# LAKE ICE COVER DEVELOPMENT AND MELTWATER MIXING IN THE SPRING ACIDIFICATION OF SMALL CANADIAN PRECAMBRIAN SHIELD LAKES

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by

Watershed Ecosystems Program
of the
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# Abstract

The winter cover of Plastic Lake was found to be a porous two-way barrier to both lake and atmospheric derived water. The most severe pH depressions recorded in Plastic Lake appeared to be a result of snow and rain water entering the lake directly through macro openings in the ice cover. Slush lenses within the ice cover contained a disproportionate amount of the total winter cover ionic load, being quite concentrated (conductance up to 246.4 uS/cm) and strongly acidic (pH down to 3.55). The winter cover was a significant source of hydrologic and chemical inputs (particularly nitrogen compounds) to Plastic Lake during the ice covered period (Jan-May).

At least two pH depressions in the littoral zones occurred in Plastic Lake during the study season. The pH depressions eventually influenced the entire surface of the lake to a depth of at least 2.5m. Near shore chemistry was found to vary dramatically in response to various rain-on-snow events. Dye tracings of stream water and direct runoff indicate that inflow area geometry and thermal density differences strongly influenced meltwater mixing in Plastic and other study lakes. Dye-tagged meltwater was generally confined to the upper 1.2m of Plastic Lake.

# Acknowledgements

The completion of this work would not have been possible without the help and encouragement of a number of individuals.

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Allan Chapman assisted me in setting up the entire Plastic Lake sampling grid through some particularly trying for leaving his own graduate work to come and help me in the field after the 'stove' incident which allowed me to complete the field season. My trailer mates Rob and Rob Shibatani assisted me in the field, kept my spirits up, fed me and helped me through a long and somtimes difficult field season. Martin Van Haaften and Steve Gardiner both assisted me with the drafting of the numerous diagrams.

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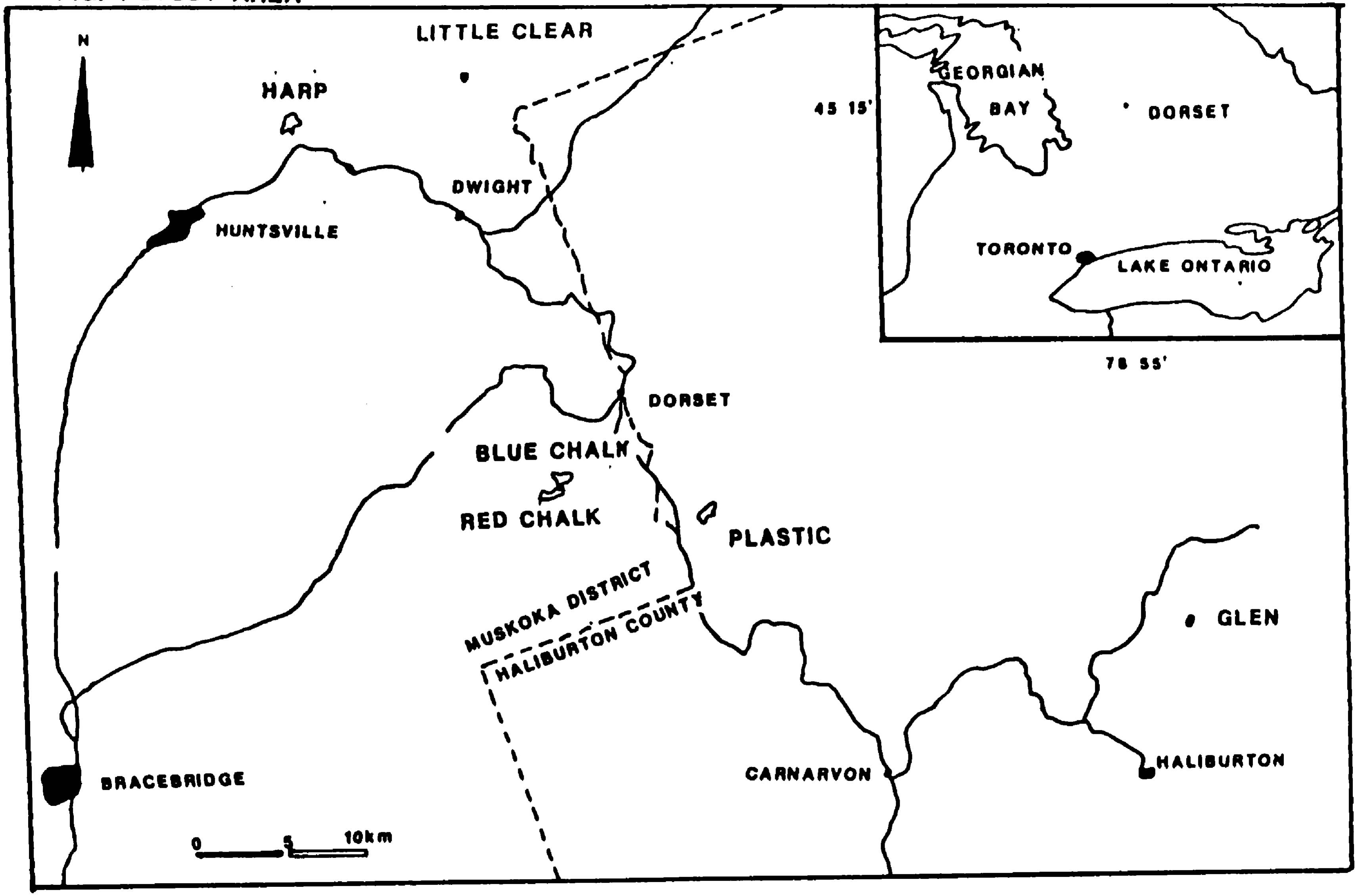
## Section 1 Introduction and literature review

This research deals with acidic precipitation and its influence on water quality during snowmelt. The research was carried out on small Precambrian Shield lakes, especially Plastic Lake, in the Muskoka- Haliburton area of south-central Ontario, Canada (Fig. 1). It involved the study of lake ice formation, evolution, and decay, and the distribution and entrainment of acidic snowmelt water within ice-covered lakes. The research objectives consisted of documenting the spatial and temporal extent of spring lake acidification within the study lakes, and defining the physical and chemical roles of the winter lake cover in the spring lake acidification process. The section begins with a review of pertinent literature dealing with snow chemistry and lake acidification during snowmelt. This is followed by a description of the development and decay of a lake's winter cover and its effect on the limnology of the lake. Finally, a dicussion of some of the basic equations and approachs used to predict lake inflow dynamics is presented. The research consisted of gathering field observations and applying existing inflow mixing theory to explain those observations. The work was carried out to determine what portion of the lacustrine environment is influenced by acidic snowmelt water within ice-covered lakes, and to identify lakes or in-lake areas that might be vulnerable to spring acid shocks. It is hoped that a better understanding

FIG. 1 STUDY AREA



of the effect of lake inflow dynamics on spring lake water quality will emerge.

## A. Spring lake acidification

Snow and other ice play dominant roles in the annual hydrogeochemical cycle of lakes and their catchments in cool-temperate regions world-wide. Their relative importance generally increases with latitude and altitude. Increasing concentrations of acid precursors ($SO_x$ and $NO_x$), and other airborne pollutants have been found in all types of precipitation from around the globe (reviewed in Haines 1981). Wet deposition during rain, snowfall, and fog, dew or rime events, along with dry deposition, all contribute to the atmospheric loading of a snowpack. Snow which accumulates on a lake's ice surface and in its terrestrial drainage basin and which may be incorporated into the lake's ice cover during slushing events (Shaw 1965) often contains significant amounts of nutrients, acids and trace metals which are released to receiving water bodies during snowmelt (Groterud 1972a, Elgmork et al. 1973, Hagen and Langeland 1973, Johannessen et al. 1977, Adams et al. 1979, Barica and Armstrong 1979, Franzin and McFarlane 1981, Skartveit 1981, Zajac and Grodzinska 1982, Murphy and Shinsky 1983, Shewchuck 1985).

Snowpack chemistry has been found to vary both vertically (Elgmork et al. 1973), and horizontally (Scheider et al. 1984). Scheider et al. (1984) found significant spatial variability in snowpack chemistry on the mesoscale of hundreds of metres. It is believed that spatial variation in snowpack chemistry is the result of forest canopy alterations of incident precipitation, rather than spatial differences in incident precipitation (summarised by Marmorek et al. 1984). Elgmork et al. (1973) found distinct horizontal bands within a snowpack which displayed widely contrasting pH, $SO_4^{-2}$, and conductivity values. These bands appeared to be preserved within the snowpack so long as ambient temperatures remained below freezing.

Changes in the mass of various ions within a snowpack have been observed in a number of studies, even during periods without apparent melt (eg. Jeffries and Snyder 1981). Jones and Sochanska (1985) found significant changes in snowpack chemistry (especially $Al^{+3}$, $PO_4^{-3}$, $Mn^{+2}$ and $K^+$), during melt-free periods, when free water existed in the snowpack. Within-snowpack transformations are believed associated with microbial decomposition of forest-derived organic matter in the snowpack. The relative importance of these within-pack transformations is often difficult to assess quantitatively because of the great spatial variability of snowpack chemistry (Marmorek et al. 1984).

Several studies have shown that pollutants tend to be preferentially removed from the snowpack during early melt events (Johannessen and Henriksen 1978, Jeffries and Semkin 1983, Scheider et al. 1984 and Jones et al. 1984). Johannessen and Henricksen (1978) found 70-80% of the total

$SO_4^{-2}$, $NO_3^-$ and $H^+$ in the snowpack was lost in the initial 30% of the meltwater during field and laboratory lysimeter studies. Brimblecombe et al. (1985) and Tsiouris et al. (1985) report that there appears to be a preferential ion elution sequence in this early meltwater, with $SO_4^{-2} > NO_3^- > NH_4^+ > K^+ > Ca^{+2} > Mg^{+2}, H^+ > NaCl$. This also increases the acidity of the initial meltwater and leaves the remaining snowpack solute-depleted and relatively rich in NaCl. The low solubility of inorganic compounds within the ice crystal during snow formation leads to this meltwater concentration effect. It is believed that most impurities are excluded to the surface of individual snow crystals during snow crystal formation. The ripening of the snowpack creates a series of veins through which rain and meltwater can pass and quickly dissolve impurities from the ice crystal surface (Seip 1980). Simulations and models of the chemical depletion of a snowpack are reported by Colbeck (1984) and Hibberd (1984).

As spring radiation inputs increase, "destructive" metamorphism of the individual snow crystals proceeds and the snowpack ripens (Sommerfeld and LaChapelle 1970, Colbeck 1982). The migration of water through the snowpack is dominated by vertical unsaturated flow unless impeded by ice layers or the ground surface, which may divert water laterally as saturated flow. Colbeck (1972 and 1978) formulated a kinematic wave-model to predict meltwater movement through snowpacks, and several field studies

studies (reviewed by Wankiewcz 1978) have demonstrated its merit. The presence of the snowpack has been found to delay the arrival of the meltwater wave at the ground surface by up to twelve hours or more, depending upon snow depth, temperature, grain size and melting rate. When the wave reaches the base of the snowpack there is an abrupt efflux of water from that snowpack. In shallow snowpacks, the peak of the efflux is equal to the peak rate of melting, but may be slightly dampened if the snowpack is several metres deep (Dunne 1983).

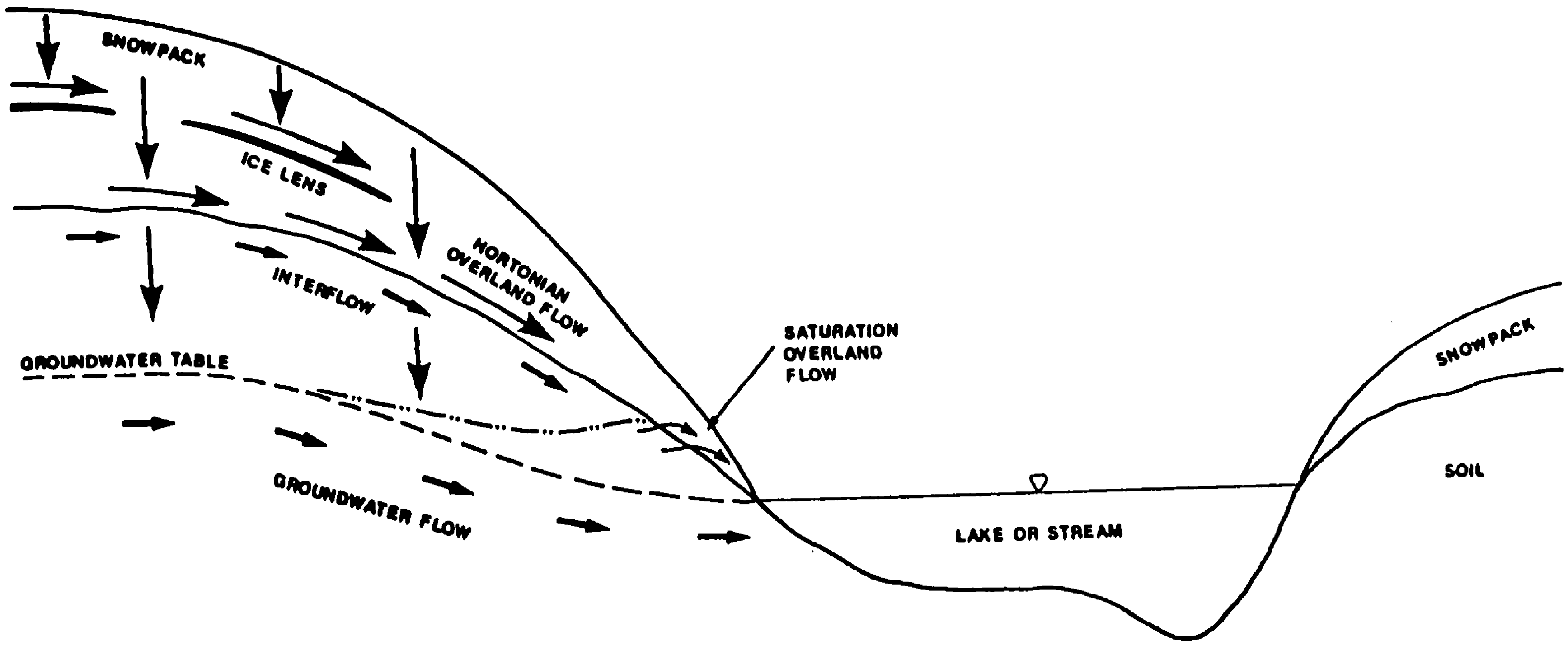
The movement of water from the snowpack through the terrestrial system has received much attention in the literature in recent years (reviewed in Dunne 1983). It has become widely accepted that variable source area, rather than widespread Hortonian overland flow, provides most of the runoff from small catchments in humid areas (Dunne et al. 1975, Dunne 1978). Snowmelt rates are generally lower than most flood-producing rainfall intensities. Therefore, Hortonian overland flow during snowmelt is unlikely, unless the infiltration capacity of the soil is reduced by soil frost. The type of soil frost is also important, as "concrete frost" renders soils relatively impermeable while "porous frost" has little effect on the infiltration capacity (Post and Dreibelbis 1942, Trimble et al. 1958). The occurrence and characteristics of soil frost are known to be influenced by weather, vegetation, snowpack depth and soil characteristics, however a quantitative model for prediction and extent of soil frost is lacking (Dunne 1983).

Saturation overland flow and subsurface flow represent two ends of the spectrum of variable source area processes. The relative importance of each transport process will depend on topography, soil properties and rainfall characteristics and, indirectly, on climate, vegetation and land use (Freeze 1974, Dunne 1978). The pathways of snowmelt runoff are the same as those used to describe rainfall runoff. However, the presence of the snowpack, and several different interactions between the snowpack and the soil matrix influence the timing and the relative importance of each hydrologic pathway (Fig. 2).

When the efflux of meltwater from the snowpack exceeds the infiltration capacity of the soil, water accumulates as a thin saturated layer at the base of the snowpack and migrates downslope, often along the base of the snowpack. Where the infiltration capacity of the soil is relatively large, all meltwater can enter the soil and generate subsurface flow. In portions of a catchment, the influx of meltwater may raise the water table to the soil surface creating saturated conditions and return flow through the base of the snowpack. Percolation or rainfall onto the saturated areas can produce saturation overland flow which may augument any return flow (Dunne 1983).

The type of hydrologic pathway is important, as spatial and temporal variations in stream chemistry have been

Fig. 2 SNOWMELT WATER PATHWAYS (modified from Price et al., 1978)



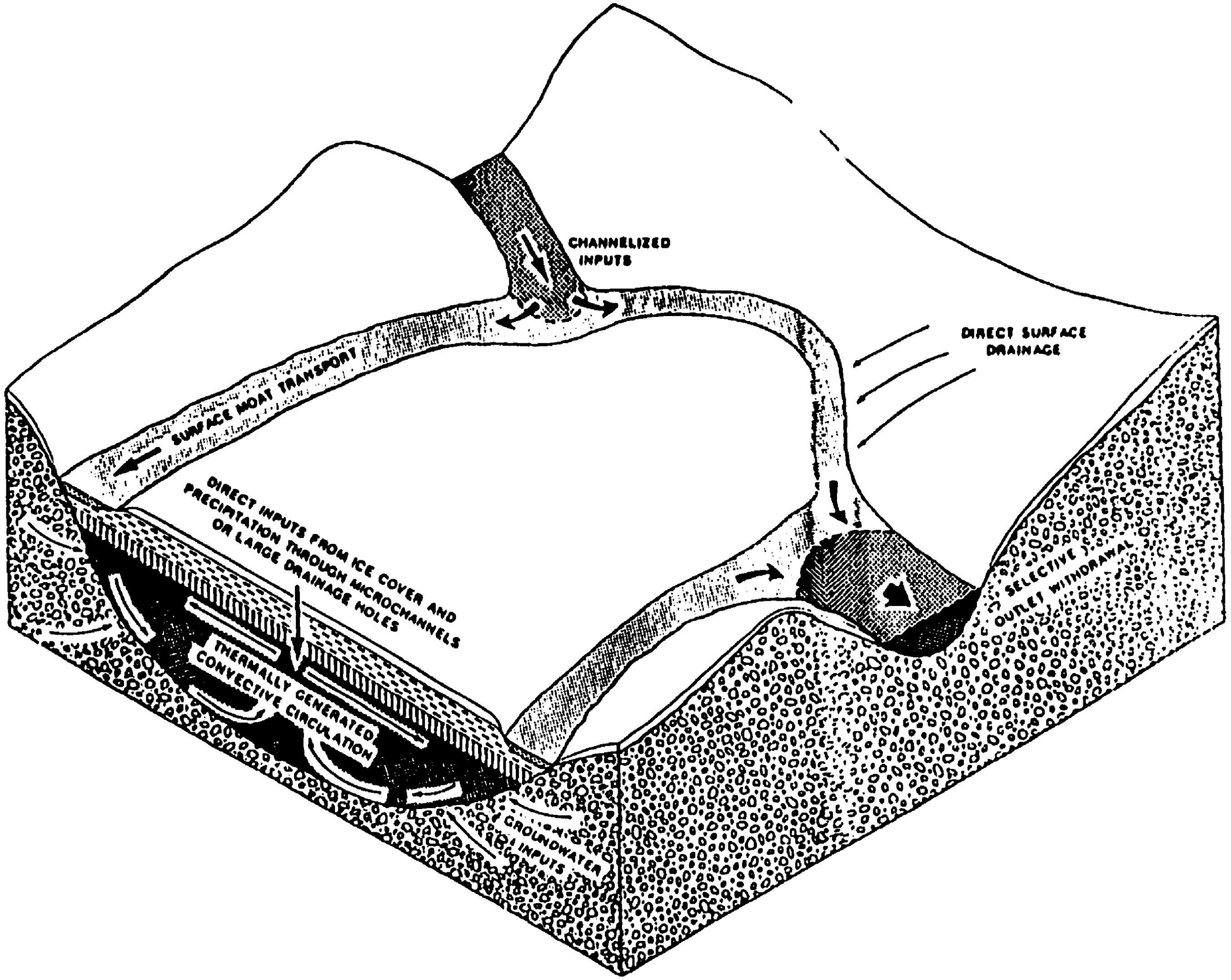
attributed to differences in soil contact time (reviewed in Marmorek et al. 1984). Soil physical (infiltration capacity, depth etc.), and chemical (cation exchange capacity, organic content, etc.) characteristics interact to influence the biotic (eg. $NO_3^-$ reduction) and abiotic (eg. $SO_4^{-2}$ adsorption) processes which chemically modify snowmelt runoff before it enters a stream channel or lake.

It is well documented that pH depressions often occur in the poorly buffered surface waters of North American and European lakes during spring runoff (reviewed in Jeffries et al. 1979 and Memorandum of Intent 1983) and that these depressions pose a potential threat to aquatic biota (Harvey et al. 1981, Canadian Govt. 1985). The acidification of water during snowmelt can be quantified as the water's loss of alkalinity (Dillon and Lazerte 1986). The three methods whereby this can happen are: dilution by low alkalinity snowmelt water, change in the organic acid content, and addition of strong mineral acids. The relative importance of strong mineral acids (nitric and sulphuric) varies from system to system (Dillon and Lazerte 1986). With the exception of studies such as Charette et al. (1984) and Gunn and Keller (1985), little has been reported as to the spatial (vertical and horizontal dimensions), and temporal (initiation and duration) extent of these episodic events within lakes. In addressing the potential impact of spring runoff on aquatic biota, it is important to delimit that portion of the aquatic environment which is likely to be exposed to acidic meltwaters, and to determine the potential chemical concentrations to which biota within these zones could be exposed.

Potentially in poorly buffered areas that are influenced by acidic deposition, an entire stream system can be influenced by acidic snowmelt as a result of turbulent mixing (Leivestad and Muniz 1975, Jeffries *et al*. 1979, Hall and Likens 1980, Bjarnborg 1983, Keller 1983, Johnson 1985). First order streams are generally influenced more than higher order streams (Lam and Bobba 1984 and Schnoor *et al*. 1984). Dilution, sediment buffering and alkalinity (if present), serve to reduce the severity of the impact of the spring acid pulse in the lacustrine environment. However, portions of a lake may be influenced by acidic meltwater almost to the same degree as its inflows. The meltwater impact zones within a lake are likely to be inlets and areas adjacent to these inlets, with the exact dimensions of the affected area being determined by the volume, flow velocity, depth of entry and density of the inflowing water mass, as well as the geometry of the inflow site (Fig. 3). Headwater lakes are likely to be more severely impacted by acidification than higher order lakes (Schnoor *et al*. 1983).

The following section discusses the winter lake cover, its forms, and influences on a lake during its growth and decay.

Fig. 3 Snow Meltwater Pathways Through an Ice-covered Lake



## B. Lake ice initiation, evolution and decay

Climatological factors such as temperature, radiation, precipitation, windspeed, etc., determine the spatial and temporal patterns of both dry and wet deposition and influence both the accumulation and ablation of terrestrial and floating snowpacks. These same climatic factors will also determine the formation sequence, duration, and type of ice cover that forms on a lake each year, as well as the release of meltwater from it and associated pollutants.

A lake's winter cover exerts a physical control over the energy inputs into the water body and also acts alternately as a sink, and a source, of water and solutes to the lake. Any discussion of spring meltwater dynamics would not be complete without some reference to the roles of the lake's winter cover.

In autumn, lakes undergo a net deficit of energy, as losses through radiation, convection and condensation/ evaporation exchange exceed gains. As the lake's summer thermal stratification breaks down and a turnover takes place, cold, dense water descends and is replaced by warmer, lighter water from below (Hutchinson 1975). Under high wind or other turbulence, this fall turnover can continue until the entire water column is circulating at a temperature well below 4°C, the temperature of maximum density (Schindler *et al.* 1974). Eventually a situation arises where less dense, cool water overlays warmer, denser water during a calm period and the lakes surface freezes over.

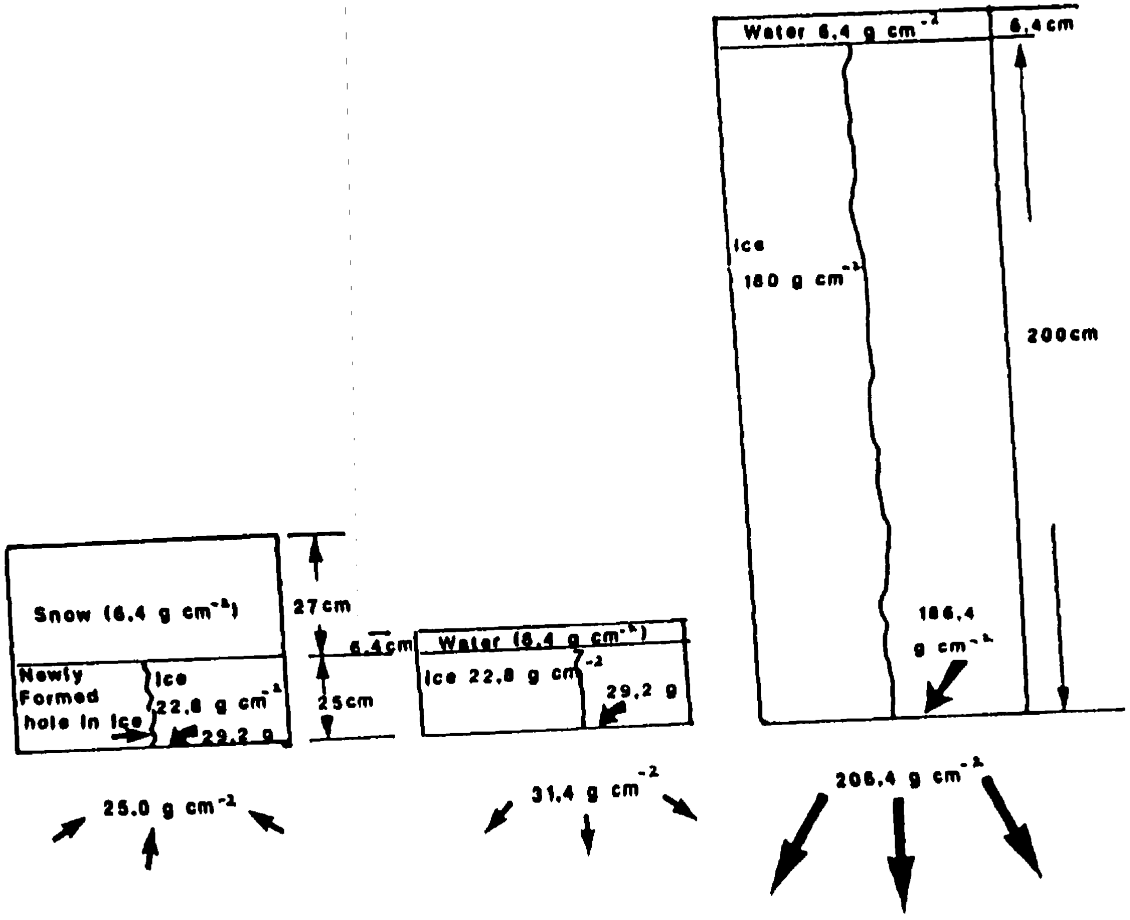
The initial orientation of the tiny platelets and other crystals of ice which form on the surface of the freezing water is, to some degree, random, but as the sheet thickens, some crystals grow downwards much more quickly than others, pinching out those crystals which have different orientations and producing a fairly orderly body of crystals (Gow 1986). Unlike sea-ice where the horizontal orientation of the long or c-axis is favoured, lake ice can be composed of vertically or horizontally orientated crystals, or even a combination of the two (Knight 1962, Pounder 1965). The end result is a sheet composed of columnar crystals or "candles", elongated in the vertical plane, parallel to the direction of the heat flux between the lake and atmosphere. This pure, translucent ice is known as "black" ice.

After the ice sheet is established, the lake continues to lose heat at its upper surface, through the ice sheet, to the cold overlying atmosphere. As more water molecules are added to a growing ice crystal, its structure becomes more regular and symmetrical. Because this highly organized structure cannot accommodate other molecules without a severe local strain, salts, air and other solutes are rejected by the advancing surface of the growing ice crystal in this case, into the underlying lake water. Both air and dissolved solutes accumulate just ahead of the advancing crystal surface. As air concentrations increase, bubbles begin to nucleate and grow as more air diffuses into them. Fast freezing will lead to a large number of small bubbles in the ice matrix, as there is insufficient time for the air to diffuse and produce larger bubbles. Slow freezing produces ice that is largely bubble-free, as rejected air has time to diffuse away from the freezing interface before bubble nucleation occurs (Chalmers 1959, Pounder 1965).

A variant of this initial freezing scenario occurs when freeze-up takes place during a substantial snowfall or at a time when the lake surface is agitated. In this case the initial ice sheet is composed of "white" or "snow" ice. This ice type contains a considerable concentration of air bubbles and the freezing takes place around the individual snow nuclei. As a result this ice is granular and is opaque to natural light. Falling snow strongly influences the developing ice sheet. The relatively low thermal conductivity of the snow, as compared to the ice, reduces heat loss to the atmosphere, slowing the growth of the black ice. As surface snow is metamorphosed, redistributed and deflated, the rate of black ice growth will vary, both temporally and spatially (Adams and Prowse 1980).

If sufficient snow is present, the ice surface will be depressed below the hydrostatic water level. Should thermal cracking occur, as a result of rapid and large temperature changes (Gold 1966, 1967, Weeks 1967, Wilson et al. 1954), or the ice sheet become isothermal (ca. $-1^{\circ}C$), (Brownman 1974) while the ice sheet is depressed, its surface and the overlying snowcover will be flooded with lake water (Fig 4). The depth of flooding will be higher than the depth of ice

Fig. 4 Pressure differences at the bottom of holes or cracks in ice resulting from snow and water loading of the ice cover



depression because of capillary rise into the overlying snowpack. The initial result is a layer of slush (saturated wet snow, Colbeck 1982), largely composed of lake water, underlying a now thinner snowpack. Below-freezing temperatures will cause the slush to start freezing from its surface downwards toward the ice sheet. Additional snowcover may serve to insulate the slush lens, allowing it to persist for long periods of time. While a slush lens is present, black ice ceases to grow, as the thermal gradient between lake and atmosphere is interrupted, and black ice thickness may actually decrease as the ice sheet is depressed into warmer water (Adams 1981). Since slushing can occur several times per winter, multiple slush lenses may be present in an ice sheet at any one time.

White ice can also form without the involvement of lake water. Terrestrial runoff or rainwater may saturate a portion of a floating snowpack and may later freeze, resulting in a new white ice layer superimposed on the previous winter cover (Kingsbury 1983). White ice densities range from 0.78-0.91 $g/cm^3$, while black ice densities range from 0.90-0.917 $g/cm^3$ (Adams 1976).

The establishment of a winter cover dramatically alters the energy flow through a lake and therefore influences the winter-spring physical, chemical and biological cycling that occurs within it. Mass and energy exchanges from evaporation/condensation cease, the net radiative flux is altered and sensible exchanges become negligible. Because of the high latent heat of melting of ice (333.46 $J/cm^3$), the melting of the ice cover (depending on climatological regime and thickness), can be the dominant term in the annual heat budget of a lake (Brewer 1958, Schindler et al. 1974, Adams and Lasenby 1978). Some lakes suffer oxygen deficiencies during winter for the lake is sealed from its atmospheric oxygen source while in-lake oxygen demand continues (Mathias and Barica 1980, Babba and Prepas 1985, Welch and Bergmann 1985, etc.) . The loss of oxygen is somewhat balanced by freezeout of oxygen from the ice cover into a decreasing water volume, but any slushing event and subsequent white ice development represents an oxygen loss from the underlying water. Salts and other solutes are also excluded from a growing black ice cover, increasing their concentrations in a decreasing water volume. The slushing of the lake again represents a loss of solutes to the lake (Adams and Lasenby 1985); however at spring breakup or earlier, these lake-derived ions, as well those ions deposited from winter precipitation, enter the unfrozen lake.

At the beginning of the spring break-up period, snowmelt runoff from the surrounding drainage basin may flood onto the ice surface, producing dark slush ice. At the same time snow cover on the ice surface begins to densify and melt. The ice around the near shore areas generally begins to melt first because of its darkened surface and consequent lower albedo, the relatively small volume of water in this area, which warms rapidly, and also because the ice is thinner at the lake margins where the lake is shallow. Snow drifts which accumulate in some downwind nearshore areas may however retard ice-melt at these locations. Eventually the ice cover melts completely around the lake edge, leaving a free floating ice pan. Melt occurring at the ice surface produces meltwater which flows over the ice and drains either into the lake at the ice margins or through holes that develop along old thermal cracks, ice fishing holes, etc.. Water draining through these holes often enters the lake in a turbulent vertical vortex (Allan 1986). These vortices are driven by a combination of the initial head difference between lake and meltwater and the pressure imbalance created by this additional water (Fig. 4), (Woodcock 1974, Allan 1986a). The magnitude of these pressure differences is dependent on both the hydraulic head of the surface water and the thickness of the ice sheet.

It is interesting to note that if an ice sheet is depressed by a snowcover, lake water will move upwards through any opening in the ice cover. If the same ice sheet is depressed by an equivalent amount of rain or runoff water, this water will drain down into the lake (Fig. 4). The different responses are a result of pressure differences at the bottom of the hole in the ice sheet. When an ice sheet is loaded with snow, the pressure at the base of the ice cover is equal to the sum of the weight of the snow and ice cover (29.2g/$cm^2$ in Fig.4). The pressure at the base of the hole is equal only to the weight of the water height in the hole (25g/$cm^2$ in Fig. 4). This represents a low pressure area through which lake water will flow upwards, slushing the overlying snowpack. When an ice sheet is loaded by liquid water, the pressure at the base of the hole is equal to the weight of the column of water in the hole plus the weight of the water on the ice surface (31.4g/$cm^2$ in Fig. 4). This represents a high pressure area where surface water will drain downwards into the lake. If the ice sheet is quite thick, as it is in arctic lakes, the pressure at the bottom of the hole can be high and can transport surface water to substantial depth in the lake (Fig. 4, Allan 1986a).

Once surface meltwater drains away, a porous, white, crumbly lattice is left. Large amounts of solar energy are reflected by this surface because of its high albedo. Any solar energy that does penetrate the ice sheet will cause internal melting. As this internal melt proceeds, water accumulates beneath the ice surface, causing the ice sheet to take on a black appearance. This decrease in albedo increases absorption, and melt by solar radiation, and eventually wind and water currents rapidly break up the deteriorating ice cover. Circulation is induced, bringing warmer water to the surface, rapidly melting any residual ice (Williams 1967, Heron 1985).

## C. Lake inflow dynamics

Lake water quality is greatly influenced by the degree of inflow entrainment (mixing), that occurs within a lake. It follows that the water quality downstream of a lake system will also be influenced by the amount of mixing that occurs within each lake. The ability to predict the degree of entrainment of inflows, including the products of the winter cover, has tremendous implications for water quality management. For example, it may be possible to identify lakes which are vulnerable to spring acid pulses from various morphometric and hydrologic indices.

A major effect of a lake's ice cover on lake circulation is to seal the unfrozen water body from most atmospheric turbulence. This allows a weak "inverse" thermal stratification to develop, with colder, less dense water overlying denser, warmer water (Hutchinson 1975). This inverse thermal stratification acts to confine snowmelt inflows to the upper surface waters (Schindler et al. 1974, Prentki et al. 1979, Hendry et al. 1980, Bergmann and Welch 1985, Allan 1986, Linsey 1983, personal communication). Several documented cases of pH depressions under ice cover with inverse stratification are found in the literature (Groterud 1972, Hultberg 1977, Henriksen and Wright 1977, Jeffries et al. 1979, Lazerte 1984, Baird et al. 1985 and Gunn and Keller 1985). The presence of the ice cover increases the probability of occurrence, and the potential severity, of an acid pulse by confining the pollutant to a small, shallow area where relatively little dilution can occur. The shallow littoral zones of lakes are the most productive areas of most lakes and act both as spawning grounds and nursery areas for several important and desireable fish species (Jeffries et al 1979, Gunn and Keller 1985).

The input of water into a lake can cause considerable alteration to water quality characteristics such as temperature, dissolved gases and solutes within the receiving body (Stauffer and Armstrong 1985, Elser and Kimmel 1985). Parameters such as inflow volume, density and depth, lake basin shape, etc., will control the distribution and residence time of inflows within a lake (Kaajosari 1966, Wunderlich 1971, Kvarnas and Lindell 1973, Carmack et al. 1979, 1986). Inflow mixing within lakes has been described by mathematical models which solve a series of equations for turbulent motion and mean motion (Svensson 1978). However, these models are exceedingly complex and require large amounts of computer time (Hansen 1978). A simplified approach, integrating the equations of motion over the depth of a layer, with either empirical or theoretical expressions for the exchange of matter between layers, has been used with success and appears more practical. Examples of this approach, developed to describe inflow and outflow dynamics in open and ice covered lakes, include Schab and Katz 1974, Hansen 1978, Stigebrandt 1978, Killworth and Carmack 1979, Svensson and Larsson 1980, Stewart and Martin 1982, Bengtsson 1986.

The movement of water into a lake from its surrounding terrestrial catchment via channelised and unchannelised flow can be described as a two-phase process (Fischer <u>et al</u>. 1979). During the first phase, incoming water pushes and displaces relatively stagnant lake water out into the lake until buoyancy forces become sufficient to arrest the forward momentum of the inflowing water mass. Once the initial forward momentum of an inflow is reduced, the incoming water mass will move to a lake layer of similar density and proceed through the lake either as interflow, underflow or throughflow (Fig 5). The initial flux of kinetic energy ($K_I$) to the lake from an inflow is given by the integral defined in equation 1.

$$K_I = \int_A 1/2\, \rho_i u^3 dA \qquad (1)$$

where u= velocity $m^3 s^{-1}$

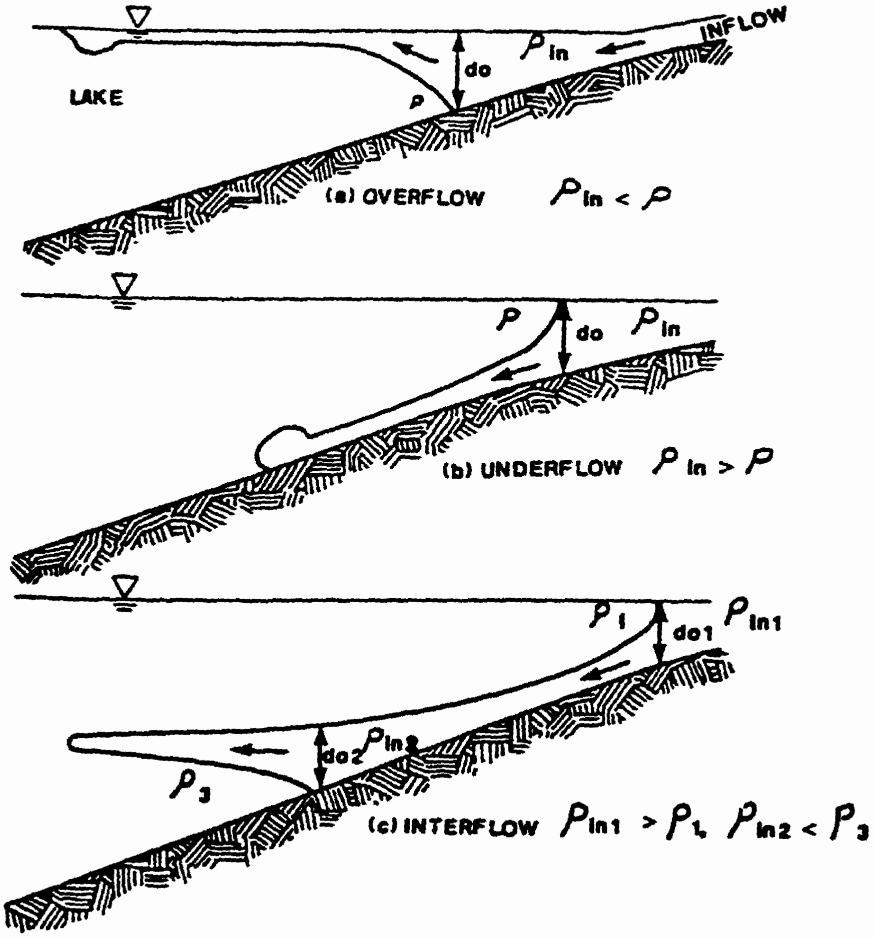
A= cross sectional area $m^2$

$\rho_i$= density of inflowing water $kg/m^3$

(Fischer <u>et al</u>. 1979)

The buoyancy forces which counteract this inflow energy develop from variations in fluid density (thermal or concentrational), and are expressed by Archimedes' Principle whereby a body that is immersed in a fluid is buoyed by a force equal to the weight of the fluid displaced by the body

FIG. 5 TYPES OF LAKE INFLOW



(in this case the incoming water mass), (Vennard 1955, Turner 1979).

The vertical mixing in an ice covered lake is generally restricted to inlet regions, while the main part of the lake, outside of the outlet area, can be looked upon as a storage and transport region, (Fig 6), (Stigebrandt 1978). The way an inflow enters a lake depends on the geometry of the inflow, the volume of flux ($Q_i$, defined below) in the inflow and the density difference ($\Delta\rho$), between inflow and lake water. If the transition between inflow and lake is abrupt like a channel entrance sitting on a vertical wall, two scenarios are possible. Depending on the magnitude of the densimetric Froude number (the ratio of gravitational to inertial forces acting on a fluid) as defined in equation 2.

$$Fd=u_i/(g(\Delta\rho/\rho_o)H)^{1/2} \qquad (2)$$

where H= depth of inflow

B= rectangular cross sectional width

g= acceleration due to gravity

$u_i$ is defined by $Q_i= u_i x B x H$

$\rho_o$= lake water density

$\Delta\rho= \rho_i-\rho_o$

(Stigebrandt 1978)

If Fd<1, then lake water will penetrate up into the inflow in the same manner as a salt wedge in an estuary (Fig 7). If Fd>1, then lake water cannot penetrate into an inflow and the inflow will discharge into the lake like a

FIG. 6 ICE-COVERED LAKE DYNAMIC REGIMES

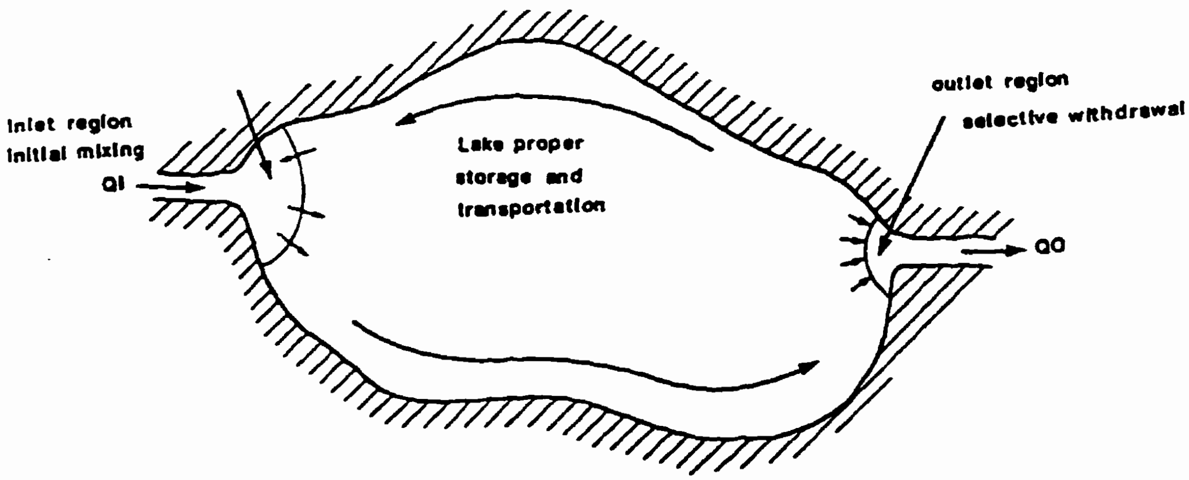
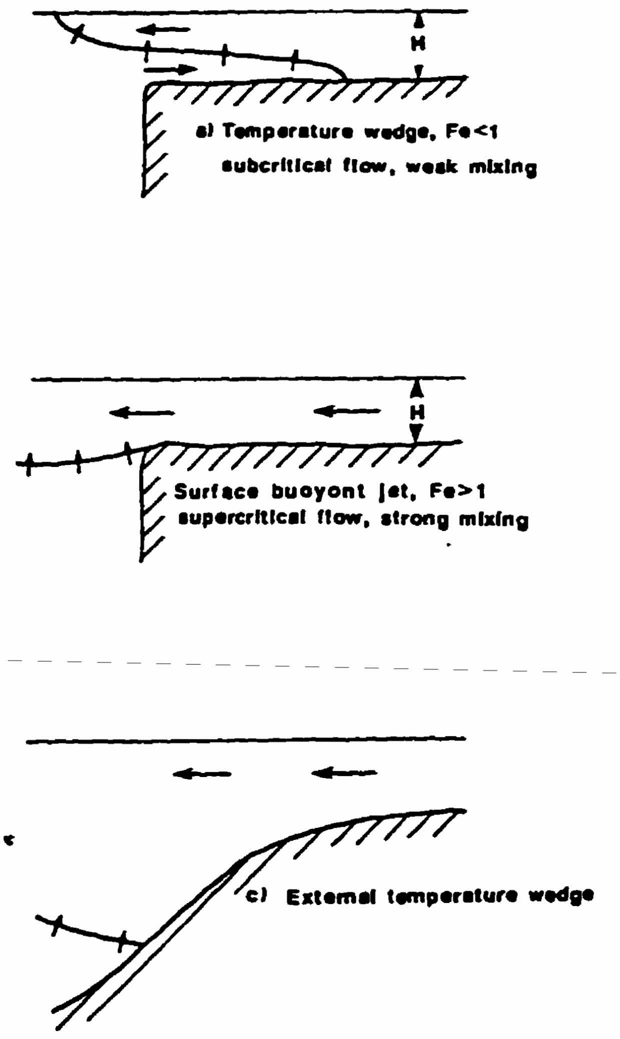


**Fig. 7** DYNAMIC POSSIBILITIES OF RIVER- LAKE INTERACTIONS



jet (Fig 7). The mixing is known to be small in the temperature wedge case (subcritical flow). In the jet case (supercritical flow) the mixing can be quite large depending on the magnitude of the Froude number and the geometrical conditions in the lake. If the transition from river to lake is geometrically smooth, the river water can possibly follow the diverging boundaries of lake surface and bottom (Fig 7). This is known as an external temperature wedge and it is believed that flow under this scenario will be subcritical and the mixing weak (Stigebrandt 1978).

The mixing and entrainment of water masses in a lake depend on the boundary conditions between the inflowing fluid and the resident fluid. A certain amount of mixing always accompanies water entering a lake because of the lateral and vertical boundary transfers between moving and quiescent water. Boundary layers are formed whenever a fluid moves over a surface. In the lake inflow case, the surface would consist of the relatively stationary resident lake water. The type of fluid flow turbulent, or laminar, is of considerable importance to lake mixing. In laminar flow, the properties of the two fluids can only be transferred by random thermal movement of molecules (molecular diffusion). This means that the rate of transport of heat, and dissolved gases and solutes, will be relatively slow. Under turbulent flow conditions, discrete parcels or eddies of fluid move randomly from one stream to another. This provides a very efficient transport mechanism known as eddy diffusion or turbulent transport. A model for mixing between lake and inflow water should give the net amount of volume fluxes through the border between mixing zone and lake proper. To calculate this, one must know the vertical distribution of the mean horizontal current velocity normal to the border, $u_{in}(z,t)$. However there is no way to calculate $u_{in}$ for either the temperature wedge case or the jet case within a lake (Stigebrandt 1978).

The energy available for mixing may be estimated by calculating the decrease in mean potential energy as the inflow water enters the lake. The initial potential energy of a lake inflow system ($P_I$) is given in equation 3.

$$P_I=\rho_o V_o g\bar{z}_o+\rho_i V_i g\bar{z}_i. \qquad (3)$$

where $V_o$ and $V_i$ are the lake and inflow volumes respectively.

$\bar{z}_o$ and $\bar{z}_i$ are the height of centres of mass of the lake and inflow volumes.

(Fischer <u>et al</u>.1979)

The potential energy available for mixing after the inflow has entered the lake becomes equation 4.

$$P_I-P_f=\Delta\rho V_i g(z_i-\bar{\zeta}_i) \qquad (4)$$

Where $\bar{\zeta}$ = the height of the mass of the inflow water within the lake.

