05-Aug-88		7.2	2500	2540	1600	264	490	90	25	2	49	765	11.5	321.8
Angus	21-Oct-88	3	7.26	2800				473	95.	29.1	2.32	37.	1450		
Angus	05-Jul-89	4.6	7.01	2560	2470	1740	253	554	86	29	2.1	35	1460		308
Angus	07-Feb-89		7.1	2700	2700	1540	326	468	91.	29	2.4	41	1850	14.19	397.39
Half-way	28-Apr-86		3.6	920	730	500	90	180	14	1.9	2.8	2	560		109.7
Half-way	28-May-86		7.1	2500	2600	1600	280	500	90	28	1.3	31	1500	4.5	341.3
Half-way	30-Jun-86		7.1	3400	2500	1800	270	560	89	25.9	1.7	34	1400		329.1
Half-way	30-Jul-86		6.9	2500	2600	1700	250	550	91	29	2.4	34	1500		304.8
Half-way	29-Jun-87	21	8.1	2300				571	95.	22.2	3.8	20	1261		0.0
Half-way	11-May-88		6.84	2500	2460	1700	271	540	79	20	2.3	19	1300	5.7	330.3
Half-way	05-Aug-88		7.1	2600	2570	1600	274	500	86	23	2.3	40	23	12.9	334.0
Half-way	21-Oct-88	3	7.02	2810				559	88.	28.6	2.22	31	1416		
Half-way	05-Jul-89	4.4	7.07	2550	2450	1730	258	555	83	29	2.1	28	1440		315
Half-way	06-Feb-89		7.1	2700	2700	1530	333	471	87	27	2.4	28	1750	17.54	405.93

that ground water chemistry is usually fairly constant over time, while surface waters are influenced by precipitation, ground water seepage, evapotranspiration, and biological activity. The data shown in Table 2 indicate that the marl ponds' chemistry is more variable with respect to the absolute concentrations of ionic species, as well as the relative concentrations.

The trilinear diagrams indicate that the chemistry of ground water discharge (evident in the springs and in the marl ponds) is greatly affected by the dissolution of gypsum ($CaSO_4.2H_2O$).

Table 2 also shows that the variability of chemistry in the marl ponds is related to the time of year at which a particular pond was sampled. For instance, Klewi pond No. 1 shows a large increase in specific conductance over the period 19-May-1988 to 21-October-1988. The data always show an increase in the con

Table 2: Hydrochemical Analyses, Waters from the Marl Ponds
(mg/L unless otherwise indicated)

Location	Date	Temp (C)	pH	Cond. (mmho/cm)	Ca	Mg	Na	K	Cl	SO4	HCO3
Klewi1	29-Jun-87	20.5	8.65	1.88	255	213	96	6.2	12.4	611	1312.1
Klewi1	19-May-88	4.7	8.2	1.88							
Klewi1	29-Jul-88	17.9	8.68	2.52							
Klewi1	15-Aug-88	15.1	8.67	2.72							
Klewi1	21-Sep-88	6.2	8.27	3.56							
Klewi1	21-Oct-88	0.2	8.42	4.41	526	222	205	8.88	273	1743	589.4
Klewi1	03-Nov-89	0	7.17	11.27	1420	830	678	32	1020	6200	534.0
Klewi1	21-Jun-90	21	9.06	3.56	423	210	180	9.8	269	1770	67.0
Klewi2	19-May-88	2.6	7.97	2.45							
Klewi2	29-Jul-88	18.1	8.47	3.51							
Klewi2	15-Aug-88	15.8	8.44	4							
Klewi2	21-Sep-88	5.9	8.18	5.22							
Klewi2	21-Oct-88	0.3	8.12	0.259							
Klewi2	19-May-88	4.5	8.25	0.75							
Klewi2	29-Jul-88	17.9	8.05	1.351							
Klewi2	15-Aug-88	15.4	8.11	1.508							
Klewi2	21-Sep-88	5.9	8.39	2.33							
Klewi2	21-Oct-88	0.1	8.51	0.408							
LB1	19-May-88	8.5	7.73	1.51							
LB1	29-Jul-88	17.4	7.79	2.08							
LB1	15-Aug-88	20.1	7.57	2.33							
LB2	19-May-88	8.5	7.89	1.47							
LB2	29-Jul-88	21.9	8.72	1.968							
LB2	15-Aug-88	20.4	8.53	2.21							
LB3	19-May-88	9.4	8.2	1.21							
LB3	29-Jul-88	24.3	9.16	1.87							
LB3	15-Aug-88	21.1	8.56	2.1							
NK1	19-May-88	5	7.7	0.99							
NK1	29-Jul-88	18.2	8.65	1.563							
NK1	15-Aug-88	15.9	8.61	1.658							
NK1	21-Sep-88	7.3	8.21	2							
NK1	21-Oct-88	0.3	8.47	1.479							

Table 2, Continued: Hydrochemical Analyses, Waters from the Marl Ponds
(mg/L unless otherwise indicated)

Location	Date	Temp (C)	pH	Cond. (mmho/cm)	Ca	Mg	Na	K	Cl	SO4	HCO3
NK2	19-May-88	5.2	8.28	0.838							
NK2	29-Jul-88	18.2	8.44	1.393							
NK2	15-Aug-88	15.9	8.71	1.514							
NK2	21-Sep-88	7.63	8.63	1.86							
NK2	21-Oct-88	0.1	8.56	1.09							
NK3	19-May-88	4.6	8.1	0.381							
NK3	29-Jul-88	18	7.82	0.692							
NK3	15-Aug-88	15.4	8.15	0.722							
NK3	21-Sep-88	7.1	8.51	0.91							
NK3	21-Oct-88	0.1	8.58	0.858							
Nyar1	19-May-88	6.5	7.98	1.68							
Nyar1	29-Jul-88	18.2	8.6	2.65							
Nyar1	15-Aug-88	16.3	8.82	2.75							
Nyar1	21-Sep-88	7	8.44	3.27							
Nyar1	21-Oct-88	1	8.36	3.41							
Nyar2	19-May-88	5.7	8.11	1.2							
Nyar2	29-Jul-88	17.9	8.75	1.909							
Nyar2	15-Aug-88	15.9	8.76	2.02							
Nyar2	21-Sep-88	6.4	8.21	2.54							
Nyar2	21-Oct-88	0.5	8.16	2.34							
Nyar3	19-May-88	6.9	7.96	1.46							
Nyar3	29-Jul-88	18.2	8.23	2.2							
Nyar3	15-Aug-88	16.3	8.03	2.32							
Nyar3	21-Sep-88	7.5	8.44	2.72							
Nyar3	21-Oct-88	1.5	8.49	3							
PPM GO3	18-Jul-88		7.6	3.1	530	160	44	3	101.	1700	203.9
PPM GO3	18-Jul-88		7.5	3.1	540	160	50	3	137	1700	189.1
Sass1	29-Jun-87	20	8.3	1.125	186	65.	29.	5.6	24.5	442	377.6
Sass1	19-May-88	4	8.31	0.92							
Sass1	29-Jul-88	17.4	8.12	1.555							
Sass1	15-Aug-88	14.9	7.91	1.733							
Sass1	21-Sep-88	6.2	8.18	2.22							
Sass1	21-Oct-88	1.4	8.53	1.308	390	131	66	8.67	54.6	1132	501.5
Sass1	03-Nov-89	0.1	6.71	5.65	1040	395	194	25	186	4060	396.0
Sass1	21-Jun-90	19.6	8.86	2.2	326	118	58	11	51	1240	73.0
Sass2	19-May-88	4.1	8.45	1.09							
Sass2	29-Jul-88	16.8	7.96	2.06							
Sass2	15-Aug-88	14.5	7.95	2.27							
Sass2	21-Sep-88	5.6	8.41	2.69							
Sass2	21-Oct-88	-0.01	9	1.187							
Sass3	19-May-88	4.2	7.87	1.2							
Sass3	29-Jul-88	15.6	7.89	2.32							
Sass3	15-Aug-88	12.9	7.65	2.48							
Sass3	21-Sep-88	5.4	8.35	2.71							
Sass3	21-Oct-88	0	8.45	0.799							
SK1	29-Jun-87	30	8.77	2.2	454	117	23.	4.5		923	866.2
SK1	19-May-88	6.6	8.06	1.6							
SK1	29-Jul-88	19.6	8.51	2.11							
SK1	15-Aug-88	15.7	7.07	1.681							
SK1	21-Sep-88	7.3	8.13	3.06							

Table 2, Continued: Hydrochemical Analyses, Waters from the Marl Ponds (mg/L unless otherwise indicated)

Location	Date	Temp (C)	pH	Cond. (mmho/cm)	Ca	Mg	Na	K	Cl	SO4	HCO3
SK1	21-Oct-88	1.5	8.35	3.62	825	106	28.	2.22	31	1416	1270.8
SK1	03-Nov-89	0.6	7.36	5.84	1270	185	104	13	124	3680	252.0
SK1	21-Jun-90	27.1	8.78	2.56	633	77	39	5.4	48	1780	60.0
SK2	19-May-88	8.6	8.18	1.17							
SK2	29-Jul-88	20.5	8.7	1.864							
SK2	15-Aug-88	17.8	8.79	1.924							
SK2	21-Sep-88	8	8.21	2.45							
SK2	21-Oct-88	1.1	7.86	3.02							
SK3	19-May-88	8	8.82	0.38							
SK3	29-Jul-88	18.7	6.98	1.511							
SK3	15-Aug-88	16.3	7.24	2.62							
SK3	21-Sep-88	8.8	7.5	0.242							
SK3	21-Oct-88	1.8	8.32	0.804							

centration of chemical species (as indicated by specific conductance) in the ponds over the period spring to late winter. This is due to the greater relative contribution of ground water to the volume of water in each pond, as snowmelt is used up and ground water discharge takes precedence over precipitation in the late summer and fall.

Remote Sensing

Saskatchewan Research Council Study

The results of the Saskatchewan Research Council (SRC) remote sensing contract were presented in a report submitted to Canadian Parks Service in July, 1988 (Saskatchewan Research Council, 1988). Although SRC was not successful in using the LANDSAT Multi-spectral Scanner (MSS) image for delineating areas of ground water discharge in the Park, the NOAA satellite image (Figure 2, page 8 of the SRC report) showed a good correspondence between areas of ground water discharge as indicated by the presence of marl ponds, and emission in the near infra-red. The NOAA image was taken in late autumn, when the contrast between the temperature of the ground water recharge zones and ground water discharge zones is the greatest, yet no ice or snow has formed to interfere with the emmision of infra-red radiation from the ground surface. Darker colours on the figure show areas of higher ground temperature. There appears to be a distinctly higher ground temperature in an area surrounding the Caribou mountains, extending northward to Great Slave Lake. To the east, the ground temperature falls off until red areas on the image are very small and patchy. It is assumed that ground water discharge areas are measurably warmer than recharge areas, and that the higher infrared emittance from the area around the Caribou Mountains is due to discharge from a major ground water flow system originating in the mountains themselves.

Aerial Photography

Aerial photographs were used to delineate areas of ground water discharge, as indicated by a combination of solution karst, and marl pond development. The analysis indicates that the study areas selected for this study are all within a zone of discharging solution karst. This is confirmed by geochemical and hydrological data described above.

LANDSAT Thematic Mapper Imagery

In 1989, LANDSAT Thematic Mapper (TM) images were obtained from the Canada Centre for Remote Sensing, in the form of false colour images of the entire Park and surrounding region. The thematic mapper images, with their high resolution, were used with aerial photographs, to identify areas of ground water discharge.

SUMMARY AND CONCLUSIONS

It is likely that the Caribou Mountains are a large regional recharge feature. Precipitation falling on the uplands infiltrates downward, into underlying Devonian aquifers, then radially outward and upward into discharge areas characterized by solution karst. The extensive discharge area shows up as a relatively high emittor in the near-infrared as detected by the NOAA satellite.

Gauge measurements of the ponds show strong annual fluctuations in water level elevation, with maxima occurring right after the spring snowmelt, and minima occurring in late summer, presumably when evapotranspiration has removed water at a rate greater than it is replenished from ground water. When evapotranspiration shuts down in the fall, ground water inflow causes the water levels to rise, and the rise is augmented with spring snowmelt the following year.

The data collected so far indicate a definite decline in the ponds over the period of record, visible despite cyclical annual fluctuations. When one considers the cyclical hydraulic regime of the major rivers and Great Slave Lake, it would appear that no substantial increase in pond and shallow ground water levels can be expected to occur until after the mid-nineties.

The record of flow from Angus Tower and Half-way springs indicates that they are affected by seasonal changes in ground water recharge (snowmelt, and precipitation). Angus Tower spring is affected by meteoric water input in a more direct and regular way than Half-way spring. Although the reason for this is unknown at this time, these data tell us is that discharge from the springs is not made up exclusively of ground water upwelling from a regional flow system, but is in fact controlled to a large degree by local recharge. With the exception of a few samples, the hydrochemistry of the two springs is very constant over the period of sampling. Ground water chemistry is regulated by mineral dissolution in the subsurface, which explains the constancy in ionic ratios on the trilinear diagrams. The fact that three spring samples plot far off the norm on the diagram, however indicates that local, rapid recharge of precipitation or snowmelt may be routed to spring discharge before significant alteration in chemistry can take place.

Ground water levels show the same basic pattern of rise and fall as the ponds do, but with a smaller annual fluctuation.

Surface water and ground water elevations show a distinct decline over the period of record. It is likely that this is due to the gradual reduction in total annual precipitation, which drives the cyclical fluctuations in major rivers and lakes in the region. Spring discharge measurements also show a direct relationship to meteoric water input. If one attributes the drop in marl pond levels to the 10 or 11-year precipitation cycle, then water levels can be expected to start rising again in the mid-1990's.

Ground water hydrochemistry is controlled to a large degree by the dissolution of carbonates and gypsum in the subsurface. The Muskeg Formation of Upper Middle Devonian age is probably the source of calcium sulphate which characterizes the water quality of the marl ponds in the Park. Owing to the great size of the flow system controlled by the topography of the Caribou Mountains, it is likely that consistent changes in the rate of ground water discharge over time will take place very slowly, and would not be visible over the short time that data has been collected for this study.

RECOMMENDATIONS

This report has presented a variety of hydrogeologic, hydraulic, and geochemical data, in a general way. More detailed information on the hydrochemistry and hydrogeology of the Alberta portion of the Park was collected in the early nineteen-seventies by Alberta Research Council, but not yet published (R. Stein, pers. comm). It would be very cost-effective if the Canadian Parks Service provided the resources and struck an agreement with the Alberta Research Council, to extend this database into the Northwest Territories portion of the Park. In so-doing, it would be possible to quantify ground water influx to various areas of the Park (based on geology, hydraulics, geochemistry and stable isotopes), and provide Parks personnel with high-quality scientific information on a world-class geological feature in their Park. Because much of the work has already been done, Parks would receive a huge amount of information virtually free. The Research Council would at the same time receive sufficient funding for pursuing its mapping and research role in Northern Alberta. Information coming out of the research would enhance the Park interpretive program. From the perspective of wetland productivity, it would also allow Parks personnel to predict where the expanding whooping crane population will nest, and set land use priorities accordingly. It is therefore recommended that Canadian Parks Service retain the Alberta Research Council to extend their database into the NWT, complete the associated data interpretation, and provide an extensive, detailed report on findings.

REFERENCES CITED

Polson, J., and Whiting, J. (1988): Use of remotely sensed data for hydrologic investigations in Wood Buffalo National Park; Saskatchewan Research Council Publication E-905-14-E-88

Weyer, K. U. (1983): Salt Dissolution, Karst Geology, Glacial Events, and Ground water flow in the Pine Point region, N.W.T.; unpublished draft report, National Hydrology Research Institute, Environment Canada.

Geological Testing Consultants, (1983): Hydrogeological evaluation of the Pine Point-Great Slave Lake Region; unpubl. consultant's report to Environment Canada, March 30, 1983.

Buffalo River

The Buffalo River shows a similar pattern of long-term flow fluctuation (Figure 5), with relatively low flows occurring in 1980 and 1981, and a cyclical flow pattern over the period of record (1969-1990). The data do not indicate any long-term trend toward lower flows in the Buffalo River, which tends to confirm the observations made above for the Slave. There are times of year that discharge of the Buffalo River approaches zero, indicating that baseflow derived from the deep regional flow system is relatively small. This is because the drainage area of the Buffalo River is mainly on the northern flank of the Caribou Mountains (Figure 2). Long-term, stable baseflow to the river from the regional flow system would not be expected to make up a large part of the river's hydrograph, because of the tendency for regional ground water flow to discharge at lower elevations through more permeable geological strata. This is evidenced by the development of karst in the foreland basin surrounding the Caribou Mountains.

Hay River

The Hay River drains a much larger area than the Buffalo, and therefore has a higher total annual discharge, and baseflow component (Figure 6). The 10 to 11 year cyclical pattern is visible. Again, 1980 shows a significantly lower discharge than in any other year of record. As with the Buffalo River, the baseflow component of the Hay River is very low, relative to the mean annual flow.

Great Slave Lake

Monthly mean water level data for Great Slave Lake were obtained from the Water Survey of Canada, and plotted in Figure 7. These data show a very similar and well-defined cyclicity, with a period of approximately 11 years. The lake level appears to have reached a maximum in 1988, and is currently on the decline. The next minimum to be reached in the cycle will probably occur in mid 1992, after which water levels will begin to rise again.

Surface Water Gauges

A series of graphs (Figure 8) shows the elevation data for the various marl ponds monitored at 10 separate sites in the Park. Three gauges are monitored at each site, and the measurements are expressed relative to an arbitrary datum at each site. Data are shown in Appendix A.

