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GROUNDWATER INVESTIGATIONS RELATED TO THE LOCATION AND SUCCESS OF KOKANEE SALMON SPAWNING, FLATHEAD LAKE, MONTANA: PRELIMINARY RESULTS, APRIL, 1982-JUNE, 1983

Prepared for

Montana Fish, Wildlife and Parks
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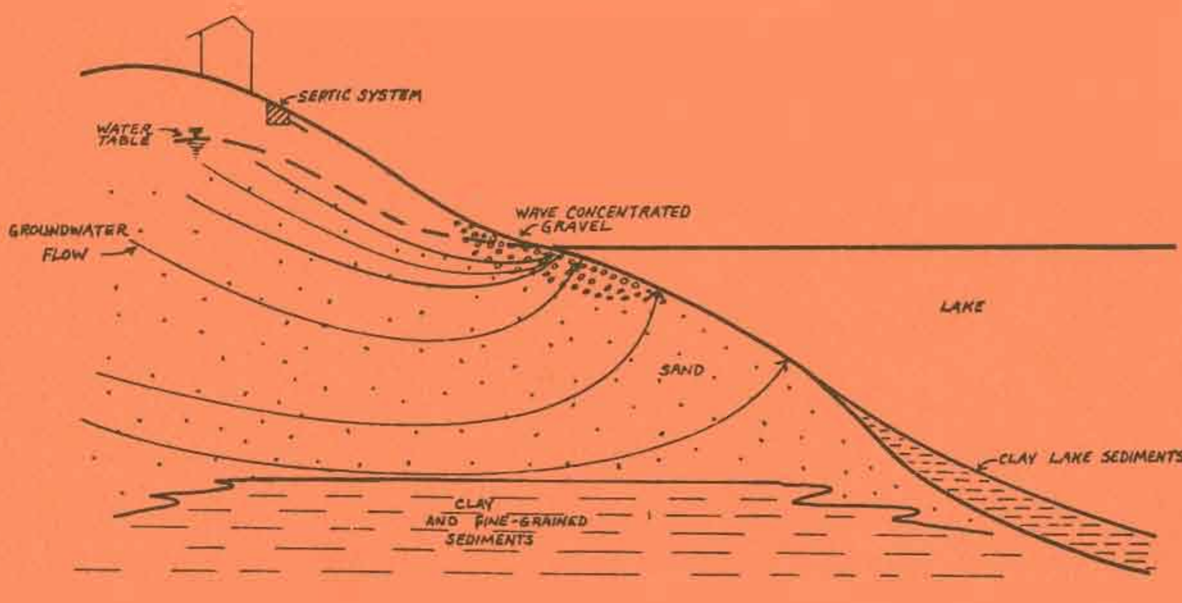

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ABSTRACT

Nine Kokanee Salmon spawning sites were studied from April 1982 to June 1983. Selected sites were instrumented with seepage meters and shallow wells. Hydraulic gradient, hydraulic conductivity and apparent and true groundwater velocity were determined within 10 m of the lake at selected sites. Analyses of study results indicate Flathead Lake is a groundwater discharge lake. The local groundwater system is affected by lake stage fluctuations and surface stream recharge in the shoreline area. Redds which are exposed during early lake stage decline often are unwetted by the water table for months. Average apparent groundwater velocity values for submerged sites range from 0.22 to 0.47 cm/hr and from 6.2 to 118 cm/hr in the exposed shore area. Groundwater is a calcium bicarbonate type with a TDS range of 100 to 300 mg/l. Concentrations of DO are generally lower in wells than seepage meter collected groundwater.

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INTRODUCTION

Kokanee salmon spawning research conducted by the Montana Department of Fish, Wildlife and Parks (FWP) has lead investigators to hypothesize that the shoreline groundwater flow system is important to site selection and success. As a result, hydrogeologic investigation of the Flathead Lake shore environment was voluntarily initiated by the principle author and FWP field crews in March 1982 through June 1982. Study was continued during the summer of 1982 with limited support by the University of Montana and a FWP personal services contract covering field expenses until January 1983. Detailed FWP funded hydrogeologic investigations were begun on five spawning sites in January 1983 and are continuing as part of a two year proposed study. The results of hydrogeologic investigation for the period of March 1982 through June 1983 will be presented in the report.

GOALS AND OBJECTIVES

The goal of the hydrogeologic research is to provide FWP researchers with a quantitative determination of the groundwater system operating in existing spawning areas and other selected sites. The objectives of the two-year research effort are threefold:

1. Identification of the occurrence, movement, quantity and quality of groundwater systems associated with documented spawning areas and other selected sites.

2. Establishment of the effect of lake stage change and shoreline development on the associated groundwater system.

3. Establishment of the general shoreline hydrogeology on a reconnaissance level.

The period of study covered by this report has concentrated on the first and second objectives though results should be considered preliminary.

STUDY APPROACH

The design of the research completed and ongoing is based on a conceptual model of how the lake shore groundwater system functions. The development of the model was based on limited available hydrogeologic data for Flathead Lake and the vicinity, a number of lake studies and basic hydrogeologic theory.

Conceptual Model

Conceptually, Flathead Lake acts as a groundwater discharge area for regional and local groundwater flow (Figure 1). The groundwater systems operating in the Flathead Lake region are believed to be complex requiring a detailed knowledge of the local geologic framework and hydrologic system. The discharge will vary over time at a given point on the shoreline because of a natural response to climatic variation in the annual quantity of available recharge. Discharge will also vary laterally, based on the differing ability of geologic materials which are distributed around the lake to accept and transmit water. The water chemistry may vary at a given point over time naturally and will vary laterally because of the various geologic compositions of aquifer systems connected to the lake (Figure 2).

Lake-groundwater interactions have been studied in the midwest, Canada and Florida using field trechniques and computer modeling. Seepage meters which directly measure groundwater discharge into lakes were originally described by Lee (1977) and have been used successfully by Fellows and Brezonik (1980) and Lee and Cherry (1979). Modeling of lake-groundwater interactions has been done by a number of workers. Winter (1976, 1978) has modeled two and three dimensional simulations of groundwater flow regimes near lakes with varying aquifer characteristics such as thickness and permeability.

Figure 1: ***REGIONAL CONCEPTUAL MODEL OF FLATHEAD LAKE***

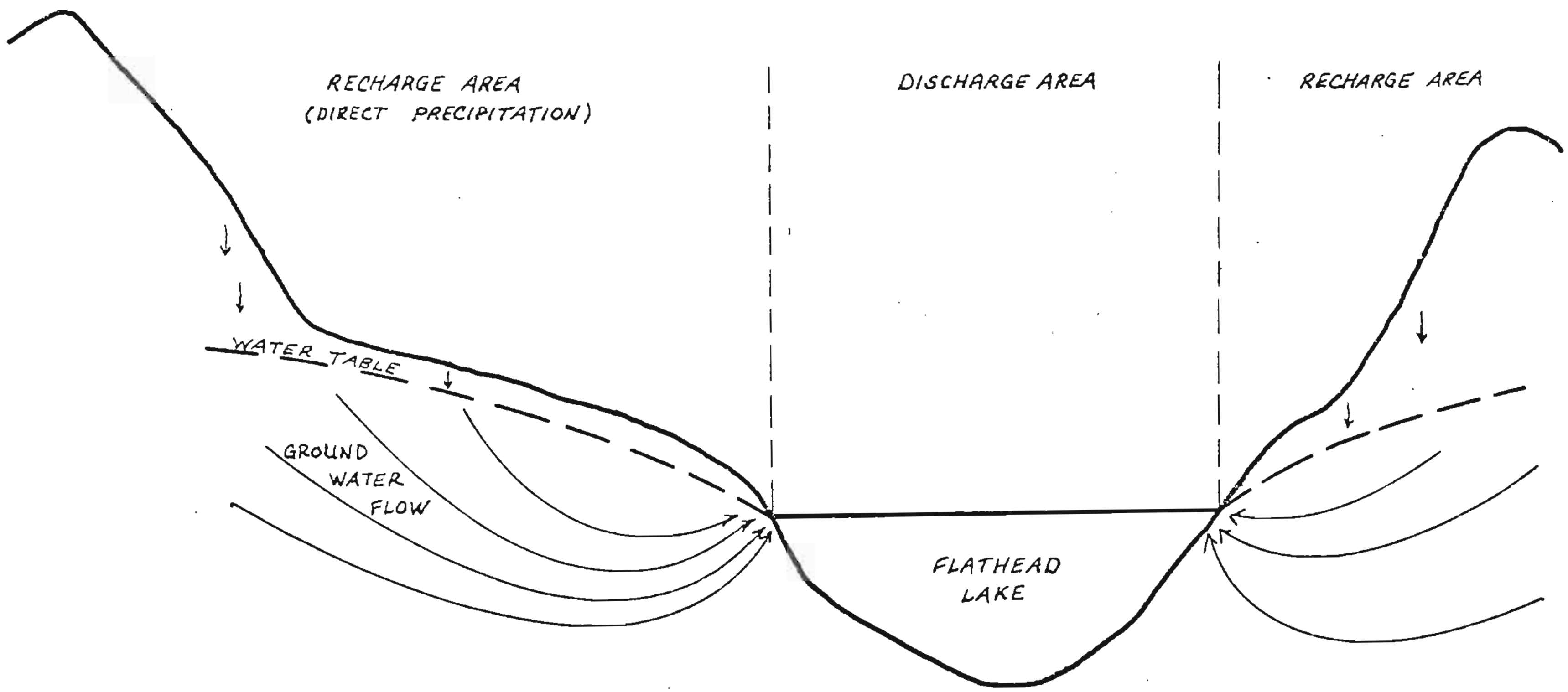
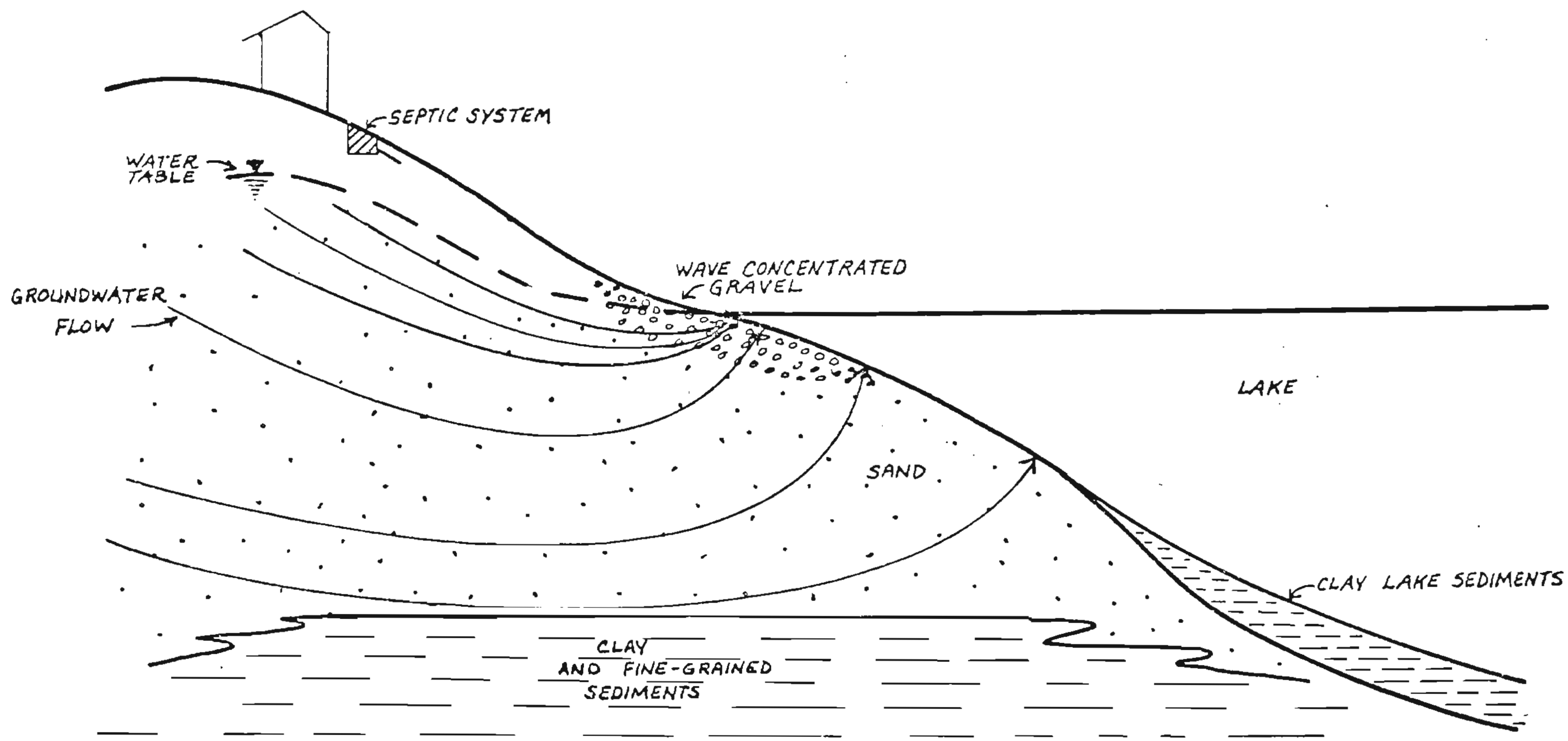


Figure 2: **CONCEPTUAL MODEL OF SHORELINE GROUNDWATER**



McBride and Pfannkuch (1975) modeled the distribution of groundwater seepage throughout a lakebed and found exponentially decreasing rates of groundwater at the lake bottom as one moves away from the shoreline. Munter and Anderson (1981) modeled variations in the rate of groundwater flow as well as seasonal reversals of groundwater flow around lakes due to variations in recharge.

These studies have been conducted primarily on relatively small lakes situated in glacial till. The size and more complex geologic setting of Flathead Lake make direct comparisons with these studies difficult but the basic hydrogeologic principles still apply. This is especially true for the shallow aquifer in the glacial sediments surrounding parts of the lake. It is primarily this shallow system which discharges into the lake through the spawning areas.

Man-induced variations of discharge rates and quality further complicate the interpretation of the shoreline groundwater system. Regulation of the lake stage by Kerr Dam changes the discharge rate by dropping the lake stage starting in October or November through early April. This results in steepening the groundwater gradient near the lake shore and results in a temporary increase in shoreline groundwater discharge. During the rise in stage from April through May, groundwater discharge is probably reduced or eliminated as the groundwater gradient is flattened or reversed for periods. Discharge rates from May through early fall, at which time the reservoir stage is held at 881.79 m, will vary in response to natural annual recharge.

A second man-induced effect on the shoreline groundwater system may result from land-use practices adjacent to the lake. Landowners surrounding the lake withdraw groundwater, slightly reducing discharge to the lake in some areas. Disposal of sewage by septic tank-drain field or seepage ring will alter the local quality of groundwater discharging to the lake. Fruit production and agriculture practices at the northern end of the lake may also effect the groundwater systems. Possible effects include aquifer recharge by irrigation water which is of different quality than the natural shallow groundwater system.

Methods

The methodology was designed to evaluate the conceptual model. Wells were constructed to monitor the position of the water table and its response to natural and man-induced stress. The direction of groundwater flow was interpreted from water table maps. Hydrogeologic parameters required to quantify flow were determined and direct measurements of groundwater discharge were made. Shallow groundwater quality was determined.

Hydrogeologic investigations were undertaken at nine sites selected by the FWP staff (Figure 3). Kokanee spawning was observed at each site during fall 1982. During the period of detailed investigation, since Janaury 1983, the hydrogeologic sites of Skidoo Bay, Pine Glen, Dr. Richard's South, Hochmark's and Crescent Bay received the most concentrated effort. A discussion of general methodology used at a number of sites will be presented and then the methodology used at each site will be discussed in detail.

The occurrence of groundwater was evaluated by reviewing driller's reports and water right claims on file at the Kalispell Water Rights Office, DNRC. Two types of wells were constructed at selected sites, those with a diameter of 3.2 cm and 7.6 cm (Figure 4). Wells were developed by pumping and surging. The 7.6 cm diameter well was driven using a driving weight and tripod and equipped with a continuous water level recorder. Water levels were measured in small diameter wells weekly from installation in late January 1983 until removal because of high lake stage in May 1983. Water level data were utilized to evaluate the depth of groundwater in spawning areas, to find the effect of lake stage change on the position of the water table and to interpret the direction of groundwater movement.

Figure 3:
LOCATION OF HYDROGEOLOGIC STUDY SITES

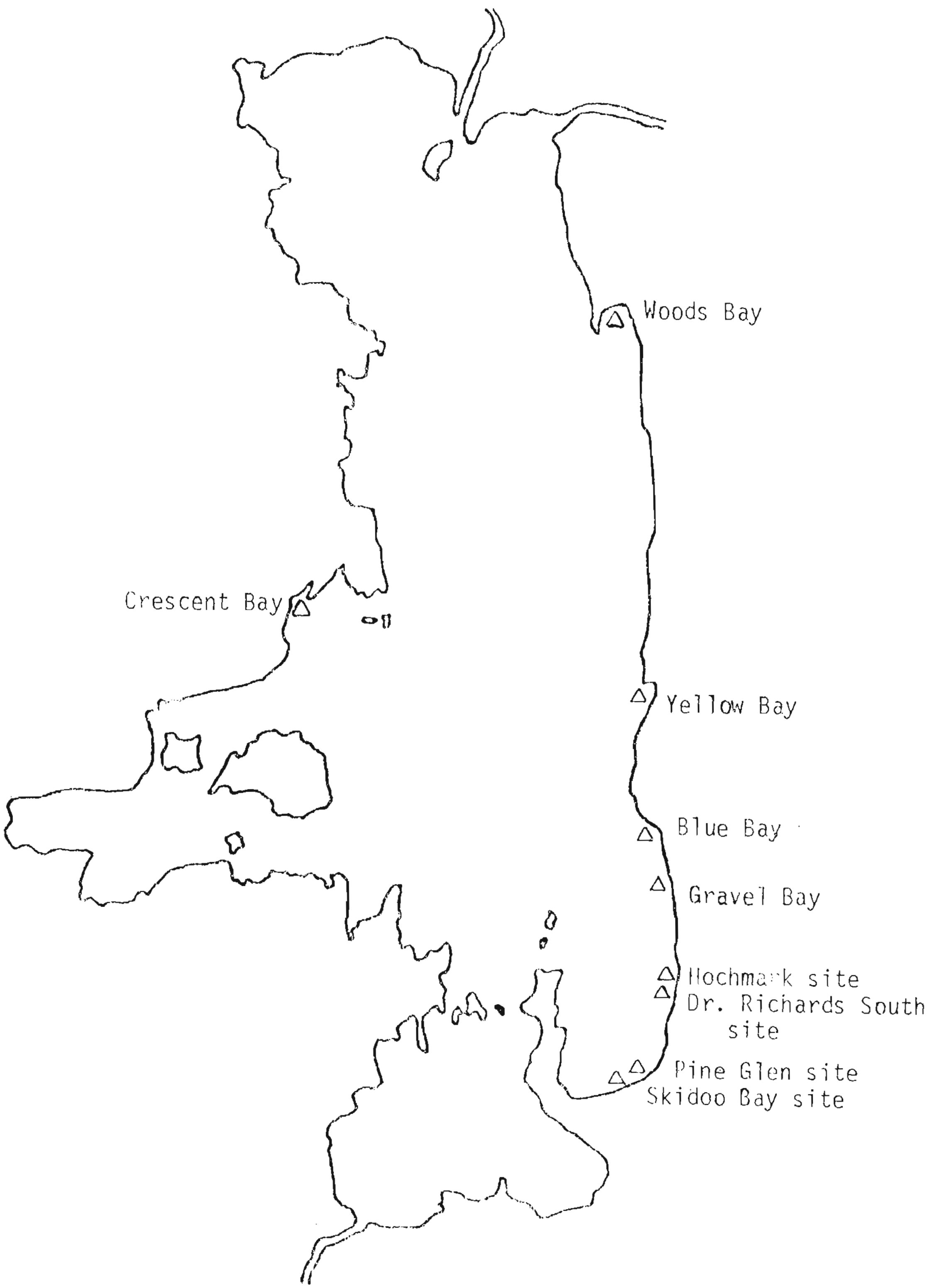
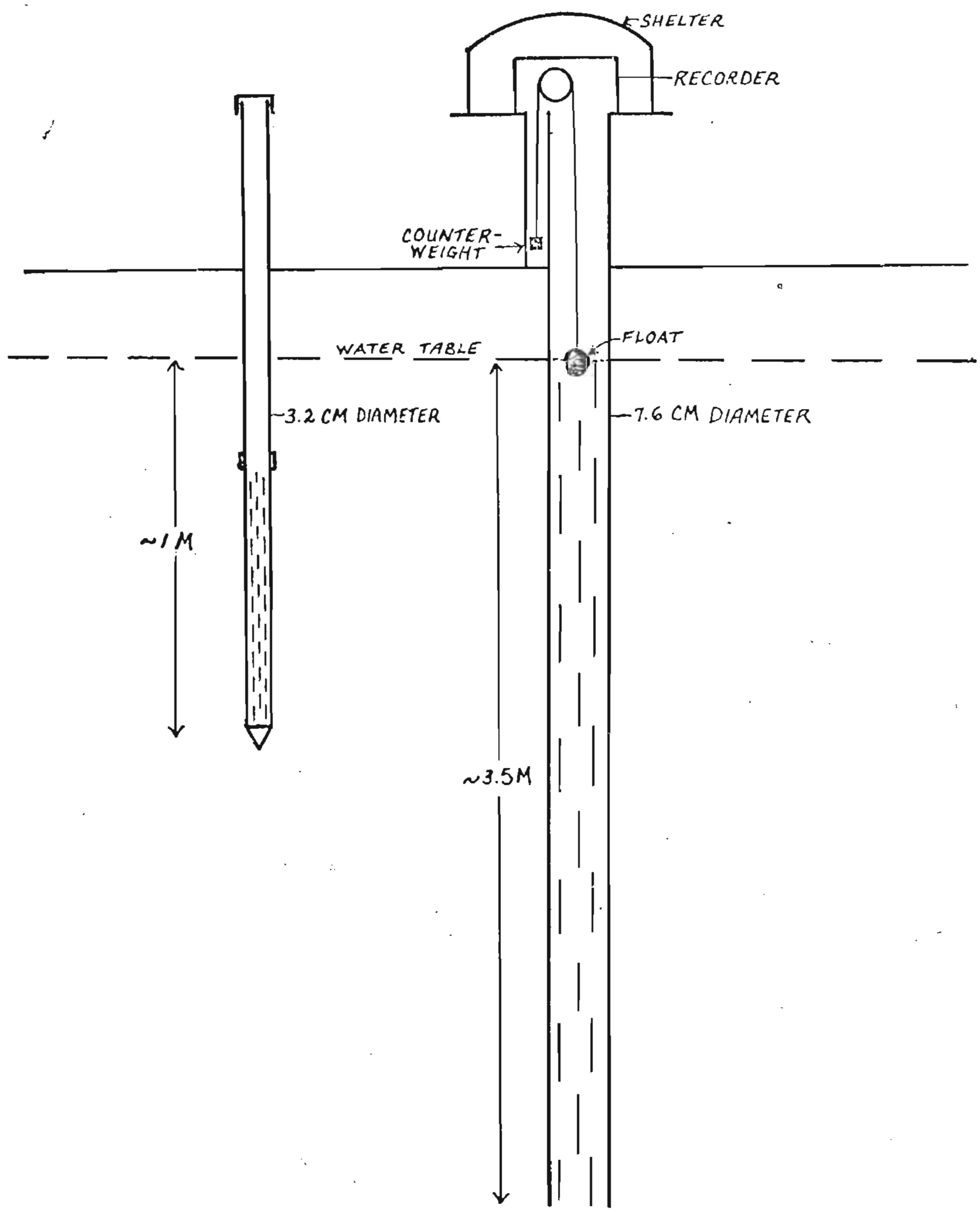


Figure 4: DESIGN OF PROJECT WELLS



Weekly to bimonthly water level elevations were contoured to produce water table maps. The direction of groundwater flow was assumed to be perpendicular to the lines of equal water table elevation, equipotential lines, and in the direction of decreasing water table elevation. This convention is based on standard hydrogeologic theory and the assumption that the near shore sand and gravel is homogeneous and isotropic. Even with the actual anisotropic nature of the material, the general direction of flow would not vary significantly from perpendicular to the equipotential lines.

Quantification of groundwater flow was accomplished by using a number of techniques. The first device used at a number of sites was the seepage meter (Figure 5). The meter was installed utilizing scuba equipment by gently rotating the meter into the substrate. At most sites a line of at least three meters were installed perpendicular to shore in order to determine the seepage rate variation with depth of water and distance from shore. Also at selected times, three to four meters were spaced parallel to shore at one elevation to determine seepage variation along the shore line. Rates of groundwater discharge were measured by attaching a deflated plastic bag and later detaching the bag and measuring the volume of water collected over a measured time period. Because the cross sectional area of the meter is known, the rate of inflow or flux can be calculated using the basic groundwater equation known as Darcy's law.

$$Q = -K\ i\ A \tag{1}$$

Where, under steady state conditions:

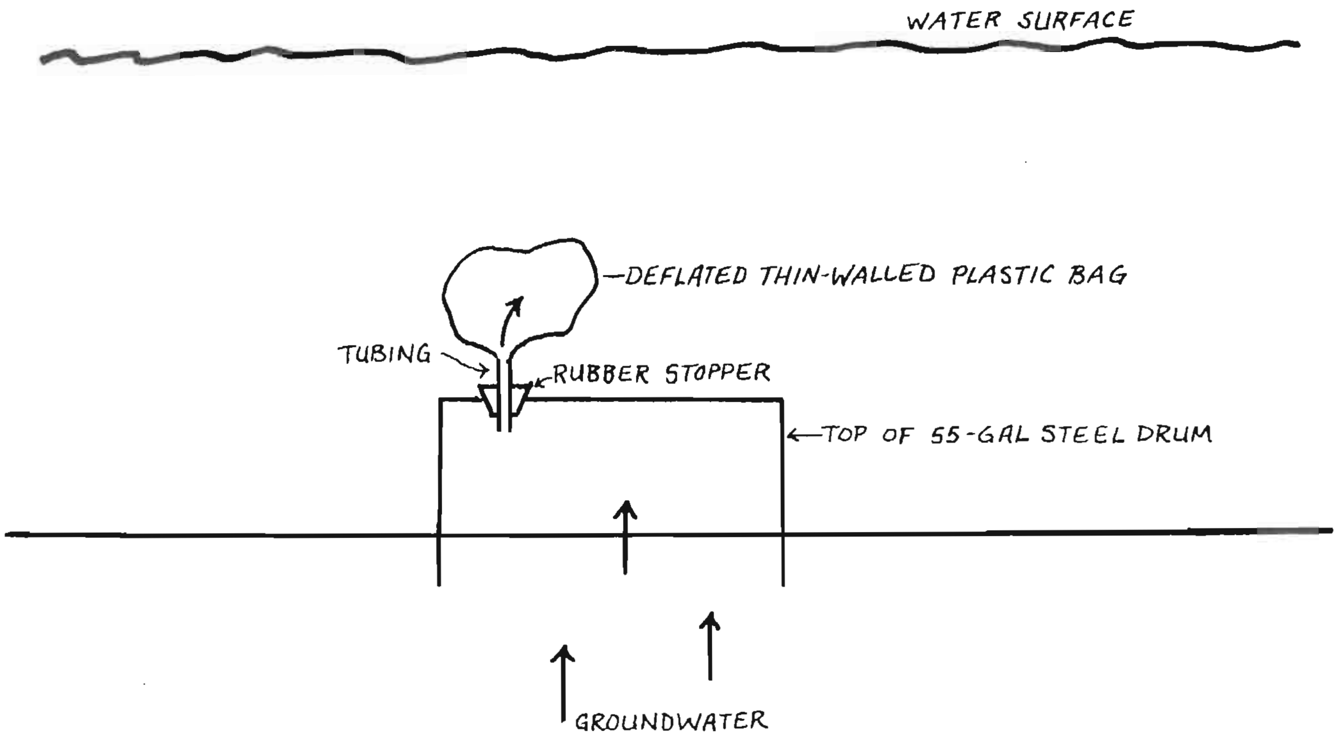
Q = groundwater discharge, cm^3/hr

K = hydraulic conductivity, cm/hr

i = hydraulic gradient, cm/cm (the negative sign indicates flow is in the direction of decreasing head)

A = cross sectional area, cm^2

Figure 5: **SEEPAGE METER**



To determine the rate of groundwater discharge in $cm^3/(cm^2 hr)$ the direct measurement of Q/A derived by the seepage meter is utilized and referred to as the specific discharge, Darcy flux or apparent velocity. Meters were left in place once installed and when all original lake water had been displaced groundwater quality samples were also collected. The use of seepage meters to quantify the flux of groundwater through the lake bottom assumes the lake surface is undisturbed by waves, in steady state. Meter data were collected on what were considered calm days.

A second series of tests were conducted in an attempt to determine the parameter of hydraulic conductivity (K) required in equation (1). Once a value of K, which is a property of the medium and fluid, is derived and combined with the hydraulic gradient (i), the rate of groundwater flow measured as apparent veolocity, $v^* = Ki = Q/A$, can be calculated. Values of K were determined at selected sites by tracer tests, bail tests and standpipe test methods as described in Appendix A.

In quantifying groundwater flow in study areas the actual velocity of groundwater flow is also of interest. It is calculated from the following relation:

$$v = Q/(An) = Ki = v^*/n \qquad (2)$$

where v = true velocity, cm/hr

n = porosity, dimensionless

v*, Q, A, K, i where previously defined.

The porosity was assumed to be .25 for the sand, gravel and cobbles found at the study sites (Davis, 1969).

A third series of tests used a dye tracer to directly measure the direction and rate of groundwater flow at a number of sites. Point dilution, pit dilution and other dye pit tests on shore used rhodamine WT dye to determine the apparent and true velocity of groundwater flow in a 10 m zone on shore adjacent to the lake edge. The details of each test methodology are described in Appendix B.

Water quality of the groundwater was determined from samples collected from project installed wells and seepage meters. Temperature, pH and dissolved oxygen were determined in the field at some sites. pH was determined by meter and dissolved oxygen, DO, was determined using the modified Winkler method. DO samples were pumped from wells using a hand operated Black and Decker Jack Rabbit Pump and from lake bottom gravel by a FWP designed probe and the same pump. Samples were analyzed for NO_3, PO_4, Cl, SO_4, HCO_3, Ca, Mg, Na, K, and TDS by Dr. Juday of the University of Montana Chemistry Department utilizing standard techniques.

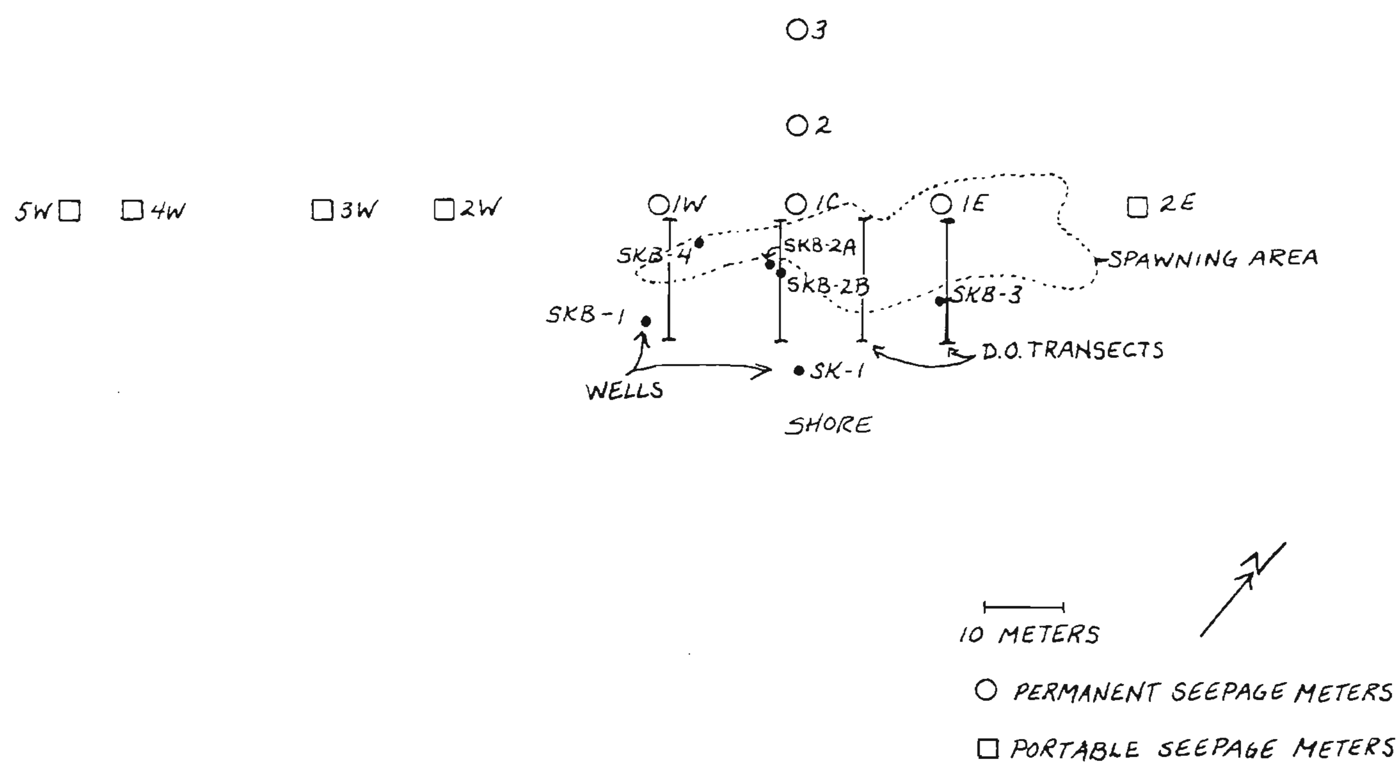
The following discussion includes specifics of the methods used at each study site.

Skidoo Bay

A 7.6 cm diameter well was constructed in October 1982 and a continuous water level recorder was installed. Four sandpoint wells were driven below the water table in late January and weekly to bimonthly water level measurements were made. A fifth sandpoint was installed in late March as the lake receded. Measurements continued until early May when the wells were removed as they were inundated by the lake. Well design data are presented in Appendix C. Water table maps and depth to water maps and profiles were constructed to predict groundwater flow direction and relate the position of the water tables to the position of the redds.

Five seepage meters were installed in Skidoo Bay and seepage data were collected monthly from 4-22-82 through 1-25-83 (Figure 6). A lake bed profile showing the location of seepage meters is presented in Appendix E. Data

Figure 6: LOCATION OF SEEPAGE METERS, WELLS AND SPAWNING AREA SKIDOO BAY SITE



collection stopped when the meters became exposed in late January. Measurements were resumed in May 1983. In addition, portable seepage meters were installed parallel to the shoreline at the approximate elevation of the shallowest permanent meter. Four portable meters were installed on 8-5-82, five on 10-13-82 and four on 12-10-82.

Groundwater flow rates were quantified by the use of seepage meter data, water table maps, standpipe dye and pump tests, pit dye tests and bail tests. Permeability of the gravels and apparent and actual groundwater velocities were determined.

Water quality data from seepage meters were collected in September and November 1982 and in January and May 1983. Water samples were also collected from two of the sandpoints in March 1983 and one well in May 1983. Dissolved oxygen data were collected from seepage meters and 12-19-82 and 3-15-83 along DO transects.

Crescent Bay

A 7.6 cm diameter well was constructed in October 1982 and a continuous water level recorder was installed. Five sandpoint wells were driven below the water table in late January and weekly to bimonthly water level measurements were made. Two additional sandpoints were installed in early March as the lake receded. Measurements continued until early May when the wells were removed as they were inundated by the lake. Water table maps and depth to water maps and profiles were constructed to predict groundwater flow direction and relate the position of the water table to the position of the redds.

Three seepage meters were installed in Crescent Bay north of Harvey's dock on 4-30-82. Measurements were made once a month until 7-16-82 when the shallow and deep meters were removed. Three new meters were then installed south of Forman's dock and one meter was left north of Harvey's dock (Figure 7). Seepage data were collected monthly from these four meters until the meters were exposed in late January 1983. A lake bed profile showing the location of seepage meters is presented in Appendix E. Measurements were resumed in May 1983. In addition, portable seepage meters were installed parallel to the shoreline at the approximate elevation of the middle permanent meter. Six portable meters were installed on 8-16-82 and 10-26-82.