(Fischer <u>et al</u>. 1979)

The geometry of the receiving water body can strongly influence the mixing of an inflow. Shallow water in the inlet region can result in weak mixing. In this case the inflow can be in contact with the lake bottom, and vertical entrainment of lake water into the inflowing water mass will be hampered. In some cases the entire lake inlet region will be totally mixed however; a narrow or shallow sound downstream will limit any further mixing despite an increase of mixing energy. The inlet region is then said to be overmixed.

Once the inflow has moved into the lake with the accompanying mixing, its momentum slows, and the second phase of lake inflow dynamics occurs; the inflow seeks its own density within the lake's density gradient. The critical section where this occurs is characterized by the densimetric Froude number ($F_o$), defined below.

$$F_o = (Q/A_o)/\sqrt{g(\Delta\rho/\rho_i)}\,d_o \approx 0.5. \qquad (5)$$

where Q= inflow rate.

$A_o$= cross sectional area at the critical reservoir section.

$d_o$= the depth of the critical reservoir section.

(Wunderlich 1971).

As mentioned earlier, an ice cover seals a water body from most atmosphere-generated turbulence (Bengtsson 1986). Because of this lack of atmospheric mixing, differences in water density can play a large role in determining the distribution and residence time within a lake, for any inflows that occur during the ice covered period. For small ice-covered lakes, inflows can have a short residence time either because of a lack of mixing or because of a short in-lake travel time when an inflow is in close proximity to the outlet region. This often "short circuits" the lake, and results in little alteration of the inflow quality characteristics as reflected in the lake outflow. Lake outflows "selectively" withdraw water from specific layers within a lake. Often only the surface layer of ice covered natural lakes can leave a lake because of bedrock or other controls on outlet shape (Stigebrandt 1978). The thickness of this withdrawal layer ($d_1$) can be estimated by equation 6.

$$d_1 = 4.5a_1 \qquad (6)$$

with $a_1 = ((Q_1/B_1)/\sqrt{g\varepsilon_1})^{1/2}$

and $\varepsilon_1 = (1/\rho_i)(d\rho/dz)_1$

Modified from (Wunderlich 1971)

Direct precipitation on the lake surface (either as snow or rain), is impeded from reaching the lake by the ice cover. The water and the chemical inputs from this source will reach the lake eventually, but usually at a date later than the actual precipitation event. An ice-covered lake is not totally sealed from these inputs, as precipitation can enter the underlying water by three different routes: by percolation through micropores which develop at the ice crystal boundaries when the ice sheet becomes isothermal at ca. -1°C (Brownman 1974); through thermal or other cracks which occur during the white ice building process (Shaw 1965) and at other times; or through natural (Katsaros 1981, Woodcock 1984) or man-made holes as turbulent vertical vortices when the ice surface is flooded (Allan 1986a). Precipitation inputs in the first two cases are likely confined to the surface layers of a lake, just under the ice where their final distribution will be determined by convective thermal circulation processes (Fig. 3), (Mortimer and Mackereth 1958, Likens and Ragotzkie 1961, Palmer and Izatt 1972, Bengtsson 1980, 1981, Rahmm 1985, Welch and Bergmann 1985). Precipitation and snowmelt that enter the water body by the third route act much more like a stream input and can influence the receiving water body to a depth of 5.5m or more (Allan 1986a).

## Section 2 Objectives

The major objective of this research was to undertake a detailed field study of a small Precambrian Shield lake during the spring snowmelt to document spatial and temporal variations in winter cover and nearshore water quality. It sought to determine the severity and spatial extent of the impact of acidic runoff on the littoral zone of such a lake. It was hypothesized that thermal, and possibly concentrational, density differences, would inhibit mixing between incoming and resident lake water. A possible consequence of this lack of mixing would lead to a shorter residence time for snowmelt runoff within a lake, and increased concentrations of acidic meltwater within the lake's littoral zones. It follows that there should be differences in water quality between shoreline sites, with each site being influenced to different degrees by different meltwater pathways (channelized flow, non-channelized surface flow, groundwater inputs and lake cover runoff), and also between the nearshore zones and the lake's "deep hole", which is the regular sampling site of limnologists. Also, if there is a lack of mixing within a lake and overflow is occurring, the lake's outflow should respond relatively quickly to inflow changes and reflect the changes in water quality of these inflows. It was proposed to use natural and artificial fluorescent tracers to track snowmelt inputs under the ice cover and to identify specific areas of the lake influenced by each particular inflow. Under-ice inflow behavior was to be explained in terms of some simple inflow and physical limnologic dynamics described in the literature.

A second major objective was to try to predict the mixing depth of a lake's inflows from watershed morphometric and topographic data. It was proposed to accomplish this by determining the mixing depths of several lakes in the study area during the snowmelt and developing an empirical relationship between the mixing depth and the topographic information using multivariate statistical techniques. The underlying assumption here is that a lake's mixing depth is related to the proportion of inputs coming from defined stream channels as opposed to non-channelized surface runoff and groundwater.

A third major objective was to document the spatial and temporal changes in the physical and chemical parameters of the study lake's winter cover. It was believed that by monitoring a lake's winter cover in this manner, it would be possible to determine if the winter cover could account for any of the observed changes in nearshore water quality. It was also an objective to determine the potential solute loading from the winter cover. The inputs from a headwater lake's winter cover are important because they represent an appreciable percentage of the annual loadings to the lake. Such inputs are not appreciably altered by the terrestrial basin and they may appreciably modify terrestrial runoff within a lake.

## Section 3 Study area

The study area for this research was the lakes and watersheds of the Muskoka-Haliburton region Ontario, Canada (NTS 1960 a,b,c,d), (Fig. 1). This area has been investigated by the Ontario Ministry of the Environment (OME) since 1975 as part of the Lakeshore Capacity Study and/or the Acid Precipitation in Ontario Study.

This section is divided into two parts. The first is a regional overview of the climate, geologic history and bedrock and surficial geology of the area. The second comprises a description of Plastic Lake and its watershed followed by a brief description of other lake catchments investigated.

## A. Climate

The mean annual temperature from the Dorset weather station is 4.4°C (Table 1) with four months below 0°C, January being the coldest month (-11.0°C), and July the warmest (17.7°C), (AES 1982). The lakes in the area are generally ice-covered from December 1-15 until April 15-May 1, four to five months of the year (Scheider et al. 1983). Mean peak lake ice thickness recorded in the area is 58.0 cm. (Allen 1977). The mean annual rainfall recorded at Dorset is 804.3 mm (Table 3), with a further 271.6 mm (water) of precipitation falling as snow (Table 4). Mean total precipitation for the ice-on period is 444.4 mm, of which 47.0% falls as rain (Table 2), (AES 1982). Generally, each month during the ice-on period receives some precipitation in the form of rainfall. On average the highest precipitation month is November (116.6 mm total) and the lowest is March (63.0 mm total), (Table 2).

## B. Regional bedrock and surficial geology

The following is largely taken from Jeffries and Snyder (1983). The study area is located near the southern fringe

Table 1 Mean Daily Temperature (°C), Dorset, Ont.

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -11.0 | -10.2 | -4.1 | 4.2 | 10.6 | 16.0 | 17.7 | 16.9 | 12.4 | 7.1 | 0.3 | -7.3 | 4.4 | 1 |
| -13.6 | -7.8 | -3.7 | 3.8 | 11.1 | - | - | - | - | - | - | - | - | 2 |

1 Data source:- AES (1982) data record 5-19 years inclusive along with any other available data.

2 Data source:- (I. Smith unpublished data from 1985).

Table 2 Mean Monthly Total Precipitation (mm), Dorset, Ont.

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 104.0 | 71.8 | 63.0 | 74.4 | 74.8 | 105.6 | 87.9 | 100.2 | 110.1 | 91.2 | 116.6 | 102.6 | 1102.2 | 1 |
| 69.9 | 103.9 | 117.4 | 101.2 | 89.5 | - | - | - | - | - | - | - | - | 2 |

1 Data source:- AES (1982) 5-19 year record inclusive along with any other available data.

2 Data source:- (I.Smith unpublished data from 1985).

Table 3 Mean Monthly Total Rainfall (mm), Dorset, Ont.

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16.8 | 16.6 | 30.9 | 61.9 | 75.0 | 105.6 | 87.9 | 100.2 | 110.1 | 87.9 | 81.1 | 30.3 | 804.3 | 1 |
| 0.2 | 42.0 | 44.6 | 60.9 | 89.5 | - | - | - | - | - | - | - | - | 2 |

1 Data source:- AES (1982) 5-19 year record inclusive along with any other available data.

2 Data source:- (I. Smith unpublished data from 1985).

Table 4 Mean Monthly Snowfall (cm), Dorset, Ont.

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72.4 | 51.0 | 38.3 | 8.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 35.1 | 65.8 | 271.6 | 1 |
| 69.7 | 61.9 | 72.8 | 40.3 | 0.0 | - | - | - | - | - | - | - | - | 2 |

1 Data Source:- AES (1982) 5-19 year record inclusive along with any other available data.

2 Data Source:- (I. Smith unpublished data from 1985).

of the Canadian Shield, a large region of Precambrian bedrock which covers nearly half of Canada. The geology of the area is a result of rock formation and orogenic alteration during Precambrian times followed by long-term erosion (ca. 954.9 my), and eventually Pleistocene glaciation (ca 0.1 mybp). The major effects and currently observed features in the study area can be attributed to the Wisconsin glaciation (Ontario File Report 1977), which lasted approximately from 80 to 12 thousand years BP. Glacial erosion rounded and polished the rock knobs and ridges, scoured many basins now occupied by lakes and re-deposited numerous types of glacial debris.

Presently one third of the area is exposed bedrock or covered by extremely thin drift (a few tens of centimetres). The remaining two thirds is primarily covered by thicker till deposits with significant occurrences of clay and sand plains interspersed with hills or ridges of sand and gravel. Typical landscape includes rocky knobs and ridges separated by lakes and/or swampy lowlands with disjointed drainage patterns attributable to structural controls.

The study area is located within the Grenville Province and is distinguished by certain metasedimentary and metavolcanic rocks. The largest proportion of these rocks are of granitic composition, usually granite gneisses and migmatites, while marbles, quartzites, amphibolites and various igneous intrusives (pegmatites, diorites, ultrabasics, etc.) are of lesser importance. The predominating bedrock minerals are quartz, feldspars, biotite and horneblende (Hewitt 1967). All these minerals are silicates and extremely resistant to weathering and incapable of providing much buffering capacity to surface water systems.

The surficial deposits which occur in the study area are generally composed of unconsolidated material laid down during Quaternary glaciations, plus more recent stream and beach deposits. all the above have been altered somewhat by weathering in the intervening time period (Chapman 1975).

### B. Plastic lake drainage basin

The following is largely taken from Girard *et al.* (1985). Plastic Lake ($45^{\circ}$N,$78^{\circ}$W, elev. 376.4m asl) is a 32.14 ha Precambrian Shield headwater lake (Fig. 8). It has a mean depth ($\bar{z}$) of 8 m and a maximum depth (Zm) of 16 m. Plastic lake morphometric indices are presented in Table 5.

The 95.5 ha watershed contains one small open water pond in subwatershed number five. Plastic Lake is fed by one perennial stream (Plastic 1) and four dominant ephemeral streams (Plastic 2,3,5 and 6), (Fig. 9). Its basin appears to have being formed by glacial scouring on structurally -weakened bedrock at the intersection of several bedrock faults.

Approximately 52% of the catchment is drained by channelized flow. The Plastic Lake shoreline consists largely of shallow (<30 cm) organic or gravel material

FIG. 8 PLASTIC LAKE BATHYMETRY

Haliburton Co.
Sherborne Tp.
Lat 45° 11' Long. 78° 50'

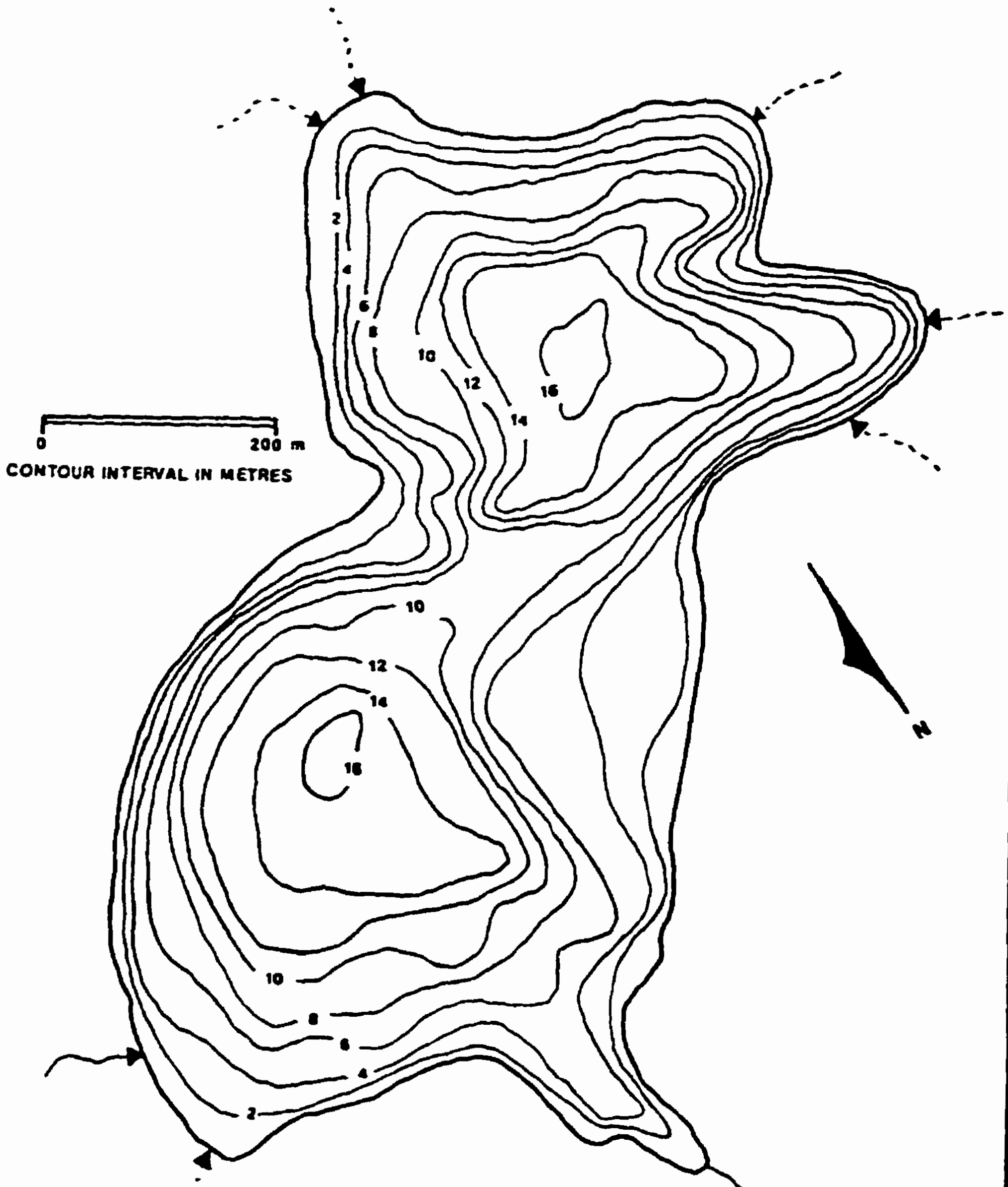
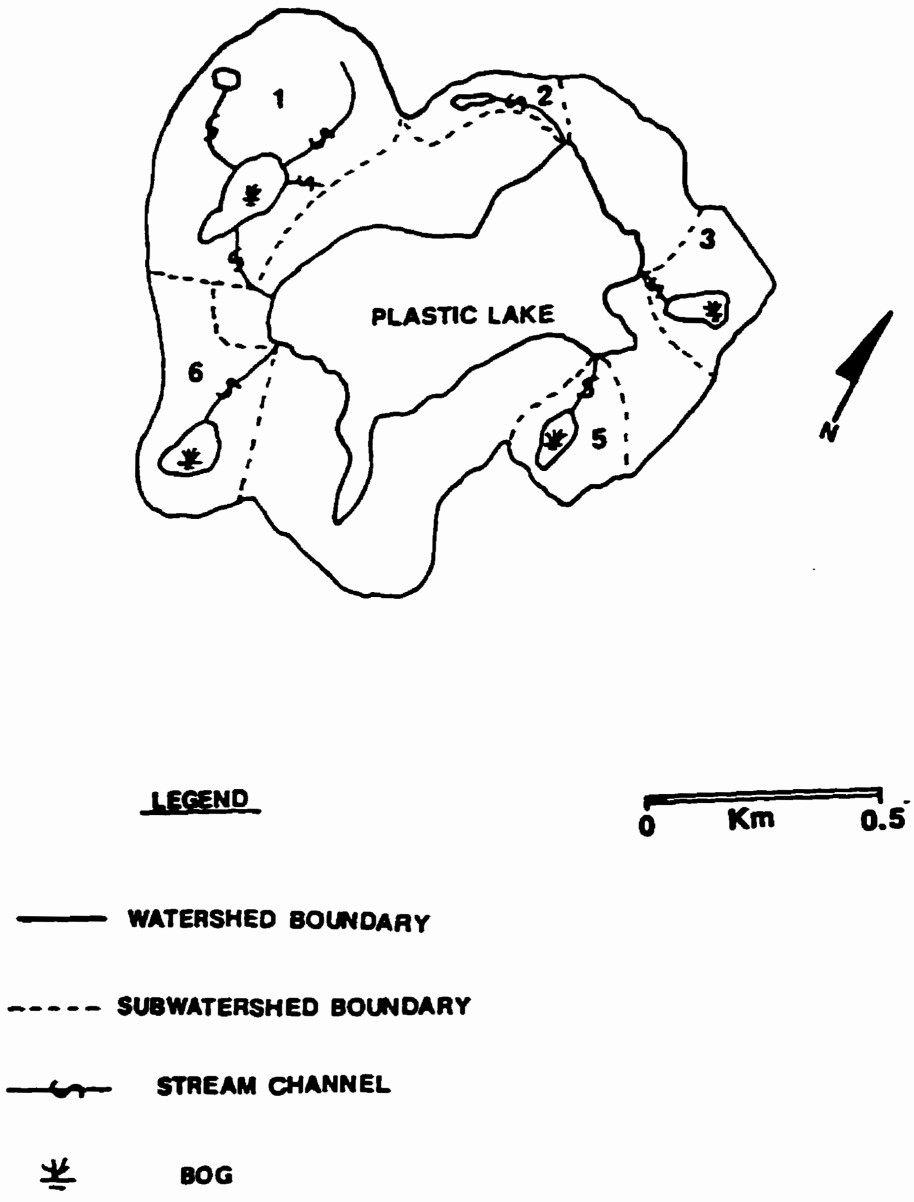


Table 5 Plastic Lake morphometry summary

| | |
|---|---|
| Lake area (ha) | 32.14 |
| Drainage basin total less lake area (ha) | 95.50 |
| Gauged terrestrial drainage (ha) | 23.34 |
| Lake volume V ($m^3$ x $10^5$) | 25.8 |
| Mean depth $\bar{z}$ (m) | 8.0 |
| Maximum depth Zm (m) | 16.0 |
| Shoreline length L (km) | 2.92 |
| Shoreline development $D_L$ | 1.45 |
| Volume development $D_v$ | 1.50 |

FIG. 9 BASIN DESIGNATION OF THE PLASTIC LAKE WATERSHED



interspersed with boulders (65%), or bare rock (24%). Smaller sections consist of moderately thin (>30 cm), organic or gravel material (9%), and boulders with no fines (<2%), (see methods section). Direct runoff that does not enter the lake via channelized flow is generally confined to the upper few centimetres of the lake upon entry by exposed or near-surface bedrock.

The Plastic Lake watershed bedrock consists of hard, erosion-resistant gneiss with a substantial igneous component. Ortho-gneiss forms the high polished ridge tops, while fault zones and beds with stronger metasedimentary characteristics tend to dominate the valleys. A small meta-gabbro plug is present on the east shoreline of the lake.

The surficial deposits in the Plastic Lake watershed are generally quite thin (<2 m), and dominated by a shallow, discontinuous, sandy basal till. The thin soil and surficial deposits saturate quite quickly during snowmelt. Depressions in the bedrock allow the accumulation of organic matter and are water-saturated much of the year. Soils in the watershed are quite thin and range between weakly-developed podzols and poorly developed brunisols. A pit-mound terrain has developed as mature trees topple as a result of the thin, sandy surficial cover.

The forest is dominated by conifers, with _Tsuga canadiensis_ _(L.)_ _Carr_. and _Pinus strobus_ _L._ being common. _Picea mariana_ _(Mill.)_ _B.S.P_. dominates the water saturated sphagnum bog areas, while hardwoods such as *Acer sp.* and *Betula sp.* are common in areas with slightly thicker till deposits.

Mean chemistry concentrations for Plastic Lake during 1984 are given in Table 6.

The locations of the other lakes investigated in the study are given in Fig. 1. It should be noted that Red Chalk Lake is a double basin lake and Glen Lake's watershed is underlain by deep surficial deposits of carbonate-rich till (Scheider *et al*. 1983).

Table 6. Mean* Plastic Lake chemical concentrations 1984 (P. Dillon unpublished studies).

| | |
|---|---|
| pH | 5.72 |
| Total inflection point alkalinity (TIPAlk) (mg/l as $CaCO_3$) | 0.52 |
| Cond (uS @25°C) | 24.7 |
| $Ca^{+2}$ (mg/l) | 2.0 |
| $Mg^{+2}$ (mg/l) | 0.46 |
| $Na^{+}$ (mg/l) | 0.47 |
| $K^{+}$ (mg/l) | 0.23 |
| $Cl^{-}$ (mg/l) | 0.35 |
| $SO_4^{-2}$ (mg/l) | 6.7 |
| $NO_3^{-}$ (ug/l) | 21 |
| Total Kjeldahl nitrogen (TKN) (ug/l) | 215 |
| Total unfiltered phosphorus (PPUT) (ug/l) | 6.3 |
| Total aluminum (TAl) (ug/l) | 34 |
| Disolved organic carbon (DOC) (mg/l) | 2.35 |

*Volume-weighted, whole-lake yearly means.

## Section 4. Methods

### A. Hydrometeorologic

Air temperature and precipitation data were obtained from the Environment Canada meteorological station at Dorset, Ont. ca. 10 km from Plastic Lake, (I. Smith unpublished data). Meteorological methods are summarized in Locke and deGrosbois (1986) and Locke and Scott 1986. Hydrologic data for the period January 3, 1985 to May 13, 1985 were provided by P. Dillon and L. Scott (O.M.E., Dorset research centre (D.R.C.)). All hydrologic methods are described in detail in Scheider et. al. (1983).

The Plastic Lake water budget was calculated as outlined in equation 7.

$$\text{Input} = \text{Output} \pm \text{Storage} \qquad (7)$$

Where $\text{Input} = Pr + Q_{P1} + Q_{rest}$

$Pr$= precipitation falling on the lake surface

$Q_{P1}$= Plastic 1 flow

$Q_{rest}$= Plastic 1 flow * $3.09^{a}$

$^{a}$3.09 is equal to the ratio of the area of ungauged Plastic Lake cathment: Plastic 1 area.

$\text{Output} = Q_{POF}$

$Q_{POF}$= Plastic Lake Outflow flow

Evaporation was assumed to be zero during the period of ice cover (Schindler et al. 1976). Change in storage was solved as the residual in the water budget equation.

### B. Precipitation chemistry

Precipitation chemistry was obtained from P. Dillon of the OME Dorset research centre. Bulk deposition was collected from the Plastic Lake OME precipitation collection site. Precipitation chemistry collection procedures are outlined in Locke and Scott (1986). Collection periods ranged from four to sixteen days during the study period. Calculations of the input of material to the lake from precipitation were carried out as outlined in equation 8.

$$Pr_{in} = Prz\ (m) * A_0\ (m^2) * [c]\ (mg/m^3) \qquad (8)$$

Prz= Precipitation depth

$A_0$= Lake area

[c]= Parameter concentration

$Pr_{in}$= direct precipitation inputs

Missing values on January 10 for major cations, TKN and DOC were estimated as a proportion of the recorded $SO_4^{-2}$ value for that sample. Quality control for samples was carried out by the MOE as outlined in Locke (1985). Charge balances for chemistry samples were calculated as outlined in equation 9.

$$(Cat.\ \mu eq/l - An.\ \mu eq/l)/((Cat.\ \mu eq/l + An.\ \mu eq/l)/2) * 100 = \%\ C.I. \qquad (9)$$

Cat.= cations

An.= anions

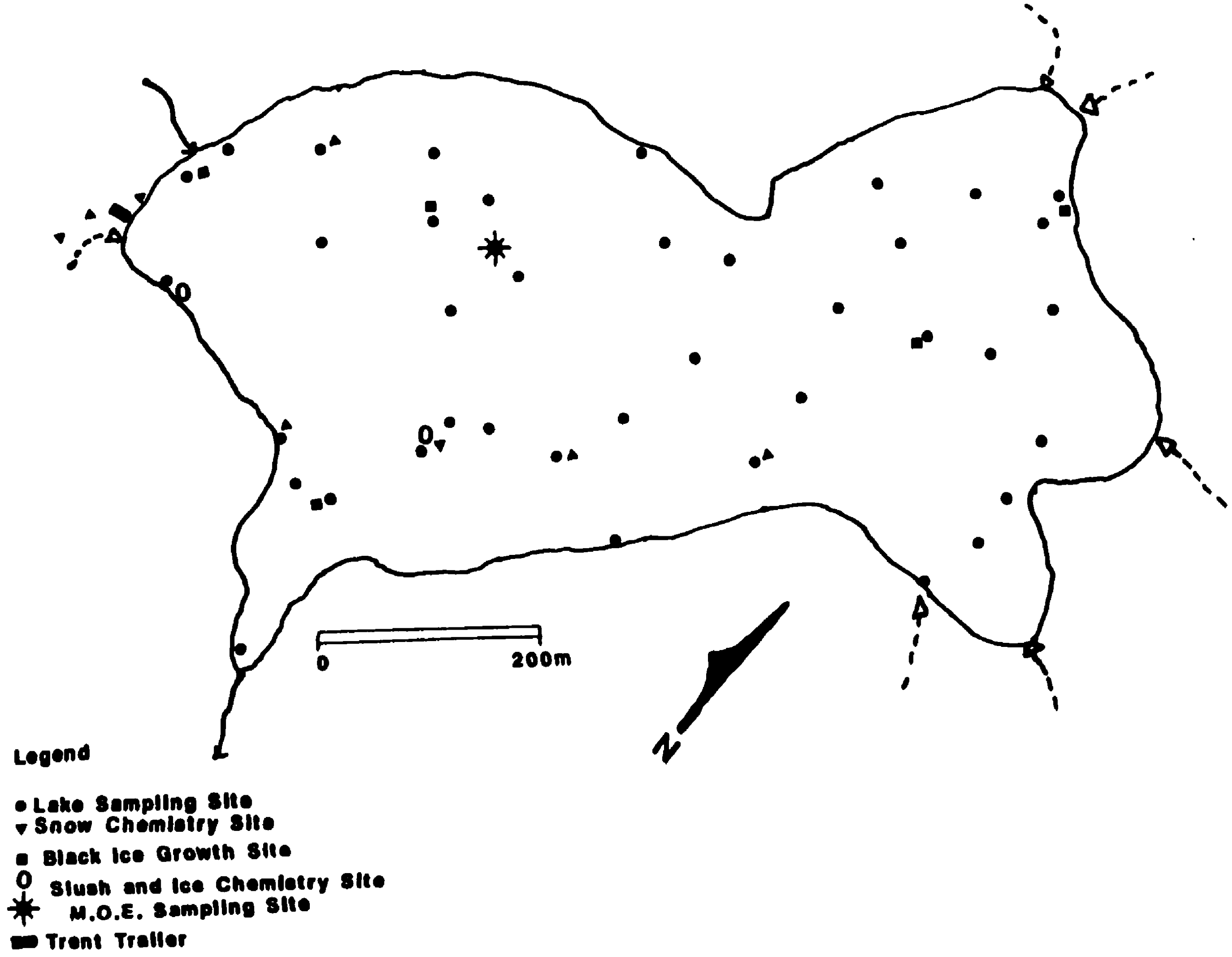
C.I.= charge imbalance

Cations included in the precipitation charge balance were $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $H^{+}$ and $NH_4^{+}$. Anions included were $SO_4^{-2}$, $NO_3^{-}$ and $Cl^{-}$.

### C. Snow sampling

A three point terrestrial snow course was maintained near the Plastic Lake landing (Fig 10). The purpose of the terrestrial snow course was to gain some idea of the timing, and magnitude of chemical flux from the terrestrial basin, to the streams and study lake. Biweekly measurements of snowpack depth, water equivalence and density were conducted with a standard snow tube (Goodison *et al*. 1981). The same measurements were made on the lake surface snowcover until the presence of slush made the determination of water equivalence and density by this method inaccurate. Thereafter only snow depth was recorded. The floating snowpack was sampled to assess the timing and magnitude of the chemical and water flux from it to both the lake and the lake ice cover. In addition to the standard volume measurements, snowpack stratigraphy was measured throughout the winter on both the terrestrial and lake snowpacks by the methods outlined by Adams and Prowse 1978.

Fig. 10 Plastic Lake Sample sites



## D. Snow chemistry

Snow samples were collected at sites adjacent to the snow measurement sites. Initial samples were collected with a clean plastic scoop, until in-pack ice lenses rendered this method impractical. After March 1, a plexiglass tube (1.5 m in length, 10 cm I.D.) was used to sample the snowpack. The corer was inserted vertically to the base of the snowpack and any litter material at the base of the core was removed. The snow core was extruded into clean plastic bags and brought to the DRC where the samples were allowed to melt at room temperature (12-24 hours). Samples collected after March 6 were filtered through a 76 u nitex mesh before analysis. Snow samples collected before this time were not filtered, therefore particulate matter may have influenced the total unfiltered phosphorus, (PPUT) and the total kjeldahl nitrogen (TKN) values reported for these samples. There is some controversy over exactly how to deal with litter within the snowpack. The nitex filtering removed large organic material such as pine needles which would cause serious overestimation of the PPUT and TKN which was available to runoff. By leaving this material in the sample bag any mobile solutes on the litter surface should be accounted for, while material within the actual structure of the litter is not included.

Remaining samples were poured into 600 ml polystyrene sample jars and submitted to the OME laboratory in Rexdale for chemical analysis. Analytical methodology for total kjeldahl nitrogen (TKN), total unfiltered phosphorus (PPUT), total aluminum (TAL), inflection point alkalinity (TIP Alk), major cations and Anions are outlined in OME (1981). Two subsamples of the original sample were poured off. One subsample was submitted to the Dorset chemistry lab for total aluminum (TAL) analysis (Lazerte 1984). A second subsample was analyzed for pH and specific conductance by the author. Specific conductance was measured with a Barnstead Hind Conductivity Bridge standardized to KCl standards (American Public Health association (APHA) 1969), and the readings corrected to 25°C (Edwards *et al.* 1975). Initially pH was determined with a Sargent-Welch pH meter model PBL. After April 9, a Fischer Acumet pH meter was utilized. Both pH meters were standardized to buffers of pH 4 and 7 and were checked every five to ten samples for drift and re-standardized when necessary. Five replicate snow samples were collected at random throughout the sampling season and analyzed for pH and specific conductance to assess variability associated with the sampling and analytical technique. Charge balances were calculated as outlined in equation 9. Parameters included in the charge balance were the same as those in the precipitation chemistry, with the exception of $NH_4^+$, which was not analyzed.

## E. Lake ice cover

Plastic Lake was sectioned on a 100m grid. Coordinates within each grid section were randomly chosen to develop a

35 point stratified random sampling matrix (Fig. 10). The initial thickness of the white ice layer was determined by drilling to the black ice interface and measuring its thickness. Afterwards, a 1m long wooden stake was frozen in place and the height from the ice surface to the top of the stake was recorded (Fig. 11). Any subsequent white ice growth or ablation was determined from this initial reading. The measurements were discontinued when surface ice melt became apparent and the stakes loosened (Roulet 1981).

Five additional sites on the grid were chosen at random and a black ice measuring device was installed at each site (Fig. 11), (Adams 1984). Initial black ice thickness was determined by drilling through the ice cover and measuring the total ice thickness, minus the white ice thickness. The use of these devices was not entirely successful as continued slushing and snowfall prevented several of the devices from freezing in place. When this occurred, black ice thickness was periodically checked by drilling.

### F. Lake ice chemistry

The Plastic Lake ice cover was sampled three times during the study period. Ice chemistry was sampled at sites 3 and 19 (Fig. 10). Site 3 represents an open lake site while site 19 represents an ice "edge" situation. The initial samples were collected from ice chips from an ice auger (Groterud 1972a). Subsequent samples were collected by removing ice blocks with an ice saw. Samples were bagged and brought to the DRC where they were melted at room

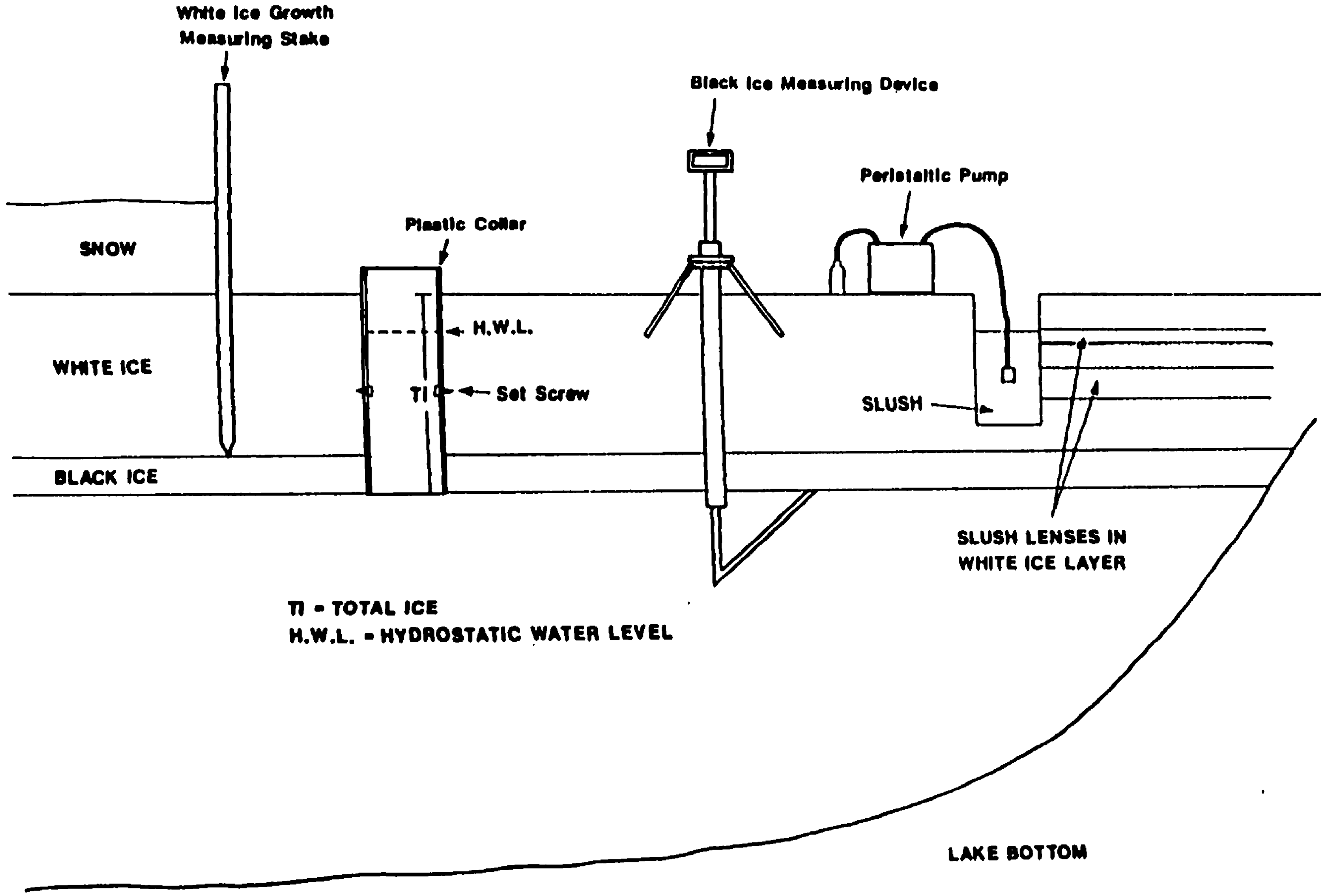


Fig. 11 CROSS-SECTIONAL DIAGRAM OF COMPOSITE ICE MONITORING AND LAKE SAMPLING SITE

temperature (12-36 hours). Ice samples were not filtered but otherwise were treated in the same manner as snow samples. Charge balances for the ice samples were calculated as described in the snow chemistry section.

### G. Slush chemistry

Initial slush samples were collected with a plastic scoop, bagged and brought to the Dorset centre where they were poured off into 600 ml sample jars and submitted to the Rexdale and Dorset laboratories for analysis. Subsequent slush samples were collected by drilling through the overlying ice cover and withdrawing the sample with a peristaltic pump into the same type of sampling jar (Fig. 11), (Gunn and Keller 1985). Sample variance and sample charge balances were calculated in the same manner as outlined in the snow chemistry section. The physical and chemical parameters of the different components of the winter cover of Plastic Lake (snow, slush, white ice, and black ice), were measured to assess the magnitude and the possible influence these components might have on the spring hydrochemical regime of the lake.

### H. Lake sampling

Plastic Lake was sampled five times during the study period by the OME. The south basin deep hole (Fig. 10), was sampled as described by Scheider et al. (1983) and quality control of samples was carried out by the MOE as outlined in

Locke (1985). OME lake chemistry data were supplied by P. Dillon, DRC.

To determine the spatial and temporal trends in lake chemistry, a whole-lake sampling scheme was initiated. At each of the thirty-five white ice sites and the five black ice sites, a hole was drilled through the ice cover and a plastic collar (50 cm long, 10 cm I.D. white plastic PVC pipe) was frozen in place (Fig. 11). The purpose of the collar was to prevent surface rain and meltwater draining into the underlying water column which would skew the sample results (Wolfe 1979). Because the lake ice surface was depressed and had a positive hydrostatic water level, the network was not put into place until March 10. All lake sampling undertaken prior to this date was carried out through natural holes in the ice cover, or through holes that had been drilled for the black ice devices. The plastic collar once frozen in place, appeared to keep out most of the surface drainage successfully.

Each of the forty sample points was sampled ca. fortnightly before April and weekly afterwards. A 1.5 m integrated tube sample was collected from each site. Specific conductance, pH and natural fluorescence were analyzed immediately upon collection at the field station on Plastic Lake. Specific conductance and pH were determined as outlined in the snow chemistry section. Background or natural fluorescence was determined with a generator-powered Turner Mk III Automatic Fluorometer, utilizing a Kodak 47b and a 2A primary filter combination (maximum excitation 490 nm), and a 2A-12 secondary filter (maximum emission 520 nm), (Smart and Laidlaw 1977, Allan 1986b). The determination of sample variance was carried out as outlined in the snow chemistry section. In addition to the above parameters, five sites (BI1, 1, 9, 19 and 31, Fig 10) were sampled in the same manner for: $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $SO_4^{-2}$, $Cl^{-}$, $NO_3^{-}$, dissolved organic carbon (DOC), TAL, PPUT, TKN and inflection point alkalinity (TIP Alk.). These sites were sampled to assess the variability of nearshore chemistry and represented different shoreline types. Sites BI1 and 19 are adjacent to stream entrances, while Site 1 was located in the lake outlet region. Sites 19 and 31 were located adjacent to areas of direct runoff. Site 19 was located adjacent to a low marshy shoreline, and site 31 adjacent to a rocky shoreline. In addition to the regular integrated tube sampling, the five shoreline sites were profiled for pH, specific conductance, temperature and natural fluorescence to assess vertical changes over time. Natural fluorescence and pH samples were withdrawn with a peristaltic pump and analyzed as outlined above. Temperature and specific conductance were measured in situ with a Yellow Springs Instruments combination temperature/ conductivity meter.

Charge balances for lake water were calculated as outlined in the snow chemistry section, with the following changes: $H^{+}$ was added to the sum of the cations only if the sample pH was below 5.2, and organic acidity ($A^-$), was added to the anion sum. Organic acidity was calculated from DOC and pH measurements by the Oliver method (Oliver _et al_. 1983), as outlined in LaZerte and Dillon (1984). Bicarbonate was calculated as outlined in Rustad _et al_. (1986), but was not included in the charge balance because of it's low concentrations.

In addition to the Plastic Lake sampling, a survey of several lakes in the Dorset area (see Fig. 1), was carried out just prior to ice-out (April 16-20) to put the Plastic Lake results in a regional perspective. The lake area adjacent to the major stream input of each lake was profiled and sampled for temperature, conductance, pH and natural fluorescence. Samples were collected and analyzed in the same manner as samples from Plastic Lake.

### _I. Shoreline mapping_

The Plastic Lake shoreline area was investigated to determine the approximate depth of entry of unchannelized flow into the lake. The shoreline was divided into four classes; 1.) shallow (<30 cm) gravel or organic material interspersed with boulders, 2.) bare rock, 3.) moderately thin (>30cm) organic or gravel material and 4.) boulders with no fines. The entire lake shoreline was traversed and the bare rock, moderately thin organic or gravel, and boulder sections were measured by chaining. The remaining group, thin organic or gravel deposits interspersed with boulders was solved for as the difference of the sum of the length of the first three groups minus the total shoreline length.

## J. Stream chemistry

Plastic 1 inflow and Plastic Lake outflow streams were sampled throughout the study period by OME. Samples were collected and analyzed as described by Scheider et al. (1983) and quality control assessment maintained by the MOE as outlined by Locke (1985). Stream chemistry data were supplied by P. Dillon of the OME Dorset Research Centre. Charge balances were calculated in the manner outlined in the lake sampling section. Plastic Lake stream inputs and outputs were calculated as described in equations 10 and 11.

$$(P_1\ m^3 + P_{rest}\ m^3) * P1\ [c]\ mg/m^3 = S_{in}\ mg$$

$S_{in}$= Inflow inputs (10)

$$P_{of}\ m^3 * \ Pof\ [c]\ mg/m^3 = S_{out}\ mg$$

$S_{out}$= Outflow outputs (11)

Mean daily parameter concentrations were determined by linear interpolation between samples.

## K. Dye tracing

Several small (25-250 gm), additions of a fluorescing dye tracer were made to the various inflows entering Plastic Lake while it was ice-covered. The purpose of the dye additions was to determine the depth and areal extent to which each inflow influenced the lake, and to determine the residence time of these inflows. A fluorescing dye tracer, sodium fluorescein, was added to Plastic 1 inflow three times during the 1985 study period. A measured amount of dye was added 10 m above the lake entrance to ensure total mixing, and movements of the dye plume under the lake's ice cover were traced along a grid laid out over the ice surface (Bergmann and Welch 1985). Samples were withdrawn with a peristaltic pump and the presence of the dye was determined with the fluorometer/filter combination outlined in the lake sampling section. Dye presence was determined by a fluorometer reading two standard deviations (± four fluorescent units) over the measured stream or lake background fluorescence. During the April 24-27 period 1986, dye additions to the Plastic 6 Inflow and a direct surface drainage area near Site 31 were made to trace inputs from these two sources. A sampling transect, running outwards from each dye input site, was sampled for coincident measures of temperature, pH, specific conductance and natural fluorescence (Allan 1986b).

Natural fluorescence was found to be a useful natural tracer for streamwater inputs within Plastic Lake. The determination of background or natural fluorescence was made using the same filter/fluorometer combination as in the dye trace studies.