Each site shows a consistent yearly fluctuation in water level elevation. The general pattern consists of a rise in elevation during snowmelt, with the peak occurring sometime in the early summer. The water levels then fall off during the growing

FIGURES

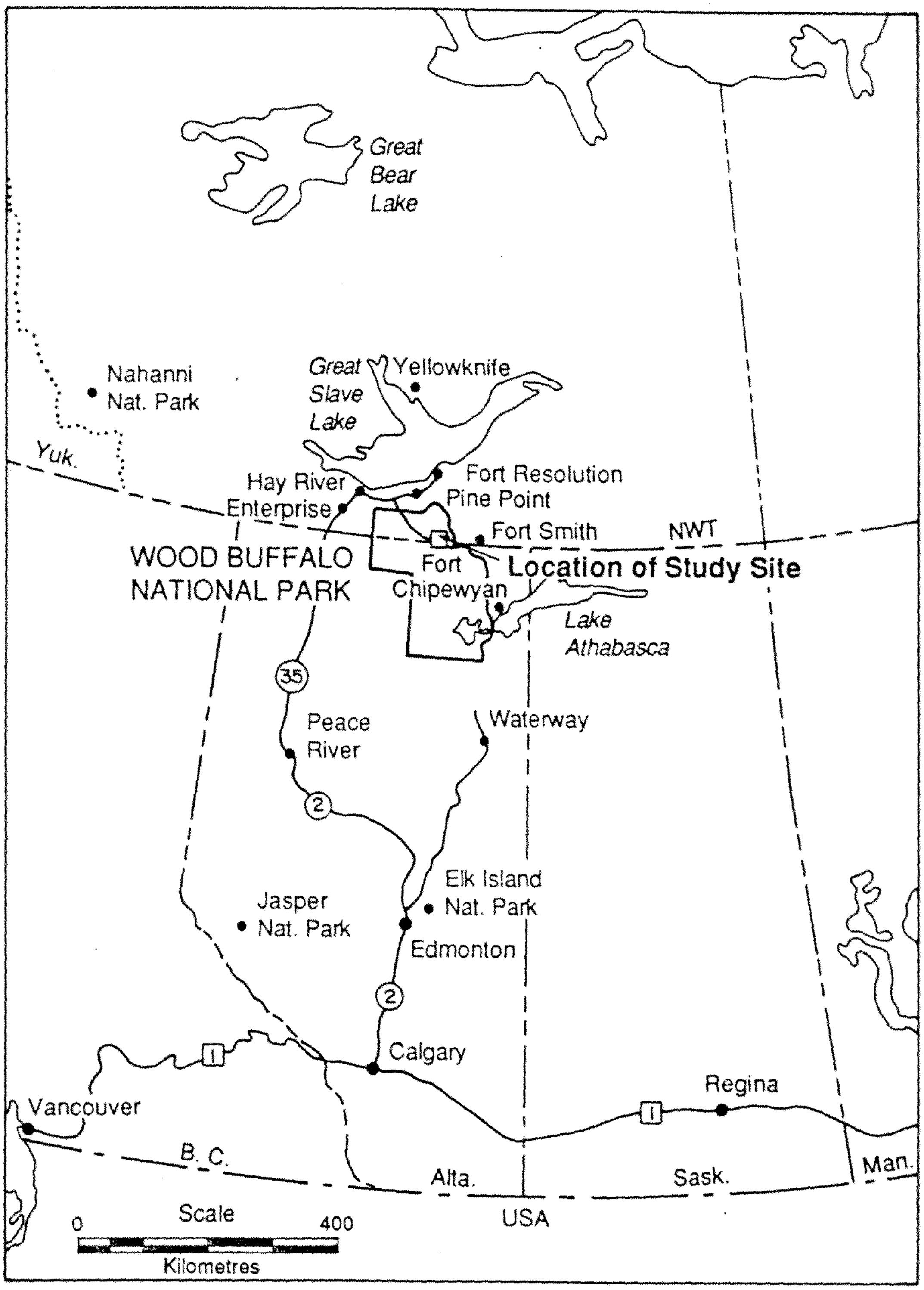


Figure 1:

Location of Wood Buffalo National Park

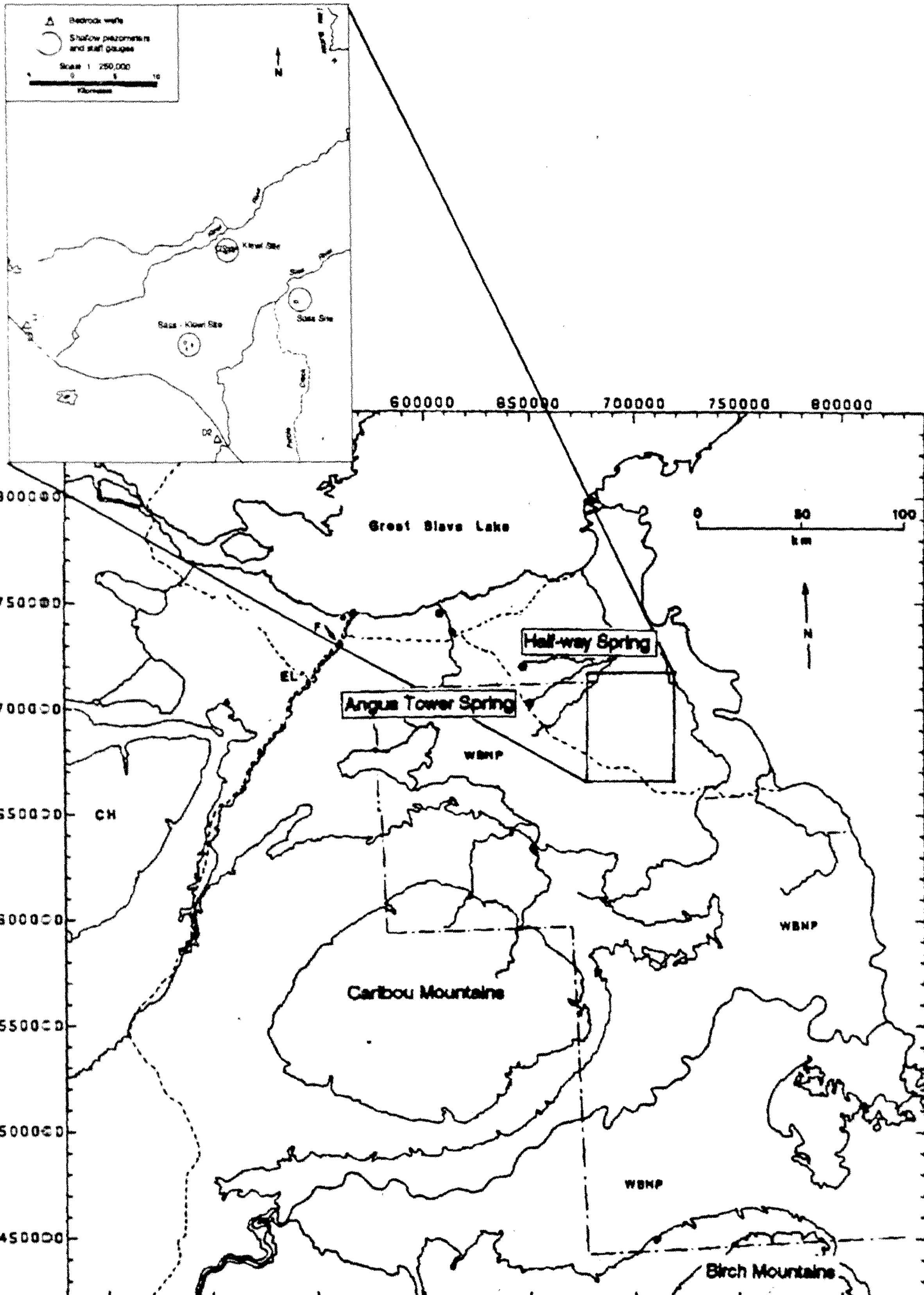


Figure 2: Location of Study Sites and Springs

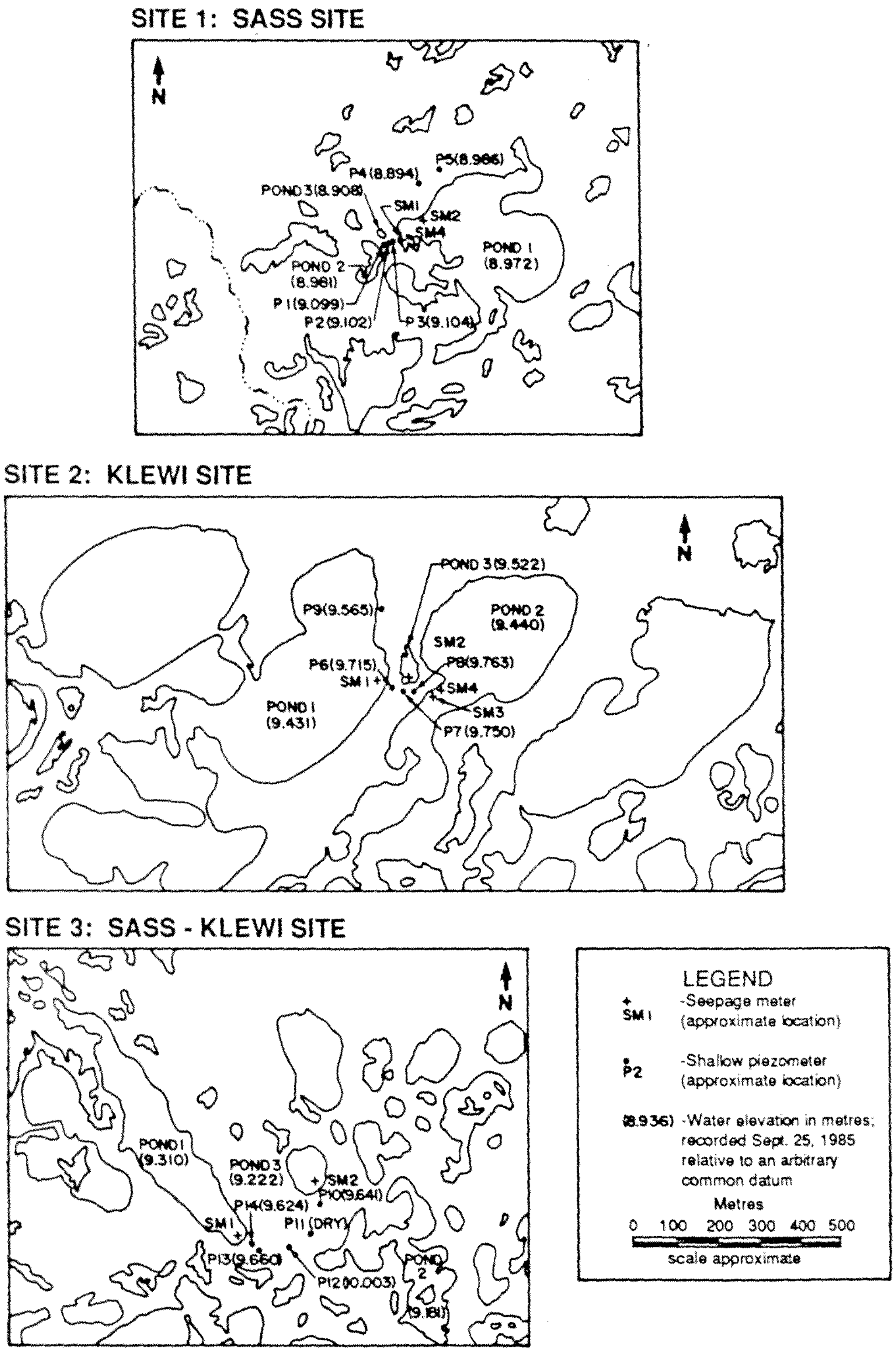


Figure 3: Detailed Map of Study Sites

Figure 4: Instantaneous Discharge,

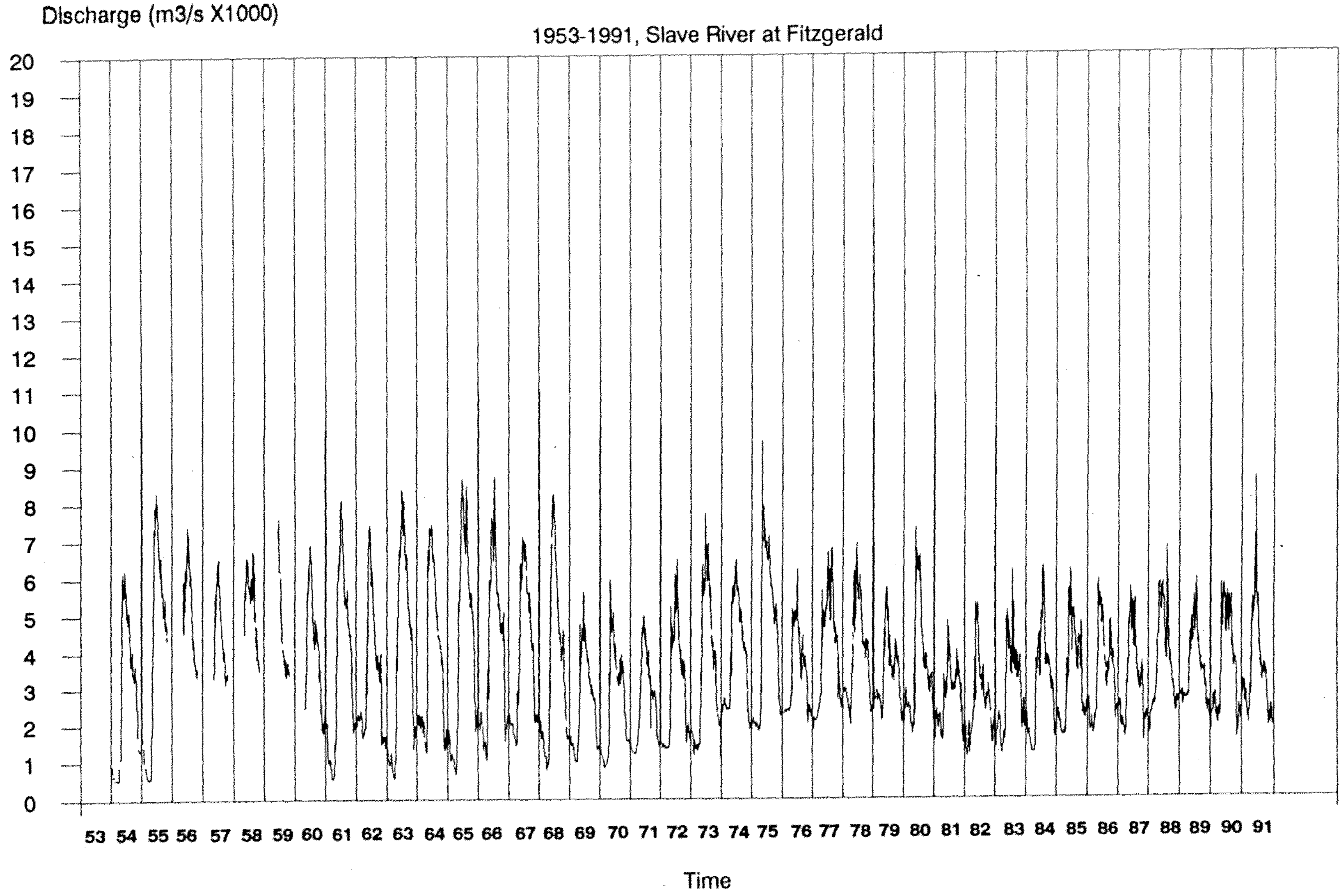


Figure 5: Instantaneous Discharge

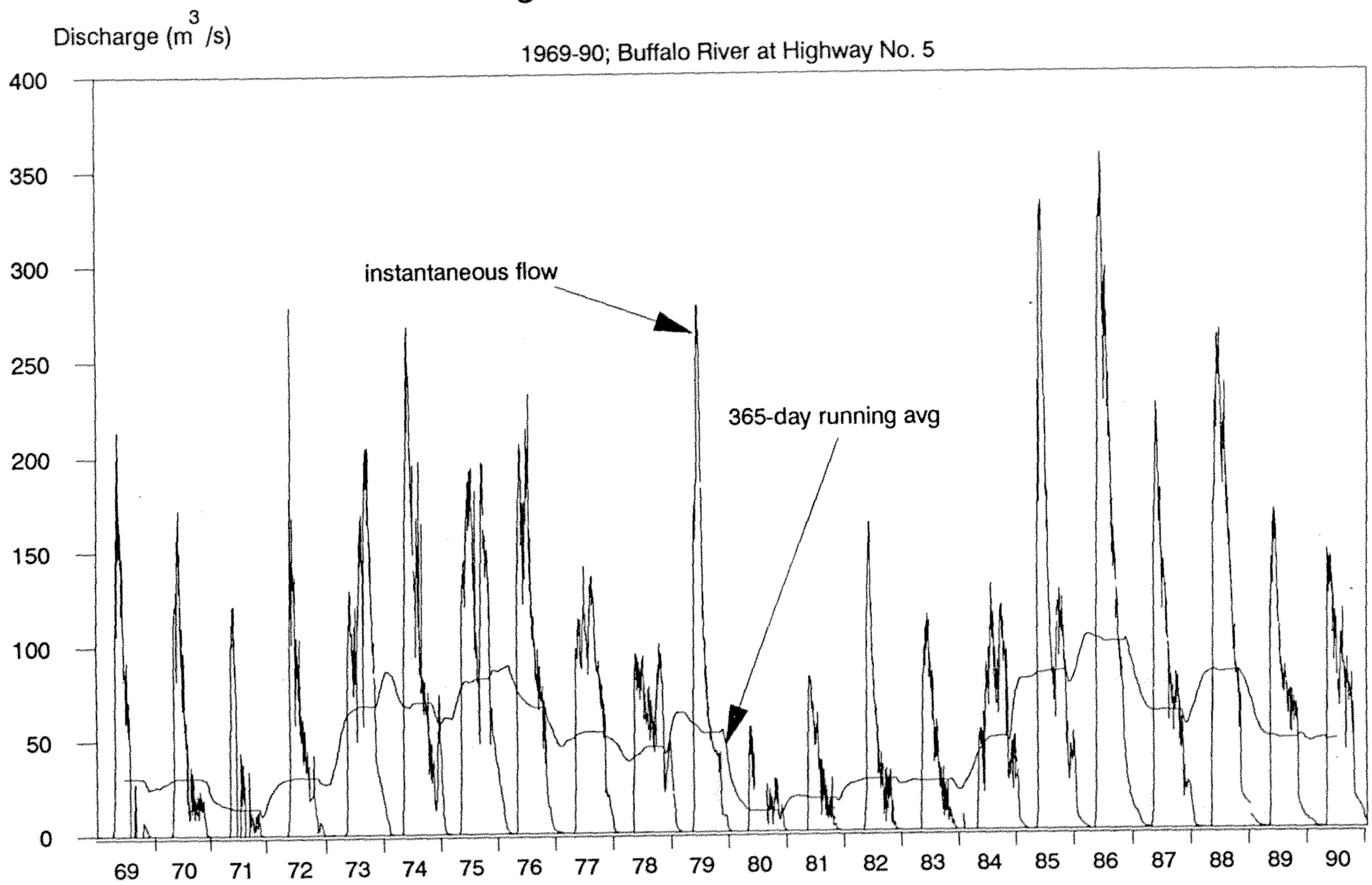


Figure 6: Mean Monthly Discharge

1963-1990, Hay River near Hay River

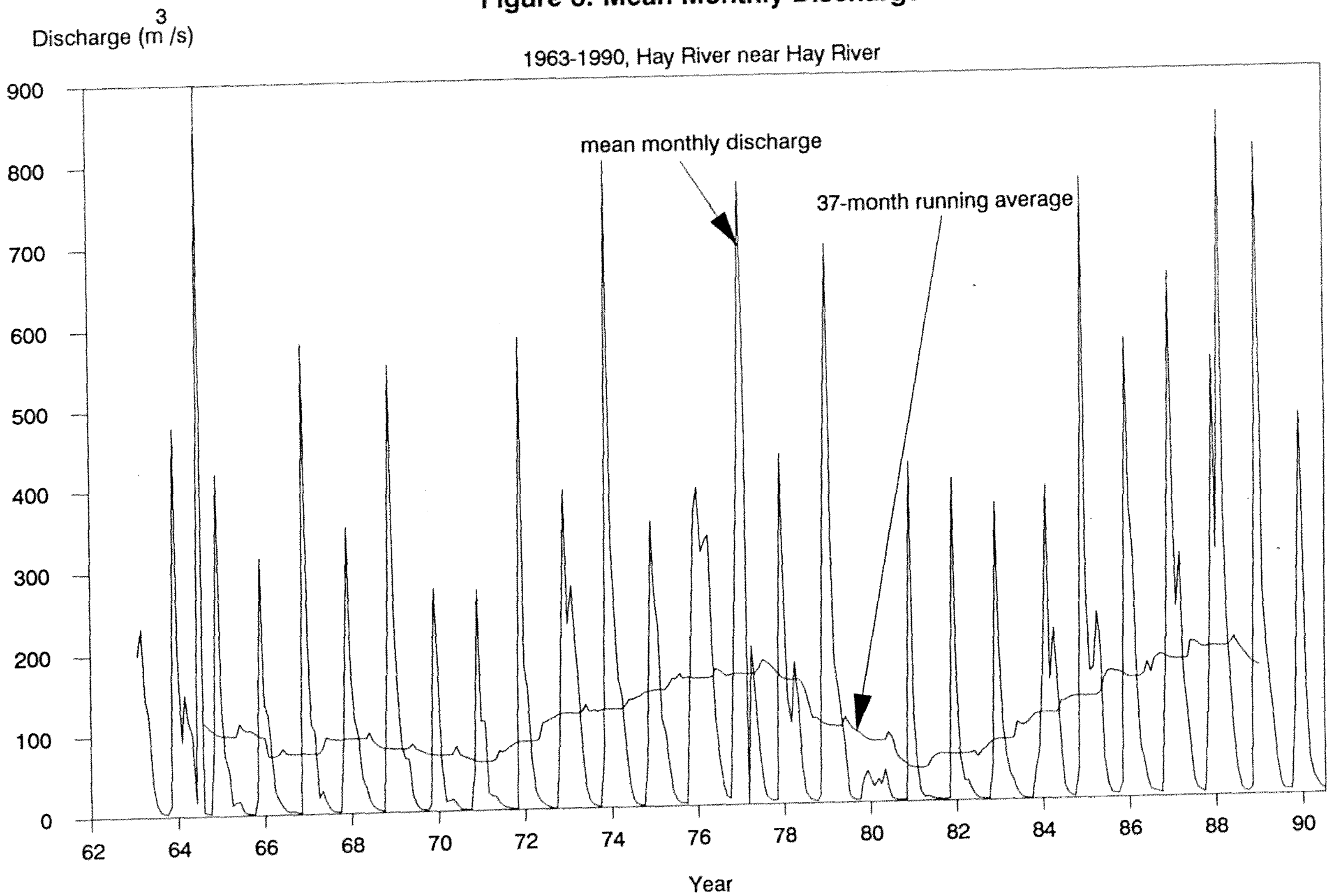


Figure 7: Lake Elevation, 1956-1990

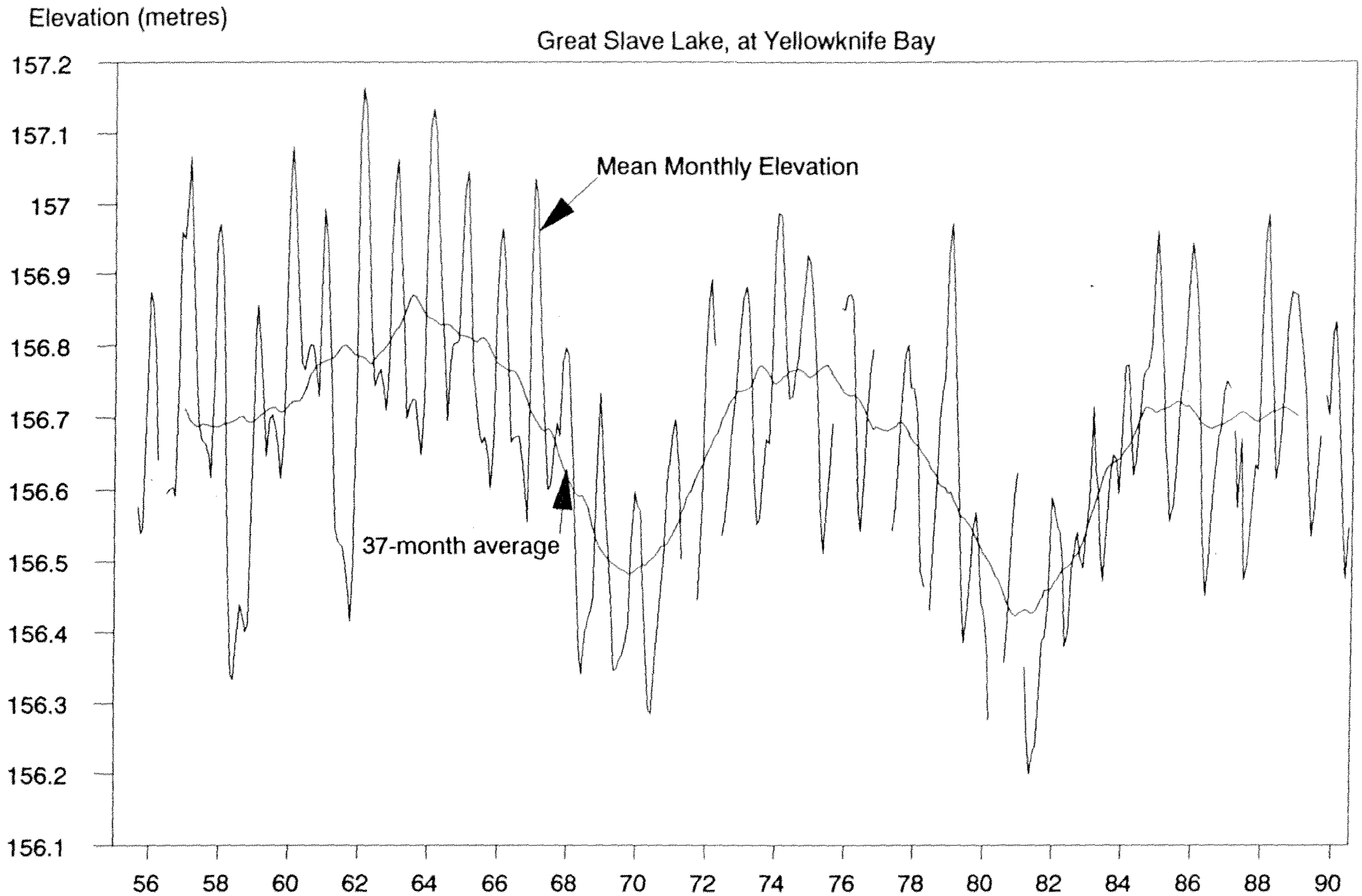


Figure 8a: Marl Pond Gauge Readings

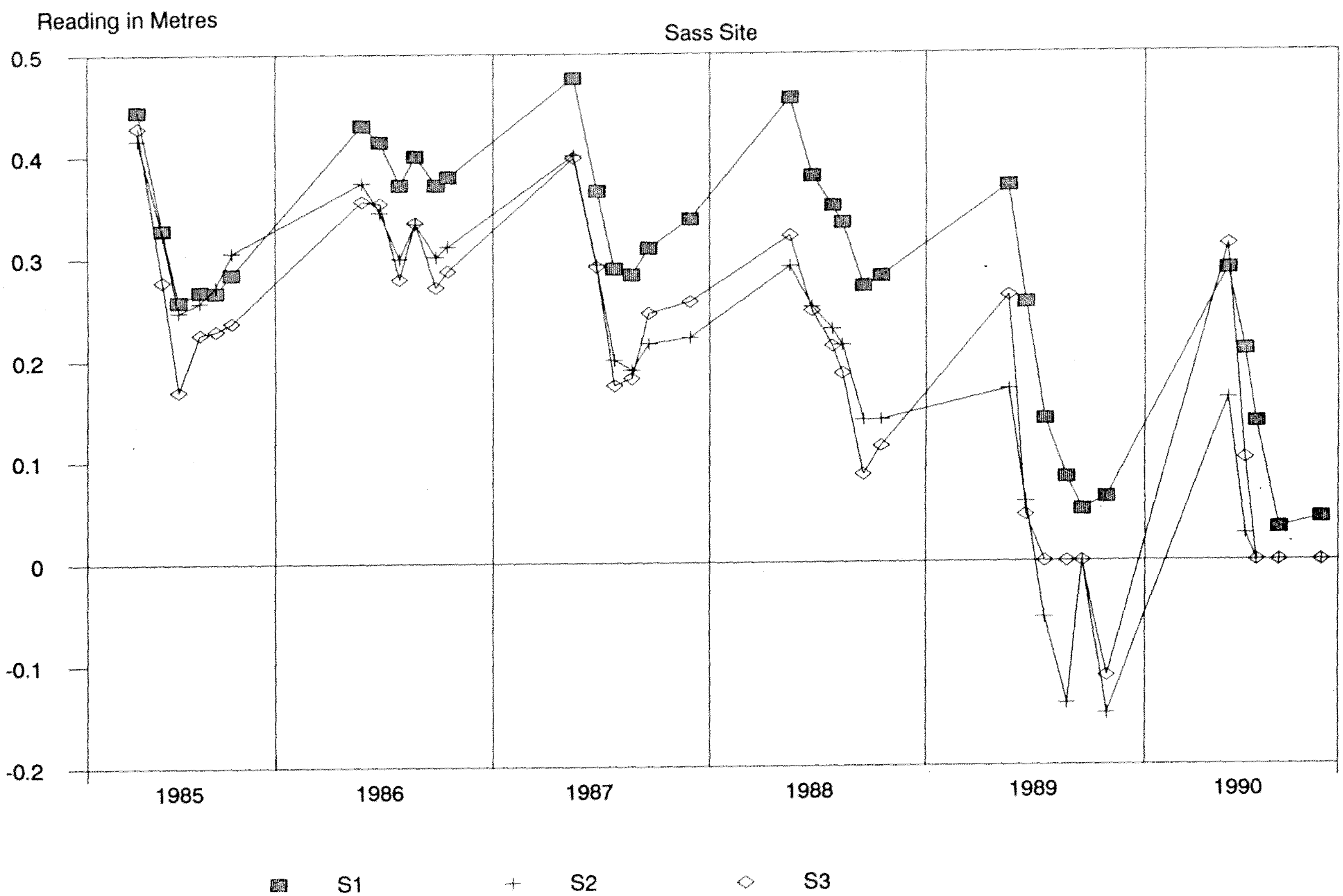


Figure 8b: Marl Pond Gauge Readings