Groundwater flow rates were quantified by the use of seepage meter data, water table maps, standpipe dye and pump tets, pit dye tests and bail tests. Permeability of the gravels and apparent and actual groundwater velocities were determined.

Discharge of Big Lodge Creek, which entered the study, area was estimated between early March, early May 1983.

Water quality data from seepage meters were collected in September and November 1982 and in January 1983. Water samples were also collected from two of the sandpoints in March 1983 and three wells in May 1983. Dissolved oxygen data were collected from seepage meters and on 1-28-83, 3-17-83 and 6-6-83 along DO transects.

Hochmark's

Two Sandpoint wells were driven below the water table in late January and weekly to bimonthly water level measurements were made. A third Sandpoint was installed in late March as the lake receded (Figure 8). Measurements continued until early May when the wells were removed as they were inundated by the lake. Water table maps and depth to water maps and profiles were constructed to predict groundwater flow direction and relate the position of the water table to the position of the redds.

Figure 7:

LOCATION OF SEEPAGE METERS AND WELLS,

CRESCENT BAY SITE

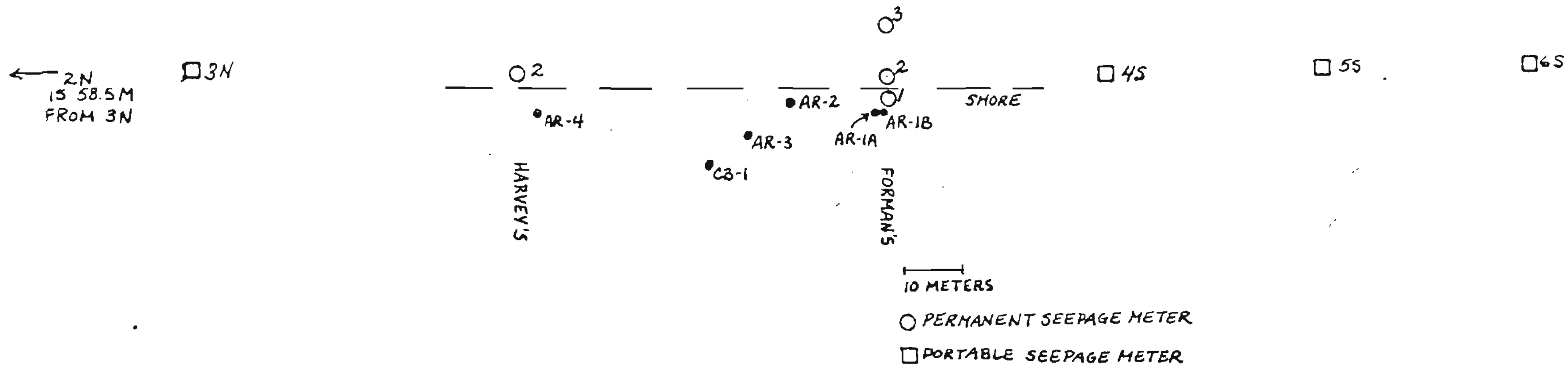
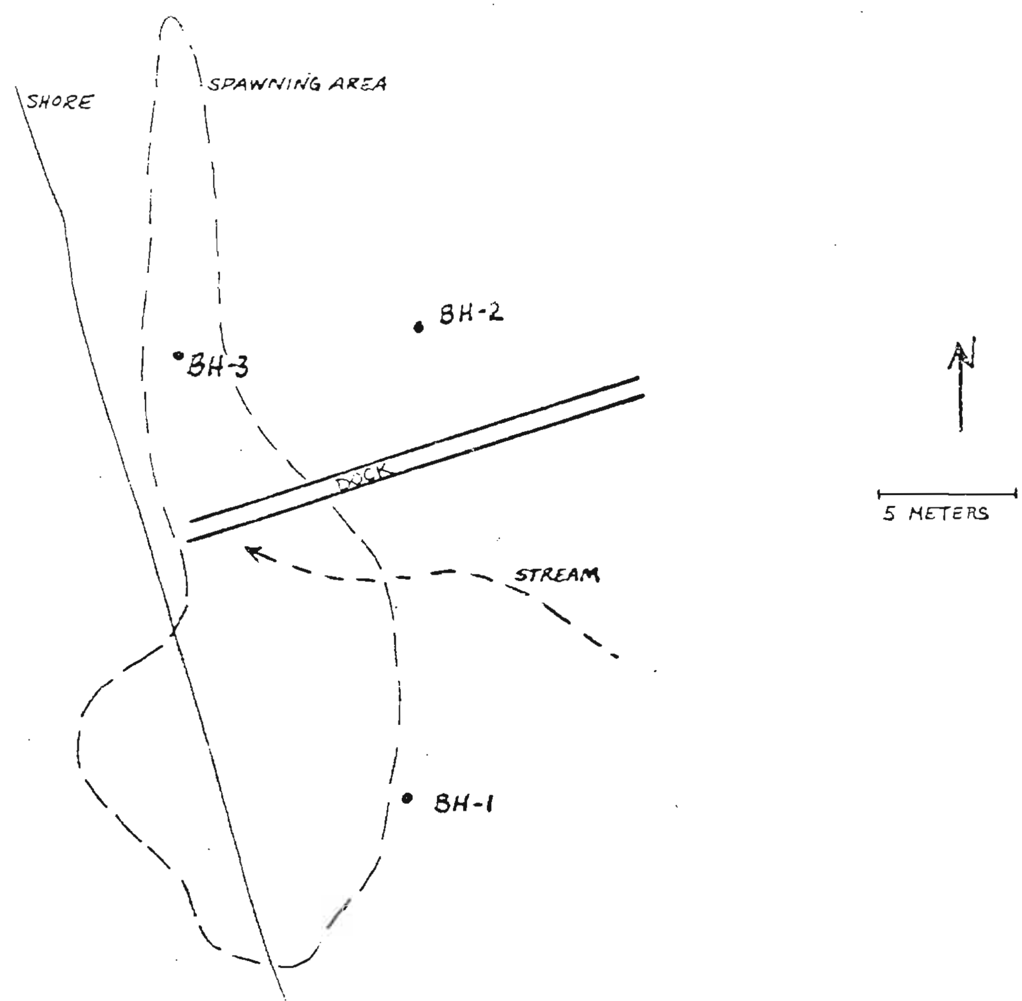


Figure 8:

LOCATION OF WELLS AND SPAWNING AREA
HOCHMARK SITE



Groundwater flow rates were quantified by the use of water table maps, standpipe dye and pump tests, pit dye tests and bail tests. Permeability of the gravels and apparent and actual groundwater velocities were determined.

The discharge of Station Creek was estimated between early March, early May 1983.

Water quality data were collected for one well and the creek on 5-23-83. Dissolved oxygen data were collected from wells and in April and May 1983 and at random points in the submerged gravel in March 1983.

Pine Glen

Three sandpoint wells were driven below the water table in late January and weekly to bimonthly water level measurements were made. A fourth sandpoint was installed in late March as the lake receded (Figure 9). Measurements continued until early May when the wells were removed as they were inundated by the lake. Water table maps and depth to water maps and profiles were constructed to predict groundwater flow direction and relate the position of the water table to the position of the redds.

Groundwater flow rates were quantified by the use of water table maps, standpipe dye and pump tests, pit dye tests and bail tests. Permeability of the gravels and apparent and actual groundwater velocities were determined.

Water quality data were collected for one well 3-30-83. Dissolved oxygen data were collected from wells in April and May 1983 and at random points in the submerged gravel in March 1983.

Dr. Richard's South

Two sandpoint wells were driven below the water table in late January and weekly to bimonthly water level measurements were made. A third sandpoint was installed in late March as the lake receded (Figure 10). Measurements continued until early May when the wells were removed as they were inundated

Figure 10:
LOCATION OF WELLS AND SPAWNING AREA
DR. RICHARDS SOUTH SITE

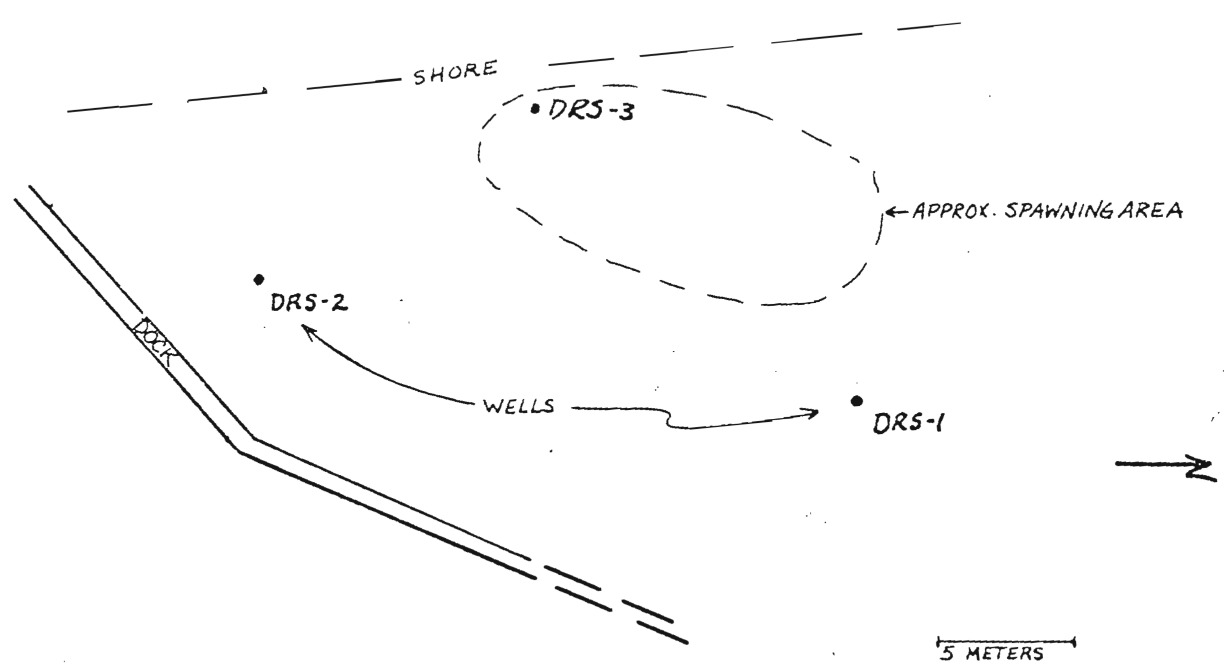
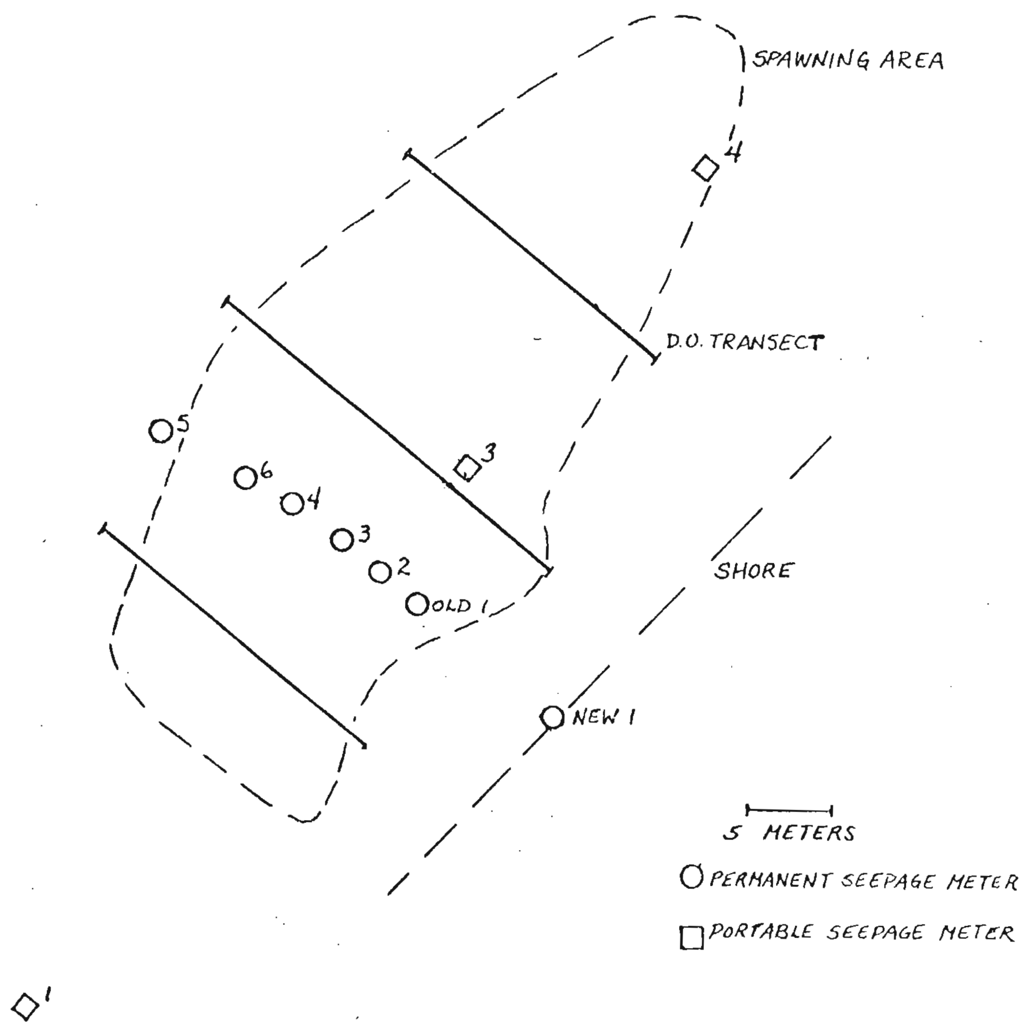


Figure 11:
LOCATION OF SEEPAGE METERS AND SPAWNING AREA
YELLOW BAY SITE



Gravel Bay

Four seepage meters were installed in a line perpendicular to shore during November 1982. Two meters at 876.37 m, approximately the same elevation as meter 2S, were also installed in November 1982 (Figure 12). Measurements were obtained monthly through June 1983. A lake bed profile showing the location of seepage meters is presented in Appendix E. Four additional portable meters were installed during late April and early May 1983 parallel to shore at the approximate elevation of 876.37 m.

Water quality samples were obtained from meter 1 in January and February 1983 and at meter 4 in January 1983. Three dissolved oxygen transects were made in November 1982, March 1983 and June 1983.

Wood's Bay

Three seepage meter transects separated by 12 m and perpendicular to shore were operated in May 1983 (Figure 13). A lake bed profile showing the locations of seepage meters is presentd in Appendix E. Three dissolved oxygen transects were laid out and sampled in April 1983. One transect was sampled in May 1983.

Blue Bay

A line of three seepage meters was installed at Blue Bay in May 1982. Sporatic data were obtained because gravel movement was sufficient each month to displace the meters. Water quality data were obtained for two meters during September and November 1982 and for Blue Bay Creek. Because of the uncertaintly in seepage meter locations, Blue Bay will be reinstrumented in the fall of 1983. All data collection efforts will be summarized in the report next year.

Figure 12:

LOCATION OF SEEPAGE METERS AND SPAWNING AREA
GRAVEL BAY SITE

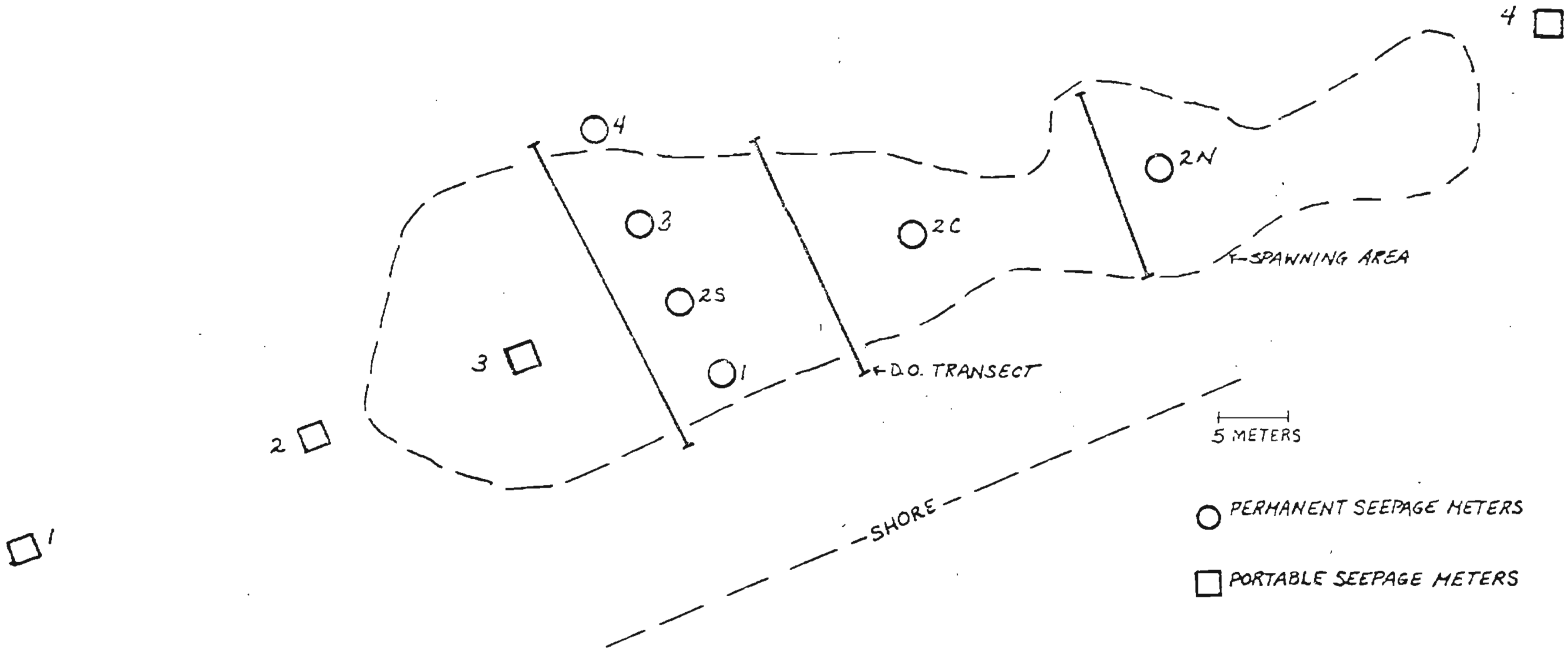


Figure 13:

LOCATION OF SEEPAGE METERS AND SPAWNING AREA

WOODS BAY SITE

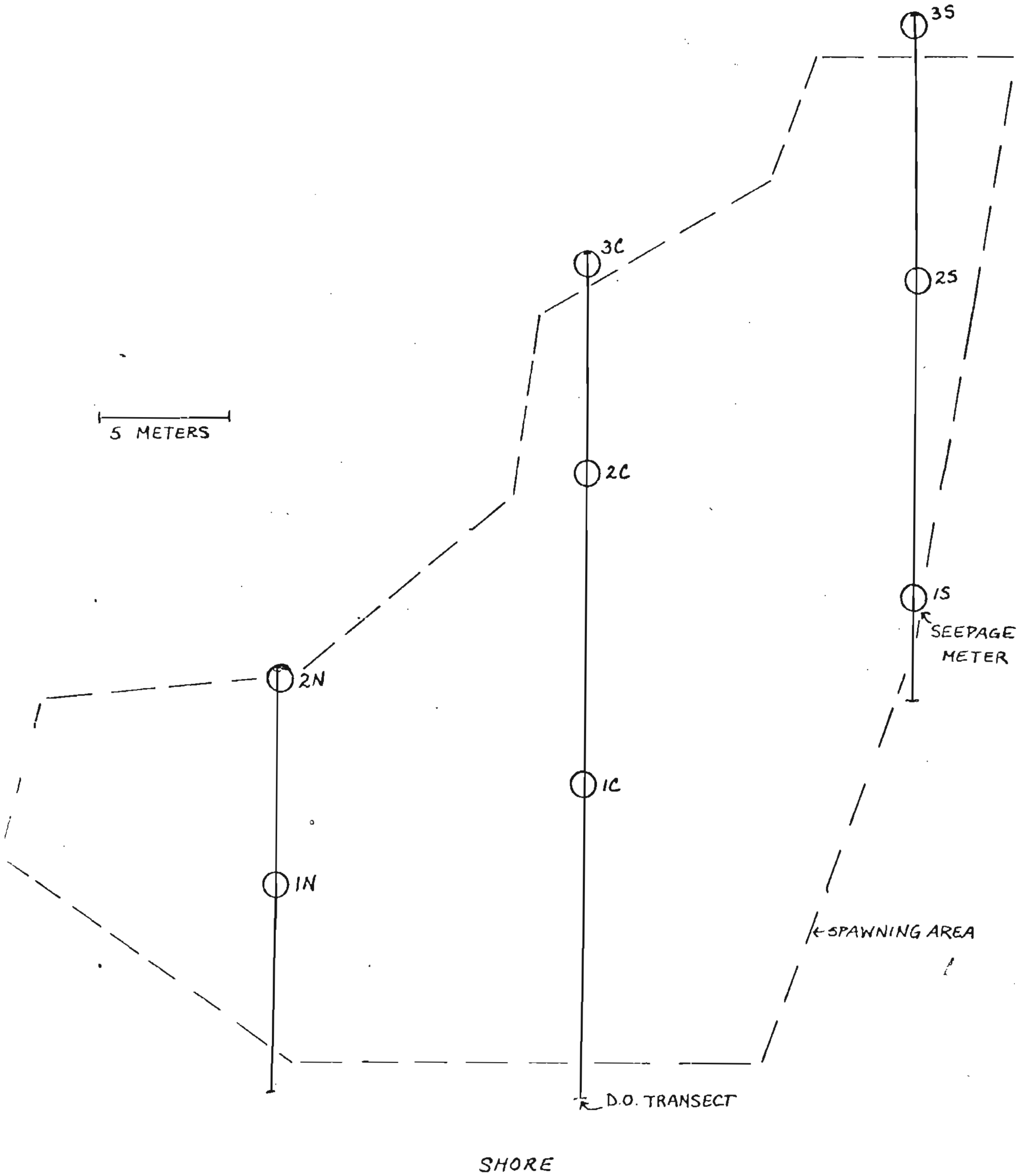
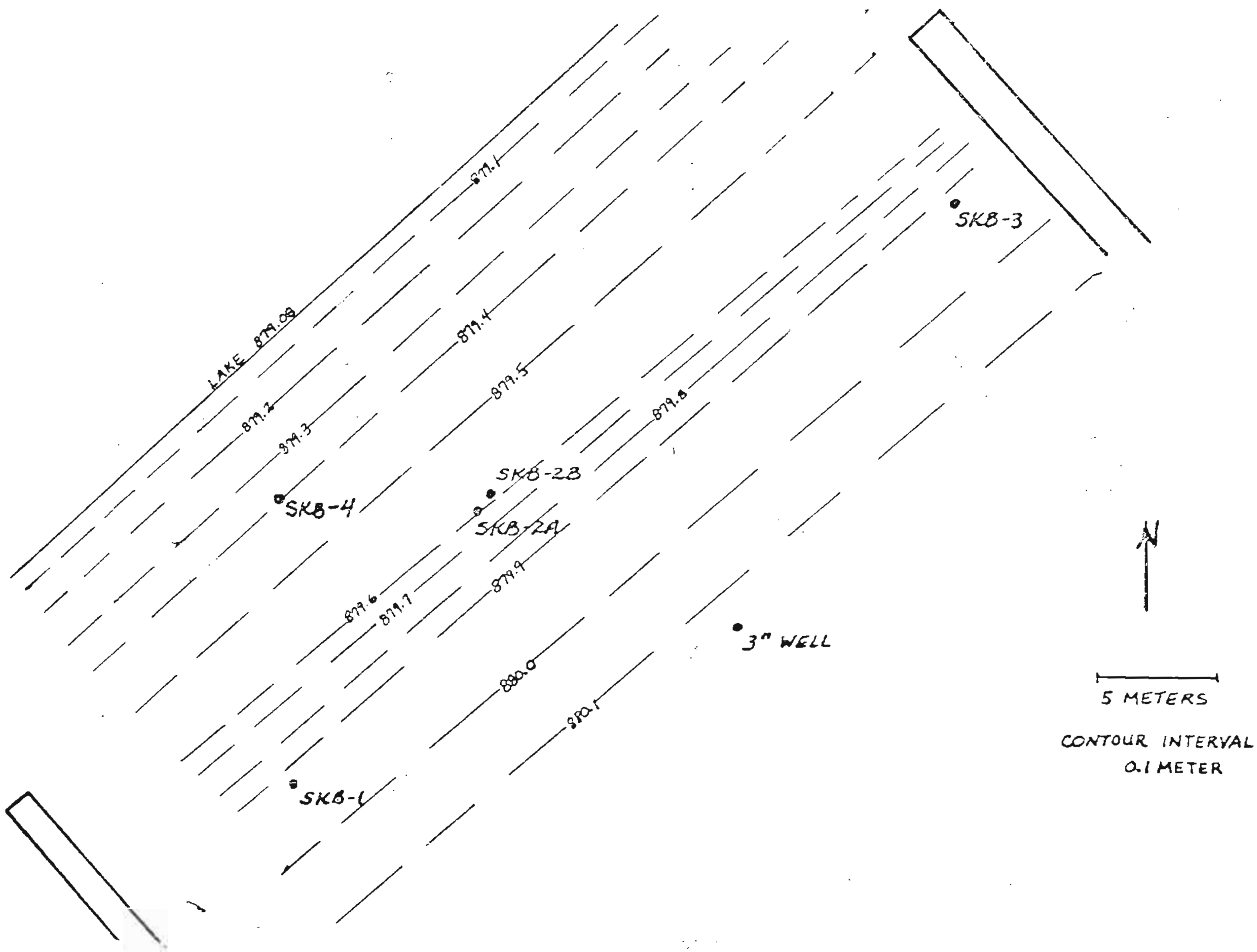


Figure 16:
WATER TABLE MAP 3/18/83
SKIDOO BAY SITE



elevations which correspond to a water table being less than 15 cm below land surface, the typical limits of redd development, can be depicted from the profile. Generally less than 1 m of shoreline adjacent to the lake had a water table within 15 cm of land surface. The lake bed slope and slower rate of decline of water levels in wells through March 1983 and early April 1983 provided for a 3.5 m strip of shoreline adjacent to the lake to have a water table within 15 cm of land surface.

The results of the operation of seepage meters at Skidoo Bay are shown in Table 1 as apparent velocities given in $cm_3/(cm^2hr)$ or cm/hr. Data are most complete for meters 1(C), 1W, 1E, 2 and 3. A semi-logrithmic plot of apparent velocity data vs. distance from a fixed control point on shore for the three meters located perpendicular to shore 1(C), 2 and 3 is presented in Figure 17. For the period of record, seepage rates declined with distance from shore in all cases bestween 1(C) and 2 and increased slightly between meters two and three 50% of the time and decrased 50% of the time. Seepage also generally decreased from 4-29-82 through 11-23-82 then increased from 12-10-82 to 1-25-83. Two additional seepage meters, 1W and E, 16 m and 20 m to the west and east of 1(C) and at the same elevation were also operated from 4-22-82 through 6-25-83. These meters were used to evaluate the lateral differences in apparent velocities. Seepage rates determined by seepage meter at 1(C) ranged from 0.08 to 0.93 cm/hr and averaged 0.47 cm/hr. At meter 2 rates ranged from 0.05 to 0.34 cm/hr and averaged 0.18 cm/hr. Meter 3, farthest from shore, yielded rates of from 0.11 to 0.40 cm/hr and averaged 0.21 cm/hr. Results of these two seepage meters and up to five additional meters located about 20 m further west or east of meters 1W and 1E are presented in Figure 18. Apparent velocity values at 1C were greater than velocities measured at adjacent sites with the exception of data from 4-27-82 and 5-5-82. Meter 1C was located just north of the area of concentrated spawning (Figure 6). Data collected at

Table 1: Seepage meter results, Skidoo Bay site ($cm^3/(cm^2 hr)$)

Location	Elevation (m)	1982													1983		
		4/22	4/29	5/4	5/5	5/14	6/10	6/30	7/13	8/5	9/16	10/13	11/23	12/10	1/25	5/24	6/29
1(C)	879.14	0.292	0.926	0.600	0.079	0.694	0.280	0.463	0.374	0.35	0.44	0.31	0.19	0.49	1.06	missing	missing
1W	879.14	0.380	0.040	0.336	0.227	0.351	0.213	0.218	0.227	0.22	0.25	0.30	couldn't	0.28	0.42	0.24	0.19
1E	879.14	-	0.324	0.112	0.455	0.210	0.173	0.186	0.108	0.20	0.14	0.14	find	0.18	0.27[1]	0.16	0.15
2	878.98	0.336	0.295	-	0.047	0.240	0.130	0.173	0.114	0.16	0.13	0.13	0.18	0.18	0.25	0.18	0.16
3	878.91	0.402	0.364	-	-	0.302	0.212	0.193	0.137	0.16	0.14	0.17	0.11[1]	0.16	0.18	~0.055	0.14
New (O)	879.49										0.43	0.34[1]	gone				
Portables																	
E	879.14									0.212		0.278		0.130			
2W	879.14									0.212		0.371		0.265			
3W	879.14									0.132		0.216		-			
4W	879.14									0.081		0.176		0.261			
5W	879.14									-		0.263		0.109			

[1] Anaerobic smell.

[2] Hole in bag

Other data: 5/5/82--1E and 1W moved into spawning area (same elevation).
6/10/82--Readings may not be accurate due to some tube blockage.

Figure 17:

SKIDOO BAY SITE APPARENT VELOCITY PROFILE

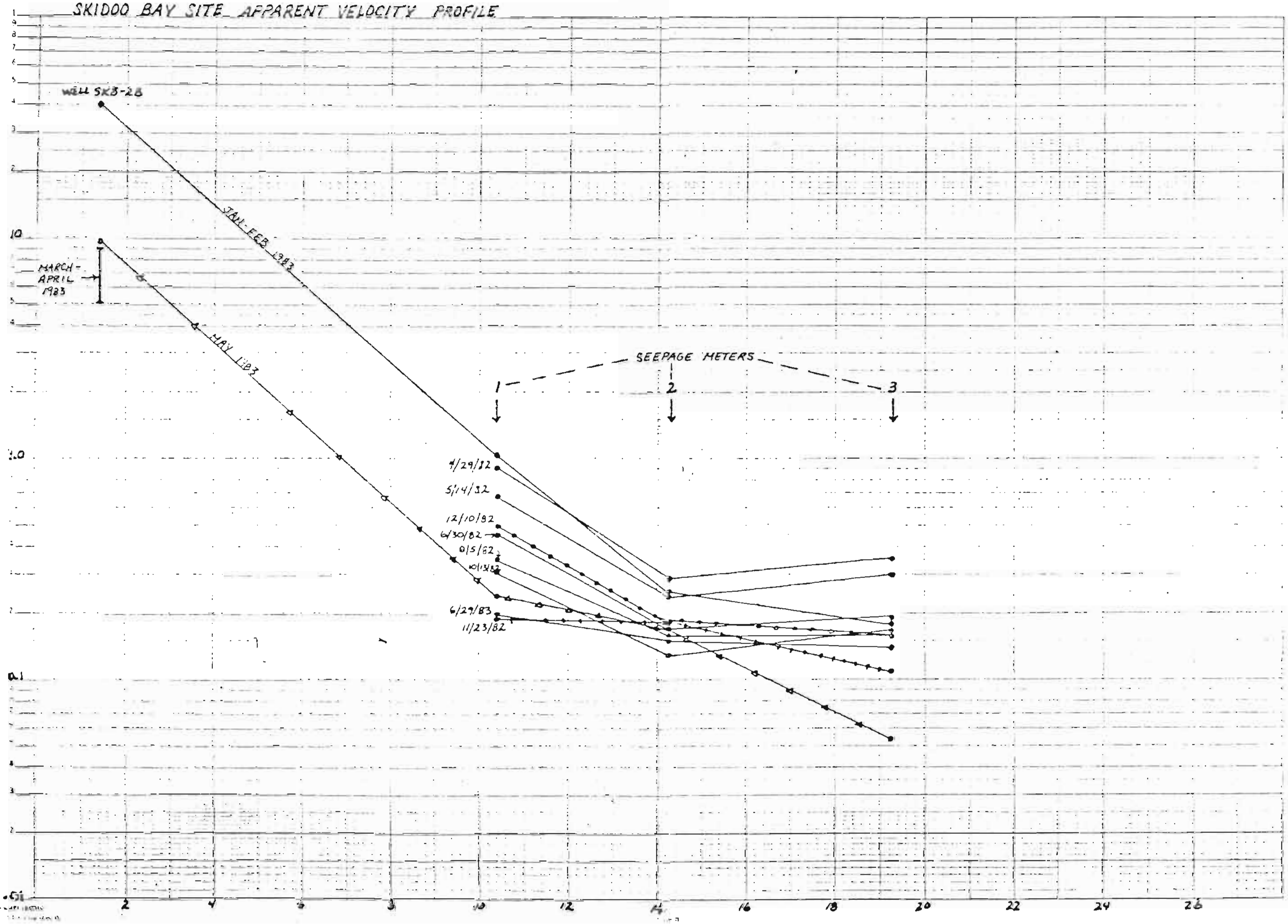
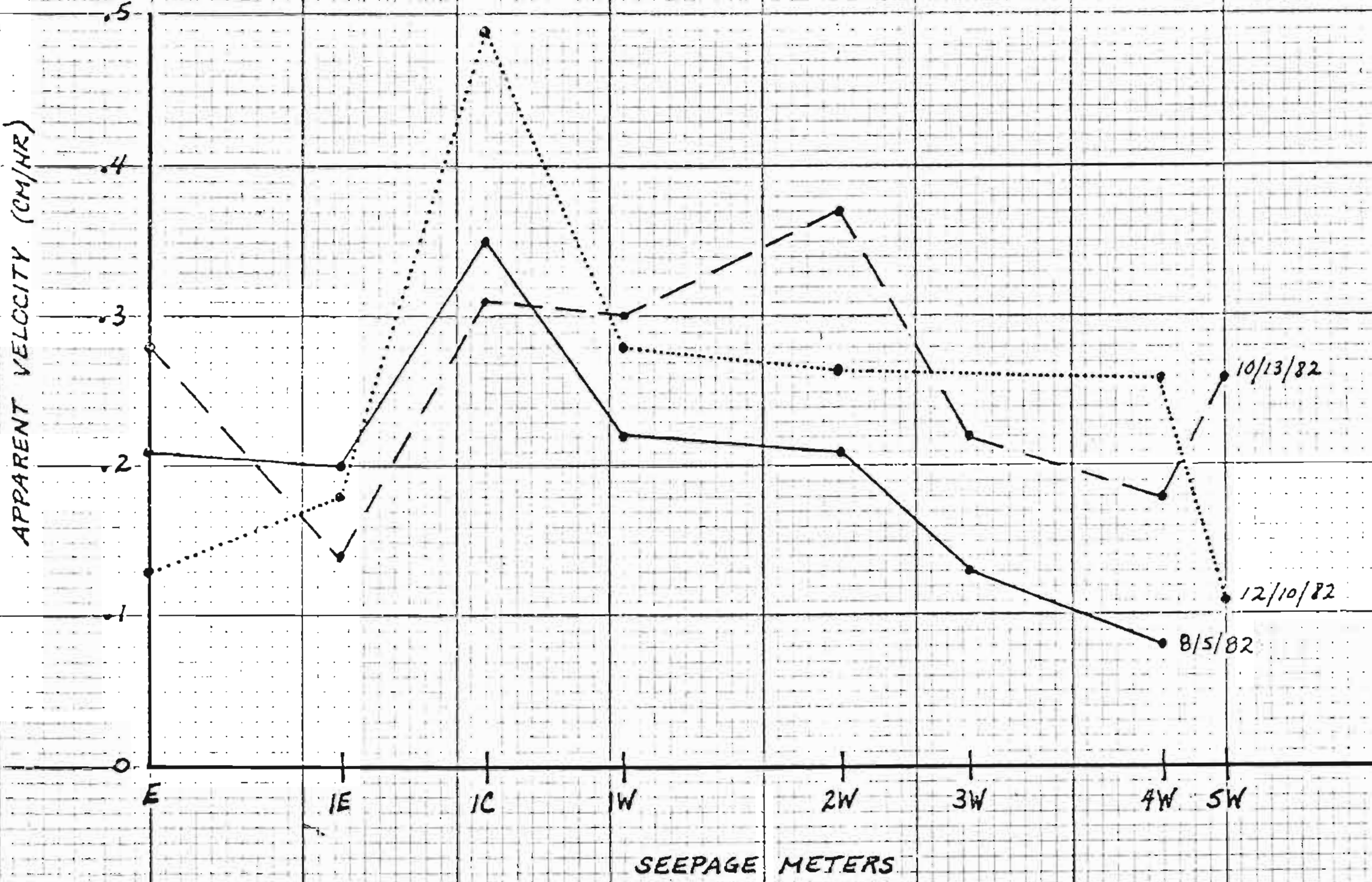


Figure 18: SEEPAGE VARIATION PARALLEL TO SHORE

SKIDOO BAY SITE



meter 1W ranged from 0.04 to 0.42 cm/hr with an average rate of 0.27 cm/hr. Meter 1E yielded a range of rates from 0.11 to 0.46 cm/hr and averaged 0.21 cm/hr.