The major source of natural fluorescence in freshwater is believed to be a yellow organic substance, likely a carboxylic acid (Shapiro 1957). Christian and Glassemi

**Fig. 12a**

Fluorescence vs. Colour (Hu)

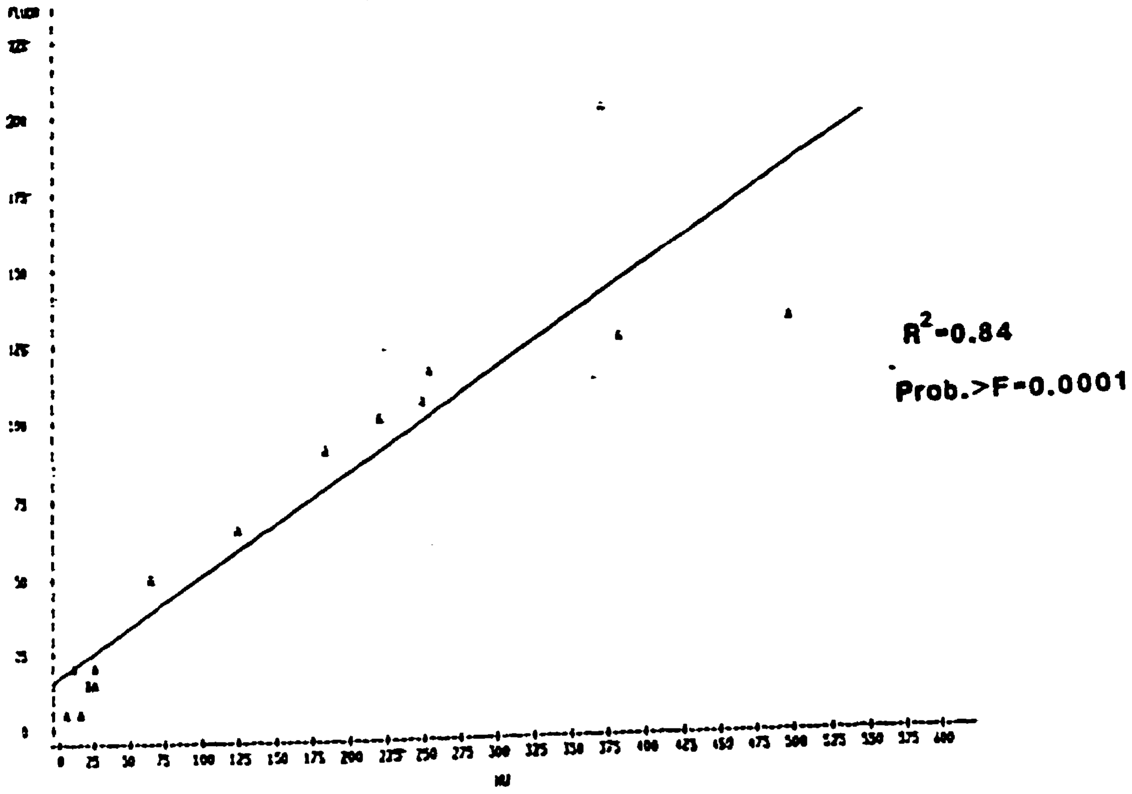


**Fig. 12b**

Fluorescence vs. Dissolved Organic Carbon (mg/l)

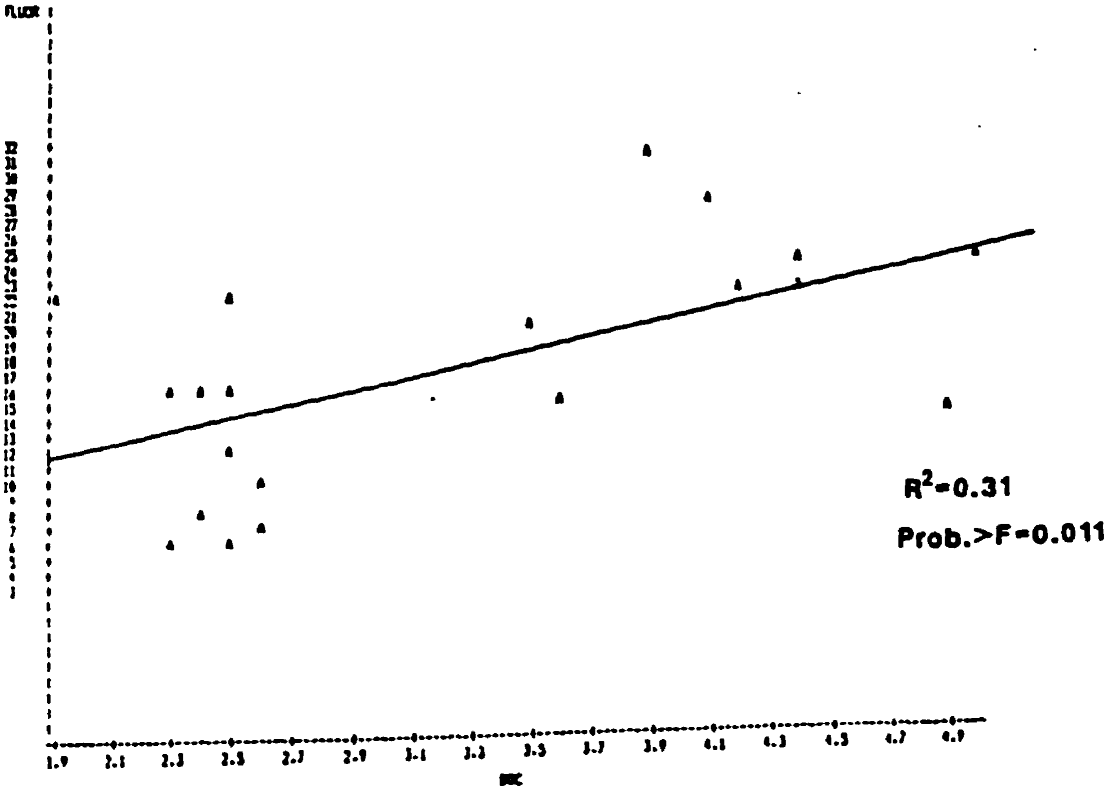


Fig. 12c

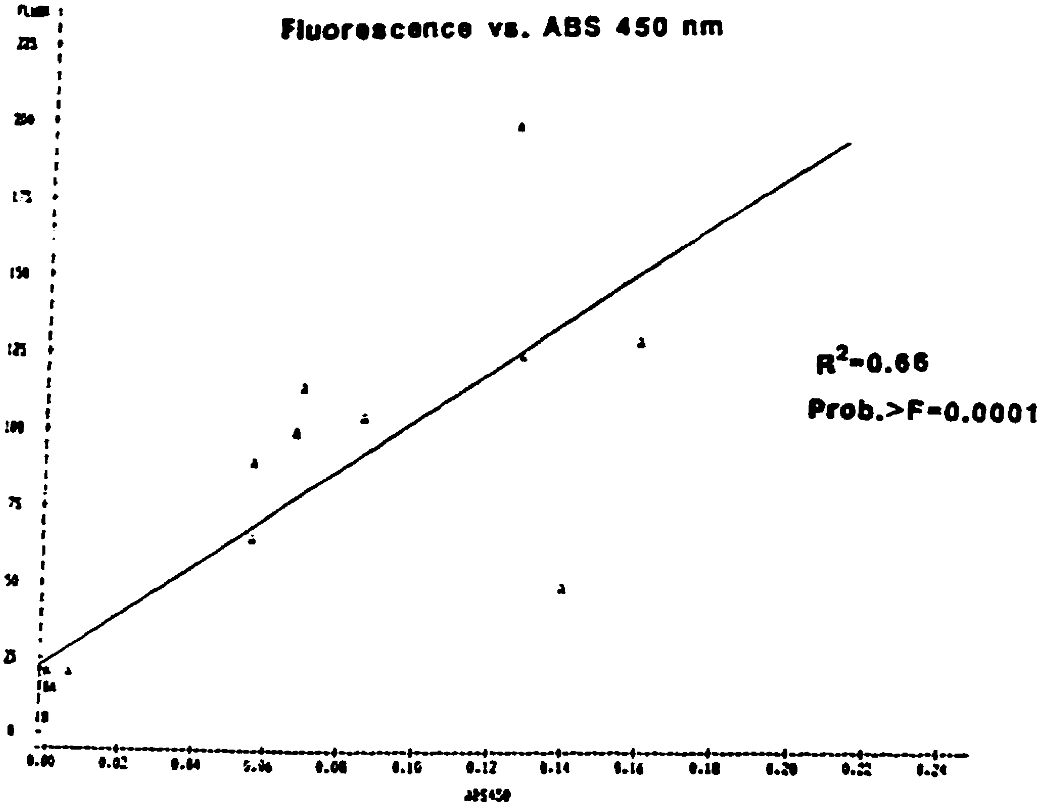
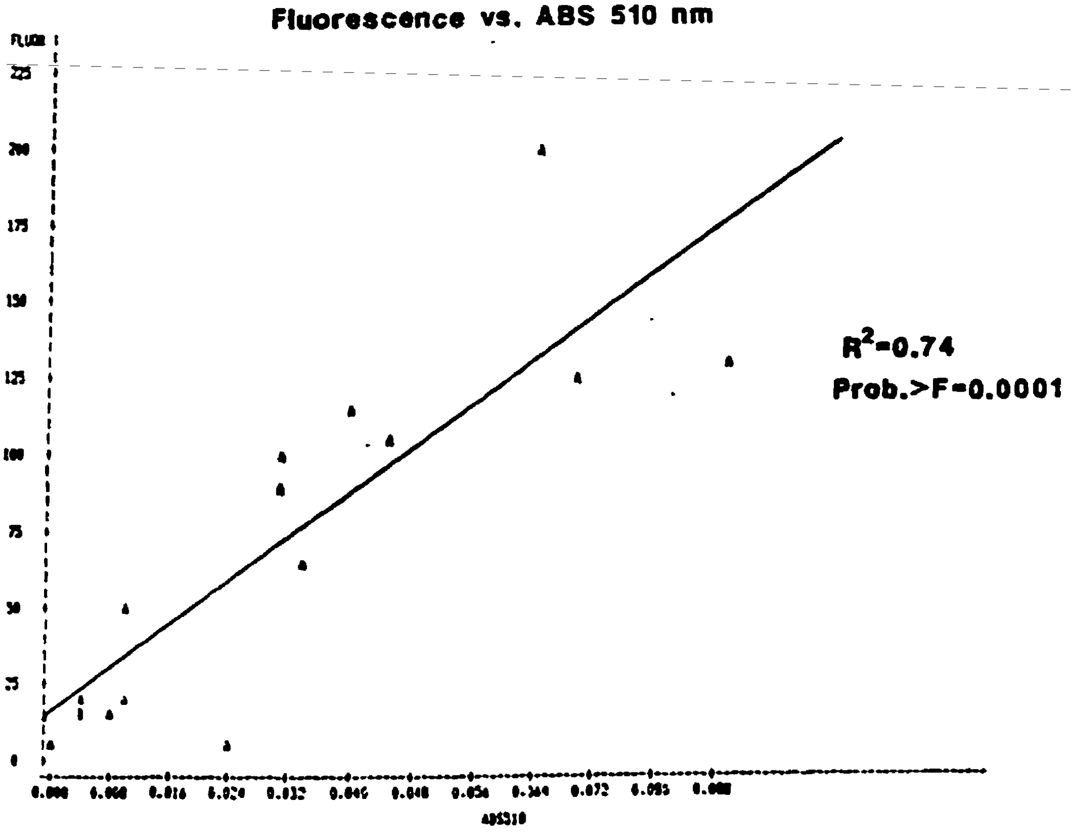


Fig. 12d



(1966) believed the substance to be similar in nature to a fulvic acid. The high background fluorescence found in the stream water in the study area is likely a result of meltwater contact and export of fulvic acid from organic soils. The relationships between natural fluorescence, DOC, water colour (in Hazen units), and light absorbance at 510nm and 450nm are shown in Figs. 12a, b, c and d. All relationships were highly significant (p>=0.99 or higher). This would be expected, particularly if the natural fluorescence is produced by yellow-green compounds as indicated in the literature. Christman and Ghassemi (1966) mentioned the possibility of using background fluorescence as an alternative measurement of water colour. Natural fluorescence has been previously utilized in some limnological studies as a means of identifying different water masses within a lake (Spain et al. 1969 and Spain and Andrews 1970). Background fluorescence was not useful in distinguishing between Plastic Lake water and lake surface ice and snow meltwater and terrestrial runoff contributed to the lake through mineral soils. Natural fluorescence was quite low (4-8 fluorescent units) in water from these sources, and they were indistinguishable from each other (Allan 1986b).

## Section 5 Results

### A. Meteorologic

Daily summaries of temperature and precipitation data from the study period are included in Tables A1, A2, A3 and

A4 in Appendix 1. The 1985 mean monthly temperature was lower for January and April, and higher for February and March than the mean monthly values reported by the Atmospheric Environment Service (1982a) for the Dorset climatological station. February, March and April received much more wet precipitation and January received less wet precipitation than the mean monthly values reported by the (AES 1982b), for the Dorset climatological station. Significant rain-on- snow events occurred 21-24 February (40.2 mm, event 1), 11-12 March (17.2 mm, event 2), 27-31 March (27.2 mm, event 3), 4-5 April (33.6 mm, event 4) and 14-19 April (23.5 mm, event 5). Above average snowfall was recorded at the Dorset climatological station for March and April, 1985 (Atmospheric Environment Service 1982b). The largest single snowfall event recorded during the study period occurred on March 4, (35 mm, w.e.).

## B. Precipitation chemistry

A summary of precipitation chemistry collected at the OME Plastic Precipitation Site #2 is presented in Table A5 in Appendix 1. Charge balance was generally quite good $\bar{x}$= 6.92%, sd 7.2%. Precipitation, either rain or snow, was always acidic ($\bar{x}$= 4.27 s.d. 20 ueq/l). $SO_4^{-2}$, $Ca^{+2}$,$Mg^{+2}$ and $NH_4^+$ all tended to increase from mid-March to the conclusion of the study period. $H^+$ was the dominant cation (28-85%) followed by $NH_4^+$ (.3-43%), and $Ca^{+2}$ (0.6-25%). $NO_3^+$ was equal to or greater than $SO_4^{-2}$ until early March, thereafter $SO_4^{-2}$ was the dominant anion. A summary of the mass of precipitation inputs to the Plastic Lake ice surface is presented in Table 11.

## C. Terrestrial snow course

Physical and chemical data from the terrestrial snow course (T1, T2 and T3) are presented in Table B1 in Appendix 2. Temporal trends in snowpack stratigraphy are presented in Figs B1a and B1b in Appendix 2. Physical and chemical temporal trends are presented in Figs. B2a to B2p in Appendix 2. Five replicate samples were taken at one site and pH and conductance values were determined for each replicate. Hydrogen ion had a 24% variation about the mean while conductance had a 9.7% variation about the mean. This variation is an estimate of both sampling technique and analytical error. Charge balance ranged from -48.0% to +52.0% for terrestrial snow samples. The poor ionic balance can possibly be attributed to the analytical detection limit values used for some charge balances. The generally low concentrations of most ionic parameters within the snowpack are close to the detection limit of most analyses and are not as accurate as the values reported at higher concentrations. Another possibility may be the exclusion of $NH_4^+$ from the charge balance as it was not analysed in terrestrial snow samples. The ionic load per square metre over time of the terrestrial snowpack is given in Table 7.

Table 7
Water, ionic and nutrient load of the Plastic Lake terrestrial snowpack over time

| Date | $H_2O$ cm | $H^+$ ueq/m² | $Ca^{+2}$ | $Mg^{+2}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{-2}$ | DOC | TAL | PPUT | TKN | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/m² | | | | | | | ug/m² | mg/m² | | |
| Feb 11 | 8.7 | 2841.2 | 9.6 | 4.4 | 12.8 | 15.0 | 10.4 | 90.7 | 116.3 | 157.8 | 6.4 | 59.3 | 41.3 |
| Feb 19 | 9.0 | | | | | | | | | | | | |
| Feb 22 | 10.5 | 4364.7 | 11.6 | 6.3 | 6.3 | 23.8 | 17.9 | 210.1 | 130.3 | | 6.1 | 67.3 | 64.6 |
| Mar 01 | 10.8 | 2927.4 | 11.9 | 5.4 | 6.5 | 18.4 | 14.0 | 64.1 | 138.9 | | 3.6 | 47.8 | 46.9 |
| Mar 05 | 12.8 | 2432.6 | 25.6 | 9.0 | 17.8 | 40.8 | 34.4 | 82.0 | 122.0 | 368.5 | 2.9 | 52.6 | 45.9 |
| Mar 13 | 11.2 | | | | | | | | | | | | |
| Mar 17 | 8.9 | 2613.3 | 10.7 | 4.8 | 5.8 | 50.6 | 19.4 | 57.6 | 156.2 | 766.0 | 3.5 | 36.3 | 44.2 |
| Mar 27 | 23.5 | 3429.0 | 69.8 | 16.0 | 36.1 | 96.3 | 47.2 | 200.0 | 376.7 | 1483.3 | 7.9 | 110.1 | 82.8 |
| Mar 30 | 12.4 | | | | | | | | | | | | |
| Apr 02 | 17.3 | | | | | | | | | | | | |
| Apr 11 | 18.0 | 3275.9 | 62.1 | 18.5 | 15.7 | 21.0 | 13.8 | 139.1 | 203.7 | 1969.7 | 6.1 | 96.9 | 52.2 |
| Apr 19 | 16.4 | | | | | | | | | | | | |
| Apr 22 | 2.0 | | | | | | | | | | | | |
| Apr 23 | 3.0 | 89.1 | 2.3 | 4.4 | 4.2 | 13.8 | 6.0 | 13.1 | 83.5 | 65.5 | 4.5 | 59.4 | 3.7 |

## D. Plastic Lake snowcover

Snow depth and chemistry results from the five sampling points (3, 4, 6, 18 and 34), on Plastic Lake is presented in Table B2 in Appendix 2. Temporal trends in lake snow depth and chemistry are presented in Figs. B2a to B2p in Appendix 2. Temporal trends in snowpack stratigraphy are presented in Fig. B3 in Appendix 2. Spatial trends in snow depth over time are illustrated in Figs. B4a to B4l. Charge balances from lake snow samples were invariably negative (-1.0 to -61.5%). This negative balance likely results from the causes discussed in the terrestrial snow section, particularly the absence of $NH_4^+$ from the charge balance equation. Five replicate results from one sampling point were collected during the study period and analysed for pH and conductance to assess sampling and analytical variability. Hydrogen ion had a 14% variation about the mean while conductance had a 5% variation about the mean for the five replicates. The ionic load over time for the floating snowpack is given in Table 8.

## E. Plastic Lake icecover

Ice thickness and chemistry from the two sampling sites on Plastic Lake (3 and 19), are presented in Table B3 in Appendix 2. Ice growth over time plotted against freezing degree days is presented in Fig. B5 in Appendix 2. The proportions of each winter cover component (black ice, white ice, slush and snow), at these two sites is presented in Fig. B6 in Appendix 2. Spatial trends in ice thickness over

Table 8

1985 Water, ionic and nutrient load for the Plastic Lake snow cover over time.

| Date | $H_2O$ | $H^+$ | $Ca^{+2}$ | $Mg^{+2}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{-2}$ | DOC | TAL | PPUT | TKN | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | ueq/m$^2$ | mg/m$^2$ | | | | | | | ug/m$^2$ | mg/m$^2$ | | |
| Jan 28 | 7.1 | 2826.6 | 7.1 | 1.4 | 4.3 | 2.8 | 2.1 | 78.1 | 49.7 | | | 11.4 | |
| Jan 30 | 0.9 | 367.9 | | | | | | | | | | | |
| Feb 11 | 1.8 | 1080.6 | 1.8 | 0.9 | 2.0 | 0.4 | 3.1 | 14.5 | 12.1 | 30.7 | .10 | 2.0 | 15.0 |
| Feb 23 | 3.6 | 594.0 | 25.9 | 5.4 | 7.2 | 0.7 | 9.7 | 102.3 | 36.0 | | .28 | 8.4 | 12.3 |
| Mar 05 | 5.6 | 1183.8 | 5.6 | 2.8 | 3.3 | 1.1 | 4.4 | 46.4 | 33.9 | | .66 | 13.7 | 15.3 |
| Mar 18 | 1.4 | 596.8 | 5.8 | 0.9 | 0.8 | 0.4 | 2.9 | 14.8 | 14.0 | 324.0 | .21 | 8.1 | 12.7 |
| Apr 11 | 0.7 | 97.7 | 2.5 | 0.9 | 0.8 | 0.2 | 0.5 | 11.4 | 5.4 | 172.6 | .11 | 4.5 | 3.3 |

time are presented in Figs. B7a to B7g. Ice chemistry charge balances were generally poor (+149 to -75%) owing to the detection limit values used in most charge balances and the dilute nature of the ice cover.

### F. Plastic Lake slush chemistry

Slush chemistry from the two sampling sites (3 and 19), is presented in Table B4 in Appendix 2. Temporal trends in slush thickness at sites 3 and 19 are presented in Fig. B8 in Appendix 2. The slush thickness was measured lakewide on February 10 and April 1 and accounted for 21.0% and 7.3% respectively of the total ice volume but could occupy from 0% to 44.8% of the total lake ice cover at any one point. Temporal trends in slush chemistry at the two sites are presented in Figs. B9a to B9n. Five replicate samples were collected at each site and analysed for pH and specific conductance. Variation about the mean ranged from 4.4% to 13.2% for pH and 0.8 to 2.34% for specific conductance. Charge balance was general quite good early in the study period because of the high ionic strength. The ionic load of the ice cover, including the slush component, for sites 3 and 19 is given in Table 9.

### G. Plastic Lake hydrology

Mean daily flows for the Plastic 1 inflow and Plastic lake outflow are presented in Tables C1 and C3 in Appendix 3. Hydrographs for Plastic Inflow 1 and the Plastic Lake outflow are presented in Figs. C1 and C3. The water budget

Table 9
Water, ionic and nutrient load of the 1985 Plastic Lake ice and slush cover over time

| Date | Site | $H_2O$ cm | $H^+$ ueq/m² | $Ca^{+2}$ | $Mg^{+2}$ | $Na^+$ | $K^+$ | $Cl^-$ mg/m² | $SO_4^{-2}$ | DOC | TAL ug/m² | PPUT | TKN mg/m² | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb 10 | 3 | 35.3 | 5028.1 | 201.1 | 42.4 | 60.6 | 19.2 | 49.9 | 830.1 | 612.5 | 2300.0 | 2.0 | 41.2 | 63.8 |
| 1 | 3 | 15.6 | 21.8 | 57.4 | 64.9 | 50.8 | 68.8 | 38.5 | 47.9 | 20.7 | 74.1 | 13.3 | 28.0 | 22.9 |
| 2 | 3 | 79.3 | 55.6 | 41.6 | 33.0 | 47.5 | 29.2 | 56.1 | 50.2 | 77.6 | 24.3 | 81.5 | 68.0 | 52.5 |
| 3 | 3 | 5.1 | 22.6 | 0.9 | 2.1 | 3.0 | 1.9 | 5.4 | 1.9 | 1.8 | 1.6 | 5.2 | 3.9 | 24.6 |
| 4 | 3 | .210 | .750 | .016 | .017 | .105 | .049 | .264 | .079 | .050 | .468 | .127 | .254 | .718 |
| Feb 10 | 19 | 40.2 | 9995.9 | | | | | | | | | | | |
| 1 | 19 | 37.3 | 59.7 | | | | | | | | | | | |
| 2 | 19 | 58.2 | 29.5 | | | | | | | | | | | |
| 3 | 19 | 4.5 | 10.8 | | | | | | | | | | | |
| 4 | 19 | .184 | .375 | | | | | | | | | | | |
| Mar 15 | 3 | 47.0 | 15019.5 | 79.1 | 23.5 | 28.1 | 9.4 | 55.6 | 439.7 | 326.8 | 3084.5 | 3.2 | 189.7 | 157.0 |
| 1 | 3 | 22.4 | 84.0 | 53.1 | 22.1 | 22.4 | 22.3 | 47.2 | 68.0 | 38.6 | 64.7 | 32.3 | 28.8 | 73.6 |
| 2 | 3 | 77.1 | 15.2 | 45.6 | 77.0 | 77.2 | 76.6 | 52.0 | 31.2 | 60.8 | 35.1 | 66.8 | 70.5 | 24.8 |
| 3 | 3 | 0.4 | 0.8 | 1.3 | 0.9 | 0.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.2 | 0.9 | 0.7 | 1.6 |
| 4 | 3 | .461 | .796 | .335 | .186 | .601 | .370 | .601 | .320 | .332 | .746 | .254 | .237 | .751 |
| Mar 18 | 19 | 55.6 | 9462.5 | 174.1 | 51.6 | 90.4 | 28.2 | 77.3 | 932.0 | 603.5 | 12673.0 | 5.7 | 144.8 | 98.9 |
| 1 | 19 | 17.1 | 55.2 | 70.9 | 55.2 | 69.4 | 67.4 | 61.4 | 80.5 | 59.8 | 87.0 | 10.0 | 23.6 | 70.6 |
| 2 | 19 | 80.2 | 39.2 | 25.6 | 43.2 | 29.6 | 31.6 | 34.7 | 18.2 | 37.7 | 10.6 | 86.0 | 70.9 | 18.0 |
| 3 | 19 | 5.6 | 3.4 | 1.5 | 1.0 | 1.1 | 3.9 | 1.3 | 2.5 | 2.5 | 6.6 | 3.9 | 5.5 | 11.4 |
| 4 | 19 | .388 | 1.264 | .152 | .085 | .187 | .123 | .432 | .151 | .180 | .181 | .146 | .311 | 1.192 |
| Apr 22 | 3 | 24.1 | 779.2 | 120.4 | 16.9 | 19.3 | 4.8 | 12.0 | 21.7 | 48.2 | 240.8 | 1.2 | 19.3 | 6.0 |
| 2 | 3 | | | | | | | 100 | | | | | | |
| 4 | 3 | 1.47 | 24.6 | .488 | .557 | 1.2 | 11.3 | 4.5 | 23.3 | 4.4 | 21.2 | 1.8 | 6.1 | 30.3 |
| Apr 22 | 19 | 37.5 | 3707.3 | 99.6 | 31.2 | 28.3 | 23.8 | 22.1 | 85.1 | 162.1 | 4062.5 | 2.8 | 74.9 | 12.4 |
| 1 | 19 | 89.2 | 17.7 | 2.0 | 14.3 | 17.2 | 1.7 | 9.2 | 29.0 | 17.5 | 15.9 | 16.0 | 15.2 | 87.6 |
| 2 | 19 | 10.8 | 82.3 | 98.0 | 85.7 | 82.8 | 98.3 | 90.8 | 71.0 | 82.5 | 74.1 | 84.0 | 84.8 | 43.7 |
| 4 | 19 | 1.0 | 5.2 | .595 | .301 | .806 | 2.3 | 2.5 | 5.9 | 1.3 | 1.3 | .763 | 1.6 | 14.7 |

1 Percentage of total load contained in the slush component.
2 Percentage of total load contained in the ice component.
3 percentage of total load contained in the snow component.
4 Ratio of precipitation load to ice and slush load to that point in time.

Table 10
1985 Plastic Lake water budget($m^3$)

| Period | Inputs<br>Stream | Precipitation | Total | Outputs<br>Plastic Outflow | Storage | mm of lake level |
|---|---|---|---|---|---|---|
| Jan 03-Jan 06 | 6999.74 | 3953.22 | 10952.96 | 16450.56 | -54967.6 | -17.1 |
| Jan 07-Jan 13 | 5009.41 | 3535.40 | 8544.81 | 17159.04 | -8614.2 | -26.8 |
| Jan 14-Jan 20 | 2240.27 | 6588.70 | 8828.97 | 11914.56 | -3085.7 | -9.6 |
| Jan 21-Jan 27 | 1682.76 | 4692.44 | 6375.20 | 9771.84 | -3396.6 | -10.6 |
| Jan 28-Feb 03 | 1956.40 | 996.34 | 2952.74 | 8907.84 | -5955.1 | -18.5 |
| Feb 04-Feb 10 | 660.73 | 321.40 | 982.13 | 7464.96 | -6482.9 | -20.2 |
| Feb 11-Feb 17 | 500.94 | 11216.86 | 11717.80 | 7862.40 | 3856.1 | 12.0 |
| Feb 18-Feb 24 | 6268.66 | 20216.06 | 26484.72 | 9979.20 | 16506.2 | 51.4 |
| Feb 25-Mar 03 | 24523.72 | 4146.00 | 28669.72 | 19422.72 | 9247.2 | 28.8 |
| Mar 04-Mar 10 | 4220.00 | 13434.50 | 17654.50 | 19543.70 | -1889.2 | -5.9 |
| Mar 11-Mar 17 | 21140.70 | 7810.00 | 28950.70 | 21435.80 | 7514.9 | 23.4 |
| Mar 18-Mar 24 | 7392.20 | 32.10 | 7424.30 | 14368.20 | -6943.9 | -21.6 |
| Mar 25-Mar 31 | 29883.20 | 13563.10 | 43446.30 | 23552.60 | 19893.7 | 61.9 |
| Apr 01-Apr 07 | 32718.50 | 16359.20 | 49007.70 | 45022.90 | -4054.8 | -12.6 |
| Apr 08-Apr 14 | 20373.50 | 8902.80 | 29276.30 | 29203.30 | 73.0 | 0.2 |
| Apr 15-Apr 21 | 78375.80 | 6685.10 | 85060.90 | 72083.60 | 12977.3 | 40.4 |
| Apr 22-Apr 28 | 102910.14 | 610.66 | 103520.80 | 115188.40 | -11677.6 | -36.3 |
| Apr 29-May 07 | 15491.34 | 7842.16 | 23333.50 | 14748.50 | 8585.0 | 26.7 |
| May 06-May 12 | 23060.36 | 4692.44 | 27752.80 | 19932.40 | 7820.2 | 24.3 |
|  | 385408.37 | 135598.48 | 521006.85 | 489509.65 | 31497.2 | 98.0 |

for the 1985 January-May period for Plastic Lake is presented in Table 10. The water budget is divided into 19 weekly intervals starting on Dec. 31, 1984 and ending May 12, 1985. The budget was carried out to May 12, which corresponded to the first stage reading after ice-out by the Ministry of the Environment. As lake storage was the residual term in the water budget, the stage reading acted as a check on the accuracy of the water budget. The predicted storage change, when compared to the observed storage change, overestimated the inputs to Plastic Lake by 8.17%. This is likely an overestimate of the actual error as evaporation was not considered in the three weeks of open water at the end of the budget period which would have reduced this discrepancy slightly. The use of a stream (Plastic 1), to predict the ungauged proportion of the basin could possibly account for the input overestimate (Winter 1981).

## H. Inflow-outflow chemistry

Chemistry from Plastic 1 inflow during the study period is presented in Table C2 and Plastic Lake outflow chemistry is presented in Table C4 in Appendix 3. Charge balance was generally quite good for both streams. The mean charge balance was +7.1% for Plastic 1 and +7.4% for the outflow. Concentrational trends for Plastic Inflow 1 and Plastic Lake outflow are presented in Figs. C2a to C2p and C4a to C4o respectively. The chemical budget for Plastic Lake during the study period is presented in Table 11.

Table 11

1985 Chemical Budget Plastic Lake Jan-May

| Parameter | Runoff | Precipitation | Total | Output | Storage | In:Out |
|---|---|---|---|---|---|---|
| $H^+$ (keq) | 18.1485 | 7.1859 | 25.3345 | 4.3598 | 20.9765 | 5.81 |
| ALKTI (kg) | -1125.9397 | -359.6155 | -1485.5552 | -240.5854 | -1244.9698 | -6.17 |
| $Ca^{+2}$ (kg) | 647.3468 | 23.0453 | 670.5133 | 957.0800 | -286.5667 | .70 |
| $Mg^{+2}$ (kg) | 147.0426 | 3.9562 | 150.9988 | 223.9410 | -72.9422 | .67 |
| $Na^+$ (kg) | 174.2050 | 7.4024 | 181.6074 | 222.1590 | -40.5516 | .82 |
| $K^+$ (kg) | 51.5336 | 2.8777 | 54.4113 | 103.5700 | -49.1587 | .53 |
| $Cl^-$ (kg) | 79.6224 | 20.3024 | 99.9248 | 160.7880 | -60.8632 | .62 |
| $SO_4^{-2}$ (kg) | 2761.7065 | 264.9800 | 3026.6866 | 3257.0300 | -230.3434 | .93 |
| $NO_3^-$ (kg) | 9.3125 | 70.7864 | 80.0989 | 47.5281 | 32.5708 | 1.69 |
| TKN (kg) | 69.0017 | 49.0988 | 118.1005 | 94.2990 | 23.8015 | 1.25 |
| PPUT (kg) | 2.0078 | 0.7754 | 2.7833 | 2.2809 | 0.5024 | 1.22 |
| TAL (kg) | 99.7858 | 1.7261 | 101.5119 | 32.4395 | 69.0724 | 3.13 |
| DOC (kg) | 2288.8535 | 81.2758 | 2370.1293 | 1142.8000 | 1227.3293 | 2.07 |

## I. Plastic Lake chemistry

The MOE, Plastic Lake integrated "deep hole" chemistry collected by the Ministry of the Environment is presented in Table D1 in Appendix 4. Charge balance was generally quite good ($\bar{x}$=12.9%). The integrated 1.5m shoreline chemistry is presented in Table D2 in Appendix 4. Here again, charge balances were generally quite good ($\bar{x}$=11.3% for all five sites). Five replicate samples were collected at one site and analysed for specific conductance and pH. The variation about the mean was 13.2% for pH and 2.3% for conductance. Chemical trends over time, plotted against the results of the regular MOE sampling, are presented in Figs. D1a to D1o. Profiles over time at each shoreline site are presented for temperature (Figs. D2a-D2e), $H^+$ (Figs D3a to D3e), conductance (Figs. D4a to D4e) and natural fluorescence (Figs. D5a to D5e). Spatial trends in Plastic Lake are presented for surface $H^+$ (Figs. D6a to D6i), conductance (Figs D7a to D7h) and natural fluorescence (Figs D8a to D8g).

To put the Plastic Lake observations into a regional context, chemical profile data were sampled from five other Dorset area lakes. Hydrogen ion, specific conductance, temperature and natural fluorescence profiles were collected from the path of the largest lake inflow during the spring runoff at Blue Chalk, East Red Chalk and Main Red Chalk, Little Clear and Glen Lake are presented in Figs. D9a to D9f in Appendix 4.

### J. Dye tracing

Five dye additions were made over the course of the study period. Three additions were made to Plastic 1, one addition to Plastic 6 and one addition to some direct drainage near site 31 (Fig. 10). One dye addition to Plastic 1 could not be sampled because of equipment problems. The results of the various dye traces are presented in Figs. E1-E4 in Appendix 5. The corresponding $H^+$, conductance, natural fluorescence and temperature profiles along the Plastic 6 sampling transect (Fig. E4) are presented in Fig. E5 in Appendix 5.

## Section 5. Discussion

### A. Terrestrial snowpack

Results from the terrestrial snow course must be viewed with caution as they represent only a three point sample. This must be kept in mind, particularly in view of the natural spatial variability found within a forest snowpack (Brimblecombe et al. 1985, Jones 1985). A comparison with the more extensive snowcourse carried out by R. Shibatani in the Plastic 1 watershed indicates that the three point snowcourse underestimated the large snowcourse water equivalent and snow depth by ca. 31%. The coefficient of variation for most chemical species ($Na^+$, $K^+$ and $Cl^-$ in particular), is often greater than 50% (Figs. B2g, i and p). It is believed that a large amount of this variation can be attributed to forest canopy processes and the heterogeneous distribution of organic litter within the snowpack. The results from this snowcourse do however, give an indication of physical and chemical trends within the forest snowpack during the study period, particularly those trends which are consistent over time.

The terrestrial snowpack structural stratigraphy changed markedly in response to the various rain-on-snow events of the study period. During the 1985 season, there was almost always a basal or near-basal ice lens except for the final sampling on April 11, when the base of the snowpack was flooded (Fig B1a and B1b). The terrestrial snowpack structure was initially multilayered and complex

(Fig B1a), until the first rain-on-snow event in late February (event 1), (Table A2, Fig C1). The stratigraphy on March 1, after this rainfall and thaw, exhibited the results of unsaturated wet metamorphism, a homogeneous structure composed of 1-2mm rounded, partially melted, crystals, overlying a basal ice lens. Snowpack water equivalent remained relatively constant after event 1 although pack depth decreased by approximately 30% and density almost doubled (Fig.B2a). Because there was no increase in water equivalence, despite the addition of some 41.2mm of water, a large portion of the February rain must have flushed directly through the snowpack (Fig. B1a). As ambient temperatures decreased, the remaining snowpack froze and hardness increased from 0 to 10 g/cm$^2$ to 75 to 250 g/cm$^2$. Thereafter any further snowfall accumulated on the surface of this "hard residual" snow.

Rain-on-snow events on March 11-12 (event 2), March 27-31 (event 3) and April 4-5 (event 4) do not appear to have altered the basic crystal stratigraphy of the snowpack except to incorporate any newly deposited snow into the same type of crystal structure as the underlying snowpack through unsaturated wet metamorphism (Figs. B1a and b). The stratigraphy site was flooded on April 21 so that no snow remained on it. Peak water equivalence for the terrestrial snowpack was recorded on March 25 (Fig. B2a). It appears that a large portion of the event 2 rainfall (Table A3, Fig C1), froze, and was stored within the snowpack.

The chemical loading of the terrestrial snowpack displays two peaks, on February 22 and March 27 (Table 7). The early snowpack exhibited the highest conductivity and $H^+$ and $SO_4^{-2}$ load, despite having a water equivalence of only 10.5 cm as compared to 23.5 cm on the second sampling date (Table B1). Conductance, $H^+$, $SO_4^{-2}$, $NO_3^-$, PPUT and TKN all exhibited a decrease in concentration within the snowpack, after the February rainfall event, until the final snowmelt (Figs. B2d, e, f, h, j, k and m). This is likely a result of the fractionation effect described by Johannessen and Henricksen (1977). The above-mentioned chemical species were likely removed quite quickly from the snow crystal surfaces, as rain filtered through the snowpack, leaving the remaining snowpack quite dilute. Sulphate displays a particularly large decrease of ca. -60% while $H^+$ (-33%), $NO_3^-$ (-27%), PPUT (-40%) and TKN (-30%) all show smaller declines (Table 7). Base cations ($Ca^{+2}$, $Mg^{+2}$, $Na^+$ and $K^+$) displayed little or no change in concentration as a result of these ions being present only at detection limit levels in the snowpack before the first rainfall (Table B1).

Plastic Inflow 1 discharge increased some 55X during event 1 (Table C1 and Fig. C1), and the highest $H^+$, $K^+$, $Cl^-$, $SO_4^{-2}$, $NO_3^-$, TKN, PPUT and conductance values of the study period were recorded in the stream water at that time (Table C2, Figs C2a, f, g, h, i, j, k and o).

Lithologically-derived materials, such as $Ca^{+2}$, $Mg^{+2}$ $K^+$ and TAL, show general increases in concentration within the snowpack with time (Figs. B2c, i, n and o). There are three possible sources for this material to the snowpack, the leaching of organic matter from the forest or forest litter and/or the entrainment of runoff water that had been in contact with soil within the snowpack. The increased $K^+$ concentrations are likely a result of the former (particularly Tsuga canadiensis (L.) Car. litter within the snowpack), and the $Ca^{+2}$, $Mg^{+2}$ and TAL increases as a result of the latter. The highest concentrations of PPUT, DOC and TKN were recorded on the final sample date, April 21 (Table 7, Figs. B2k, l and m) while the concentration of all other ions were at their lowest within the snowpack (conductance ca. 8.5 µS/cm). The snowpack at this time was saturated with runoff water and appeared to contain a great deal of suspended organic matter. Neither $Na^+$ or $Cl^-$ displayed discernible concentrational trends over time within the terrestrial snowpack (Figs. B2g and p).

In summary, rain-on-snow events (particularly the first), appeared to dramatically alter both the chemical and physical characteristics of the terrestrial snowpack. The snowpack became more homogeneous and dilute in several ions as a result of these rain events. Snow chemistry was quite variable spatially, likely as a result of canopy processes and the presence of organic litter within the snowpack.

## B. Plastic Lake winter cover

The 1985 winter cover of Plastic Lake, at various times during the winter, consisted of different permutations of black ice, white ice, slush, standing water and snow. The sources of water for these lake cover components were the lake itself, precipitation and, in some marginal zones, terrestrial runoff.

Plastic Lake froze over on January 4. The black ice component of the ice cover grew quite rapidly until January 10 when it comprised some 61% of the ice cover (13cm black ice, 18cm total ice), (Figs. B5 and B6). This rapid increase in ice cover corresponds quite closely to the freezing degree day curve (Fig. B5). Black ice constituted only ca. 21% of the total ice volume at peak ice thickness, recorded on March 13 (Fig B5). Black ice growth was interrupted by a major slushing event that began on January 10. Growth ceased once the thermal gradient between the lake and atmosphere was disrupted by the presence of this liquid layer on the ice surface. There is some indication that total black ice thickness may have actually decreased slightly after this first slushing event (Fig. B5).

There appeared to be two major periods of white ice growth as a result of lake water slushing, one period after freeze-up and one smaller event later in the season (Fig. B5). The first slushing event began soon after the completion of freeze-up and continued until early February producing some 32cm of slush and white ice (Figs. B5 and B6). A second slushing event began close to February 23, coincident with the February thaw (Table A2), and continued until the 10th of March, producing an additional 13cm of slush and white ice (Fig B5). The second period of white ice growth was initiated by a combination of the February rainfall saturating the lake snowpack and freezing in place and slushing from lake water when the ice cover became depressed by the 35cm snowfall on March 4 (Tables A2 and A3). A small superimposed slushing event began on April 4 when rainfall saturated the lake's snowcover and froze in place, producing some five centimetres of additional white ice (Table A4, Fig. B5). The ice cover began ablating soon after April 10, and had melted completely by April 28 (Fig. B5 and B6).

Several large holes in the ice cover (locally known as "blow holes"), persisted from freezeup until late February. These holes were likely formed when the thin developing ice cover was depressed by snowfall into the underlying warmer lake which caused the thin ice to melt (Woodcock 1974, Kastaros 1981). Additional snowfall insulated these holes from freezing.

Observations of the progression of the slushing of the lake surface (Figs. B4 a, b and c) indicated that the holes, rather than thermal cracks, were the initial source of the lake water which flooded the lake surface as the ice was depressed by snow loading. The low snow depth areas in Fig. B4a (within the 25cm isoline), were locations of slushed snow. The slushing of the lake proceeded from these areas (Fig. B4b). During the February rainfall, these same holes afforded an opportunity for rain and slush to enter the lake in vertical turbulent streams as the ice cover attempted to attain a pressure equilibrium (Fig. 4). Drainage through each hole appeared quite substantial, eroding 5-10cm deep channels in the ice cover and enlarging the holes to some 50cm in diameter. However, a rough estimate of the water that drained into the lake, taking into account the change in snowcover, the growth in ice cover and the precipitation inputs from February 23 to March 2, indicates that only ca. 4.6mm of water over the lake's surface or ca. 1,486m$^3$, could have entered the lake in this way.

The frequent snowfalls, rains, thaws and freezeups during the study period contributed to the development of a complex winter cover (Fig. B6). The ice blocks taken from Plastic Lake on the 15th and 18th of March illustrate this point with three separate layers of slush (saturated wet snow), being sandwiched between four separate sheets of ice (Fig. B6). The initial slushing and white ice growth period produced the two lower layers of slush within the ice blocks in Fig. B6. The lower of these two lenses persisted at 23 of the 40 sampling sites as late as April 1. The upper slush lens developed during the second white ice growth period and only persisted at 5 of the 40 sampling points on April 1. On no occasion was the ice cover completely frozen at every sample site. Slush lenses persisted at some points until breakup. Some lenses actually appeared to freeze and later thaw as the ice cover warmed and cooled in response to the ambient air temperature, particularly in April. There was a positive correlation ($P>F=.001$, $r^2= 0.45$) on Feb. 10 between slush thickness and total ice thickness but there was no correlation, ($P>F=.3089$, $r^2=.0272$) on April 1. No correlation existed between slush depth and snow thickness on the two sampling dates. However, the presence of these slush lenses must have been somehow related to the slushing and snowcover history at each sampling site.

Peak ice thickness was recorded on March 13 at 54.2cm (Fig. B5 and B7c). This corresponds to 6% of the total Plastic Lake volume or 143,000$m^3$ of water when corrected for the density of the ice cover (0.86$g/cm^3$, Adams 1976). Approximately 49% of the volume of water contained in the ice cover can be accounted for by the precipitation that fell on the lake surface from freezeup to March 13, the rest of the ice volume consists of lake water. This is likely an overestimate of the proportion of precipitation within the ice cover as some precipitation drained into the lake through the ice during rainfall events and snow lost from the ice surface by sublimation and deflation is not accounted for. The percentage of precipitation in the ice cover is higher than one would expect when slushing is entirely caused by lake water but may be reasonable, given the white ice development attributable to rain-on-snow events. The peak ice volume (143,000$m^3$) represents a value of 38.9% of the total terrestrial and 26.2 % of the total hydrologic inputs to Plastic Lake from freezup until the end of April (Table 10).

Total ice thickness was remarkably homogeneous over the lake surface until the final sampling date on April 21 (Figs. B7a to B7g). The coefficient of variation in ice thickness averaged 6.3% until April 21 whereupon it increased to 20% as ice began to ablate. Generally the lake margins had a slightly thicker ice cover (as a result of white ice growth), than the remainder of the lake throughout the study period (Fig B7a to B7g). The western shore line exhibited a consistently thicker ice cover throughout the study period, and was the last portion of the lake to undergo breakup (R. Shibatani, personal communication). The thickened ice in this zone may be a result of terrestrial runoff saturating the snowpack and freezing in place, or a result of the human activity. The ice appeared dark brown in this zone which leads one to believe that terrestrial runoff may have flowed on to the ice surface at various times and frozen in place (cf. Kingsbury, 1983). This area also receives the most snowmobile traffic during winter which would serve to compact the snow cover allowing ice growth to proceed more rapidly. The ablating ice cover on April 21 (Fig. B7g), displays an interesting pattern with the area around Plastic 1 inflow and the northern shoreline, which receives the peak afternoon sunlight, ablating earlier than the southern shoreline which is shaded.

### C. Plastic Lake snowcover

The 1985 Plastic Lake snowcover displayed three peaks in snow depth, early January, mid-February and mid-March, otherwise the snow depth on Plastic Lake was less than 15cm (Fig B2b). The floating snowpack was quickly compacted as a result of slushing from the lake as the ice surface was depressed, and by the frequent rainfall events during the study period. During late March, the ice surface was totally devoid of snow for approximately two weeks.

An illustration of the influence of slushing events on the structure and thickness of a floating snowpack is provided in Fig. B3. On January 25, the snowpack at sampling site 3 was 36cm (6.9cm w.e.), thick and displayed a complex, multilayered stratigraphy. Lake water had begun to slush this site and the bottom 5cm of the snowpack was saturated. On January 30 the snowpack was overlain by some 7cm of new snow while the underlying crystal structure was undergoing saturated and unsaturated wet metamorphism in the slushed portion of the profile (Colbeck 1982). As slushing progressed, the snowpack depth decreased by 8cm while water equivalence increased to ca. 18.82cm through the addition of lake water. Sixty-eight per cent (19cm), of the remaining snowpack was saturated or wet on January 30. This indicates that a large percentage of the original water incorporated into white ice is lake derived when the snowpack is slushed by lake water. As ambient temperatures dropped, this slushed portion of the snowpack was incorporated into the underlying ice cover leaving a reduced snowpack.

The influence of slushing on the spatial distribution of snowcover is illustrated in the sequence of Figs. B4a to

B4c. Snow depth was relatively uniform on January 21-25, with slushing beginning in the areas encircled by the 25cm isoline. On January 30, only the centre of the lake and a small area in the east basin had not yet been slushed. Snow depth had decreased by 50% and the coefficient of variation had increased from 17% to 50%. On February 10, the snowpack had decreased by a further 8% but the coefficient of variation had decreased to 21% as the entire lake had been slushed. The same sequence is repeated in Fig. B4d through B4f and B4g through B4j. After each major snowfall, snow depth decreased quite rapidly as the snowpack was incorporated into the ice cover by slushing and the frequent thaws and rain-on-snow events (Fig. B2b).

Several distinct physical and chemical differences existed between the terrestrial snowcover and the Plastic Lake snowcover. The snowcover on Plastic Lake never attained the depth or the water equivalence of the surrounding terrestrial snowcover after mid-February, as a result of the frequent slushing events and disappeared entirely for periods of time (Figs. B2a and b). Because of the large macro openings in the ice, slushing occurred rapidly whenever the ice cover was depressed. The floating snowpack began accumulating 19 days earlier than the terrestrial snowpack (I. Smith unpublished data), as a result of the late freeze-up of Plastic Lake and ablated some three weeks earlier (R. Shibatani personal communication), both as a result of its not being shaded by the surrounding forest and its shallower depth.

The Plastic Lake snowcover did not show the same chemical trends as the terrestrial snowpack, again as a result of the frequent slushing events and the flooding of the snowpack by lake water. Ionic concentrations in the floating snowpack fluctuated wildly in response to precipitation and slushing events (Figs. B2c to p). These fluctuations were amplified by the magnitude of the volume of the new lake water or precipitation event water in relation to the small volume of older snow present in the lake snowpack. This differs from the terrestrial snowpack where a large volume of old, dilute, snow muted the influence of any new precipitation event (Fig. B2c to p). The peaks in $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $Cl^{-}$, and $SO_4^{-2}$ and the minimum of $H^{+}$ recorded in the Plastic Lake snowcover on February 23 are a result of sites 34 and 18 being influenced by lake water (Figs. B2c, f, g, h, o and p, Table 8). Peak loads of these ions and DOC (excluding $H^{+}$), were recorded on this sampling date. Peak $H^{+}$ loads were recorded on January 30, February 11 and March 5, after relatively fresh snowfalls (Fig B2f and Table 8).

The influence of the forest canopy on a snowpack's chemistry is displayed in Figs. B2i, k and l where mean DOC, PPUT and $K^{+}$ concentrations were significantly ($p>Z=0.0$ Wilcoxon 2 sample test), higher in the terrestrial snowpack than the adjacent floating snowpack. Presumably these differences are a result of the leaching of organic matter that was present in the terrestrial snowpack (Jones 1985, Jones and Sochanska 1985).

### D. Slush and ice chemistry

As the Plastic Lake snowpack slushed and began to freeze, exsolution of ions and gases into a decreasing volume of highly concentrated slush occurred. This process was reflected by the high concentrations of ions found within these slush lenses (Table B4). The lenses were very acidic, with pH's as low as 3.55 being recorded ($\bar{x}$=4.07 for site 3 and 4.42 for site 19), with conductivities as high as 246 uS/cm ($\bar{x}$=62.7 for site 3 and $\bar{x}$=34.3 for site 19) on May 7 (Table B4). The peak concentrations recorded on March 7 at site 3 are interesting in that they occurred after a cold spell of four days (Table A3), and one would expect that these lenses would freeze, concentrating ions into ever thinner layers. However, the single largest snow event of the study period occurred on March 4 (35cm, Table A3), and probably insulated the underlying slush lenses. Also, no rapid thinning of the slush was measured (Fig B8). The high concentrations present at site 3 were reconfirmed the same day by resampling.

All chemical parameters measured in the slush lenses at the two sites followed the same general concentrational trends except for TAL and PPUT. Site 19 did not display the same increase in concentration as Site 3 on March 7 but showed a later, smaller, increase as slush thickness decreased in mid March (Figs. B9a-n). Concentrations of most parameters are very similar between the two sites except for the March 7 values. Both sites generally exhibited stable or slowly declining concentrations with time except for the the two concentrational peaks mentioned above. Total aluminum and PPUT differ from other chemical parameters in their concentrational trends. Site 19, located near the lake margin (Fig 10), exhibited TAL values some 3x higher than the mid lake site (Fig B9l). As mentioned earlier in this section, the Site 19 ice cover appeared to be influenced by some terrestrial runoff. The high TAL may be attributed to this lithologic source. Slush PPUT values are perplexing (Fig. B9m). Site 19 follows the same general trend as the other parameters until mid-March when it began to increase. The increase in PPUT concentration at this site may possibly be attributed to nearshore runoff but this is not reflected in the other chemical parameters. The trends in PPUT concentration at site 3 are more difficult to explain. The peak PPUT concentration here appeared offset by two weeks from all the other parameters. A possible explanation for this later peak may be the relatively poor freeze-out efficiency exhibited by phosphorus during ice growth (Welch and Legault 1986). The phosphorus within the slush lens may not become concentrated until the final freezing of the lens resulting in the later peak concentrations.

The chemistry of the ice component of the winter cover was generally quite dilute (conductance 15.88 - 1.94 µS/cm, Table B3). The relatively pure state of the ice cover is a result of the efficient exclusion of most ions into slush lenses and the underlying lake during ice growth. The ice samples from the uppermost layers, collected on March 15 and 18 and April 22, were generally more acidic and concentrated than the deeper ice layers (Table B3, Fig. B6). The surface ice layers often contained partially metamorphosed snow which may account for their higher acidity and ionic strength.