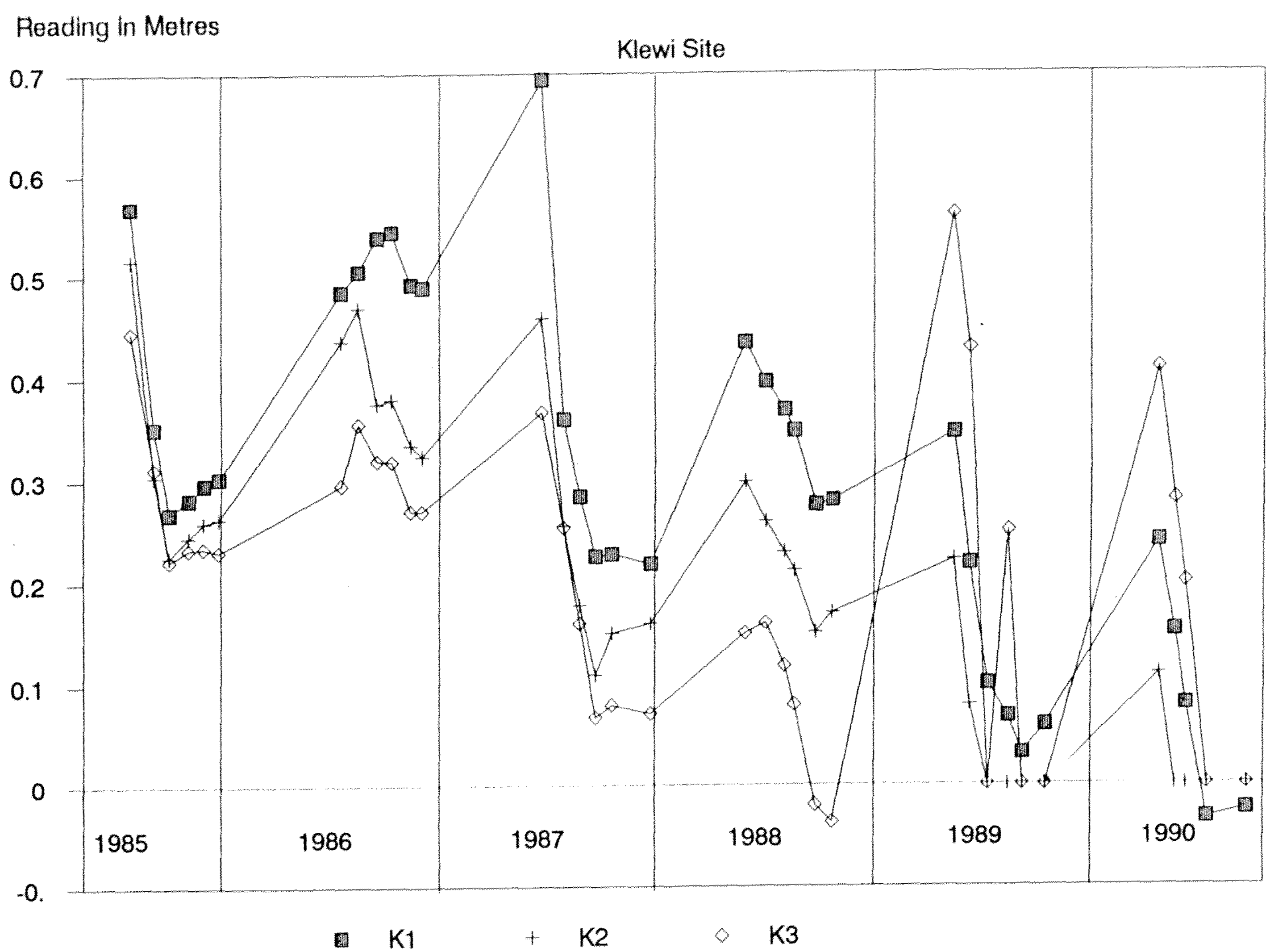


Figure 8c: Pond Gauge Readings

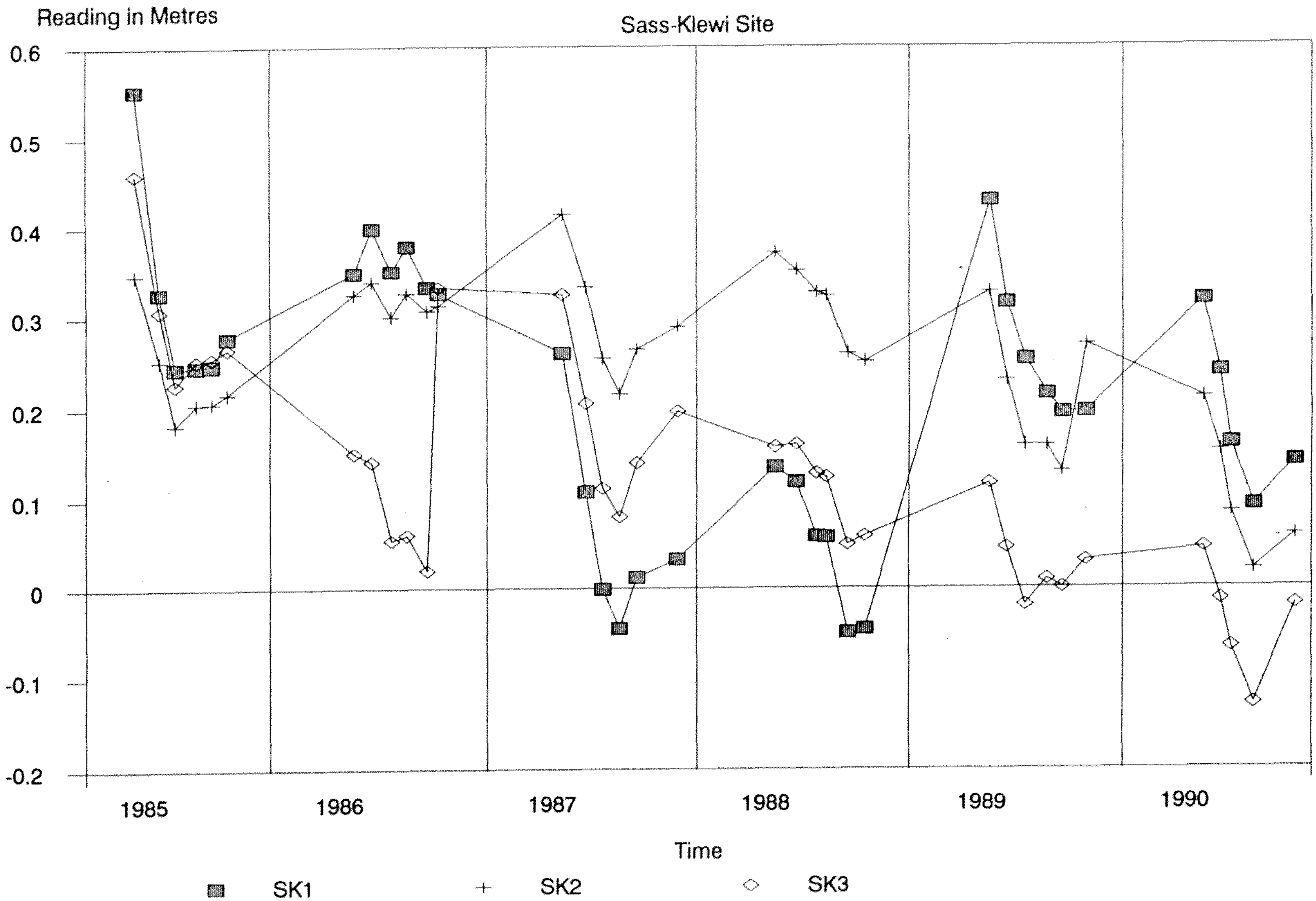


Figure 8d: Marl Pond Gauge Readings

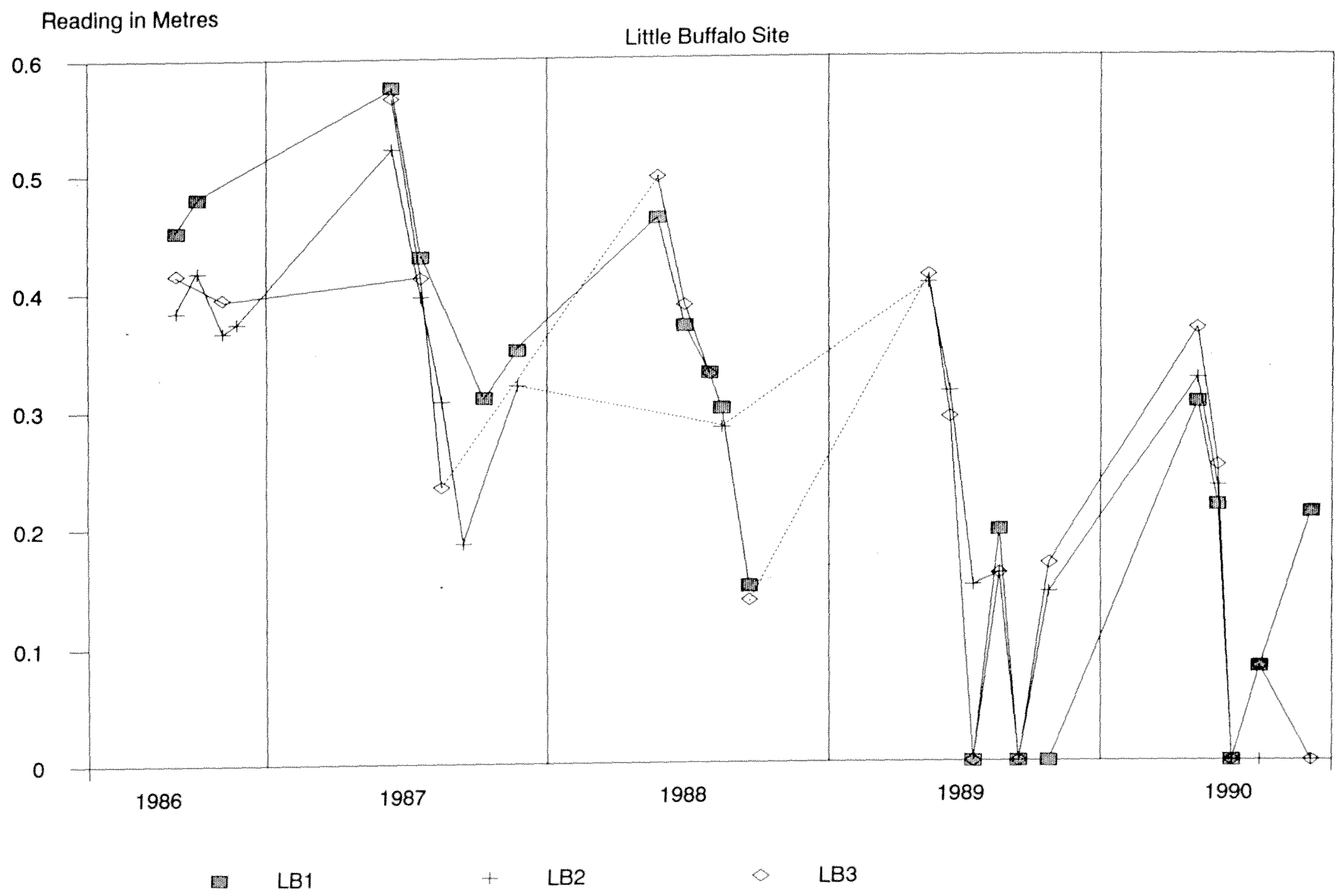


Figure 8e: Marl Pond Gauge Readings

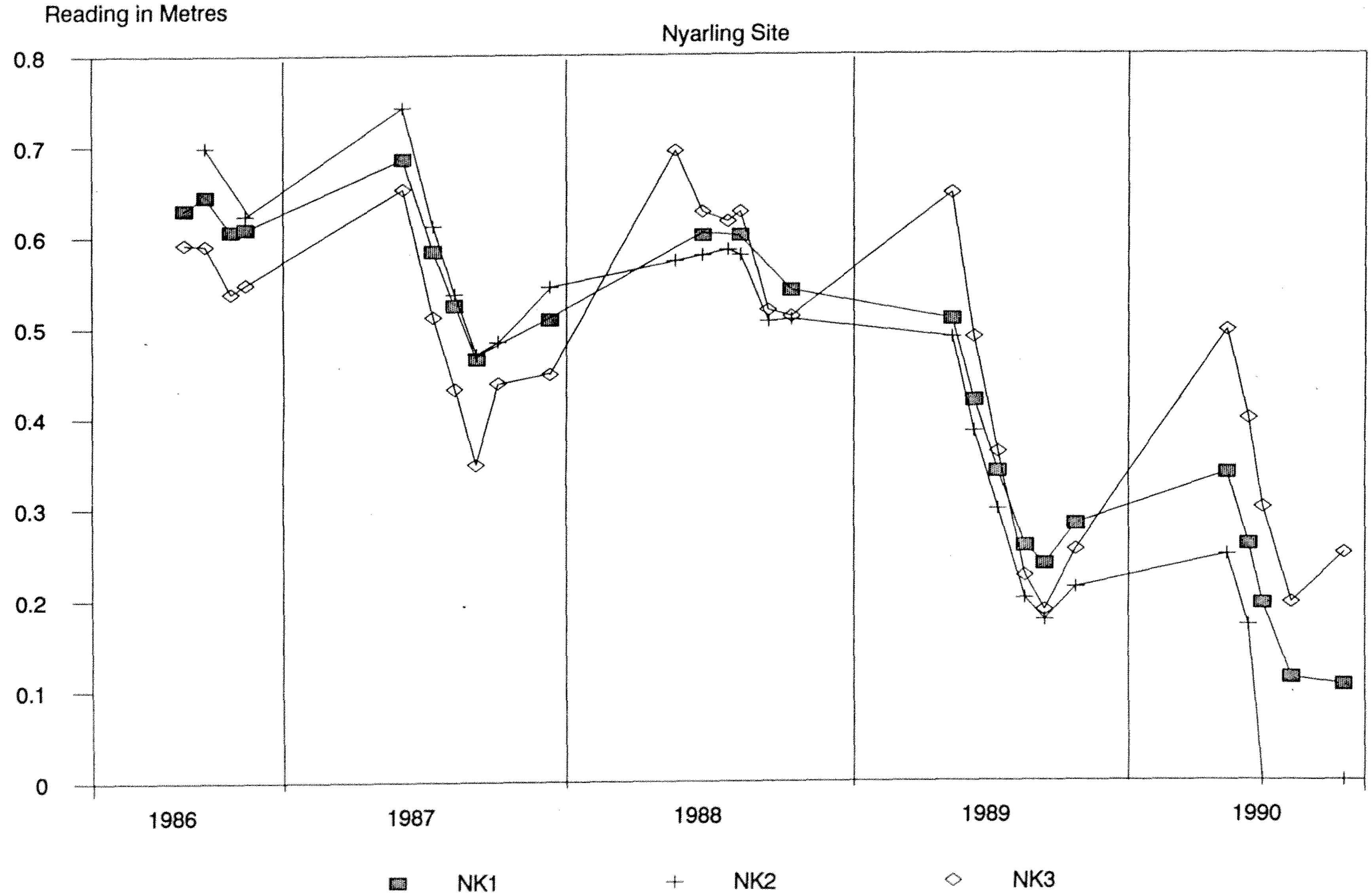


Figure 8f: Marl Pond Gauge Readings

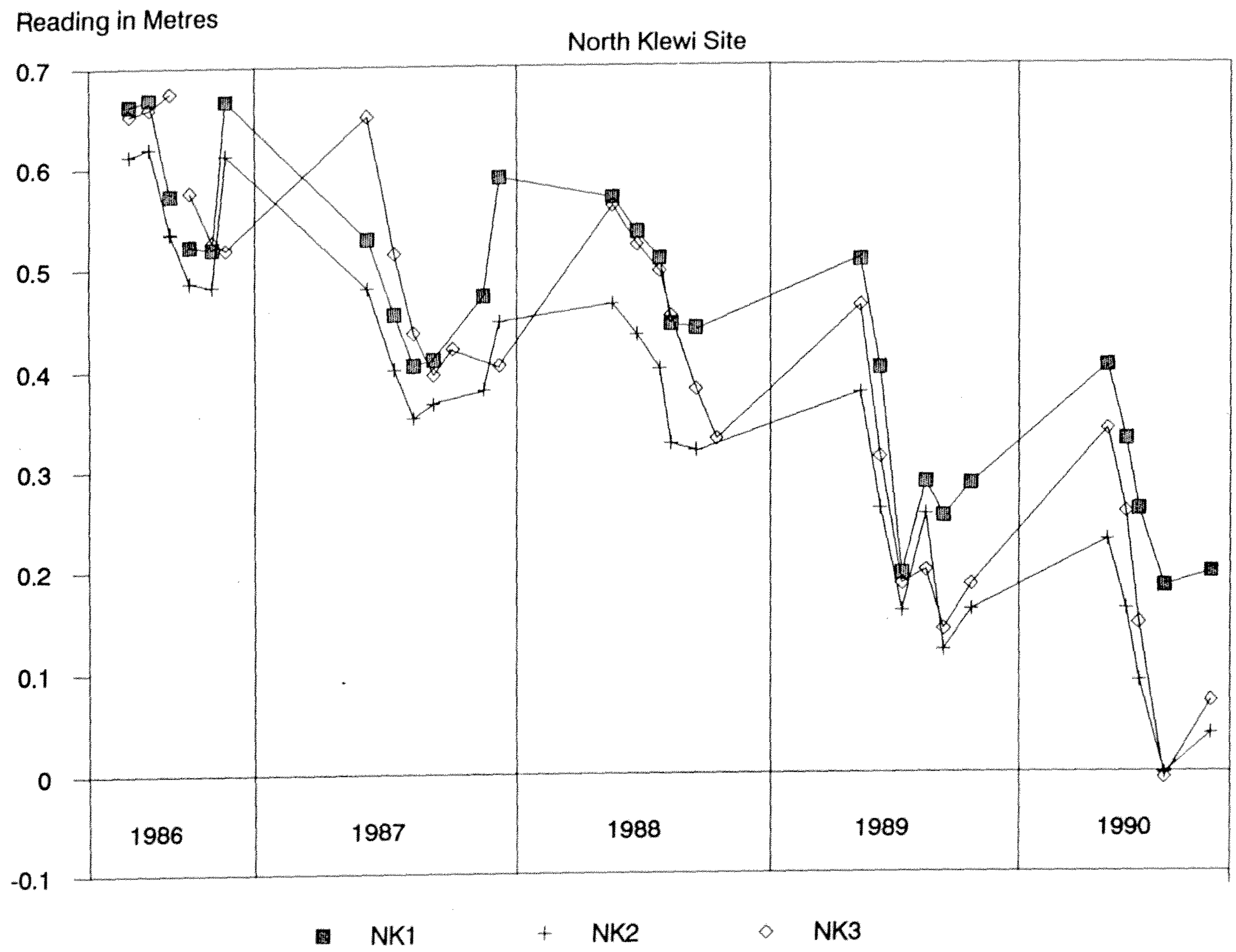


Figure 9a: Ground Water Elevation

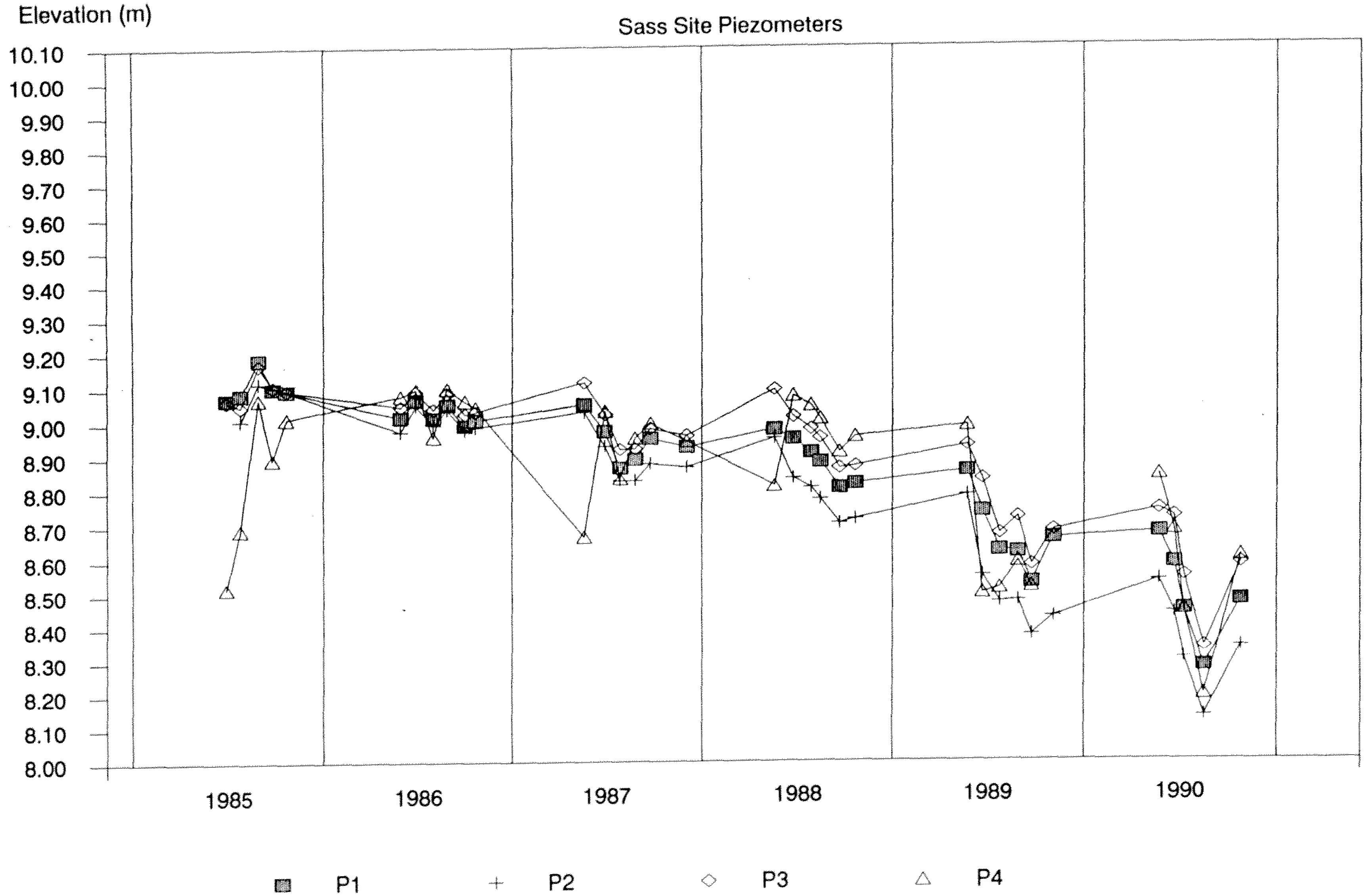


Figure 9b: Ground Water Elevation

Sass Site

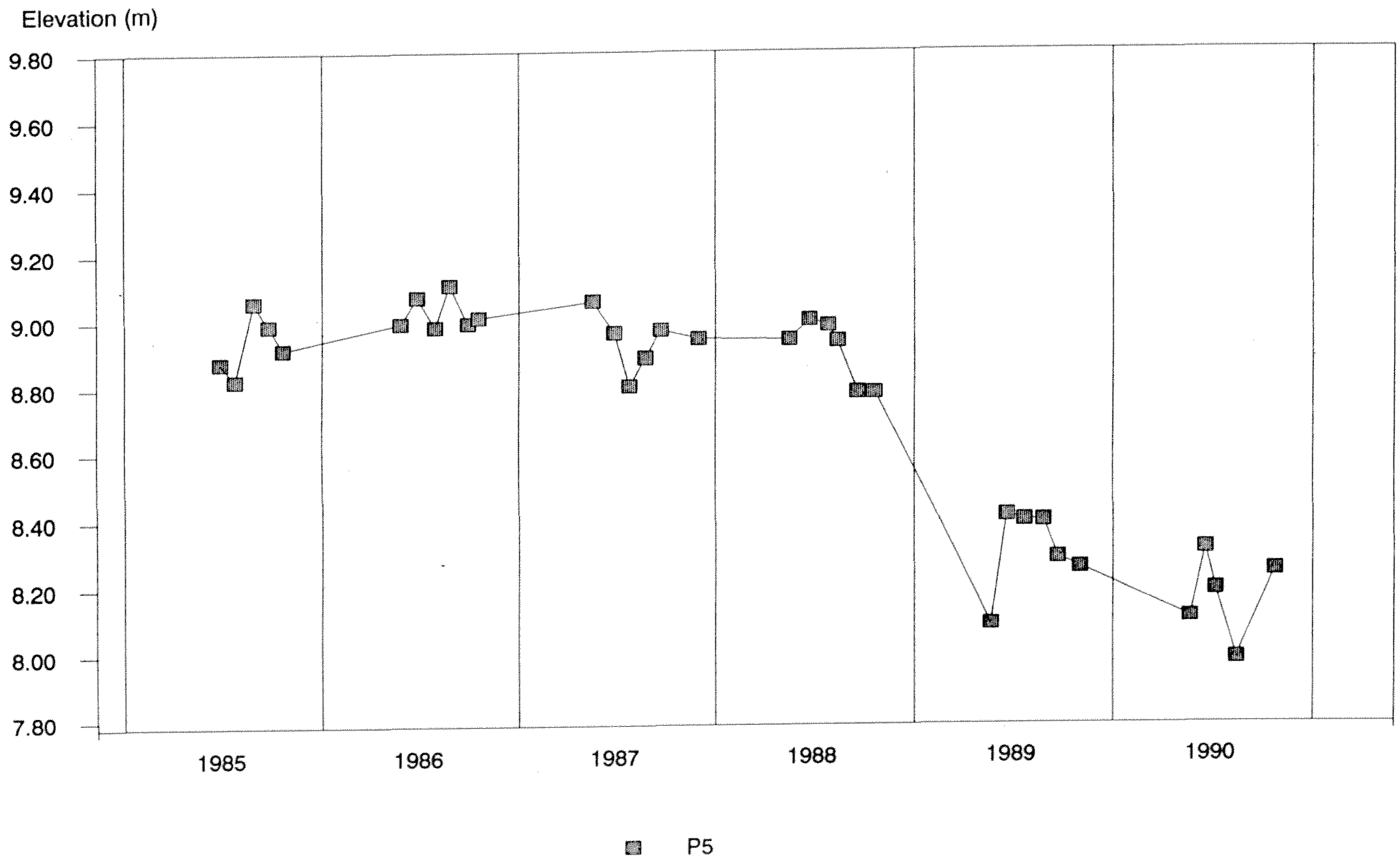


Figure 9c: Ground Water Elevation

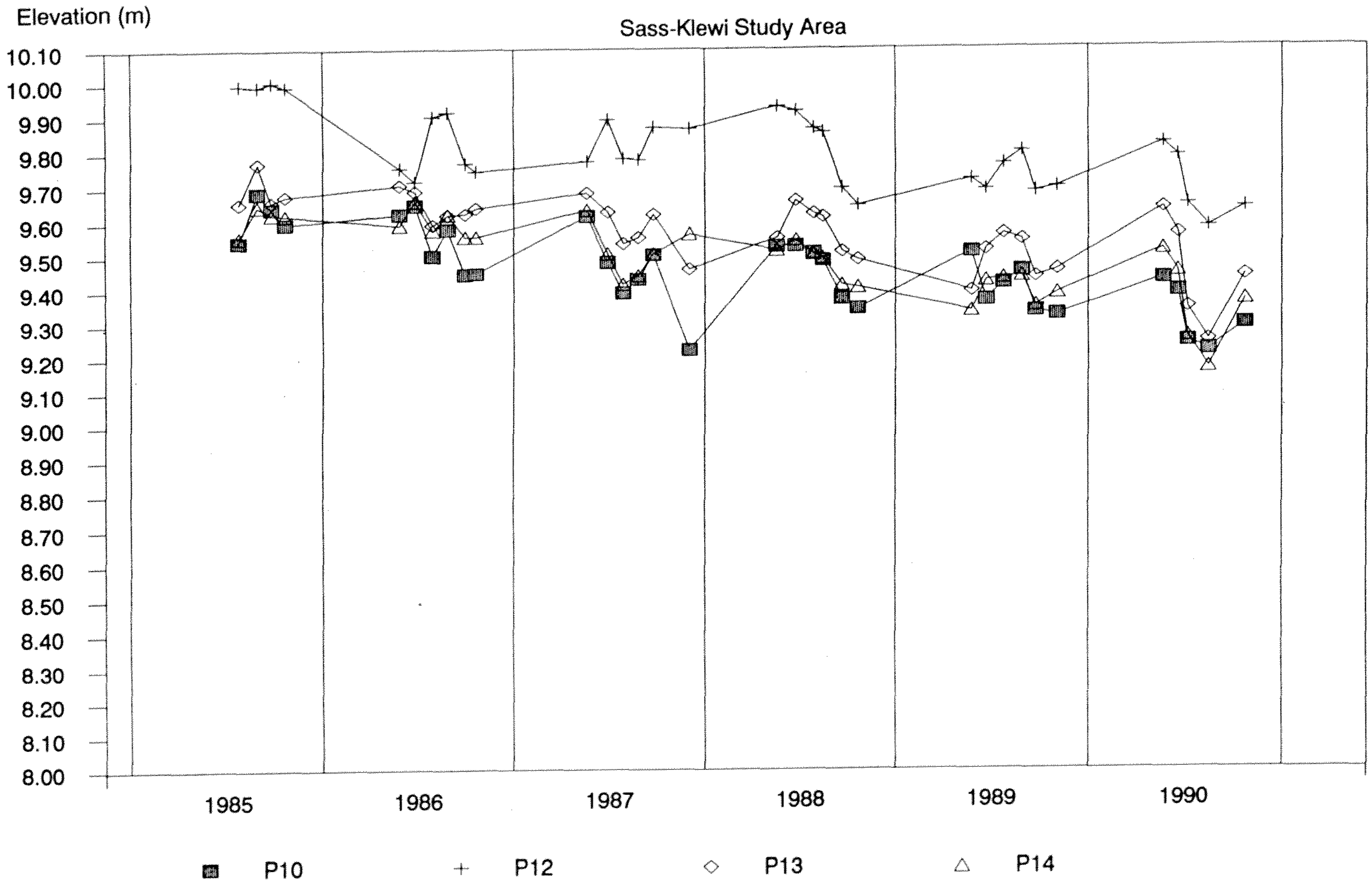


Figure 9d: Ground Water Elevation

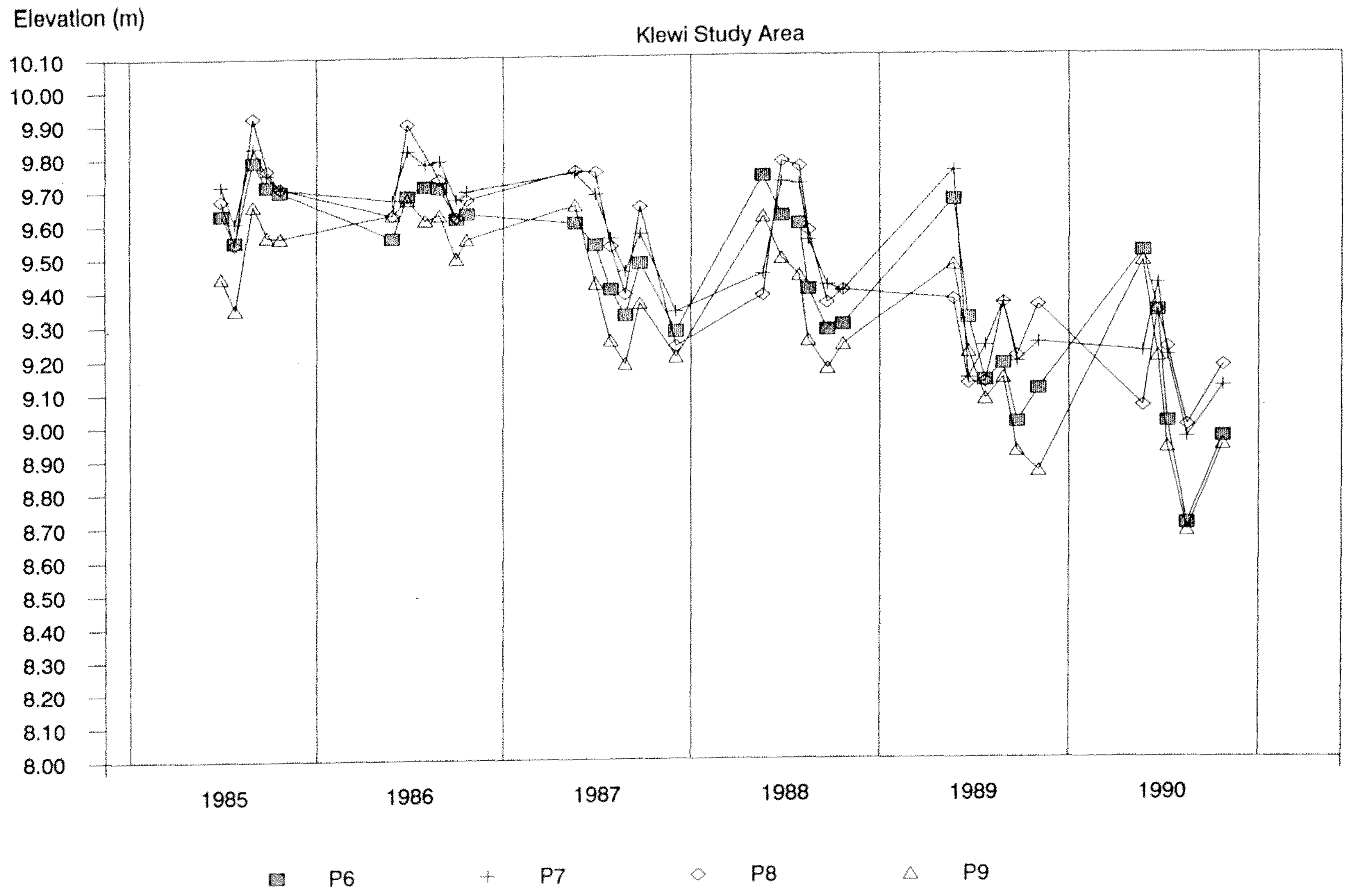


Figure 10: Depth to Water (M)