Apparent and true velocity measurements of groundwater within 1 m of the water table were derived from tracer tests and standard calculations. Results are summarized in Table 2. Measurements of hydraulic conductivity (K) by standpipe pump test, dye test and bail test yielded values of 207,277 and 49 cm/hr. Based on examination of the sediments and field test data, a value of 207 cm/hr was selected to be representative. This value was multiplied by the hydraulic gradient measured perpendicular to equipotential lines for the dates shown and apparent and true velocities were calculated. Direct apparent velocity measurements by dye pit dilution and standpipe dilution methods correlated well with calculated velocities on the same days of measurement. Apparent velocities ranged from 5.8 to 18.3 cm/hr, and based on calculated values a mean value of 8.46 cm/hr during the falling stage period of measurement 2-2-83 to 4-20-83 and a mean with only two values of 8.9 cm/hr during the period of rise from 4-27-83 to 5-7-83. True velocity means for the falling and rising lake stage periods of measurement were 37.9 cm/hr and 35.5 cm/hr, respectively.

Apparent velocity data collected further out in the lake by seepage meters show mean values of 0.47 to 0.21 cm/hr. Figure 17 shows the relationship between apparent velocity near the water table on the landward side of the lake and the seepage meter values. The January data indicate seepage rates increasing as water shallows which is consistent with literature reported relationships for discharge lake systems.

Groundwater quality data derived from shallow project wells and seepage meters is presented in Table 3. Water is generally a calcium bicarbonate type with a TDS of about 200 mg/l. The pH ranges from 7.7 to 8.3. It is similar

Table 2: Values of apparent and true velocities (cm/hr). v* = apparent velocity; v = true velocity

	Skidoo		Pine Glen		Hochmark's		Dr. Richard's		Crescent	
Method and Date	v*	v	v*	v	v*	v	v*	v	v*	v
K x i (using standpipe K data)										
2/2/83	12.8	55	27	110	6.1	25	2'	7	128	512
2/7/83	12.0	48	24	98	6.3	25	0	0		
2/11/83	7.5	30	15	61	5.4	22	2	7	128	512
2/21/83	11.4	46	58	,232	6.5	26	3.5	14	143	573
3/5/83	9.7	39	64	256	6.7	27	8	32	149	597
3/19/83	5.8	23	62	250	6.8	27	7	28	120	482
3/23/83	9.1	36	58	232	6.7	27	4	18	122	488
4/6/83	9.7	39	24	98	6.6	26	2	7	122	488
4/20/83	6.2	25	17	67	7.1	29	3	11	122	488
4/27/83	8.1	32	11	45	5.9	24	6'	25'	104	415
5/7/83	9.7	39	11	45	4.6	18	0.9	3.5	114	457
5/18/83									90	360
5/21/83									76	305
Dye Pit Dilution										
3/5/83									62.5	125
3/25/83	18.3	36.6								
3/29/83					826	1652				
4/6/83			3.0	6.0						
Standpipe Dilution										
4/27/83	8.8	16.9								
5/18/83					21.0	35.3				
6/1/83			1.3	7.0			189 or 61	577 186		
Pit Tests-maximum velocity		max v		max v		max v		max v		max v
1/25/83		73.2		732		4115		238		
2/2/83										146 329
2/21/83				no results		566 2067 128		no results		146 311 677
3/5/83										348
3/25/83		49.4								
3/28/83						4023				
Seepage Meters										
4/82	0.04-0.93								0.30	
5/82	0.05-0.69								0.06-0.37	
1/83	0.18-1.06								0.09-0.20	

' Gradient away from shore.

Table 3 : Groundwater Quality Data, Skidoo Bay site.

Location Date	Meter #	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	T 'C
				Ion Concentration in mg/l											
Seepage Meter Data															
	1														
9-17-82			7.7	0.122	0.003	0.45	2.4	149	38.4	5.9	1.8	1.0	200	255	17.2
11-24-82			7.7	0.053	<0.001	0.30	2.8	117	27.6	6.1	1.4	0.5	156		
1-26-83			7.7	0.144	0.002	0.45	1.8	142	35.6	6.0	1.9	0.9	189		
	2														
5-24-83			11.1												
	3														
9-17-82			7.7	0.005	0.001	0.45	1.8	154	39.1	6.0	1.9	1.2	204		
11-14-82			7.9	0.099	0.001	0.36	2.5	124	30.3	5.9	1.6	0.6	166		
1-26-83			7.8	0.146	0.002	0.47	2.3	140	35.2	6.1	2.0	0.8	188		
5-23-83			8.0	0.175	0.004	0.41	1.8	149	36.8	6.9	2.0	1.0	199		
	1W														
5-23-83		11.5													
	1E														
5-23-83		4.8													
Well Data															
SKB-1	1														
3-30-83			7.7	0.157	<0.001	0.60	2.5	152	38.4	6.3	2.1	1.1			
5-23-83		7.8	8.3	0.154	0.002	0.47	2.7	152	36.3	7.8	2.1	1.1	204		
SKB-2A	2A														
3-30-83			8.0	0.120	<0.001	0.47	1.4	139	33.1	6.6	2.1	1.1	185		
SKB-3	3														
5-23-83		8.9	8.2	0.473	0.002	0.58	2.2	164	39.6	8.1	2.1	1.1	222		

to Flathead Lake water except calcium and bicarbonate concentrations are slightly higher and the TDS is about 60 mg/l greater. Seepage meter data collected 11-24-82 was slightly lower in TDS, about 160 mg/l though data were consistent for the shallow and deep meters.

The dissolved oxygen data from the seepage meter samples ranged from 4.8 mg/l (5-24-83, 1E) to 11.5 mg/l (1W). DO transects measured by probe samples in December and March consistently found concentrations of greater than 5.2 mg/l from 12 to 10 m from the shoreline (Table 4). DO values for wells taken 4-25-83 showed values of 7.8 to 8.7 mg/l in the shallow wells and 5.7 mg/l in well SKB-2A a well penetrating approximately 0.93 m below land surface.

Crescent Bay

The fluctuations of the water table at well CB-1 which have been recorded since October 1982, lake stage at Kerr Dam and the hydrograph of well AR-2 are presented in Figure 19. The straight line shown for well CB-1 represents no significant change while the lake rose and fell. Hydrographs of wells AR-1A, AR-1B, AR-2, AR-3, AR-4, AR-5 and AR-6 are presented in Appendix D. Water levels in all wells appeared to fluctuate independently of lake stage change with the exception of a general rise in water level which corresponds to lake stage rise in late April at all wells except CB-1 and AR-3. A stream, Big Lodge Creek, enters the beach area from the west near AR-1A, AR-1B and AR-5. Discharge measurement taken just before the stream reached the beach area varied from 0.02 to 0.05 m^3/sec from March to May with an average discharge of 0.03 m^3/sec.

A water table profile and a water table contour map for 3-18-83, are presented in Figures 20 and 21. The groundwater movement is from the higher topography to the west to the lake shore. Flow is usually perpendicular to the lake shore with groundwater discharge to the lake. Profile data suggest the groundwater gradient was to the lake during periods of lake stage decline

Table 4 : DO Transect Data, Skidoo Bay site

Transect Location	Elev. (m)	Dist. Shore (m)	Date 12-19-83	Date 3-15-83	Date	
Line #1	881.2	0	-	-		1.5 meters from west stake
	880.6	4	12.8	-		
	800.0	8	11.2	7.1		
	879.4	12	8.9	7.4		
	879.2	16	9.1	6.1		
Line #2	881.3	0	-	-		13.7 meters from west stake
	880.8	4	11.0	-		
	880.1	8	9.6	7.9		
	879.5	12	9.7	8.6		
	879.1	16	-	8.4		
Line #3	881.3	0	-	-		25.9 meters from west stake
	880.8	4	9.2	-		
	880.2	8	9.4	7.0		
	879.5	12	9.5	7.4		
	879.2	16	8.5	9.1		
Line #4	881.4	0	-	-		38.1 meters from west stake
	880.8	4	9.5	-		
	880.2	8	10.1	8.9		
	879.5	12	9.2	8.9		
	879.2	16	5.5	8.6		

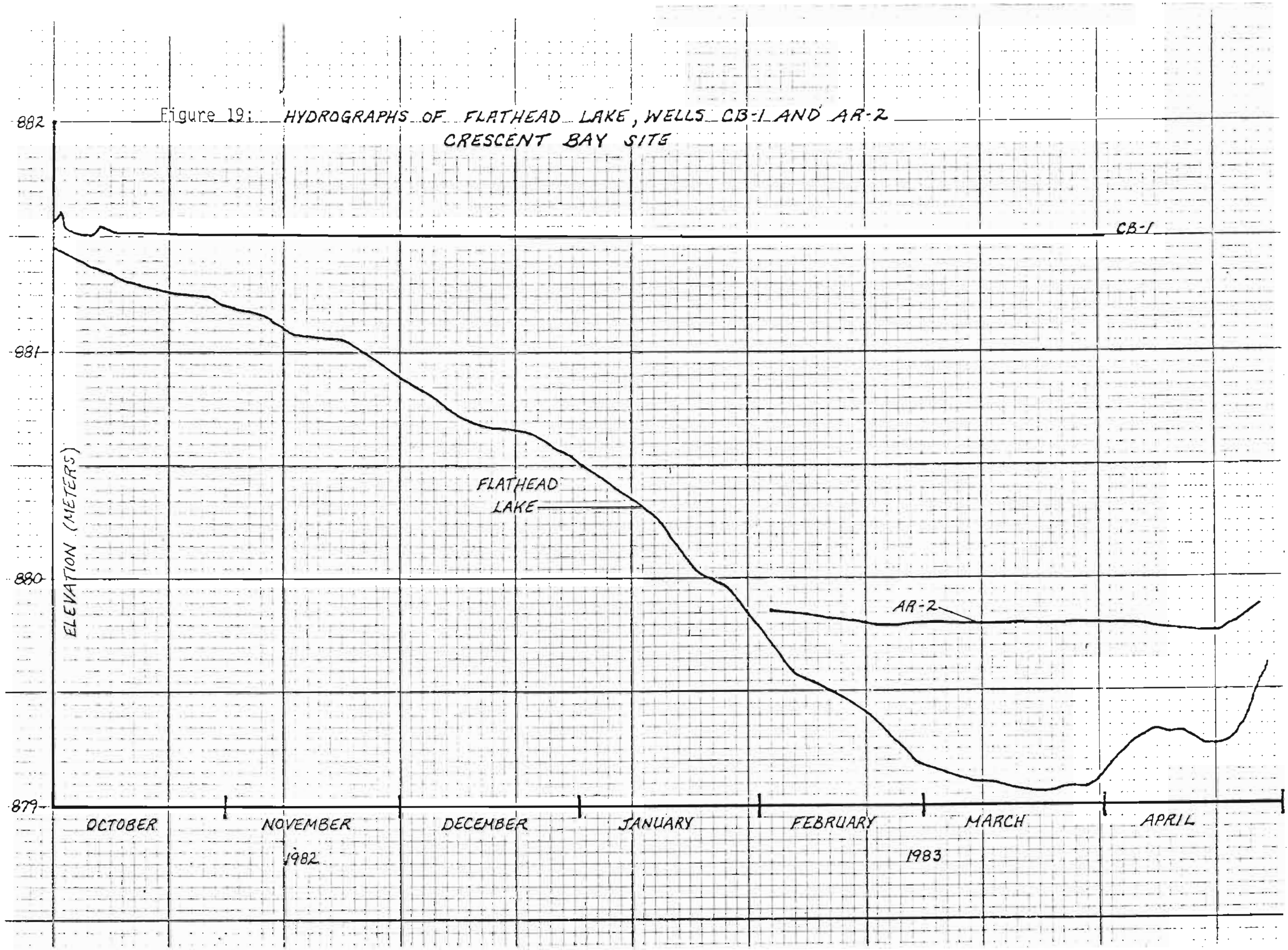


Figure 19: HYDROGRAPHS OF FLATHEAD LAKE, WELLS CB-1 AND AR-2 CRESCENT BAY SITE

Figure 20: CRESCENT BAY SITE WATER TABLE PROFILES 1983

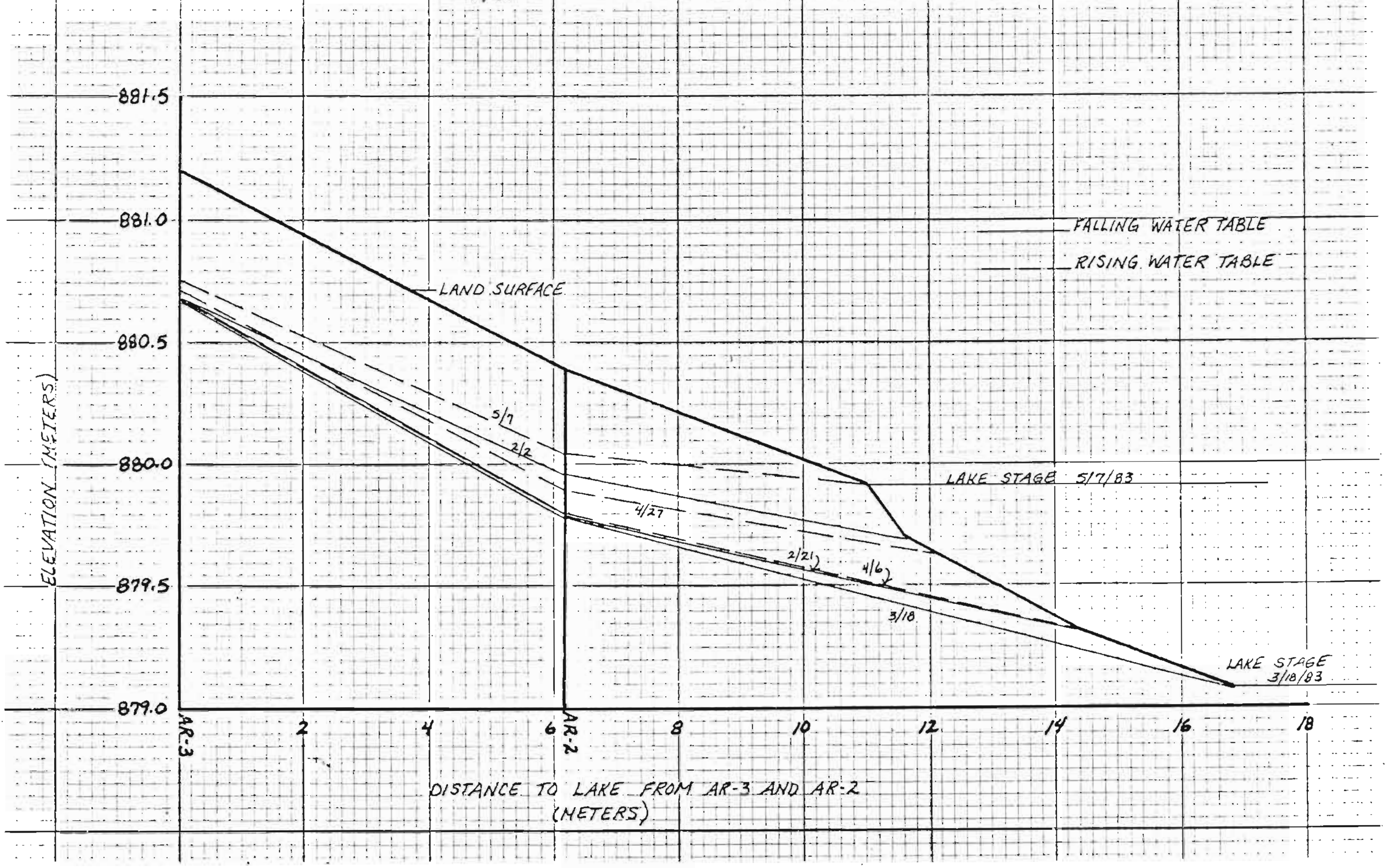
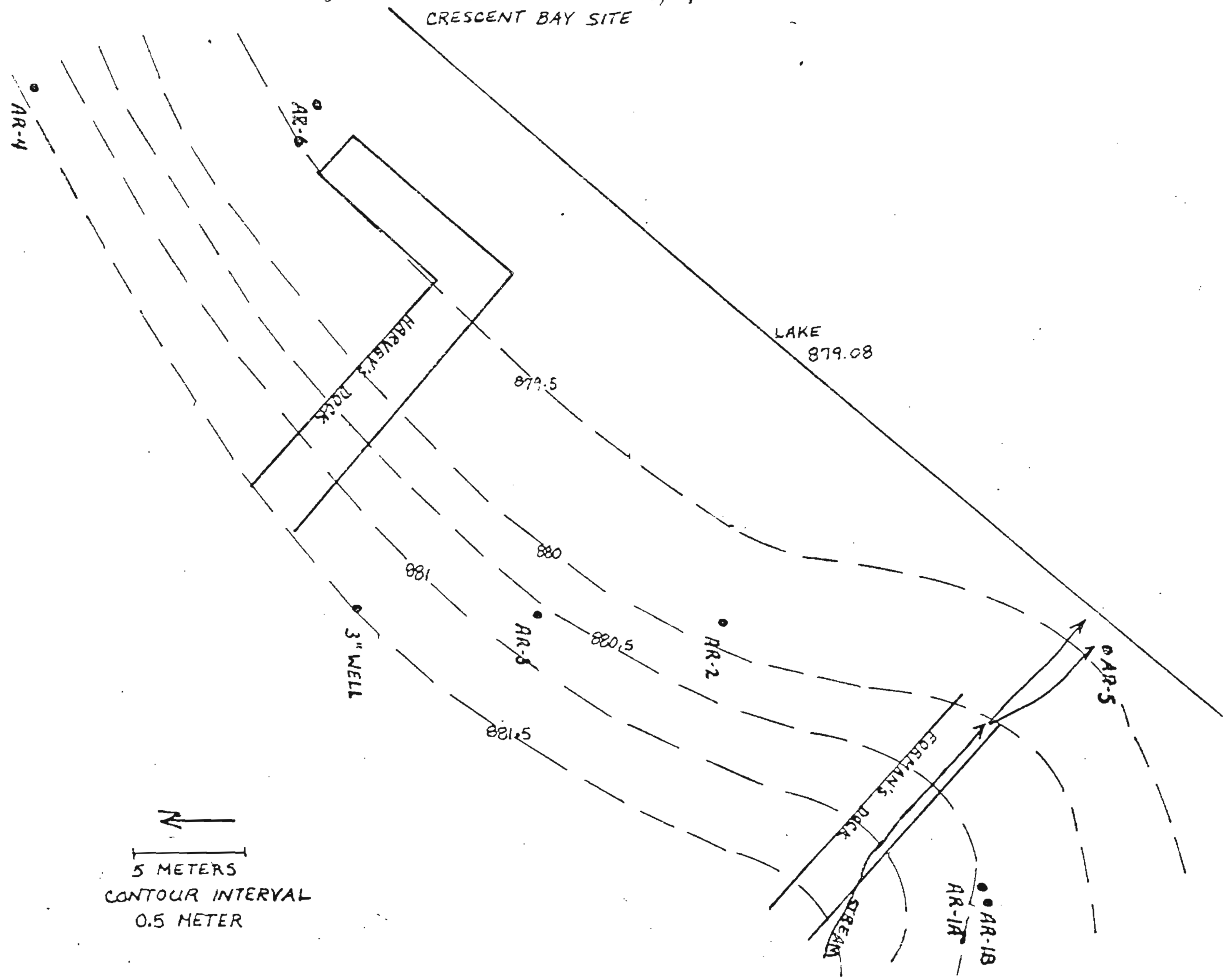


Figure 21: WATER TABLE MAP 3/18/83
CRESCENT BAY SITE



and rise. A strip of shore area adjacent to the lake about 0.8 m wide remained wetted to a depth of 15 cm by the water table during lake stage decline until late February when an area of up to 7.8 m remained wetted to within 15 cm adjacent to the lake as a portion of the beach with a lower slope was encountered. During lake stage rise a strip about 0.8 m wide adjacent to the lake contained a water table which was less than 15 cm below land surface.

Results of seepage meter apparent velocities are shown in Table 5. Seepage rates generally declined with distance from shore. Seepage rates were lower from November through January. However, a general overall trend is not apparent. Seepage rates at old meter 2 ranged from 0.15 to 0.68 cm/hr with an average rate of 0.32 cm/hr. Partial records for new meter 1 ranged from 0.07 to 0.38 cm/hr and averaged 0.22 cm/hr. Ranges and means for new meters 2 and 3 were 0.14 to 0.29 cm/hr with a mean of 0.21 cm/hr and 0.03 to 0.26 cm/hr with a mean of 0.10 cm/hr, respectively. A plot of apparent velocities on and off shore versus distance is presented in Figure 22. Values measured on shore are three orders of magnitude greater than seepage meter data. Variation of seepage rates at elevation 880.06 m as measured by new meter 2 and six portable meters is shown in Figure 23. The highest seepage rates on 8-16-82 appear to be related to ephemeral stream recharge near Harvey's and an area to the south. On 10-26-82 seepage rates were greatest 43 m south of the area in which Big Lodge Creek discharges to the beach.

Apparent and true velocities of groundwater on shore within the upper 1 m of the saturated sand and gravel beach were determined by standpipe pump test, dye test and bail test determination of hydraulic conductivily combined with hydraulic gradient data and by dye pit dilution techniques (Table 2). Hydraulic conductivity data varied from 8.1 cm/hr by bail test to 895-1811 cm/hr by standpipe pump test and dye tests methods. Based on the coarse nature of the earth material a value of 1,524 cm/hr was selected to be a

Table 5: Seepage meter results, Crescent Bay site ($cm^3/(cm^2hr)$)

	Location	Elevation (m)	1982 4/30	1982 5/10	1982 6/9	1982 7/16	1982 8/16	1982 9/26	1982 10/26	1982 11/23	1982 12/11	1983 1/25	1983 2/2	1983 5/24	1983 6/6
	1	878.97	-	0.341	0.630										New elevations
	2	878.66	0.312	0.370	0.330	0.683	0.34	0.20	0.39	0.15	0.26	0.20			880.06
	3	878.51	0.307	0.058	0.103										
South of Forman's Dock	New 1	880.74				0.38	0.26	0.17	0.20	0.07	0.23	missing			880.70
	New 2	880.06				0.28	0.14	0.14	0.29	0.15	0.23	buried			880.06
	New 3	878.94				0.26	0.062	0.17	0.11	0.03	0.03	0.09	-0.12	0.001	
Portables	1N	880.06					0.06		0.24						replaced meters
	2N	880.06					0.08		0.32						new elevations
	3N	880.06					0.15		0.32						
	4S	880.06					0.13		0.43						
	5S	880.06					0.25		0.32						
	6S	880.06					0.31		0.23						

Figure 22:

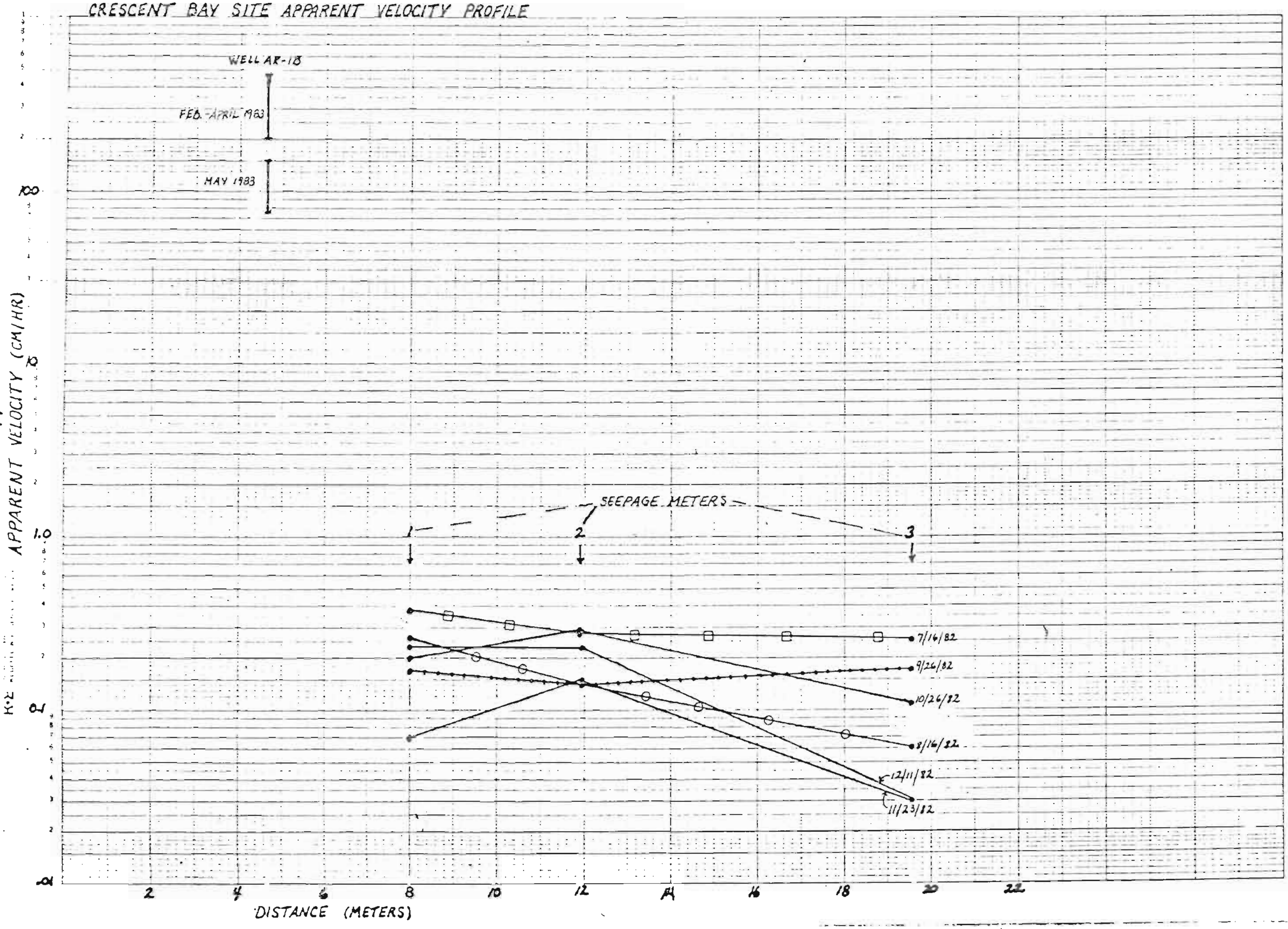
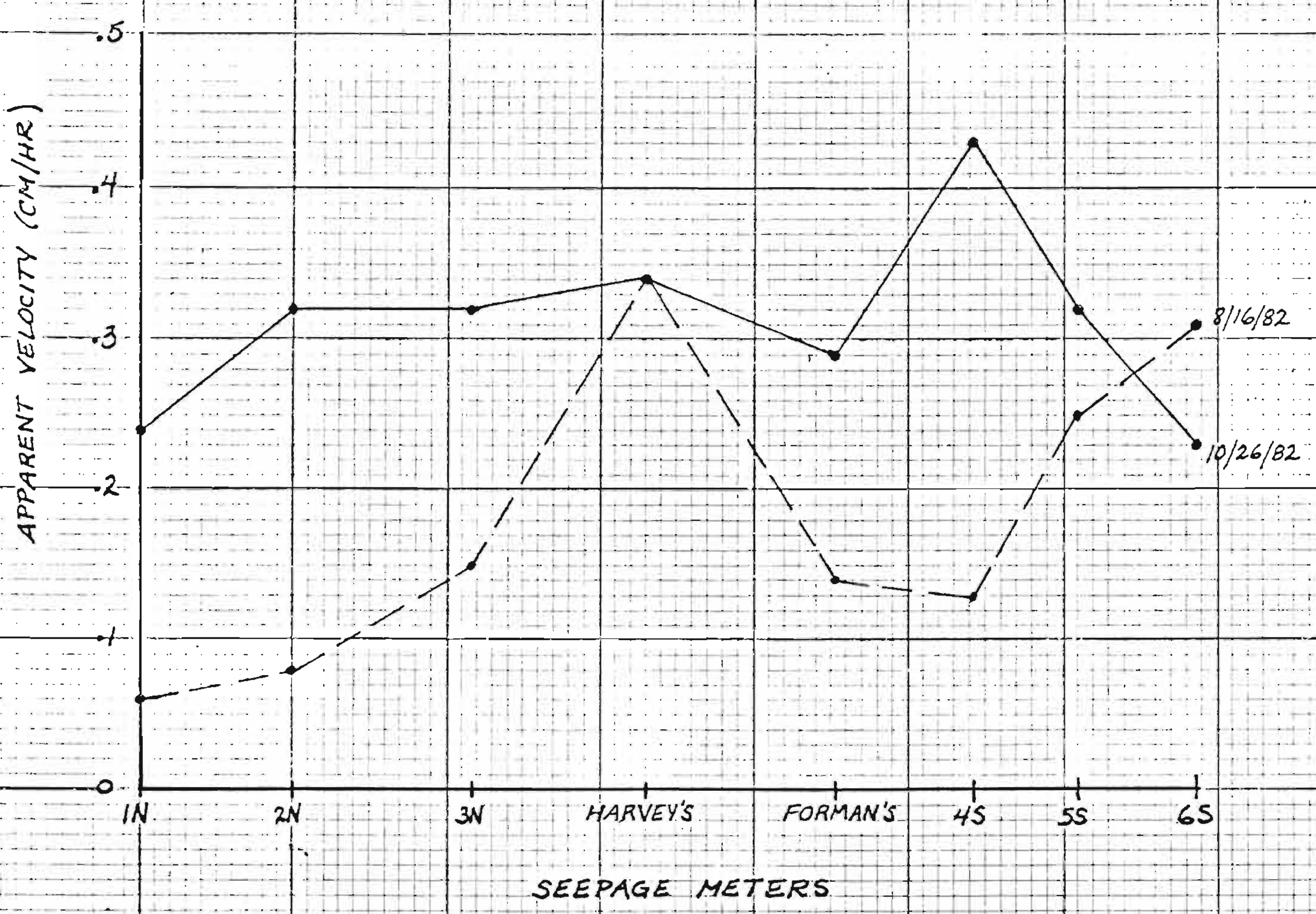

CRESCENT BAY SITE APPARENT VELOCITY PROFILE
WELL AR-18
FEB.-APRIL 1983
MAY 1983
SEEPAGE METERS
1
2
3
7/16/82
9/26/82
10/26/82
8/16/82
12/11/82
11/23/82
APPARENT VELOCITY (CM/HR)
100
10
1.0
0.1
.01
2
4
6
8
10
12
14
16
18
20
22
DISTANCE (METERS)

Figure 23: SEEPAGE VARIATION PARALLEL TO SHORE
CRESCENT BAY SITE



representative hydraulic conductivity. Calculations of apparent velocities ranged from 76 to 149 cm/hr with a mean of 118 cm/hr. A dye pit dilution determinations of v* on 3-5-83 yielded a value of 62 cm/hr.

Groundwater quality data derived from sandpoint wells, seepage meters and surface streams are presented in Table 6. Water in seepage meters is generally a calcium bicarbonate type. Seepage meter water is lower in TDS than well water, about 200 mg/l vs. 300 to 400 mg/l. Concentration of calcium and bicarbonate are greater in the well water. Both creeks show water very similar to that found in the shallow wells with the exception of AR-4 which is more similar in quality to seepage meter groundwater. However, the analysis looks suspect as pH and calcium values seem out of line with other analyses. Dissolved oxygen values for wells AR-1A, AR-2, AR-3 and AR-4 obtained on 4-25-83 were 1.6, 2.0, 2.8 and 1.3 respectively. Dissolved oxygen sampling transects near Forman's dock were obtained on 1-28-83, 3-17-83 and 6-6-83 (Table 7). DO values dropped from 9.9 mg/l near shore to 0.2 mg/l 12 m from shore on 1-28-83. On 3-17-83 values dropped from the 10 mg/l range to near shore to 0.5 mg/l 20 m from shore. On 6-6-83 during lake stage rise levels were 2.6 and 6.7 mg/l near shore and increased to 9.7 mg/l 20 m from shore. One transect near Harvey's dock obtained 1-28-83 showed levels of DO in the 7 to 10 mg/l range out to 16 m from shore then 0.0 mg/l 19 m from shore.

Hochmark's

The water level fluctuations at wells BH-1, BH-3 and the lake stage at Kerr Dam are presented in Figure 24. The hydrograph data for BH-2 is presented in Appendix D. The period of record, January to May 1983, for BH-1 and BH-2 had average water level elevations and water level changes of 880.72 m and 0.04 m and 880.32 m and 0.03 m, respectively. During the same period the lake stage declined 0.88 m and rose 1.22 m. Water levels in well BH-3 varied 0.03 m from late March to late April while the lake stage rose 0.18 m

Table 6 : Groundwater Quality Data, Crescent Bay site.

Location Date	Meter #	DO	pH	Ion Concentration in mg/l: NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	T °C		
Shallow	1																
9-26-82		9.6															
11-24-82			8.0	0.129	0.001	0.46	3.1	139	31.8	8.1	1.8	0.7	186				
CBFD	2																
9-26-82		9.6												200			
11-24-82			7.9	0.013	<0.001	0.33	2.1	146	34.5	7.5	1.3	0.7	192				
1-26-83			7.6	0.007	<0.001	0.42	2.5	157	35.5	8.9	1.6	0.8	206				
Old #2 CBH																	
9-26-82		7.6															
11-24-82			7.9	0.039	<0.001	0.25	2.6	109	25.3	6.3	1.2	0.4	145				
1-26-83			7.9	0.073	0.001	0.35	3.2	119	27.6	7.2	1.3	0.6	159				
Well Data																	
AR-1A																	
5-23-83			8.3	0.005	<0.001	2.8	4.0	320	62.1	25.2	5.7	2.3	422				
AR-1B																	
5-23-83			8.2	0.403	0.011	1.1	3.1	258	52.4	17.6	4.3	1.9	342				
AR-3																	
5-23-83			8.2	0.955	0.005	1.9	4.5	326	67.2	22.2	5.7	2.5	438				
AR-4																	
5-23-83			9.9	0.019	<0.001	1.58	<1.0	116	15.8	20.6	6.7	3.1	194				
AR-5																	
3-30-83			8.0	0.407	0.008	1.29	3.2	281	60.0	17.9	5.1	2.2	373				
Big Lodge Creek, Surface water																	
5-23-83			8.3	0.388	0.012	1.1	2.9	258	52.6	16.8	5.4	1.7	342				
Ephemeral stream near Harvey's																	
5-23-83			8.3	0.720	0.006	2.0	3.6	291	58.4	23.0	4.3	1.8	390				

Table 7 : DO Transect Data, Crescent Bay site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 1-28-83	Date 3-17-83	Date 6-6-83						
Line #1	881.8	0	-	-	2.6	Forman's					
	881.1	4	-	9.7	0.7						
	880.7	8	-	10.5	8.1						
	880.1	12	9.9	10.6	4.8						
	879.6	16	8.2	10.7	7.7						
	879.0	20	1.2	5.5	9.7						
	878.7	24	0.2	0.5	-						
Line #2	880.6	0	9.9			Harvey's					
	880.1	4	10.3								
	879.6	8	10.2								
	879.3	12	9.2								
	878.6	16	7.3								
	878.5	20	0.0								

Figure 24: HYDROGRAPHS OF FLATHEAD LAKE AND WELL BH-1 HOCHMARK SITE

and fell 0.09 m. Station Creek discharged to the beach and lake between BH-1 and BH-2. During the period of March to May 1983, flow discharge measurement ranged from 0.03 to 0.09 m^3/sec with an average of 0.06 m^3/sec.