## E. Chemical loading by the Plastic Lake winter cover

The total ionic load of the winter cover was only calculated for two sample sites (site 3 and 19). A total winter cover chemical budget for the entire lake, given the spatial and temporal variability found in the volume and chemistry of all three of the lake cover components (Table 9), was logistically impossible. The peak ionic load for the two sites was recorded from the March 15 and March 18 samples. Spatially, the peak ionic load was recorded at the nearshore site 19 for all parameters except TKN, $NO_3^-$ and $H^+$. The increased loading at the shoreline site can mostly be attributed to the greater volume of ice there. Another source of ions for this site may be the terrestrial runoff which appeared to influence this portion of the lake.

The slush component of the winter cover generally carried a greater percentage of the ionic load than its volume would indicate (Table 9). This concentrational effect is caused by exolution of ions and gases from the advancing ice front into the narrowing slush lens. Two parameters which did not exhibit this exsolution effect were PPUT and TKN whose concentrations were generally proportional to the volume of each cover component (Table 9). Welch and Legault (1986), and Groterud (1972a) both report poor freezeout efficiencies for phosphorus and nitrogen from black ice which means that more of these nutrients may be incorporated into the ice structure in comparison to other ions.

As the season progressed, an increasing proportion of the total ionic load contained in the winter cover could be accounted for by precipitation inputs to its surface. Throughout the study period, precipitation could account for most of the $H^+$ and $NO_3^+$ found in the lake cover at both sites. This not surprising given the high concentrations of these two ions recorded in the precipitation in this region (Table A5). There appeared to be a decrease in the total ionic load of $Ca^{+2}$, $Mg^{+2}$, $Na^+$, $K^+$, $SO_4^{-2}$ and DOC from Feb. 10 to March 15 at site 3, despite a 33% increase in ice volume. This may be an indication of a leaching of the ice cover by rainfall. Rainfall appeared to percolate quite quickly through the ice cover, probably through micro-channels like those described by Brownman (1974). This definately occurred during the first rain-on-snow event as the surface water of Plastic Lake experienced substantial offshore pH depressions (Fig. D6c). The surface waters at this time also had extremely extremely low natural fluorescence values (Fig. D8d), indicating an non-terrestrial source for this water. Ions from the ice cover may be added directly to the lake by this rainwater in much the same manner as they are removed from a snowpack by a rain-on-snow event. The influence of the terrestrial runoff on the winter cover at site 19 is reflected in the low ratios of precipitation inputs to cover load for most parameters when compared to the open lake site 3.

The lake cover on April 22 displayed a decreased ion load as a result of ablation of the ice cover, Site 19 less so than Site 3 (Table 9). Some ions, such as $Ca^{+2}$, did not appear to be lost in proportion to the decline in ice volume. This appeared to be a result of the saturation of the decaying ice matrix by lake water.

The importance of the 1985 winter cover within the spring water and chemical budget framework for Plastic Lake is summarized in Tables 11 and 12. It should be borne in mind that Plastic Lake occupies 25.2% of its total catchment area. Precipitation on the lake surface during the study period contributed ca. 26% of the total water to Plastic Lake during this time. Hydrogen ion, $Cl^-$ and PPUT appeared to be contributed to the lake in proportion to the volume of precipitation for this period. Precipitation on the lake's surface appeared to contribute a substantial portion of the total $NO_3^-$ and TKN inputs to the lake (88% and 41%

Table 12
Contribution to Plastic Lake from direct precipitation and slushed lake water expressed as a percentage of the total external inputs to Plastic Lake for the 1985 study period.

| | External precipitation load | Internal lake load |
|---|---|---|
| $H_2O$ | 26.0 | 8.23 |
| $H^+$ | 28.4 | 0.0004 |
| TIPAlk | -28.1 | 17.2* |
| $Ca^{+2}$ | 3.4 | 13.2 |
| $Mg^{+2}$ | 2.6 | 13.6 |
| $Na^+$ | 4.1 | 10.8 |
| $K^+$ | 5.3 | 16.6 |
| $Cl^-$ | 20.3 | 12.0 |
| $SO_4^{-2}$ | 8.7 | 9.1 |
| $NO_3^-$ | 88.4 | 1.1 |
| TKN | 41.6 | 6.9 |
| PPUT | 27.9 | 3.1 |
| TAL | 1.7 | 1.5 |
| DOC | 3.4 | 3.8 |

* 17.2 kg as $CaCO_3$ added to the lake through internal loading.

respectively), reflecting the efficient retention of nitrogen by the terrestrial catchment. The terrestrial runoff contributed a far greater percentage of the $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $SO_4^{-2}$, TAL and DOC inputs to the lake when compared to precipitation inputs.

An estimate of the internal loading to Plastic Lake from lake water that had slushed the overlying snowcover over the course of the winter is also presented in Table 12. The lake water was assumed to have concentrations equal to those reported by MOE on January 28 (Table D1 in Appendix 4). The volume of this water was assumed to equal 51% of the total ice cover minus the volume of the black ice component. The water input from this source is estimated as some 8.2% of the total external inputs from precipitation. This internal loading contributes most of the parameters in proportion to the volume of input except for $H^{+}$, $NO_3^{-}$, PPUT, TAL and DOC which are contributed relatively less. The internal loading to the lake appears to be a more important source of major cations and alkalinity than the precipitation component of the lake winter cover.

The physical structure and chemical nature of Plastic Lake's winter cover was complex and dynamic. Both changed dramatically in response to the frequent rain-on-snow events, snow loading and final thaw. The floating snow cover appeared to be chemically and physically distinct from the terrestrial snowpack throughout most of the study period. Chemical and physical differences between adjacent snowpacks could be attributed to slushing and subsequent white ice growth on the lake surface, and forest canopy processes within the terrestrial catchment. The winter cover and the precipitation component contained within it, appeared to contribute significant portions of the water and chemical (particularly nitrogen), inputs to Plastic Lake during the 1985 spring runoff period. The different winter cover components (slush, snow and ice), differed greatly in their ionic concentrations. The various slush lenses appeared quite concentrated and acidic, as a result of freezout, and carried a far greater percentage of the total winter cover ionic load than their volume would indicate.

The winter cover appeared to be quite porous during the study period. There appeared to be both macro and micro openings which allowed precipitation inputs into the lake and lake water out on to the ice surface throughout the study period. The presence of the slush lenses within the ice cover meant that the temperature of the ice cover was ca. $0^{o}$C while they were present. This allowed microchannels at the individual ice grain boundaries to remain open. These channels allowed any rain water on the lake surface to percolate through the ice cover leaching it of various ions. The presence of the macro openings allowed acidic water to enter the lake, unbuffered, in substantial short-lived vertical streams during rainfall events (Fig. D6c). These same openings allowed lake water to slush the lake snowcover whenever the ice cover was depressed. This influenced both the spatial ice growth and the final chemical distributions within the winter cover over the entire lake surface.

## F. Plastic inflow chemistry and hydrology

The Plastic Inflow 1 hydrograph displayed five separate discharge peaks during the study period (Fig. C1). The first four peaks are attributable to rain-on-snow events (Fig. C1, Tables A2, A3 and A4). The final, and by far the largest, discharge peak was the result of a combination of a rain-on-snow event and the final large radiative snowmelt (Tables A4 and C1, Fig. C1). Event 5 and the final snowmelt quickly ablated the terrestrial snowpack (Fig. B2a), and the Plastic Lake ice cover (Fig. B5). The final rain and snowmelt discharge peak (April 15-28), contributed ca. 40% of the total terrestrial runoff inputs to Plastic Lake for the period of Jan 03 to April 30, 1985 (Table 10).

The trends in streamwater chemistry in Plastic Inflow were dominated by the meteorologic and hydrologic sequence for the study period. As the Plastic 1 inflow discharge decreased to baseflow in January and most of February (Fig. C1 and Table C1), concentrations of $H^+$, $SO_4^{-2}$, TAL and conductance declined (Figs C2a, h, l and o, Table C2). Alkalinity, $NO_3^-$, PPUT, DOC, $A^-$ and colour increased (Figs. C2b, i, k, m, n, and p, Table C2), while $Ca^{+2}$, $Mg^{+2}$, $Na^+$, $K^+$, $Cl^-$ and TKN (Figs. C2c, d, e, f, g, and j, Table C2), remained relatively constant.

The decrease in streamwater concentrations, as discharge declined, is possibly a result of a decrease in the contributions of areas within the catchment that contribute relatively higher $H^+$ and $SO_4^{-2}$ concentrations than other portions of the catchment. Total aluminum and conductance are influenced by the $H^+$ concentration in the waters of the study area. As pH declines, TAL is mobilized (reviewed by Campbell and Stokes 1985), while hydrogen ion influences conductance to a large degree in the dilute Shield waters of the study area (APHA 1965). Therefore the declines in conductance and TAL, as well as the increase in alkalinity, are likely linked to the decrease in $H^+$ concentration within the stream water. The increase in concentration of PPUT and $NO_3^-$ is likely a result of a decreased demand placed on these nutrients by the terrestrial system because of the dormancy of plant and microbial metabolism during the winter period. Dissolved organic carbon, $A^-$, and colour concentrations are linked, and their small increase in concentration may be attributed to a decrease in dilution by the reduced flows of this period.

Dissolved organic carbon, $A^-$, colour and $Na^+$ all displayed decreases in concentration during event 1 as a result of dilution (C2e, m, n and p, Table C2). Alkalinity decreased in concentration (ca. -30 ueq/l), largely as result of an increase in strong acid ($HNO_3$ ca. +15 ueq/l and $H_2SO_4$ ca. +34ueq/l), stream water concentrations (Table C2). All other parameters displayed an increase in concentration as a result of event 1. The source of these ions to the stream is a combination of water stored within the soil matrix, which becomes displaced into the stream by snowmelt (piston flow), and direct inputs of ions from snow and rainwater to the stream channel.

The hydrologic yield from Event 1 almost equalled the precipitation inputs for that period. Hydrogen ion and $SO_4^{-2}$ were exported from the terrestrial basin in proportion to the decrease in snowpack load (Table 7). The observed decreases in the terrestrial snowpack load of PPUT (13.4x), TKN (3.4x) and $NO_3^-$ (17.2x) were greater than the calculated stream export for event 1, indicating that these nutrients were either being retained by the terrestrial system, or that this water was not reaching the stream channel but rather displacing pre-existing soil water. Calcium, $Mg^{+2}$, $Na^+$, $Cl^-$, TKN, PPUT, TAL, DOC, $A^-$ and colour all displayed declining trends in stream water chemistry as snow meltwater and rainwater contributed a larger portion of the streamflow as the season progressed after event 1 (Table C2, Figs. C2c, d, e, g, j, k, l, m, n and p). Sulphate displayed a relatively stable concentration after event 1 until its concentration declined because of dilution during the final large snowmelt event in late April (Fig. C2h, Table C2). After event 1, $NO_3^-$ concentrations generally remained near trace values as the terrestrial basin retained this ion quite efficiently (Fig. C2i, Table C2). Small, short-lived, $NO_3^-$ concentration peaks were associated with events 2, 3 and 5. The source of these small peaks was likely the flushing of new snow in the near stream snowpack. Small peaks in streamwater concentration were displayed by $H^+$, $Ca^{+2}$, $Mg^{+2}$, $Cl^-$, $SO_4^{-2}$, $NO_3^-$, PPUT, TAL, DOC, $A^-$, conductance and colour during events 2 an 3 (Figs C2c, d, g-i, k-p, Table C2). All chemical parameters except PPUT displayed a decrease in streamwater concentration because of dilution during the peak snowmelt and discharge period in late April (Figs. C2 a-p, Table C2). Phosphorus values may have been influenced by the increased suspended load of organic matter that appeared to accompany peak discharge. Alkalinity, TKN, $Cl^-$, $A^-$, DOC, colour and PPUT all exhibited increases in streamwater concentration once snowmelt was completed in early May (Figs. C2b, g, k, m, n, and p).

### G. The hydrologic and chemical influence of snow and ice melt on Plastic Lake, 1985.

The sampling program initiated on Plastic Lake was designed to investigate the influence of meltwater runoff within the lake spatially, in the horizontal and vertical planes, as well as temporally. The purpose of this sampling program was to determine the spatial extent to which Plastic Lake was influenced by spring runoff and to determine the spatial and temporal extent of any pH depressions associated with this meltwater. It was unfortunate that the large early slushing event prevented the establishment of the whole lake sampling grid until early March, after event 1, which we have seen had a profound effect on stream chemistry. Sampling during and before the initial rainfall event was conducted through natural holes in the ice surface along the western shoreline and only suface water pH, conductance and natural fluorescence data were obtained at 12 of the 40 regular sampling sites.

It is useful to begin to examine the influence of snowmelt on Plastic Lake during the study period, by first examining the MOE deep hole integrated chemistry results (Table D1). Most chemical parameters during the study period displayed a slight decrease in concentration 5%-10% which is well within the variation that can be attributed to sampling and analytical variance (ca. 10%, P. Dillon, personal comunication). Aluminum displayed a small increase which is also within the sampling and analytical variance.

Hydrogen ion (+35%), Alk (-60%), $NO_3^-$ (+75%) and $Cl^-$ (+24%) displayed more substantial changes. The observed $Cl^-$ change may be suspect because of an initial low value which is in error. The $Cl^-$ increase is not a general trend over the study period for that ion which is further evidence of an possible initial underestimate (Table D1). Approximately 1/3 of the $NO_3^-$ increase may be attributed to inputs through precipitation on to the lake surface (Table 11). The rest of nitrate increase within Plastic Lake must be generated through internal processes, principally the decomposition of organic matter within the lake. Although the actual increases in $H^+$ and decrease in alkalinity are slight, both trends are consistent through the study period (Table D1). The increase in $H^+$ can be roughly balanced, on an equivalence basis, by the increase in $NO_3^-$ concentration within the lake.

The chemical budget for Plastic Lake during the study period (Table 11), reflects the trends in deep hole integrated results for most chemical parameters. Chloride, TKN, PPUT, TAL and DOC display the opposite trend in concentration to that predicted by the chemical budget. Chloride changes may possibly be attributed to error (previously discussed), while Plastic Inflow 1 (upon which the terrestrial input portion of the budget is based), may not be a good predictor for the ungauged portion of the basin for DOC and TAL inputs (P. Dillon personal communication). Aluminum and DOC may also precipitate out from low pH stream water as it mixes with slightly higher pH Plastic Lake water. Internal processes such as organic decomposition are likely quite important in regulating the concentrations of TKN and PPUT within Plastic Lake.

The chemistry budget indicates that Plastic Lake retained $H^+$, $NO_3^-$, TKN, PPUT, TAL and DOC during the study period while a net export of $Ca^{+2}$, $Mg^{+2}$, $Na^+$, $K^+$, $Cl^-$ and $SO_4^{-2}$ seems to have occurred (Table 11). The input:output ratio for $SO_4^{-2}$ is quite close to one, certainly within the error of the budget method, indicating that $SO_4^{-2}$ outputs are roughly balanced by inputs. Generally Plastic Lake appeared to have become slightly more dilute in base cations, alkalinity decreased and the observed increase in $H^+$ was roughly balanced by an increase of $NO_3^-$ within the lake.

## H. Nearshore and surface water chemistry

The integrated surface (1.5m) water chemistry displayed much more dramatic responses to snow and ice melt inputs than the integrated deep hole results during the study period (Table D2, Figs. D1a-o). These results were not unexpected given that the measurements were taken close to the input source (shorelines and stream entrances), before much dilution within the lake could take place. The results are important however, as they offer a closer approximation of the water quality to which biota are exposed in the littoral zones during the spring runoff, than the deep hole integrated values.

Four of the five sites (Site 1 near the lake outflow being the exception) displayed, higher $H^+$ concentrations throughout the study period than the deep hole results (Fig. D1a). The mean $H^+$ for these four sites was significantly different than the integrated chemistry results (Wilcoxon two sample rank test (p> F= 0.0026).

Site 1 generally displayed a delayed response to all concentrational changes within the lake as a result of its isolated position with regards to the main lake body (Fig. 10). The outlet area of Plastic Lake has a relatively small area of the terrestrial basin draining directly into it, which would also contribute to the observed delayed response of site 1.

Hydrogen ion data from February, during event 1, indicated that Site 31 (adjacent to a rocky shoreline) appeared to experience a substantial pH depression (Fig. D1a). A pH depression also occurred at all sites except site 1 during event 2 in mid March. This pH depression is also reflected by the shoreline profile data Fig. D3a-e and the whole-lake surface pH distributions Fig. D6a-i. Site BI1 (adjacent to the Plastic 1 inflow), displayed the highest $H^+$ increase (up to 50 $\mu$eq/l). Hydrogen ion concentrations declined within two weeks in three of the four sites (Site 9 adjacent to Plastic Inflow 5 (Fig. 10), being the exception). A smaller $H^+$ increase was exhibited at sites 1, 31 and BI1 during event 4 in late March. A final peak in $H^+$ concentration occurred on April 10 just before event 5 (Fig. D1a). Hydrogen ion concentrations decreased during the final runoff event likely as a result of dilution from the ice cover and snowmelt runoff.

Negative alkalinities were recorded at four of the five sites throughout the entire study period (Fig D1b). Alkalinity also became negative at site 1 during event 3 and remained so until the final sampling date on April 21. Alkalinity trends at the remaining four sites generally followed one another with site BI1 (adjacent to Plastic Inflow 1) displaying the largest alkalinity depression (as low as -1.6 mg/l as $CaCO_3$). The largest alkalinity decline occurred during event 2 in mid-March.

Conductance values recorded in the surface water of the shoreline sites followed almost the exact same trends as recorded for $H^+$ (Fig. D1c). This indicates that conductance in these dilute waters is largely a function of $H^+$ concentration rather than total ionic strength of the water. Site 1, in the outflow area, again displayed a delayed response to snowmelt inputs with conductance only increasing in late March.

Shoreline surface water $Ca^{+2}$, $Mg^{+2}$, $Na^+$, $K^+$, $Cl^-$, $SO_4^{-2}$, PPUT, TAL, and TKN all displayed similar concentrational patterns over time (Figs D1d, f, g, h, i, k, l and m). Concentration of these parameters appeared to decrease in response to event 2 and within two weeks had increased to pre-event concentrations or higher. Little or no dilution is evident in response to event 3.

Concentrations of the above parameters peaked on the April 10 sampling, and thereafter rapidly decreased in response to ice and snowmelt runoff by April 21. Site 1 again, tended to lag behind the other sites, exhibiting a slow increase in these parameters until April 10 before becoming more dilute.

Conductance , $H^+$, $Na^+$, $SO_4^{-2}$, PPUT, TAL, DOC, TKN and natural fluorescence all appeared to be more concentrated or higher in this surface, nearshore, water than in the lake as a whole (Figs. D1a, c, f, i, l, m, n and o).

Total aluminum and DOC displayed substantial differences between shoreline sites. TAL concentrations reached much higher concentrations at sites 19, 31 and BI1 than recorded at sites 1 or 9 or the integrated deep hole results (Fig D1m). Site 9 displayed the same pattern but did not reach the same TAL concentrations as the other three sites. Dissolved organic carbon values at sites 1 and and 31 were always lower than those recorded for the other three shoreline sites (Fig. D1n). Sites 1 and 31 displayed no DOC response during the study period while the other three sites responded in the same general manner as the other parameters listed above. Differences in DOC and natural fluorescence values obtained from the five sites may be attributed to the presence of organic soils within the terrestrial basin adjacent to sites 9, 19 and BI1.

Nitrate displayed an increase at sites 9, 19, 31 and BI1 in response to event 2 in mid March which was opposite to the trend displayed by the parameters mentioned above

(Fig. D1j). Concentrations of $NO_3^-$ declined to pre-event 2 levels by early April. A very slight increase in $NO_3^-$ concentrations was recorded during late April. Site 1 $NO_3^-$ concentrations exhibited a gradual build-up during the study period, peaking in early April and declining thereafter.

Natural fluorescence displayed a similar pattern to DOC with sites 1 and 31 having lower values than the other three sites (Fig D1o). Site 19 displayed a fluorescence peak during the February rainfall event while little or no response was exhibited at sites 1 and BI1. Site 1 and 31 displayed gradual increases of fluorescence throughout the study period. Site 31 declined quite rapidly on April 22, in response to dilution by ice and snow meltwater. Site BI1 displayed the largest decrease in fluorescence in response to the final snowmelt runoff. The natural fluorescence recorded in mid-lake was 4 units.

## I. Quantification of shoreline acidification

As mentioned in the introduction, the acidification process is the reduction in alkalinity. The reduction in alkalinity can be caused by dilution, an increase in organic acidity and an increase in strong mineral acids ($HNO_3$ and $H_2SO_4$), (Dillon and Lazerte 1986). Table 13 presents a quantitative breakdown of the causes of the reduction of alkalinity at each of the five shoreline sites. There are four samples with full chemistry that exhibited increases in acidity during the study (March 14, 18 and April 11 and 20) for sites 9, 19, 31 and BI1. The initial MOE integrated

Table 13
Contributions by dilution, organic acidity and mineral acid anions to the observed alkalinity losses in Plastic Lake littoral zones, 1985.*

| Site 1 | $H^+$ | Cations | Anions | $NO_3^-$ | $SO_4^{-2}$ | $A^-$ |
|---|---|---|---|---|---|---|
| Feb12 | 2.6 | | | | | |
| Feb23 | 7.5 | | | | | |
| Mar02 | 0.2 | | | | | |
| Mar07 | 2.4 | 12.7 | 11.0 | 5.0 | 3.1 | 2.4 |
| Mar14 | 4.0 | 1.6 | 11.1 | 1.2 | 5.2 | 0.1 |
| Mar18 | 2.7 | | | | | |
| Mar26 | 2.8 | 17.8 | 21.4 | 8.6 | 10.0 | 2.3 |
| Mar28 | 3.6 | | | | | |
| Apr01 | 5.5 | | | | | |
| Apr03 | 8.2 | 10.6 | 55.7 | 11.9 | 39.0 | 0.7 |
| Apr09 | 14.7 | | | | | |
| Apr11 | 22.8 | 17.5 | 33.4 | 10.7 | 19.8 | -0.8 |
| Apr20 | 15.1 | -38.6 | -11.6 | 3.2 | -17.7 | -0.6 |
| Apr21 | 11.2 | | | | | |
| Site 9 | | | | | | |
| Mar02 | 22.8 | | | | | |
| Mar07 | 8.7 | 3.8 | 9.2 | 1.1 | 5.2 | 7.2 |
| Mar14 | 25.3 | 18.2 | 11.1 | 19.6 | -11.4 | -1.1 |
| Mar18 | 27.2 | | | | | |
| Mar26 | 31.6 | 21.4 | 68.2 | 26.8 | 38.5 | 5.4 |
| Mar28 | 29.3 | | | | | |
| Apr01 | 14.3 | | | | | |
| Apr03 | 17.7 | 9.3 | 25.6 | 1.6 | 19.2 | 11.3 |
| Apr09 | 17.7 | | | | | |
| Apr11 | 29.3 | 2.8 | 25.5 | 3.2 | 19.4 | 5.7 |
| Apr20 | 11.2 | -45.9 | -20.7 | 3.9 | -27.5 | 0.1 |
| Apr21 | 9.2 | | | | | |
| Site 19 | | | | | | |
| Feb12 | 3.0 | | | | | |
| Feb23 | 6.6 | | | | | |
| Mar02 | 13.6 | | | | | |
| Mar07 | 10.3 | 16.9 | 13.0 | 2.9 | 7.3 | 8.4 |
| Mar14 | 38.4 | -12.0 | 17.2 | 17.5 | -3.1 | 4.0 |
| Mar18 | 17.2 | | | | | |
| Mar26 | 7.0 | 22.2 | 31.0 | 4.6 | 23.5 | 8.6 |
| Mar28 | 13.6 | 26.3 | 37.2 | 3.9 | 30.4 | 13.1 |
| Apr01 | 10.6 | | | | | |
| Apr03 | 9.7 | | | | | |
| Apr09 | 22.8 | | | | | |
| Apr11 | 33.2 | 15.1 | 36.9 | 3.2 | 30.8 | 10.8 |
| Apr20 | 11.8 | -45.8 | -12.5 | 4.6 | -20.0 | |
| Apr21 | 15.5 | | | | | |
| Site 31 | | | | | | |
| Mar02 | 37.5 | | | | | |
| Mar07 | 2.3 | 9.6 | 12.4 | 4.3 | 5.2 | 1.6 |
| Mar14 | 37.5 | -12.5 | 24.9 | 18.9 | 3.1 | -3.5 |
| Mar18 | 13.2 | | | | | |
| Mar26 | 16.8 | | | | | |
| Mar28 | 20.6 | | | | | |
| Apr01 | 8.7 | | | | | |
| Apr03 | 9.5 | 9.3 | 30.8 | 7.1 | 20.8 | 0.4 |
| Apr09 | 15.1 | | | | | |
| Apr11 | 37.5 | -3.5 | 28.8 | 9.6 | 16.3 | -4.2 |
| Apr20 | 11.2 | -55.8 | -12.8 | 11.8 | -27.5 | -4.8 |
| Apr21 | 13.2 | | | | | |
| Site BI1 | | | | | | |
| Feb12 | 9.2 | | | | | |
| Feb23 | 9.7 | | | | | |
| Mar02 | 13.9 | | | | | |
| Mar07 | 45.6 | 33.9 | 21.3 | 1.8 | 16.7 | 18.5 |
| Mar14 | 37.5 | -12.5 | 12.8 | 18.2 | -8.3 | 6.0 |
| Mar18 | 7.9 | | | | | |
| Mar26 | 16.8 | 21.8 | | | 13.6 | 12.4 |
| Mar28 | 20.1 | | | | | |
| Apr01 | 22.8 | | | | | |
| Apr03 | 29.3 | 14.5 | 40.1 | 2.5 | 34.8 | 16.9 |
| Apr09 | 30.1 | | | | | |
| Apr11 | 15.1 | 15.9 | 30.8 | 2.5 | 25.4 | 11.3 |
| Apr20 | 8.2 | 60.5 | -31.6 | 5.7 | -40.2 | -1.4 |
| Apr21 | | | | | | |

*The January 28 values for the "deep hole" integrated samples (Table D1) were used as the basis of calculating whether any decrease or increase occured in any of the parameters. The sum of cations was calculated as the sum of the base cations $Ca^{+2}$, $Mg^{+2}$, $Na^+$ and $K^+$ in ueq/l. The sum of the anions was calculated as the sum of $SO_4^{-2}$ and $NO_3^-$.

lake sample value was used as a baseline against which acidification change was assessed. Pre-runoff samples from each site would have been preferred for use as a baseline, but were unavailable because of the early sampling problems. Site 1 displayed an acidity increase only on April 11 and 21. Dilution appeared to play a part in the pH depressions recorded on March 14 and April 21. A major dilution of cations, and to a lesser extent anions, is indicated by the April 21 results. The hydrogen ion increase during peak snowmelt was only 8.2 to 15.5 ueq/l higher than the baseline values. Sulphate concentrations appeared to decrease during the peak snowmelt event while $NO_3^-$ remained relatively stable. The dilution of $SO_4^{-2}$ was only 66 to 43% of the dilution observed in base cations during the peak snowmelt. This indicates that runoff was $SO_4^{-2}$ enriched with respect to base cations during the peak snowmelt. The relatively stable $NO_3^-$ concentrations are possibly a result of $NO_3^-$ being released by the ice cover and organic decomposition. Organic acidity is of consequence only at sites 9, 19 and BI1.

Organic acidity (an empirical estimate of the abundance of dissociated and complexed caboxyl groups in solution, $A^-$, (Oliver et al. 1983)), plays a role in the acidity increase recorded on March 26 and April 11 at sites 19 and BI1, with $A^-$ contributing more of the observed anion increase than $NO_3^-$ on those occasions. Organic acidity only approaches the importance of $SO_4^{-2}$, in contributing to the reduction in alkalinity, at site BI1 adajacent to Plastic 1.

The March 14, $NO_3^-$ increase accounts for the first recorded acidification pulse, with $SO_4^{-2}$ concentrations actually showing a slight dilution at most sites. Sulphate generally appeared to be the dominant acidifying agent during the March 26 and April 11 samples. The reduction of alkalinity in the littoral, surface, waters of Plastic Lake during the study period appeared to be caused by the addition of strong acid anions $SO_4^{-2}$ and $NO_3^-$. Organic acidity was only important at sites near streams that contained organic soils within their catchments. Dilution of alkalinity occurred during the peak snowmelt. Sulphate concentrations decreased during peak snowmelt because of dilution but not to the same degree as base cations.

### J. Shoreline profile data

Conductance, temperature, pH and fluorescence profiles were also collected at each of the five shoreline sites to assess the vertical influence of spring runoff on Plastic Lake.

The Plastic Lake shoreline sites exhibited a typical winter stratification under the ice surface (Hutchinson 1975, Figs. D2a-e). These shoreline sites were generally quite cold throughout the study period (max. observed temperature 4.0°C, in late April), with temperatures only beginning to rise on March 15 at four of the sites and April 10 at site BI1. A breakdown of the temperature stratification appeared to have occurred in mid-March at four of the sites (site 9 being the exception), possibly indicating a mixing of the water column. This breakdown in thermal stratification appeared correlated with low pH and high conductance water (Figs. D3a-e and D4a-e).

The profile results indicate that two separate pH depressions occurred during the study period (and possibly a third in late February that was not sampled) (Fig. D3a-e). The first pH depression appears to be in response to event 2 in mid-March and lasted for ca. two weeks. The second pH depression began in response to events 3 and 4, and persisted to the end of the study period (April 22). Both events increased $H^+$ to approximately the same levels (50-60 $\mu$eq/l), but the peak $H^+$ concentrations of the second pH depression appeared to occur slightly deeper than the first at some sites. This may be a result of dilute ice melt water overlying the terrestrial runoff water on the second sampling date. This three layer scenario is indicative of an interflow type of situation, (Fig. 5). Site 1, near the lake outflow, experienced only one pH depression, in mid-April, which was not as severe as those experienced in the other sampling sites (Fig. D3b). The maximum depth recorded for a pH depression below pH 5 was ca. 2.5 metres, at sites 19, BI1 and 9. This indicates that a substantial portion of Plastic Lake's littoral zone may be exposed to these low pH levels.

Conductivity profiles followed the same general trends as $H^+$ (Figs. D4a-e). Peak conductance values were recorded at the same depths and times as the high $H^+$ concentrations. The conductivity profiles were generally more complex than those of $H^+$ as a result of a sediment maximum also being displayed. Low conductivity water was found adjacent to the underside of the ice cover on the final sampling date. This is attributed to ice ablation.

Natural fluorescence values did not correspond with peaks in $H^+$ or conductance (Figs. D5a-e), during the first pH depression at the shoreline sites. Peak fluorescence values were recorded at all sites after the cessation of the first pH depression and only during the second pH depression was there any agreement between the two patterns. The high fluorescence values at depth indicate that terrestrial meltwater had mixed to a depth of at least 3m at site BI1 adjacent to Plastic 1 inflow (Fig. D5a-e). There is evidence of an interflow pattern of meltwater during the final profile, with lake ice meltwater overlying terrestrial runoff water which in turn is overlying the resident lake water.

## K. Whole-lake surface water response to acidification

To determine the whole lake spatial response of Plastic Lake surface waters to snowmelt, an integrated 1.5m tube sample was also collected from each of the 40 sample sites on a ca. fortnightly basis. The samples were collected to assess the horizontal distribution of meltwater inputs and the whole lake change in surface water quality that occurred during the study period. Specific conductance, pH and natural fluorescence were measured for each sample.

Figs. D6a-i display the lakewide surface water concentrations of $H^+$. Only a partial sample was obtained during the first rainfall event (areas within the dashed line, 12 sites, Figs. D6a and b). The area sampled during the initial rain-on-snow event, February 23, indicated a 33% increase in $H^+$ concentration in the surface waters adjacent to Plastic 1 with small areas developing pH's below 5 (Fig. D6a and b). Surface $H^+$ concentrations appear to have increased dramatically on March 2 after the cessation of the first rain-on-snow event (Fig. D6c). Local pH depressions are indicated well away from the lake margins. These mid-lake pH depressions appeared associated with areas where lake surface snow and rain water from event 1 had drained through large holes into the lake. The area adjacent to Plastic Inflow 1, the west central basin and the southern shoreline appeared to be areas of the lake that were influenced to a greater degree by melt and rainwater. The lake centre and outflow region did not appear to be influenced by the first rain-on-snow event. Peak lake-wide $H^+$ concentrations (33.73 μeq/l) were recorded on the March 13 sampling date (Fig. D6d), after event 2. Hydrogen ion concentrations increased near Plastic Inflow 1 and the entire lake surface, except for a small region near the lake outflow, experienced pH values below 5. Lake-wide $H^+$

concentrations declined to ca. 14.02 µeq/l on Mar 18 and were relatively constant through event 3 in early April.

Surface water $H^+$ concentrations again increased on April 9/10 to 22.63 µeq/l after event 4. Large areas of the eastern basin and the lake centre appeared to be influenced during this pH depression. Lake-wide $H^+$ concentration declined on the final sampling date (April 21), likely as a response to dilution from the ablation of the lake's ice cover.

The distributions of $H^+$ indicate that pH depressions in Plastic Lake were lake-wide and episodic in nature during the study period. Acid pulses were largely in response to rain-on-snow events. The highest hydrogen ion concentrations were recorded near sites adjacent to natural holes in the ice cover which allowed snow and rainwater on the lake ice surface to enter the lake directly on March 2. Standard errors were large ($\bar{x}$= 49.2%), both as a result of the spatial heterogeneity of $H^+$ across the lake and the variation attributable to sampling and analytical error.

Acidity in the area adjacent to Plastic Inflow 1 was generally greater than the rest of the lake. The lake outflow area (site 1), and the east shoreline generally experienced reduced $H^+$ concentrations when compared to the rest of the lake, possibly becuse of a delayed snowmelt in these areas.

Conductance generally followed the trends of $H^+$ concentrations (D7a-h). Peak conductance values were almost always associated with areas with high $H^+$ concentrations. The lake-wide conductance peak was recorded on April 9/11 ($\bar{x}$= 39.48). High conductance values were reflected by the high $H^+$ values recorded in the west basin on this sampling date. Lake-wide conductivities declined quite dramaticaly (-33%), on April 21 in response to ablation of the ice cover and accompanying dilution of the surface water.

Lake-wide natural fluorescence increased throughout the study period, with the highest values always associated with the Plastic 1 inflow area and the area adjacent to Plastic Inflows 5 and 6 (Fig. D8a-g). These areas of the Plastic Lake drainage basin contain organic soils which contribute the organic acid compounds which cause this natural fluorescence. The lake centre exhibited low fluorescence throughout the study period and it was only on April 8, when streamwater was distributed throughout the entire lake, that fluorescence values in this area increased above four fluorescent units (Plastic Lake background values). Low fluorescence values were recorded on March 2 and March 13 (Fig. D8c and d), indicating that the water responsible for the observed low pH values was contributed by rain and snow from the ice surface rather than terrestrial runoff.

## L. Plastic Lake outflow hydrology and chemistry

Plastic Lake outflow's hydrologic response to the various rain-on-snow events during the study period is dampened somewhat in comparison to the terrestrial stream response (Figs. C1 and C3), because of the storage capacity of the lake system. However the timing of the peak discharge from the lake occurred only one day later than the peak terrestrial discharge, indicating a fast response to major runoff events. There was a small hydrologic response to the March 4 snowfall event which loaded the lake ice cover with 35cm of snow (Fig. C3).

There were several subtle (in comparison to inflow chemistry), concentrational trends evident in outflow chemistry in the February-March period (Figs. C4a-o). The chemical response to the first rain-on-snow event, in February, was not as dramatic as the Plastic 1 inflow response, however a slight reduction in alkalinity is evident (Fig. C4b) along with small, sharp, increases in $H^+$, $SO_4^{-2}$, $NO_3^-$, TAL, DOC, conductance and colour (Figs C4a, h, i, l, m and o). This indicates that at least part of the lake is responding quite quickly to these inputs and is exporting this water much quicker than the theoretical flushing time, (TFT, equation 12), would seem to predict if the entire lake was mixing at this time.

$$\text{TFT (yrs)} = \text{Lake vol } (m^3)/\text{Yearly Outflow Volume } (m^3) \qquad 12$$

Hutchinson 1975

Hydrogen ion, $SO_4^{-2}$, $NO_3^-$ and conductance displayed increasing outflow concentrations until the beginning of April when they increased dramatically, in response to events 4 and 5. Sodium, $K^+$, TAL, DOC and colour all displayed peaks just prior to peak discharge, before their concentrations decreased as a result of dilution. Phosphorus was the only element which appeared to increase throughout the peak snowmelt discharge.

### M. Response of Little Clear, Glen, Harp, E. Red Chalk, Red Chalk and Blue Chalk Lakes to spring meltwater inputs

Temperature, pH, conductance and natural fluorescence profiles were collected at the above lakes, at sites adjacent to the largest single input source for each lake (Figs.D9a-f). All of the study lakes exhibited a slight decline in conductance beneath the ice cover (possibly up to 2m in Harp Lake). Hydrogen ion increases were generally confined to the water directly beneath the ice cover of these lakes (Harp (50cm), Blue Chalk (50cm), Little Clear (50cm) and Red Chalk Lakes (2m)). The tiny pH depression in Glen Lake, which is well buffered, can probably be attributed to dilution by ice ablation. The E. Red Chalk Lake sampling site is influenced both by the Blue Chalk outflow and Red Chalk 1 inflow stream and any pH depression in this lake may be masked by the influence of the Blue Chalk outflow. Little Clear, Harp, Blue Chalk, Red Chalk and Glen Lake all displayed an interflow pattern of fluorescence. These lakes exhibited low fluorescencing water for the first 50cm below the ice cover (surface ice melt), followed by a peak in fluorescence, indicating terrestrial runoff water, (to ca. 2 1/2m in Red Chalk Lake). Lower fluorescent lake water was found below these two layers .

One of the initial study objectives was to try to determine if there was a relation between mixing depth and inflow drainage area. It was postulated that the volume of inflow would be determined by the drainage area and therefore the energy available for mixing and mixing depth would be some function of that drainage area. However as we have seen in Plastic Lake, meltwater pulses are episodic events that vary spatially and temporally. There is no guarantee that we sampled the maximum mixing depth achieved by these inflows. Despite the differences in drainage areas between these basins, the maximum mixing depth, indicated by these profiles (2-3m), falls within the maximum mixing depth indicated by the Plastic Lake temporal profiles (Figs. D2a-D5e). It seems likely therefore, that the maximum mixing depth achieved by these small inflows is not simply dependent on volume of flow, but also on thermal density differences between water masses and inflow geometry.

### N. Dye tracing and inflow dynamics

The results of the fluorescein dye traces conducted within Plastic Lake are summarised in Figs. E1 to E5. The first dye addition to Plastic 1 was made on March 8, 1985 (Fig. E1). Plastic 1 discharge was quite low (2.21 l/sec) and only a ca. 10g. addition of fluorescein was made. The dye was traced 30m offshore over 4 hours before darkness made sampling impractical. During this time period, the dye reached a depth of ca. 1m and travelled at a mean velocity of ca. 0.125 m/min. Dye concentrations were highest in the initial 50cm of the water column below the ice cover. Dye measurements were continued on March 9, 28.5 hours after the original dye addition had been made. The dye plume had only travelled an additional 15m out into the lake but appeared to have dispersed outwards in a lateral direction several tens of metres. No dye could be detected below 50cm on day two and the highest dye concentrations were recorded in the initial 25cm of the water column below the ice cover.

A second, larger (25g), dye addition was made to Plastic 1 on March 29, 1985 at a substantially higher flow (21.5 l/sec, Fig. E2). The dye was traced ca. 100m out into the lake over 7.5 hours. The dye reached a depth of ca. 1.2m and travelled at a mean velocity of ca. 0.214m/min. Dye concentrations were highest in the initial 60cm below the ice cover. Dye sampling was continued on March 30, 24.5 hours after addition. The dye was present in much lower concentrations and could only be detected a further 20m offshore. Unlike the first dye addition, the dye plume was relatively compact (ca. 30m in width). Both dye traces indicate that Plastic 1 water was confined to the upper metre of the water column, under the ice cover, although it did contact the sediments close to shore. These tracer patterns are indicative of overflow situations. The first dye addition appeared to remain within the immediate inflow area and diffused slowly outwards once its initial momentum was lost. The second dye addition moved quite rapidly out into the lake and was probably transported out of the immediate inflow area by the second sampling. The dye that was detected on day two was quite dilute and may have been a residue of dye introduced slowly to the lake from the inflow area, well after the dye addition. Both dye additions indicate that streamflow from Plastic 1 can be mixed to at least 1.2m in depth, which would explain the $H^+$, conductance and fluorescence profile data in Figs. D3 to D5. It is interesting to note that even though the stream discharge had increased 9X from addition 1 to addition 2, the mixing depth did not appear to have increased. This indicates that mixing energy from Plastic 1 may be dissipated in the inflow area as a result of confining inflow geometry.

Fluorescein dye additions were made to two different Plastic Lake inflows in 1986. A small (5g) dye addition was made to a seepage input (Plastic seep 3) near shoreline site 31, on March 31, (Figs. 10 and E3). Powdered dye was added to the rocks above the lake and runoff water draining over the rocks was allowed to carry the dye into the lake. A ca. 1m area of open water existed adjacent to the shoreline and the dye appeared to mix completely to the lake bottom in this zone. A slight breeze transported the dye plume 3m laterally downwind before the dye went under the ice. Unlike the stream additions, the dye appeared to travel slowly along the lake bottom beneath a thin (5-20cm) layer of surface icemelt. At ca. 4m and 1m below the ice cover, the dye appeared to be displaced upwards by lake water and was confined to a ca. 50cm layer between the surface ice melt and the resident lake water (15-75cm below the ice cover). It is possible that the dye in the nearshore area mixed completely within the first 4m as the result of the establishment of a small thermal bar in this area. Water in the open area may have been warmed and circulated down under the ice within a small thermal cell which would explain the observed dye pattern. Dye moved quite slowly (ca. 0.025m/min), in relation to the dye velocities observed for stream inputs. The dye peak adjacent to the ice cover was a result of a small dye addition to the ice surface which indicates surface ice melt was percolating down through the ice cover. This porosity in an ablating ice cover was also observed by Bergmann and Welch (1985) at Saqvaqjuac, where rhodamine dye was observed to percolate through a 1.2m thick, decaying, ice cover. The dye probably moved through the ice cover and entered the lake through the type of microfissures described by Brownman (1974).

A dye addition was also made to Plastic 6 inflow. Discharge was ca. 18 l/sec at the time of dye addition (Fig. E4). Dye-labelled water appeared to displace lake water for a short horizontal distance (19m), near the stream entrance. Afterwards it was confined to the upper 25cm of the water column, under the ice cover. Once the labelled streamwater reached ca. 20m offshore, no dye was detected below 25cm beneath the icecover and the inflowing streamwater was segregated from the lake bottom in an overflow situation (Fig. 5). Mean dye velocity over 40m was ca. 0.22m/min and a slower (0.08 m/min.) lateral dispersion was also recorded. The stream water from Plastic 6 appeared to be quite confined in the initial inflow area which must reduce the amount of mixing that occurs from this input. The geometry of the inflow area serves to confine this inflow to the upper 25cm of the water column. Coincident measures of natural fluorescence, conductance and $H^+$ all displayed peaks within the Plastic 6 dye path (Fig. E5).

These results agree quite well with the rhodamine dye trace results published by Bergmann and Welch (1985) from Saqvaqjuac, N.W.T. and results obtained from a combined tritium/ rhodamine dye addition to Lake 240 at the Experimental Lakes Area (E.L.A), (G. Linsey personal communication). Bergmann and Welch (1985) found that dye-tagged water floated in a thin layer, 0-100cm below the ice, and extended over the entire ice-subsurface. Dye-tagged inputs reached lake outflows as soon as three days after addition. Flow rates extracted from the Saqvaqjuac study ranged from 0.02m/min to 0.08m/min. The dye velocities recorded from Plastic Lake appear higher than the Saqvaqjuac additions because they were only recorded over small distances near the inflow source. The dye tracings from all three studies indicate that the residence time for snowmelt inputs is likely overestimated, if they are assumed to mix with the entire sub-ice water compartment. The Plastic Lake dye tracings generally support the contention that the most deleterious influences of snowmelt runoff occur in the upper 1m of the water column in Precambrian Shield lakes with small inflows and shallow ground water inputs.

From the dye tracing and chemistry profile results it appears that meltwater movement and its influences within the study lakes were generally confined to the upper 3m of the water column, particularly in the littoral zones. In the pelagic zones of the lake, the influences were generally confined to the upper metre of the water column. In the Dorset area lakes, the most severe acid pulse and chemical changes were largely confined to the upper metre of the water column and often the top 50cm. It is clear that inflowing meltwater must be less dense than the resident lake water.

Temperature measurements from both streamwater and lakewater profiles within the Plastic Lake system, indicate that the incoming meltwater is slightly (ca. 0.0001 $g/cm^3$), less thermally dense than the resident lake water. Calculation of dissolved solids between the two water masses indicates that the inflowing stream water is slightly (0.000002 $g/cm^3$), more dense then the resident lake water. Therefore the density differences which separate the two water masses appear to be thermal in nature.

To help explain the water quality patterns observed during snowmelt, some aspects of the physical dynamics of the Plastic Lake system were calculated. The peak kinetic energy, developed by Plastic Inflow 1 at 96 l/sec, is calculated as 39.33 J (Equation 1). The stability (S), or work needed to mix a small area near the entrance of Plastic Inflow 1, represented by site BI1 (36m$^2$ area, 2m deep with a volume profile obtained from direct measurements), was calculated as outlined in equation 12, utilizing the temperature measurements from the study period for site BI1 (Fig. D2d).

$$S=g/A_o\int_0^{2m}(z-z_g)A_z(1-\rho_z)d_z \qquad (12)$$

Hutchinson 1975

Stability was found to vary from 0.45 to 1.45 J. over the study period. Kinetic energy supplied by each of the rain-on-snow events ranged from 0.7 to 5.3 J. It is evident that Plastic Inflow 1 can mix this small nearshore lake volume quite easily at peak flow and often at much lower flows, which would explain the presence of high fluorescing and low pH water at site BI1 at depths of 2-3m (Figs D3b and D5b). However the temperature stratification and chemical stratification that was evident during the study period at site BI1 indicates that this mixing was intermittent at best. It is likely the main vector of force for Plastic 1 is such that it is directed out over the surface of the lake rather than towards the lake centre. This was indicated in the dye tracings. It is also evident that Plastic 1 inflow does not supply nearly enough energy to mix large areas of Plastic Lake even when it is stratified quite weakly as it is under the ice cover.

By evaluating equations three and four for Plastic 1 and Plastic Lake we find that the actual energy available for mixing appears to be a negative value because the inflowing water mass is less dense than the lake. It appears that Plastic Lake actually becomes more stable as a result of the addition of this lighter water to the lake surface. The actual kinetic energy supplied to the inflow area by Plastic 1 is obviously not negative, and there does appear to be enough energy available to mix the shallow littoral zones near the stream entrance, at least during some flow periods, but clearly there is not enough energy to mix the entire lake. An evaluation of Equation 2 indicates that Plastic Inflow 1 develops an Fd number of ca. 18 at peak flow. The positive Fd number indicates that Plastic inflow 1 will project into the lake. However, the relatively small magnitude of this number indicates that the inflow will behave as indicated by the external temperature wedge scenario outlined in the Introduction and Fig. 7. Mixing is expected to be weak under this scenario and eventually buoyancy forces will cause this meltwater to travel through Plastic Lake as an overflow Fig. 4, (Stigebrandt 1978).

This overflow is evident in the outflow chemical response. If the inflowing snowmelt water remains largely segregated from the resident lake water inflow, concentrational changes should be reflected quite rapidly in the ice-covered lake's outflow. A crude attempt to model this overflow flow-through effect was applied to Plastic Lake to predict observed outflow chemistry. Two simulations, which mixed different volumes of the lake with a prorated chemical input (based on Plastic Inflow 1), were employed to predict the observed trends in outflow chemistry. A surface exchange simulation, which exchanged only the upper 50cm of the water column beneath the ice cover, and one that mixed the entire lake, were run for the various chemical parameters. The output budgets for this model are displayed in Table 14 and the actual and predicted trends for $Ca^{+2}$ are presented in Fig. 13. It appears that a surface exchange model explains the observed trends in $Ca^{+2}$ chemistry better than the fully mixed model which exhibited almost no temporal response.