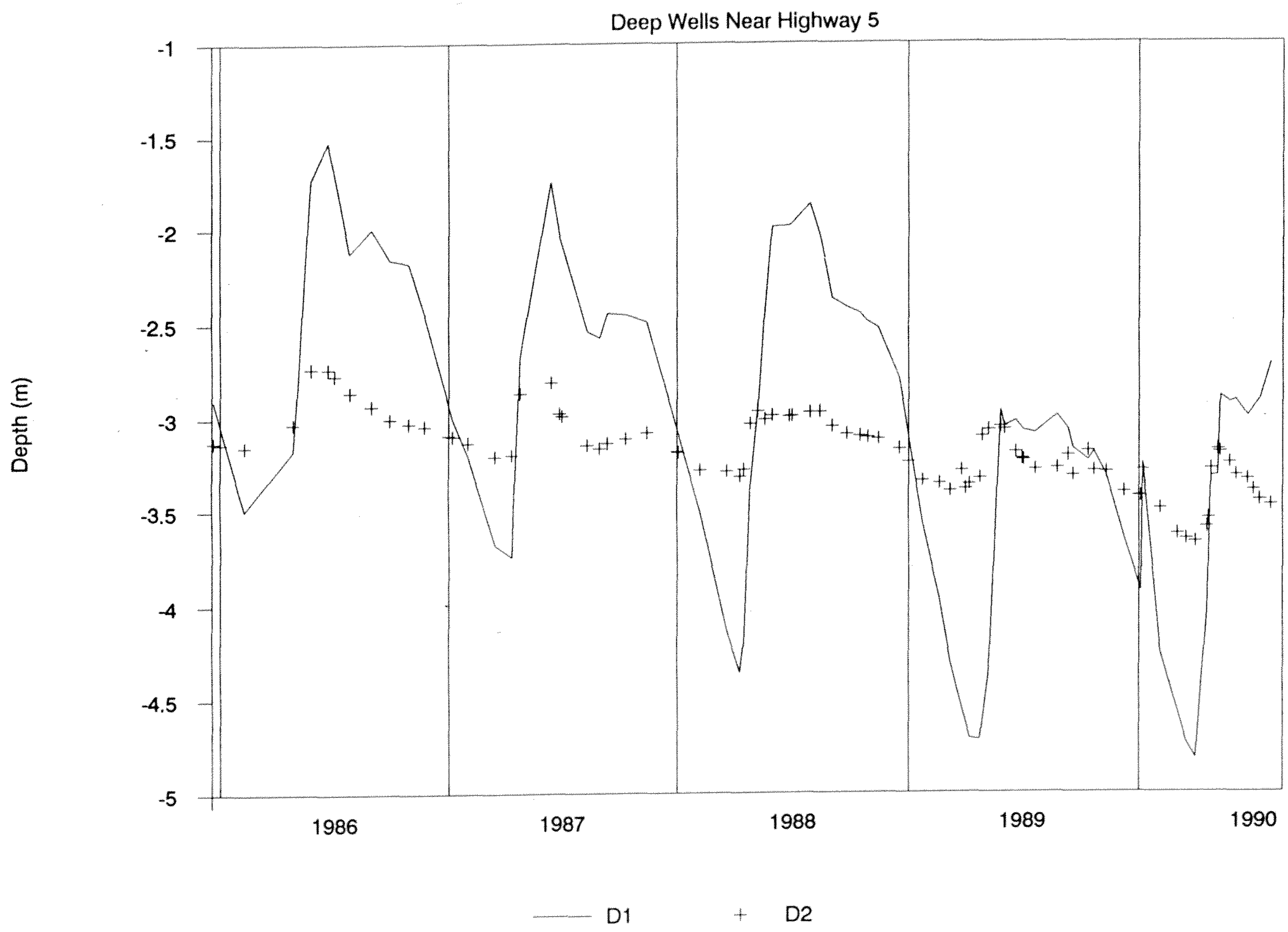


Figure 11: Measured Discharge, 1985-90

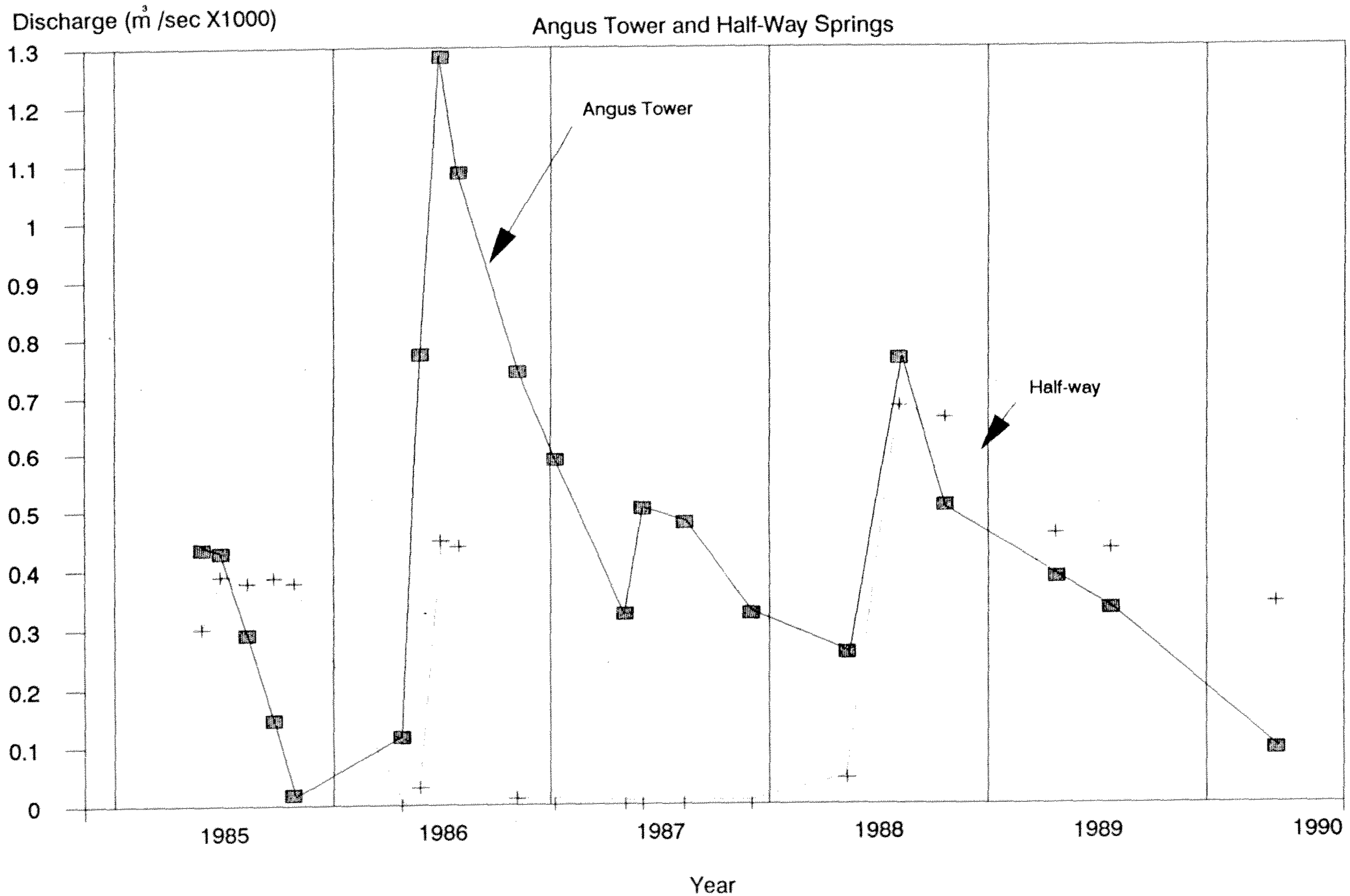


Figure 12: Precipitation Record

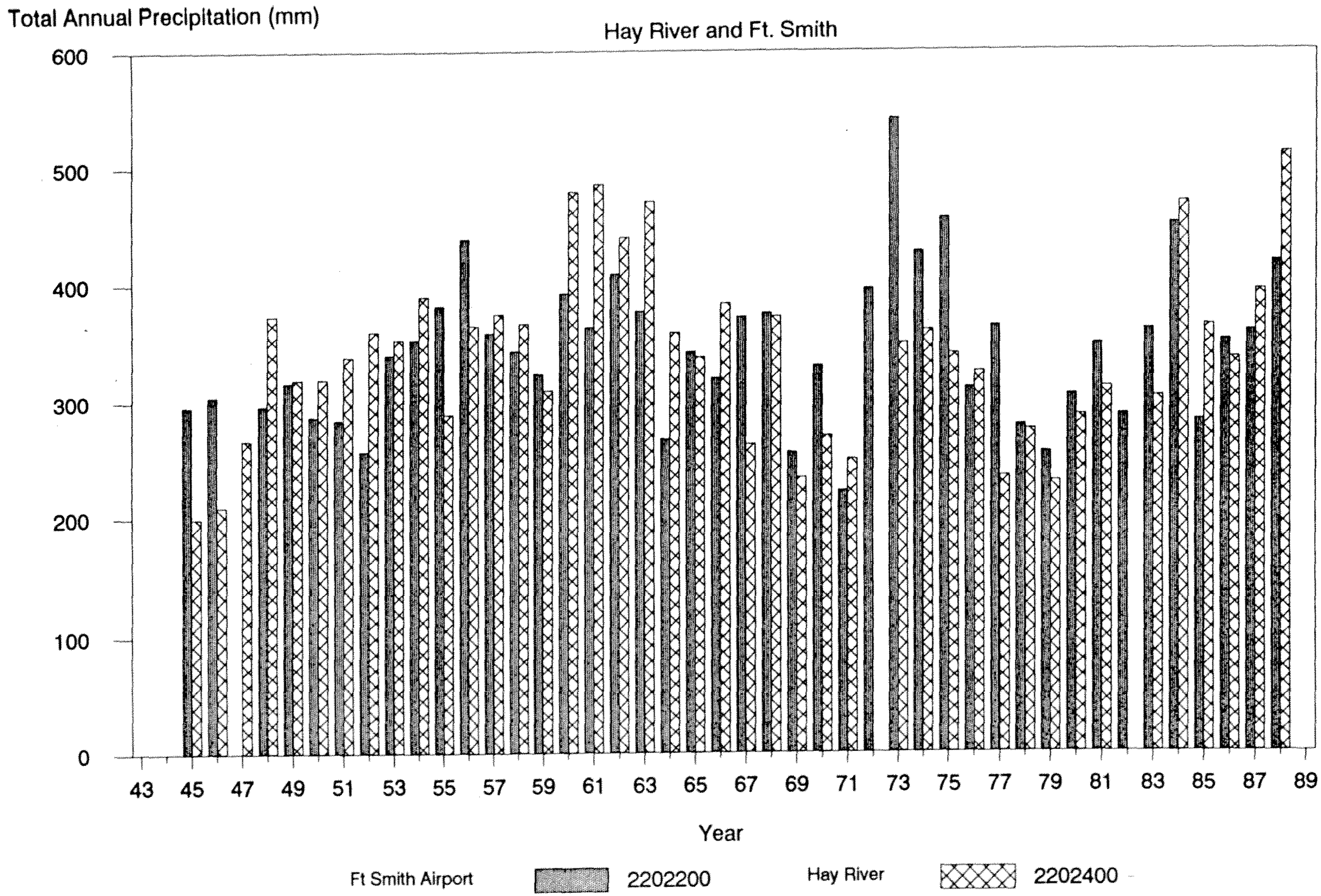


Figure 13: Piper Trilinear Plot

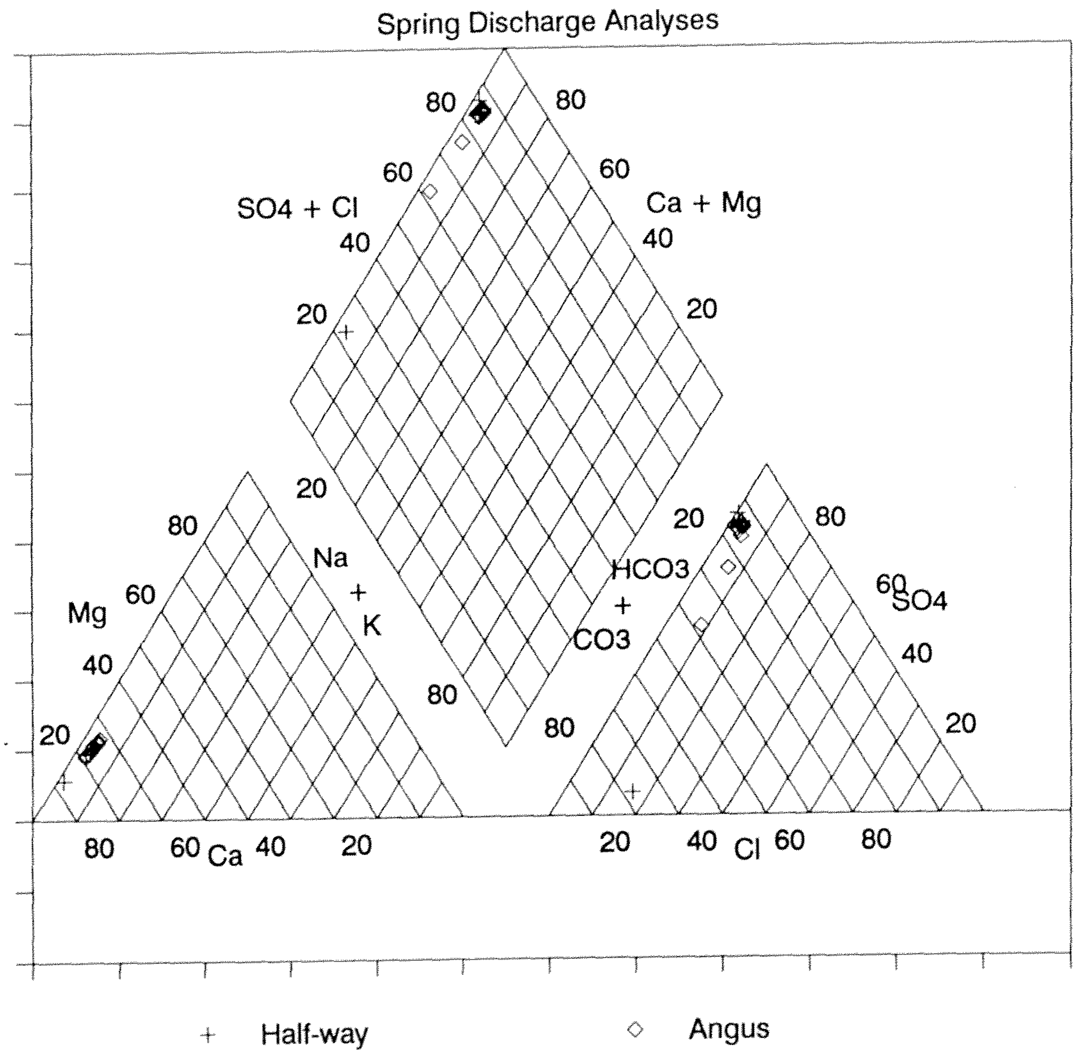
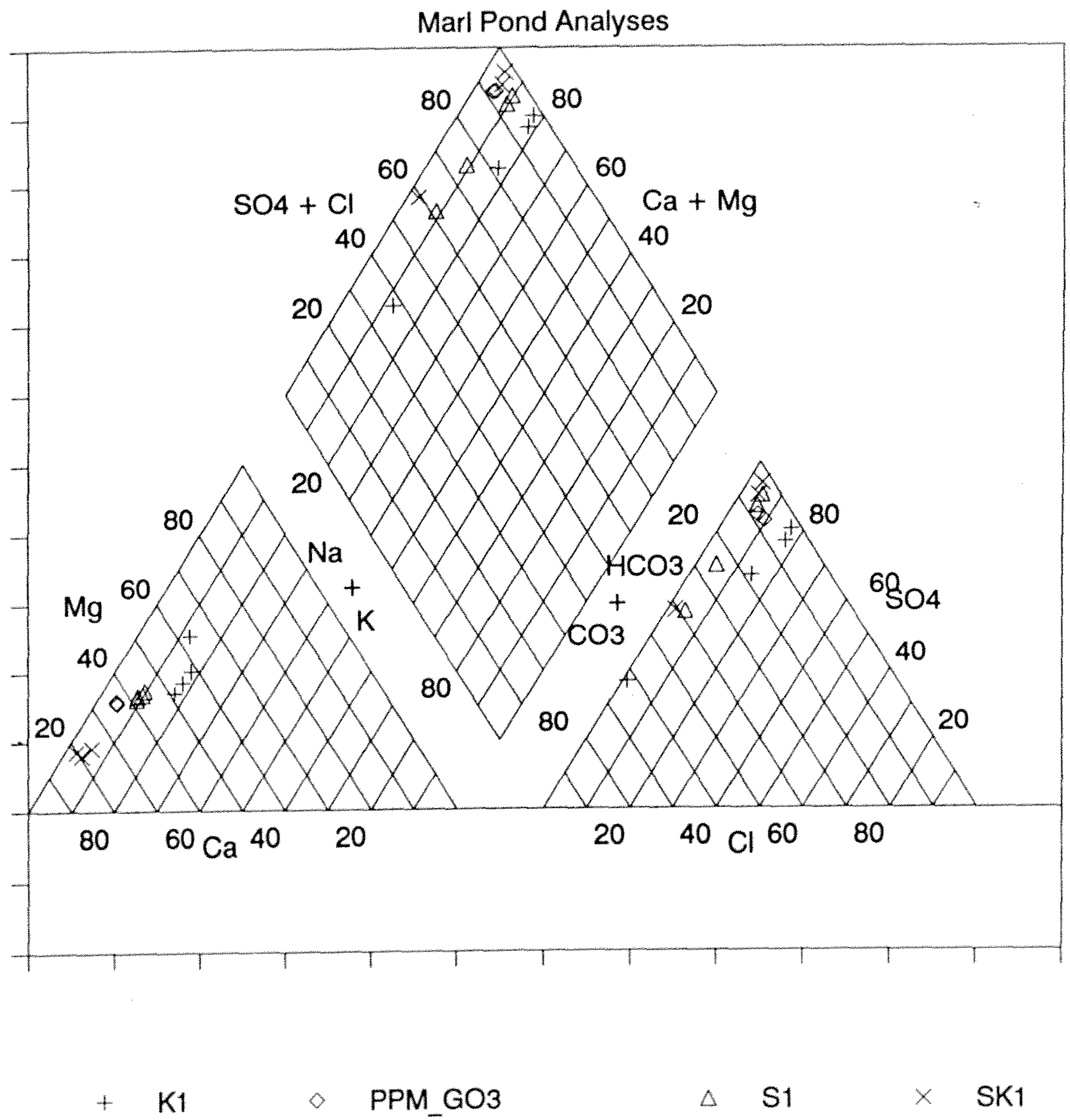