A water table profile derived from well data and lake stage data at Hochmark's and a contour map of the water table at 3-18-83 are presented in Figures 25 and 26. The groundwater movement is from the higher topography east of the site to the lake. Flow at the site is basically perpendicular to the lake shore with groundwater discharge to the lake. Station Creek is shown to be a losing stream, recharging the groundwater system. The profile shows during both falling and rising lake stage, groundwater flow is to the lake. The water table elevation also did not fall below the 15 cm depth during the period of study for any of the shore area within the study area exposed by the change in stage.

Apparent and true velocities of groundwater flow within 1 m of the water table were derived from tracer tests and standard calculations. Results are summarized in Table 2. Measurement of hydraulic conductivity near the water table by standpipe pump test, dye test and bail test yielded values of 66, 1,426 to 5,305 and 1.31 cm/hr. Based on the nature of the aquifer material a value of 66 cm/hr was selected to be representative hydraulic conductivities. These values were multiplied by the hydraulic gradient measured perpendicular to the equipotential lines for the dates shown. Apparent velocity values ranged from 4.6 to 7.1 cm/hr and averaged 6.2 cm/hr. One pit dilution measurement of v* yielded 826 cm/hr and standpipe dilution techniques 21.0 cm/hr. Maximum apparent velocities determined by pit dye tests yielded values of 128 to 4,115 cm/hr.

Groundwater quality data derived from shallow well BH-1 and Hochmark Creek are presented in Table 8. Both waters are a calcium bicarbonate type. Water collected at BH-1 has a lower pH, 7.2-7.9, and TDS, 112 to 157 mg/l,

Figure 25: HOCHMARK SITE WATER TABLE PROFILES
1983

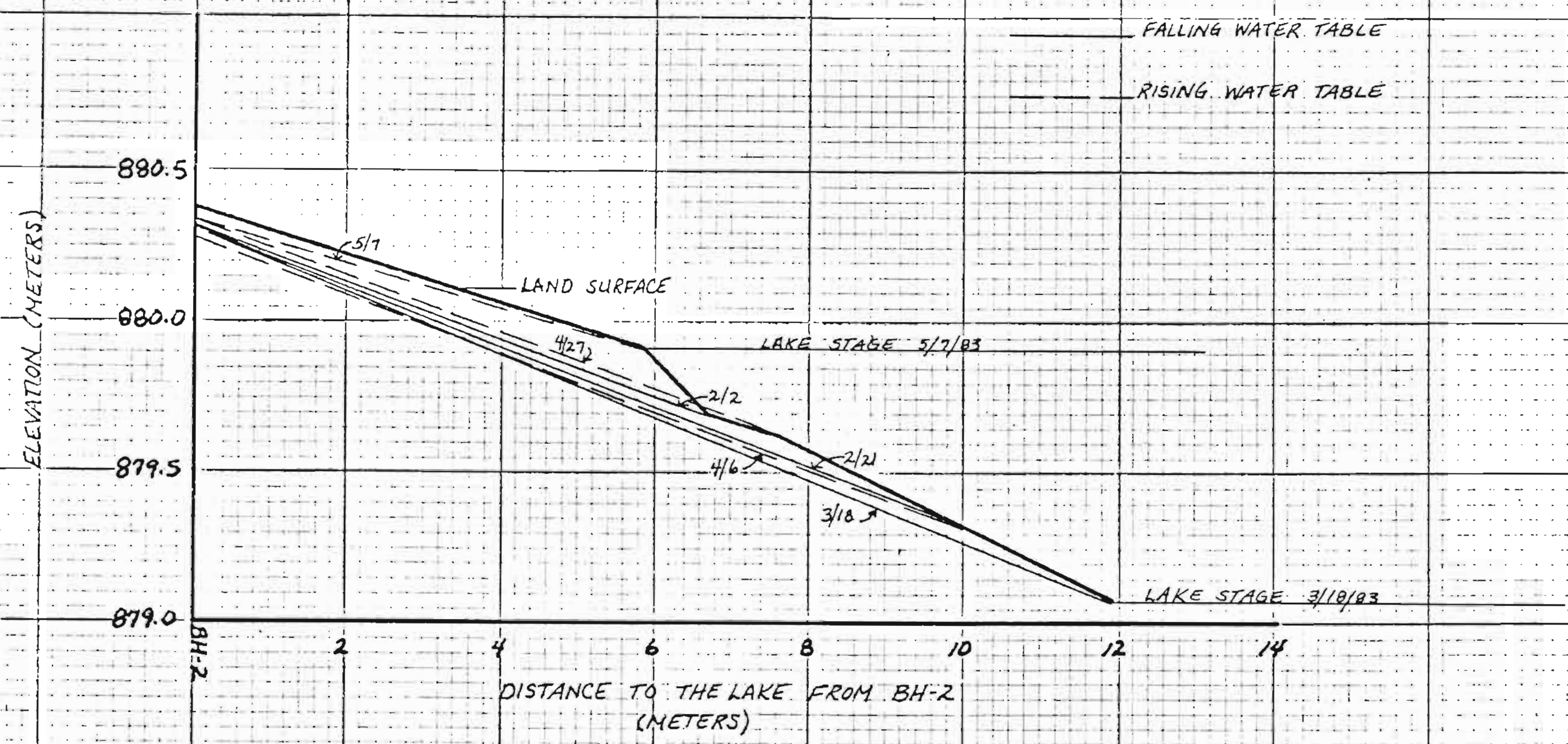


Figure 26: WATER TABLE MAP 3/18/83
HOCHMARK SITE

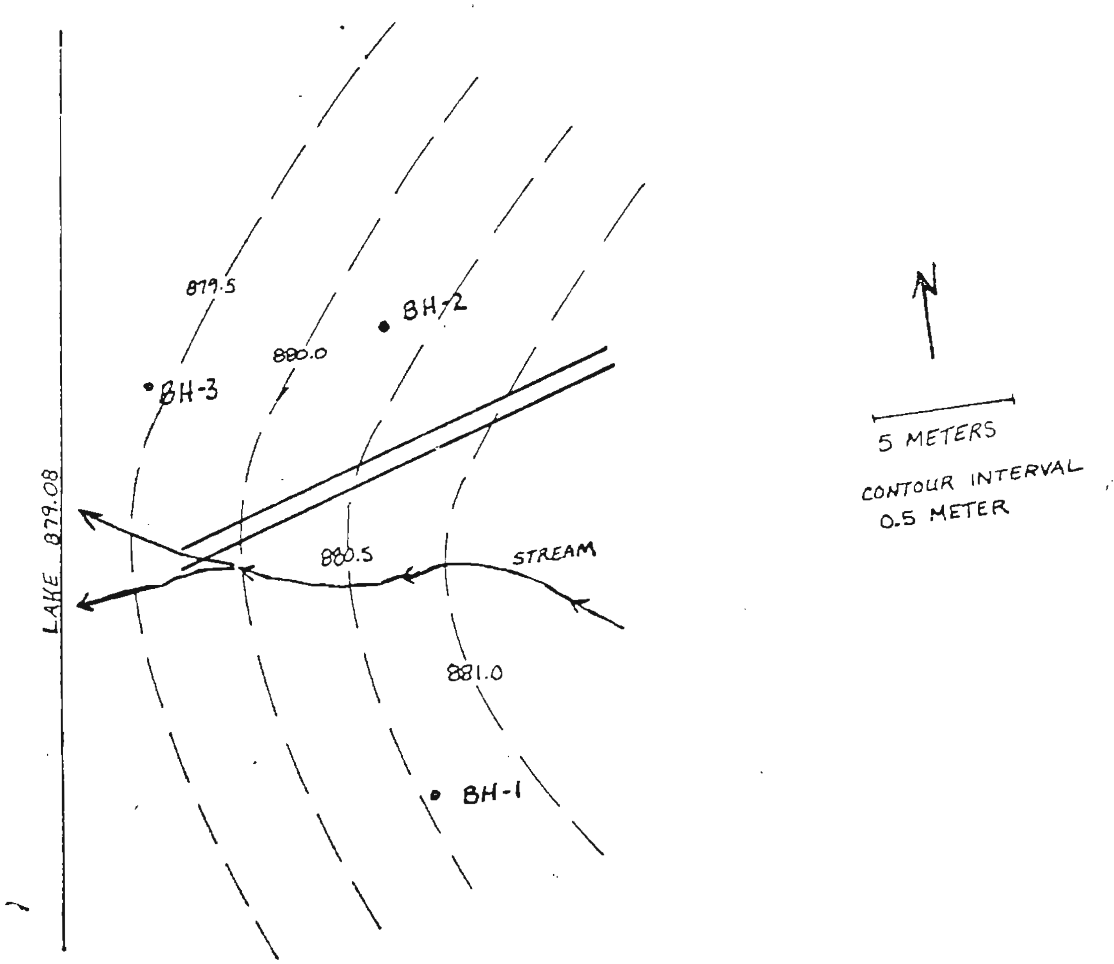


Table 8 : Groundwater Quality Data, Hochmark's site.

Location Date	Meter =	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	°C
				Ion Concentration in mg/l											
Well Data															
BH-1															
3-30-83			7.2	0.019	<0.001	0.38	2.5	105	24.8	4.5	2.1	0.9	112		
5-23-83			7.9	0.025	0.001	0.24	1.9	118	29.4	4.8	1.8	0.8	157		
Station Creek Data															
5-23-83			8.3	0.72	.0006	2.0	3.6	291	58.4	23.0	4.3	1.8	390		

than creek water which has a TDS of 300 mg/l and a pH of 8.3. All ionic constituents tested for in the samples were higher in the creek than groundwater. The quality of the groundwater appears more similar to lake water than creek water. Groundwater dissolved oxygen values taken along gravel transects ranged from 8.5 to 12.3 mg/l on 3-16-83 (Table 9). Wells BH-1, BH-2 and BH-3 had values which ranged from 4.3 to 10.2 mg/l on 4-25-83 with values increasing closer to the lake shore line and values of 1.8 to 5.7 mg/l at wells BH-1 and BH-2 respectively on 5-13-83.

Pine Glen

The water level fluctuation at wells PG-1 and PG-3 and the lake stage at Kerr Dam are shown in Figure 27. Hydrographs of wlls PG-2A and PB-2B are pressented in Appendix D. The water levels parallel the lake stage decline in late January and early February. However, they depart from the 0.01 m/d rate of lake stage decline to a rate of 0.009 m/d from mid February through mid March. Water levels in wells then basically paralleled lake stage rise which began in late March.

A water table profile derived from well PG-1, lake stage data and a contour map of the water table on 3-18-83 are presented in Figures 28 and 29. The groundwater movement is generally from the higher topography to the east to the lake shore. Flow at the site is perpendicular to the lake shore with discharge to the lake. The profile data indicates groundwater discharged to the lake during lake stage rise and fall. During lake stage decline a 1 m zone adjacent to the lake shore remained wetted by groundwater to 15 cm or less. By lake rise in May, the area wetted by groundwater exceeded a width of 4 m parallel to shore.

Apparent and true velocities of groundwater flow were determined and are presented in Table 2. Measurements of hydraulic conductivity near the water table were made by standpipe pump test and dye pit dilution tests which

Table 9 : Dissolved Oxygen Transects, Hochmark's site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 3-15-83	Date	Date						
Line #1	880.6	0	10.0								
	880.3	4	9.1								
	879.7	8	12.3								
	879.2	12	11.7								
	878.8	16	8.5								
	878.6	20	11.2								

Figure 27: HYDROGRAPHS OF FLATHEAD LAKE AND WELL PG-1, PINE GLEN SITE

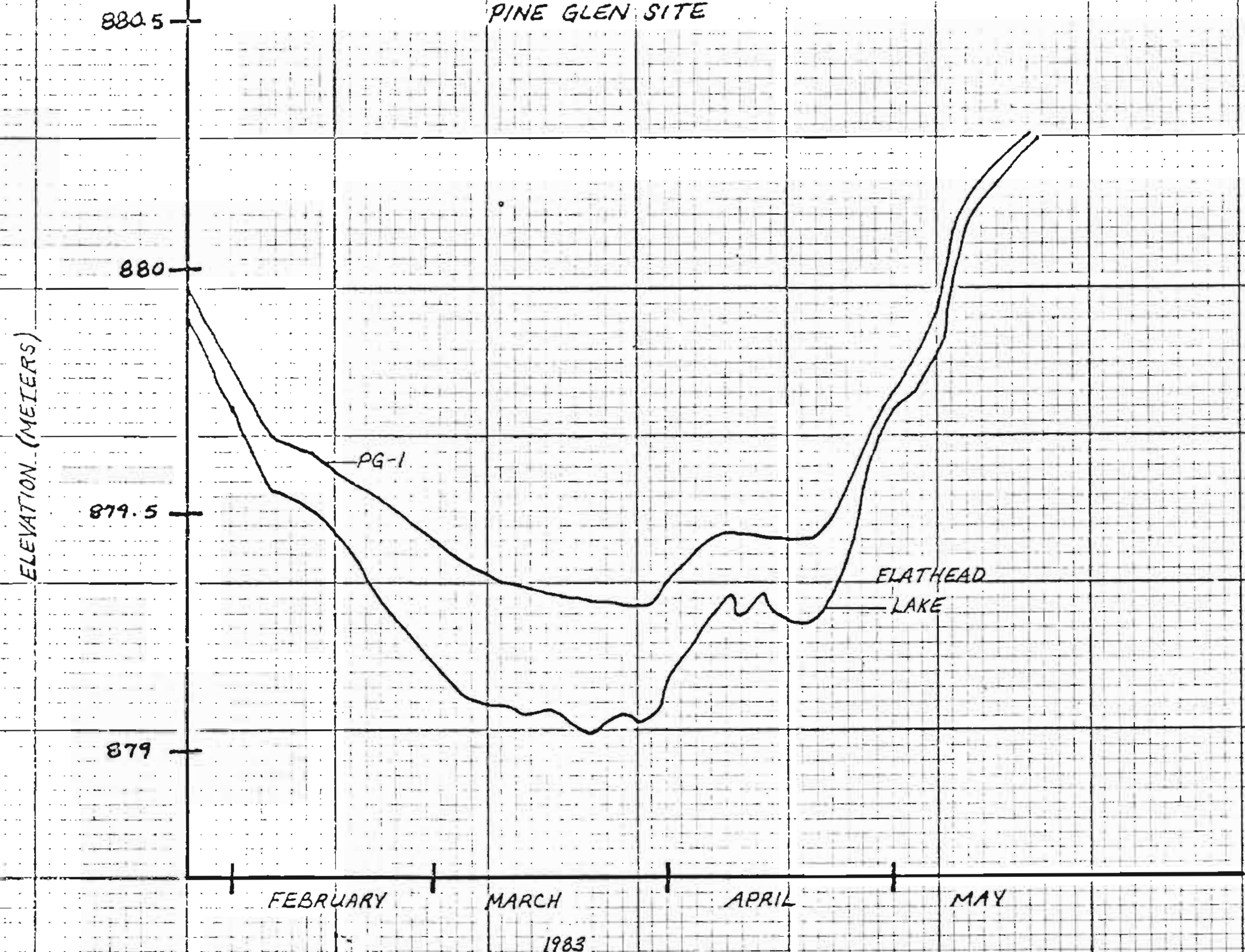


Figure 28: PINEGLEN SITE WATER TABLE PROFILES 1983

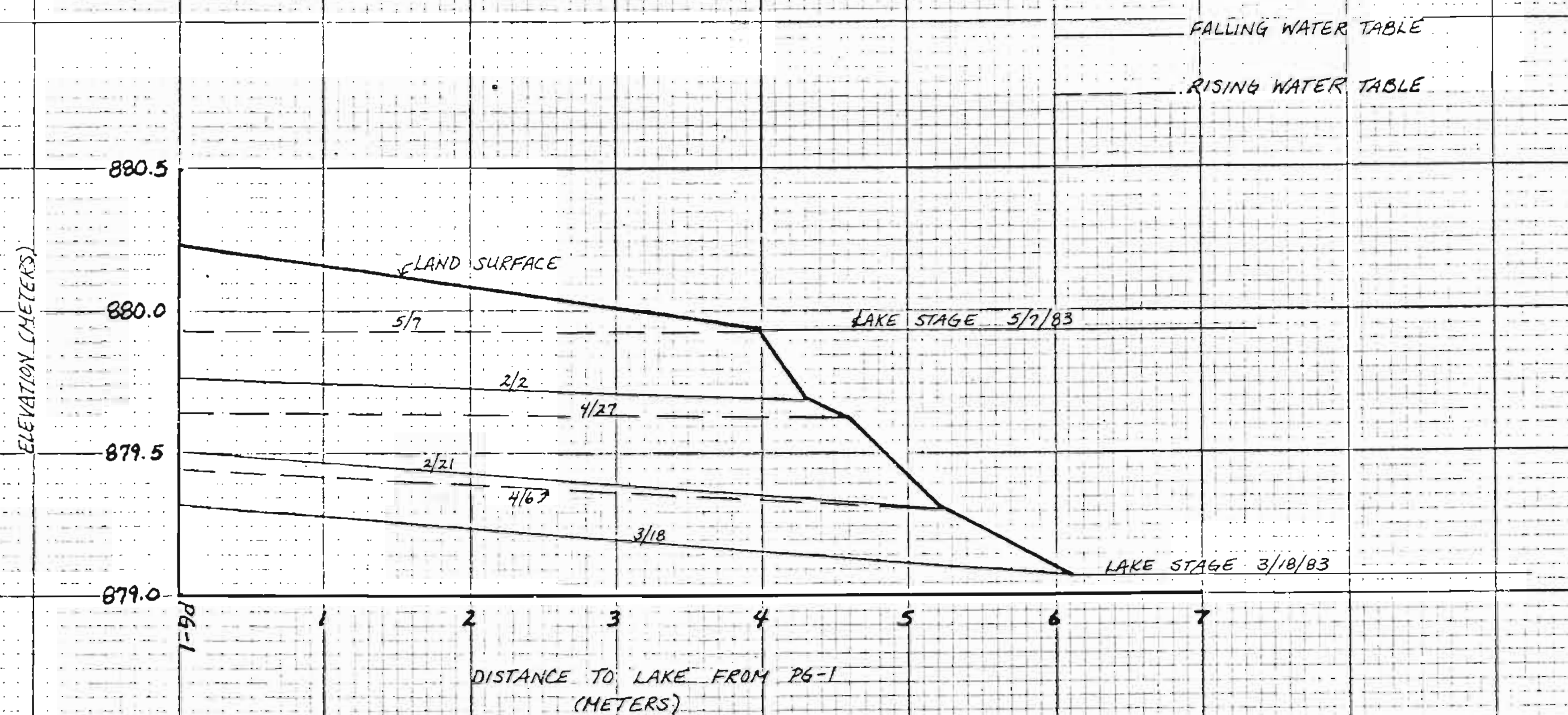
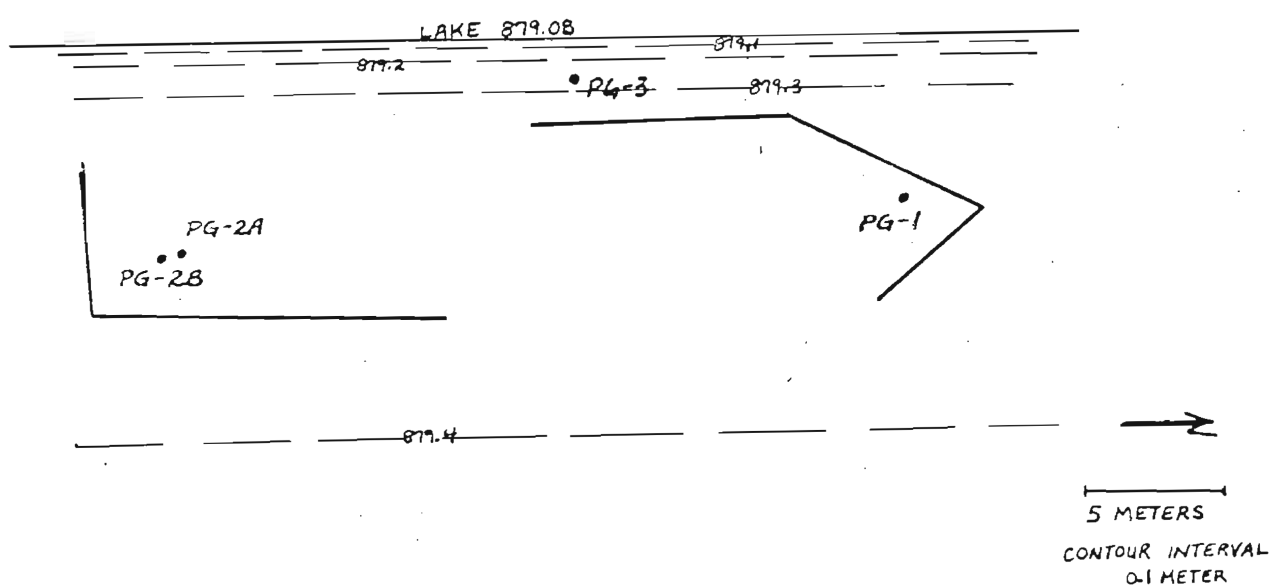


Figure 29: WATER TABLE MAP 3/18/83
PINEGLEN SITE



yielded values of 2,255 and 6,689 cm/hr respectively. An average value of 2,255 cm/hr was selected and multiplied by the measured hydraulic gradient. Apparent velocities ranged from 11 to 64 cm/hr with an average value of 33.7 cm/hr. Dye pit dilution and standpipe dilution techniques yielded values of 3.0 and 1.3 cm/hr respectively. A maximum velocity measured on 1-26-83 was 73.2 cm/hr.

Groundwater quality data were derived from well PG-2A on 3-30-83 (Table 10). Water is a calcium bicarbonate type with a TDS of 298 mg/l. Groundwater dissolved oxygen data from wells PG-2B and PG-3 were 6.8 and 8.5 mg/l respectively on 4-25-83 and 7.5, 9.1 and 7.7 mg/l for wells PG-1, PG-2A, PG-2B respectively on 5-13-83. Groundwater dissolved oxygen from gravel transects ranged from 7.5 to 8.8 mg/l and 8.5 to 9.5 mg/l on 12-19-82 and 3-16-83, respectively (Table 11).

Dr. Richard's South

The water level fluctuations at wells DRS-1 and DRS-3 and the lake stage at Kerr Dam are shown in Figure 30. A hydrograph of well DRS-2 is presented in Appendix D. The water levels in the wells paralleled the decline in lake stage and the elevation of lake stage from late January to late February 1983 and then departed declining at a rate of 0.004 m/d until late March. As lake stage rose in April and May the rate of groundwater rise and water table elevation closely paralleled lake stage. Water levels in wells DRS-1 and DRS-2 were measured to be less than lake stage on 4-6-83 and 4-27-83.

A water table profile derived from well data, DRS-2, and lake stage data and contour maps of the water table at 3-18-83 and 4-27-83 are presented in Figures 31, 32, and 33. The groundwater movement is generally from the higher topography to the east of the site to the lake with discharge to the lake. Flow at the site is basically perpendicular to the shore line. However, dye tracer testing performed on 1-26-83 and water levels measured on 4-27-83

Table 10 : Groundwater Quality Data, Pine Glen site.

Location Date	Meter #	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	T °C		
						Ion Concentration in mg/l											
Well Data																	
PG-2A																	
3-30-83		7.6	0.045		0.003	0.60	3.2	226	51.9	12.3	2.8	1.5	298				

Table 11 : DO Transect Data, Pine Glen site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 12-9-83	Date 3-16-83	Date						
Random data points	880.3		7.5	-							
	879.9		8.4	-							
	879.7		9.5	9.5							
	879.4		10.2	9.0							
	879.1		9.3	9.5							
	879.0		9.5	9.5							
	879.3		8.7	8.5		In front of north corner of new pilings					
	879.4		9.5	9.5		North edge of spawning area					
	879.6		8.8	9.2		South edge of spawning area					

Figure 30: HYDROGRAPHS OF FLATHEAD LAKE AND WELL DRS-1, DR. RICHARDS SOUTH SITE

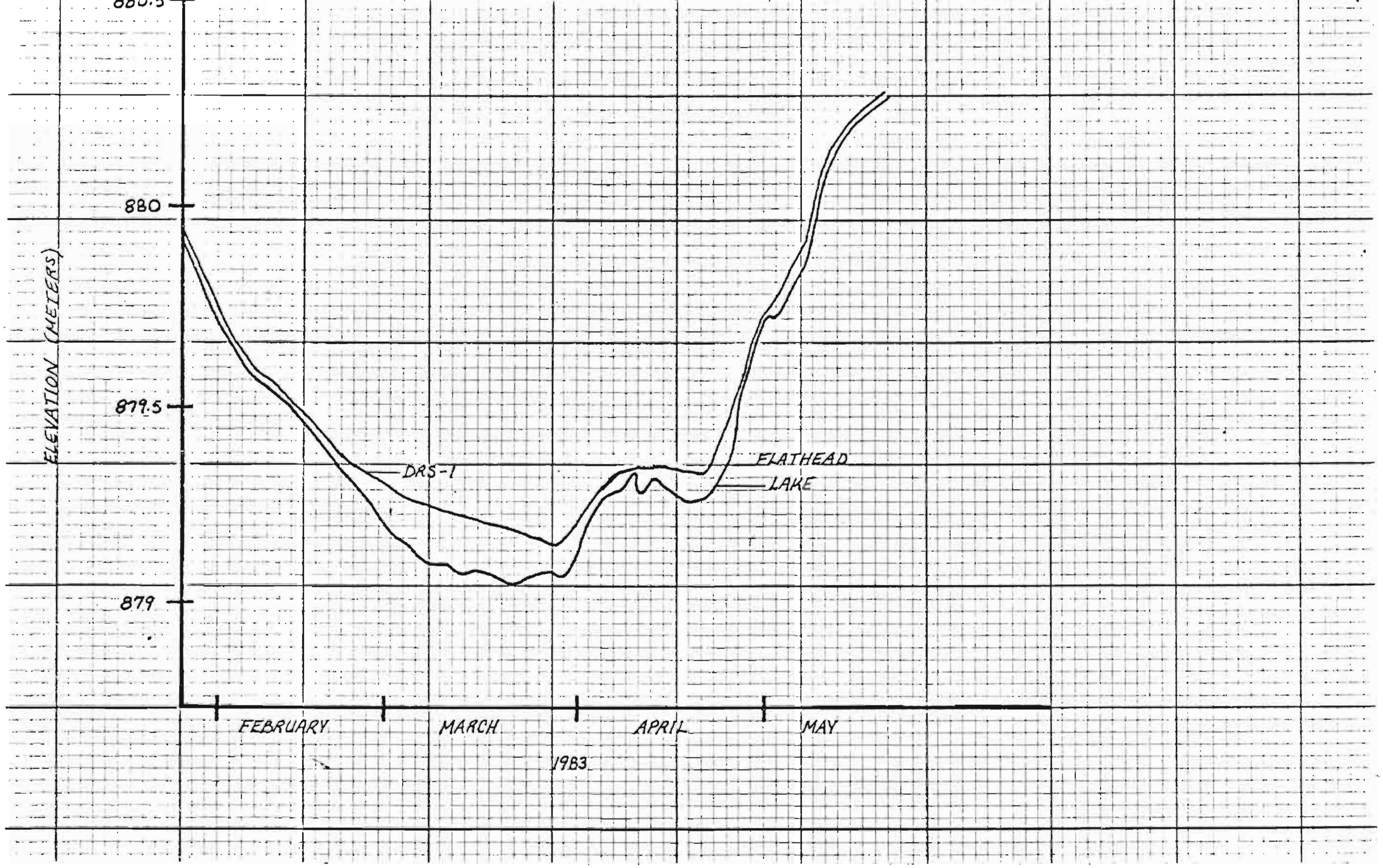


Figure 31: DR. RICHARDS SOUTH SITE WATER TABLE PROFILES 1983

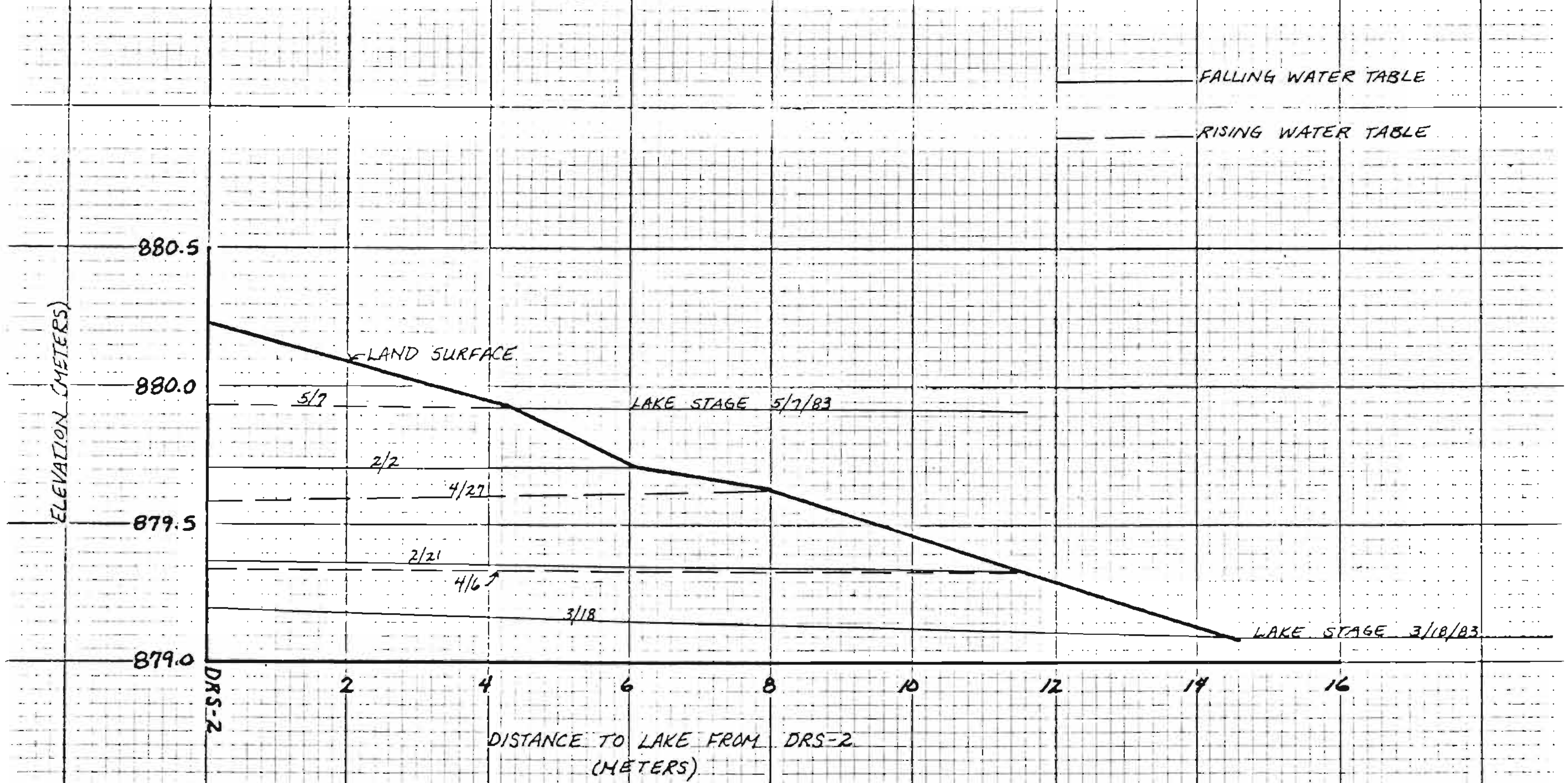


Figure 32: WATER TABLE MAP 3/18/83
DR. RICHARDS SOUTH SITE

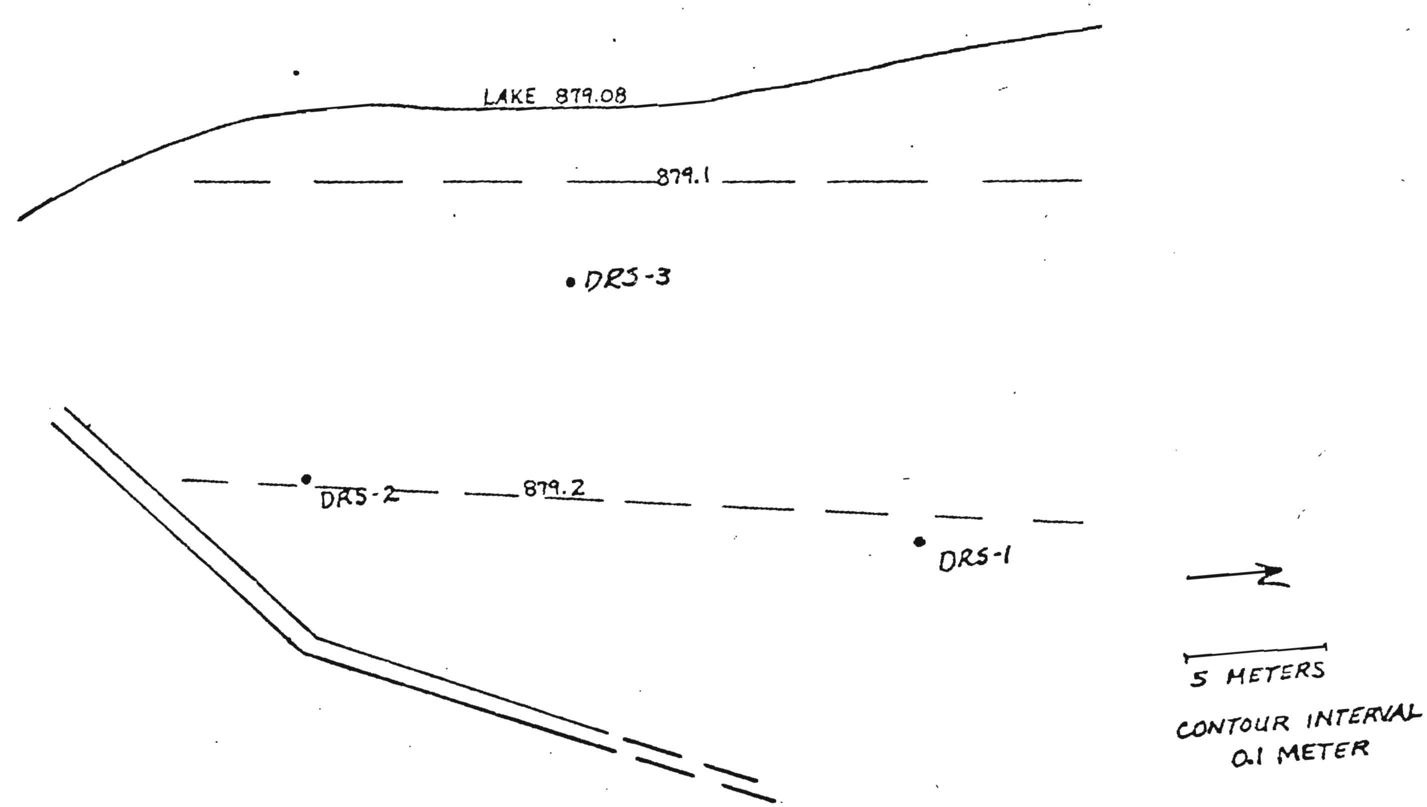
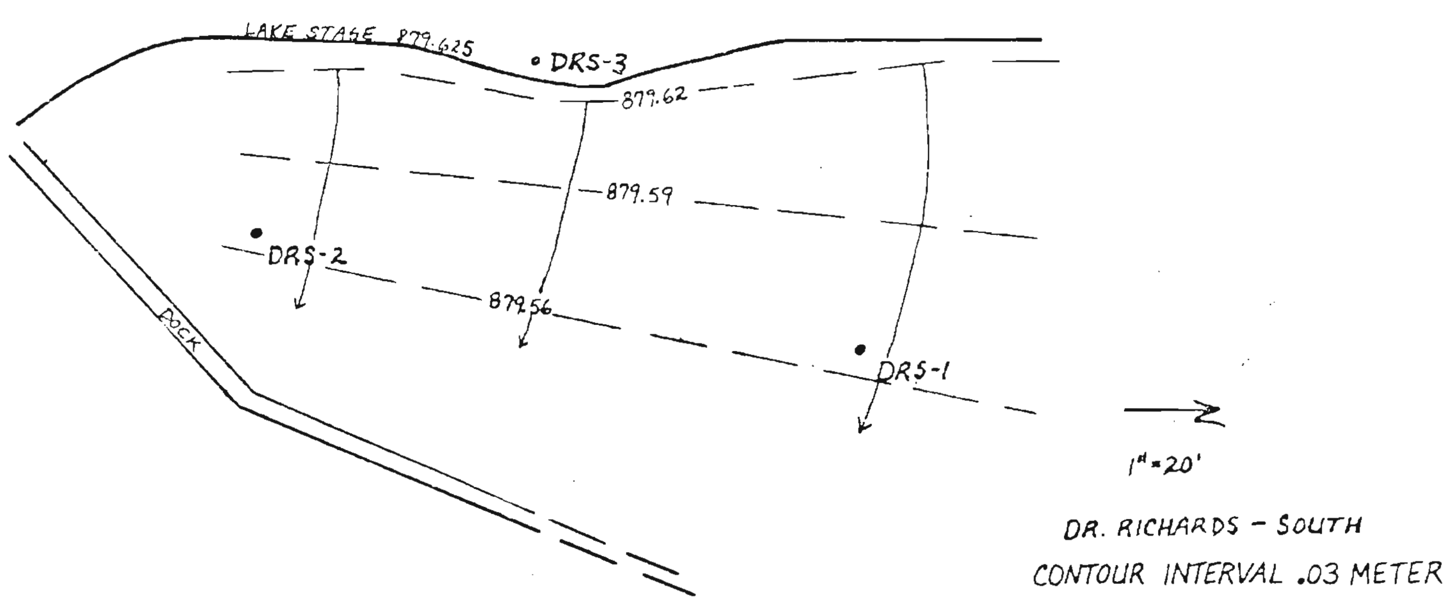


Figure 33:

WATER TABLE MAP : DR. RICHARDS SOUTH SITE 4/27/83



indicated a reversal of flow with water moving away from the lake to the east. The general slopes of the water table profile also show the very slight reversal in gradient. Figure 31 also shows that as the stage fell and rose the water table remained fairly flat. On the average a band off shore 1 m wide adjacent to the lake remained groundwater wetted within 15 cm of the land surface as the stage fell and rose.