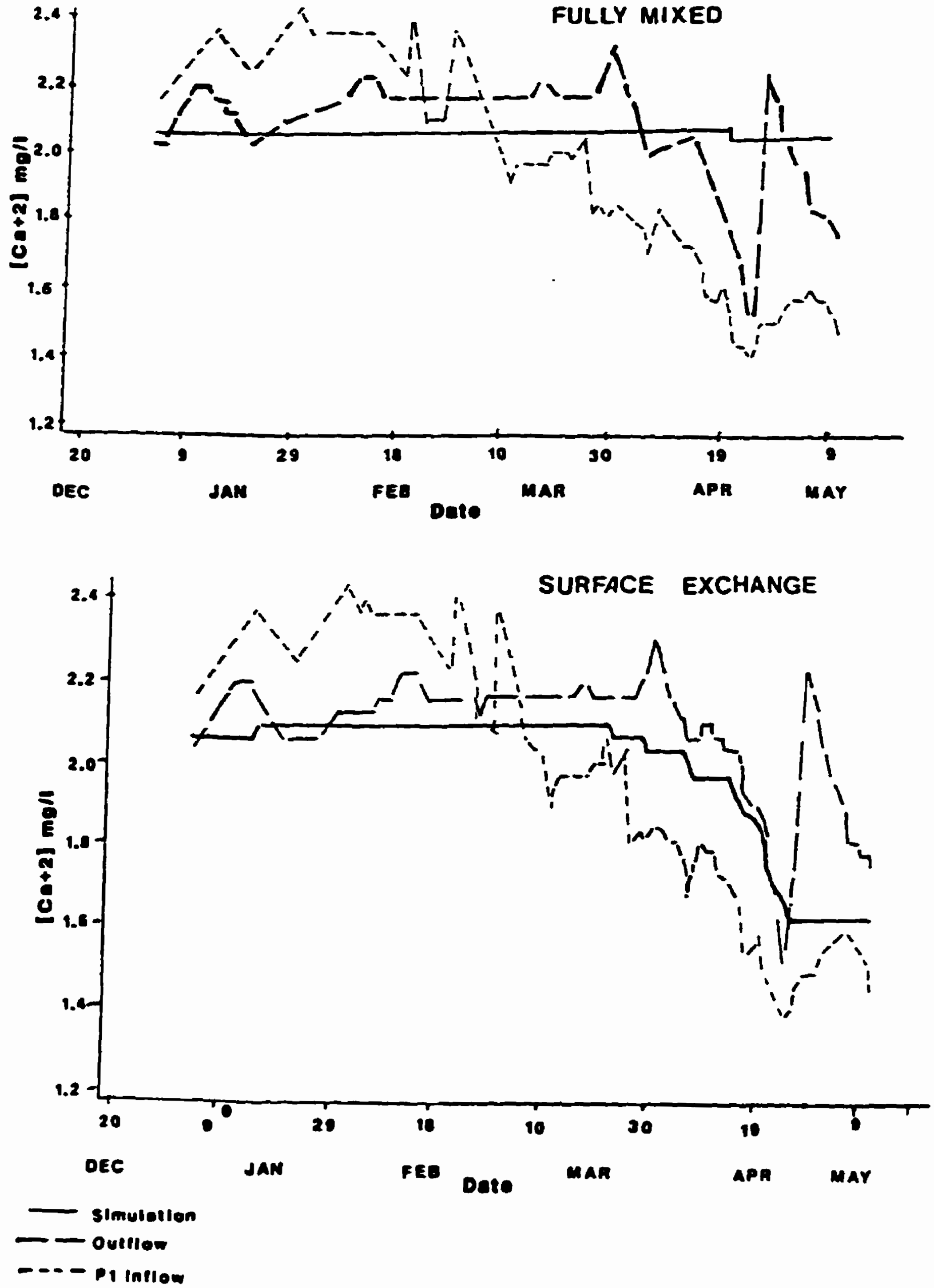
It is recognized that this approach has serious limitations. The simulations do not take into account inputs from the ice cover which obviously play a part in the final observed outflow dilutions. However, the surface exchange simulation and the observed actual $Ca^{+2}$ dilution both begin ca. 1 week before the ice cover began ablating, indicating that some terrestrial runoff is leaving the lake directly. Also, if the ice cover inputs are leaving the outflow at this time, it means that this inflow component has a shorter residence time than one would predict. This preferential loss of ice melt water has been reported from the Saqvaqjuac studies by Bergmann and Welch (1985). The simulations also do not take into account any internal

Table 14
Comparison of surface and whole lake mixing simulations with actual Plastic Lake outflow budget.

| | Fully Mixed | Surface Exchange | Actual |
|---|---|---|---|
| $H^+$ (keq) | 1.2 | 13.2 | 4.4 |
| TIPAlk* (kg) | 107.8 | -351.8 | -240.6 |
| $Ca^{+2}$ (kg) | 993.9 | 923.5 | 957.1 |
| $Mg^{+2}$ (kg) | 230.6 | 212.2 | 223.9 |
| $Na^+$ (kg) | 223.4 | 228.9 | 222.2 |
| $K^+$ (kg) | 99.8 | 81.9 | 103.6 |
| $Cl^-$ (kg) | 124.6 | 119.3 | 160.7 |
| $SO_4^{-2}$ (kg) | 3149.2 | 3410.4 | 3257.0 |
| $NO_3^-$ (kg) | 10.1 | 12.5 | 47.5 |
| TKN (kg) | 91.7 | 90.7 | 23.8 |
| PPUT (kg) | 2.5 | 2.5 | 2.3 |
| TAL (kg) | 23.1 | 79.9 | 32.4 |
| DOC (kg) | 1141.3 | 2118.2 | 1142.8 |

*Kg of $CaCO_3$

**Fig. 13 Comparison of surface exchange and fully mixed simulations for Plastic Lake outflow [Ca+2]**



changes that may have occurred within the lake with regards to non-conservative chemical parameters. The simulations also rely exclusively on the use of Plastic 1 to predict the entire terrestrial inputs to the lake, which may not be appropriate for some parameters. The simulation also utilised the initial MOE integrated sample as a baseline reservoir concentration. An error in this initial concentration could grossly affect the predicted output from each simulation.

The surface exchange, and the fully mixed simulations, predicted the calculated exports of $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $SO_4^{-2}$ and PPUT within 10% of the actual export from Plastic Lake. The fully mixed simulation also performed well in predicting $K^{+}$ and DOC exports. However the fully mixed simulations did not in any case match the observed temporal trends in outflow chemistry. The fully mixed simulation's success can mostly be attributed to the similar inflow and lake concentrations of the Plastic Lake system. An attempt was made to correct for alkalinity reduction within each reservoir as there were great differences in alkalinity concentration between the Plastic Lake inflows and outflow. The surface exchange simulation performed substantially better than the fully mixed simulation but still underestimated alkalinity export by some 46%. The results from the simulations are mixed. The surface exchange model appeared to predict most actual chemical trends quite well but did not perform as well in predicting the actual export budgets. It is possible that, perhaps by increasing the reservoir of the surface exchange simulation to ca. 1m below the ice cover, most budget results could be improved substantially. Neither simulation predicted TKN or $H^+$ adequately.

## Section 6 Conclusions

Plastic Lake exhibited whole-lake episodic temporal pH depressions in response to the several rain-on-snow events that occurred during the study period. It must be recognised that the results are decidedly year and somewhat site specific. The study period was influenced both by a late forming ice cover and by several large rain-on-snow events, both of which are not uncommon to this area. The episodic nature of the recorded pH depressions, have also been observed in lakes near Sudbury, Ont. by Gunn and Keller 1985. The severity of the whole-lake surface water pH depressions (ca. 1.17 pH units), recorded in Plastic Lake is equivelent to the epilimnetic pH depressions reported in the literature (summarised in Jeffries et al. 1979). The Plastic Lake surface water pH's recorded (down to pH 3.92), combined with relatively high aluminum values (up to 204 ug/l as TAL), are within the range of water quality which is likely toxic or stressfull to aquatic biota (Dillon et al. 1984, Gunn and Keller 1984, Leivestad and Muniz 1976, etc.). The loss of alkalinity within Plastic Lake could mainly be attributed to the addition of both $H_2SO_4$ and $HNO_3$. Dilution of alkalinity occurred during the peak snowmelt and organic acidity was a minor component of alkalinity loss at most sampling sites. This quantification of alkalinity loss is similar to the results reported by Lazerte and Dillon (1984) for Plastic Inflow 1 in previous years. Littoral areas differed spatially and temporally in their chemical response to spring runoff but were influenced to a greater degree than the lake centre.

The chemical influences of snow and ice melt varied spatially over the lake surface and with depth. Eventually the entire lake was influenced by meltwater to a depth of 2 to 3m, with the greatest chemical responses occurring in the upper 1m of the water column. The Plastic Lake outflow region and the eastern shoreline were influenced to a lesser degree than the rest of the lake, possibly because of the delayed snowmelt and small terrestrial contributing areas of these sites. Meltwater from stream inputs appeared to travel quite rapidly under the ice cover while direct drainage inputs travelled quite slowly and were relatively diffuse. Peak concentrations of terrestrial runoff water were found directly under the ice cover and were often associated with low pH, high conductivity and high natural fluorescence values.

Thermal density differences and low stream energies appear to be the major cause of meltwater stratification within the study lakes. All of the Dorset area lakes sampled exhibited similar mixing depths and meltwater responses. Mixing depth appears to be related both to stream energy and inflow geometry. It must be borne in mind that the lakes sampled generally have shallow till deposits in their terrestrial drainage basins. Any Shield lakes with deeper till deposits could experience substantial groundwater inputs during spring runoff, which would profoundly influence both the concentration and distribution of meltwater within the lake (Charette et al. 1984). The inflows to most of the study lakes were generally quite small. Large inflowing rivers could quite conceivably turn over an ice-covered lake or at least profoundly influence the distribution of meltwater within it (Carmack et al. 1979).

The winter cover of Plastic Lake changed physically as well as chemically as the study season progressed. The ice component was largely white ice or snow ice. The formation of this ice appeared to be caused by the flooding of the ice surface by both lake and rain water. The source of the lake water appeared to be several large natural holes rather than the classic thermal cracking scenario observed in colder areas (Shaw 1965). The winter cover of Plastic Lake acted as a porous, two-way, barrier to both lake water and precipitation during the study year. The ionic load of the lake winter cover appeared to be leached by rainfall and possibly lake water in much the same way as the terrestrial snow pack. Slush lenses contained a disproportionate share of the ionic load of the winter cover as a result of freezeout. Although the winter cover is not as important a source of hydrologic and chemical inputs as it is in arctic lakes (Welch and Legault 1986), it does contribute significantly to the winter-spring water and chemical budgets. The winter cover appeared to be a significant source of nitrogen compounds to the lake during the study period. The snow component of the lake winter cover differed dramatically (both physically and chemically), when compared to the adjacent terrestrial snowpack.

The results of this study indicate that the most deleterious effects of spring snowmelt acidification of Precambrian Shield lakes occurs in the shallow, littoral, areas although the entire lake surface can be affected. The most severe acid pulses can occur long before the final terrestrial snowmelt in response to rain-on-snow events, and these events are episodic in nature. Acidification can also be caused by rain and snow entering the lake in direct vertical streams which can cause substantial local reductions in alkalinity.

In lake basins with shallow till horizons and low energy stream inputs, runoff water is generally confined to the upper portion of the water column by thermal density differences although it can be mixed deeper by increased stream inputs. The segregation of this meltwater short circuits the lake and decreases the residence time of these inputs. As indicated by Bergmann and Welch (1985), the actual residence time of these runoff inputs in any given year will be determined by the proportion of the total runoff that occurs while the lake is ice covered.

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# Appendix 1 Meteorologic data and precipitation chemistry

Table A1
January precipitation and temperature summary Dorset climatological station. (I. Smith unpublished data)

| | Temperature (°C) | | Precipitation (mm, water) | |
|---|---|---|---|---|
| Day | Max | Min | Rain | Snow |
| 1 | -9.0 | -12.0 | T | 10.0 |
| 2 | -8.0 | -22.0 | | 0.6 |
| 3 | -4.5 | -24.0 | | T |
| 4 | -3.0 | -9.0 | | 0.8 |
| 5 | -8.5 | -17.5 | | 4.4 |
| 6 | -11.0 | -12.5 | | 7.0 |
| 7 | -12.5 | -15.0 | | 7.0 |
| 8 | -16.5 | -22.0 | | |
| 9 | -13.5 | -35.0 | | |
| 10 | -14.0 | -34.5 | | |
| 11 | -8.5 | -24.0 | | 0.2 |
| 12 | -5.0 | -24.0 | | 2.6 |
| 13 | -2.5 | -8.0 | 0.2 | 1.0 |
| 14 | -2.0 | -8.0 | | 4.0 |
| 15 | -19.0 | -25.0 | | 0.2 |
| 16 | -9.5 | -35.0 | | 2.8 |
| 17 | -7.5 | -16.0 | | 4.0 |
| 18 | -5.5 | -15.0 | | 5.6 |
| 19 | -9.0 | -10.5 | | 2.0 |
| 20 | -19.5 | -25.0 | | 1.9 |
| 21 | -11.0 | -28.5 | | 1.4 |
| 22 | -5.0 | -15.5 | | 2.0 |
| 23 | -3.0 | -7.5 | | 3.0 |
| 24 | -2.5 | -13.5 | | 2.2 |
| 25 | -5.0 | -8.5 | | 0.5 |
| 26 | -10.0 | -22.0 | | 0.5 |
| 27 | -7.0 | -15.0 | | 5.0 |
| 28 | -5.0 | -9.5 | | T |
| 29 | -7.0 | -28.0 | | |
| 30 | -5.0 | -27.0 | | |
| 31 | -7.0 | -17.5 | | |
| Mean | -8.2 | -18.9 | Total 0.2 | 69.7 |

T= Trace ( 0.2mm).

Table A2
February precipitation and temperature summary Dorset climatological station. (I. Smith unpublished data)

| | Temperature (°C) | | Precipitation (mm, water) | |
|---|---|---|---|---|
| Day | Max | Min | Rain | Snow |
| 1 | -5.5 | -12.0 | | |
| 2 | -12.0 | -22.0 | | |
| 3 | -6.5 | -22.5 | | 2.0 |
| 4 | -11.0 | -24.5 | | T |
| 5 | -8.5 | -22.0 | | 0.6 |
| 6 | -8.0 | -22.5 | | T |
| 7 | -13.0 | -22.5 | | T |
| 8 | -13.0 | -20.0 | | T |
| 9 | -8.5 | -16.5 | | |
| 10 | -2.5 | -10.5 | | |
| 11 | 2.5 | -15.0 | | 1.0 |
| 12 | 1.0 | -0.5 | 1.8 | 2.5 |
| 13 | 1.5 | -1.0 | | 8.0 |
| 14 | -6.5 | -7.5 | | 5.1 |
| 15 | -9.0 | -12.5 | | 2.0 |
| 16 | -5.5 | -15.0 | | 10.5 |
| 17 | -4.5 | -10.5 | | 4.0 |
| 18 | -2.0 | -9.5 | | 15.0 |
| 19 | -4.0 | -6.0 | | 6.5 |
| 20 | -1.5 | -15.0 | | 1.0 |
| 21 | 4.5 | -11.0 | 10.4 | |
| 22 | 4.5 | 2.0 | 2.2 | |
| 23 | 3.5 | 0.5 | 23.6 | |
| 24 | 3.0 | 1.5 | 4.0 | 0.2 |
| 25 | 2.0 | -5.5 | | |
| 26 | 1.5 | -1.5 | | 3.0 |
| 27 | -9.0 | -12.5 | | T |
| 28 | 2.5 | -21.5 | | 0.5 |
| Mean | -3.7 | -12.0 | Total 42.0 | 61.9 |

T= Trace ( 0.2mm).

Table A3
March precipitation and temperature summary Dorset climatological station. (I. Smith unpublished data)

| Day | Temperature (°C) Max | Min | | Precipitation (mm, water) Rain | Snow |
|---|---|---|---|---|---|
| 1 | 7.0 | -1.5 | | 0.2 | 7.0 |
| 2 | 1.0 | -3.0 | | | T |
| 3 | -7.5 | -18.5 | | | 2.0 |
| 4 | -3.0 | -15.5 | | | 35.0 |
| 5 | -1.5 | -14.5 | | | 3.0 |
| 6 | -1.5 | -28.0 | | | |
| 7 | 1.0 | -19.5 | | | 3.0 |
| 8 | 3.0 | -1.5 | | | 0.8 |
| 9 | 2.5 | -11.5 | | | |
| 10 | 8.0 | -13.5 | | | |
| 11 | 7.5 | -6.5 | | 13.8 | |
| 12 | 4.0 | 2.0 | | 3.4 | |
| 13 | 5.0 | -4.0 | | | 0.5 |
| 14 | 4.0 | -1.5 | | | 0.5 |
| 15 | -4.5 | -12.0 | | | 6.0 |
| 16 | 2.0 | -17.5 | | | T |
| 17 | -4.0 | -9.5 | | | |
| 18 | -3.0 | -27.5 | | | |
| 19 | 5.5 | -16.0 | | | T |
| 20 | -0.5 | -9.0 | | | |
| 21 | 0.0 | -19.0 | | | |
| 22 | 7.5 | -17.0 | | | |
| 23 | 8.0 | -9.0 | | | |
| 24 | 5.0 | -2.0 | | | |
| 25 | 2.5 | -8.5 | | | |
| 26 | 7.0 | -13.0 | | | |
| 27 | 13.5 | -2.0 | | 6.2 | |
| 28 | 4.0 | 0.0 | | 17.4 | |
| 29 | 4.0 | 0.0 | | 0.6 | |
| 30 | 3.0 | -6.0 | | | |
| 31 | 1.5 | -4.0 | | 3.0 | 15.0 |
| Mean | 2.6 | -10.0 | Total | 44.6 | 72.8 |

T= Trace ( 0.2mm).

Table A4
April precipitation and temperature summary Dorset climatological station. (I. Smith unpublished data)

| | Temperature (°C) | | | Precipitation (mm, water) | |
|---|---|---|---|---|---|
| Day | Max | Min | | Rain | Snow |
| 1 | 1.5 | -2.5 | | | 3.6 |
| 2 | -1.0 | -3.5 | | | 3.0 |
| 3 | 1.0 | -13.0 | | | 3.0 |
| 4 | 7.0 | -2.0 | | 14.0 | 4.0 |
| 5 | 6.5 | 0.5 | | 19.6 | T |
| 6 | 3.0 | 1.5 | | | 3.7 |
| 7 | 4.0 | -7.0 | | | |
| 8 | 0.0 | -9.5 | | | |
| 9 | -3.0 | -15.5 | | | |
| 10 | 0.5 | -14.5 | | | 19.0 |
| 11 | 2.0 | -7.5 | | | |
| 12 | 8.0 | -14.5 | | | |
| 13 | 7.0 | -3.0 | | T | 4.0 |
| 14 | 15.0 | -0.5 | | 4.7 | |
| 15 | 10.5 | 2.0 | | 1.2 | |
| 16 | 10.5 | 1.5 | | | |
| 17 | 4.5 | -8.0 | | 16.3 | T |
| 18 | 10.5 | -1.0 | | 2.3 | |
| 19 | 10.5 | -1.0 | | 1.0 | |
| 20 | 14.5 | 2.0 | | | |
| 21 | 25.0 | 1.0 | | | |
| 22 | 27.0 | 3.0 | | | |
| 23 | 28.0 | 3.0 | | | |
| 24 | 22.5 | 6.0 | | | |
| 25 | 15.5 | 8.0 | | T | |
| 26 | 15.0 | 0.0 | | | |
| 27 | 13.0 | -1.0 | | 1.8 | |
| 28 | 11.5 | 1.0 | | | |
| 29 | 18.0 | -3.5 | | | |
| 30 | 20.5 | 0.5 | | | |
| Mean | 10.3 | -2.6 | Total | 60.9 | 40.3 |

T= Trace ( 0.2mm).

Table A 5
Plastic 1 Precipitation chemistry, (P. Dillon unpublished studies)

| Date | pH | Alk** | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | $NH_4^{+}$ | $NO_3^{-}$ | TKN | PPUT | TAL | DOC | Anions | Cations | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | | | | | | | ug/l | | | | | mg/l | ueq/l | | % |
| Jan 03 | 4.50 | -1.61 | .07 | .010 | .025 | .035 | .12 | 1.15 | 150 | 290 | 190 | 2.25 | 3 | 0.5 | 48.0 | 48.6 | 1.2 |
| Jan 10 | 4.22 | -3.06 | | | | | .17 | 0.90 | 100 | 700 | | 3.35 | 7 | | 73.5 | | |
| Jan 22 | 4.29 | -2.71 | .03 | .010 | .060 | .010 | .15 | 0.85 | 115 | 725 | 140 | 2.75 | 6 | 0.5 | 73.7 | 64.7 | -13.0 |
| Jan 30 | 4.22 | -3.44 | .06 | .010 | .100 | .020 | .20 | 0.80 | 70 | 800 | 120 | 3.20 | 21 | 0.5 | 79.4 | 73.9 | -7.2 |
| Feb 13 | 4.39 | -2.20 | .07 | .010 | .095 | .010 | .20 | 0.95 | 55 | 400 | 90 | 4.50 | 24 | 0.5 | 54.0 | 53.4 | -1.2 |
| Feb 21 | 4.18 | -3.30 | .10 | .020 | .090 | .025 | .23 | 1.00 | 4 | 440 | 200 | 4.70 | 2 | 0.5 | 58.7 | 77.5 | 27.6 |
| Feb 25 | 4.18 | -3.40 | .01 | .005 | .030 | .010 | .09 | 1.80 | 130 | 450 | 150 | 1.65 | 1 | 0.5 | 72.2 | 77.8 | 7.6 |
| Mar 07 | 4.47 | -1.59 | .18 | .035 | .055 | .005 | .10 | 1.25 | 175 | 400 | 230 | 3.40 | 8 | 0.5 | 57.4 | 60.8 | 5.7 |
| Mar 13 | 4.08 | -4.20 | .51 | .050 | .080 | .050 | .20 | 3.15 | 460 | 950 | 510 | 8.35 | 34 | 0.8 | 139.1 | 150.4 | 7.8 |
| Mar 29 | 4.30 | -2.50 | .31 | .040 | .040 | .025 | .12 | 2.25 | 310 | 450 | 350 | 4.65 | 12 | 0.7 | 82.4 | 93.4 | 12.5 |
| Apr 04 | 4.30 | -2.94 | .05 | .010 | .005 | .015 | .09 | 1.90 | 165 | 370 | 510 | 3.50 | 14 | 0.6 | 68.5 | 65.8 | -4.0 |
| Apr 09 | 4.33 | -2.48 | .18 | .030 | .040 | .020 | .16 | 2.15 | 245 | 380 | 490 | 5.15 | 31 | 1.0 | 76.4 | 78.0 | 2.0 |
| Apr 17 | 4.00 | -5.80 | .38 | .070 | .115 | .030 | .35 | 5.35 | 830 | 1000 | 960 | 36.50 | 34 | 0.8 | 192.7 | 189.8 | -1.5 |
| Apr 23 | 4.68 | -1.31 | .31 | .045 | .030 | .015 | .07 | 2.30 | 450 | 335 | 500 | 3.30 | 6 | 0.4 | 73.8 | 73.9 | 0.1 |
| May 07 | 4.35 | -2.35 | .20 | .055 | .035 | .055 | .12 | 2.95 | 550 | 435 | 659 | 3.30 | 4 | 0.5 | 95.9 | 101.4 | 5.6 |
| N | 15 | 15 | 14 | 14 | 14 | 14 | 15 | 15 | 15 | 15 | 14 | 15 | 15 | 14 | 15 | 14 | 14 |
| $\bar{x}$ | 4.27 | -2.86 | .18 | .029 | .057 | .023 | .16 | 1.92 | 254 | 542 | 364 | 6.04 | 14 | 0.6 | 83.0 | 86.4 | 6.9 |
| sd | 20.16* | 1.13 | .15 | .021 | .033 | .015 | .07 | 1.22 | 227 | 230 | 252 | 8.57 | 12 | 0.2 | 37.1 | 38.9 | 7.2 |

* H sd=ueq/l
** mg/l as $CaCO_3$

# Appendix 2 Terrestrial and floating snow, ice and slush physical and chemical data

Fig. B1a

TERRESTRIAL SNOWPACK STRATIGRAPHY

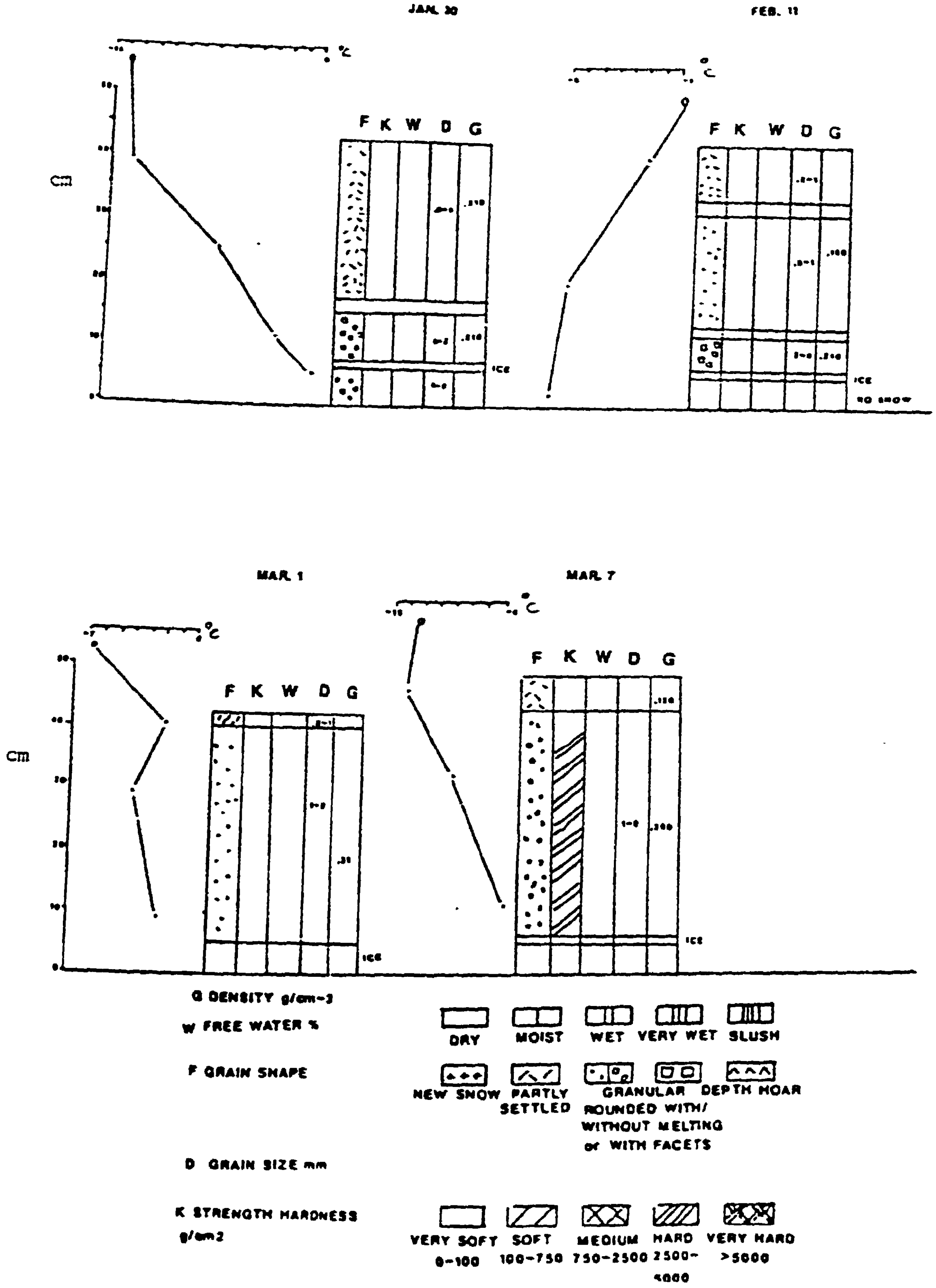


Fig. B1b TERRESTRIAL SNOWPACK STRATIGRAPHY

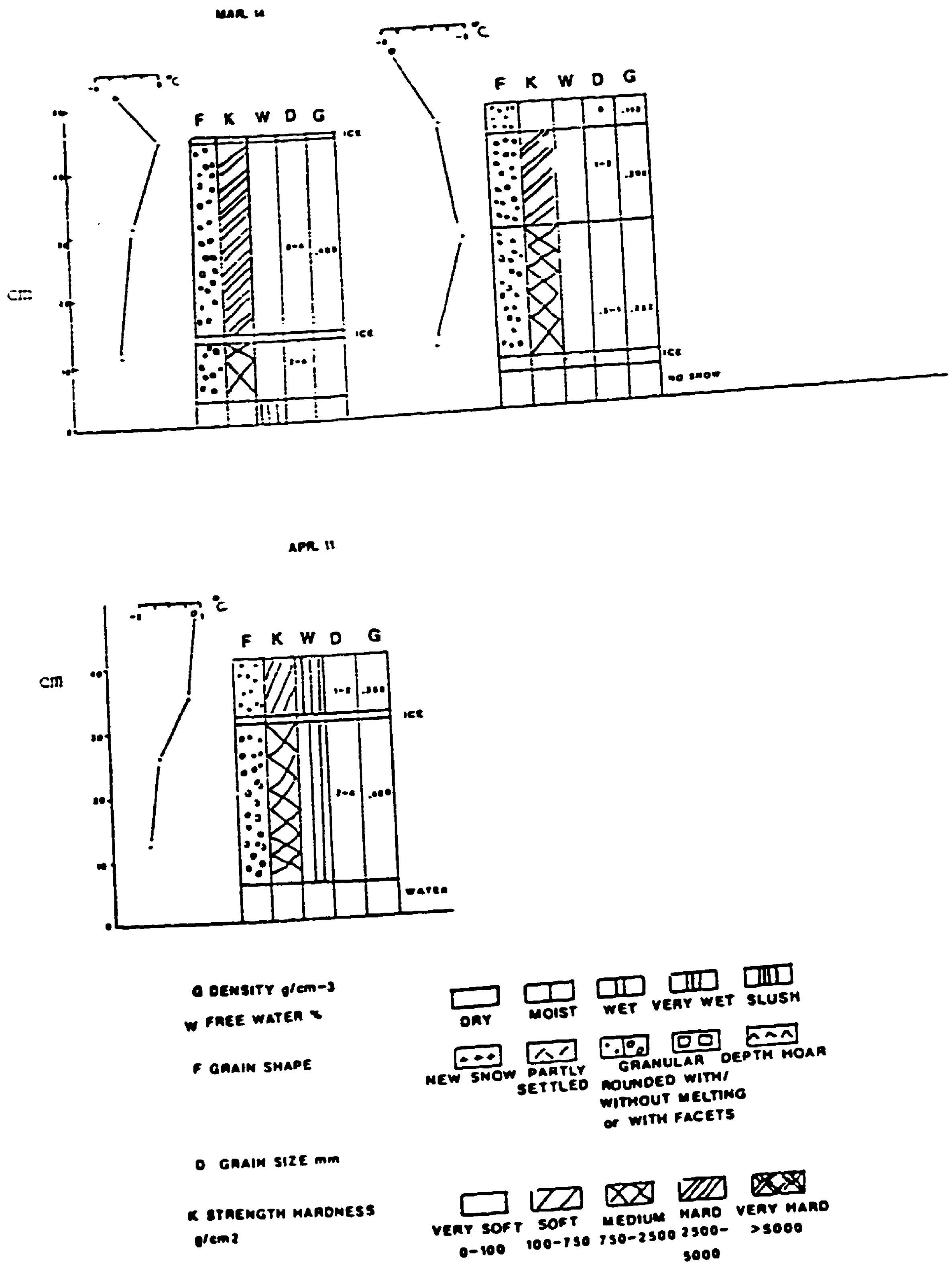


Table B1

1985 Plastic Lake Terrestrial Snow Samples

Site T1

| Date | Depth | We | Density | Cond | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | ALKTI | TAL | PFUT | TKN | $NO_3^{-}$ | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | cm | g/cm | uS.cm | | mg/l | | | | | | | | ug/l | mg/l | | | ueq/l | | % |
| Feb 11 | 25.4 | 5.08 | 0.200 | 16.30 | 4.60 | .10 | .05 | .10 | .64 | .10 | 0.97 | 1.9 | -1.60 | 2 | .023 | 0.33 | 0.505 | 54.94 | 59.06 | -7.23 |
| Feb 19 | 39.9 | 5.84 | 0.146 | | | | | | | | | | | | | | | | | |
| Feb 23 | 28.4 | 6.35 | 0.223 | 25.09 | 4.40 | .10 | .10 | .06 | .56 | .25 | 1.55 | 2.1 | -0.21 | | .138 | 0.75 | 0.695 | 69.96 | 88.93 | -23.88 |
| Feb 27 | 27.9 | 6.35 | 0.227 | | | | | | | | | | | | | | | | | |
| Mar 01 | | | | 18.36 | 4.65 | .10 | .05 | .06 | .36 | .15 | 1.35 | 2.4 | -2.00 | | .049 | 0.79 | 0.425 | 43.31 | 62.67 | -36.55 |
| Mar 03 | | | | 12.67 | 4.68 | .10 | .05 | .06 | .34 | .15 | 0.20 | 1.4 | -0.85 | 5 | .026 | 0.32 | 0.295 | 41.30 | 29.45 | 33.50 |
| Mar 06 | 27.9 | 7.37 | 0.264 | | | | | | | | | | | | | | | | | |
| Mar 13 | 19.0 | 5.33 | 0.286 | | | | | | | | | | | | | | | | | |
| Mar 17 | 21.6 | 7.40 | 0.227 | | | | | | | | | | | | | | | | | |
| Mar 25 | 32.5 | 15.00 | 0.461 | | | | | | | | | | | | | | | | | |
| Mar 27 | | | | 14.99 | 4.72 | .55 | .11 | .12 | .52 | .18 | 0.53 | 1.7 | -1.10 | 12 | .041 | 0.50 | 0.380 | 74.07 | 43.24 | 52.57 |
| Mar 30 | 27.9 | 10.70 | 0.382 | | | | | | | | | | | | | | | | | |
| Apr 02 | 38.1 | 15.70 | 0.413 | | | | | | | | | | | | | | | | | |
| Apr 11 | 44.4 | 17.30 | 0.389 | 12.10 | 4.71 | .45 | .13 | .06 | .09 | .08 | 0.71 | 1.1 | -1.00 | 13 | .032 | 0.59 | 0.275 | 57.56 | 36.67 | 44.34 |
| Apr 19 | 33.0 | 16.00 | 0.484 | | | | | | | | | | | | | | | | | |
| Apr 22 | 7.0 | 2.30 | 0.327 | | | | | | | | | | | | | | | | | |
| Apr 23 | | | | 8.53 | 5.78 | .10 | .15 | .24 | .12 | .27 | 0.50 | 4.6 | 0.36 | 1 | .190 | 2.35 | 0.140 | 30.83 | 28.01 | 9.58 |
| $\bar{x}$ | 28.7 | 9.28 | 0.310 | 15.43 | 4.67 | .21 | .09 | .10 | .38 | .17 | 0.83 | 2.2 | -0.91 | 7 | .071 | 0.80 | 0.388 | 53.14 | 56.33 | 29.7 |
| sd | 9.7 | 5.03 | 0.107 | 5.31 | 11.1 | .20 | .04 | .07 | .21 | .07 | 0.49 | 1.2 | 0.80 | 6 | .066 | 0.71 | 0.179 | 15.69 | 21.3 | 17.0 |
| N | 13 | 13 | 13 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 5 | 7 | 7 | 7 | 7 | 7 | 7 |

T2

| Date | Depth | We | Density | Cond | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | ALKTI | TAL | PFUT | TKN | $NO_3^{-}$ | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb 11 | 46.5 | 10.4 | 0.224 | 17.46 | 4.43 | .10 | .05 | .26 | .10 | .15 | 0.97 | 1.5 | -1.90 | | .157 | 1.26 | 0.455 | 60.12 | 56.90 | 5.50 |
| Feb 19 | 71.1 | 10.2 | 0.143 | | | | | | | | | | | | | | | | | |
| Feb 22 | 51.6 | 11.2 | 0.197 | 22.24 | 4.34 | .10 | .05 | .06 | .02 | .15 | 2.00 | 0.8 | -2.70 | | .020 | 0.44 | 0.585 | 57.93 | 87.63 | -40.80 |
| Feb 27 | 43.9 | 12.5 | 0.283 | | | | | | | | | | | | | | | | | |
| Mar 01 | | | | | | .10 | .05 | .06 | .04 | .15 | 0.25 | 0.8 | -1.70 | | .039 | 0.34 | 0.410 | | 38.70 | |
| Mar 05 | 58.5 | 15.7 | 0.269 | | | .30 | .10 | .06 | .04 | .20 | 0.65 | 0.9 | -1.40 | | .017 | 0.37 | 0.375 | | 45.94 | |
| Mar 13 | 57.2 | 11.9 | 0.209 | | | | | | | | | | | | | | | | | |
| Mar 17 | 38.1 | 9.5 | 0.307 | 19.05 | 4.54 | .10 | .05 | .06 | .46 | .20 | 0.90 | 1.1 | -1.50 | 8 | .032 | 0.39 | 0.550 | 52.32 | 63.64 | -19.52 |
| Mar 25 | 42.2 | 26.2 | 0.324 | | | | | | | | | | | | | | | | | |
| Mar 27 | | | | 13.97 | 4.80 | .30 | .06 | .10 | .08 | .17 | 0.66 | 1.0 | -0.99 | 9 | .017 | 0.34 | 0.290 | 42.15 | 39.24 | 7.16 |
| Mar 30 | 38.1 | 13.7 | 0.360 | | | | | | | | | | | | | | | | | |
| Apr 02 | 50.8 | 18.0 | 0.355 | 12.77 | | | | | | | | | | | | | | | | |
| Apr 11 | 64.8 | 18.3 | 0.282 | 8.64 | 4.89 | .20 | .07 | .10 | .05 | .05 | 0.59 | 0.5 | -0.76 | 9 | .024 | 0.42 | 0.235 | 34.25 | 30.47 | 11.69 |
| Apr 19 | 36.3 | 17.0 | 0.467 | | | | | | | | | | | | | | | | | |
| $\bar{x}$ | 46.1 | 13.4 | 0.263 | 15.69 | 4.55 | .17 | .06 | .10 | .11 | .15 | 0.86 | 0.9 | -1.56 | 9 | .044 | 0.51 | 0.414 | 49.36 | 51.79 | 16.9 |
| sd | 17.5 | 6.1 | 0.115 | 4.87 | 23.4 | .10 | .02 | .07 | .16 | .05 | 0.55 | 0.3 | 0.63 | 1 | .051 | 0.33 | 0.128 | 10.93 | 19.44 | 14.4 |
| N | 13 | 13 | 13 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | 8 | 8 | 8 | 8 |

*Table B1 cont'd*

**1985 Plastic Lake Terrestrial Snow Samples**

**Site T3**

| Date | Depth cm | We cm | Density g/cm | Cond uS.cm | pH | $Ca^{+2}$ mg/l | $Mg^{+2}$ mg/l | $Na^{+}$ mg/l | $K^{+}$ mg/l | $Cl^{-}$ mg/l | $SO_4^{-2}$ mg/l | DOC mg/l | ALKT* mg/l | TAL ug/l | PPUT mg/l | TKN mg/l | $NO_3^{-}$ mg/l | Cations ueq/l | Anions ueq/l | Imbalance % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb 11 | 40.6 | 10.7 | 0.263 | 18.63 | 4.50 | .10 | .05 | .06 | .02 | .10 | 1.14 | 0.9 | -2.10 | 2 | .017 | 0.28 | 0.475 | 43.85 | 60.46 | -31.86 |
| Feb 19 | 63.5 | 11.1 | 0.176 | | | | | | | | | | | | | | | | | |
| Feb 22 | 55.4 | 14.0 | 0.252 | 22.05 | 4.41 | .10 | .05 | .06 | .24 | .15 | 2.20 | 1.2 | -2.50 | | .053 | 0.75 | 0.600 | 56.76 | 92.86 | -48.26 |
| Feb 27 | 45.5 | 13.7 | 0.290 | | | | | | | | | | | | | | | | | |
| Mar 01 | | | | 15.52 | 4.49 | .10 | .05 | .06 | .20 | .10 | 0.55 | 1.2 | -1.70 | | .021 | 0.37 | 0.455 | 49.19 | 46.75 | 5.08 |
| Mar 05 | 62.2 | 15.2 | 0.245 | 13.45 | 4.66 | .10 | .05 | .26 | .60 | .40 | 0.85 | 0.8 | -1.00 | | .028 | 0.50 | 0.375 | 57.64 | 55.75 | 3.33 |
| Mar 13 | 49.5 | 16.3 | 0.328 | | | | | | | | | | | | | | | | | |
| Mar 17 | 53.3 | 9.9 | 0.238 | 15.89 | 4.60 | .10 | .05 | .06 | .58 | .20 | 0.30 | 2.1 | -1.00 | 8 | .039 | 0.36 | 0.365 | 51.67 | 37.94 | 30.64 |
| Mar 25 | 49.8 | 29.2 | 0.342 | | | | | | | | | | | | | | | | | |
| Mar 27 | | | | 17.02 | 4.95 | .10 | .06 | .22 | .65 | .24 | 1.19 | 2.1 | -1.10 | 1 | .045 | 0.57 | 0.395 | 47.34 | 59.74 | -23.16 |
| Mar 30 | 39.9 | 12.7 | 0.318 | | | | | | | | | | | | | | | | | |
| Apr 02 | 53.3 | 18.3 | 0.343 | 11.40 | | | | | | | | | | | | | | | | |
| Apr 11 | 61.0 | 18.3 | 0.300 | 13.92 | 4.65 | .30 | .11 | .10 | .21 | .10 | 1.02 | 1.8 | 0.29 | 11 | .045 | 0.61 | 0.360 | 56.13 | 49.75 | 12.04 |
| Apr 19 | 41.9 | 16.3 | 0.388 | | | | | | | | | | | | | | | | | |
| Apr 22 | 14.0 | 3.6 | 0.255 | | | | | | | | | | | | | | | | | |
| Apr 23 | | | | 8.53 | 5.51 | .05 | .15 | .08 | .69 | .16 | 0.41 | 1.7 | | 3 | .130 | 1.80 | 0.115 | 35.96 | 21.26 | 51.38 |
| $\bar{x}$ | 48.5 | 14.6 | 0.288 | 15.16 | 4.63 | .12 | .07 | .11 | .40 | .18 | 0.96 | 1.5 | -1.28 | 5 | .047 | 0.66 | 0.392 | 49.81 | 53.06 | 25.7 |
| sd | 13.0 | 5.9 | 0.057 | 3.97 | 23.4 | .08 | .04 | .08 | .26 | .10 | 0.60 | 0.5 | 0.85 | 4 | .036 | 0.49 | 0.138 | 7.43 | 20.64 | 18.3 |
| N | 13 | 13 | 13 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | 8 | 8 | 8 | 8 |

* mg/l as $CaCO_3$
** pH sd= ueq/l $H^+$

## Table B2

1985 Plastic Lake snowcover

| Date | Depth | Cond | pH | Ca+2 | Mg+2 | Na+ | K+ | Cl- | SO4-2 | DOC | TAL | ALKT* | PPUT | TKN | NO3- | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | uS/cm | | mg/l | | | | | | | ug/l | mg/l | | | | ueq/l | | % |
| **Site 34** | | | | | | | | | | | | | | | | | | |
| Jan 30 | 10.1 | 16.06 | 4.57 | | | | | | | | | | | | | | | |
| Feb 11 | 13.0 | 31.01 | 4.24 | 0.1 | .05 | .10 | .02 | .15 | 0.81 | 0.5 | 2 | -3.90 | .004 | .08 | 0.890 | 71.50 | 84.62 | -16.8 |
| Feb 23 | 16.0 | 15.47 | 4.80 | 0.7 | .15 | .10 | .02 | .15 | 3.00 | 1.0 | | -0.88 | .005 | .15 | 0.210 | 67.98 | 81.68 | -18.3 |
| Mar 05 | 5.0 | 12.65 | 4.65 | 0.1 | .05 | .06 | .02 | .05 | 0.95 | 0.6 | | -1.30 | .008 | .16 | 0.280 | 34.61 | 41.18 | -17.3 |
| Apr 11 | 9.0 | 13.24 | 4.84 | 0.3 | .13 | .12 | .01 | .09 | 1.42 | 0.8 | 14 | -0.34 | .013 | .57 | 0.415 | 45.60 | 63.15 | -32.3 |
| x̄ | 10.6 | 17.69 | 4.56 | 0.3 | .10 | .10 | .02 | .11 | 1.54 | 0.72 | 8 | -1.60 | .008 | .24 | 0.454 | 54.92 | 67.66 | -21.2 |
| s.d. | 4.2 | 7.59 | 17.6 | 0.3 | .05 | .03 | .00 | .05 | 1.00 | 0.22 | 8 | 1.58 | .004 | .22 | 0.305 | 17.75 | 20.05 | 7.4 |
| N | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Site 18** | | | | | | | | | | | | | | | | | | |
| Feb 23 | 20.0 | 20.58 | 4.59 | 0.9 | .20 | .16 | .02 | .20 | 3.35 | 1.2 | | -1.50 | .010 | .25 | 0.345 | 94.54 | 100.02 | -5.6 |
| Mar 05 | 7.0 | 11.10 | 4.71 | 0.1 | .05 | .06 | .02 | .10 | 0.75 | 0.7 | | -1.00 | .010 | .25 | 0.285 | 31.72 | 38.78 | -20.2 |
| Mar 18 | 9.0 | 23.62 | 4.45 | 0.4 | .05 | .06 | .02 | .20 | 0.80 | 1.0 | 21 | -1.70 | .015 | .53 | 0.755 | 62.68 | 76.19 | -19.5 |
| Apr 11 | 12.0 | 9.86 | 5.04 | 0.2 | .11 | .14 | .02 | .05 | 1.22 | 0.7 | 28 | -0.45 | .015 | .50 | 0.325 | 34.75 | 50.01 | -36.0 |
| x̄ | 12.0 | 16.30 | 4.65 | 0.4 | .10 | .10 | .02 | .14 | 1.53 | 0.9 | 24 | -1.16 | .012 | .38 | 0.428 | 55.92 | 66.25 | -20.3 |
| sd. | 5.7 | 6.84 | 11.1 | 0.4 | .07 | .05 | .00 | .08 | 1.23 | 0.2 | 5 | 0.56 | .003 | .15 | 0.220 | 29.27 | 27.43 | -36.0 |
| N | 4 | 4 | 4 | 4. | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Site 6** | | | | | | | | | | | | | | | | | | |
| Jan 30 | 16.5 | 22.52 | 4.41 | | | | | | | | | | | | | | | |
| Feb 11 | 11.9 | 31.64 | 4.15 | 0.1 | .05 | .16 | .02 | .25 | 0.73 | 0.6 | 2 | -3.90 | .006 | .08 | 0.925 | 87.37 | 88.28 | -1.0 |
| Feb 23 | 16.0 | 16.32 | 5.50 | 1.6 | .20 | .30 | .02 | .75 | 2.25 | 1.1 | | 0.46 | .008 | .25 | 0.740 | 109.86 | 120.82 | -9.5 |
| May 06 | 5.5 | 10.55 | 4.70 | 0.1 | .05 | .06 | .02 | .10 | 0.75 | 0.6 | | -1.10 | .020 | .22 | 0.220 | 32.18 | 34.14 | -5.9 |
| Apr 11 | 9.5 | 12.14 | 4.90 | 0.4 | .11 | .14 | .02 | .05 | 1.55 | 0.7 | 30 | -0.70 | .017 | .70 | 0.495 | 48.20 | 69.01 | -35.5 |
| x̄ | 11.9 | 18.63 | 4.54 | 0.6 | .10 | .16 | .02 | .29 | 1.32 | 0.8 | 16 | -1.31 | .013 | .31 | 0.595 | 69.40 | 78.06 | -13.0 |
| sd. | 4.6 | 8.62 | 26.8 | 0.7 | .07 | .10 | .00 | .32 | 0.73 | 0.2 | 20 | 1.85 | .007 | .27 | 0.306 | 35.64 | 36.26 | 15.4 |
| N | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Site 4** | | | | | | | | | | | | | | | | | | |
| Jan 30 | 14.5 | 37.34 | 4.10 | | | | | | | | | | | | | | | |
| Feb 11 | 22.4 | 26.40 | 4.30 | 0.1 | .05 | .10 | .02 | .15 | 0.73 | 0.8 | | -3.20 | .006 | .15 | 0.175 | 64.08 | 67.61 | -5.4 |
| Feb 23 | 23.0 | 12.91 | 4.80 | 0.3 | .10 | .30 | .02 | .15 | 2.70 | 0.8 | | -0.83 | .007 | .20 | 0.705 | 52.61 | 75.08 | -35.2 |
| Mar 05 | 6.5 | 13.18 | 4.65 | 0.1 | .05 | .06 | .02 | .05 | 0.75 | 0.5 | | -1.40 | .010 | .28 | 0.325 | 34.61 | 40.22 | -15.0 |
| Apr 11 | 10.0 | 16.50 | 4.75 | 0.4 | .13 | .10 | .05 | .05 | 1.98 | 0.8 | 24 | -0.95 | .011 | .68 | 0.560 | 54.07 | 82.61 | -41.8 |
| x̄ | 15.3 | 21.27 | 4.43 | 0.2 | .08 | .14 | .03 | .10 | 1.54 | 0.7 | 24 | -1.59 | .008 | .33 | 0.441 | 51.34 | 66.36 | -24.3 |
| sd. | 7.3 | 10.51 | 27.4 | 0.2 | .04 | .11 | .02 | .06 | 0.97 | 0.2 | | 1.10 | .002 | .24 | 0.214 | 12.26 | 18.48 | 17.0 |
| N | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Site 3** | | | | | | | | | | | | | | | | | | |
| Jan 28 | 21.0 | 22.51 | 4.40 | 0.1 | .02 | .06 | .04 | .03 | 1.10 | 0.7 | | | | .16 | | 50.08 | | |
| Jan 30 | 7.6 | 27.98 | 4.45 | | | | | | | | | | | | | | | |
| Feb 11 | 10.2 | 30.22 | 4.20 | 0.1 | .05 | .10 | .02 | .15 | 0.89 | 0.6 | 2 | -3.80 | .006 | .09 | 0.870 | 77.06 | 84.86 | -9.6 |
| Feb 22 | 15.5 | 15.10 | 4.71 | 0.2 | .10 | .10 | .02 | .15 | 2.75 | 0.9 | | -1.00 | .009 | .32 | 0.265 | 42.57 | 80.40 | -61.5 |
| Mar 05 | 5.8 | 12.09 | 4.65 | 0.1 | .05 | .06 | .02 | .10 | 0.95 | 0.6 | | -1.20 | .013 | .36 | 0.765 | 34.61 | 41.52 | -18.1 |
| Mar 18 | 4.5 | 39.40 | 4.21 | 0.5 | .10 | .06 | .04 | .25 | 1.70 | 1.1 | 30 | -2.80 | .017 | .74 | 1.310 | 98.47 | 135.95 | -32.0 |
| Apr 11 | 11.0 | 13.78 | 4.87 | 0.4 | .11 | .04 | .05 | .07 | 1.62 | 0.7 | 19 | -0.59 | .014 | .59 | 0.460 | 45.52 | 68.54 | -40.4 |
| x̄ | 10.8 | 23.01 | 4.44 | 0.2 | .07 | .07 | .03 | .12 | 1.50 | 0.8 | 17 | -1.88 | .012 | .38 | 0.634 | 58.08 | 82.25 | -32.3 |
| sd. | 5.79 | 10.10 | 19.9 | 0.2 | .03 | .02 | .01 | .08 | 0.70 | 0.2 | 14 | 1.36 | .012 | .38 | 0.634 | 24.51 | 34.43 | 20.2 |
| N | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 5 | 5 | 6 | 5 | 6 | 5 | 5 |