Figure 14: Piper Trilinear Plot



APPENDICES

APPENDIX A

Marl Pond Elevation Readings

Marl Pond Elevation Readings

Dates	K1	K2	K3	S1	S2	S3	SK1	SK2	SK3
17-May-85	0.568	0.516	0.445	0.444	0.416	0.428	0.553	0.347	0.459
28-Jun-85	0.352	0.304	0.312	0.328	0.324	0.278	0.326	0.252	0.306
25-Jul-85	0.268	0.226	0.222	0.258	0.248	0.17	0.244	0.182	0.226
29-Aug-85	0.282	0.245	0.233	0.268	0.257	0.226	0.246	0.205	0.252
25-Sep-85	0.297	0.26	0.235	0.267	0.273	0.229	0.247	0.206	0.255
22-Oct-85	0.303	0.263	0.231	0.285	0.306	0.237	0.277	0.216	0.265
28-May-86	0.485	0.436	0.296	0.43	0.374	0.356	0.348	0.324	0.151
27-Jun-86	0.504	0.469	0.356	0.414	0.345	0.354	0.398	0.338	0.142
31-Jul-86	0.538	0.375	0.32	0.372	0.3	0.28	0.35	0.3	0.054
26-Aug-86	0.544	0.38	0.319	0.4	0.334	0.335	0.378	0.326	0.06
30-Sep-86	0.492	0.335	0.27	0.372	0.302	0.272	0.332	0.306	0.02
20-Oct-86	0.488	0.324	0.27	0.38	0.312	0.288	0.325	0.312	0.332
20-May-87	0.694	0.458	0.367	0.476	0.401	0.398	0.26	0.414	0.324
29-Jun-87	0.36	0.256	0.254	0.366	0.294	0.292	0.108	0.332	0.205
28-Jul-87	0.284	0.178	0.16	0.29	0.2	0.175	-0.001	0.254	0.112
26-Aug-87	0.226	0.11	0.068	0.284	0.19	0.182	-0.045	0.215	0.08
24-Sep-87	0.228	0.15	0.08	0.31	0.216	0.246	0.012	0.264	0.14
03-Dec-87	0.218	0.16	0.072	0.338	0.222	0.257	0.032	0.288	0.196
19-May-88	0.434	0.298	0.15	0.456	0.292	0.322	0.135	0.37	0.157
25-Jun-88	0.396	0.26	0.16	0.38	0.252	0.248	0.118	0.35	0.16
29-Jul-88	0.368	0.23	0.118	0.351	0.23	0.213	0.058	0.326	0.128
15-Aug-88	0.348	0.212	0.08	0.334	0.214	0.186	0.057	0.322	0.124
21-Sep-88	0.276	0.151	-0.02	0.272	0.14	0.086	-0.05	0.259	0.048
21-Oct-88	0.28	0.17	-0.037	0.282	0.14	0.114	-0.046	0.25	0.058
23-May-89	0.346	0.222	0.56	0.37	0.17	0.262	0.428	0.326	0.117
21-Jun-89	0.218	0.08	0.428	0.255	0.058	0.045	0.314	0.23	0.045
23-Jul-89	0.1	d	d	0.14	-0.055	d	0.252	0.158	-0.02
28-Aug-89	0.068	d	0.25	0.082	-0.14	d	0.214	0.158	0.009
23-Sep-89	0.032	d	d	0.05	d	d	0.194	0.13	0
03-Nov-89	0.06	d	0	0.062	-0.15	-0.113	0.195	0.268	0.03
24-May-90	0.24	0.11	0.408	0.288	0.16	0.312	0.316	0.21	0.044
21-Jun-90	0.152	0	0.28	0.208	0.026	0.1	0.238	0.152	-0.014
10-Jul-90	0.08	d	0.2	0.136	d	d	0.16	0.084	-0.067
17-Aug-90	-0.033	d	d	0.032	d	d	0.092	0.02	-0.13
26-Oct-90	-0.025	d	d	0.042	d	d	0.14	0.058	-0.02

APPENDIX B

Ground Water Elevation Readings at Marl Pond Study Sites

Date	LB1	LB2	LB3	N1	N2	N3	NK1	NK2	NK3
28-May-86							0.662	0.612	0.652
27-Jun-86							0.668	0.619	0.658
29-Jul-86	0.452	0.384	0.416				0.572	0.535	0.674
30-Jul-86				0.63		0.592		0.534	
27-Aug-86	0.48	0.418		0.644	0.698	0.59	0.522	0.486	0.575
30-Sep-86		0.366	0.395	0.606		0.538	0.519	0.482	0.526
20-Oct-86		0.374		0.608	0.623	0.548	0.666	0.612	0.518
20-May-87	0.575	0.522	0.566	0.685	0.742	0.652	0.528	0.48	0.65
29-Jun-87	0.43	0.396	0.412	0.583	0.611	0.512	0.454	0.4	0.514
28-Jul-87		0.307	0.234	0.524	0.537	0.432	0.404	0.352	0.436
26-Aug-87		0.186		0.465	0.47	0.348	0.41	0.366	0.395
24-Sep-87	0.31				0.484	0.438			0.421
09-Nov-87	0.35	0.32					0.472	0.38	
03-Dec-87				0.508	0.544	0.448	0.588	0.447	0.404
19-May-88	0.462		0.497		0.572	0.693	0.568	0.464	0.56
25-Jun-88	0.37		0.388	0.6	0.578	0.626	0.534	0.434	0.522
29-Jul-88	0.33		0.329		0.584	0.615	0.508	0.4	0.496
15-Aug-88	0.3	0.284		0.6	0.578	0.626	0.444	0.325	0.452
21-Sep-88	0.15		0.138		0.506	0.518	0.44	0.318	0.38
21-Oct-88				0.54	0.508	0.512			0.33
23-May-89		0.406	0.413	0.508	0.488	0.646	0.506	0.376	0.462
21-Jun-89		0.314	0.292	0.418	0.384	0.488	0.4	0.26	0.311
23-Jul-89	d	0.15	d	0.34	0.298	0.362	0.195	0.158	0.185
28-Aug-89	0	0.16	0.16	0.258	0.2	0.225	0.286	0.254	0.198
23-Sep-89	d	d	d	0.238	0.176	0.187	0.252	0.12	0.14
03-Nov-89	d	0.144	0.168	0.282	0.212	0.254	0.284	0.159	0.184
24-May-90	0.304	0.324	0.366	0.338	0.248	0.496	0.402	0.228	0.338
21-Jun-90	0.216	0.232	0.25	0.26	0.17	0.398	0.328	0.16	0.256
10-Jul-90	d	0	d	0.194	d	0.3	0.258	0.09	0.146
17-Aug-90	0.08	?	0.08	0.112	d	0.195	0.182	-0.002	-0.006
26-Oct-90	0.21	d	d	0.104	d	0.25	0.196	0.038	0.07

Ground Water Elevation Readings at Marl Pond Study Sites

Site	Piez	date	Elev. (m)	Reading	Top (m)
Sass	1	28-Jun-85	9.068	1.192	10.26
Sass	1	25-Jul-85	9.082	1.178	10.26
Sass	1	29-Aug-85	9.184	1.076	10.26
Sass	1	25-Sep-85	9.099	1.161	10.26
Sass	1	22-Oct-85	9.092	1.168	10.26
Sass	1	28-May-86	9.017	1.243	10.26
Sass	1	27-Jun-86	9.065	1.195	10.26
Sass	1	31-Jul-86	9.015	1.245	10.26
Sass	1	26-Aug-86	9.052	1.208	10.26
Sass	1	30-Sep-86	8.992	1.268	10.26
Sass	1	20-Oct-86	9.008	1.252	10.26
Sass	1	20-May-87	9.052	1.208	10.26
Sass	1	29-Jun-87	8.975	1.285	10.26
Sass	1	28-Jul-87	8.868	1.392	10.26
Sass	1	26-Aug-87	8.892	1.368	10.26
Sass	1	24-Sep-87	8.953	1.307	10.26
Sass	1	03-Dec-87	8.928	1.332	10.26
Sass	1	19-May-88	8.979	1.281	10.26
Sass	1	25-Jun-88	8.951	1.309	10.26
Sass	1	29-Jul-88	8.91	1.35	10.26
Sass	1	15-Aug-88	8.882	1.378	10.26
Sass	1	21-Sep-88	8.805	1.455	10.26
Sass	1	21-Oct-88	8.817	1.443	10.26
Sass	1	23-May-89	8.855	1.405	10.26
Sass	1	21-Jun-89	8.735	1.525	10.26
Sass	1	23-Jul-89	8.623	1.637	10.26
Sass	1	28-Aug-89	8.617	1.643	10.26
Sass	1	23-Sep-89	8.529	1.731	10.26
Sass	1	03-Nov-89	8.656	1.604	10.26
Sass	1	24-May-90	8.673	1.587	10.26
Sass	1	21-Jun-90	8.583	1.677	10.26
Sass	1	10-Jul-90	8.448	1.812	10.26
Sass	1	17-Aug-90	8.278	1.982	10.26
Sass	1	26-Oct-90	8.472	1.788	10.26
Sass	2	28-Jun-85	7.963	1.71	9.673
Sass	2	25-Jul-85	9.009	0.664	9.673
Sass	2	29-Aug-85	9.116	0.557	9.673
Sass	2	25-Sep-85	9.102	0.571	9.673
Sass	2	22-Oct-85	9.093	0.58	9.673
Sass	2	28-May-86	8.976	0.697	9.673
Sass	2	27-Jun-86	9.05	0.623	9.673
Sass	2	31-Jul-86	8.995	0.678	9.673
Sass	2	26-Aug-86	9.039	0.634	9.673
Sass	2	30-Sep-86	8.978	0.695	9.673
Sass	2	20-Oct-86	8.988	0.685	9.673
Sass	2	20-May-87	9.031	0.642	9.673
Sass	2	29-Jun-87	8.932	0.741	9.673
Sass	2	28-Jul-87	8.83	0.843	9.673
Sass	2	26-Aug-87	8.831	0.842	9.673
Sass	2	24-Sep-87	8.879	0.794	9.673
Sass	2	03-Dec-87	8.869	0.804	9.673
Sass	2	19-May-88	8.953	0.72	9.673
Sass	2	25-Jun-88	8.834	0.839	9.673

Sass	2	29-Jul-88	8.806	0.867	9.673
Sass	2	15-Aug-88	8.773	0.9	9.673
Sass	2	21-Sep-88	8.703	0.97	9.673
Sass	2	21-Oct-88	8.715	0.958	9.673
Sass	2	23-May-89	8.783	0.89	9.673
Sass	2	21-Jun-89	8.549	1.124	9.673
Sass	2	23-Jul-89	8.471	1.202	9.673
Sass	2	28-Aug-89	8.475	1.198	9.673
Sass	2	23-Sep-89	8.375	1.298	9.673
Sass	2	03-Nov-89	8.426	1.247	9.673
Sass	2	24-May-90	8.533	1.14	9.673
Sass	2	21-Jun-90	8.438	1.235	9.673
Sass	2	10-Jul-90	8.303	1.37	9.673
Sass	2	17-Aug-90	8.129	1.544	9.673
Sass	2	26-Oct-90	8.338	1.335	9.673
Sass	3	28-Jun-85	9.063	0.454	9.517
Sass	3	25-Jul-85	9.048	0.469	9.517
Sass	3	29-Aug-85	9.167	0.35	9.517
Sass	3	25-Sep-85	9.104	0.413	9.517
Sass	3	22-Oct-85	9.094	0.423	9.517
Sass	3	28-May-86	9.048	0.469	9.517
Sass	3	27-Jun-86	9.089	0.428	9.517
Sass	3	31-Jul-86	9.04	0.477	9.517
Sass	3	26-Aug-86	9.085	0.432	9.517
Sass	3	30-Sep-86	9.025	0.492	9.517
Sass	3	20-Oct-86	9.032	0.485	9.517
Sass	3	20-May-87	9.115	0.402	9.517
Sass	3	29-Jun-87	9.024	0.493	9.517
Sass	3	28-Jul-87	8.922	0.595	9.517
Sass	3	26-Aug-87	8.923	0.594	9.517
Sass	3	24-Sep-87	8.982	0.535	9.517
Sass	3	03-Dec-87	8.962	0.555	9.517
Sass	3	19-May-88	9.093	0.424	9.517
Sass	3	25-Jun-88	9.014	0.503	9.517
Sass	3	29-Jul-88	8.98	0.537	9.517
Sass	3	15-Aug-88	8.953	0.564	9.517
Sass	3	21-Sep-88	8.864	0.653	9.517
Sass	3	21-Oct-88	8.87	0.647	9.517
Sass	3	23-May-89	8.929	0.588	9.517
Sass	3	21-Jun-89	8.829	0.688	9.517
Sass	3	23-Jul-89	8.669	0.848	9.517
Sass	3	28-Aug-89	8.717	0.8	9.517
Sass	3	23-Sep-89	8.579	0.938	9.517
Sass	3	03-Nov-89	8.679	0.838	9.517
Sass	3	24-May-90	8.738	0.779	9.517
Sass	3	21-Jun-90	8.718	0.799	9.517
Sass	3	10-Jul-90	8.545	0.972	9.517
Sass	3	17-Aug-90	8.337	1.18	9.517
Sass	3	26-Oct-90	8.581	0.936	9.517
Sass	4	28-Jun-85	8.519	1.978	10.497
Sass	4	25-Jul-85	8.69	1.807	10.497
Sass	4	29-Aug-85	9.069	1.428	10.497
Sass	4	25-Sep-85	8.894	1.603	10.497
Sass	4	22-Oct-85	9.014	1.483	10.497
Sass	4	28-May-86	9.077	1.42	10.497
Sass	4	27-Jun-86	9.095	1.402	10.497
Sass	4	31-Jul-86	8.959	1.538	10.497
Sass	4	26-Aug-86	9.099	1.398	10.497

Sass	4	30-Sep-86	9.062	1.435	10.497
Sass	4	20-Oct-86	9.045	1.452	10.497
Sass	4	20-May-87	8.667	1.83	10.497
Sass	4	29-Jun-87	9.033	1.464	10.497
Sass	4	28-Jul-87	8.835	1.662	10.497
Sass	4	26-Aug-87	8.954	1.543	10.497
Sass	4	24-Sep-87	8.997	1.5	10.497
Sass	4	03-Dec-87	8.945	1.552	10.497
Sass	4	19-May-88	8.812	1.685	10.497
Sass	4	25-Jun-88	9.074	1.423	10.497
Sass	4	29-Jul-88	9.048	1.449	10.497
Sass	4	15-Aug-88	9.009	1.488	10.497
Sass	4	21-Sep-88	8.912	1.585	10.497
Sass	4	21-Oct-88	8.957	1.54	10.497
Sass	4	23-May-89	8.988	1.509	10.497
Sass	4	21-Jun-89	8.497	2	10.497
Sass	4	23-Jul-89	8.512	1.985	10.497
Sass	4	28-Aug-89	8.589	1.908	10.497
Sass	4	23-Sep-89	8.517	1.98	10.497
Sass	4	03-Nov-89			
Sass	4	24-May-90	8.84	1.657	10.497
Sass	4	21-Jun-90	8.68	1.817	10.497
Sass	4	10-Jul-90	8.448	2.049	10.497
Sass	4	17-Aug-90	8.192	2.305	10.497
Sass	4	26-Oct-90	8.602	1.895	10.497
Sass	5	28-Jun-85	8.874	1.39	10.264
Sass	5	25-Jul-85	8.823	1.441	10.264
Sass	5	29-Aug-85	9.056	1.208	10.264
Sass	5	25-Sep-85	8.986	1.278	10.264
Sass	5	22-Oct-85	8.914	1.35	10.264
Sass	5	28-May-86	8.992	1.272	10.264
Sass	5	27-Jun-86	9.071	1.193	10.264
Sass	5	31-Jul-86	8.979	1.285	10.264
Sass	5	26-Aug-86	9.106	1.158	10.264
Sass	5	30-Sep-86	8.99	1.274	10.264
Sass	5	20-Oct-86	9.008	1.256	10.264
Sass	5	20-May-87	9.056	1.208	10.264
Sass	5	29-Jun-87	8.96	1.304	10.264
Sass	5	28-Jul-87	8.8	1.464	10.264
Sass	5	26-Aug-87	8.886	1.378	10.264
Sass	5	24-Sep-87	8.967	1.297	10.264
Sass	5	03-Dec-87	8.941	1.323	10.264
Sass	5	19-May-88	8.937	1.327	10.264
Sass	5	25-Jun-88	8.997	1.267	10.264
Sass	5	29-Jul-88	8.98	1.284	10.264
Sass	5	15-Aug-88	8.933	1.331	10.264
Sass	5	21-Sep-88	8.779	1.485	10.264
Sass	5	21-Oct-88	8.778	1.486	10.264
Sass	5	23-May-89	8.084	2.18	10.264
Sass	5	21-Jun-89	8.407	1.857	10.264
Sass	5	23-Jul-89	8.392	1.872	10.264
Sass	5	28-Aug-89	8.391	1.873	10.264
Sass	5	23-Sep-89	8.281	1.983	10.264
Sass	5	03-Nov-89	8.251		10.264
Sass	5	24-May-90	8.104	2.16	10.264
Sass	5	21-Jun-90	8.307	1.957	10.264
Sass	5	10-Jul-90	8.186	2.078	10.264
Sass	5	17-Aug-90	7.976	2.288	10.264

Sass	5	26-Oct-90	8.242	2.022	10.264
KLewi	6	28-Jun-85	9.63	1.298	10.928
KLewi	6	25-Jul-85	9.549	1.379	10.928
KLewi	6	29-Aug-85	9.789	1.139	10.928
KLewi	6	25-Sep-85	9.715	1.213	10.928
KLewi	6	22-Oct-85	9.698	1.23	10.928
Klewi	6	28-May-86	9.557	1.371	10.928
Klewi	6	27-Jun-86	9.682	1.246	10.928
Klewi	6	31-Jul-86	9.71	1.218	10.928
Klewi	6	27-Aug-86	9.707	1.221	10.928
Klewi	6	30-Sep-86	9.614	1.314	10.928
Klewi	6	20-Oct-86	9.629	1.299	10.928
Klewi	6	20-May-87	9.598	1.33	10.928
Klewi	6	29-Jun-87	9.535	1.393	10.928
Klewi	6	28-Jul-87	9.401	1.527	10.928
Klewi	6	26-Aug-87	9.323	1.605	10.928
Klewi	6	24-Sep-87	9.481	1.447	10.928
Klewi	6	03-Dec-87	9.276	1.652	10.928
Klewi	6	19-May-88	9.738	1.19	10.928
Klewi	6	25-Jun-88	9.618	1.31	10.928
Klewi	6	29-Jul-88	9.594	1.334	10.928
Klewi	6	15-Aug-88	9.398	1.53	10.928
Klewi	6	21-Sep-88	9.279	1.649	10.928
Klewi	6	21-Oct-88	9.294	1.634	10.928
Klewi	6	23-May-89	9.663	1.265	10.928
Klewi	6	21-Jun-89	9.311	1.617	10.928
Klewi	6	23-Jul-89	9.126	1.802	10.928
Klewi	6	28-Aug-89	9.177	1.751	10.928
Klewi	6	23-Sep-89	9.004	1.924	10.928
Klewi	6	03-Nov-89	9.101	1.827	10.928
Klewi	6	24-May-90	9.508	1.42	10.928
Klewi	6	21-Jun-90	9.33	1.598	10.928
Klewi	6	10-Jul-90	9.004	1.924	10.928
Klewi	6	17-Aug-90	8.698	2.23	10.928
Klewi	6	26-Oct-90	8.959	1.969	10.928
Klewi	7	28-Jun-85	9.716	1.286	11.002
Klewi	7	25-Jul-85	9.605	1.397	11.002
Klewi	7	29-Aug-85	9.831	1.171	11.002
Klewi	7	25-Sep-85	9.75	1.252	11.002
Klewi	7	22-Oct-85	9.708	1.294	11.002
Klewi	7	28-May-86	9.672	1.33	11.002
Klewi	7	27-Jun-86	9.82	1.182	11.002
Klewi	7	31-Jul-86	9.777	1.225	11.002
Klewi	7	27-Aug-86	9.787	1.215	11.002
Klewi	7	30-Sep-86	9.672	1.33	11.002
Klewi	7	20-Oct-86	9.697	1.305	11.002
Klewi	7	20-May-87	9.75	1.252	11.002
Klewi	7	29-Jun-87	9.685	1.317	11.002
Klewi	7	28-Jul-87	9.554	1.448	11.002
Klewi	7	26-Aug-87	9.455	1.547	11.002
Klewi	7	24-Sep-87	9.567	1.435	11.002
Klewi	7	03-Dec-87	9.334	1.668	11.002
Klewi	7	19-May-88	9.446	1.556	11.002
Klewi	7	25-Jun-88	9.721	1.281	11.002
Klewi	7	29-Jul-88	9.712	1.29	11.002
Klewi	7	15-Aug-88	9.544	1.458	11.002
Klewi	7	21-Sep-88	9.411	1.591	11.002
Klewi	7	21-Oct-88	9.394	1.608	11.002