Results of apparent and true velocity calculations are summarized in Table 2. Measurement of the hydraulic conductivity within 1 m of the water table by standpipe pump test and dye dilution yield values of 876 and 9,813 cm/hr. Based on the cobbly nature of the material a value of 876 cm/hr was chosen to be representative. These values were multiplied by hydraulic gradients and apparent and true velocities were calculated. Apparent velocities calculated by this method ranged from 0 to 8 cm/hr. Standpipe dilution test derived value ranged from 61 to 189 cm/hr are maximum velocity value of 238 cm/hr was determined on 1-26-83.

Groundwater quality data derived from wells DRS-2 on 3-30-83 and DRS-1 on 5-23-83 indicated water was a calcium biccarbonate type (Table 12). The analysis of DRS-2 is very similar to lake water and well DRS-1 is lower in TDS, 100 mg/1. Groundwater dissolved oxygen data collected from wells on 4-25-83 and 5-13-83 showed values of 10.6 to 10.3 and 7.1 to 7.7 at wells DRS-1 to DRS-3 and DRS-1 and DRS-2, respectively. DO taken along gravel transects during 3-16-83 ranged from 8.9 to 11.0 (Table 13).

Yellow Bay

Water level fluctuaions at the 7.6 cm diameter well, YB-1, at Yellow Bay and the lake stage at Kerr Dam are plotted in Figure 34. The water level in the well mirrored the lake stage decline until mid December 1982 when it began declining at a rate of 0.015 m/d instead of the 0.05 m/d rate of lake stage

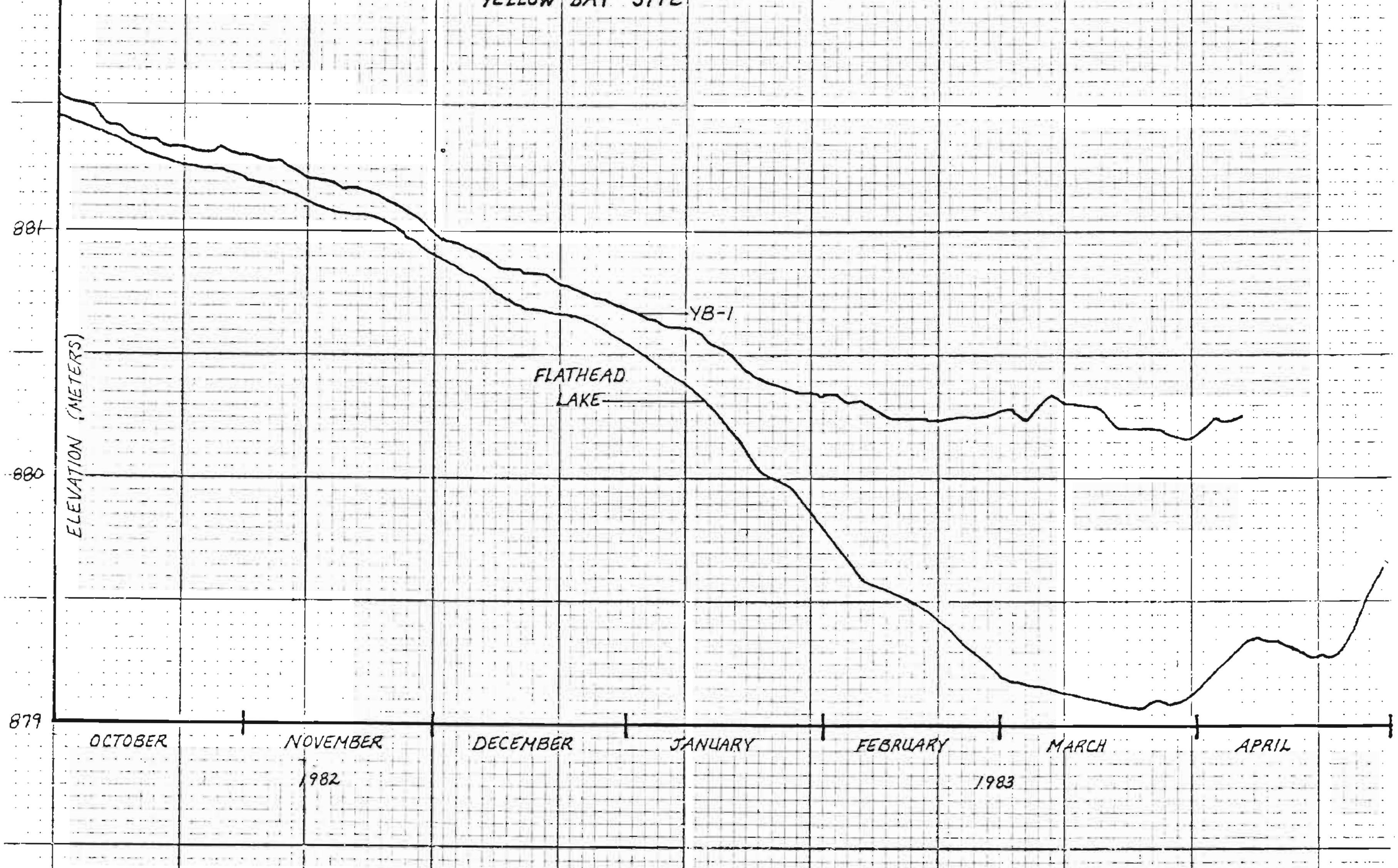
Table 12 : Groundwater Quality Data, Dr. Richard's South site.

Location Date	Meter #	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	T °C		
				Ion Concentration in mg/l													
Well Data																	
DRS-1																	
5-23-83			8.1	0.058	0.016	0.23	1.6	73	19.4	2.6	1.4	0.6	100				
DRS-2																	
3-30-83			7.6	0.102	0.010	0.37	1.9	108	26.0	5.2	2.1	0.8	145				

Table 13 : Dissolved Oxygen Transects, Dr. Richard's South site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 3-15-83	Date	Date						
Line #1		0	-			Black and white house, north					
		4	-								
		8	-								
		12	8.9								
		16	11.1								
		20	11.1								
		24	11.0								
Line #2	880.6	0	-			Black and white house, south					
	879.7	4	-								
	879.7	8	8.7								
	879.2	12	11.2								
	879.1	16	10.0								

Figure 34: HYDROGRAPHS OF FLATHEAD LAKE AND WELL YB-1
YELLOW BAY SITE



decline. The water level in the well also generally leveled off by mid February 1983. Based on Figure 34 groundwater gradients remained to the lake during the period of record.

The results of operation of the seepage meter are presented in Table 14. Seepage rates reported as apparent velocities were generally greater in June and July 1982, and February, March and June 1983. Lowest seepage rates were obtained in April 1982. Ranges and means of apparent velocity values at various meters were as follows:

#2; 0.01 to 0.55 cm/hr with a mean of 0.32 cm/hr;

#3; 0.10 to 0.60 cm/hr with a mean of 0.30 cm/hr;

#4; 0.08 to 0.77 cm/hr with a mean of 0.35 cm/hr;

#5; 0.08 to 0.48 cm/hr with a mean of 0.24 cm/hr;

#6; 0.02 to 0.64 cm/hr with a mean of 0.30 cm/hr.

Figure 35 presents a plot of apparent velocity versus distance for time of data collection. Apparent velocities generally fall between 0.1 and 0.8 cm/hr with the greater variability being between meters #4 and #5. Figure 36 presents a plot of seepage meter rates vs. parallel portable seepage meter location for various dates. In July and August 1983 seepage rates were greatest near portable meter 1 south of meter 2 in the perpendicular to shore transect. Seepage was greatest at meter 2 only on 12-20-82. The remainder of measurements found highest rates near meter 5 north of the permanent line.

Groundwater quality data collected from seepage meters and a FWP pump near meter 5 and water chemistry data for Yellow Bay Creek are presented in Table 5. The water quality of samples from meters 1, 2 and 4 all are similar to Yellow Bay Creek and Flathead Lake water chemistry. The water is a calcium bicarbonate type. Groundwater samples at meters 5 and 6 by seepage meter and FWP pump indicated low TDS water similar to other records on 9-17-82. However, by November and December pH had decreased and calcium bicarbonate and

Table 14: Seepage meter results, Yellow Bay site ($cm^3/(cm^2\ hr)$).

		1982											1983						
Location	Elevation (m)	4/22	4/29	6/4	7/9	7/13	7/22	8/10	9/16	10/13	11/23	12/20	1/25	2/22	3/30	4/21	4/22	5/24	6/29
1	879.10	0.37*	gone...																
2	878.59	0.10	bag out	0.53	0.50	0.21	0.55	0.17	0.21	0.23	0.28	0.37	0.28	0.45	buried.....				
3	878.03	0.10	0.42	0.60	0.42	0.50		0.16	0.12	0.31	0.24	0.22	0.20	0.30	buried.....				
4	877.03	0.08	0.50	0.58	0.77	0.44		0.17	0.08	0.38	0.26	0.27	0.38	0.08	0.62	0.27			
5	873.42	0.20	0.48	0.45	0.24	0.08		0.18	0.25	0.26	0.02	0.14	0.13	0.29	0.35	0.30		0.0	0.46
6	874.32								0.12	0.07	0.02	0.07	0.21	0.53	0.39	0.52		0.64	0.40
New 1	880.14								0.38	0.18	0.31	0.28	gone.....					0.0	0.13
Portables																			
1	878.59						1.04	0.11		0.53		0.18					0.03		
3	878.59						0.41	0.19		0.19		0.20							
4	787.59						0.49	0.17		0.32		0.22					0.11		
5	878.59						0.63	0.18		0.36		0.08					0.39		
6	878.59						0.19	0.18		0.25		0.11					0.42		

* redone 0.55

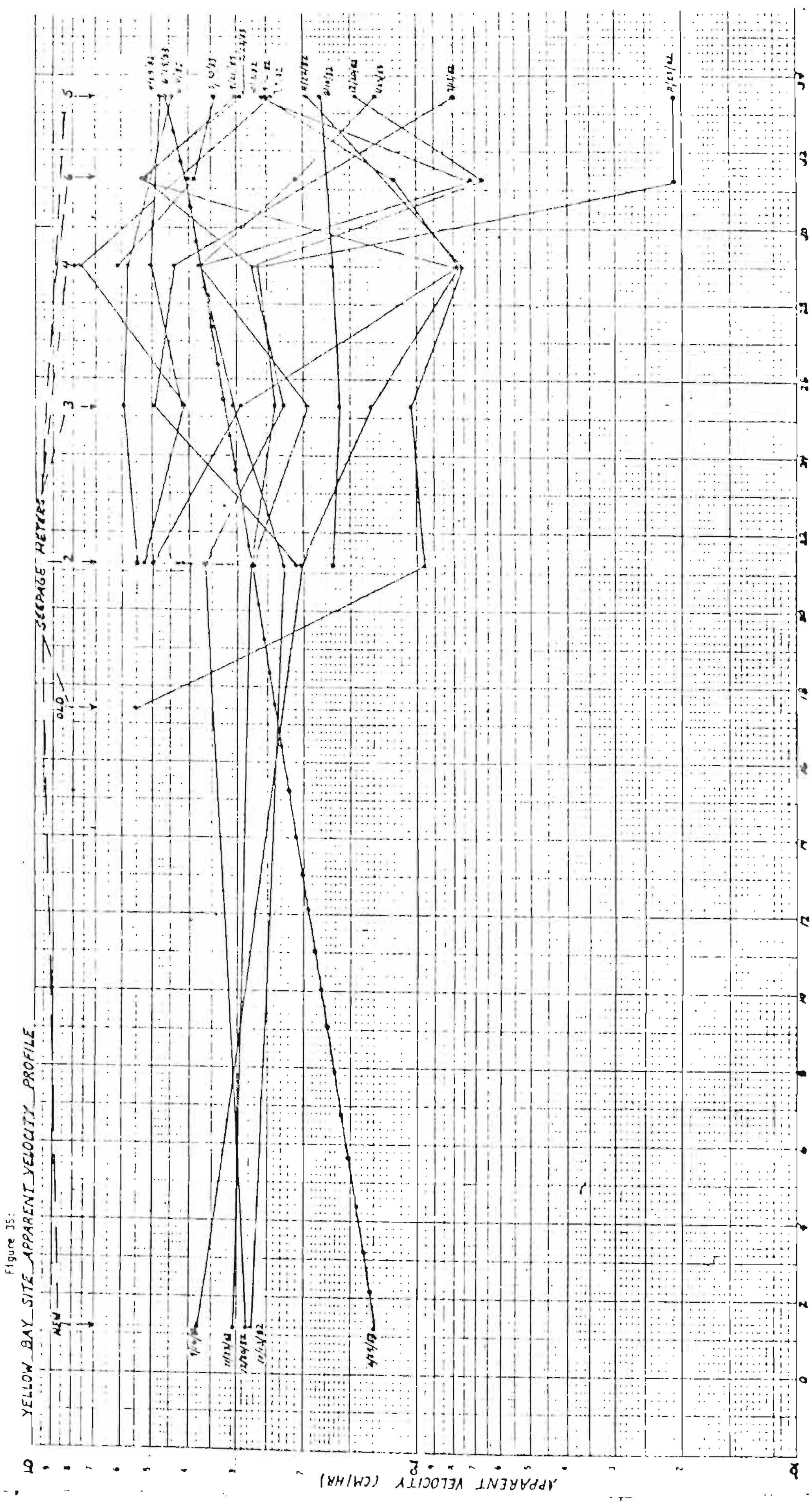


Figure 35: YELLOW BAY SITE APPARENT VELOCITY PROFILE

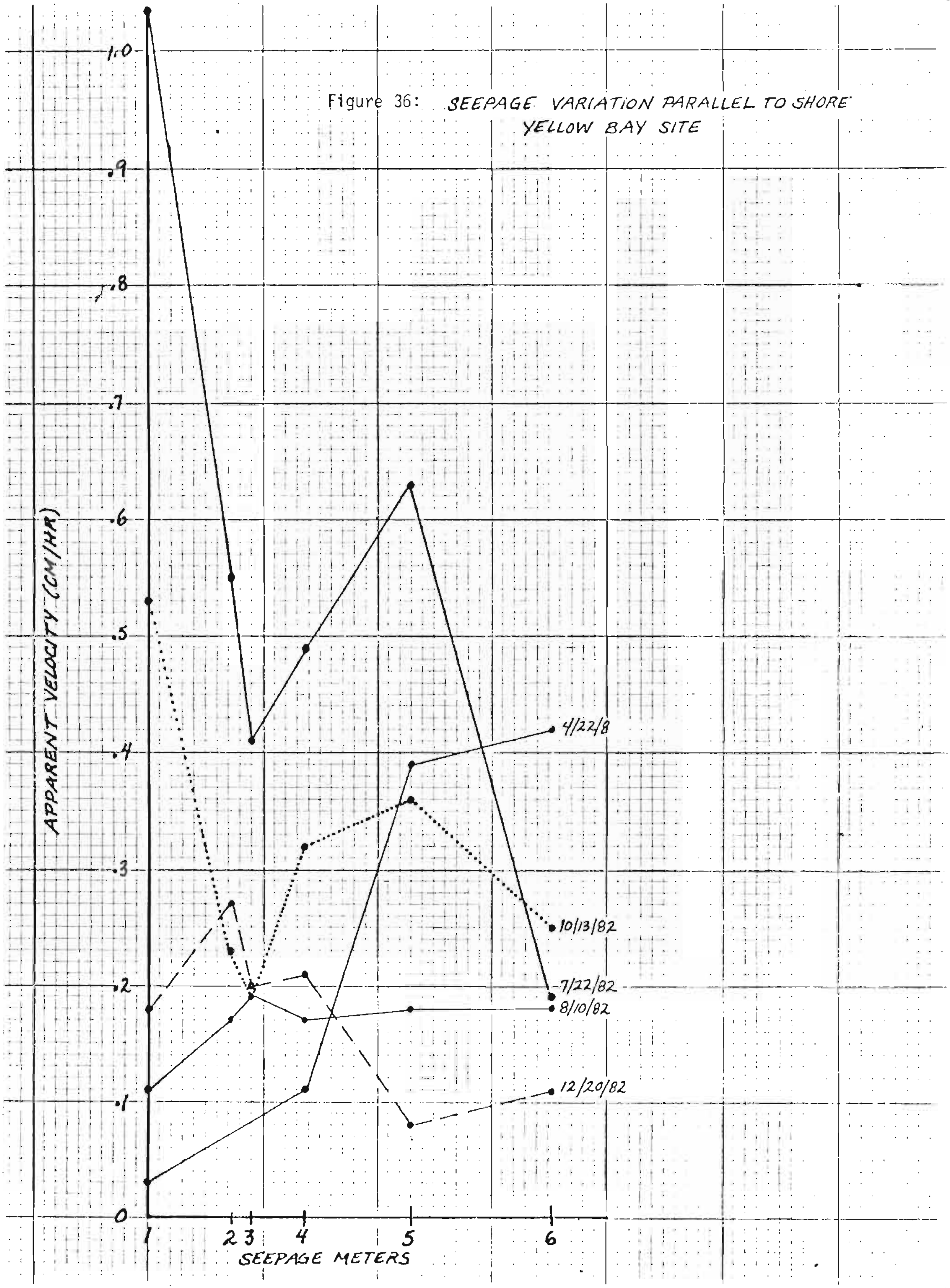


Figure 36: SEEPAGE VARIATION PARALLEL TO SHORE
YELLOW BAY SITE
APPARENT VELOCITY (CM/HR)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
SEEPAGE METERS
4/22/8
10/13/82
7/22/82
8/10/82
12/20/82

Table 15 : Groundwater Quality Data, Yellow Bay site.

Location Date	Meter #	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	SpC umhos	T °C
				Ion Concentration in mg/l											
YB	1														
11-24-82		12.7	7.7	0.028	<0.001	0.26	2.4	107	25.2	6.0	1.1	0.4	142		
1-26-83			7.7	0.086	0.001	0.20	2.9	106	25.2	6.0	1.0	0.4	142		
YB	2														
9-17-82(3")			7.9	0.022	<0.001	0.17	2.6	108	25.9	5.6	1.2	0.4	144	160	17.2
11-24-82			7.7	0.011	<0.001	0.20	2.5	112	26.8	6.0	1.1	0.4	151		
1-26-83			7.8	0.024	<0.002	0.22	2.6	105	25.1	5.8	1.2	0.6	141		
9-17-82(14")			7.8	0.012	0.002	0.19	2.5	112	27.0	5.6	1.2	0.4	149		
**															
YB	5														
9-17-82		8.8	7.9	0.025	0.002	0.18	2.4	102	24.7	5.3	1.1	0.4	136	150	16.7
11-24-82			7.9	0.053	0.001	0.23	2.3	115	28.4	5.9	1.2	0.4	157		
1-26-83			7.0	0.001	0.003	0.65	<1.0	207	51.4	8.4	2.1	1.0	270		
YB	6														
11-24-82		0.0	7.8	0.004	0.016	0.87	1.0	234	58.4	9.1	1.9	1.1	305		
3-30-83			7.5	0.010	<0.001	0.46	2.9	152	37.2	6.6	2.2	1.0	203		
Comparison Data Yellow Bay Creek															
9-17-82		12.2	7.9	0.031	0.004	0.14	2.1	104	25.8	4.1	2.0	0.6	138	160	10.6
11-24-82		13.8	7.9	0.002	0.004	0.16	1.7	102	24.8	4.2	2.0	0.6	134		3.3
3-30-83			7.9	0.037	0.005	0.16	1.5	101	24.4	4.2	2.1	0.7	135		
Jack Rabbit Pump at #5															
9-17-82		6.7	7.7	0.003	0.014	0.22	2.0	112	26.8	5.5	1.1	0.5	148	200	15.6
11-24-82		6.1	7.0	0.035	0.005	0.34	2.1	160	40.5	6.9	1.4	0.7	212		
1-26-83			7.3	0.002	0.014	0.40	<1.0	204	51.3	8.7	1.9	0.8	267		
**YB	4														
3-30-83			7.8	0.052	.0006	0.21	1.9	107	26.0	4.6	2.0	0.7	142		

TDS had increased. TDS nearly doubled to 300 m/l and comments were made about discolored water and hydrogensulfide odors. Water quality had improved slightly at meter 6 by March 1983 sampling. Dissolved oxygen data collected along three transects in 12-1-82, 4-4-83 and 6-7-83 are presented in Table 16. Lowest values were found on 12-1-82 and 6-7-83 with a range of values from 0.3 to 8.8 mg/l and 0.6 to 9.0 mg/l respectively. Dissolved oxygen values obtained on 4-4-83 generally showed a value in the 7 to 10 mg/l range near shore and as low as 0.6 mg/l at the deepest point of measurement.

Gravel Bay

Results of seepage meter operation are given in Table 17. The highest apparent velocity data were recorded in February 1983 and the lowest rates in November 1982. Ranges and means at the permanent seepage meters are as follows:

#1; 0.10 to 0.36 cm/hr with a mean of 0.22 cm/hr;

#2S; 0.11 to 0.60 cm/hr with a mean of 0.26 cm/hr;

#3; 0.15 to 0.35 cm/hr with a mean of 0.25 cm/hr;

#4; 0.0 to 0.38 cm/hr with a mean of 0.12;

#2C; 0.17 to 0.31 cm/hr with a mean of 0.24 cm/hr;

#2N; 0.03 to 0.37 cm/hr with a mean of 0.20 cm/hr.

A plot of apparent velocity variation with perpendicular distance from shore is shown in Figure 37. Apparent velocities generally are slightly lower at meter #4 farthest from shore. Figure 38 shows the variation of apparent velocities parallel to shore with distance. Flow rates were generally greatest at portable locations #1 during April and May 1983 and higher than #2S at meters #2C and #2N the majority of the time.

Groundwater quality data for Gravel Bay is presented in Table 18. The water sampled is a calcium bicarbonate type. It was lower in TDS, 119 mg/l at meter #1 than meter #4, 185 mg/l in January 1983. The pH of water from meter

Table 16 : Dissolved Oxygen Transects, Yellow Bay site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 12-1-83	Date 4-4-83	Date 6-6-83	
Line #1	879.5	0	1.8	-	8.2	15.2 meters west of east stake and 7.6 meters east of Yellow Bay Creek, all in spawning area
	879.2	4	1.6	8.7	9.0	
	879.0	8	1.0	9.4	6.7	
	878.3	12	5.7	7.1	4.7	
	876.7	16	3.6	5.2	0.6	
	875.8	19	0.3	4.0		
Line #2	879.7	0	3.4	10.9	2.5	33 meters west of east stake and 7.6 meters west of Yellow Bay Creek
	879.5	4	8.8	10.5	5.6	
	879.4	8	1.6	10.8	8.3	
	878.8	12	2.8	10.5	8.5	
	877.7	16	1.2	10.8	9.0	
	875.9	20	3.1	6.5	7.8	
	874.4	24	1.8	6.1	5.3	
	873.8	26	-	0.6	-	
Line #3	878.3	0	0.7	4.2	1.5	45.7 meters west of east stake and 22.9 meters west of Yellow Bay Creek.
	877.2	4	1.9	9.3	5.1	
	875.5	8	7.6	9.6	4.4	
	874.3	12	6.6	7.7	3.8	
	873.3	15	-	-	1.9	

Table 17: Seepage meter results, Gravel Bay site ($cm^3/(cm^2\ hr)$)

			1982		1983							
	Location	Elevation (m)	11/30	12/17	1/25	2/22	3/30	4/22	4/28	5/5	5/24	6/29
	1	878.14	0.10	-	0.22	0.36	moved	0.21			0.0	0.23
	2S	876.36	0.18	0.21	0.20	0.36	0.60	0.14	0.36	0.36	0.11	0.12
	3	874.38	0.19	0.15	0.32	0.42	0.23	0.19			0.33	0.19
	4	872.64	0.19	0.20	0.18	0.38	0.01	0.09			0.0	0.11
	2C	876.37	0.26	0.31	0.21	0.29	0.26	0.15	-	0.33	0.20	0.18
	2N	876.35	0.22	0.37	0.11	0.03	0.45	0.10	-	0.13	0.22	0.18
Portables	1	876.36							0.51	0.71		
	2	876.36							0.24	0.54		
	3	876.36							0.48	0.14		
	4	876.36							0.21	0.11		

Figure 37:
GRAVEL BAY SITE APPARENT VELOCITY PROFILE

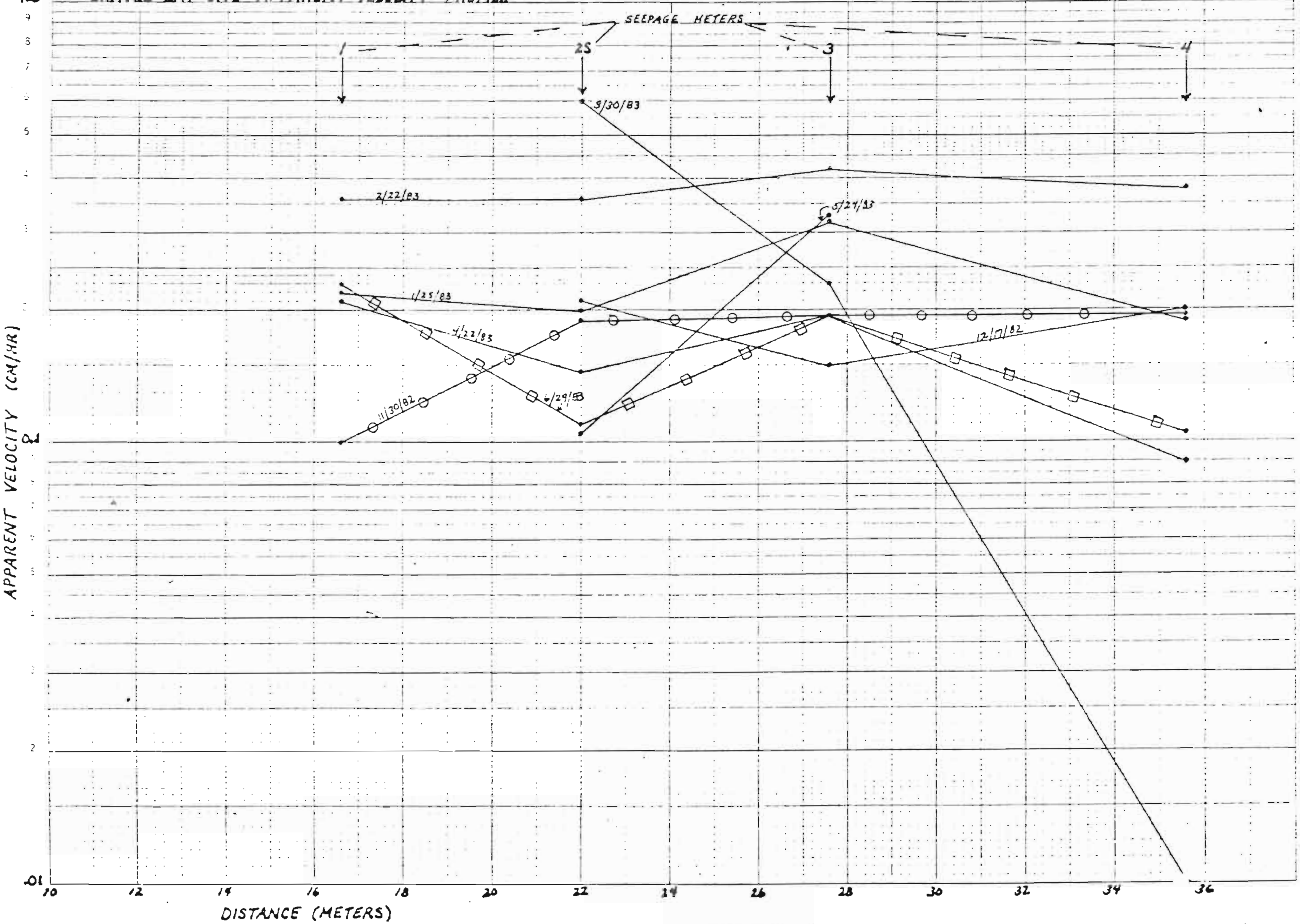


Figure 38: SEEPAGE VARIATION PARALLEL TO SHORE
GRAVEL BAY SITE

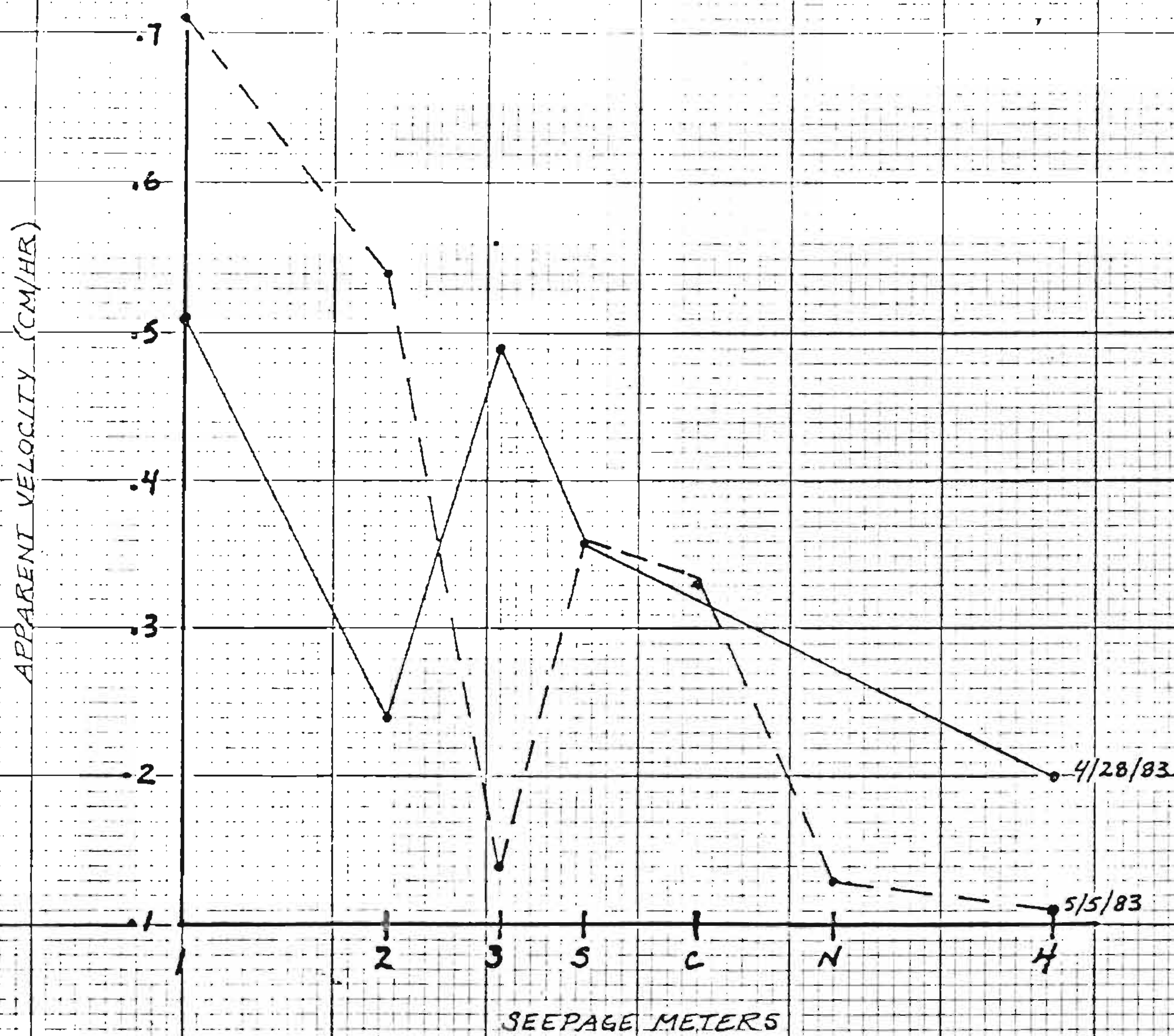


Table 18: Groundwater Quality Data, Gravel Bay site.

Location Date	Meter #	DO	pH	NO_3	PO_4	Cl	SO_4	HCO_3	Ca	Mg	Na	K	TDS	Spc umhos	°C
				Ion Concentration in mg/l											
GB	1														
1-26-83			7.5	0.011	<0.001	0.23	2.6	90	18.8	6.2	1.2	0.5	119		
3-30-83			7.8	0 033	0.001	0.26	2.9	119	28.4	6.4	1.2	0.6	158		
GB	4														
1-26-83			6.9	0.002	0.004	1.12	<1.0	141	33.9	6.8	1.3	.1.	185		

#4, 6, 9, was also low compared to meter #1. Water quality resampled at meter #1 in March 1983 was higher in TDS, 158 mg/l. The results of three dissolved oxygen transects run in November and March 1983 showed a general decrease in DO from the near shore lakeward (Table 19). One transect in June 1983 showed a similar trend. It should be noted that three of the seven transects did have lower DO values at the station closest to shore than the next two or three stations further out.

<u>Wood's Bay</u>

Seepage meter results at Woods Bay are presented in Table 20. Seepage rates generally fall between 0.07 and 0.40 cm/hr with the highest rates being at the center tansect. Figure 39 presents a plot of apparent velocity vs. distance for each transect. Seepage rates increase between the first two stations at the center and north transect and decrease along the south transect. Seepage parallel to shore appears to be greatest along the central transect.

The results of three dissolved oxygen transects are presented in Table 21. Values ranged from 1.7 to 11.7 mg/l during the April 1983 sampling. The lowest value was derived at the station closest to shore on the south transect. Values below 5 mg/l were also found from 0 to 16 m, 16 m and 8 m on the April south transect, April center transect and April north transect and the May transect, respectively.