* mg/l as $CaCO_3$

** sd=ueq/l $H^+$

Fig. B2a

TERRESTRIAL SNOWPACK DEPTH, WATER EQUIVALENT AND DENSITY

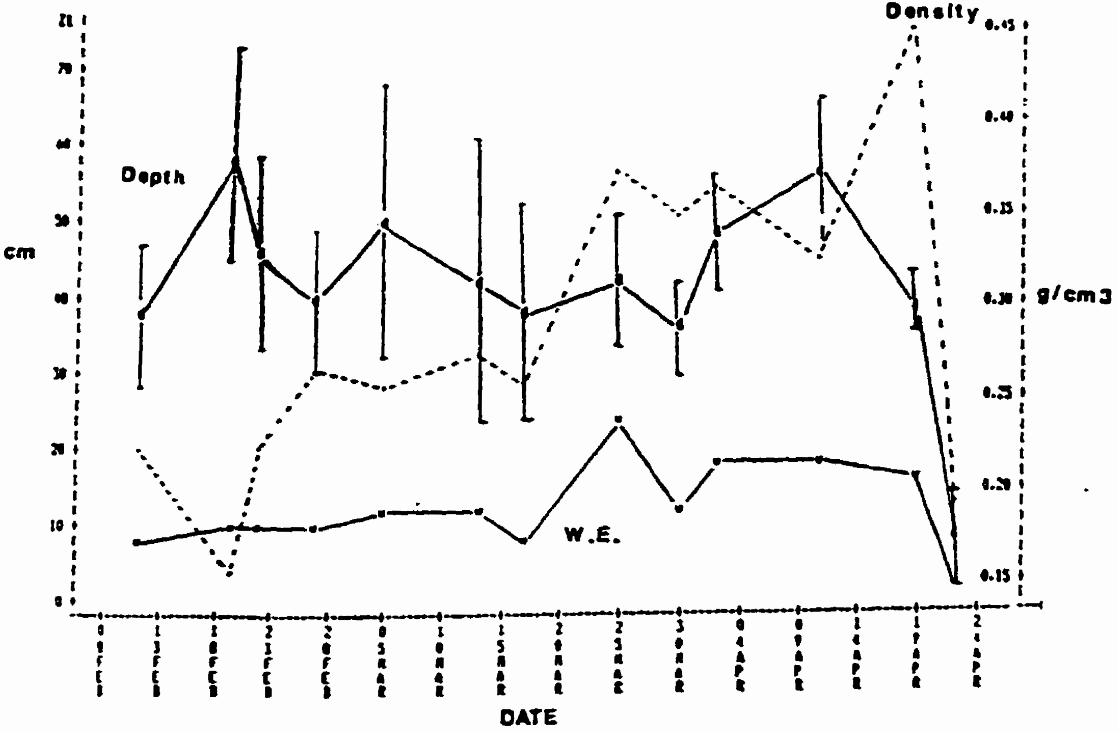
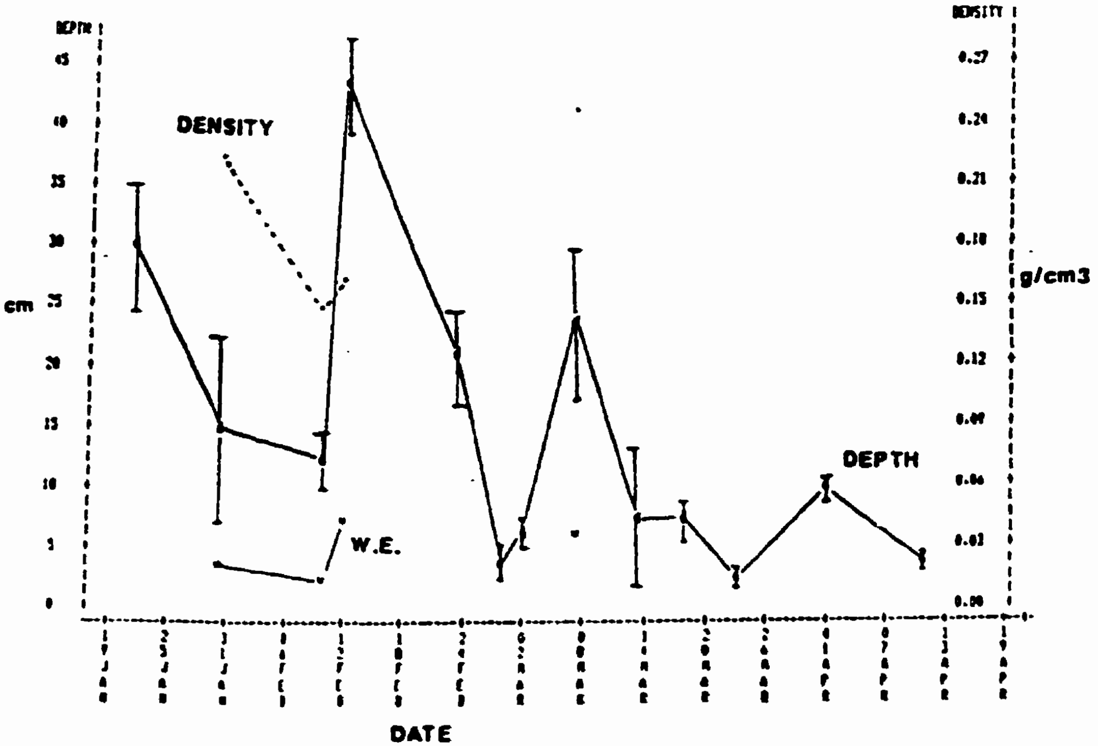


Fig. B2 b

FLOATING SNOWPACK DEPTH, WATER EQUIVALENT AND DENSITY



*Error bars equal one standard deviation.

Fig. B2c

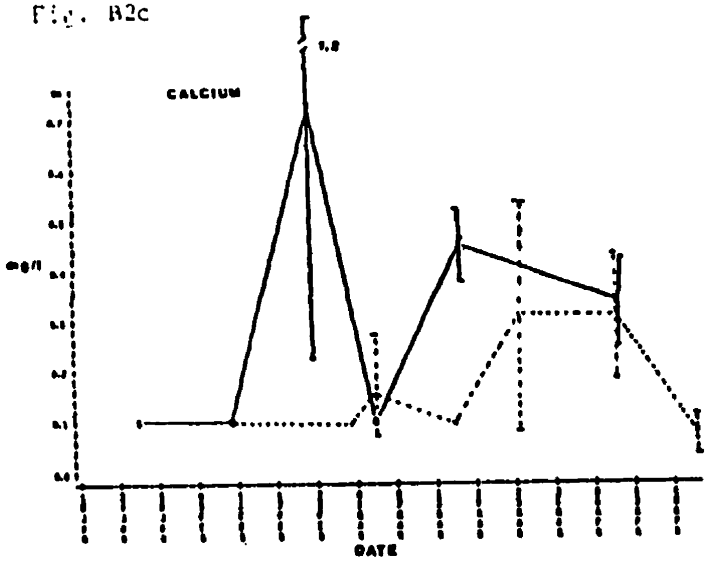


Fig. B2d

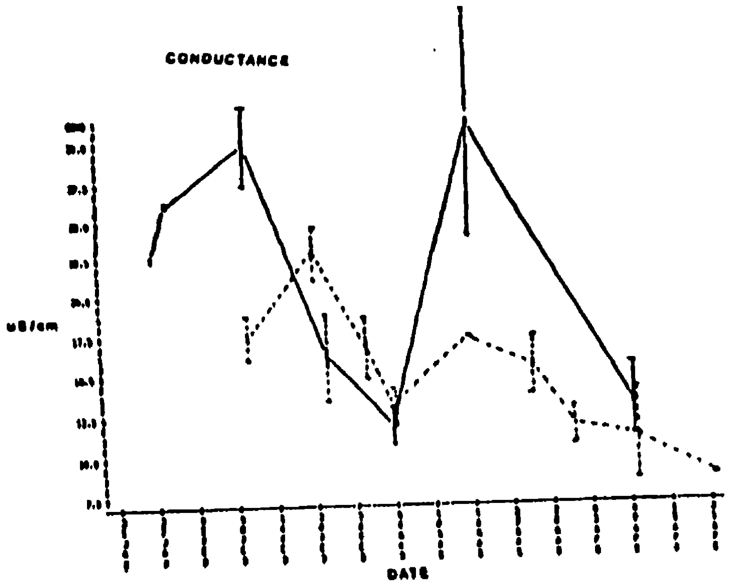
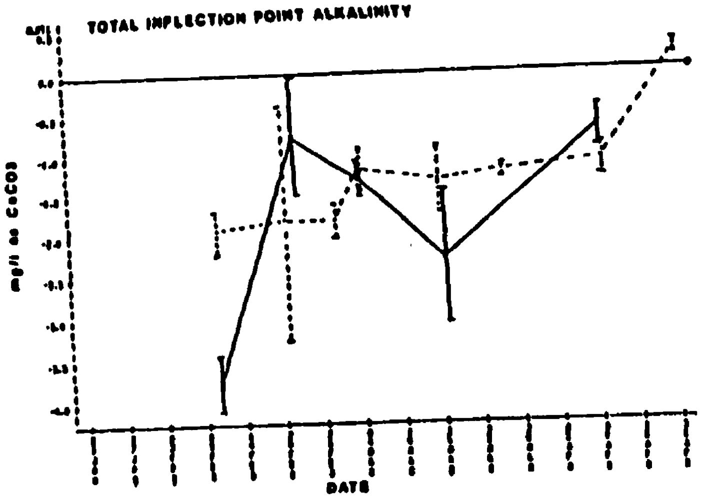


Fig. B2e



Terrestrial snowpack ·------·
Floating snowpack ·———·

Fig. B2f

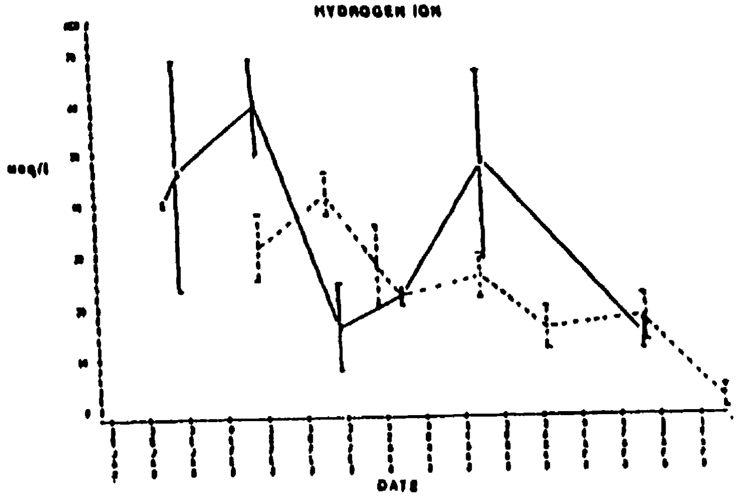


Fig. B2 g

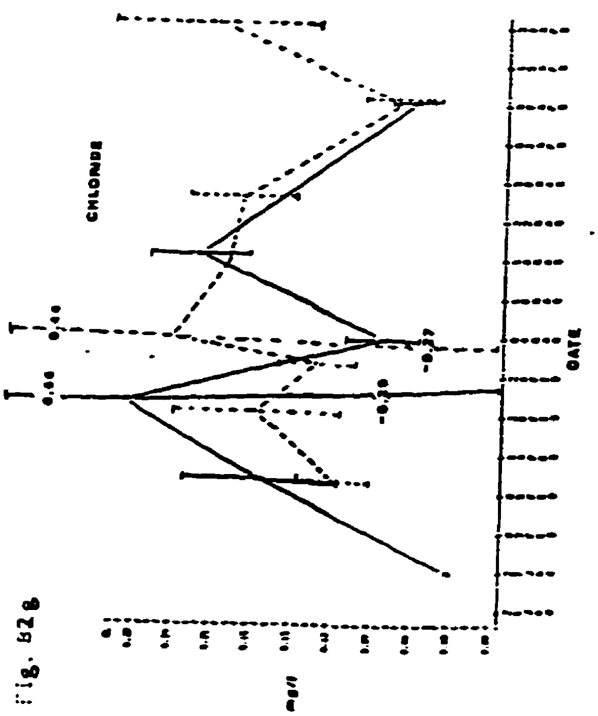


Fig. B2 h

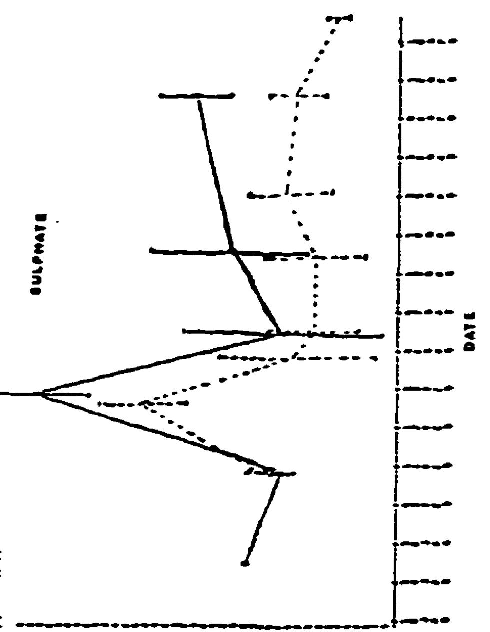


Fig. B2 i

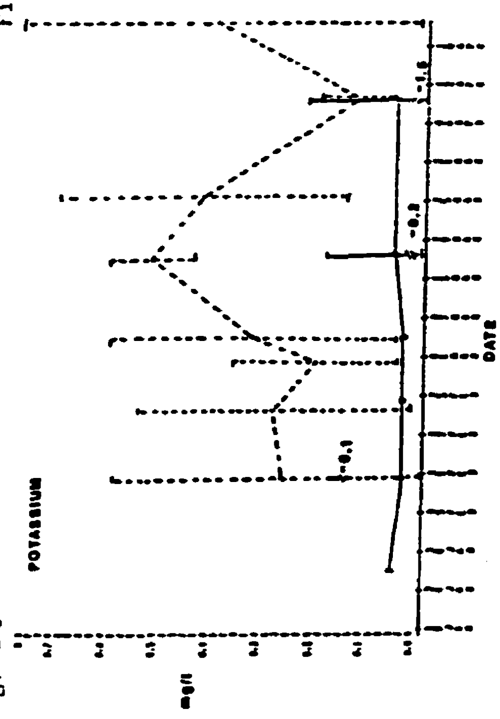


Fig. B2 j

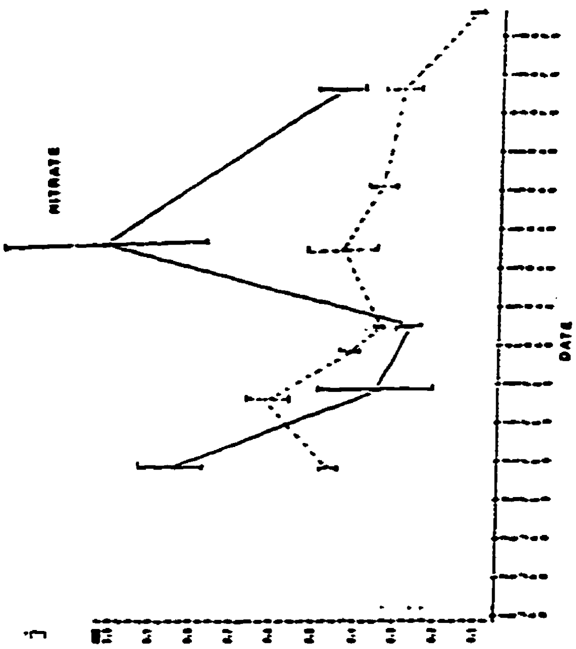


Fig. B2 k

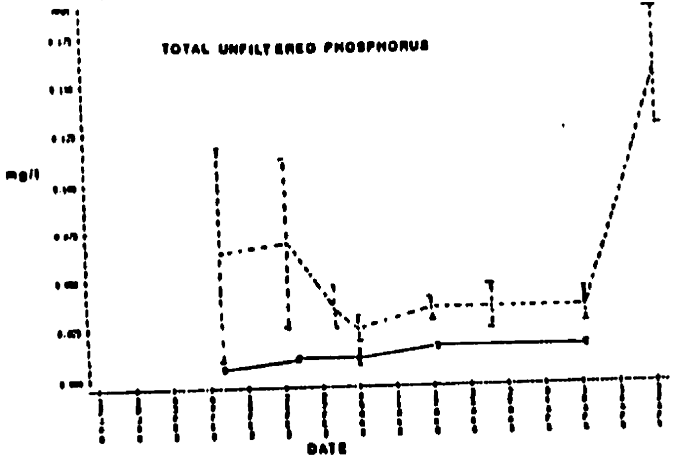


Fig. B2 l

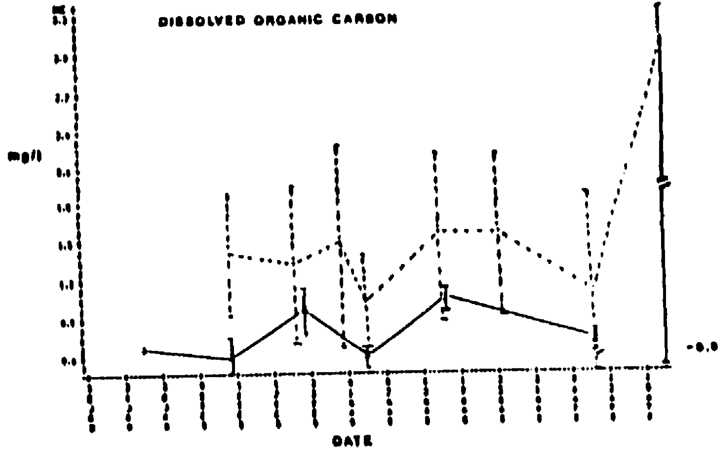


Fig. B2 m

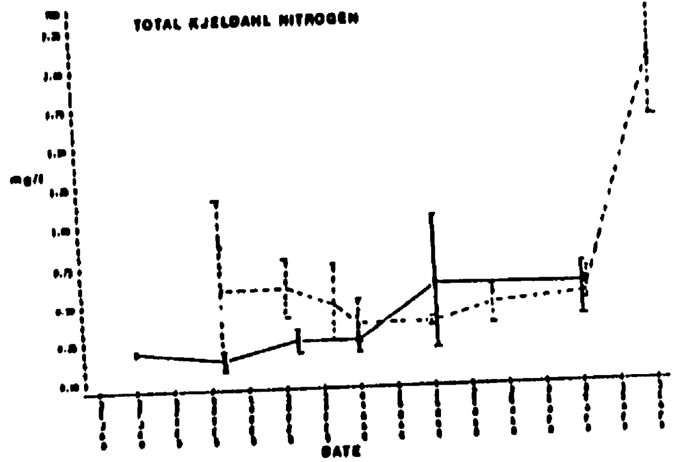


Fig. B2 n

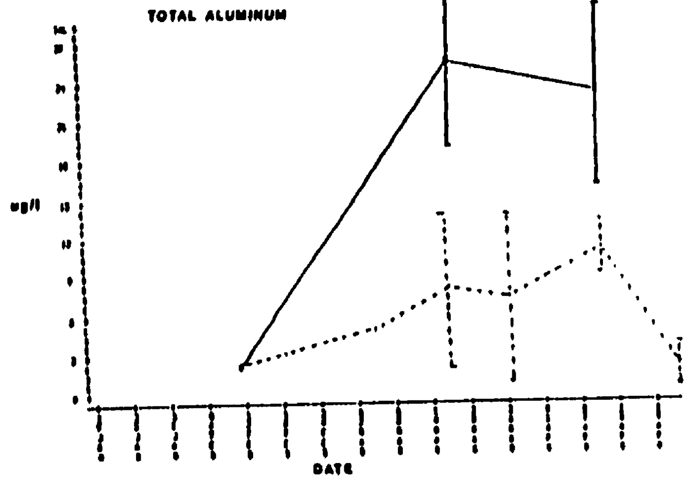


Fig.B2 o

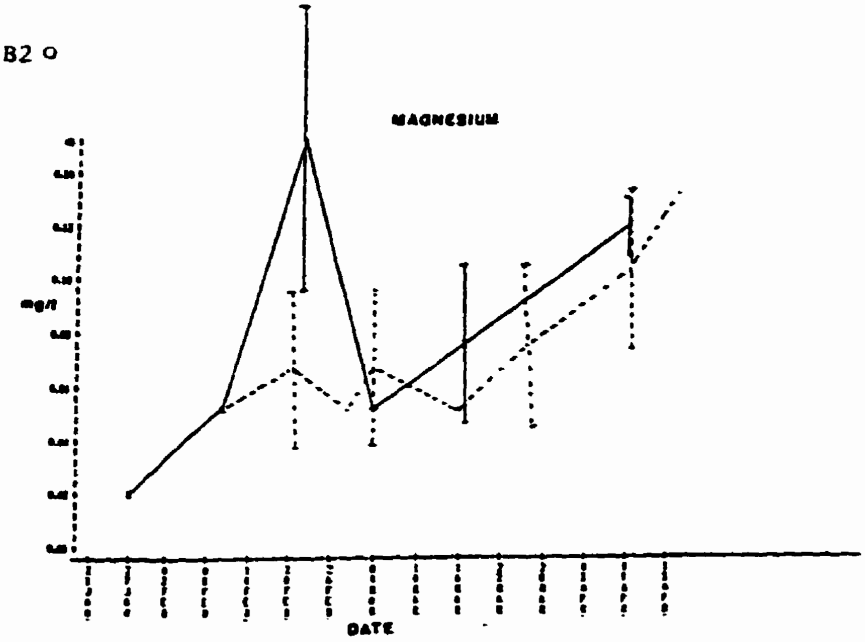


Fig. B2 p

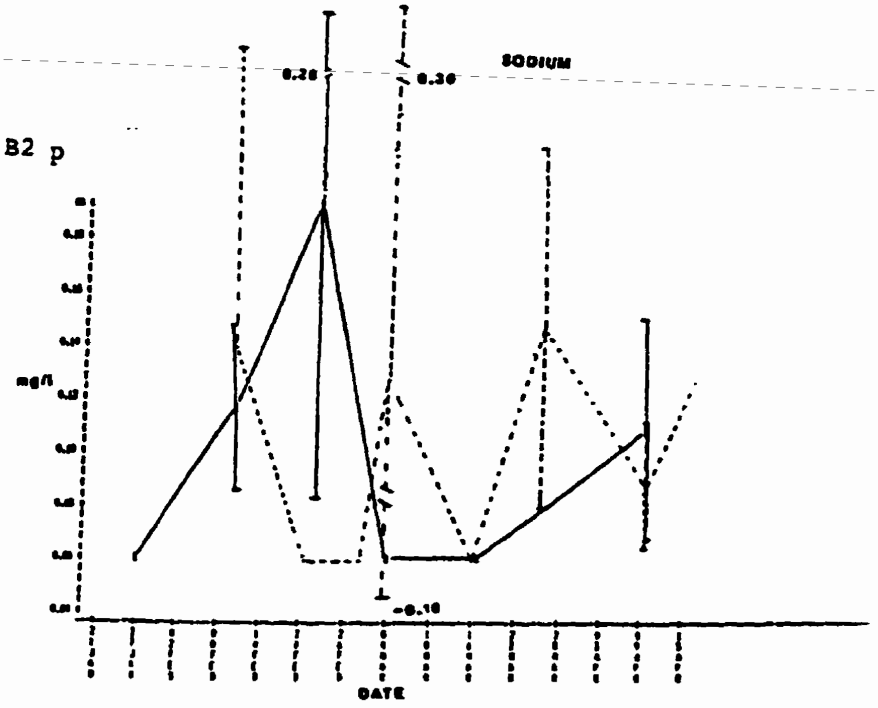
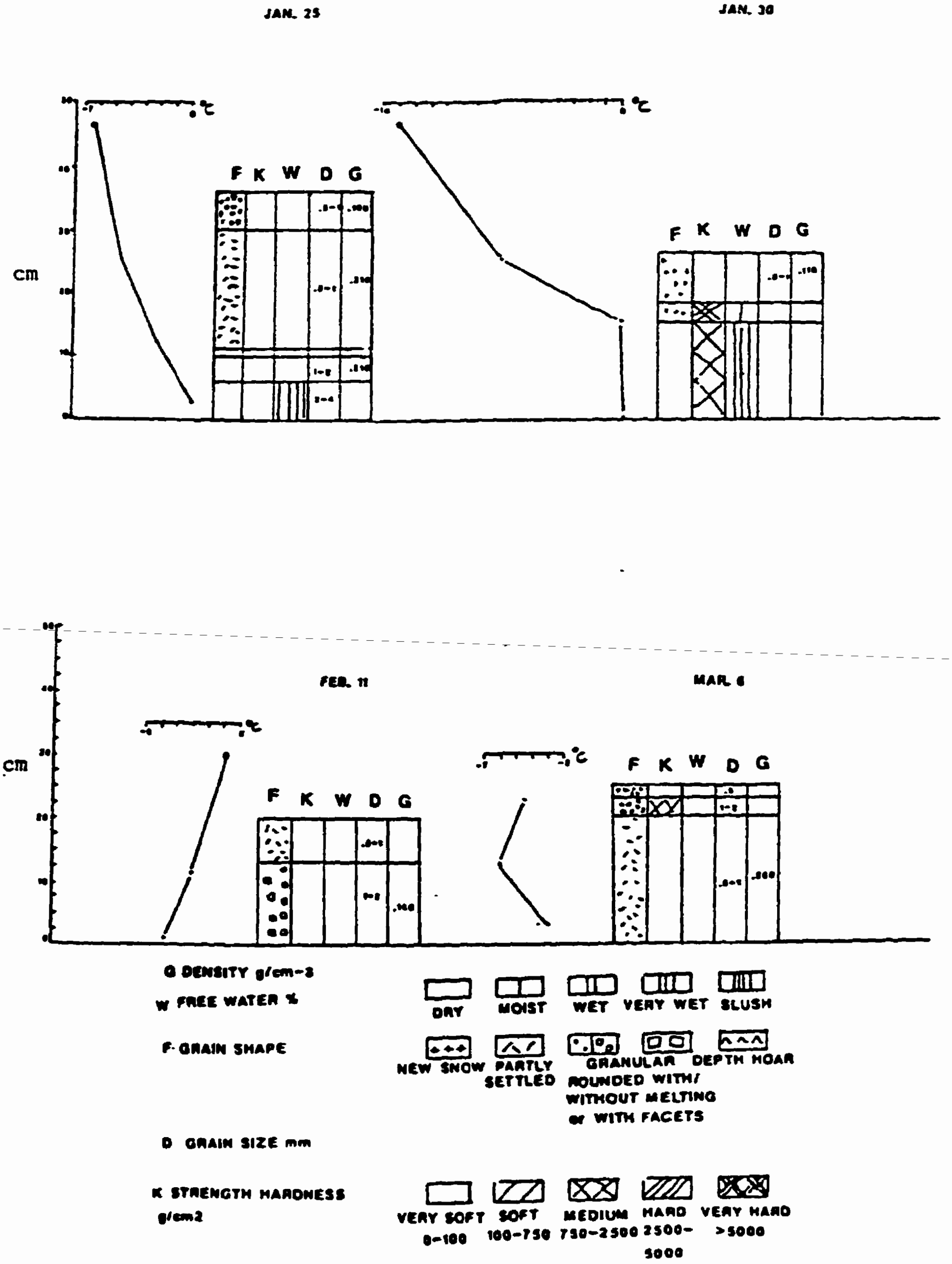


Fig. B3

FLOATING SNOWPACK STRATIGRAPHY



# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4 a

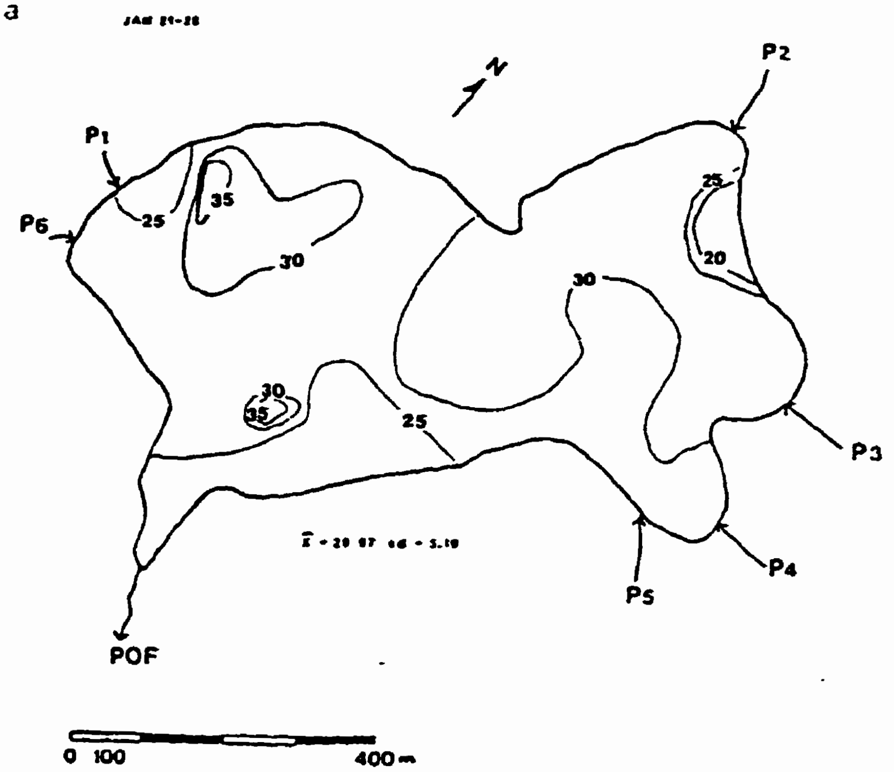
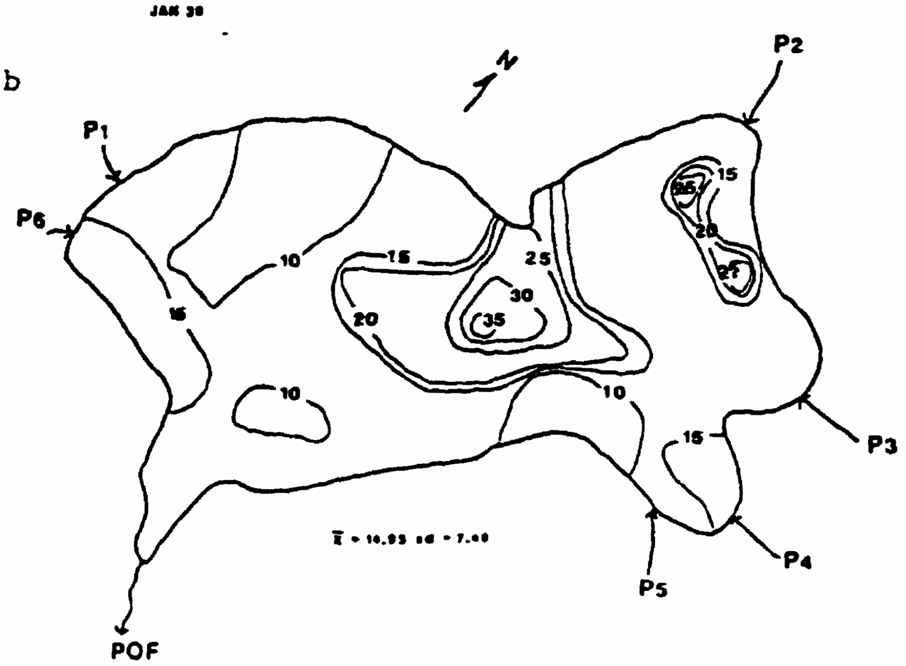


Fig. B4 b



* Isoline interval 5cm

# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4 c

FEB 10

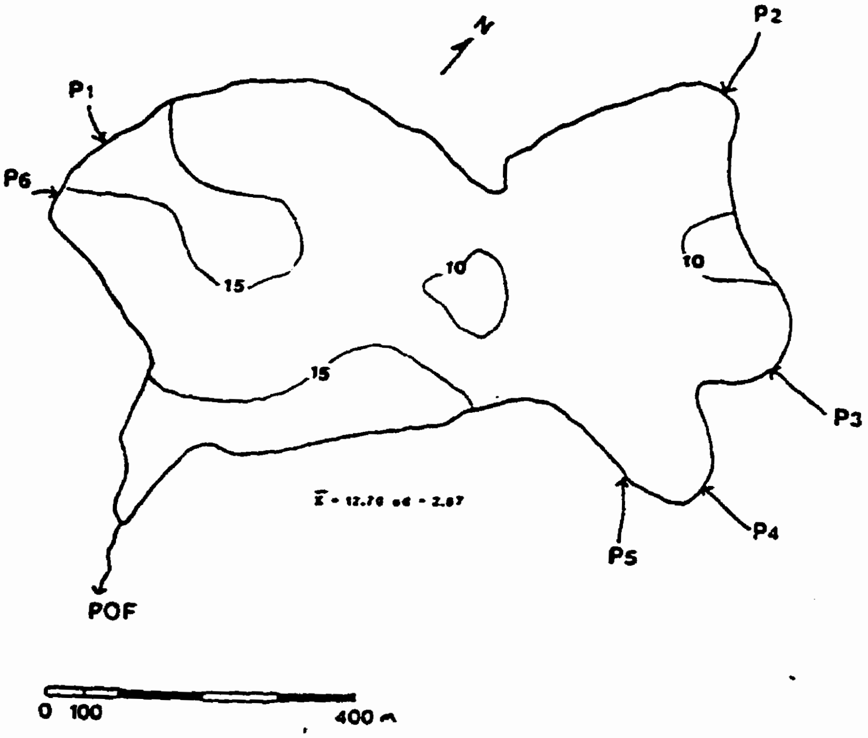
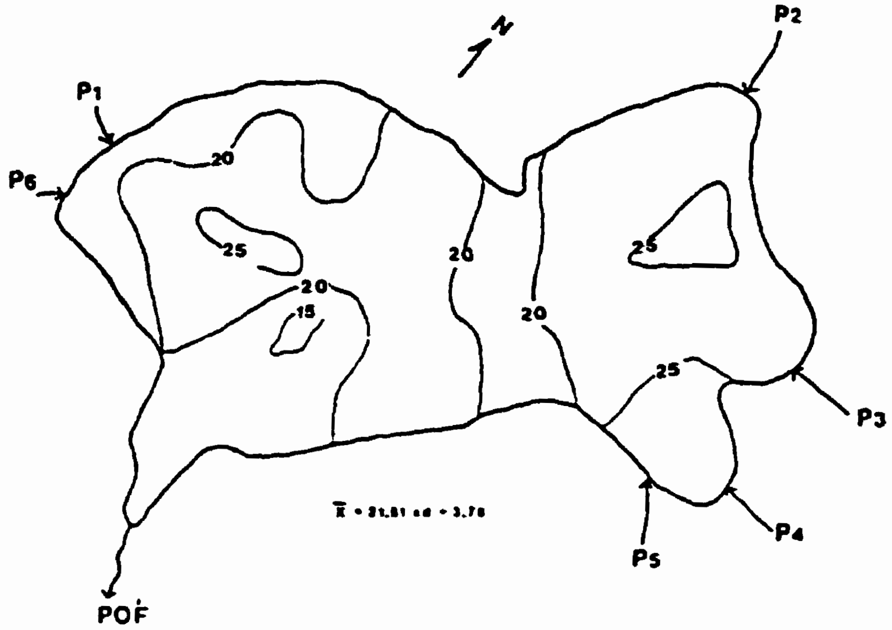


Fig. B4 d

FEB 22



# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4 e

FEB 28

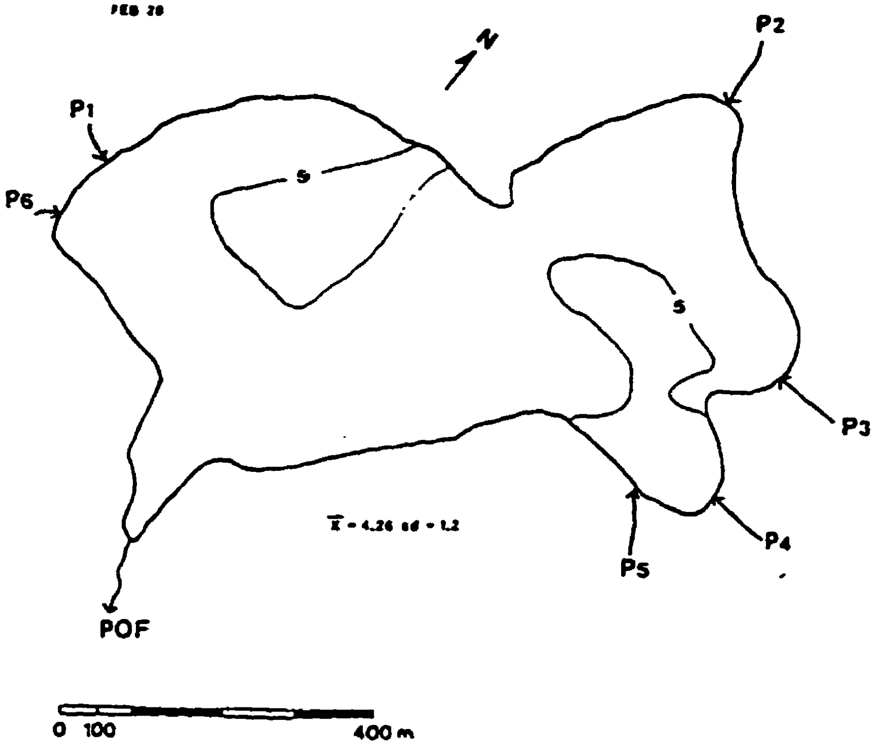
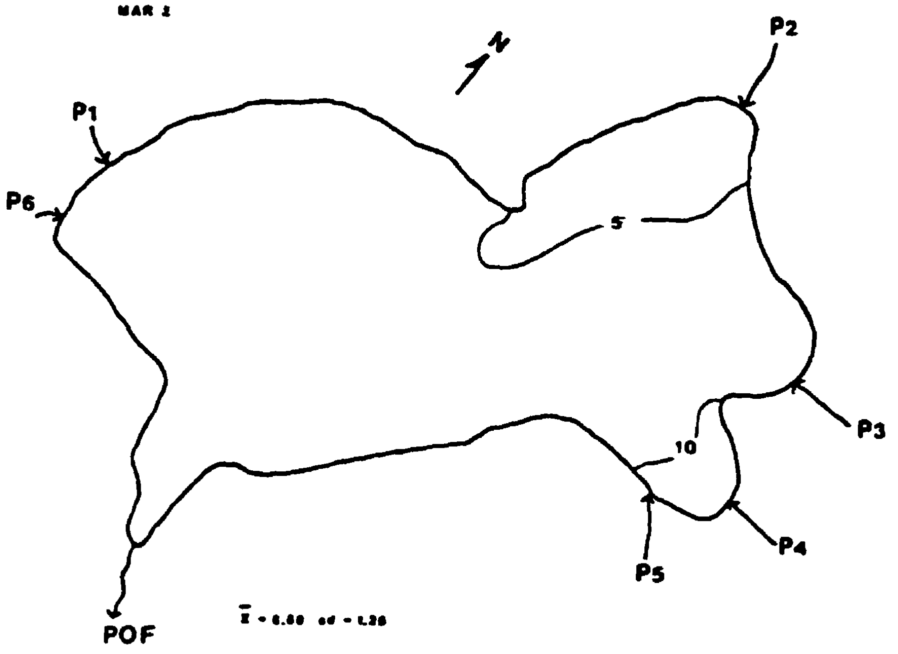


Fig. B4f

MAR 2



# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4g
MAR 7

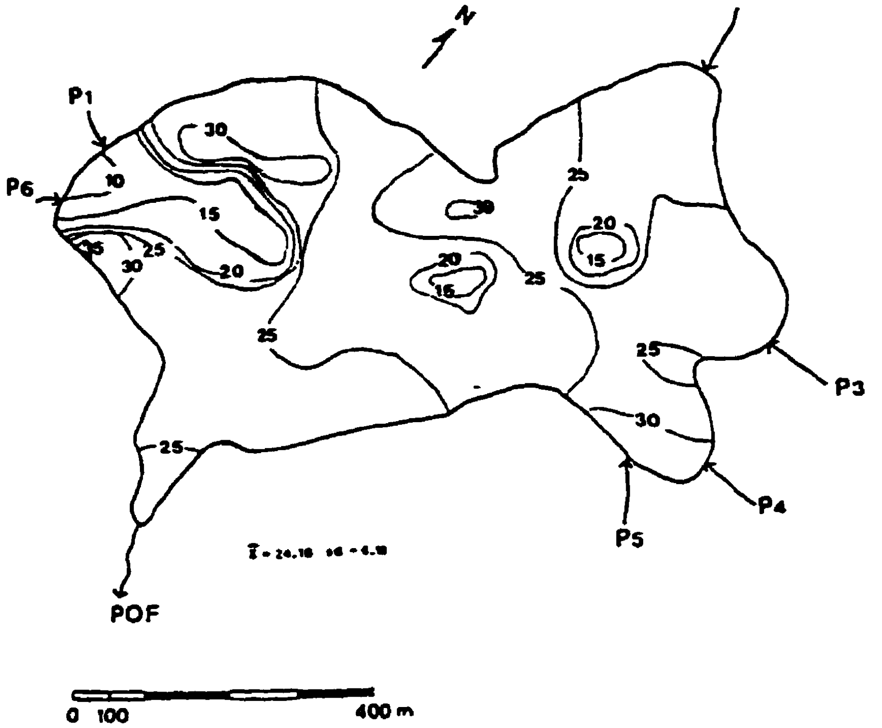
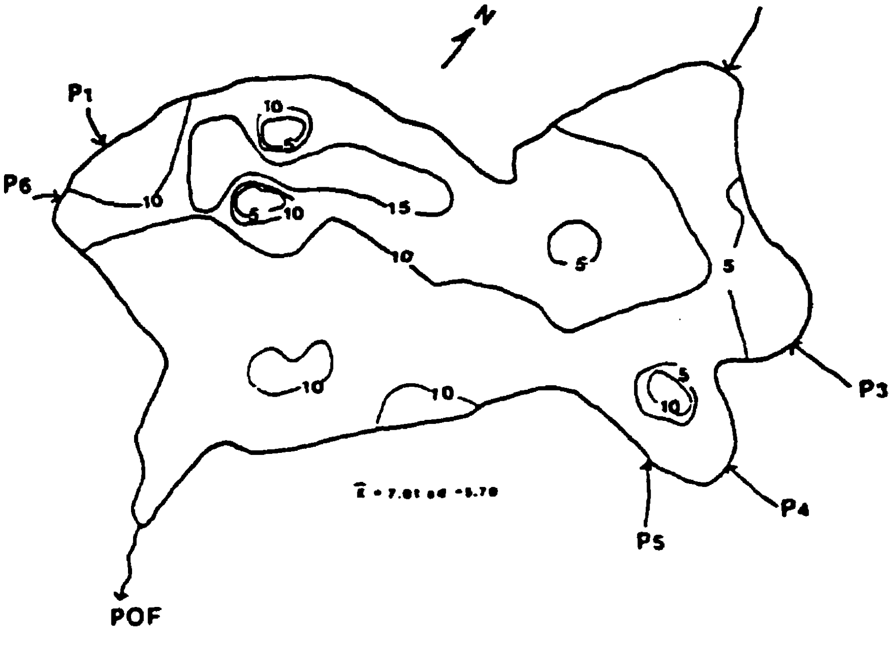