Klewi	7	23-May-89	9.752	1.25	11.002
Klewi	7	21-Jun-89	9.134	1.868	11.002
Klewi	7	23-Jul-89	9.23	1.772	11.002
Klewi	7	28-Aug-89	9.354	1.648	11.002
Klewi	7	23-Sep-89	9.182	1.82	11.002
Klewi	7	03-Nov-89	9.238	1.764	11.002
Klewi	7	24-May-90	9.212	1.79	11.002
Klewi	7	21-Jun-90	9.413	1.589	11.002
Klewi	7	10-Jul-90	9.199	1.803	11.002
Klewi	7	17-Aug-90	8.957	2.045	11.002
Klewi	7	26-Oct-90	9.109	1.893	11.002
Klewi	8	28-Jun-85	9.673	1.177	10.85
Klewi	8	25-Jul-85	9.542	1.308	10.85
Klewi	8	29-Aug-85	9.922	0.928	10.85
Klewi	8	25-Sep-85	9.763	1.087	10.85
Klewi	8	22-Oct-85	9.709	1.141	10.85
Klewi	8	28-May-86	9.625	1.225	10.85
Klewi	8	27-Jun-86	9.899	0.951	10.85
Klewi	8	27-Aug-86	9.732	1.118	10.85
Klewi	8	30-Sep-86	9.618	1.232	10.85
Klewi	8	20-Oct-86	9.672	1.178	10.85
Klewi	8	20-May-87	9.756	1.094	10.85
Klewi	8	29-Jun-87	9.752	1.098	10.85
Klewi	8	28-Jul-87	9.53	1.32	10.85
Klewi	8	26-Aug-87	9.387	1.463	10.85
Klewi	8	24-Sep-87	9.648	1.202	10.85
Klewi	8	03-Dec-87	9.233	1.617	10.85
Klewi	8	19-May-88	9.382	1.468	10.85
Klewi	8	25-Jun-88	9.782	1.068	10.85
Klewi	8	29-Jul-88	9.765	1.085	10.85
Klewi	8	15-Aug-88	9.573	1.277	10.85
Klewi	8	21-Sep-88	9.358	1.492	10.85
Klewi	8	21-Oct-88	9.395	1.455	10.85
Klewi	8	23-May-89	9.367	1.483	10.85
Klewi	8	21-Jun-89	9.118	1.732	10.85
Klewi	8	23-Jul-89	9.122	1.728	10.85
Klewi	8	28-Aug-89	9.356	1.494	10.85
Klewi	8	23-Sep-89	9.199	1.651	10.85
Klewi	8	03-Nov-89	9.348	1.502	10.85
Klewi	8	24-May-90	9.051	1.799	10.85
Klewi	8	21-Jun-90	9.332	1.518	10.85
Klewi	8	10-Jul-90	9.224	1.626	10.85
Klewi	8	17-Aug-90	8.993	1.857	10.85
Klewi	8	26-Oct-90	9.171	1.679	10.85
Klewi	9	28-Jun-85	9.445	1.003	10.448
Klewi	9	25-Jul-85	9.35	1.098	10.448
Klewi	9	29-Aug-85	9.659	0.789	10.448
Klewi	9	25-Sep-85	9.565	0.883	10.448
Klewi	9	22-Oct-85	9.561	0.887	10.448
Klewi	9	28-May-86	9.628	0.82	10.448
Klewi	9	27-Jun-86	9.673	0.775	10.448
Klewi	9	31-Jul-86	9.61	0.838	10.448
Klewi	9	27-Aug-86	9.625	0.823	10.448
Klewi	9	30-Sep-86	9.497	0.951	10.448
Klewi	9	20-Oct-86	9.553	0.895	10.448
Klewi	9	20-May-87	9.652	0.796	10.448
Klewi	9	29-Jun-87	9.42	1.028	10.448
Klewi	9	28-Jul-87	9.25	1.198	10.448

Klewi	9	26-Aug-87	9.181	1.267	10.448
Klewi	9	24-Sep-87	9.36	1.088	10.448
Klewi	9	03-Dec-87	9.201	1.247	10.448
Klewi	9	19-May-88	9.616	0.832	10.448
Klewi	9	25-Jun-88	9.491	0.957	10.448
Klewi	9	29-Jul-88	9.44	1.008	10.448
Klewi	9	15-Aug-88	9.248	1.2	10.448
Klewi	9	21-Sep-88	9.166	1.282	10.448
Klewi	9	21-Oct-88	9.236	1.212	10.448
Klewi	9	23-May-89	9.471	0.977	10.448
Klewi	9	21-Jun-89	9.213	1.235	10.448
Klewi	9	23-Jul-89	9.071	1.377	10.448
Klewi	9	28-Aug-89	9.135	1.313	10.448
Klewi	9	23-Sep-89	8.918	1.53	10.448
Klewi	9	03-Nov-89	8.857	1.591	10.448
Klewi	9	24-May-90	9.48	0.968	10.448
Klewi	9	21-Jun-90	9.198	1.25	10.448
Klewi	9	10-Jul-90	8.928	1.52	10.448
Klewi	9	17-Aug-90	8.678	1.77	10.448
Klewi	9	26-Oct-90	8.935	1.513	10.448
Sass-Klewi	10	28-Jun-85	10.025	1.162	11.187
Sass-Klewi	10	25-Jul-85	9.543	1.644	11.187
Sass-Klewi	10	29-Aug-85	9.686	1.501	11.187
Sass-Klewi	10	25-Sep-85	9.641	1.546	11.187
Sass-Klewi	10	22-Oct-85	9.595	1.592	11.187
Sass-Klewi	10	28-May-86	9.624	1.563	11.187
Sass-Klewi	10	27-Jun-86	9.649	1.538	11.187
Sass-Klewi	10	30-Jul-86	9.501	1.686	11.187
Sass-Klewi	10	27-Aug-86	9.578	1.609	11.187
Sass-Klewi	10	30-Sep-86	9.447	1.74	11.187
Sass-Klewi	10	20-Oct-86	9.45	1.737	11.187
Sass-Klewi	10	20-May-87	9.615	1.572	11.187
Sass-Klewi	10	29-Jun-87	9.482	1.705	11.187
Sass-Klewi	10	28-Jul-87	9.393	1.794	11.187
Sass-Klewi	10	26-Aug-87	9.432	1.755	11.187
Sass-Klewi	10	24-Sep-87	9.504	1.683	11.187
Sass-Klewi	10	03-Dec-87	9.224	1.963	11.187
Sass-Klewi	10	19-May-88	9.527	1.66	11.187
Sass-Klewi	10	25-Jun-88	9.529	1.658	11.187
Sass-Klewi	10	29-Jul-88	9.507	1.68	11.187
Sass-Klewi	10	15-Aug-88	9.485	1.702	11.187
Sass-Klewi	10	21-Sep-88	9.374	1.813	11.187
Sass-Klewi	10	21-Oct-88	9.345	1.842	11.187
Sass-Klewi	10	25-May-89	9.509	1.678	11.187
Sass-Klewi	10	21-Jun-89	9.369	1.818	11.187
Sass-Klewi	10	23-Jul-89	9.417	1.77	11.187
Sass-Klewi	10	28-Aug-89	9.453	1.734	11.187
Sass-Klewi	10	23-Sep-89	9.335	1.852	11.187
Sass-Klewi	10	03-Nov-89	9.325	1.862	11.187
Sass-Klewi	10	24-May-90	9.43	1.757	11.187
Sass-Klewi	10	21-Jun-90	9.393	1.794	11.187
Sass-Klewi	10	10-Jul-90	9.244	1.943	11.187
Sass-Klewi	10	17-Aug-90	9.219	1.968	11.187
Sass-Klewi	10	26-Oct-90	9.295	1.892	11.187
Sass-Klewi	12	28-Jun-85	8.804	2.652	11.456
Sass-Klewi	12	25-Jul-85	9.995	1.461	11.456
Sass-Klewi	12	29-Aug-85	9.992	1.464	11.456
Sass-Klewi	12	25-Sep-85	10.003	1.453	11.456

Sass-Klewi	12	22-Oct-85	9.99	1.466	11.456
Sass-Klewi	12	28-May-86	9.756	1.7	11.456
Sass-Klewi	12	27-Jun-86	9.717	1.739	11.456
Sass-Klewi	12	30-Jul-86	9.902	1.554	11.456
Sass-Klewi	12	27-Aug-86	9.916	1.54	11.456
Sass-Klewi	12	30-Sep-86	9.769	1.687	11.456
Sass-Klewi	12	20-Oct-86	9.746	1.71	11.456
Sass-Klewi	12	20-May-87	9.774	1.682	11.456
Sass-Klewi	12	29-Jun-87	9.894	1.562	11.456
Sass-Klewi	12	28-Jul-87	9.781	1.675	11.456
Sass-Klewi	12	26-Aug-87	9.779	1.677	11.456
Sass-Klewi	12	24-Sep-87	9.871	1.585	11.456
Sass-Klewi	12	03-Dec-87	9.867	1.589	11.456
Sass-Klewi	12	19-May-88	9.931	1.525	11.456
Sass-Klewi	12	25-Jun-88	9.917	1.539	11.456
Sass-Klewi	12	29-Jul-88	9.866	1.59	11.456
Sass-Klewi	12	15-Aug-88	9.854	1.602	11.456
Sass-Klewi	12	21-Sep-88	9.696	1.76	11.456
Sass-Klewi	12	21-Oct-88	9.644	1.812	11.456
Sass-Klewi	12	25-May-89	9.719	1.737	11.456
Sass-Klewi	12	21-Jun-89	9.688	1.768	11.456
Sass-Klewi	12	23-Jul-89	9.762	1.694	11.456
Sass-Klewi	12	28-Aug-89	9.798	1.658	11.456
Sass-Klewi	12	23-Sep-89	9.683	1.773	11.456
Sass-Klewi	12	03-Nov-89	9.696	1.76	11.456
Sass-Klewi	12	24-May-90	9.821	1.635	11.456
Sass-Klewi	12	21-Jun-90	9.783	1.673	11.456
Sass-Klewi	12	10-Jul-90	9.644	1.812	11.456
Sass-Klewi	12	17-Aug-90	9.578	1.878	11.456
Sass-Klewi	12	26-Oct-90	9.634	1.822	11.456
Sass-Klewi	13	28-Jun-85	9.307	1.993	11.3
Sass-Klewi	13	25-Jul-85	9.655	1.645	11.3
Sass-Klewi	13	29-Aug-85	9.771	1.529	11.3
Sass-Klewi	13	25-Sep-85	9.66	1.64	11.3
Sass-Klewi	13	22-Oct-85	9.677	1.623	11.3
Sass-Klewi	13	28-May-86	9.707	1.593	11.3
Sass-Klewi	13	27-Jun-86	9.69	1.61	11.3
Sass-Klewi	13	30-Jul-86	9.59	1.71	11.3
Sass-Klewi	13	27-Aug-86	9.62	1.68	11.3
Sass-Klewi	13	30-Sep-86	9.623	1.677	11.3
Sass-Klewi	13	20-Oct-86	9.64	1.66	11.3
Sass-Klewi	13	20-May-87	9.683	1.617	11.3
Sass-Klewi	13	29-Jun-87	9.628	1.672	11.3
Sass-Klewi	13	28-Jul-87	9.537	1.763	11.3
Sass-Klewi	13	26-Aug-87	9.553	1.747	11.3
Sass-Klewi	13	24-Sep-87	9.62	1.68	11.3
Sass-Klewi	13	03-Dec-87	9.46	1.84	11.3
Sass-Klewi	13	19-May-88	9.552	1.748	11.3
Sass-Klewi	13	25-Jun-88	9.66	1.64	11.3
Sass-Klewi	13	29-Jul-88	9.621	1.679	11.3
Sass-Klewi	13	15-Aug-88	9.612	1.688	11.3
Sass-Klewi	13	21-Sep-88	9.51	1.79	11.3
Sass-Klewi	13	21-Oct-88	9.488	1.812	11.3
Sass-Klewi	13	25-May-89	9.395	1.905	11.3
Sass-Klewi	13	21-Jun-89	9.515	1.785	11.3
Sass-Klewi	13	23-Jul-89	9.561	1.739	11.3
Sass-Klewi	13	28-Aug-89	9.543	1.757	11.3
Sass-Klewi	13	23-Sep-89	9.435	1.865	11.3

Sass-Klewi	13	03-Nov-89	9.456	1.844	11.3
Sass-Klewi	13	24-May-90	9.633	1.667	11.3
Sass-Klewi	13	21-Jun-90	9.56	1.74	11.3
Sass-Klewi	13	10-Jul-90	9.345	1.955	11.3
Sass-Klewi	13	17-Aug-90	9.248	2.052	11.3
Sass-Klewi	13	26-Oct-90	9.437	1.863	11.3
Sass-Klewi	14	28-Jun-85	8.149	2.466	10.615
Sass-Klewi	14	25-Jul-85	9.556	1.059	10.615
Sass-Klewi	14	29-Aug-85	9.648	0.967	10.615
Sass-Klewi	14	25-Sep-85	9.624	0.991	10.615
Sass-Klewi	14	22-Oct-85	9.62	0.995	10.615
Sass-Klewi	14	28-May-86	9.59	1.025	10.615
Sass-Klewi	14	27-Jun-86	9.661	0.954	10.615
Sass-Klewi	14	30-Jul-86	9.575	1.04	10.615
Sass-Klewi	14	27-Aug-86	9.622	0.993	10.615
Sass-Klewi	14	30-Sep-86	9.556	1.059	10.615
Sass-Klewi	14	20-Oct-86	9.556	1.059	10.615
Sass-Klewi	14	20-May-87	9.634	0.981	10.615
Sass-Klewi	14	29-Jun-87	9.507	1.108	10.615
Sass-Klewi	14	28-Jul-87	9.417	1.198	10.615
Sass-Klewi	14	26-Aug-87	9.443	1.172	10.615
Sass-Klewi	14	24-Sep-87	9.506	1.109	10.615
Sass-Klewi	14	03-Dec-87	9.563	1.052	10.615
Sass-Klewi	14	19-May-88	9.517	1.098	10.615
Sass-Klewi	14	25-Jun-88	9.545	1.07	10.615
Sass-Klewi	14	29-Jul-88	9.505	1.11	10.615
Sass-Klewi	14	15-Aug-88	9.493	1.122	10.615
Sass-Klewi	14	21-Sep-88	9.415	1.2	10.615
Sass-Klewi	14	21-Oct-88	9.407	1.208	10.615
Sass-Klewi	14	25-May-89	9.337	1.278	10.615
Sass-Klewi	14	21-Jun-89	9.425	1.19	10.615
Sass-Klewi	14	23-Jul-89	9.433	1.182	10.615
Sass-Klewi	14	28-Aug-89	9.437	1.178	10.615
Sass-Klewi	14	23-Sep-89	9.352	1.263	10.615
Sass-Klewi	14	03-Nov-89	9.388	1.227	10.615
Sass-Klewi	14	24-May-90	9.514	1.101	10.615
Sass-Klewi	14	21-Jun-90	9.451	1.164	10.615
Sass-Klewi	14	10-Jul-90	9.259	1.356	10.615
Sass-Klewi	14	17-Aug-90	9.167	1.448	10.615
Sass-Klewi	14	26-Oct-90	9.366	1.249	10.615

APPENDIX C

Ground Water Level Readings in D1 and D2

Ground Water Level Readings in Wells D1 and D2
(metres)

Date	D1	D2
21-Dec-85	-2.905	-3.128
08-Feb-86	-3.496	-3.153
27-Apr-86	-3.17	-3.03
25-May-86	-1.73	-2.735
22-Jun-86	-1.528	-2.735
26-Jul-86	-2.123	-2.862
30-Aug-86	-1.997	-2.935
29-Sep-86	-2.162	-3.005
29-Oct-86	-2.177	-3.027
23-Nov-86	-2.446	-3.041
07-Jan-87	-3.004	-3.098
01-Feb-87	-3.202	-3.132
15-Mar-87	-3.68	-3.205
11-Apr-87	-3.74	-3.198
25-Apr-87	-2.68	-2.868
14-Jun-87	-1.745	-2.808
27-Jun-87	-2.042	-2.976
11-Aug-87	-2.54	-3.145
30-Aug-87	-2.572	-3.163
12-Sep-87	-2.446	-3.137
11-Oct-87	-2.452	-3.112
14-Nov-87	-2.49	-3.082
03-Jan-88	-3.088	-3.187
06-Feb-88	-3.51	-3.283
19-Mar-88	-4.136	-3.29
09-Apr-88	-4.362	-3.321
15-Apr-88	-4.2	-3.282
26-Apr-88	-3.36	-3.034
07-May-88	-2.962	-2.965
19-May-88	-2.432	-3.012
30-May-88	-1.992	-2.99
27-Jun-88	-1.987	-2.996
29-Jul-88	-1.87	-2.975
14-Aug-88	-2.044	-2.976
02-Sep-88	-2.373	-3.049
25-Sep-88	-2.42	-3.092
16-Oct-88	-2.45	-3.102
28-Oct-88	-2.495	-3.11
14-Nov-88	-2.53	-3.119
17-Dec-88	-2.795	-3.171
23-Jan-89	-3.572	-3.346
19-Feb-89	-3.97	-3.361
09-Mar-89	-4.308	-3.402
27-Mar-89	-4.55	-3.291
03-Apr-89	-4.642	-3.394
09-Apr-89	-4.718	-3.366
25-Apr-89	-4.726	-3.334
29-Apr-89	-4.622	-3.104
09-May-89	-4.382	-3.07
28-May-89	-2.966	-3.052
03-Jun-89	-3.053	-3.069
21-Jun-89	-3.026	-3.191

03-Jul-89	-3.075	-3.234
22-Jul-89	-3.088	-3.287
25-Aug-89	-2.993	-3.28
12-Sep-89	-3.069	-3.208
19-Sep-89	-3.171	-3.318
13-Oct-89	-3.236	-3.184
22-Oct-89	-3.191	-3.293
11-Nov-89	-3.323	-3.301
09-Dec-89	-3.659	-3.409
04-Jan-90	-3.932	-3.434
07-Jan-90	-3.253	-3.288
04-Feb-90	-4.257	-3.498
03-Mar-90	-4.573	-3.632
17-Mar-90	-4.738	-3.66
31-Mar-90	-4.822	-3.674
18-Apr-90	-4.045	-3.597
21-Apr-90	-3.742	-3.551
25-Apr-90	-3.325	-3.284
06-May-90	-3.323	-3.179
09-May-90	-2.893	-3.194
24-May-90	-2.928	-3.25
03-Jun-90	-2.915	-3.319
21-Jun-90	-3.001	-3.342
10-Jul-90	-2.912	-3.454
28-Jul-90	-2.718	-3.48