DISCUSSION

The discussion section is organized in three sections: 1) Water table response to lake level change, 2) Apparent velocity trends, and 3) Groundwater quality trends. It should be noted from the preceeding sections that data

Table 19: Dissolved Oxygen Transects, Gravel Bay site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 11-30-83	Date 3-14-83	Date 6-7-83	
Line #1	878.6	0	9.0	11.4		25.9 meters east of west stake, out of spawning area, Dist 0 meters the rest are in the spawning area
	877.1	4	8.0	11.0		
	876.3	8	5.6	8.5		
	875.4	12	3.1	0.0		
Line #2	879.0	0	5.8	10.8		44.2 meters east of west stake, dist 0 meters out of spawning area, the rest are in the spawning area
	878.2	4	11.5	10.9		
	876.8	8	-	10.4		
	875.7	12	7.4	8.3		
	874.8	16	7.1	9.1		
	874.3	20	1.0	8.9		
Line #3	878.9	0	5.5	11.3	1.5	57.9 meters east of west stake, dist 0 and 4 meters are out of spawning area, the rest are in the spawning area
	877.9	4	9.8	11.4	10.1	
	876.3	8	8.7	9.3	9.2	
	875.1	12	9.0	10.8	4.8	
	873.9	16	7.6	-	7.0	
	873.0	20	7.0	8.7	7.2	
	872.4	24	5.0	0.2	0.0	

Figure 39: WOODS BAY SITE APPARENT VELOCITY PROFILE

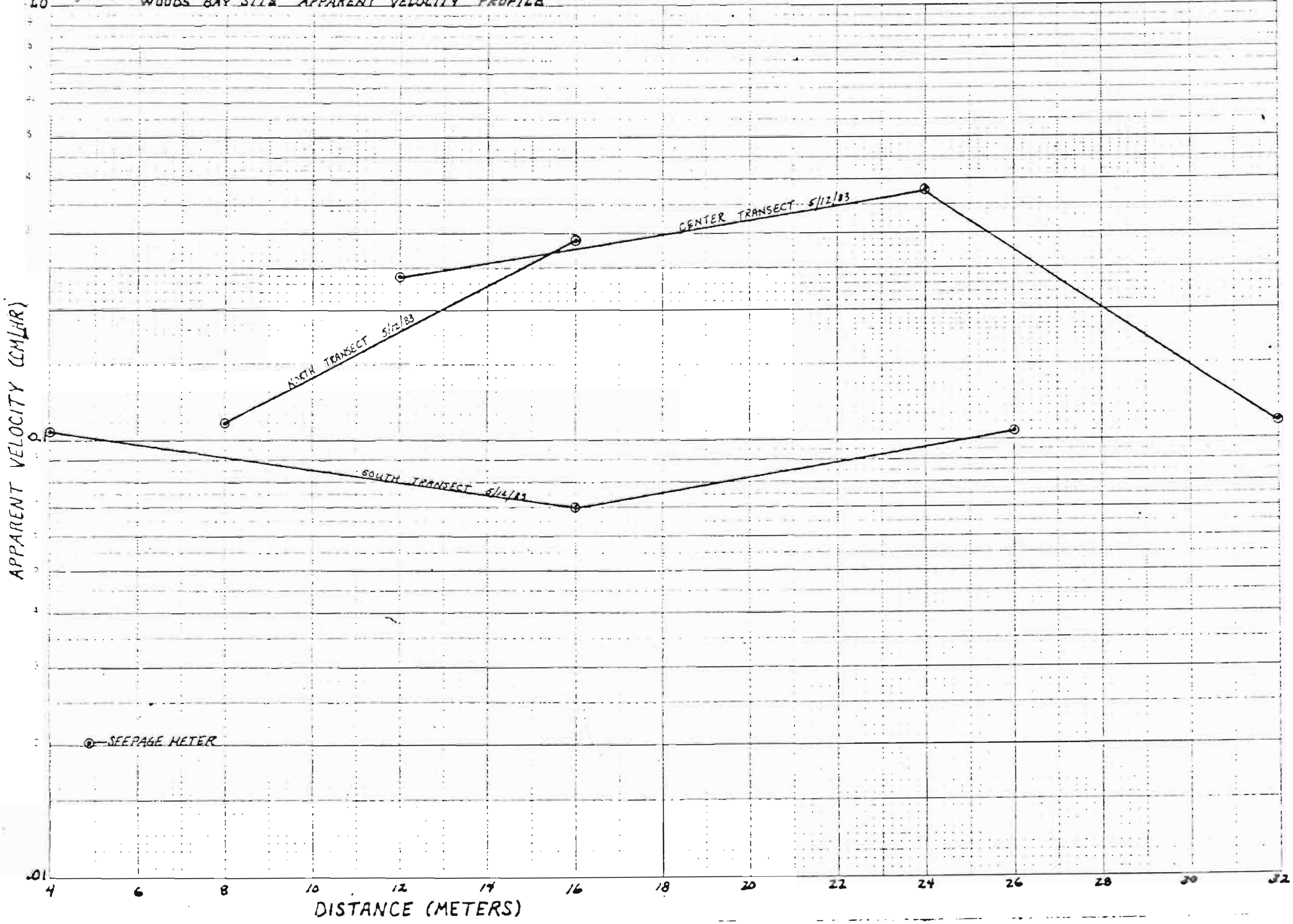


Table 2.1 : Dissolved Oxygen Transects, Woods' Bay site.

Transect Location	Elev. (m)	Dist. Shore (m)	Date 4-7-83	Date 5-18-83	Date						
Line #1	870.2	0	1.7			South transect					
	868.5	4	4.7								
	866.2	8	2.8								
	864.4	12	3.0								
	862.6	16	3.4								
	860.7	20	6.4								
	858.9	27	6.6								
Line #2	879.1	0	10.9	9.4		Center transect					
	877.6	4	6.8	5.0							
	876.8	8	6.3	4.2							
	874.9	12	5.8	9.0							
	872.0	16	7.0	10.1							
	870.7	20	6.8	9.6							
	868.7	24	5.6	6.2							
	866.7	28	6.3	6.9							
	864.7	32	7.8	7.0							
Line #3	878.8	0	11.7			North transect					
	877.0	4	8.3								
	875.0	8	9.0								
	872.9	12	7.3								
	870.8	16	3.4								
	870.2	17	7.2								

including water table fluctuations, seepage meter measurements, onshore hydrologic property testing and water quality data were not collected at all sites.

Water Table Response to Lake Level Change

The water table at the Skidoo Bay, Pine Glen, Dr. Richard's South and Yellow Bay sites all basically paralleled the lake stage decline. However the rate of water table decline was slower than the rate of lake decline. The water table at the sites again paralleled the lake stage rise in April and May. The water table at Skidoo Bay followed the rate of lake decline until late December, Yellow Bay until mid December, Pine Glen until mid February and Dr. Richard's South until late February. The sites of Pine Glen and Dr. Richard's South were the first to mirror lake stage rise in April. In contrast, the shallow water table at the Crescent Bay and Hochmark's sites showed little to no change, apparently acting independently of lake stage fluctuation.

During the lake stage change the position of the water table remained within the redd depth of 15 cm of land surface for a 6.0 to 11.6 m wide beach area adjacent to the lake at the Hochmark's site. Most other sites for which water table fluctuation data were taken had strips of beach only about 1 m wide wetted to less than 15 cm by the water table during lake stage decline. During the period from February to April a 7.8 m shore line zone at the Crescent Bay site and from March to April a 3.5 m area adjacent to the lake at the Skidoo Bay site were present in which the water table was within 15 cm of land surface. At the Dr. Richard's South site the water table was within redd depth for only a one meter wide area at all times. At the Pine Glen site a zone one meter wide wetted at redd depth existed during lake stage fall and rise until May when a large zone of 4 m was present.

The plotting of water table profiles and maps indicates that at all of the above mentioned sites, groundwater flow during stage change was always to the lake with the exception of January and April at the Dr. Richard's South site. At that site, groundwater was documented as flowing from the lake to the shore line groundwater system. The very flat gradient of the site and possible seiche effects from storms may account for at least one of the measured lake to groundwater flow events.

The shore line groundwater resonse to lake stage variation supports the original conceptual model of the lake as regional groundwater discharge area. At the sites without streams, the water table parallels lake drawdown. The rate of water table decline is slower than lake decline because the water table is receiving recharge from upland aquifer storage and from precipitation. The decline in the water table levels out as the lake level stabilizes. During this time, from early March to early April, the groundwater system approaches steady state. Surface streams which flow toward the lake locally recharge the water table system at the Crescent Bay and Hochmark's sites resulting in a high water table which responds independently of lake stage variation. In the conceptual model, periods of lake recharge to the groundwater during lake stage rise were predicted but only field confirmed at the Dr. Richard's South site. This warrants further investigation with more frequent, possibly continuous, groundwater level and lake stage data collection at selected sites. Shallow sandpoint wells constructed at sites at which water table monitoring did not occur last year would also greatly aid in further identifying the effects of lake stage variation on the shore line groundwater system.

Apparent Velocity Trends

Measurements of apparent velocity were taken on shore, in the lake, perpendicular to shore and parallel to shore. Average apparent velocity measurements on shore in study sites are presented in Table 22. Based on current data the highest rate was found at the Crescent Bay site. The hydraulic conductivity, depending on the field measurement method used, varied greatly at the Hochmark's site and the apparent velocity could be 20 times greater than calculated. Average seepage meter values derived from the meter closest to shore ranged from 0.22 to 0.47 cm/hr. On shore, values are one to three orders of magnitude greater than seepage meter values.

Seepage meter data collected along transects perpendicular to shore also provide data on the variation of rates with distance from shore and depth of water. At the Crescent Bay site the seepage rate generally decreased with distance from shore and rates were lower at all meters in November and January. At the Gravel Bay and Yellow Bay sites rates increased or decreased slightly between meters with the lowest rates recorded generally at the deeper meters. Seepage rates at the Yellow Bay site were greatest in June, July, February and March and the lowest overall in April. The Skidoo Bay site showed an increase in seepage between the first two meters then a slight decrease in seepage at the deepest meter. The groundwater seepage appeared to generally decrease from April to November at the Skidoo Bay site.

There is not enough seepage data to make broad comparisons between the deeper sites (Yellow Bay, Woods Bay, Crescent Bay) and the shallow water sites but a few observations can be made. The data for January 25, 1983, and March 30, 1983, can be compared between the deep system at Yellow Bay and the shallow system at Gravel Bay. During the January measurement the lake was almost full while during the March measurement it was near its lowest level for the year. Seepage increased significantly at all the deep meters at Yellow Bay on March 30 as compared with January 25 (the shallow meters were inoperable). Seepage also increased on March 30 at the shallow meters at Gravel Bay but decreased at the deeper meters. Without more data, it is difficult to draw

Table 22: Summary of Apparent Velocity Values (cm/hr).

Site	Location	Seepage Meter Range	Seepage Meter Average	On Shore Data Average
Skidoo Bay	#1	0.08-0.93	0.47	8.7
Crescent Bay	#2	0.07-0.38	0.22	118
Hochmark's				6.2
Pine Glen				33.7
Dr. Richard's South				3.4
Yellow Bay	#2	0.10-0.55	0.32	
Gravel Bay	#1	0.10-0.36	0.33	
Wood's Bay	#1C	0.07-0.40		

specific conclusions from this one example. Computer modeling of the groundwater system may shed some light on this question.

Seepage data collected along transects parallel to shore show the seepage is greatest in the central portion of the identified spawning area at the Skidoo Bay and Wood's Bay sites. It varies in the other sites being greater to the north or south of the center of the spawning area at the Yellow Bay site and greater at the southern portion of the Crescent Bay and Gravel Bay sites. Additional seepage meter transects in and outside of known spawning areas are needed to establish apparent velocity criteria for spawning sites.

Groundwater Quality Trends

Groundwater quality data are available for seven of the sites. Both lake and groundwater are calcium bicarbonate dominated water. This is typical of groundwater in the region (Boettcher, 1982). The TDS of the water sampled from project wells and seepage meters is closest to Flathead Lake water quality, TDS of 140 mg/l, at Yellow Bay (Table 23). Groundwater at the Crescent Bay and Hochmark's sites is lower in TDS than the associated streams, TDS 300 mg/l, which appear to be recharging the groundwater system. The DO data generally shows project wells with lower DO values than seepage meter samples collected fairly close to shore. DO values are lowest at sampling points furthest from shore. It should be noted, however, that values of between 1 and 3 mg/l have been recorded at Gravel Bay and Wood's Bay at the lake site closest to shore with values increasing at the next deeper sample sites.

Dissolved oxygen values from the gravel transects vary between the deep and shallow spawning sites. Averages of DO values at each site are consistently lower at the deep sites. Dissovled oxygen tends to increase in March as compared with January at most all of the sites, but it increases more dramatically at the deeper sites. This may be a result of increased groundwater seepage due to lake drawdown or increased recharge.

RECOMMENDATIONS

The 1983-1984 field season should include continued monitoring of physical groundwater parameters, much more extensive chemical monitoring, (especially for dissolved oxygen) and an attempt at numerically modeling the lake shore groundwater system.

Sandpoints should be installed at all sites which are currently instrumented with seepage meters and water levels should be monitored weekly during lake drawdown and bimonthly at other times. A water quality sample should be taken from each sandpoint as it is installed. A sample should be taken from one well per area every other month, always using the same well. Velocity testing should be done bimonthly in the sandpoints using the point dilution technique.

The seepage meters should continue to be operated as they are now but groundwater quality data should be collected from the meters every other month. In addition, the portable meters set parallel to shore should be extended as much as possible to non-spawning areas and should be run at least every other month.

The streams at Crescent Bay, Yellow Bay and Dr. Richard's Bay (Hochmark's) need to be monitored for discharge at the same time that water levels are recorded in the sandpoints. Ideally, discharge measurements should be made at the head of the beach and at the lake's edge. Stream recharge of the groundwater in the gravels needs to be identified for calibration of a computer model.

A numerical model will also require data from domestic wells upland from the spawning sites. These wells should be monitored several times during lake drawdown and refilling. In addition, geophysical surveys should be done at the site(s) to be modeled to determine the depth of the gravels to bedrock. This should be done when the lake is at its lowest point.

Modeling efforts should concentrate on reproducing the shallow groundwater--lake system. The USGS two dimensional finite defference model should be applied.

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APPENDIX A

METHODS FOR DETERMINING HYDRAULIC CONDUCTIVITY

I. Bail Test

A slug test described by Bouwer and Rice (1976) was done using both the standpipe apparatus and the sandpoint wells. In this method the hydraulic conductivity is determined from the rate of rise of the water level in the well after a measured volume of water is suddenly removed. The equation is based on the Thiem equation of steady state flow to a well and has been developed for partially penetrating wells in unconfined aquifers.

The test was conducted in the standpipe apparatus in which the perforations were at depths of 20-30 cm and in the sandpoint wells in which the screened interval was 1.2-1.5 m deep. In both tests, water was bailed as quickly as possible using a hand-held Jackrabbit pump. The rate of rise was measured with a steel tape and stopwatch.

Hydraulic conducitivity (K) is given by

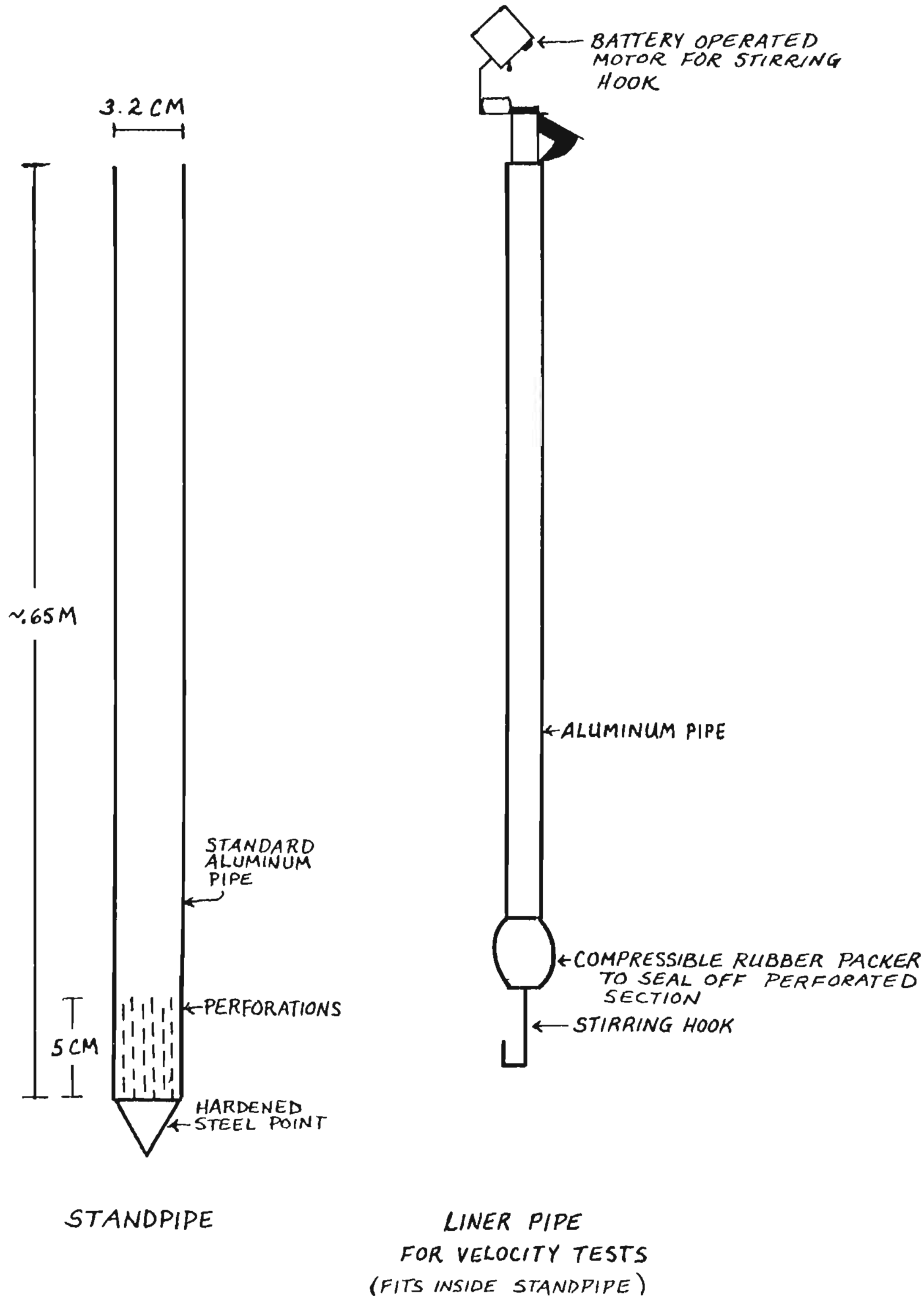
$$K = [r_c^2 \ln(Re/r_w)/(2Lt)] \ln (yo/yt)$$

in which t is the time elapsed, y is the vertical distance between water level in the well and the equilibrium height of the water table, L is the height of the perforated or screened section of the well, r_c is the inside radius of the well, r_w is the radius measured from the center of the well to the original aquifer--including a developed zone or gravel pack, and Re is the effective radius over which y is dissipated. Re can be determined from an empirical equation derived from a resistance network analog.

$$\ln (Re/r_w) = [1.1/\ln(H/r_w) + (A + B \ln[(D - H)/r_w])/(L/r_w]]^{-1}$$

H is the distance from the water table to the total depth of the well and A and B are dimensionless coefficients that are functions of L/r_w. A and B have

Figure A1: TERHUNE STANDPIPE APPARATUS



been determined by Bouwer and Rice for a range of geometries. The calculations for ln (Re/r_w) and K for each test are shown below:

Skidoo Standpipe

$$H = 30.78 \text{ cm} \qquad \ln(Re/r_w) = [1.1/2.68 + 1.5 + 0.2(6)/2.11]^{-1} = 0.59$$

$$K = (2.52 \text{ cm}^2)(0.59)/2(4.445 \text{ cm})\ (1/30 \text{ sec})\ \ln(0.34/0.03) = 0.0135 \text{ cm/sec} =$$

$$48.6 \text{ cm/hr}$$

SKB-1

$$H = 62.48 \text{ cm} \qquad \ln(Re/r_w) = [1.1/3.49 + 2.15 + 0.30(6)/20]^{-1} = 1.95$$

$$K = (2.73 \text{ cm}^2)(1.95)/76.2 \text{ cm}\ (1/20 \text{ min})\ \ln(0.67/0.07) = 0.0079 \text{ cm/min} =$$

$$0.47 \text{ cm/hr}$$

SKB-3

$$H = 48.77 \text{ cm}$$

$$\ln(Re/R_w) = [1.1/3.24 + 2.15 + 0.30(6)/20]^{1-} = 1.86$$

$$K = (2.73 \text{ cm}^2)(1.86)/76.2 \text{ cm}\ (1/4 \text{ min})\ \ln(0.025/0.01) = 0.015 \text{ cm/min} =$$

$$0.90 \text{ cm/hr}$$

Hochmark Standpipe

$$H = 30.18 \text{ cm} \qquad \ln(Re/r_w) = [1.1/2.66 + 1.5 + 0.2(6)/2.11]^{-1} = 0.59$$

$$K = (2.52 \text{ cm}^2)(0.59)/8.89\ (1/120 \text{ sec})\ \ln(0.41/0.03) = 0.00364 \text{ cm/sec} =$$

$$13.12 \text{ cm/hr}$$

BH-1

$$H = 82.30 \text{ cm} \qquad \ln(Re/r_w) = [\ 1.1/3.76 + 0.198]^{-1} = 2.04$$

$$K = 2.73 \text{ cm}^2(2.04)/76.2 \text{ cm}\ (1/38 \text{ min})\ \ln(1.63/0.21) = 0.0039 \text{ cm/min} =$$

$$0.24 \text{ cm/hr}$$

BH-2

$$H = 86.56 \text{ cm} \qquad \ln(Re/r_w) = [1.1/3.81 + 0.198]^{-1} = 2.06$$

$$K = (2.73/76.2)\ (2.06)\ /6 \text{ min}\ \ln(1.73/0.04) = 0.046 \text{ cm/min} = 2.78 \text{ cm/hr}$$

II. Tracer Test

Hydraulic conductivity was determined in the field by measuring the time interval for a fluorescent dye to travel between test holes or from a single test hole to the lake. Average interstitial velocity of the tracer through the aquifer Va is defined by Va = Kh/(nL) where K is hydraulic conductivity, h is the difference in head between the tracer injection hole and the hole or lake, n is the porosity, and L is the length of the flow path. Va is also defined by Va = L/t where t is the travel time interval between holes. These two equations yield the relationship $K = nL^2/(ht)$ (Todd, 1980).

Velocity data was acquired by digging 0.3 m diameter pits in the lakeshore 1-3 m from the water's edge. Small quantities of either rhodamine WT dye or sodium fluorescein dye were added to the pits. The first appearance of dye in either the lake or an intermediate pit was taken as the value for t. L was measured from the edge of the injection pit to the site where the dye first emerged. The value h was calculated from the average hydraulic gradient of the lakeshore determined from water levels in sandpoint wells. Porosity of the unsorted sand, gravel and cobbles is estimated at 0.25.

It should be noted that since t was taken as the first appearance of dye, this results in a maximum value for velocity and hydraulic conductivity which is be greater than the average value for the aquifer.

Calculations: $K = nL^2/(ht)$

Skidoo: $K = (0.25)(2381\ cm^2)/(2.15\ cm)(1\ hr) = 277\ cm/hr$

Pineglen: $K = (0.25)(12.040\ cm^2)/(1.21\ cm)(0.15\ hr) = 16,584\ cm/hr$

Hochmark's North: $K = (0.25)(50,873\ cm^2)/(22.3\ cm)(0.4\ hr) = 1426\ cm/hr$

Hochmark's South: $K = (0.25)(142,848\ cm^2)/(37.4\ cm)(0.18\ hr) =$

$5.305\ cm/hr$

Dr. Richards: $K = (0.25)(1570\ cm^2)/(0.16)(0.25\ hr) = 9,813\ cm/hr$

Crescent: $K = (.025)(27,091\ cm^2)/(16.1\ cm)(0.47\ hr) = 895\ cm/hr$

III. Standpipe Test

A pump test utilizing the Mark VI Groundwater Standpipe developed by Terhune (1958) was used at each site to obtain a value for hydraulic conductivity. The standpipe apparatus, shown in Figure A-1, consists of a length of 3.2 cm diameter pipe with a driving point and 5.1 cm of perforations at the lower end. The pipe is driven approximately halfway into the gravel and is then cleaned out by pumping and surging and allowed to equilibrate. The suction apparatus consists of a converted tire pump with a reversed piston and a calibrated collection cylinder. It has a length of narrow pipe with centering lugs attached to it which can be lowered into the standpipe. The narrow pipe is lowered a known distance (usually between 0.6 cm and 2.5 cm below the measured water elevation in the standpipe and is held in that position by an adjustable bracket. The first step in the testing procedure is to calculate the volume of water which must be removed from the standpipe to lower the head the calibrated distance to the tip of the suction tubing. Pumping is started and the time it takes to remove this volume of water is noted. Pumping continues and maintains the 0.6 to 2.5 cm drop in head in the standpipe. Pumping stops before the collection chamber is filled and the time and volume of water are noted. Time and volume are then corrected by subtracting the amounts necessary to initially drop the head.

These data are used in an adaptation of Darcy's law: $K = Q/AH$ in which K is the hydraulic conductivity, Q is the corrected volume of water pumped in the time interval, H is the suction head applied and A is a constant which is a function of the area and geometric shape of flow into the standpipe (Donnan, Asce and Aronovici, 1961).

The A-function was calculated for the standpipe according to the method described by Kadir (1955). The value for A in dimensions of length is taken from graphs presented by Kadir and is dependent on the ratios L/d, S/L, and

D/d where d is the diameter of the standpipe, D is the distance from the water table to the submerged end of the standpipe, L is the length of the perforated section and S is the distance from the end of the standpipe to the impermeable lower boundary. Since the standpipe was emplaced less than a foot in the gravels and since the depth to the impermeable boundary is unknown, but assumed to be very large in comparison with L, the value for S was assumed to be infinity.

Calculations are shown below:

A-function: D/d = 8.12

L/d = 1.23

S/L = infinity

From Figures 11 and 12 in Kadir (1955) A = 7.15"

Permeability: K = Q/(AH) (English units with metric conversion)

Skidoo Bay: K = 9.76 in^3/min/(7.15")(1") = 1.36 in/min = 207 cm/hr

Pineglen: K = 52.89 in^3/min/(7.15′)(1/2") = 14.79 in/min = 2255 cm/hr

Hochmark′s: K = 3.05 in^3/min/(7.15")(1") = 0.43 in/min = 65.5 cm/hr

Dr. Richard′s South: K = 20.57 in^3/min/(7.15")(1/2") = 5.75 in/min = 876 cm/hr

Crescent Bay: K = 17.90 in^3/min/(7.15")(1/4") = 10.01 in/min = 1524 cm/hr

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APPENDIX B

METHODS FOR DETERMINING APPARENT AND TRUE VELOCITY

I. Dye Pit Tests

Holes, 0.3 m in diameter, were dug in the gravels to approximately 15 cm below the water table. The holes were placed from one to three meters from the shoreline, depending on the estimated gradient. The water level in the pit was allowed to equilibrate and a fluorescent dye was stirred into the water as the timer was started. Both rhodamine WT and sodium fluorescein were used successfully. Rhodamine WT was chosen for being more stable and less likely to be lost to adsorption, as well as being nontoxic to salmon eggs and fry (Smart and Laidlaw, 1977). Sodium fluorescein, although it is photochemically sensitive and more likely to be adsorbed, is also nontoxic and gave comparable results to rhodamine WT. The short length of the flow path probably allows sodium fluorescein to be used with accuracy in this case.

When the dye came out in the lake, the timer was stopped and the length of the flow path was measured. Velocity was calculated as: v = length/time. This is a maximum value for velocity and does not represent the average value for the aquifer.

II. Dye Pit Dilution Test

The point dilution method described by Drost, et al. (1968) was used with pits dug along the shoreline. The pits are approximately a foot in diameter and four to six inches below the water table. The tracer dye, rhodamine WT, was introduced to the pit, mixed with the water and a sample of this initial concentration immediately taken. Thereafter, the pit was stirred and sampled at regularly timed intervals until most of the dye had flowed from the pit.

In the laboratory, the samples were filtered to remove any suspended sediment and then analyzed on the spectrophotometer to determine the concentration of dye. The data was plotted as ln(C/Co) versus t and a best-fit straight line drawn. An arbitrary point on this line was chosen to use for values of t and ln(C/Co) in the equation:

$$v^* = (-W/(At)) \ln(C/Co)$$

where v* is apparent velocity, W is the volume of the dilution chamber and A is the vertical cross-sectional area of the dilution chamber (Drost et al., 1968). The calculations are shown below:

$$(W/(At) \text{ reduces to } r^2h/2rht = r/2t)$$

Calculations are done with English units and converted to metric.

3/25/83 Skidoo: v*= - (9")(-1.8)/2(240 min) = .10"/min = 18.29 cm/hr

4/6/83 Pineglen: v* = - (6")(-.45)/2(180 min) = .02"/min = 3.05 cm/hr

3/28/83 Hochmark: v* = - (6")(-4.6)/2(8 min) = 5.42"/min = 826 cm/hr

3/5/83 Crescent: v* = - (7")(-3.5)/2(95 min) = .41"/min = 62.5 cm/hr

In order to obtain a value of true velocity, apparent velocity must be divided by the porosity and the factor alpha which accounts for the flow field distortion by the pit (Drost et al., 1968). Calculation of alpha for an open borehole yields a value of 2 (see calculations at the end of this appendix) and porosity is estimated at 0.25. Therefore, each value of apparent velocity shown above is divided by 0.5 to obtain a value of true velocity.

III. Point Dilution in Standpipe

The standpipe apparatus developed by Terhune (1958) was used to carry out the point dilution technique for determining groundwater velocity described by Drost et al. (1968). The standpipe, described in Appendix A and shown in Figure B-1, is filled with a liner pipe with an inflatable rubber stopper and a stirring hook on the lower end. The rubber stopper seals off a dilution chamber of known volume in the perforated section of the standpipe. The stirring hook attached to a motor at the top of the standpipe extends into the dilution chamber. The stirring rate is about 15 revolutions per minute. The dye is injected into the dilution chamber through a sphincter value using a hypodermic syringe attached to narrow metal tubing. A second syringe is used to take the dilution samples from the chamber. The sampling and analyzing procedure is the same as described previously for using the point dilution method in open boreholes.

The results of the calculations are shown below. The calculation of alpha, which is used to convert apparent velocity to true velocity is shown at the end of this appendix.

Standpipe Point Dilution Equation

Apparent Velocity: $v^* = (-W/(At)) \ln(C/Co)$

$$W/At = (r^2h)/(2rht) = r/2t$$

$$v^* = (2.494/t) \ln(C/Co)$$

W = volume

A = vertical x-sectional area

r = radius of standpipe, .625" = 1.5875 cm

h = height of dilution chamber

Hochmarks

$v^* = -2.494/15 \ln(.705/5.82) = .35\ cm^3/cm^2\ min = 21.06\ cm^3/cm^2\ hr$

Pineglen

$v^* = -2.494/60 \ln(4.8/8.0) = .02\ cm^3/cm^2\ min = 1.27\ cm^3/cm^2\ hr$

Skidoo

$v^* = -2.494/40 \ln(15.85/166.0) = .15\ cm^3/cm^2\ min = 8.79\ cm^3/cm^2\ hr$

Doc Richards

Trial 1:

$v^* = -2.494/2 \ln(4.22/52.9) = 3.15\ cm^3/cm^2 = 189.19\ cm^3/cm^2\ hr$

Trial 2:

$v^* = -2.494/4 \ln(.939/4.78) = 1.01\ cm^3/cm^2 = 60.88\ cm^3/cm^2\ hr$

Calculation of Alpha

Alpha is equal to the asymptotic width of the tracer cloud divided by the inside diameter of the well screen and accounts for flow field distortion by the well or borehole.

$Alpha = Alpha_o[1 - f(Re)]$, 0 less than or equal to f(Re) less than 1,

Assuming laminar flow, f(Re) = 0

$Alpha_o = 4/[1 + (r_1/r_2)^2] + [K_2/K_1(1 - (r_1/r_2)^2)]$, r_1 = inside radius of screen, r_2 = outside radius of screen, K_1 = K screen, K_2 = K aquifer

Open Borehole

$r_1 = r_2$ therefore $r_1/r_2 = 1$

$K_1 = K_2$ therefore $K_2/K_1 = 1$

$Alpha_o = 4/1 + 1 + 0 = 2$

$Alpha = 2(1 - f(Re)) = 2$

Standpipe

$r_1 = 0.625'' = 1.5875$ cm

$r_2 = 0.83'' = 2.1082$ cm

The perforated section is 4.445 cm long and contains 48 holes, 0.3175 cm in diameter (0.15875 cm radius)

calculate K_1--permeability of the perforated section of standpipe

$K_1 = (f \cdot pg/n) \cdot (r_H^2/ST)$

p = density of water = 1 gcm^3

g = acceleration due to gravity = 981 cm/sec^2

n = viscosity of water = 0.1124 $g/cm \cdot sec$

f - well screen perforation (area of slots/total screen area)

$$3.8\ cm^2/58.88\ cm^2 = 0.065$$

r_H - hydraulic radius of well screen slot (2 x slot area/slot circumference)

$$0.16\ cm^2/0.997\ cm = 0.16\ cm$$

S - pipe resistance coefficient of the slot

$$= 8 \text{ for circular tubes}$$

T - well screen resistance coefficient

$$\text{Log } T\ [2r'/(r_1 + r_2)]^2 = C \text{ Log } (r_H/r_2)$$

where C is a constant and r′ is an arbitrary reference radius = 25 mm.

from Drost et al. (1968) Figure 8, p. 133:

$$35 = T[2r'/r_1 + r_2],\ T = 35/1.35 = 25.93$$

$$K_1 = (0.065)(1\ g/cm^3)(981\ cm/sec^2)(0.16\ cm)^{2}/(0.1124\ g/cm\ sec)(8)(25.93) =$$

$$0.07\ cm/sec$$

assuming laminar flow:

$$\text{Alpha} = \text{Alpha}_o = 4/[1.57 + (K_2/0.07)(0.43)]$$

Site	K_2(cm/sec) (from standpipe K-test)	Alpha
Skidoo	0.0575	2.08
Pine Glen	0.63	0.74
Hochmark	0.018	2.38
Dr. Richard′s	0.243	1.31
Crescent	0.423	0.96

REFERENCES CITED

Drost, W., D. Klotz, A. Koch, H. Moser, F. Neumaier, W. Rauert, 1968. Point dilution methods of investigating groundwater flow by means of radioisotopes. Water Resources Research v. 4, no. 1, pp. 125-146.

Smart, P.L. and I.M.S. Laidlaw, 1977. An evaluation of some fluorescent dyes for water tracing. Water Resources Research v. 13, no. 1, pp. 15-33.

Terhune, L.D.B., 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Bd. Canada, 15(5), pp. 1027-1063.