Fig. B4h
MAR 13



# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4 i
MAR 18

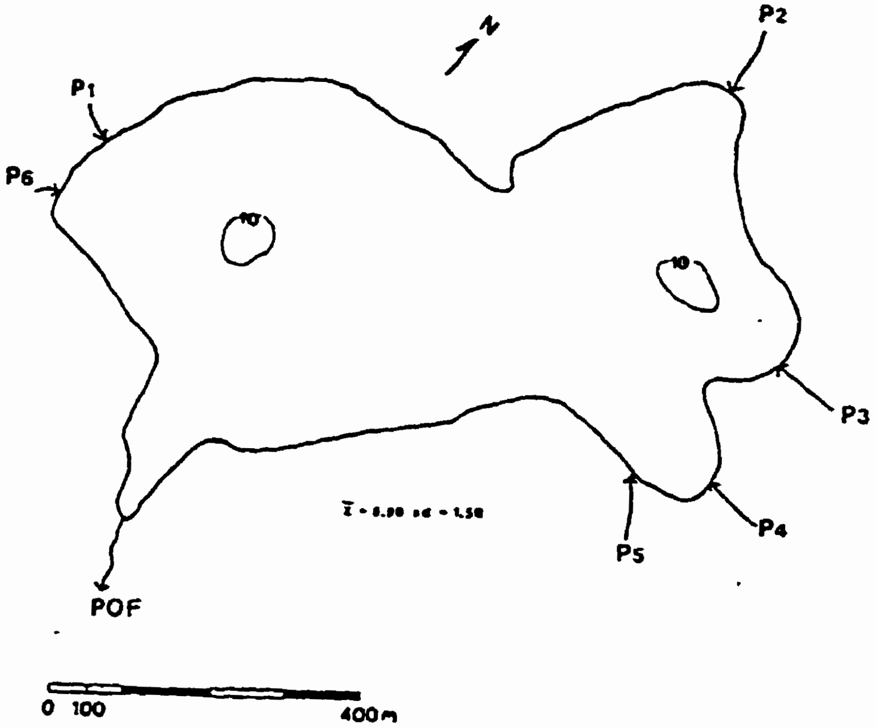
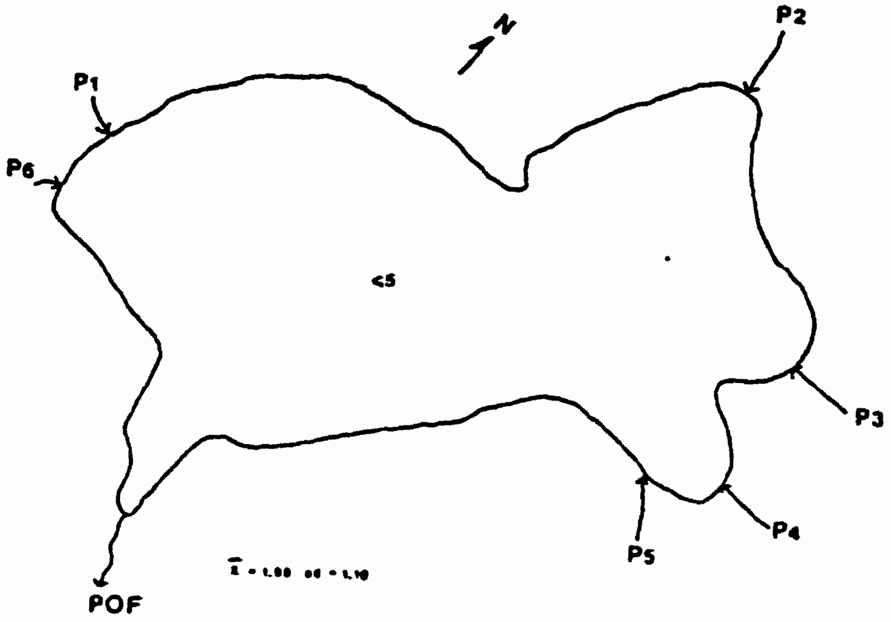


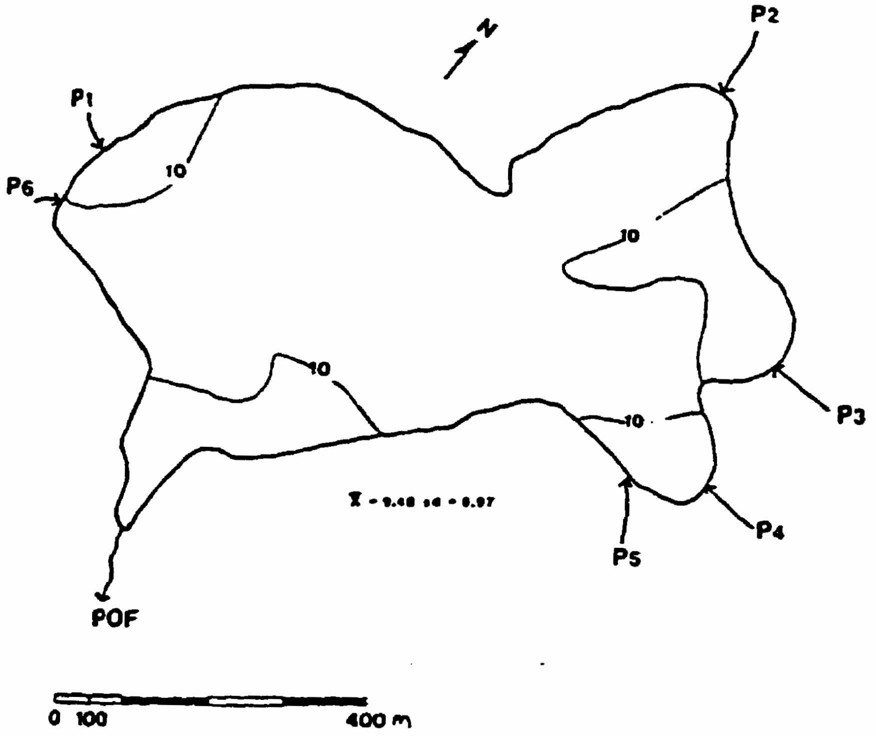
Fig. B4 j
MAR 23



# PLASTIC LAKE SNOW DISTRIBUTION 1985

Fig. B4 k

APRIL 1



APRIL 10/11

Fig. B4 l

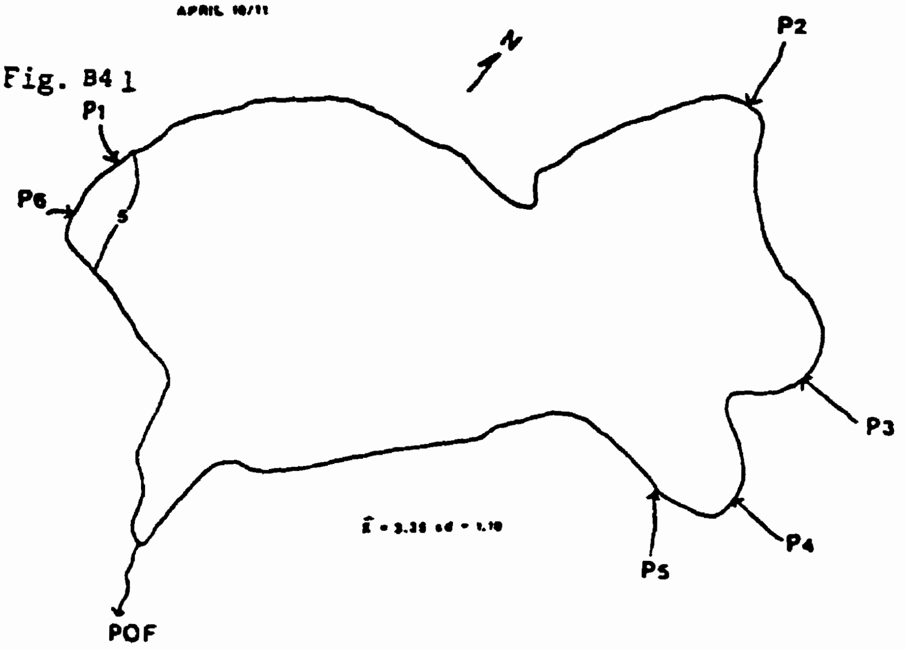


Table B3
1985 Plastic Lake Ice Chemistry

Site 1

| Date | Depth* cm | Conductance uS/cm | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | TAL | ALKTI | PPUT | TKN | $NO_3^{-}$ | Cation | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mg/l | | | | | | | ug/l | mg/l | | | | ueq/l | | % |
| Feb11 | 0-21 | 7.66 | 5.00 | .30 | .05 | .10 | .02 | .10 | 1.49 | 1.7 | 2 | -0.44 | .006 | 0.10 | .120 | 33.94 | 42.41 | -22.2 |
| Mar15 | 0-4 | 14.01 | 4.70 | .10 | .05 | .06 | .02 | .15 | 1.10 | 0.7 | 11 | -1.00 | .009 | 2.90 | .375 | 33.18 | 53.90 | -50.5 |
| Mar15 | 6-17 | 3.22 | 5.63 | .10 | .05 | .06 | .02 | .10 | 0.10 | 0.2 | 1 | -1.20 | .005 | 0.10 | .070 | 12.22 | 9.90 | 21.0 |
| Mar15 | 20-29.5 | 6.94 | 5.33 | .10 | .05 | .06 | .02 | .10 | 0.75 | 0.6 | 5 | -0.15 | .006 | 0.15 | .120 | 12.22 | 27.00 | -75.3 |
| Mar15 | 35-53 | 3.78 | 5.18 | .10 | .05 | .06 | .02 | .05 | 0.20 | 0.4 | 1 | -0.06 | .005 | 0.09 | .065 | 18.83 | 10.21 | 59.3 |
| Apr22 | 0-28 | 1.94 | 5.49 | .50 | .07 | .08 | .02 | .05 | 0.09 | 0.2 | 1 | 0.05 | .005 | 0.08 | .025 | 34.70 | 5.07 | 149.0 |
| x̄ | | 6.26 | 5.11 | .20 | .05 | .07 | .02 | .09 | 0.62 | 0.6 | 4 | -0.47 | .006 | 0.57 | .129 | 24.02 | 24.75 | 62.9 |
| sd | | 4.39 | 6.55 | .17 | .01 | .02 | .00 | .04 | 0.59 | 0.6 | 4 | 0.52 | .002 | 1.14 | .126 | 10.81 | 19.93 | 47.7 |
| n | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |

Site 19

| Date | Depth* cm | Conductance uS/cm | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | TAL | ALKTI | PPUT | TKN | $NO_3^{-}$ | Cation | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb11 | 0-21 | 15.88 | 4.90 | | | | | | | | | | | | | | | |
| Mar18 | 0-9 | 8.36 | 4.99 | .10 | .05 | .06 | .02 | .10 | 0.50 | 0.6 | 3 | -0.23 | .005 | 0.19 | .100 | 22.5 | 20.4 | 9.7 |
| Mar18 | 10-15 | 6.24 | 5.05 | .10 | .05 | .06 | .02 | .05 | 0.50 | 0.9 | 6 | -0.29 | .005 | 0.10 | .060 | 21.1 | 16.1 | 27.0 |
| Mar18 | 24.5-47.5 | 7.55 | 5.00 | .10 | .05 | .06 | .02 | .05 | 0.50 | 0.4 | 1 | -0.15 | .018 | 0.34 | .025 | 22.2 | 13.6 | 48.1 |
| Mar18 | 48.5-62 | 3.90 | 5.35 | .10 | .05 | .06 | .02 | .05 | 0.10 | 0.5 | 5 | -0.08 | .007 | 0.13 | .020 | 12.2 | 4.9 | 85.2 |
| Apr22 | 0-15.5 | 2.17 | 4.86 | .40 | .06 | .06 | .01 | .05 | 0.05 | 0.3 | 9 | -1.20 | .009 | 0.19 | .015 | 42.4 | 3.5 | 169.3 |
| Apr22 | 15.5-22.5 | 2.64 | 5.21 | .30 | .10 | .10 | .01 | .05 | 0.05 | 0.4 | 5 | -0.08 | .005 | 0.23 | .015 | 26.2 | 3.5 | 152.5 |
| Apr22 | 22.5-34.5 | 3.36 | 5.30 | .15 | .06 | .06 | .17 | .08 | 0.41 | 0.4 | 12 | -0.26 | .005 | 0.16 | .020 | 21.8 | 12.2 | 56.5 |
| x̄ | | 6.30 | 5.05 | .18 | .06 | .07 | .04 | .06 | 0.30 | 0.5 | 6 | -0.33 | .008 | 0.19 | .036 | 24.1 | 10.6 | 78.3 |
| sd | | 4.51 | 8.90 | .12 | .02 | .02 | .06 | .02 | 0.22 | 0.2 | 4 | 0.39 | .005 | 0.08 | .032 | 9.1 | 6.7 | 61.3 |
| N | | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |

*mg/l as $CaCO_3$
** sd pH= ueq/l H+

Fig. B5

Total Ice, Black Ice, White Ice and Accumulated Freezing Degree Days Over Time, Plastic Lake 1985

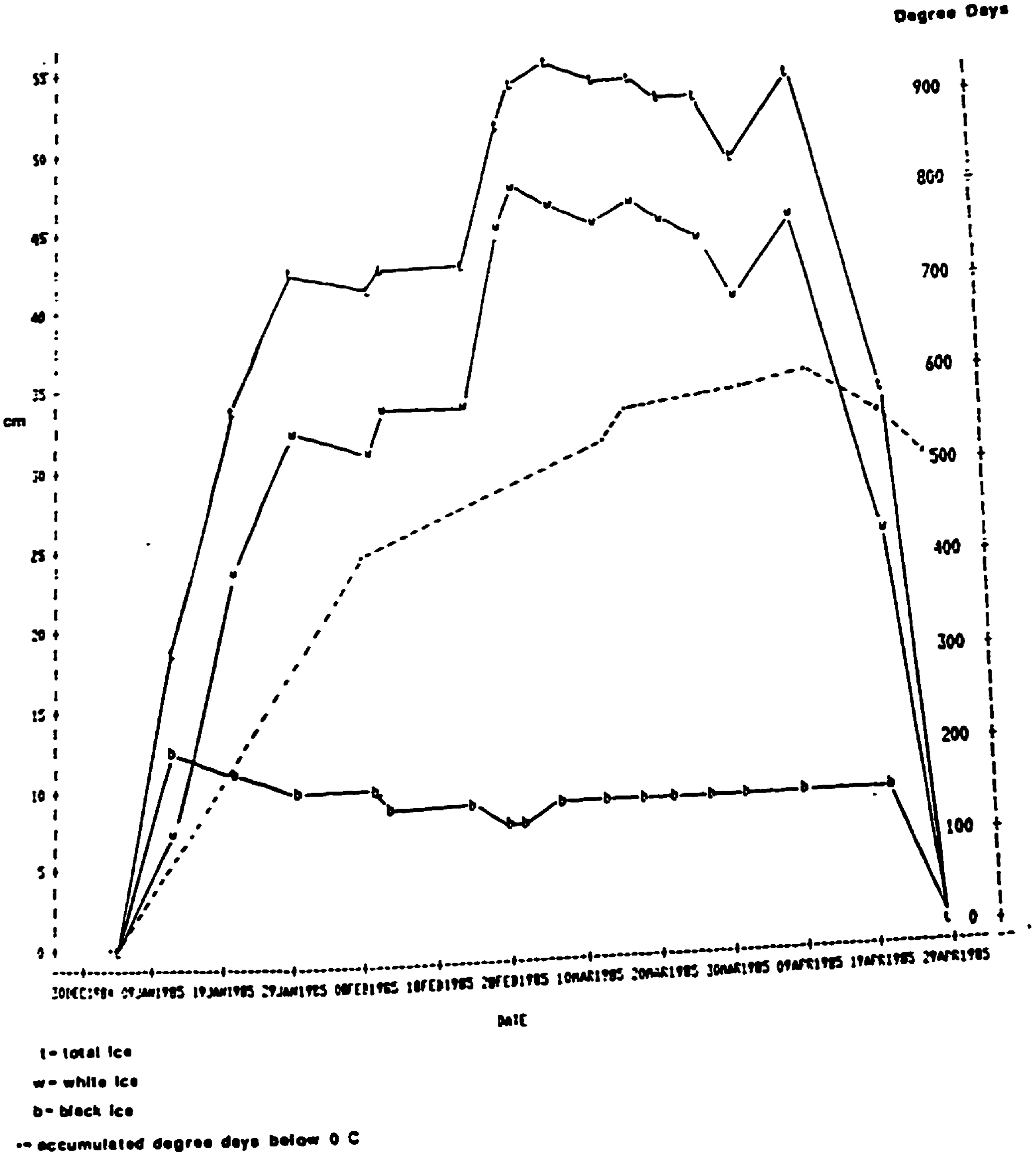
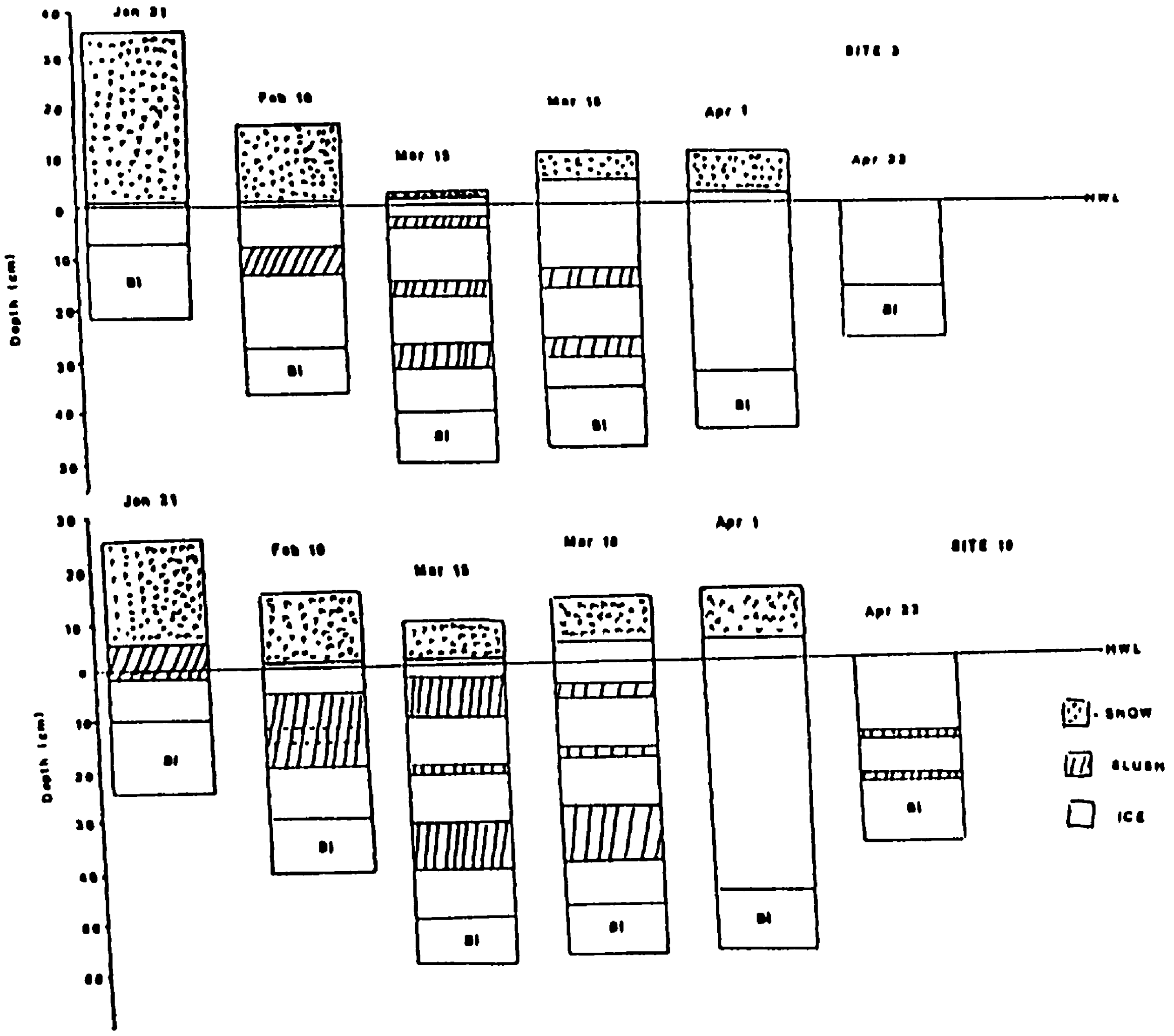


Fig. B6

1985 Plastic Lake Ice Cover Components Over Time



# 1985 Plastic Lake Total Ice Thickness Distribution

Fig. B7a

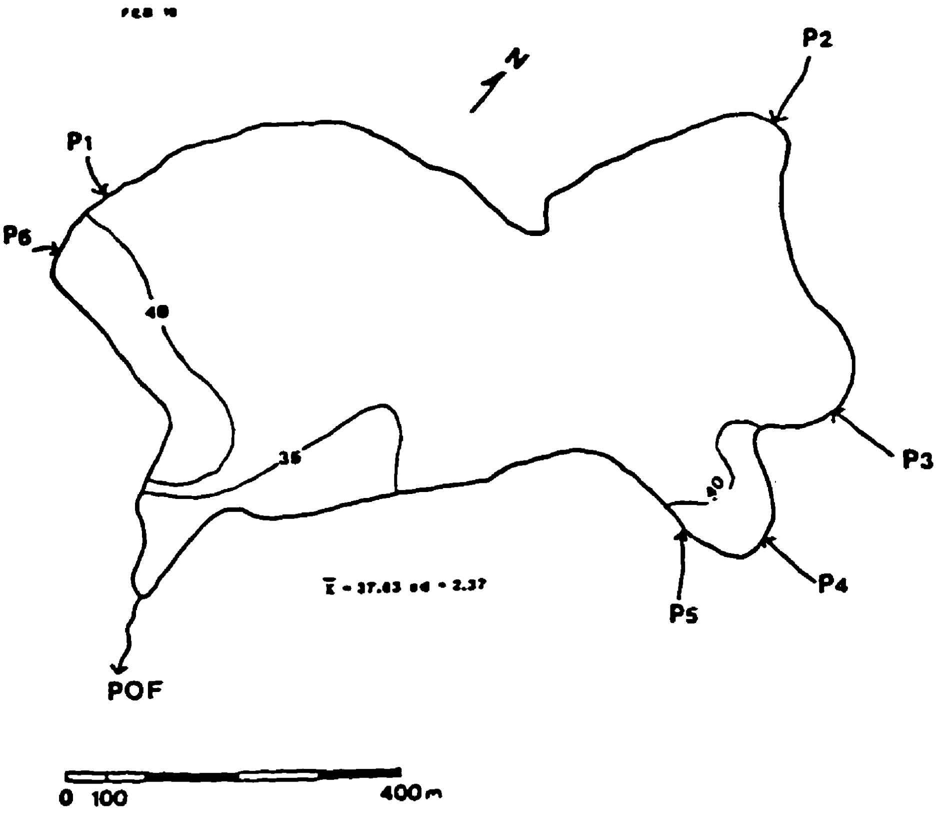
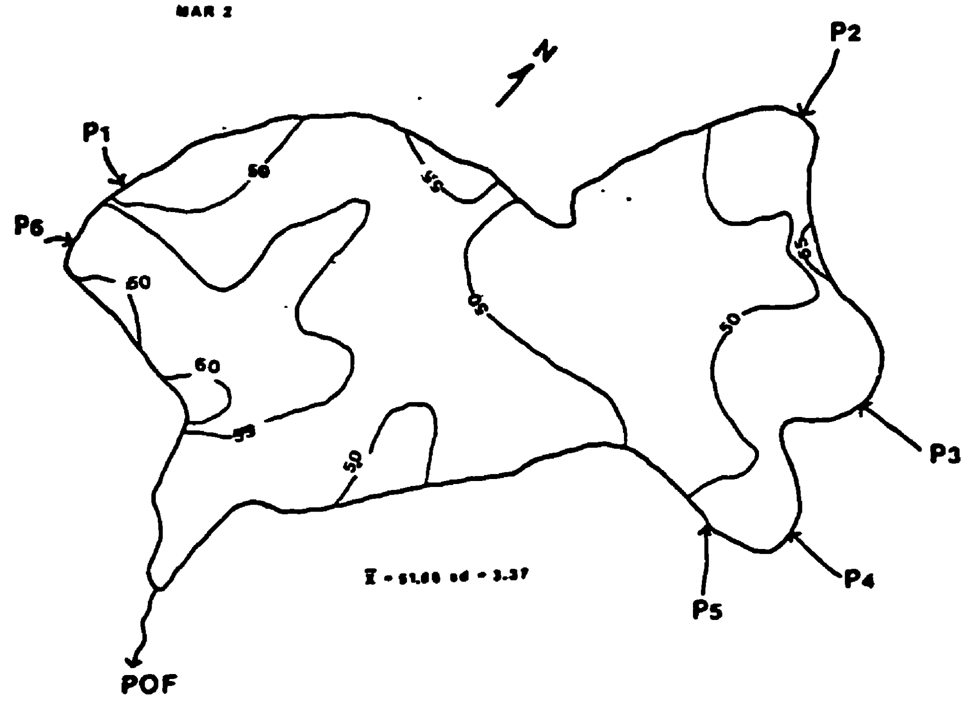


Fig. B7-b



* isoline interval 5cm

# 1985 Plastic Lake Total Ice Thickness Distribution

Fig. B7c

MAR 13

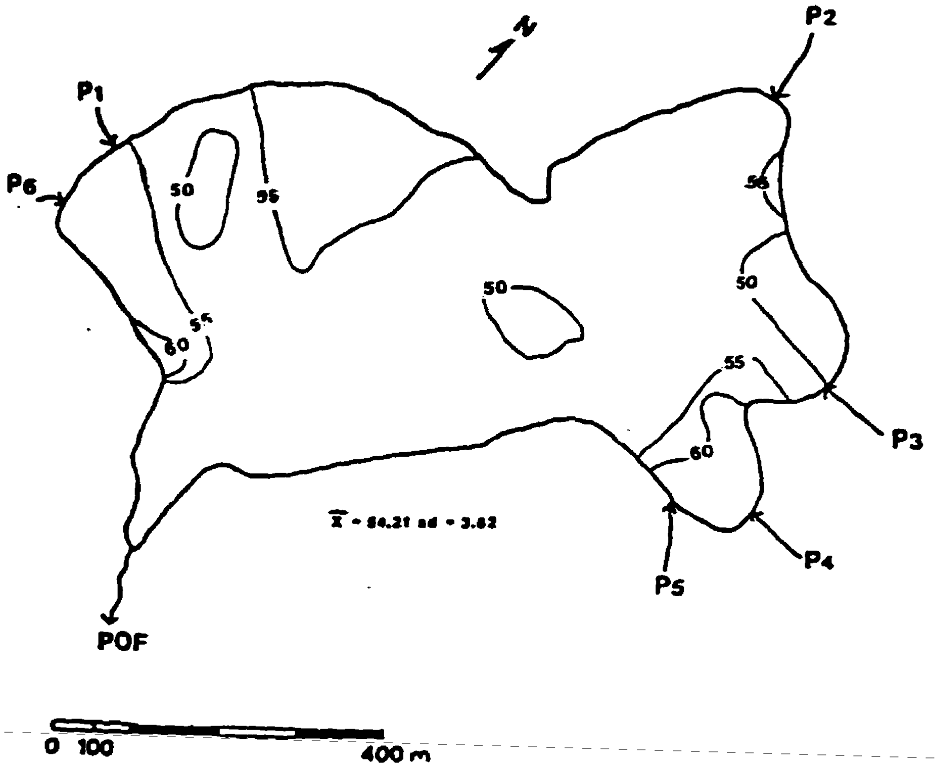
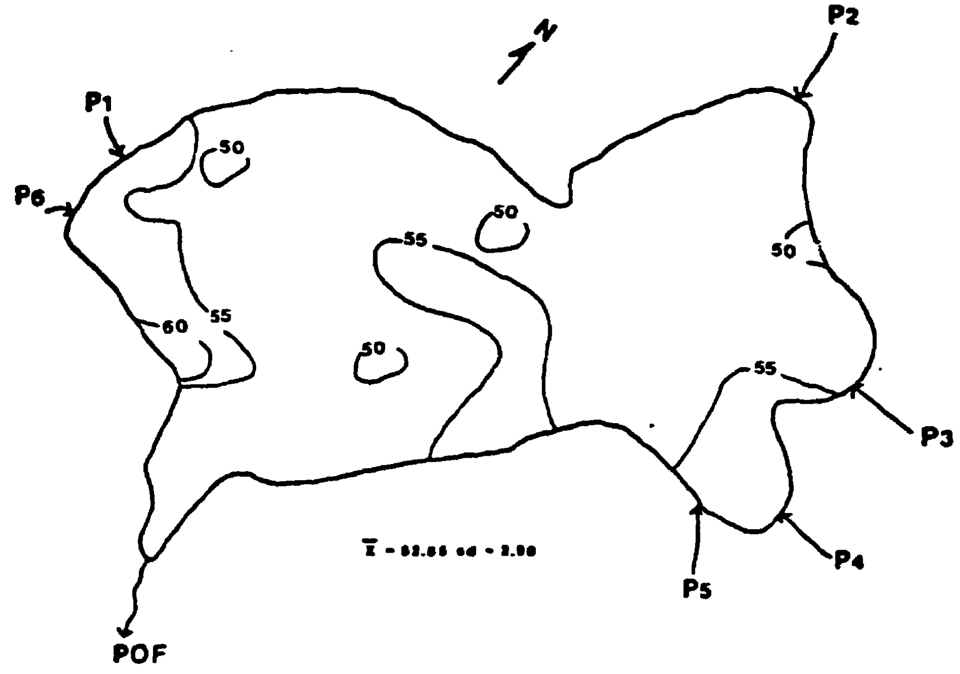


Fig. B7d

MAR 27



## 1985 Plastic Lake Total Ice Thickness Distribution

Fig. B7e APRIL 1

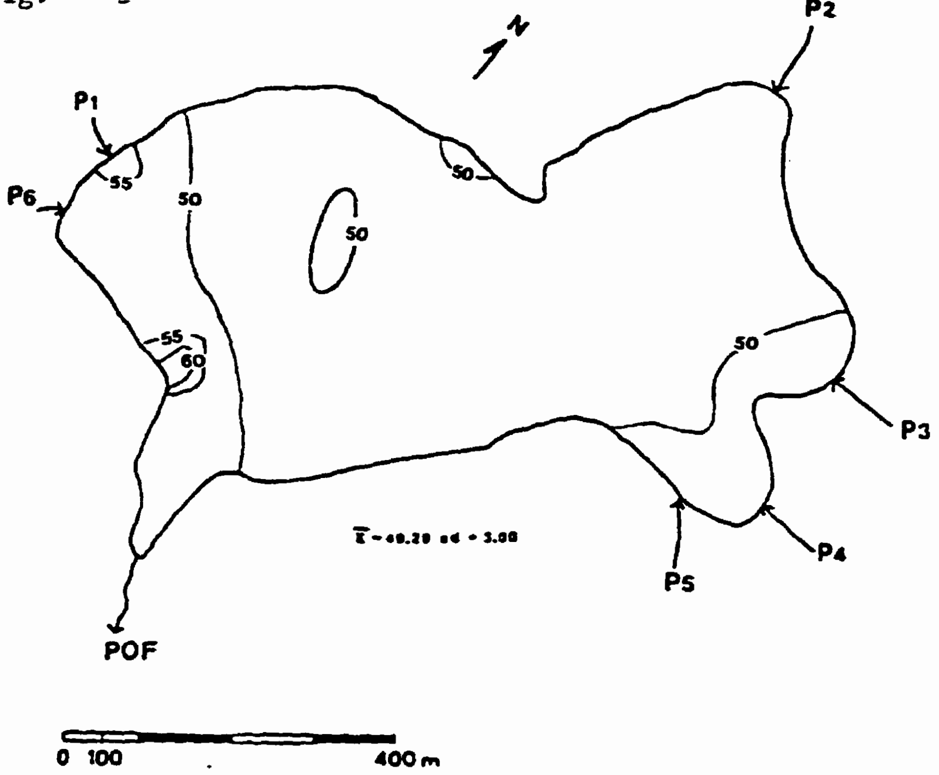
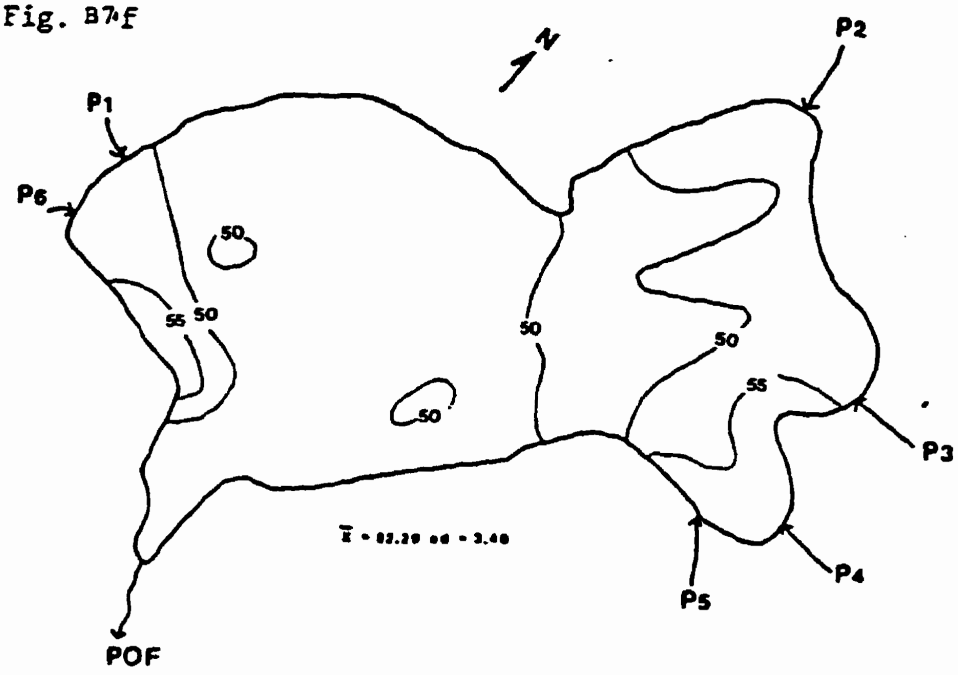


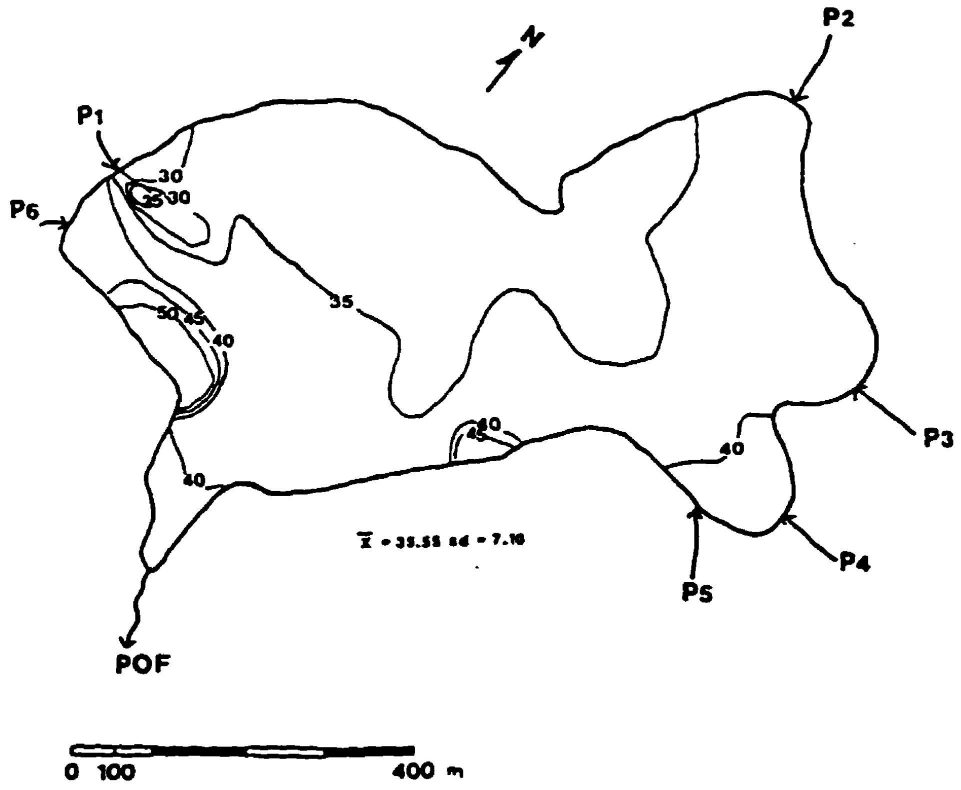
Fig. B7f APRIL 9/10



## 1985 Plastic Lake Total Ice Thickness Distribution

Fig. B7g

APRIL 21



$\bar{x}$ = 35.55 sd = 7.10

Table B4
1985 Plastic Lake Slush Chemistry

Site 3

| Date | Conductance uS/cm | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | $A^{-}$ | TAL | ALKT1* | PPUT | TKN | $NO_3^{-}$ | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/l | | | | | | | ueq/l | ug/l | mg/l | | | | ueq/l | | % |
| Jan08 | 52.8 | 4.33 | 2.70 | 0.62 | 0.66 | 0.36 | 0.56 | 10.54 | 0.53 | 0.0 | 4 | | | 0.40 | | 270.4 | | |
| Jan30 | 49.8 | 4.25 | | | | | | | | | | | | | | | | |
| Feb11 | 29.5 | 4.70 | 2.10 | 0.50 | 0.56 | 0.24 | 0.35 | 7.21 | 2.30 | 0.0 | 11 | -1.00 | .005 | 0.21 | 0.265 | 196.4 | 179.1 | 9.1 |
| Mar07 | 246.4 | 3.55 | 11.40 | 2.75 | [illegible] | 1.30 | [illegible] | [illegible] | [illegible] | 93.6 | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Mar14 | 45.4 | 3.92 | 0.40 | 0.05 | 0.06 | 0.02 | 0.25 | 2.85 | 1.20 | 0.0 | 19 | -4.10 | .010 | 0.52 | 1.100 | 147.4 | 144.9 | 1.7 |
| Mar18 | 64.4 | 3.97 | 1.90 | 0.40 | 0.50 | 0.14 | 0.35 | 5.10 | 1.80 | 0.0 | 44 | -4.30 | .010 | 0.51 | 1.100 | 260.2 | 194.6 | 28.9 |
| Mar27 | 33.9 | 4.30 | 1.55 | 0.34 | 0.44 | 0.18 | 0.63 | 9.49 | 3.00 | 0.0 | 45 | -5.40 | .014 | 0.65 | 1.000 | 179.2 | 286.7 | -46.2 |
| Apr11 | 33.5 | 4.20 | 0.30 | 0.09 | 0.20 | 0.06 | 0.22 | 2.50 | 0.70 | 0.0 | 7 | -3.50 | .005 | 0.19 | 0.590 | 95.7 | 100.4 | -4.8 |
| Apr20 | 9.3 | 4.83 | 0.05 | 0.08 | 0.06 | 0.04 | 0.27 | 5.65 | | | 6 | -0.65 | .004 | 0.20 | 0.185 | 27.5 | 138.5 | -133.7 |
| x̄ | 62.7 | 4.07 | 2.55 | 0.60 | 0.67 | 0.29 | 0.64 | 11.51 | 3.53 | 8.2 | 22 | -5.43 | .008 | 0.54 | 1.141 | 301.4 | 353.0 | 34.1 |
| sd | 70.7 | 84.5 | 3.70 | 0.89 | 0.91 | 0.42 | 0.77 | 15.31 | 5.22 | 24.5 | 18 | 5.85 | .004 | 0.47 | 1.212 | 388.5 | 477.1 | 40.5 |
| N | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 8 | 7 | 8 | 7 | 7 |

Site 19

| Date | Conductance uS/cm | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | DOC | $A^{-}$ | TAL | ALKT1* | PPUT | TKN | $NO_3^{-}$ | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan30 | 31.6 | 4.40 | | | | | | | | | | | | | | | | |
| Feb11 | 47.4 | 4.49 | 3.40 | 0.70 | 0.76 | 0.36 | 0.65 | 11.31 | 3.40 | 0.0 | 50 | -2.10 | .008 | 0.33 | 0.590 | 301.9 | 295.9 | 2.0 |
| Mar07 | 33.6 | 4.65 | 2.50 | 0.60 | 0.66 | 0.22 | 0.40 | 9.35 | 6.00 | 46.6 | | -1.40 | .006 | 0.23 | 0.075 | 230.8 | 258.0 | -11.1 |
| Mar14 | 33.6 | 4.15 | 1.20 | 0.25 | 0.26 | 0.02 | 0.45 | 8.00 | 2.90 | 0.0 | 146 | -2.40 | .007 | 0.36 | 0.465 | 163.1 | 212.4 | -26.3 |
| Mar18 | 44.8 | 4.26 | 1.30 | 0.30 | 0.66 | 0.20 | 0.50 | 7.90 | 3.80 | 0.0 | 116 | -3.10 | .006 | 0.36 | 0.735 | 178.3 | 231.0 | -25.8 |
| Mar27 | 37.5 | 4.57 | 2.45 | 0.62 | 0.74 | 0.26 | 0.53 | 9.92 | 3.90 | 0.0 | 126 | -1.60 | .008 | 0.40 | 0.430 | 239.0 | 252.2 | -5.4 |
| Apr20 | 11.1 | 4.79 | 0.05 | 0.11 | 0.12 | 0.01 | 0.05 | 0.61 | 0.70 | 0.0 | 26 | -0.76 | .011 | 0.28 | 0.175 | 33.2 | 26.6 | 22.2 |
| x̄ | 34.3 | 4.42 | 1.82 | 0.43 | 0.53 | 0.18 | 0.43 | 7.85 | 3.4 | 6.6 | 93 | -1.89 | .008 | 0.33 | 0.412 | 191.1 | 212.7 | 15.4 |
| sd | 11.8 | 19.3 | 1.20 | 0.24 | 0.27 | 0.14 | 0.20 | 3.77 | 1.7 | 17.6 | 52 | 0.82 | .002 | 0.06 | 0.249 | 91.7 | 95.4 | 10.6 |
| N | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 6 | 6 | 6 | 6 6 | 6 | 6 | 6 |

* mg/l as $CaCO_3$
** pH sd as ueq/l H+

Fig. 88

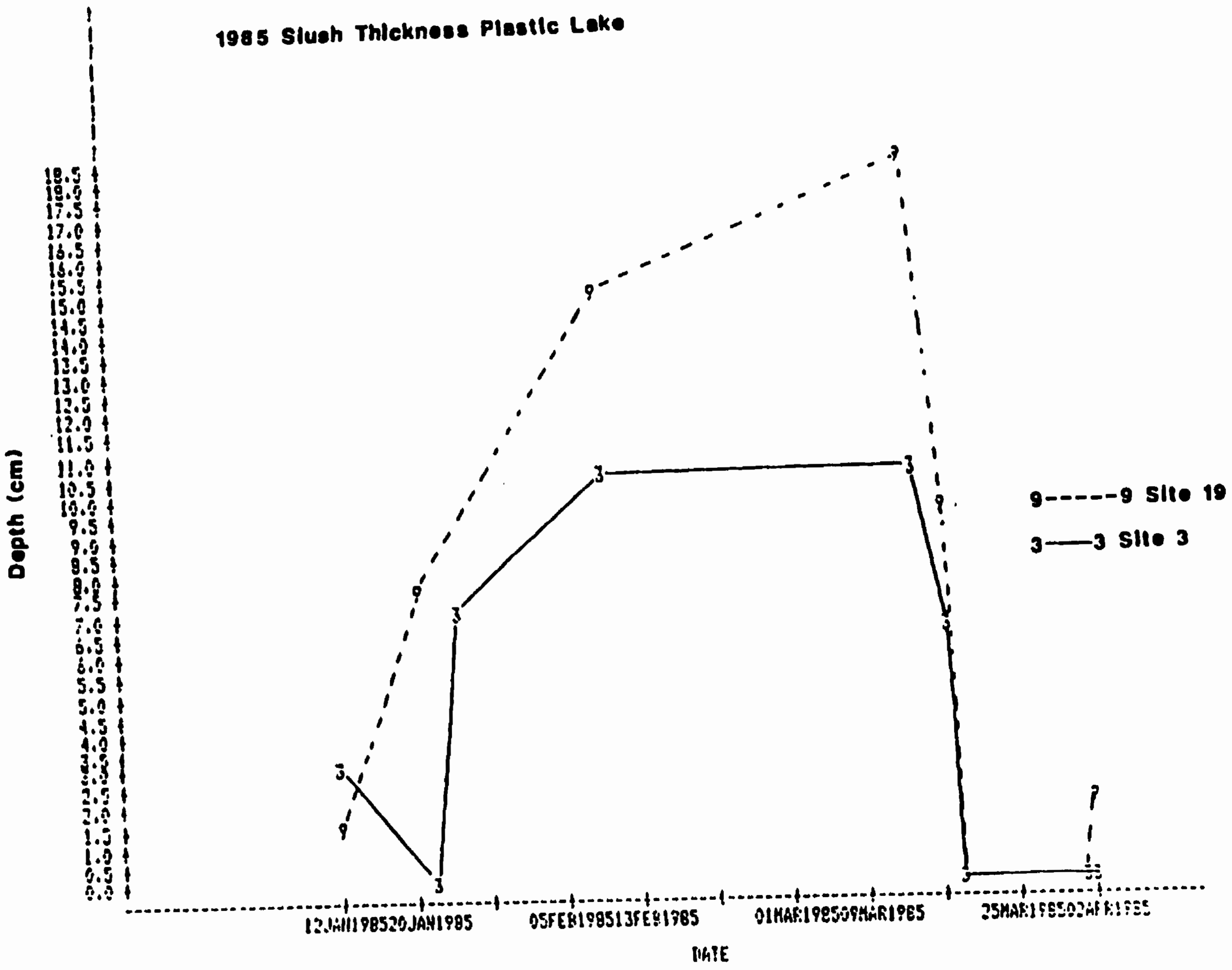

1985 Slush Thickness Plastic Lake
Depth (cm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
12JAN1985
20JAN1985
05FEB1985
13FEB1985
01MAR1985
09MAR1985
25MAR1985
02APR1985
DATE
9-----9 Site 19
3——3 Site 3

Fig. B9 a

**1985 Plastic Lake Slush Chemistry**

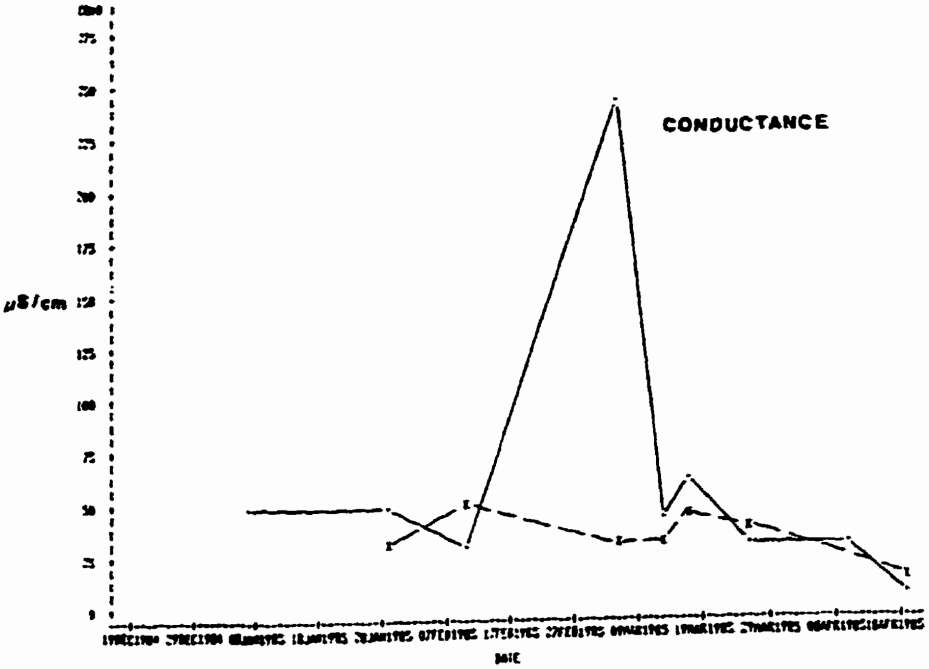
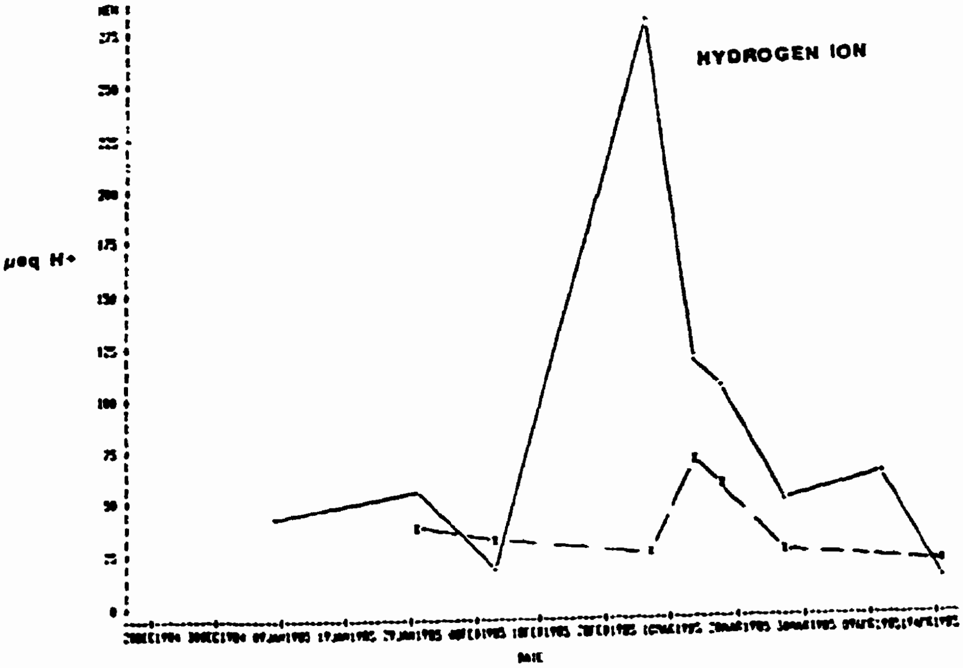