APPENDIX D

Total Monthly Precipitation, Wood Buffalo Park Region

TOTAL MONTHLY PRECIPITATION: WOOD BUFFALO PARK REGION

Station	Year	1	2	3	4	5	6	7	8	9	10	11	12	Total	Mean	Plotted Value
2202000	86	18		20.2		39.8	33.8	22	24.6	19.4	13			190.8	23.8	
2202000	87	16	5.4	0										21.4	7.13	
2202196	13							65.0	53.3	99.3	29.7		33.0	280.3	56.0	
2202196	14	2.5	5.1						34.8	83.8	11.2	32.8	0.0	170.2	24.3	
2202196	15	27.9	39.6	3.8	9.4	4.3	36.8	1.5	15.7	33.8	61.2	21.8	7.6	263.4	21.9	263.
2202196	16	24.9		14.0	1.8	13.7	48.3	112.0	43.9	28.7		26.7	8.9	322.9	32.2	
2202196	17					17.3	13.2	86.1	61.0	20.1	29.5	34.3	7.9	269.4	33.6	
2202196	18	41.4	11.7	7.1	22.9	73.7	47.0	19.6	33.0	17.0	55.4	0.0	21.6	350.4	29.2	350.
2202196	19	34.5	5.3			17.5	86.9	62.7	30.7	17.8	32.0	23.1		310.5	34.5	
2202196	20		7.6	2.0			64.5	5.1		56.6	17.8	47.0		200.6	28.6	
2202196	21	2.5	25.4	14.0		30.2	104.9	43.9	169.2	43.9	18.3	16.5	3.3	472.1	42.9	
2202196	22	6.4	6.4	14.0		34.5	27.2	69.3	32.3	31.5	29.2	7.6	15.2	273.6	24.8	
2202196	23	26.7	10.2	7.6		30.2	54.4	51.6	26.7	41.9	13.2	15.2	21.6	299.3	27.2	
2202196	24	7.6	35.6	7.6	5.1	15.2	20.6	24.1			5.1	6.1	10.2	137.2	13.7	
2202196	25	7.6	27.9	21.1	4.3	15.5	61.2	12.2	24.4	53.3	12.7	10.2	21.6	272.0	22.6	272
2202196	26	11.4	14.0	3.8	16.5	30.0	39.9	28.4	17.8	13.0	23.1	3.3	25.4	226.6	18.8	226.
2202196	27	5.1	1.3	5.8	12.7	1.3	18.3	16.3	16.3	29.7	26.7	14.0	7.6	155.1	12.9	155.
2202196	28	10.2	9.1	1.3	7.6	7.1	21.6	35.3	33.3	6.4	2.5		3.8	138.2	12.5	
2202196	29	1.3												1.3	1.3	
2202200	43									12.2	9.9			22.1	11.0	
2202200	44		1.3	3.0		17.3	39.9	48.3	5.8	14.7	24.4		30.2	184.9	20.5	
2202200	45	8.6	25.9	11.7	19.6	6.4	18.5	79.8	12.4	42.4	40.1	19.6	10.9	295.9	24.6	295.
2202200	46	12.4	9.1	13.5	16.5	27.7	29.5	56.6	37.1	27.4	28.4	15.5	30.5	304.2	25.3	304.
2202200	47	35.6	9.4	15.0	13.5	30.0	36.6	11.2	66.0	16.0	24.4	33.0		290.7	26.4	
2202200	48	9.7	12.7	15.0	7.1	6.6	36.8	56.6	39.4	45.0	11.2	27.7	28.7	296.5	24.7	296.
2202200	49	20.1	6.1	10.7	35.1	11.9	38.1	27.4	36.3	32.3	57.9	26.2	14.0	316.1	26.3	316.
2202200	50	1.8	20.1	4.3	14.7	39.4	6.1	26.7	36.6	52.8	16.3	42.2	25.7	286.7	23.8	286.
2202200	51	12.2	18.0	13.0	17.5	84.3	24.6	25.7	12.4	27.7	20.8	16.5	11.2	283.9	23.6	283.
2202200	52	13.0	17.0	16.8	18.8	19.1	28.7	21.8	32.5	25.4	25.4	19.8	18.3	256.6	21.3	256.
2202200	53	22.4	14.7	17.0	18.5	6.4	8.4	41.9	20.1	71.1	22.4	45.5	51.3	339.7	28.3	339.
2202200	54	18.5	27.4	7.1	22.6	9.9	6.1	137.4	18.8	27.2	17.5	39.6	20.6	352.7	29.3	352.
2202200	55	24.4	15.2	15.2	28.2	28.4	9.4	63.0	45.5	42.9	25.1	51.1	33.5	381.9	31.8	381.
2202200	56	17.0	23.4	8.6	22.1	25.9	85.1	52.3	29.7	46.2	42.9	55.1	30.7	439.0	36.5	439
2202200	57	21.6	21.8	8.6	13.2	9.9	19.1	102.9	11.4	39.4	61.5	21.6	27.4	358.4	29.8	358.
2202200	58	23.6	23.9	22.6	17.0	32.5	7.1	23.4	60.7	46.2	29.2	13.2	43.4	342.8	28.5	342.
2202200	59	10.7	6.1	26.7	14.7	18.8	35.1	23.6	75.4	38.1	32.3	15.0	26.9	323.4	26.9	323.
2202200	60	1.3	15.0	16.5	15.7	27.9	73.9	52.3	47.5	46.5	45.0	26.9	23.9	392.4	32.7	392.
2202200	61	19.8	12.7	23.1	8.6	5.3	15.7	53.8	42.7	56.1	33.0	51.3	40.9	363.0	30.2	363
2202200	62	27.4	17.0	17.0	2.8	29.5	75.9	95.3	22.1	47.2	32.5	16.8	25.7	409.2	34.1	409.
2202200	63	39.4	12.4	19.8	5.1	11.7	78.0	62.2	34.3	44.7	4.6	49.5	15.2	376.9	31.4	376.
2202200	64	12.4	24.4	8.4	18.3	47.0	27.9	25.1	8.8	35.3	32.3	22.6	4.6	267.1	22.2	267.
2202200	65	9.4	12.7	9.4	3.6	13.5	50.8	74.4	47.8	29.0	41.9	28.2	20.6	341.3	28.4	341.
2202200	66	28.2	11.4	15.7	37.3	21.6	20.3	37.8	32.5	37.3	50.5	16.8	9.9	319.3	26.6	319.
2202200	67	9.9	14.7	13.7	17.0	28.4	59.7	84.6	33.0	44.7	27.4	18.8	19.8	371.7	30.9	371.
2202200	68	30.5	8.4	39.1	14.7	54.1	43.2	67.6	40.6	27.9	22.6	21.8	4.8	375.3	31.2	375.
2202200	69	9.1	15.2	7.9	21.8	26.7	19.8	20.1	58.9	39.4	2.3	16.8	17.8	255.8	21.3	255.
2202200	70	18.3	18.8	9.7	34.5	25.9	14.5	51.3	74.9	35.3	20.3	9.1	17.0	329.6	27.4	329.

2202200	71	19.1	29.2	11.4	3.8	13.0	7.9	25.4	21.6	25.1	17.3	38.9	9.7	222.4	18.5	222.
2202200	72	13.0	12.7	14.2	35.3	28.4	83.6	5.3	80.5	54.4	28.7	13.0	26.4	395.5	32.9	395.
2202200	73	27.2	5.3	20.8	30.7	51.1	43.7	149.1	64.0	77.0	22.9	31.2	18.8	541.8	45.1	541.
2202200	74	27.7	27.4	18.3	9.7	40.6	88.1	63.0	43.4	27.7	25.4	17.0	38.9	427.2	35.6	427.
2202200	75	23.4	9.7	4.8	8.6	66.5	40.9	73.2	109.5	34.3	19.6	46.0	19.3	455.8	37.9	455.
2202200	76	26.9	29.5	19.6	1.3	12.4	58.2	70.1	7.1	33.5	7.9	27.9	16.0	310.4	25.8	310.
2202200	77	21.6	18.9	6.9	8.1	14.7	119.3	58.2	48.6	21.6	15.6	13.0	17.4	363.9	30.3	363.
2202200	78	9.0	0.3	7.6	13.1	14.1	38.6	64.7	8.5	69.0	28.0	6.6	19.5	279.0	23.2	279
2202200	79	1.7	6.5	10.7	20.5	20.7	23.1	57.9	27.0	32.5	28.2	11.4	15.5	255.7	21.3	255.
2202200	80	16.9	7.5	2.7	2.2	44.5	29.2	23.0	75.0	49.3	11.6	20.7	22.2	304.8	25.4	304.
2202200	81	14.4	15.2	18.9	30.0	1.7	68.2	43.7	9.5	30.3	56.8	32.1	26.8	347.6	28.9	347.
2202200	82	4.6	12.2	4.5	17.0	43.2	15.1	36.8	31.5	64.0	14.4	19.5	24.9	287.7	23.9	287.
2202200	83	28.3	20.6	10.2	0.3	36.7	12.5	99.6	69.8	17.8	45.4	14.0	5.6	360.8	30.0	360.
2202200	84	27.3	15.8	11.2	4.6	18.9	57.9	85.0	57.4	41.8	99.7	16.7	14.6	450.9	37.5	450.
2202200	85	22.5	18.9	12.5	18.4	14.1	13.3	46.2	71.6	6.9	26.8	20.1	11.3	282.6	23.5	282.
2202200	86	28.5	4.2	23	4.4	45.8	63.7	35.2	63.7	17.1	15.2	18.7	31.4	350.9	29.2	350.
2202200	87	29.6	12.2	28.1	12.1	20	42.2	24.8	60.4	48.8	27.8	28.2	24.8	359.0	29.9	359
2202200	88	16.7	10.1	6.6	10.9	68.1	82.9	91.9	65	20.4	13.4	28.2	4.6	418.8	34.9	418.
2202200	89	17.7	6.4	72	4.8	37.8	21.8	45.6	21.8		34.5	49.1	30.6	342.1	31.1	
2202400	43				9.4	6.6								16.0	8	
2202400	44	55.9	6.4	6.4	0.5	18	47.8	34.3	4.1	19.3	48.5		26.2	267.4	24.3	
2202400	45	4.8	10.9	2	6.6	1.8	16.8	44.5	9.9	34.3	37.8	22.4	7.9	199.7	16.6	199.
2202400	46	4.8	8.4	6.1	5.3	36.1	12.4	47.2	6.1	29	23.4	18.5	11.9	209.2	17.4	209.
2202400	47	7.9	4.1	14.2	29	25.1	21.8	17.3	48.5	30.5	17.5	39.1	11.4	266.4	22.2	266.
2202400	48	22.1	23.1	14	0.5	2.3	48.3	57.7	88.6	49.8	19.8	24.4	22.6	373.2	31.1	373.
2202400	49	24.9	3	6.4	43.2	9.9	21.3	5.8	27.9	38.1	71.4	53.8	13	318.7	26.5	318.
2202400	50	2.3	35.3	1	23.1	9.1	27.7	39.1	44.7	38.6	26.2	62.2	9.9	319.2	26.6	319.
2202400	51	5.8	9.7	9.1	34.3	65.5	44.2	25.4	32	41.7	22.4	20.1	27.7	337.9	28.1	337.
2202400	52	14.2	38.4	12.4	25.7	23.4	7.1	21.1	75.4	76.7	21.6	22.6	21.1	359.7	29.9	359.
2202400	53	22.4	7.4	29.5	12.2	15.2	5.3	18.8	78.5	77.2	43.4	30	13	352.9	29.4	352.
2202400	54	11.2	8.6	32	5.8	11.9	14	71.6	39.4	40.9	33.8	78	42.9	390.1	32.5	390.
2202400	55	24.4	19.8	14.2	17	4.6	16.8	33.8	8.1	48.8	29.7	33	38.4	288.6	24.0	288.
2202400	56	17	13.2	11.7	9.7	22.9	52.8	44.7	37.6	63.8	27.9	35.1	28.8	365.2	30.4	365.
2202400	57	18.5	17.3	22.1	23.1	13	36.3	126.2	12.4	25.1	14.5	43.7	22.4	374.6	31.2	374.
2202400	58	24.4	35.8	20.8	17.5	11.2	8.6	60.2	46.2	29.5	48.3	25.1	39.1	366.7	30.5	366.
2202400	59	11.7	4.3	14.5	7.9	3.3	9.7	77	45.7	24.6	47.5	26.9	36.3	309.4	25.7	309.
2202400	60	8.1	32.3	25.9	9.1	41.7	27.4	69.1	48	55.1	41.4	83.3	37.8	479.2	39.9	479.
2202400	61	36.3	16.5	29	13.7	11.4	17.8	80.8	34.5	21.3	102.	78.7	43.2	485.8	40.4	485.
2202400	62	42.9	20.3	15	2.8	16	78.5	58.4	40.4	25.9	22.6	61.7	55.6	440.1	36.6	440.
2202400	63	49.8	43.2	18.8	1.5	4.6	21.3	105.4	27.2	52.8	4.6	116.	25.4	470.9	39.2	470.
2202400	64	34.3	32	19.3	5.8	24.1	3.8	12.2	26.4	120.	35.3	32.8	12.2	358.3	29.8	358.
2202400	65	18.5	26.9	7.4	11.9	2.8	37.6	35.6	24.1	45	56.6	26.9	43.7	337.0	28.0	337
2202400	66	27.2	8.9	34.3	31	17.8	49.8	44.5	6.1	62.2	70.4	19.1	11.9	383.2	31.9	383.
2202400	67	12.4	30.2	18.5	8.4	20.6	28.2	57.2	3.8	17	24.9	26.2	15.2	262.6	21.8	262.
2202400	68	27.4	13.2	26.9	23.4	20.1	22.1	70.6	22.1	54.6	29.7	52.3	9.9	372.3	31.0	372.
2202400	69	17.8	11.4	18.3	34.8	6.4	17.8	14	55.4	16.5	3	27.4	11.2	234.0	19.5	234
2202400	70	27.2	17.3	25.1	64.3	10.4	14.2	17.3	26.4	23.1	11.2	11.9	21.1	269.5	22.4	269.
2202400	71	29.5	14.5	4.8	8.9	42.4	2.8	37.3	21.6	15.2	25.7	34.8	11.9	249.4	20.7	249.
2202400	72	13.5	19.3	16.5	28.2	24.1	38.9	11.9	52.1	57.2	20.3	14	23.6	319.6	26.6	
2202400	73	16.5	11.2	12.7	8.4	14	47.5	66.3	95.5	2.8	7.1	48.5	18.3	348.8	29.0	348.
2202400	74	22.4	20.6	19.8	3.6	21.3	43.7	44.5	47	52.1	24.1	26.9	34.3	360.3	30.0	360.
2202400	75	20.6	17.3	17.5	14	30.2	6.6	22.6	70.6	32.3	37.1	50.5	20.1	339.4	28.2	339.

2202400	76	21.1	24.9	19.6	8.1	19.6	70.6	42.4	36.6	42.9	14.5	10.9	12.7	323.9	26.9	323.
2202400	77	16.8	14.1	22.2	5	36.2	26.8	6.3	19.6	31.9	19.9	21	14.6	234.4	19.5	234.
2202400	78	7	1.6	10.3	20.8	2	43.6	71	2.8	30.5	40.1	19.8	25.3	274.8	22.9	274.
2202400	79	1.8	6.7	19.1	15	45.6	5.9	36.3	29.2	22.5	25.8	10.4	12.1	230.4	19.2	230.
2202400	80	22.6	4	2.1	1	21	4	60.7	65	60.4	10.1	19.6	16.5	287.0	23.9	287
2202400	81	4.6	15.6	9.3	52.7	0.4	7.5	18.3	54	41	65.3	23.8	18.6	311.1	25.9	311.
2202400	82		18.6	2.6	10.9	37.3	26	23.1	24.8	49	30.7	14.3	19	256.3	23.3	
2202400	83	26.3	33.8	17.6	2.4	22.5	28.5	11	72.7	53	16	12.8	6.4	303.0	25.2	303
2202400	84	28.5	20.4	12.6	2	26.1	63.6	98	59.5	40.4	81.5	20.1	17.1	469.8	39.1	469.
2202400	85	15.4	26.3	3.7	19.7	21.5	15.9	34	92.8	21.4	37.2	30.7	45.5	364.1	30.3	364.
2202400	86	22.4	6.8	39	8	19.9	64.6	23.5	62.9	14.6	21.7	21.5	30.5	335.4	27.9	335.
2202400	87	23.2	19.2	16.6	10.3	18.4	77.4	60.4	41	38.7	39	35	14.7	393.9	32.8	393.
2202400	88	20.2	13.4	10.2	17.2	57.8	126.4	92.8	57.4	34.2	57.8	18.9	5.6	511.9	42.6	511.
2202400	89	14.5	7.6	12.1		22.6	32	48.9	24.5	11.5	47.2	55.7	27	303.6	27.6	
2202405	65									30	30.2	40.4	37.1	137.7	34.4	
2202405	66	32	9.7	25.1	40.1	7.6	48.3	25.1	9.7	50.8	41.9	16	6.6	312.9	26.0	312.
2202405	67	3.8	29.5	22.6	6.4	30	52.1	91.4	17.5		13	20.3	4.1	290.7	26.4	
2202405	68	28.2	14.2	21.6	23.9	25.7	60.7	92.2	27.4	37.8	16	35.3	12.2	395.2	32.9	395.
2202405	69	13.2	13.2	13.7	18	8.4	10.4	37.6	57.9	20.3	0	32	17	241.7	20.1	241.
2202405	70	35.6	16.3	20.3	77.2	22.9	8.6	15.7	29.2	20.6	8.4	6.1	9.9	270.8	22.5	270.
2202405	71	17	15.7	3.8	11.9	52.1	4.3	48.5	48.3	53.6	22.9	47.8	5.6	331.5	27.6	331.
2202405	72	9.4	18.5	34.8	10.9	39.4	49.5	20.6		39.9	37.6	17.3	38.1	316.0	28.7	
2202405	73	31.2	12.2	11.9	4.1	29.2	61.5	67.3	122.9	2.3	16.3	39.1	14	412.0	34.3	412
2202405	74	28.2	43.4	16.8	1.5	20.1	59.9	42.2	45	46.5	2.8	25.4	27.7	359.5	29.9	359.
2202405	75	9.1	15	16.8	8.6	39.6	11.9	33	87.9	19.8	20.1	66.8	15.7	344.3	28.6	344.
2202405	76	25.4	17	18.3	1	68.6	47.2	52.1	88.9	45.5	18.8		14.2	397.0	36.0	
2202405	77	8.4	9.6	20.9		33	36	8.1	26.4	19.3	14.2		12.1	188.0	18.8	
2202405	78	8.5	2.8	16.8	40.9	0.8	31.2	66.1		27.7	40		23.6	258.4	25.8	
2202405	79	4.3	2	33.2		58.4	8.3	23.8	35	28	22.8	16.4	11.2	243.4	22.1	
2202405	80	15.3	4.4	1.2		18.6	19.6	64	40.5	61.8		33.3	14	272.7	27.2	
2202405	81	4.6	13.6	10.9	64.1			29.3	54.2	36.7		30	24.9	268.3	29.8	
2202405	82	4.4	20.6	2.4		62.9	30.8	37.7	31.8	55.6		15	31.7	292.9	29.2	
2202405	83	26.6	40	26	3.9	20.4	43.8	31.9	57.4	47.4	11.5	15.6	9	333.5	27.7	333.
2202405	84	38.2	22.3	11.1	0.4		105.7	57.9	58.7	31.2		30	23.7	379.2	37.9	
2202405	85	34.7	40.7	4.2		20.2	22.6	47.7	104.5	24.8		21.4	21	341.8	34.1	
2202405	86	34	16.4	35.7	7.4	15.4	95.5	41.8	69.5	12.9		38.8	23.2	390.6	35.5	
2202405	87	29.8	19.4	17.8		26.4	88.6	59.5	36	46.1			28.6	352.2	39.1	
2202405	88	26.6	24.3	11.9	18.6	51.4	132.5	78.3	44.7	33.4			12	433.7	43.3	
2202405	89	17	7.2	17.5	10.6	35	29.8	76.8		22.6			12.2	228.7	25.4	