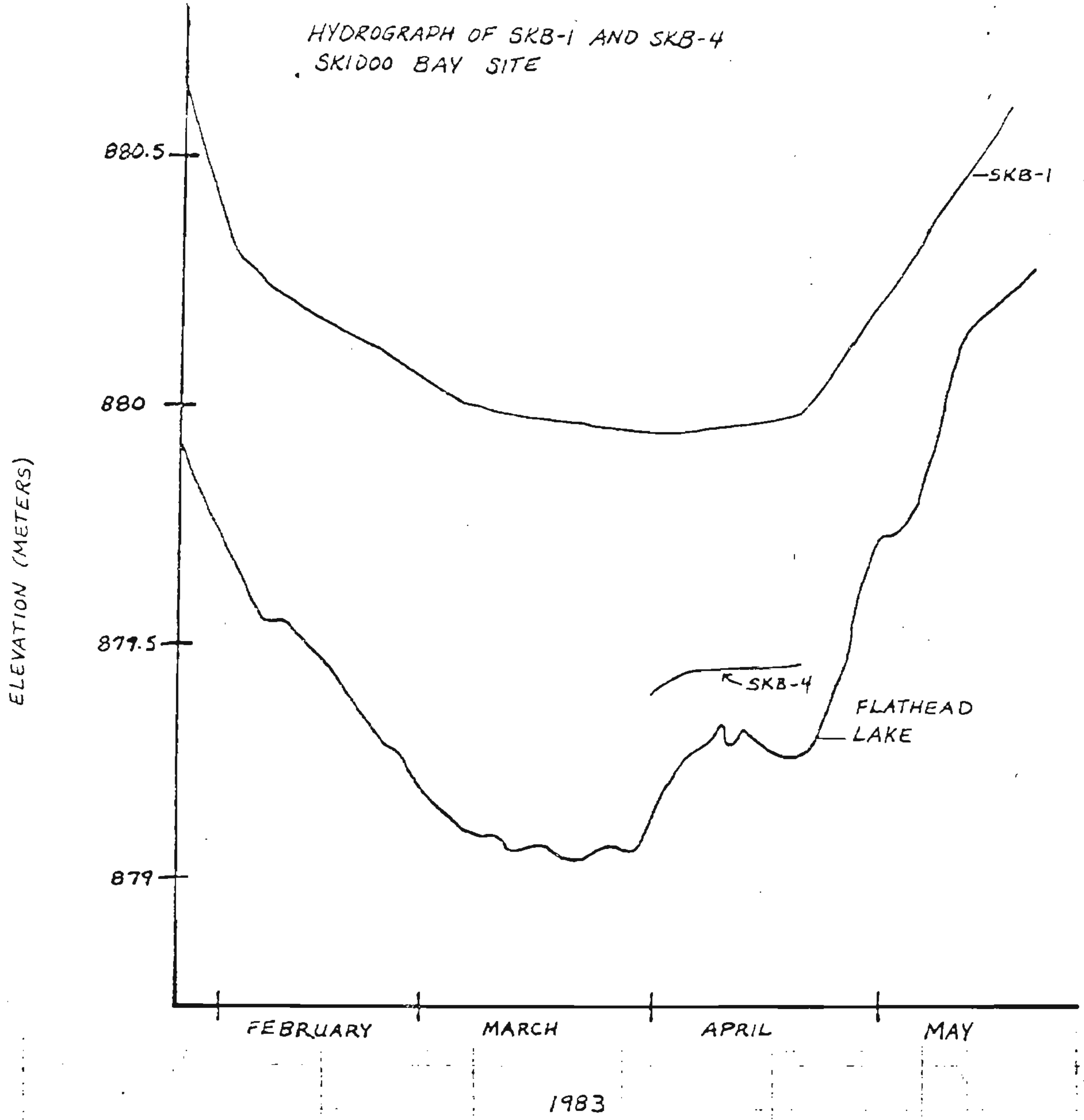
APPENDIX C :
Sandpoint Well Design Data

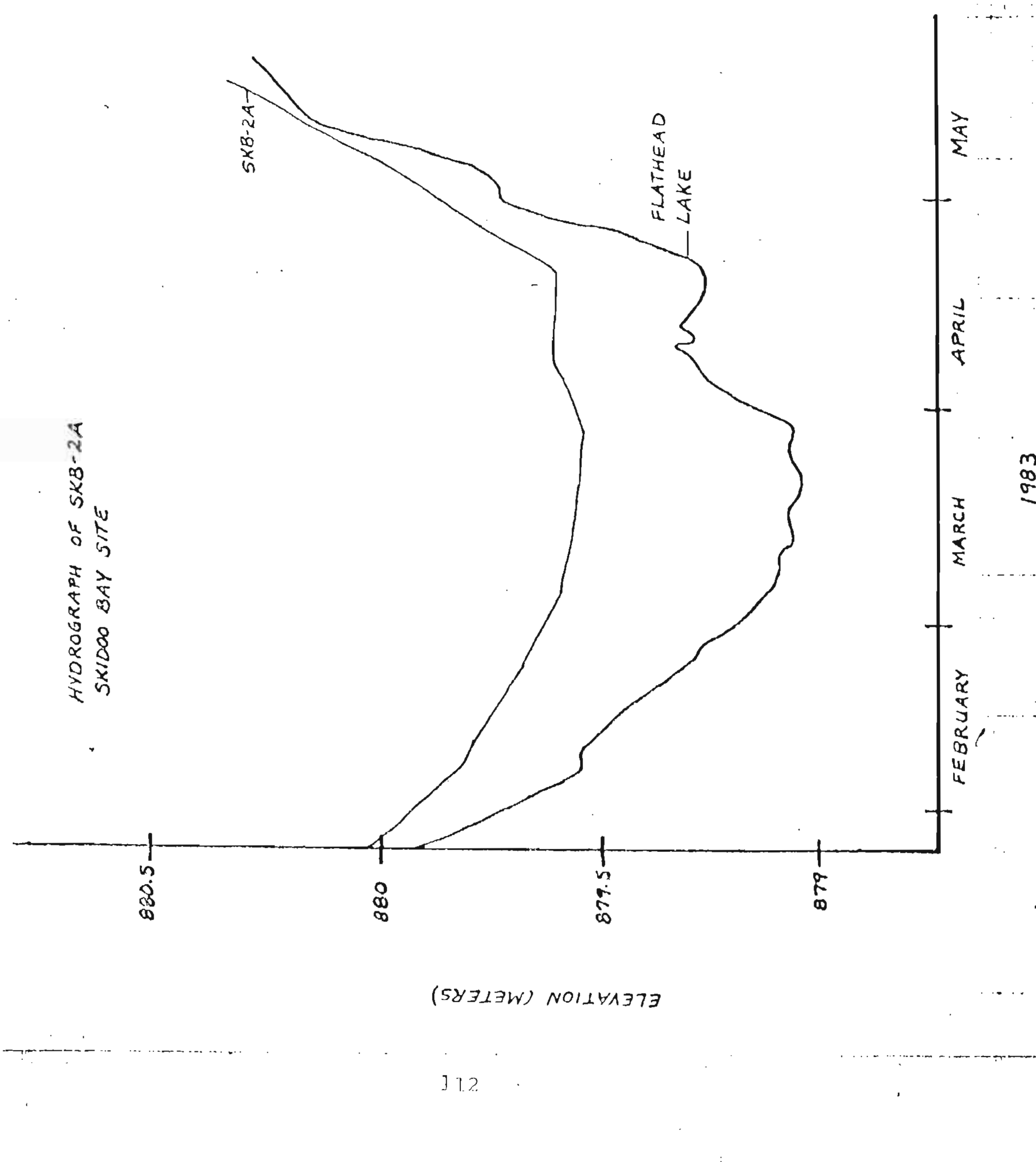
Table C1: Sand point well design data.

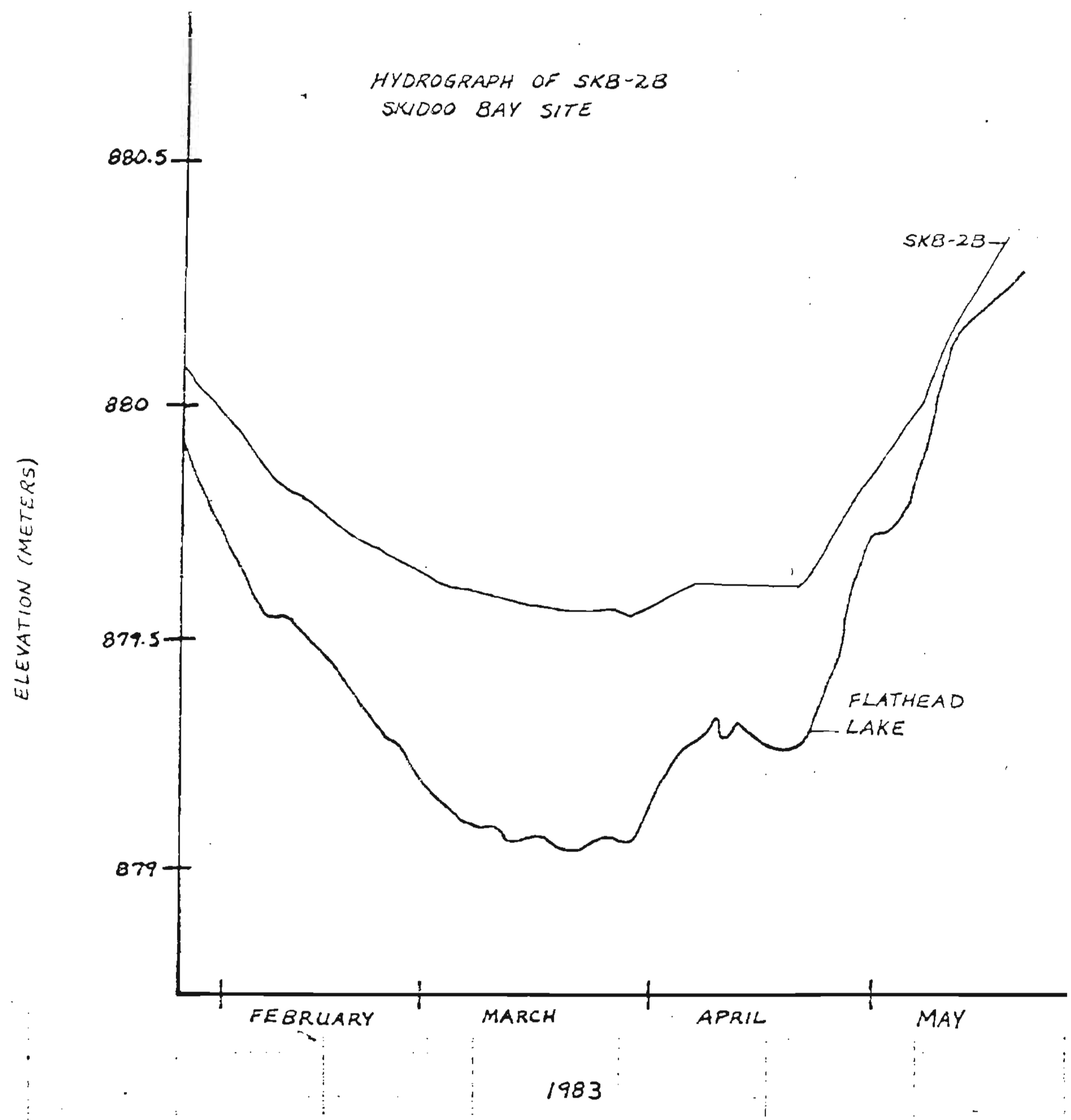
Well #	Date Completed	Below Land Surface (m) Total Depth	Depth of Perforated Interval
SKB-1	1/26/83	1.34	0.96-1.34
SKB-2A	1/26/83	1.78	1.40-1.78
SKB-2B	1/26/83	0.87	0.48-0.87
SKB-3	1/26/83	1.08	0.70-1.08
SKB-4	3/31/83	0.60	0.22-0.60
PG-1	1/26/83	1.04	0.66-1.04
PG-2A	1/26/83	1.92	1.45-1.92
PG-2B	1/26/83	1.10	0.72-1.10
PG-3	3/31/83	0.67	0.29-0.67
BH-1	1/26/83	1.22	0.84-1.22
BH-2	1/26/83	0.91	0.53-0.91
BH-3	3/31/83	0.55	0.17-0.55
DRS-1	1/26/83	1.31	0.93-1.31
DRS-2	1/26/83	1.16	0.78-1.16
DRS-3	3/31/83	0.82	0.44-0.82
AR-1A	2/2/83	1.80	1.42-1.80
AR-1B	2/2/83	0.78	0.40-0.78
AR-2	2/2/83	1.02	0.64-1.02
AR-3	2/2/83	1.24	0.86-1.24
AR-4	2/2/83	1.31	0.93-1.31
AR-5	3/2/83	0.61	0.23-0.61
AR-6	3/2/83	0.72	0.34-0.72

APPENDIX D:

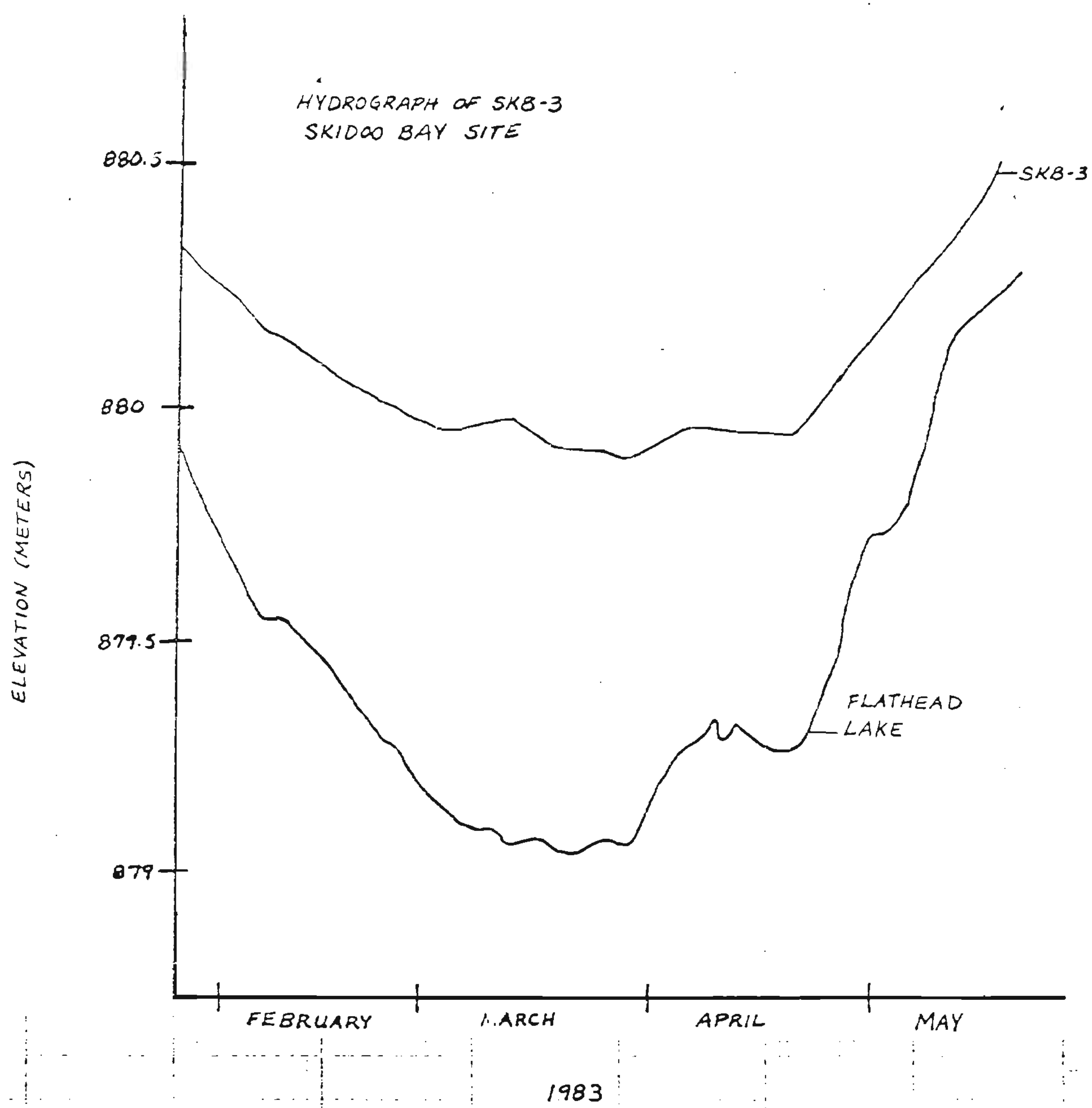
Sandpoint Hydrographs

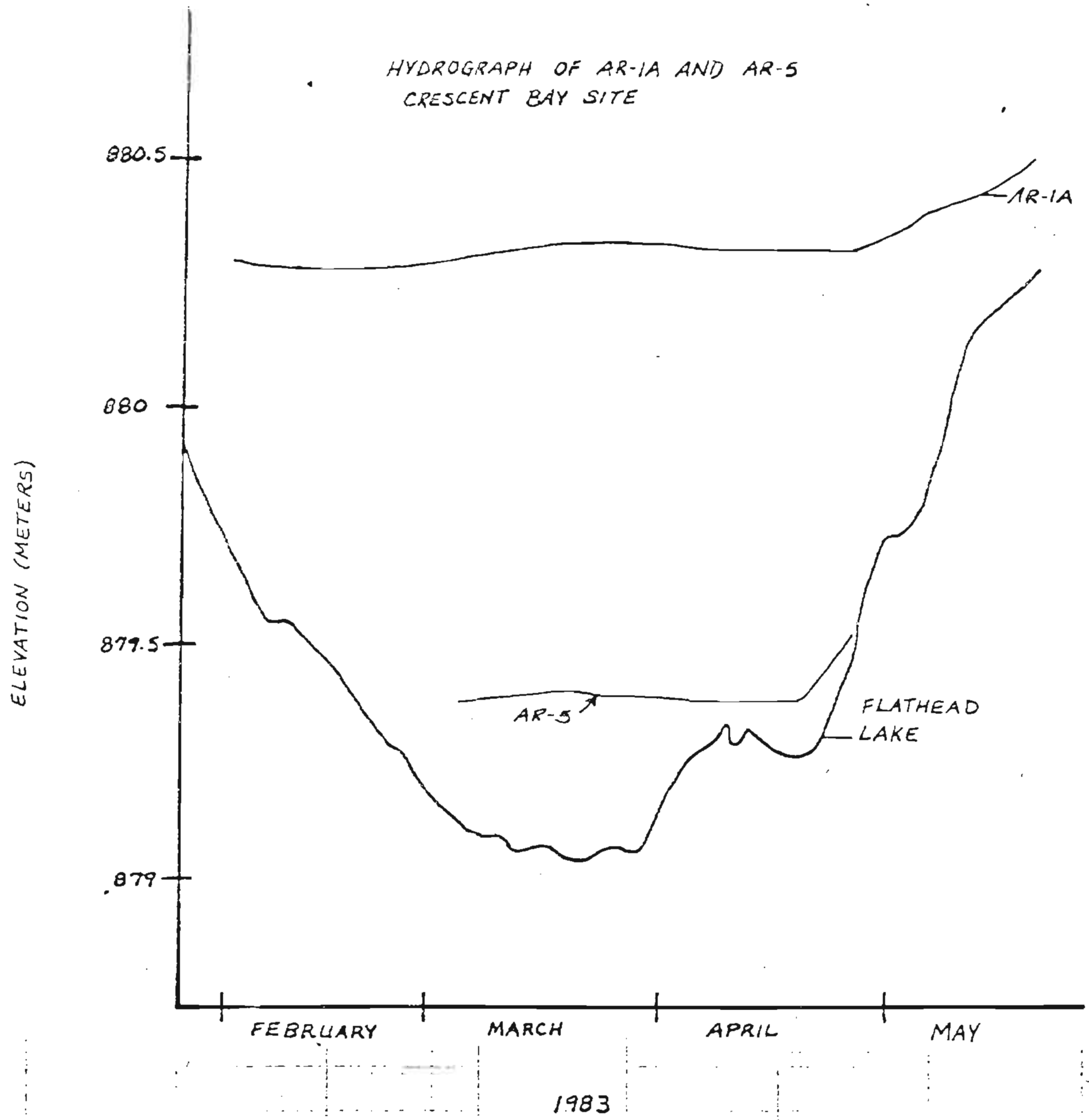

HYDROGRAPH OF SKB-1 AND SKB-4
SKIDOO BAY SITE
880.5
880
879.5
879
ELEVATION (METERS)
SKB-1
SKB-4
FLATHEAD LAKE
FEBRUARY
MARCH
APRIL
MAY
1983

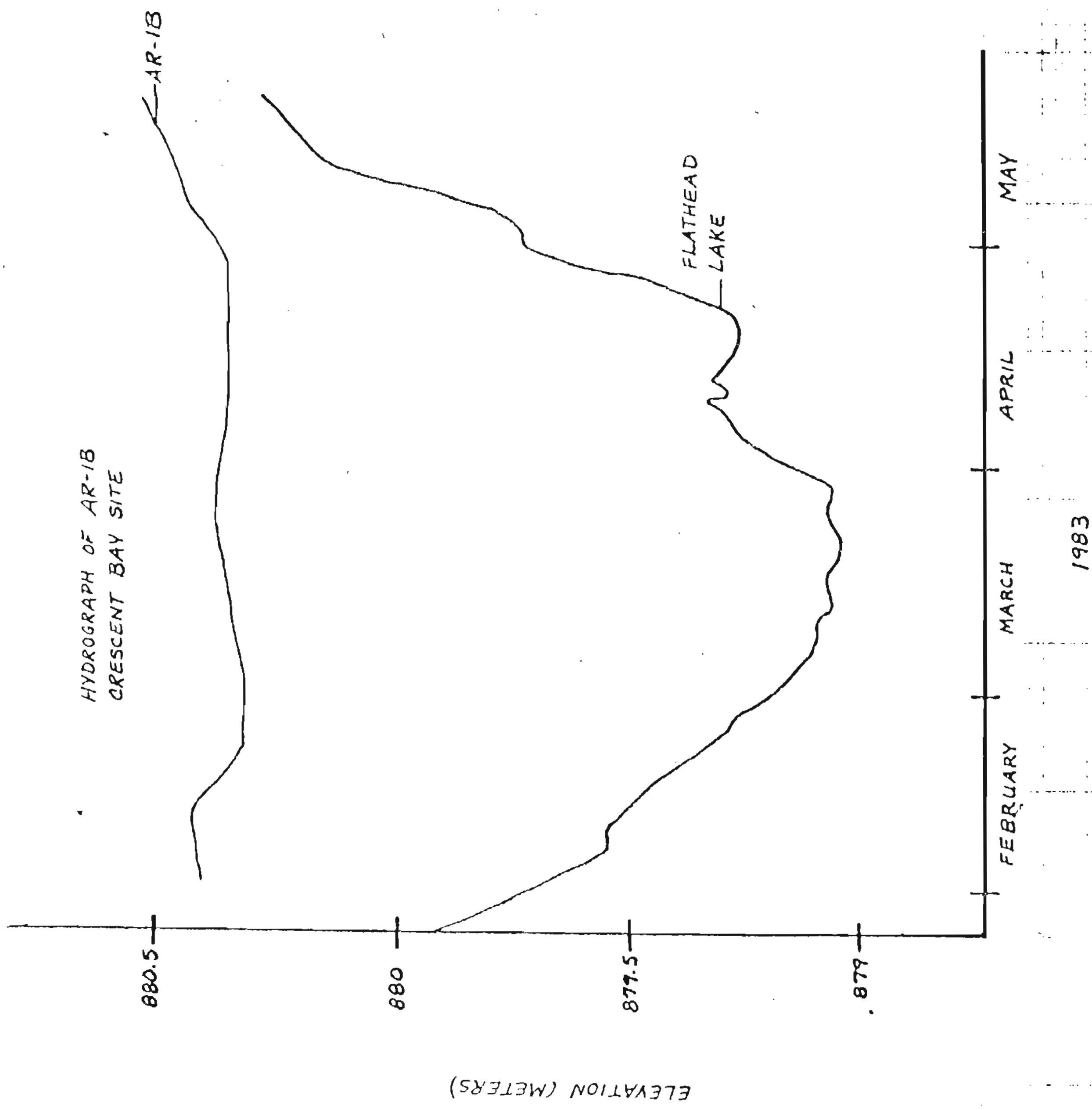

HYDROGRAPH OF SKB-2A
SKIDOO BAY SITE
SKB-2A
FLATHEAD LAKE
880.5
880
879.5
879
ELEVATION (METERS)
FEBRUARY
MARCH
APRIL
MAY
1983

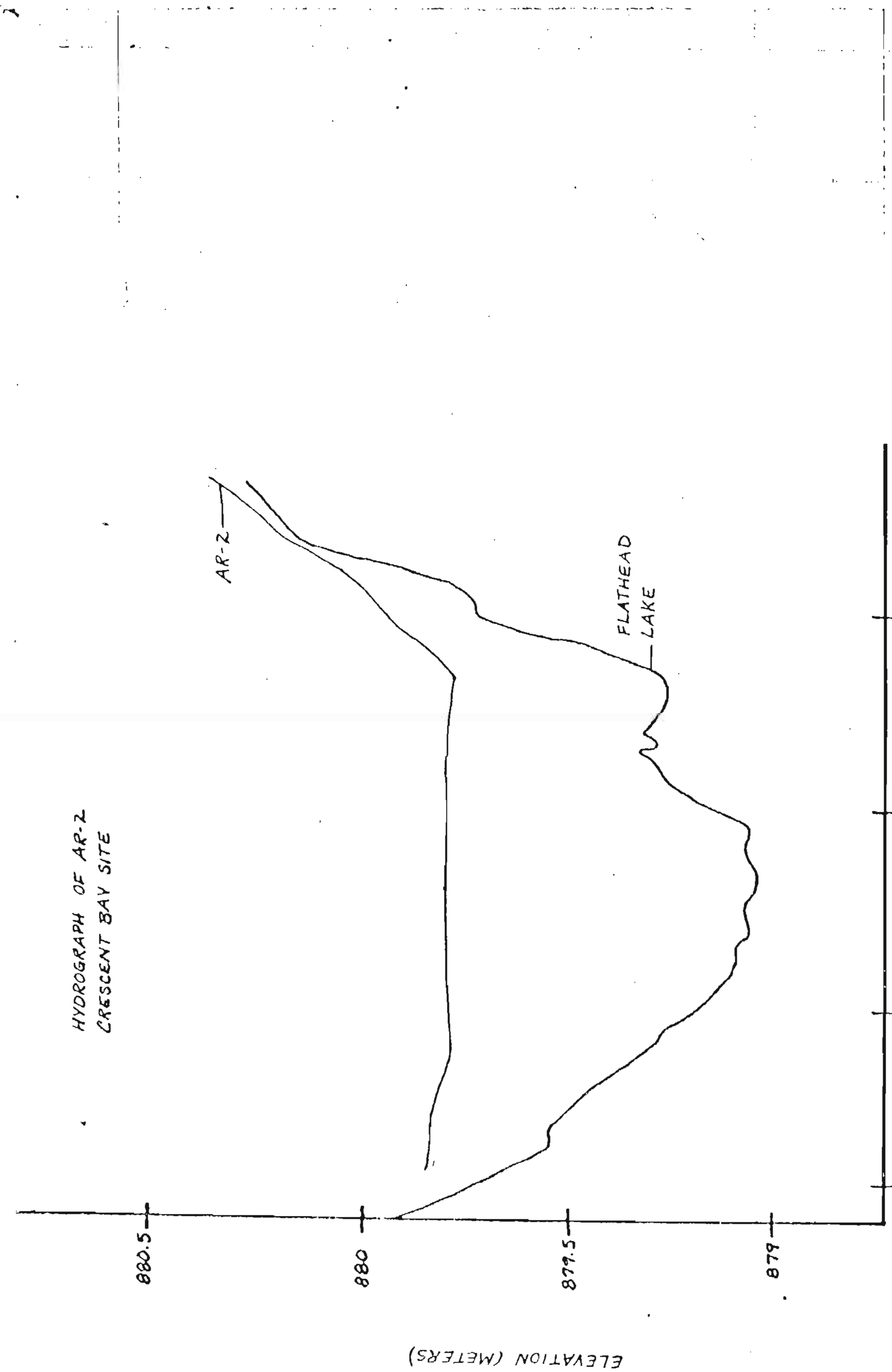


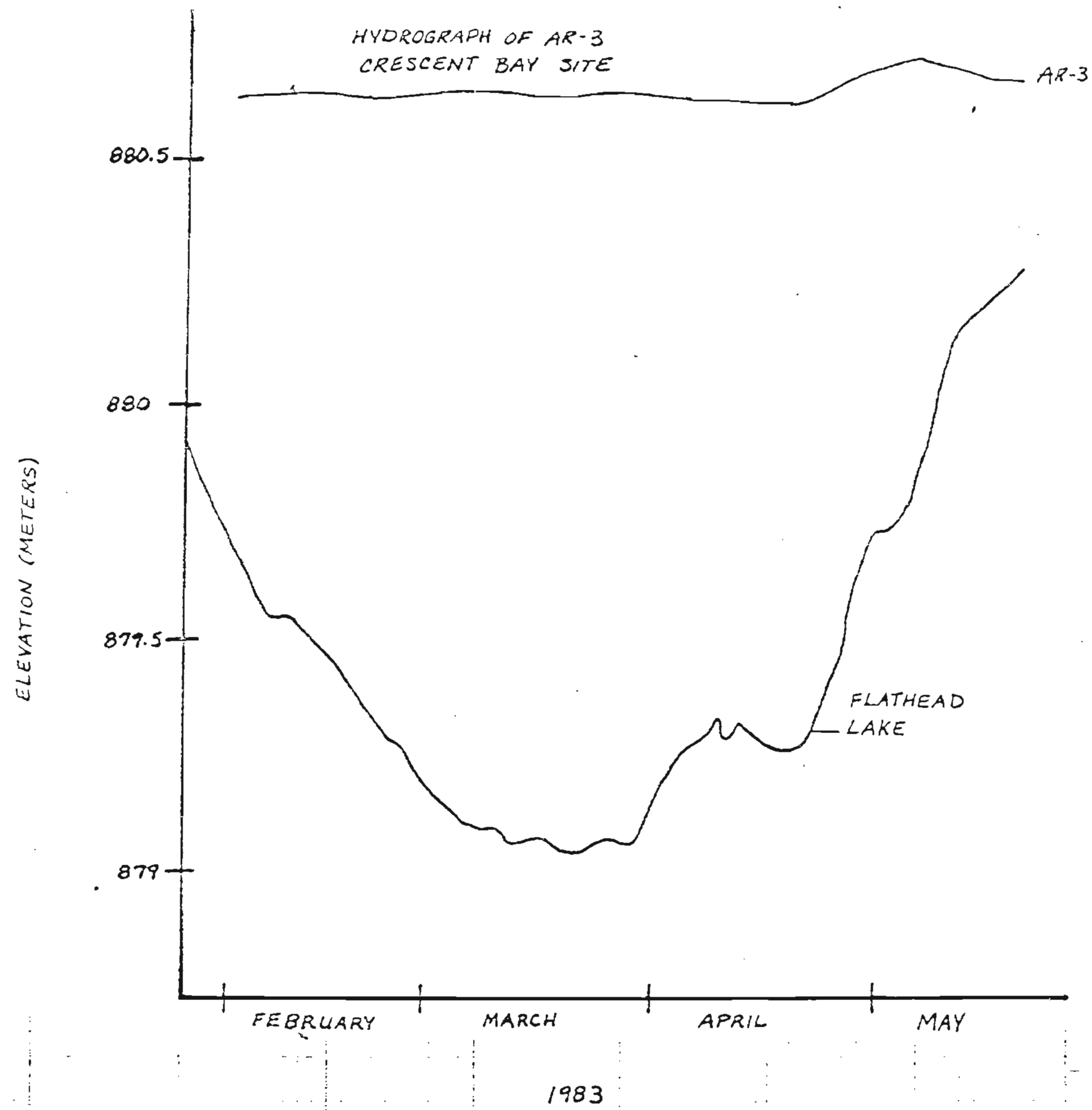
HYDROGRAPH OF SKB-2B
SKIDOO BAY SITE
880.5
880
879.5
879
ELEVATION (METERS)
SKB-2B
FLATHEAD LAKE
FEBRUARY
MARCH
APRIL
MAY
1983

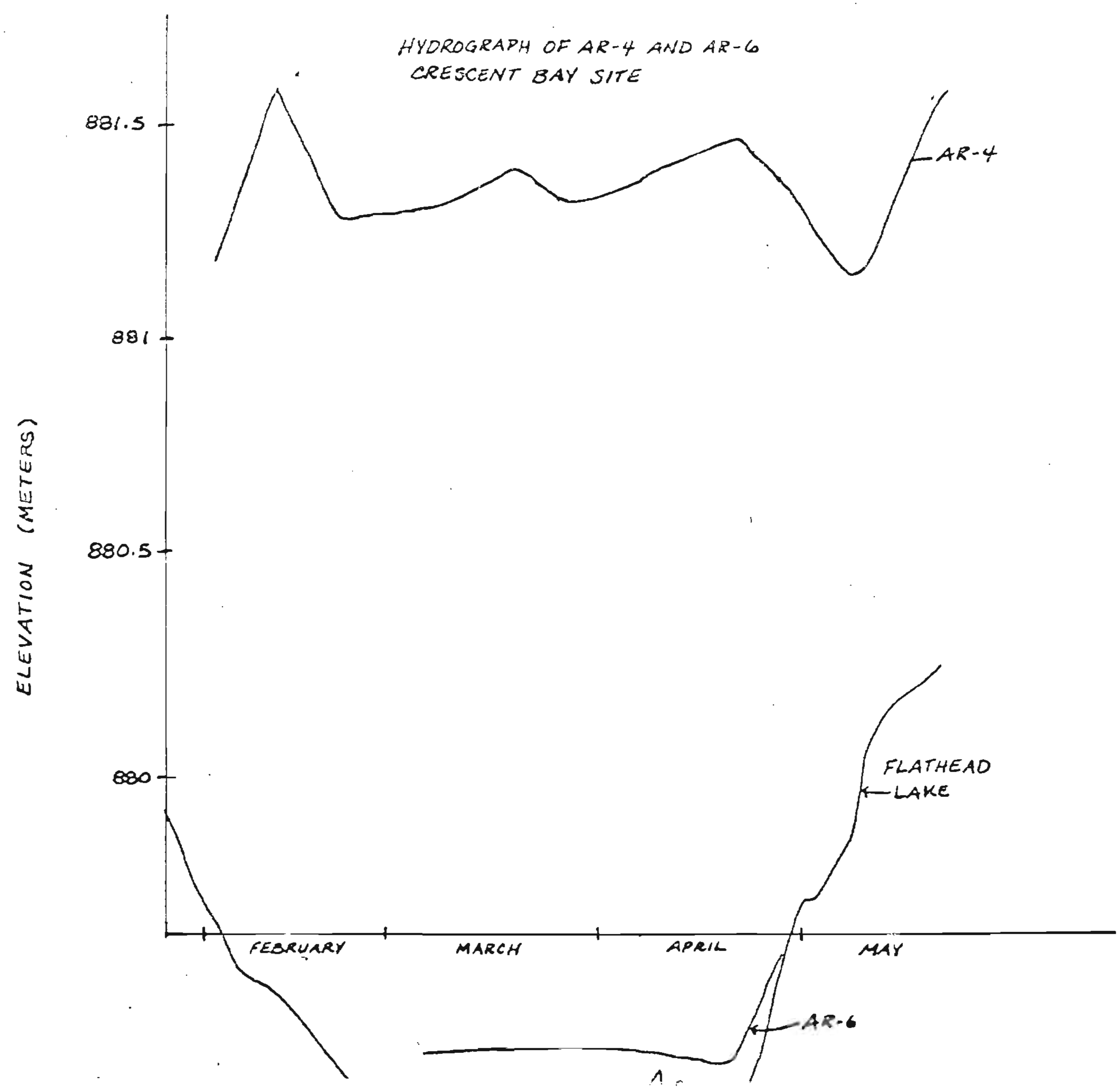

HYDROGRAPH OF SKB-3
SKIDOO BAY SITE
880.5
880
879.5
879
ELEVATION (METERS)
SKB-3
FLATHEAD
LAKE
FEBRUARY
MARCH
APRIL
MAY
1983


HYDROGRAPH OF AR-1A AND AR-5
CRESCENT BAY SITE
880.5
880
879.5
879
ELEVATION (METERS)
AR-1A
AR-5
FLATHEAD
LAKE
FEBRUARY
MARCH
APRIL
MAY
1983

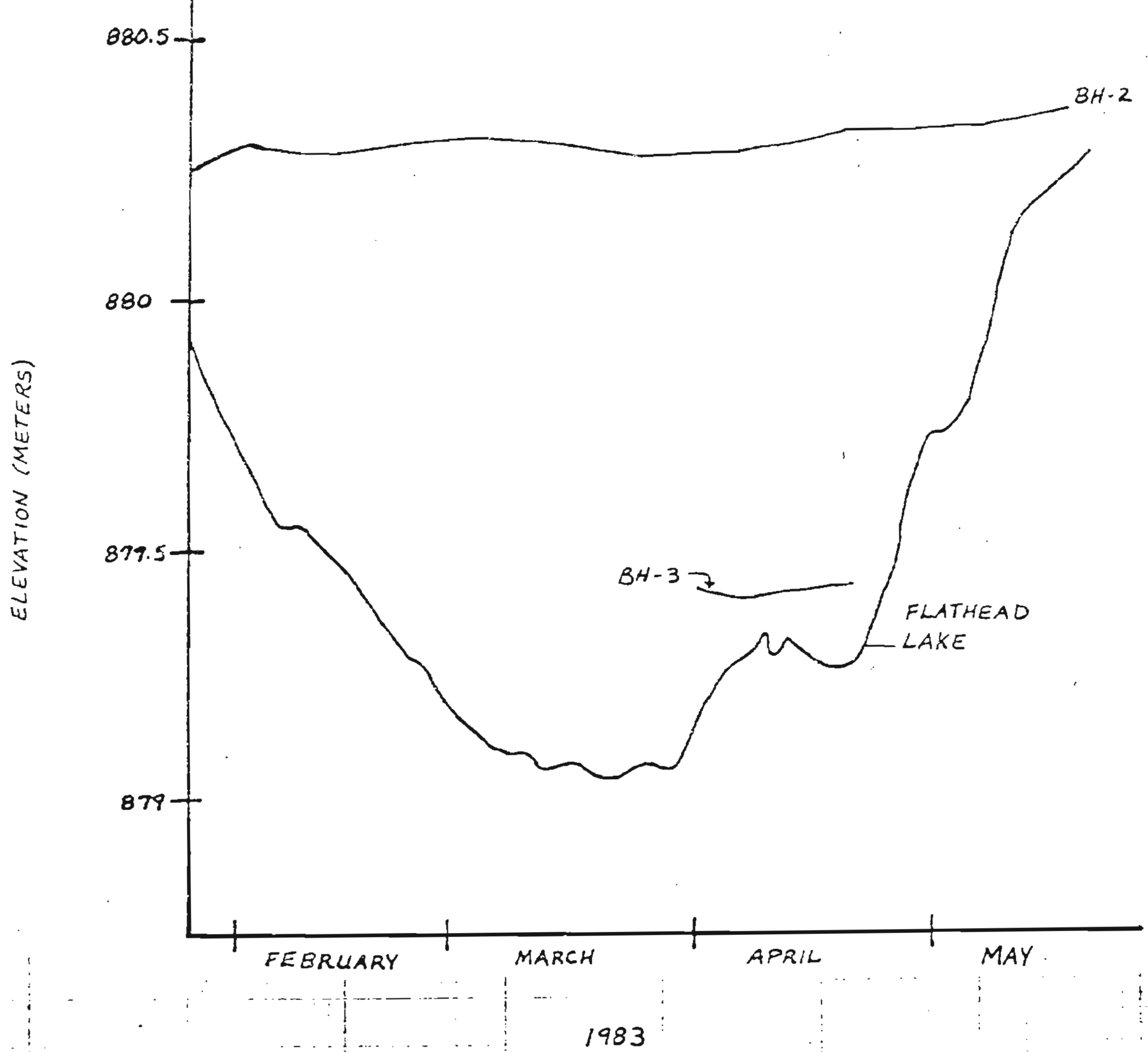

HYDROGRAPH OF AR-1B
CRESCENT BAY SITE
AR-1B
FLATHEAD
LAKE
880.5
880
879.5
879
ELEVATION (METERS)
FEBRUARY
MARCH
APRIL
MAY
1983

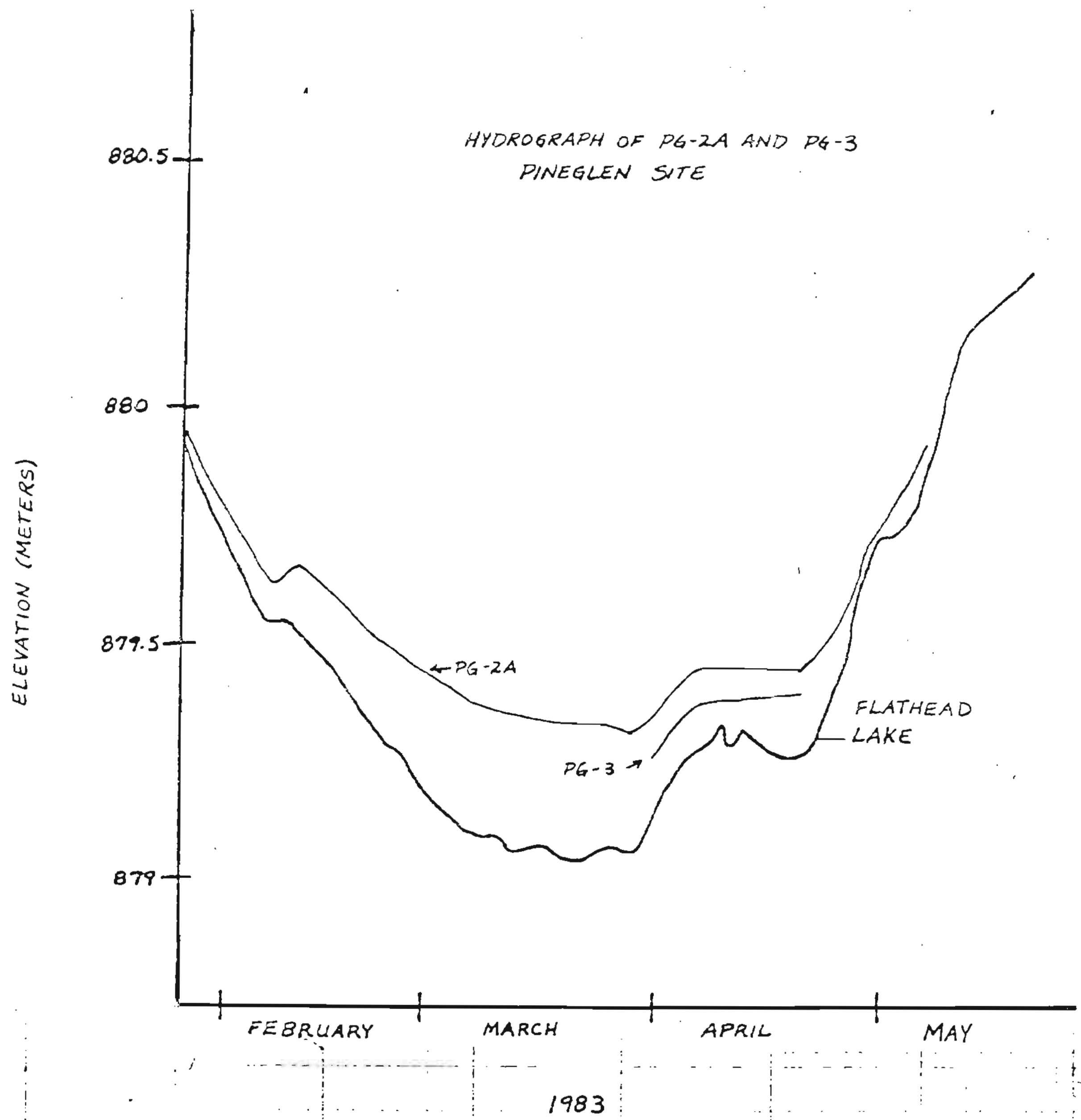

HYDROGRAPH OF AR-2
CRESCENT BAY SITE
AR-2
FLATHEAD
LAKE
880.5
880
879.5
879
ELEVATION (METERS)
FEBRUARY
MARCH
APRIL
MAY
1983


HYDROGRAPH OF AR-3
CRESCENT BAY SITE
AR-3
FLATHEAD LAKE
880.5
880
879.5
879
ELEVATION (METERS)
FEBRUARY
MARCH
APRIL
MAY
1983

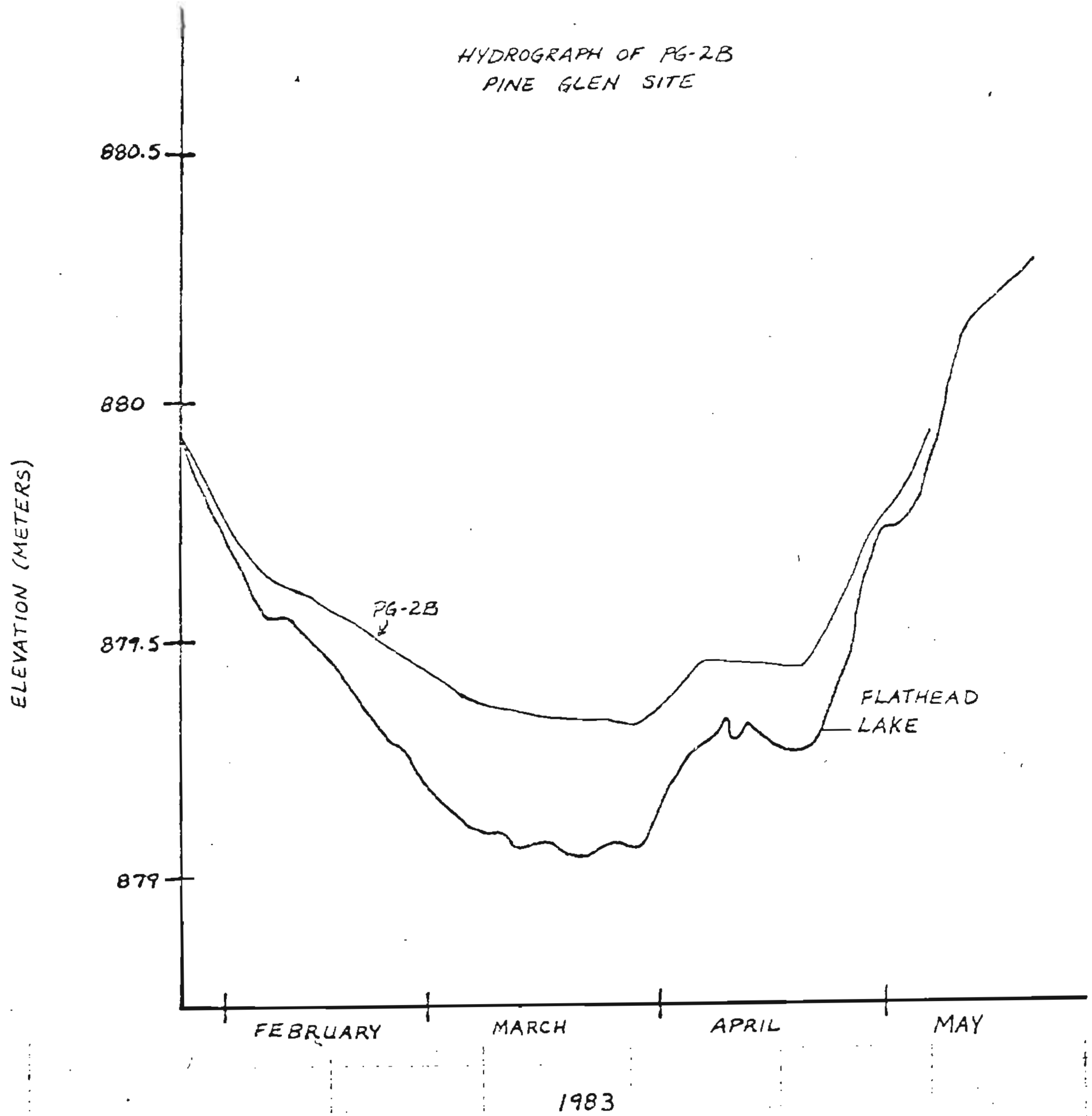

HYDROGRAPH OF AR-4 AND AR-6
CRESCENT BAY SITE
881.5
881
880.5
880
ELEVATION (METERS)
FEBRUARY
MARCH
APRIL
MAY
AR-4
FLATHEAD
LAKE
AR-6

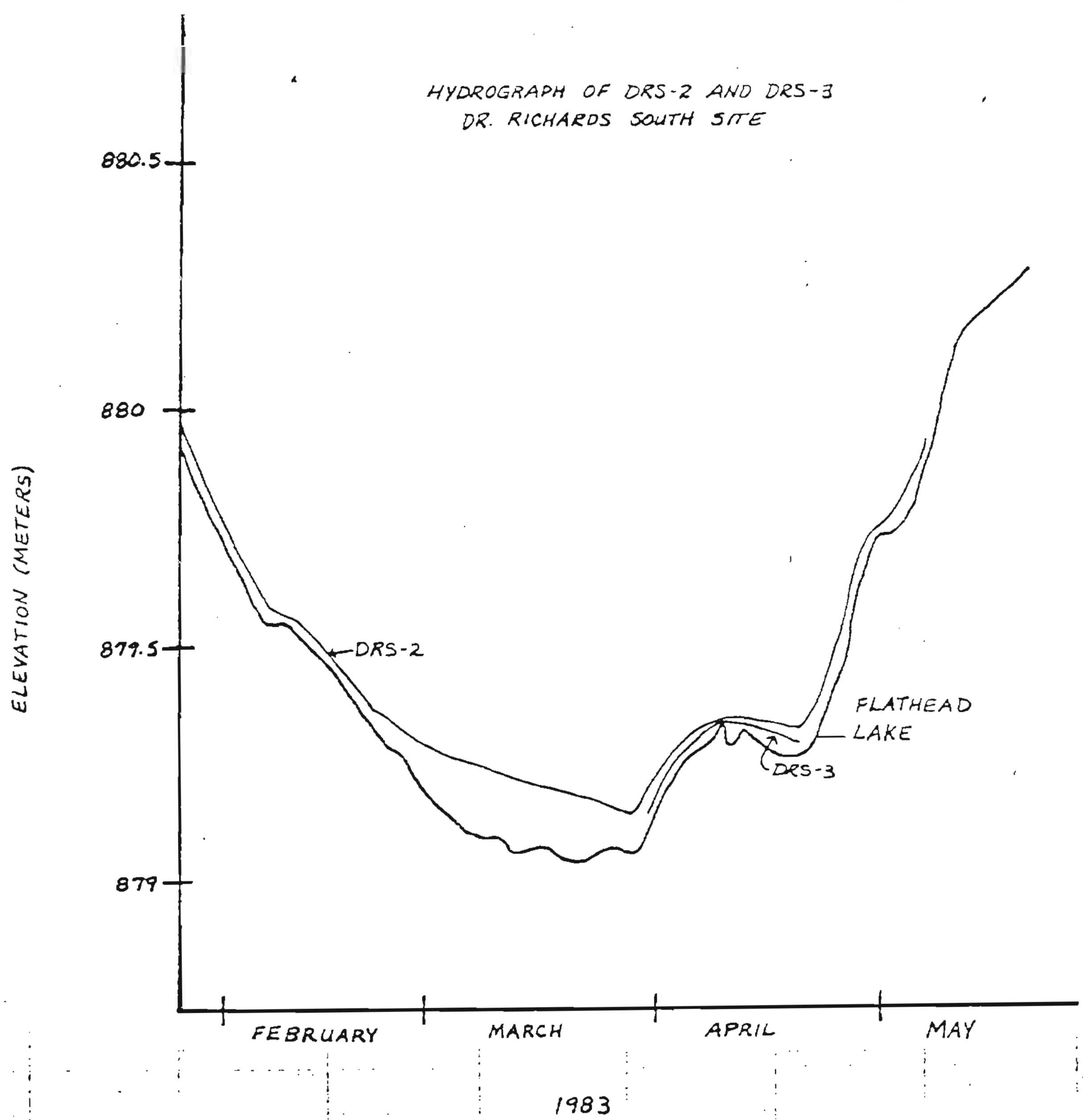
HYDROGRAPH OF BH-2 AND BH-3
HOCHMARK'S SITE





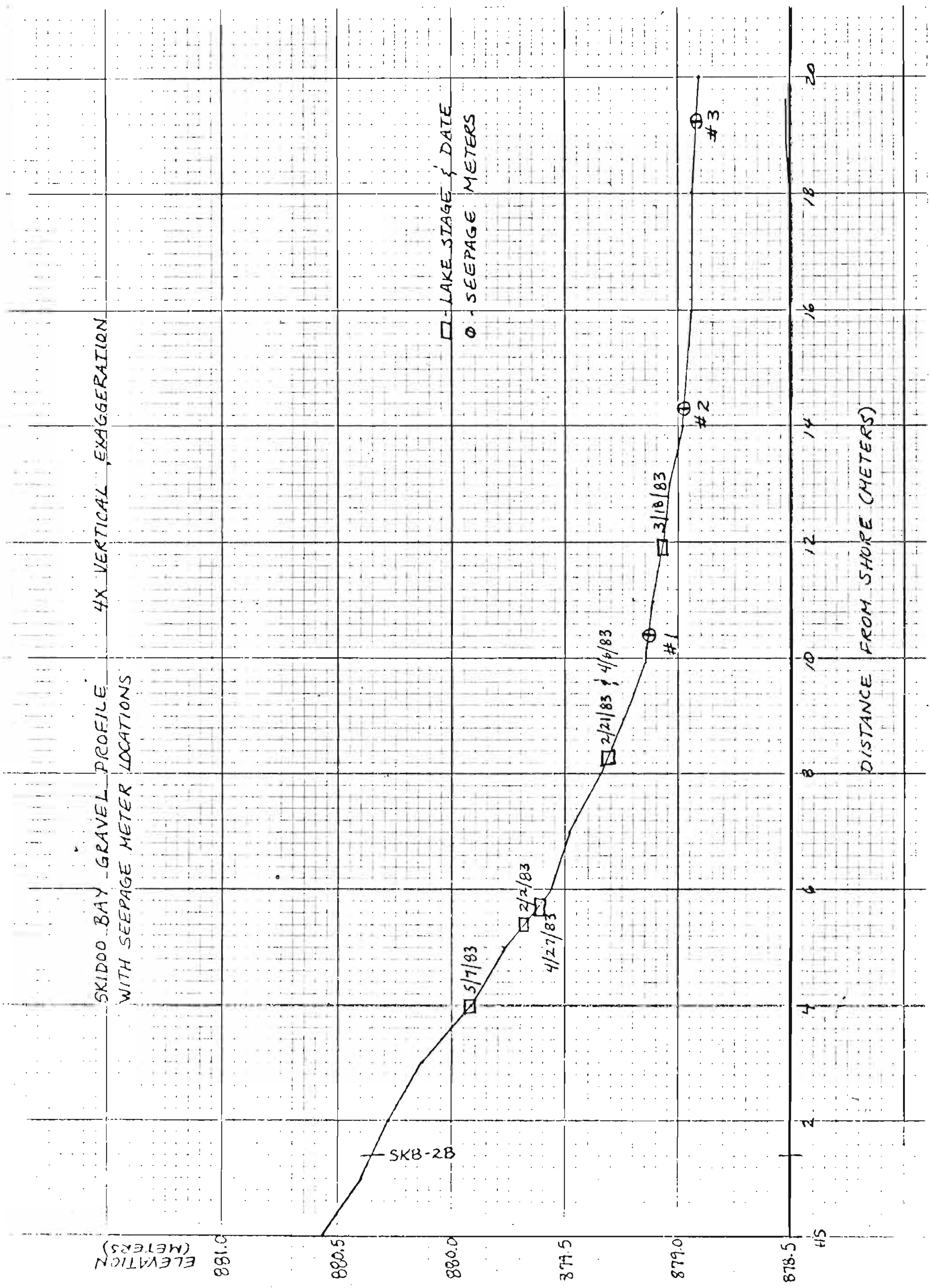
HYDROGRAPH OF PG-2A AND PG-3
PINEGLEN SITE
880.5
880
879.5
879
ELEVATION (METERS)
PG-2A
PG-3
FLATHEAD
LAKE
FEBRUARY
MARCH
APRIL
MAY
1983

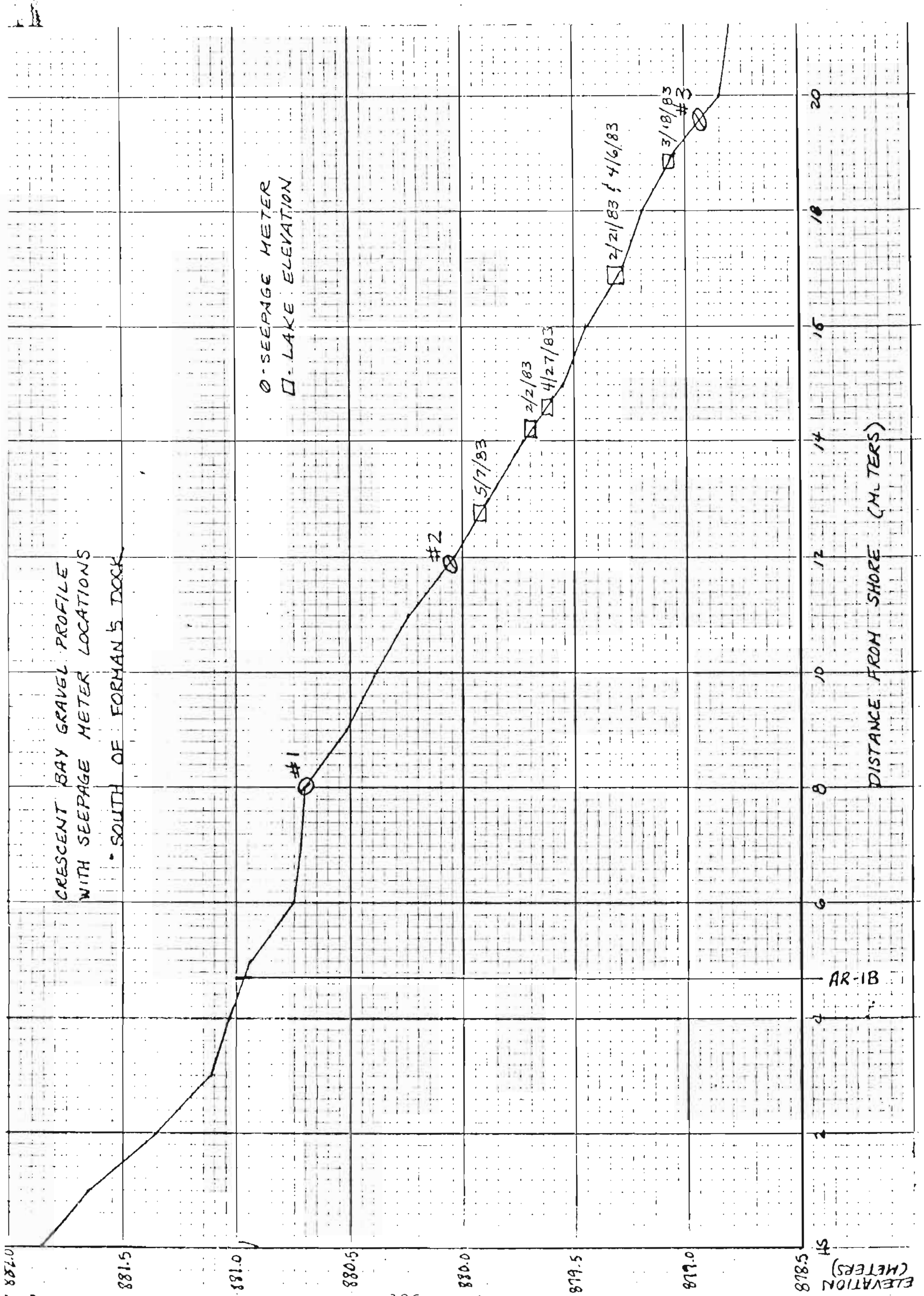

HYDROGRAPH OF PG-2B
PINE GLEN SITE
ELEVATION (METERS)
880.5
880
879.5
879
PG-2B
FLATHEAD
LAKE
FEBRUARY
MARCH
APRIL
MAY
1983


HYDROGRAPH OF DRS-2 AND DRS-3
DR. RICHARDS SOUTH SITE
880.5
880
879.5
879
ELEVATION (METERS)
DRS-2
FLATHEAD
LAKE
DRS-3
FEBRUARY
MARCH
APRIL
MAY
1983

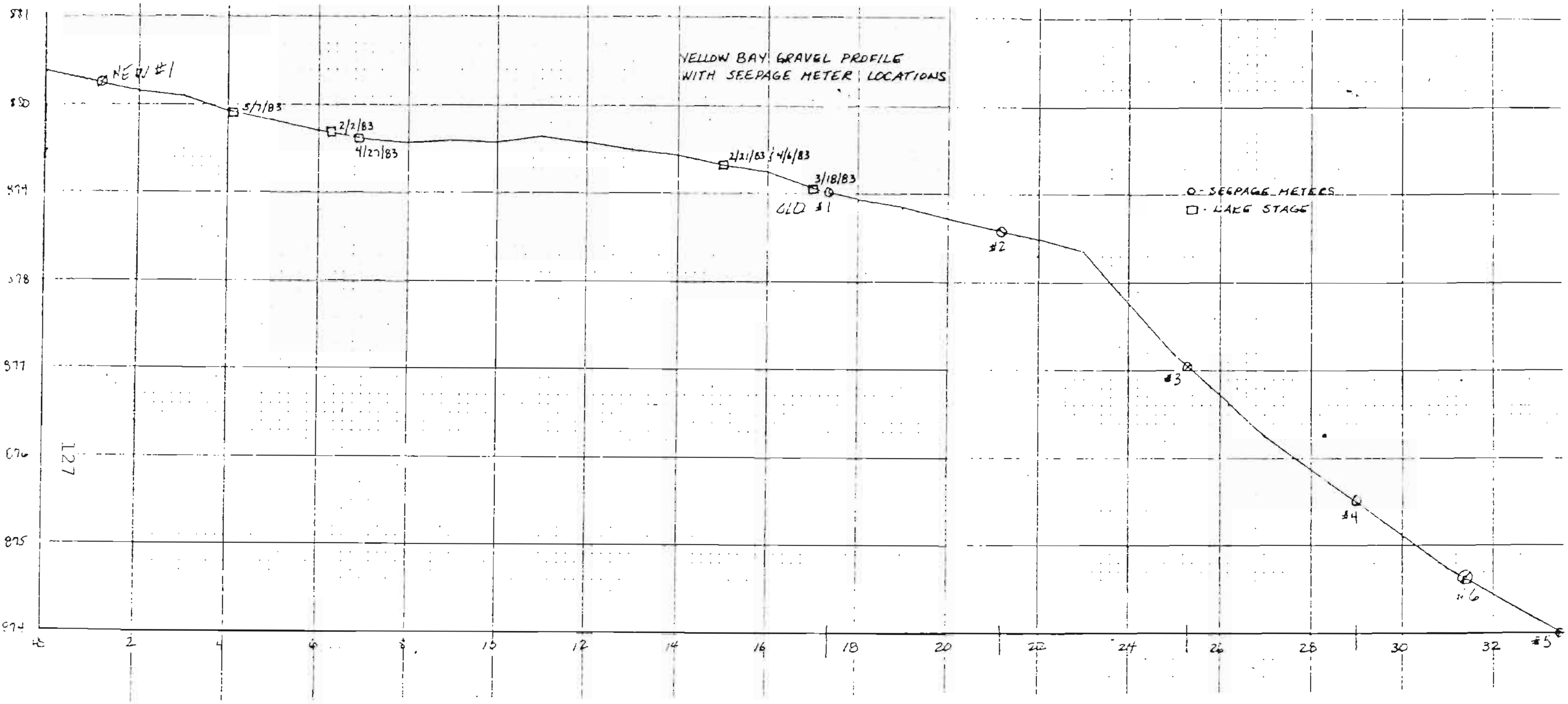
APPENDIX E:

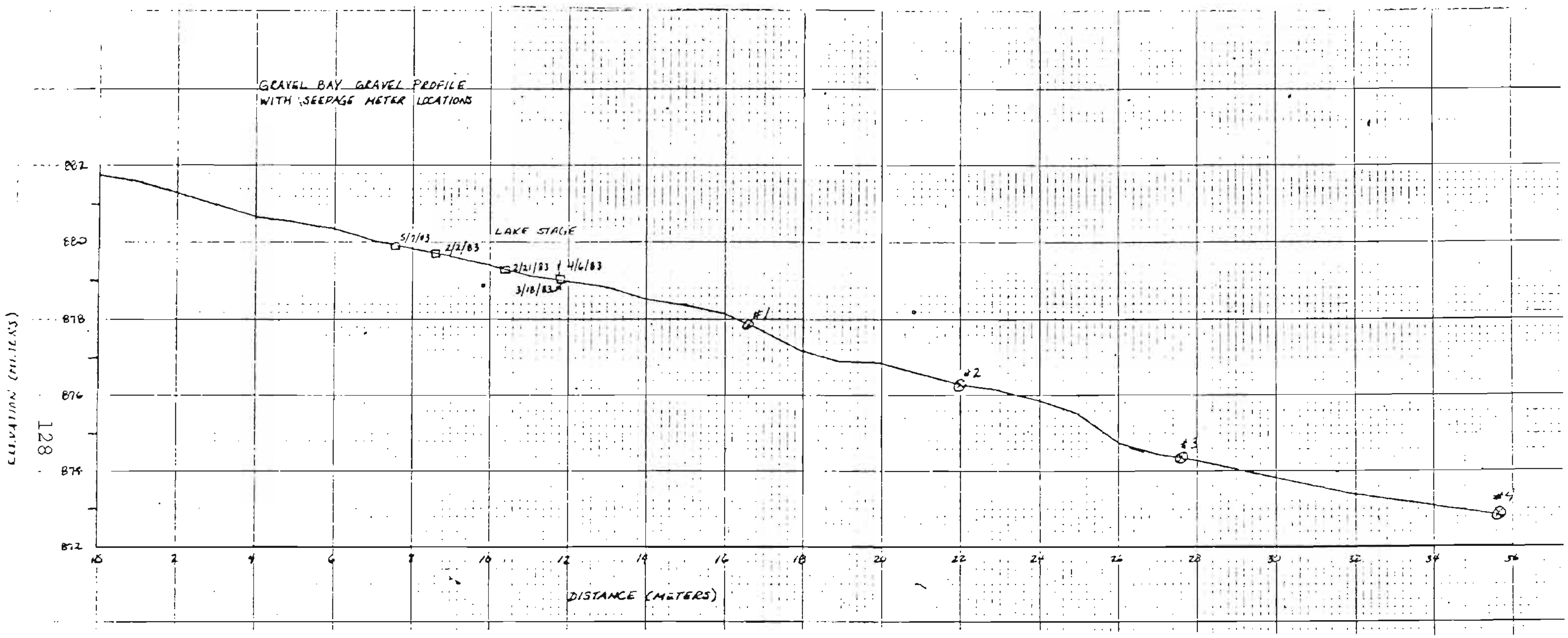
Lakebed Profiles with Seepage Meter Locations


SKIDOO BAY GRAVEL PROFILE
WITH SEEPAGE METER LOCATIONS
4X VERTICAL EXAGGERATION
□ - LAKE STAGE & DATE
⊕ - SEEPAGE METERS
5/7/83
2/2/83
4/27/83
2/21/83 & 4/6/83
3/18/83
#1
#2
#3
SKB-2B
ELEVATION (METERS)
881.0
880.5
880.0
879.5
879.0
878.5
DISTANCE FROM SHORE (METERS)
HS
2
4
6
8
10
12
14
16
18
20

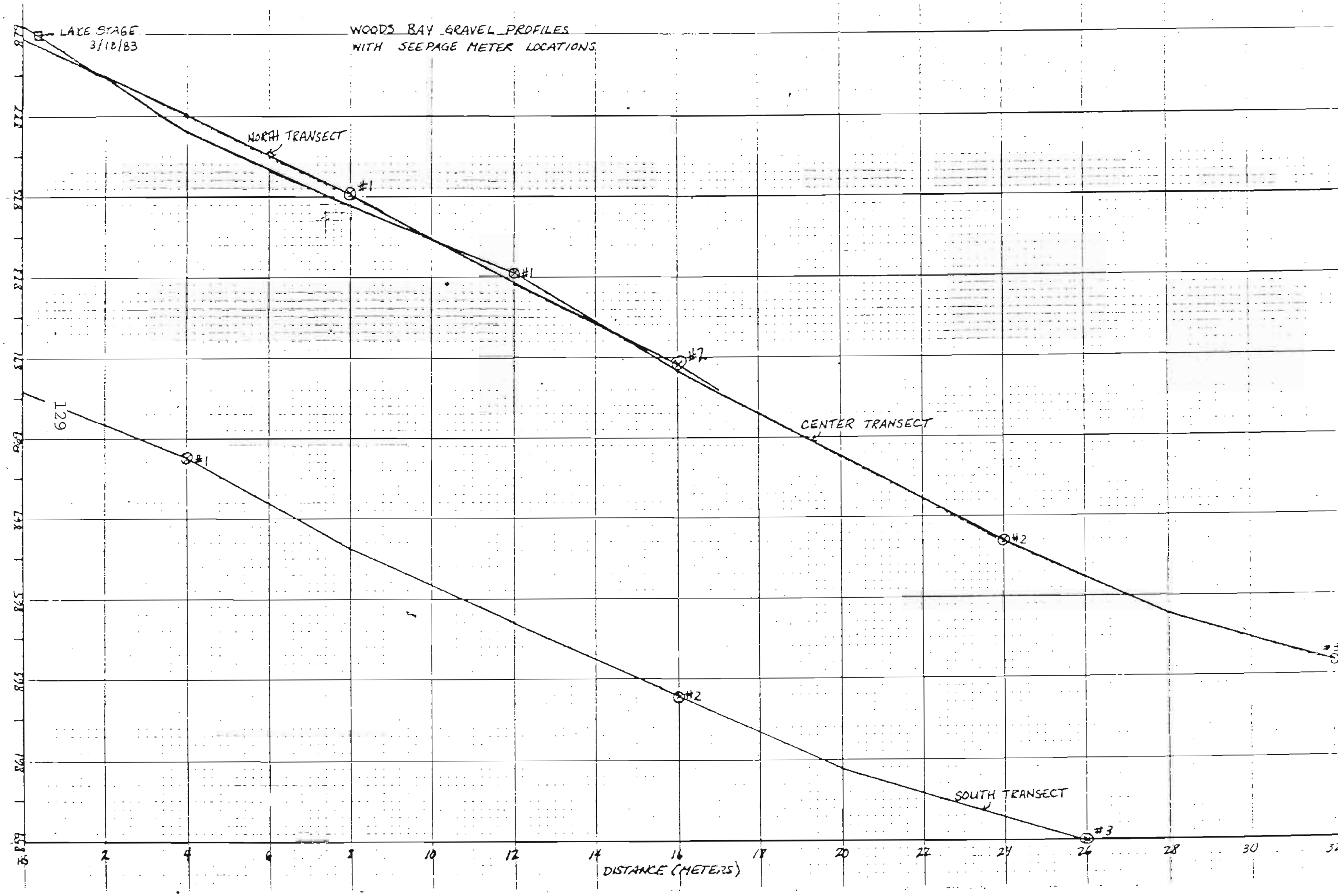


CRESCENT BAY GRAVEL PROFILE
WITH SEEPAGE METER LOCATIONS
• SOUTH OF FORMAN'S DOCK
⊘ - SEEPAGE METER
□ - LAKE ELEVATION
#1
#2
#3
5/7/83
2/2/83
4/27/83
2/21/83 & 4/6/83
3/18/83
AR-1B
DISTANCE FROM SHORE (METERS)
ELEVATION (METERS)
882.0
881.5
881.0
880.5
880.0
879.5
879.0
878.5
0
2
4
6
8
10
12
14
16
18
20


YELLOW BAY GRAVEL PROFILE
WITH SEEPAGE METER LOCATIONS
O - SEEPAGE METERS
□ - LAKE STAGE
NEW #1
5/7/83
2/2/83
4/27/83
2/21/83 ; 4/6/83
3/18/83
OLD #1
#2
#3
#4
#6
#5



GRAVEL BAY GRAVEL PROFILE
WITH SEEPAGE METER LOCATIONS
LAKE STAGE
5/7/83
2/2/83
2/21/83
4/6/83
3/18/83
#1
#2
#3
#4
ELEVATION (METERS)
882
880
878
876
874
872
DISTANCE (METERS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36


LAKE STAGE
3/18/83
WOODS BAY GRAVEL PROFILES
WITH SEEPAGE METER LOCATIONS
NORTH TRANSECT
#1
#1
#2
CENTER TRANSECT
#2
#3
#1
#2
SOUTH TRANSECT
#3
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DISTANCE (METERS)