Fig. B9 b



Site 3 ————

Site 19 x------x

# 1985 Plastic Lake Slush Chemistry

Fig. B9c

TOTAL INFLECTION POINT ALKALINITY

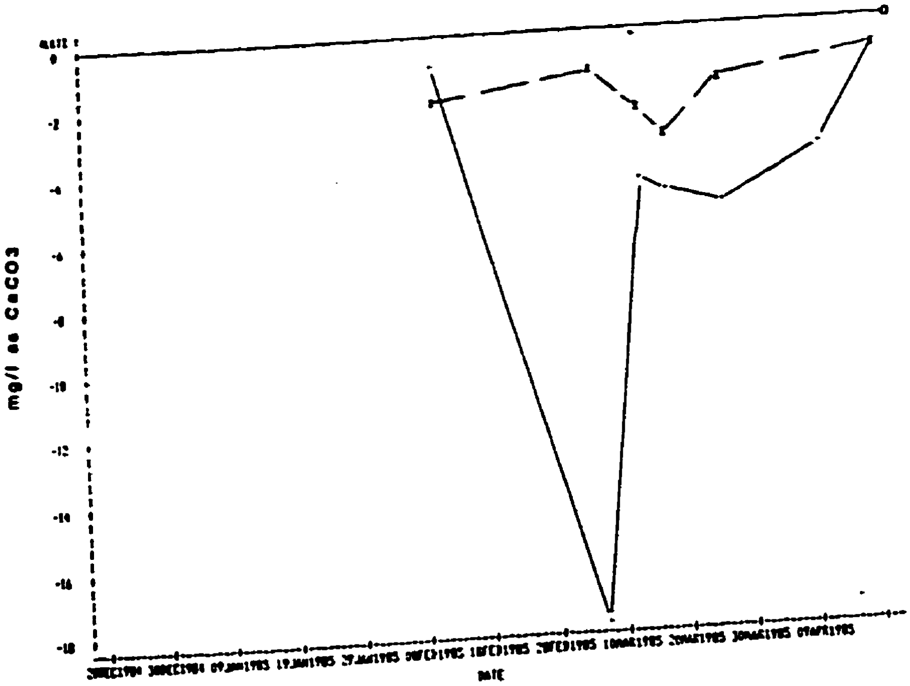


Fig. B9d

CALCIUM

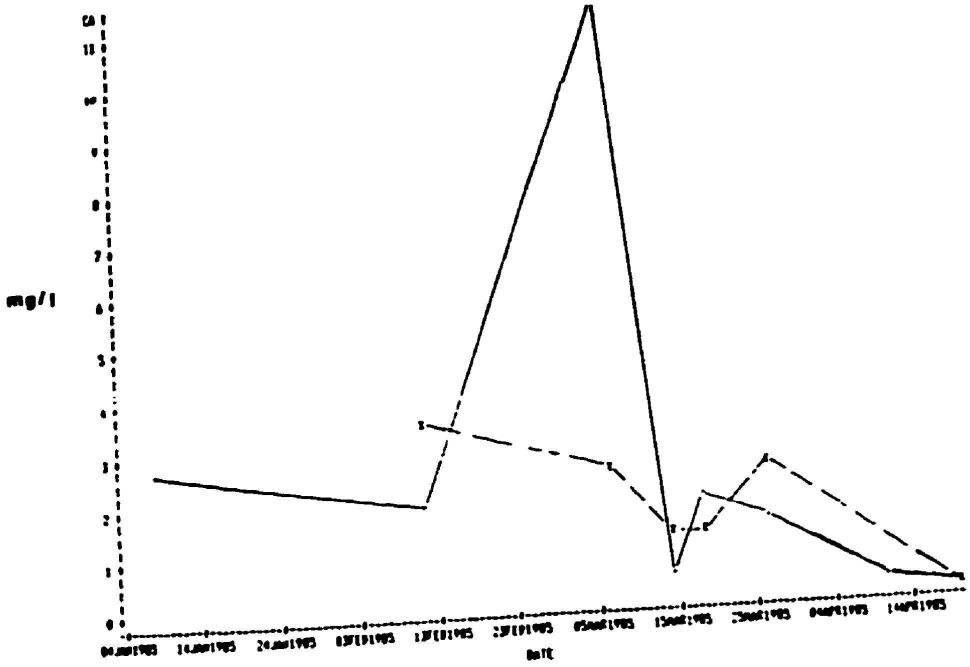


Fig. B9 ··

## 1985 Plastic Lake Slush Chemistry

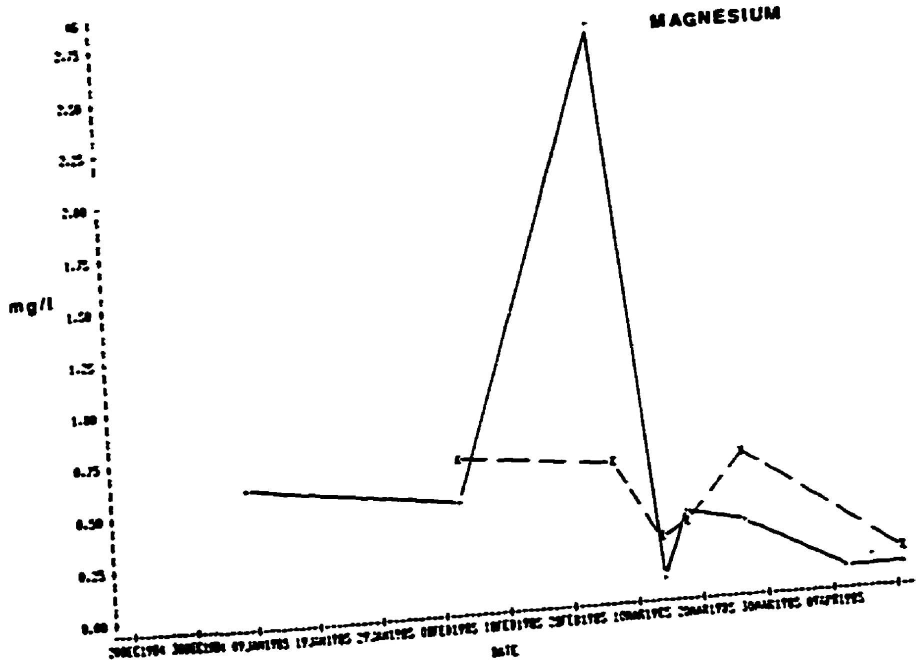
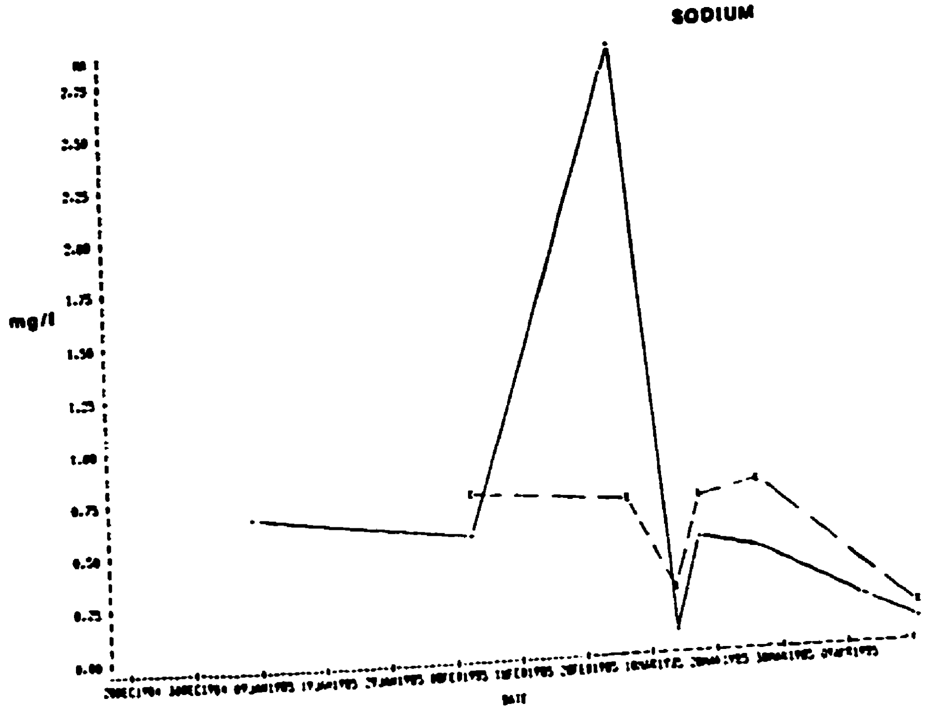


Fig. B9 f



## 1985 Plastic Lake Slush Chemistry

Fig B9g

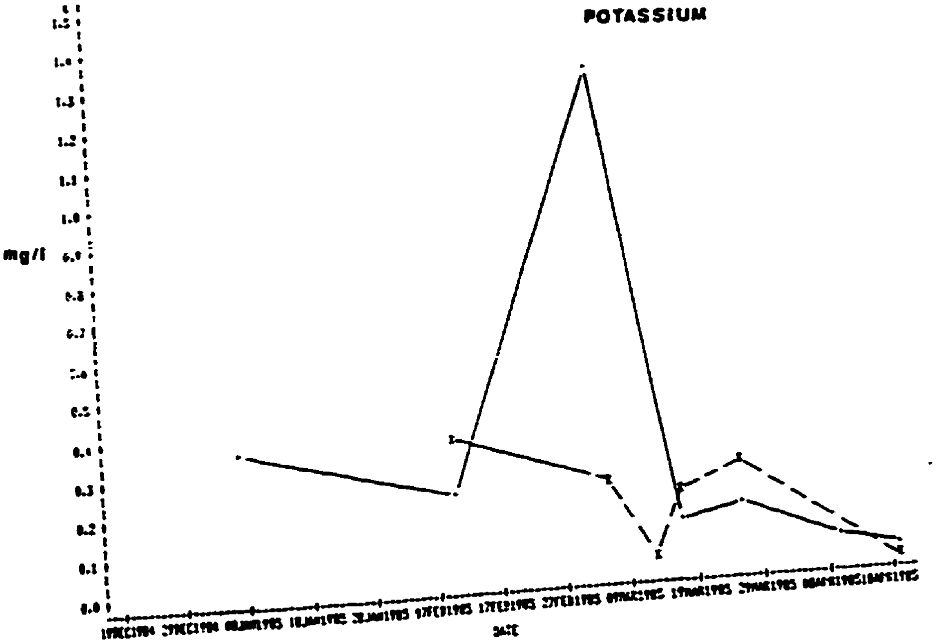
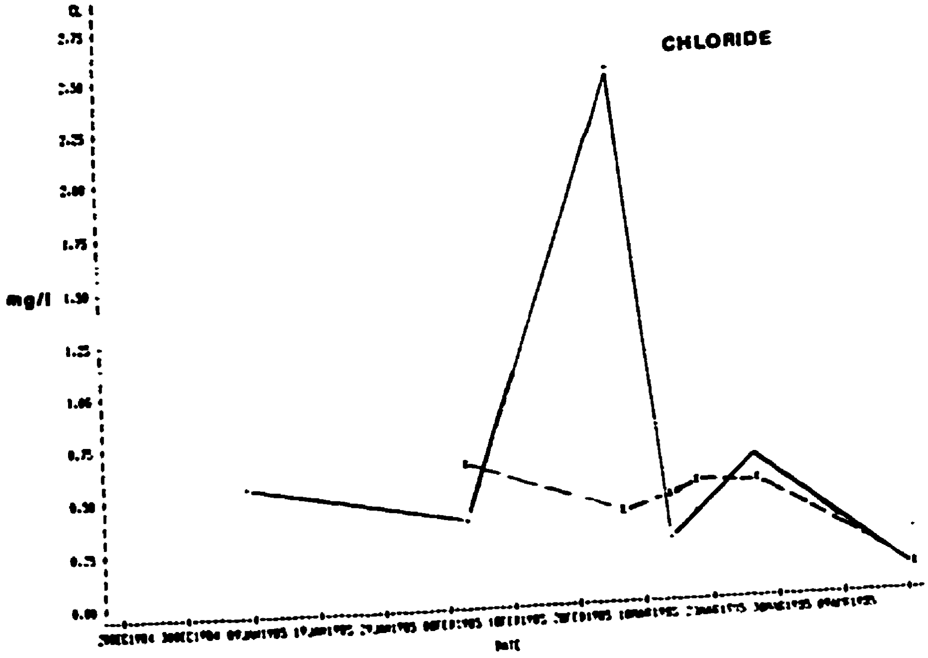


Fig. B9 h



# 1985 Plastic Lake Slush Chemistry

Fig. B9i

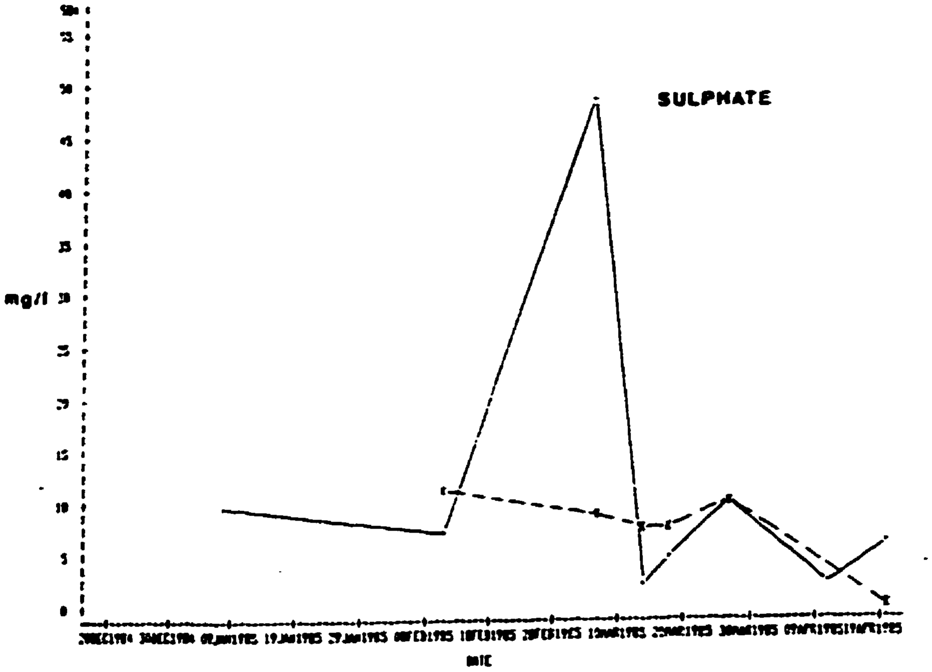
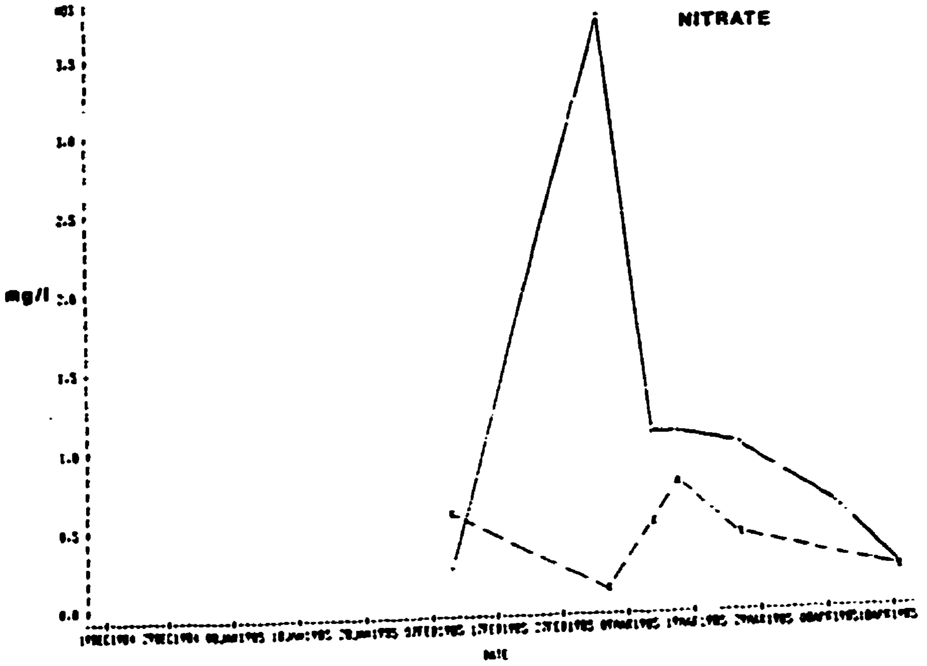


Fig. B9 j



## 1985 Plastic Lake Slush Chemistry

Fig. B9k

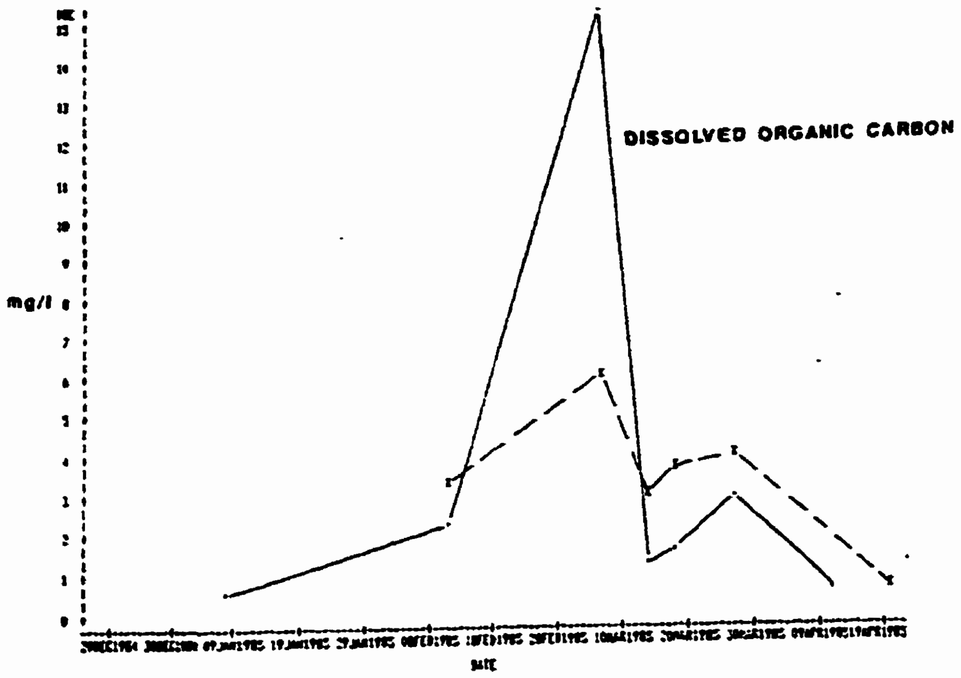
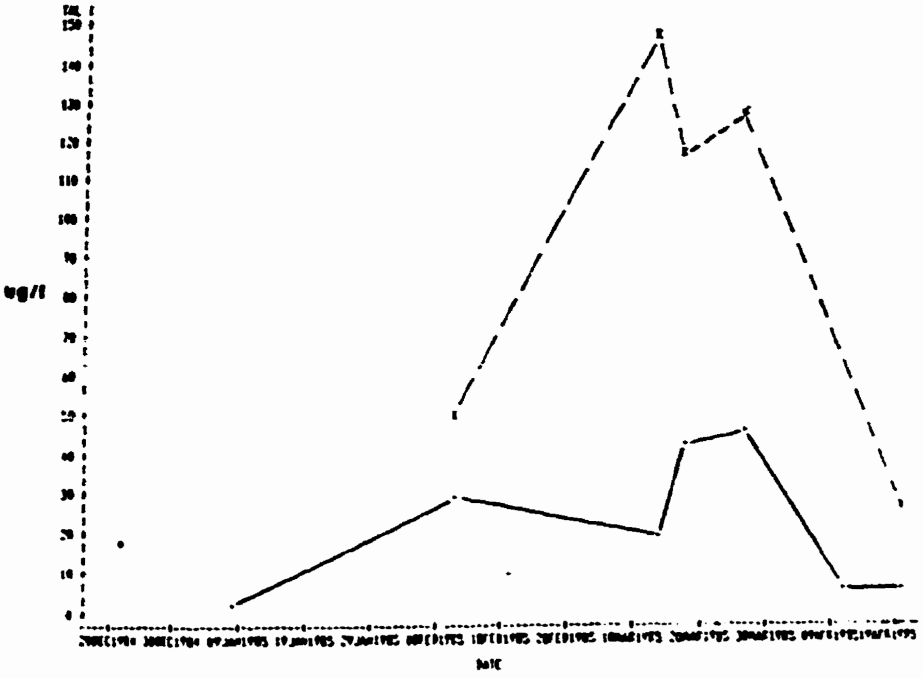


Fig. B9 l

TOTAL ALUMINUM



# 1985 Plastic Lake Slush Chemistry

Fig. 89.n

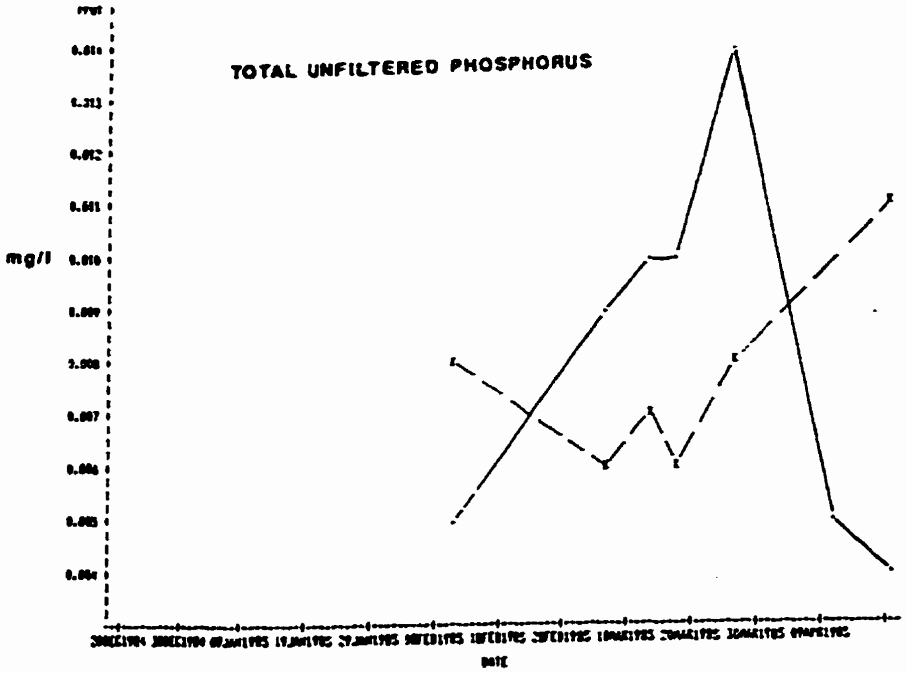
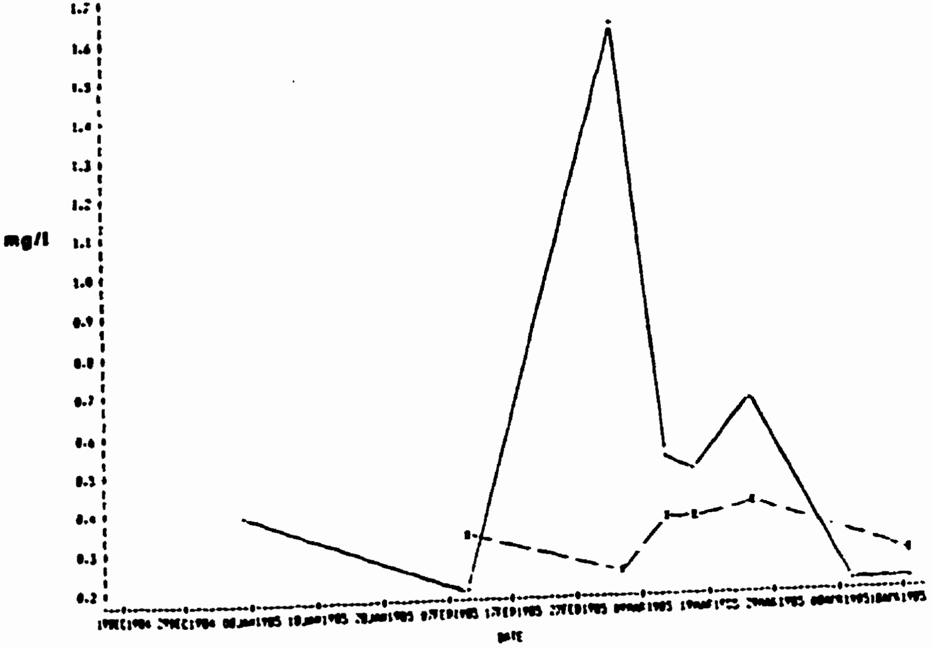

TOTAL UNFILTERED PHOSPHORUS

Fig. 39 n


TOTAL KJELDAHL NITROGEN

# Appendix 3 Plastic Inflow 1 and Plastic Lake outflow discharge and chemistry

Table C1

1985 Mean daily flow Plastic Inflow 1 (l/sec)*

| | Jan | Feb | Mar | Apr |
|---|---|---|---|---|
| 1 | | .906 | 7.00 | 14.40 |
| 2 | | .865 | 2.24 | 9.65 |
| 3 | 5.86 | .489 | 1.43 | 6.85 |
| 4 | 5.25 | .374 | 1.43 | 5.19 |
| 5 | 4.65 | .316 | .906 | 8.26 |
| 6 | 4.04 | .251 | .741 | 25.20 |
| 7 | 3.43 | .269 | 2.41 | 23.00 |
| 8 | 2.82 | .659 | 2.32 | 17.60 |
| 9 | 2.22 | 0.0 | 2.10 | 11.40 |
| 10 | 1.61 | 0.0 | 2.03 | 7.32 |
| 11 | 1.49 | 0.0 | 2.41 | 5.86 |
| 12 | 1.36 | 0.0 | 9.65 | 5.07 |
| 13 | 1.24 | .269 | 14.70 | 5.07 |
| 14 | 1.11 | .287 | 12.20 | 5.31 |
| 15 | .989 | .287 | 8.96 | 15.90 |
| 16 | .942 | .287 | 6.69 | 32.30 |
| 17 | .895 | .287 | 5.19 | 33.50 |
| 18 | .848 | .287 | 4.35 | 31.10 |
| 19 | .800 | .374 | 3.50 | 31.10 |
| 20 | .753 | .345 | 3.09 | 31.70 |
| 21 | .706 | .316 | 2.75 | 46.10 |
| 22 | .659 | 1.26 | 2.49 | 72.90 |
| 23 | .617 | 2.75 | 2.41 | 68.50 |
| 24 | .648 | 12.40 | 2.32 | 52.80 |
| 25 | .679 | 17.10 | 2.41 | 39.00 |
| 26 | .710 | 17.60 | 2.32 | 26.40 |
| 27 | .741 | 14.00 | 3.50 | 18.40 |
| 28 | .772 | 10.00 | 13.50 | 13.10 |
| 29 | .803 | | 21.50 | 10.00 |
| 30 | .834 | | 21.50 | 8.26 |
| 31 | .865 | | 19.80 | |
| Mean | 1.67 | 2.93 | 6.06 | 22.71 |
| Max | 5.86 | 17.60 | 21.50 | 72.90 |
| Min | .617 | 0.0 | .741 | 5.07 |

*P. Dillon and L. Scott unpublished data

Table C2

1985 Plastic Inflow 1 Chemistry (P. Dillon unpublished studies)

| Date:Time | pH | ALKTI* | DIC | HCO3- | Ca+2 | Mg+2 | Na+ | K+ | Cl- | SO4-2 | NO3- | TKN | TPUT | TAL | NH4+ | DOC | A- | Cond | C | Anions | Cations | balance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | ug/l | ug/l | ug/l | ug/l | ug/l | mg/l | ueq/l | uS/cm | HU | ueq/l | ueq/l | % |
| Jan03:15:4[illegible] | 4.30 | -2.85 | 1.31 | .0010 | 2.15 | .48 | .53 | .09 | .58 | 8.97 | 2 | 210 | 3.43 | 308 | 2 | 7.5 | 51.2 | 42.1 | 49 | 255.5 | 222.4 | -13.8 |
| Jan10:13:10 | 4.33 | -2.50 | 0.75 | .0006 | 2.29 | .51 | .58 | .08 | .34 | 8.88 | 65 | 210 | 3.60 | 317 | 2 | 8.0 | 55.2 | 37.0 | 55 | 253.4 | 230.4 | -9.5 |
| Jan15:11:15 | 4.37 | -2.28 | 0.65 | .0006 | 2.36 | .52 | .60 | .09 | .29 | 8.24 | 55 | 210 | 5.37 | 351 | 1 | 8.5 | 59.4 | 39.8 | 58 | 243.6 | 231.7 | -5.0 |
| Jan22:16:[illegible] | 4.25 | -3.11 | 3.62 | .0006 | 2.35 | .47 | .60 | .10 | .28 | 8.29 | 75 | 240 | 4.90 | 297 | 3 | 8.3 | 55.4 | 36.2 | 70 | 241.7 | 236.0 | -2.3 |
| Jan30:15:[illegible] | 4.44 | -1.84 | 0.60 | .0006 | 2.42 | .51 | .58 | .11 | .37 | 7.64 | 90 | 240 | 5.75 | 290 | 1 | 8.6 | 61.6 | 38.6 | 66 | 236.8 | 227.1 | -4.2 |
| Feb06:15:[illegible] | 4.48 | -1.72 | 0.56 | .0006 | 2.35 | .52 | .62 | .12 | .28 | 7.37 | 110 | 230 | 5.37 | 268 |  | 9.1 | 64.1 | 37.5 | 68 | 235.9 |  |  |
| Feb13:15: 7 | 4.53 | -1.59 | 0.51 | .0006 | 2.34 | .49 | .61 | .14 | .40 | 7.23 | 135 | 430 | 8.77 | 319 | 2 | 8.5 | 62.9 | 33.0 | 77 | 235.0 | 216.8 | -8.0 |
| Feb13:15:13 | 4.52 | -1.58 | 0.58 | .0007 | 2.42 | .52 | .62 | .13 | .35 | 7.05 | 140 | 240 | 7.00 | 318 | 3 | 9.2 | 67.7 | 34.0 | 78 | 235.1 | 224.2 | -4.7 |
| Feb2[illegible]:10:[illegible] | 4.56 | -1.40 | 0.62 | .0008 | 2.22 | .49 | .61 | .12 | .48 | 6.38 | 130 | 270 | 8.00 |  | 1 | 9.4 | 70.1 | 32.7 | 82 | [illegible] | [illegible] | -7.8 |
| Feb22:16:[illegible] | 4.39 | [illegible] | 1.16 | .0010 | 2.30 | .52 | .55 | .19 | .50 | 7.00 | 340 | 310 | 9.95 | 303 | 6 | 9.0 | 63.3 | 35.9 | 77 | [illegible] | [illegible] | -6.8 |
| Feb23:15:[illegible] | 4.36 | -2.51 | 1.40 | .0012 | 2.35 | .50 | .57 | .18 | .50 | 7.00 |  | 290 | 10.20 | 292 |  | 8.9 | 61.9 |  |  |  |  |  |
| Feb24:14:[illegible] | 4.29 | [illegible] | 2.65 | .0019 | 2.09 | .48 | .52 | .19 | .45 | 7.65 | 230 | 260 | 9.53 | 366 | 5 | 8.0 | 54.3 | 37.0 | 61 | 244.6 | 222.9 | -9.3 |
| Feb2[illegible]:11:[illegible] | 4.27 | [illegible] | 2.76 | .0019 | 2.19 | .49 | .54 | .17 | .45 | 8.25 | 105 | 220 | 8.87 | 304 | 1 | 8.5 | 57.2 | 40.4 | 63 | 251.0 | 231.2 | -8.2 |
| Feb2[illegible]:10:10 | 4.24 | -2.44 | 2.67 | .0017 | 2.06 | .47 | .54 | .15 | .40 | 8.30 | 30 | 220 | 7.80 | 251 | 6 | 7.9 | 52.4 | 41.3 | 56 | 240.6 | 226.8 | -5.9 |
| Feb2[illegible]:11:15 | 4.25 | [illegible] |  |  | 2.16 | .48 | .55 | .16 | .40 | 8.65 | 30 | 200 |  | 249 | 1 | 7.7 | 51.5 | 43.6 | 56 | 245.1 | 231.6 | -5.7 |
| Feb27:[illegible] | 4.25 | [illegible] | 2.17 | .0014 | 2.11 | .47 | .55 | .14 | .40 | 8.55 | 15 | 220 | 6.13 | 220 | 2 | 7.8 | 52.2 | 44.7 | 52 | 248.0 | 227.8 | -8.8 |
| Feb2[illegible] | 4.27 | [illegible] | 2.06 | .0014 | 2.09 | .46 | .55 | .14 | .35 | 8.45 | 10 | 200 | 6.53 | 237 | 3 | 7.8 | 52.6 | 42.1 | 53 | 240.5 | 223.4 | -7.4 |
| Mar[illegible] | 4.29 | [illegible] | 1.72 | .0012 | 2.06 | .47 | .58 | .13 | .40 | 8.85 | 10 |  |  |  | 3 | 7.3 | 50.4 | 40.8 | 52 | 247.9 | 221.4 | -11.3 |
| Mar[illegible] | 4.27 | [illegible] | 1.54 | .0015 | 2.05 | .46 | .58 | .12 | .35 | 8.75 | 20 |  |  |  | 1 | 7.4 | 50.0 | 34.6 | 58 | 244.5 | 222.2 | -9.6 |
| Mar03:12:52 | 4.31 | [illegible] | 1.17 | .0009 | 2.37 | .64 | .61 | .29 | .55 | 9.50 | 20 | 360 | 5.77 | 318 | 1 | 7.5 | 51.4 | 41.1 | 56 | 267.0 | 253.9 | -5.0 |
| Mar06:12:[illegible] | 4.35 | -2.50 | 1.19 | .0010 |  |  |  |  |  |  | 30 |  | 6.40 | 302 | 3 |  |  | 39.1 | 64 |  |  |  |
| Mar07:14:40 | 4.31 | [illegible] | 1.97 | .0007 | 2.04 | .44 | .59 | .12 | .35 | 7.35 | 25 | 240 | 5.60 | 308 | 1 | 8.0 | 54.7 | 39.4 | 61 | 220.2 | 215.8 | -2.0 |
| Mar07:17:09 |  |  |  |  | 2.13 | .46 | .60 | .12 | .30 | 7.55 |  | 250 |  |  |  | 6.0 |  |  |  |  |  |  |
| Mar08:11:26 |  |  |  |  | 2.12 | .45 | .59 | .11 | .25 | 8.00 |  |  |  |  |  | 8.4 |  |  |  |  |  |  |
| Mar1[illegible]:13:13 | 4.34 | -2.94 | 2.11 | .0017 | 1.94 | .43 | .54 | .13 | .35 | 7.40 | 145 | 230 | 5.63 | 231 | 1 | 6.9 | 48.0 | 37.8 | 48 | 224.0 | 204.8 | -9.0 |
| Mar13:10:00 | 4.34 | [illegible] | 2.79 | .0022 | 1.90 | .42 | .55 | .12 | .30 | 7.65 | 40 |  |  |  | 5 | 7.4 | 51.3 | 39.9 | 50 | 224.2 | 202.4 | -10.2 |
| Mar14:14:2[illegible] | 4.31 | -2.44 | 2.06 | .0016 | 1.98 | .42 | .56 | .10 | .25 | 7.80 | 10 | 190 | 4.43 | 458 | 1 | 7.0 | 48.1 | 37.7 | 49 | 219.8 | 209.3 | -4.9 |
| Mar1[illegible]:13:53 | 4.34 | [illegible] | 1.09 | .0009 | 1.97 | .43 | .58 | .11 | .30 | 7.75 | 20 | 190 | 4.63 | 262 | 1 | 7.0 | 48.6 | 35.3 | 55 | 220.8 | 207.5 | -6.2 |
| Mar2[illegible]:16:[illegible] | 4.38 | [illegible] | 1.07 | .0009 | 2.05 | .45 | .62 | .12 | .25 | 7.65 | 40 |  |  | 228 | 1 | 7.1 | 50.0 | 33.3 | 61 | 220.2 | 211.1 | -4.2 |
| Mar2[illegible]:19:55 | 4.41 | -1.97 | 1.04 | .0010 | 2.00 | .44 | .60 | .10 | .25 | 7.70 | 40 |  |  | 236 | 1 | 7.2 | 51.3 | 36.0 | 63 | 222.5 | 203.6 | -8.9 |
| Mar2[illegible]:12:[illegible] | 4.34 | -2.14 | 1.93 | .0008 | 1.95 | .44 | .62 | .12 | .25 | 7.70 | 45 | 230 | 5.00 | 234 | 1 | 7.2 | 50.7 | 36.6 | 60 | 222.1 | 205.3 | -7.9 |
| Mar2[illegible]:45 | 4.37 | [illegible] | [illegible] | .0008 | 2.00 | .44 | .50 | .10 | .25 | 7.70 | 50 |  |  | 228 | 1 | 7.3 | 51.2 | 36.9 | 65 | 223.0 | 206.5 | -7.7 |
| Mar2[illegible]:10:4[illegible] | 4.41 | -2.20 | 0.84 | .0008 | 2.15 | .46 | .60 | .11 | .30 | 7.75 | 50 | 200 | 5.43 | 260 | 1 | 7.2 | 51.3 | 37.0 | 61 | 225.5 | 213.0 | -5.7 |
| Mar2[illegible] | 4.38 | [illegible] | 1.98 | .0009 | 1.95 | .44 | .60 | .11 | .25 | 7.50 | 50 | 200 | 6.00 | 239 | 1 | 7.2 | 50.7 | 36.7 | 64 | 218.4 | 204.2 | -6.7 |
| Mar2[illegible] | 4.41 | [illegible] | 0.91 | .0009 | 1.95 | .44 | .58 | .13 | .30 | 7.80 | 50 | 190 | 4.93 | 275 | 1 | 7.4 | 52.7 | 35.1 | 63 | 228.0 | 201.0 | -12.6 |
| Mar27:11:4[illegible] | 4.39 | -2.04 | 1.05 | .0009 | 1.90 | .44 | .58 | .10 | .30 | 7.20 | 55 |  |  | 226 | 1 | 7.3 | 51.6 | 36.2 | 61 | 214.9 | 199.6 | -7.4 |
| Mar2[illegible]:09:3[illegible] | 4.36 | -2.54 | 1.93 | .0016 | 1.80 | .43 | .56 | .12 | .25 | 6.95 | 95 | 230 | 5.20 | 232 | 2 | 6.8 | 47.6 | 36.4 | 58 | 207.8 | 196.4 | -5.6 |
| [illegible]:34:55 | 4.32 | -2.50 | 2.46 | .0019 | 1.82 | .41 | .48 | .16 | .25 | 7.66 | 50 |  |  |  | 1 | 7.0 | 48.3 | 35.4 | 46 | 220.3 | 197.5 | -10.9 |
| Mar3[illegible] | 4.28 | -2.70 | 1.95 | .0014 | 1.81 | .44 | .50 | .16 | .25 | 8.13 | 20 |  |  |  | 1 | 6.3 | 42.9 | 36.3 | 45 | 222.1 | 204.9 | -8.0 |
| Mar31:[illegible]:55 | 4.30 | -2.60 | 1.80 | .0013 | 1.93 | .45 | .48 | .14 | .25 | 8.35 | 35 | 170 | 4.80 | 246 | 7 | 6.1 | 41.9 | 35.7 | 44 | 225.2 | 203.4 | -10.2 |
| Apr04:09:07 | 4.32 | -2.50 | 1.30 | .0010 | 1.80 | .40 | .54 | .14 | .22 | 8.39 | 20 | 220 | 4.73 | 532 | 2 | 6.9 | 47.6 | 39.3 | 51 | 230.9 | 197.8 | -15.5 |
| Apr07:09:40 | 4.29 | -2.80 | 2.01 | .0014 | 1.67 | .38 | .49 | .15 | .20 | 8.18 | 10 | 180 | 3.83 |  | 1 | 6.0 | 41.1 | 39.0 | 41 | 219.2 | 191.1 | -13.7 |
| Apr0[illegible]:09:55 | 4.31 | -2.80 | 1.24 | .0009 | 1.78 | .41 | .91 | .56 | .27 | 8.26 | 15 | 180 | 4.30 | 274 | 4 | 5.8 | 40.1 | 36.7 | 36 | 221.7 | 225.7 | 1.8 |
| Apr09:11:20 | 4.28 | -2.60 | 1.21 | .0009 | 1.83 | .40 | .53 | .18 | .20 | 7.86 | 15 | 190 | 3.50 | 249 | 3 | 5.9 | 40.3 | 37.2 | 38 | 211.5 | 204.6 | -3.3 |
| Apr1[illegible]:10:04 | 4.33 | -2.73 | 1.88 | .0014 | 1.64 | .38 | .46 | .16 | .15 | 7.32 | 30 | 180 | 4.00 | 244 | 3 | 5.6 | 38.8 | 36.1 | 39 | 199.0 | 186.4 | -6.5 |
| Apr14:12:08 | 4.37 | -2.51 | 1.41 | .0012 | 1.52 | .34 | .40 | .15 | .13 | 6.91 | 140 | 180 | 3.50 | 207 | 49 | 5.0 | 35.6 | 28.2 | 29 | 194.3 | 171.2 | -12.6 |
| Apr19:12:15 | 4.30 | -2.73 | 1.23 | .0009 | 1.53 | .36 | .48 | .20 | .12 | 6.83 | 25 | 160 | 3.77 | 198 | 3 | 5.0 | 34.7 | 35.7 | 27 | 182.9 | 182.3 | -0.3 |
| Apr20:12:37 | 4.31 | -2.57 |  |  | 1.56 | .37 | .41 | .10 | .17 | 8.17 | 10 | 130 |  |  | 4 | 4.8 | 33.4 | 34.7 | 26 | 209.1 | 177.9 | -16.1 |
| Apr2[illegible]:12:28 | 4.35 | -2.30 | 1.32 | .0011 | 1.48 | .35 | .39 | .12 | .15 | 6.80 | 10 | 140 | 4.27 | 302 | 4 | 4.5 | 31.9 | 32.5 | 31 | 179.5 | 167.6 | -6.9 |
| Apr23:11:07 | 4.33 | -2.40 | 0.80 | .0006 | 1.41 | .33 | .31 | .14 | .09 | 6.07 | 10 | 130 | 5.90 | 210 | 2 | 4.3 | 30.3 | 30.5 | 27 | 160.6 | 161.5 | 0.5 |
| Apr24:11:40 | 4.38 | -2.41 | 0.72 | .0006 | 1.39 | .30 | .35 | .10 | .09 | 5.97 | 5 | 130 | 5.07 | 174 | 4 | 4.4 | 31.6 | 30.6 | 27 | 159.4 | 153.8 | -3.5 |
| Apr25:10:51 | 4.36 | -2.55 | 0.77 | .0006 | 1.38 | .31 | .32 | .15 | .10 | 5.82 | 5 | 130 | 5.93 | 232 | 5 | 4.4 | 31.4 | 30.6 | 29 | 156.4 | 156.1 | -0.1 |
| Apr28:09:34 | 4.37 | -2.40 | 0.71 | .0006 | 1.46 | .34 | .33 | .09 | .20 | 6.07 | 5 | 160 | 5.17 | 186 | 5 | 5.4 | 38.3 | 31.2 | 38 | 171.3 | 160.5 | -6.5 |
| Apr30:09:43 | 4.37 | -2.50 | 0.86 | .0007 | 1.48 | .34 | .40 | .18 | .14 | 6.09 | 5 | 180 | 6.03 | 198 | 5 | 6.2 | 43.7 | 31.0 | 44 | 175.6 | 166.8 | -5.1 |
|  | 4.34 | -2.41 | 1.34 | .0010 | 1.96 | .43 | .54 | .14 | .29 | 7.65 | 53 | 213 | 5.75 | 273 | 3 | 7.1 | 48.2 | 36.5 | 53 | 221.3 | 205.7 | 7.1 |
|  | 45.6 | 0.34 | 0.65 | .0005 | 0.30 | .06 | .10 | .07 | .12 | 0.83 | 63 | 59 | 1.76 | 67 | 7 | 1.3 | 11.7 | 3.9 | 14 | 23.2 | 25.8 | 3.7 |
|  | 52 | 52 | 50 | 54 | 53 | 53 | 53 | 53 | 53 | 53 | 51 | 43 | 41 | 44 | 50 | 53 | 52 | 51 | 51 | 50 | 49 | 49 |

*mg/l as $CaCO_3$

** Colour in Hazen Units.

*** pH sd in ueq/l H+

Fig. C1

## 1985 PLASTIC 1 DISCHARGE JAN-APR

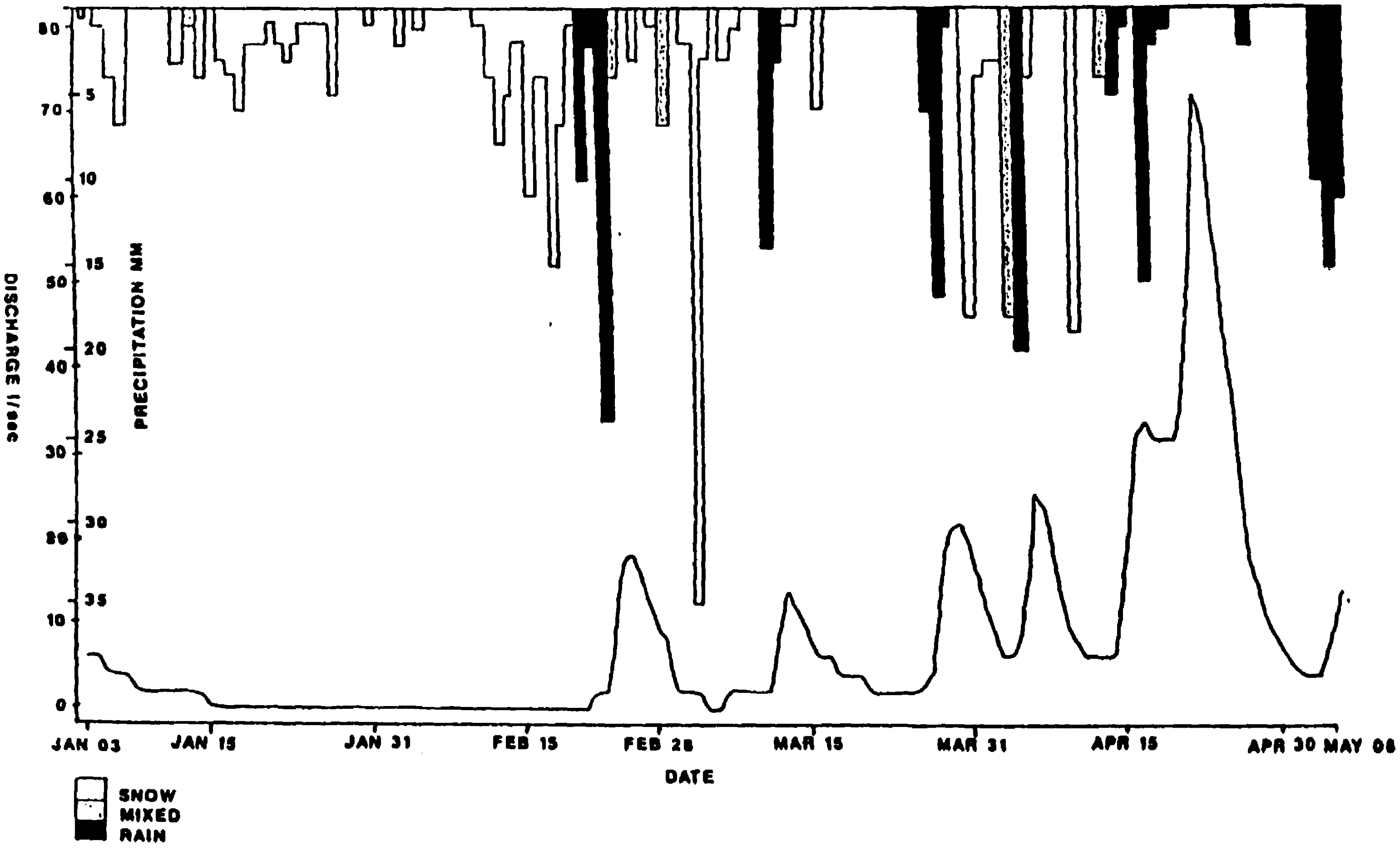


Fig. C2a

1985 Plastic Inflow 1 Chemistry Jan-May

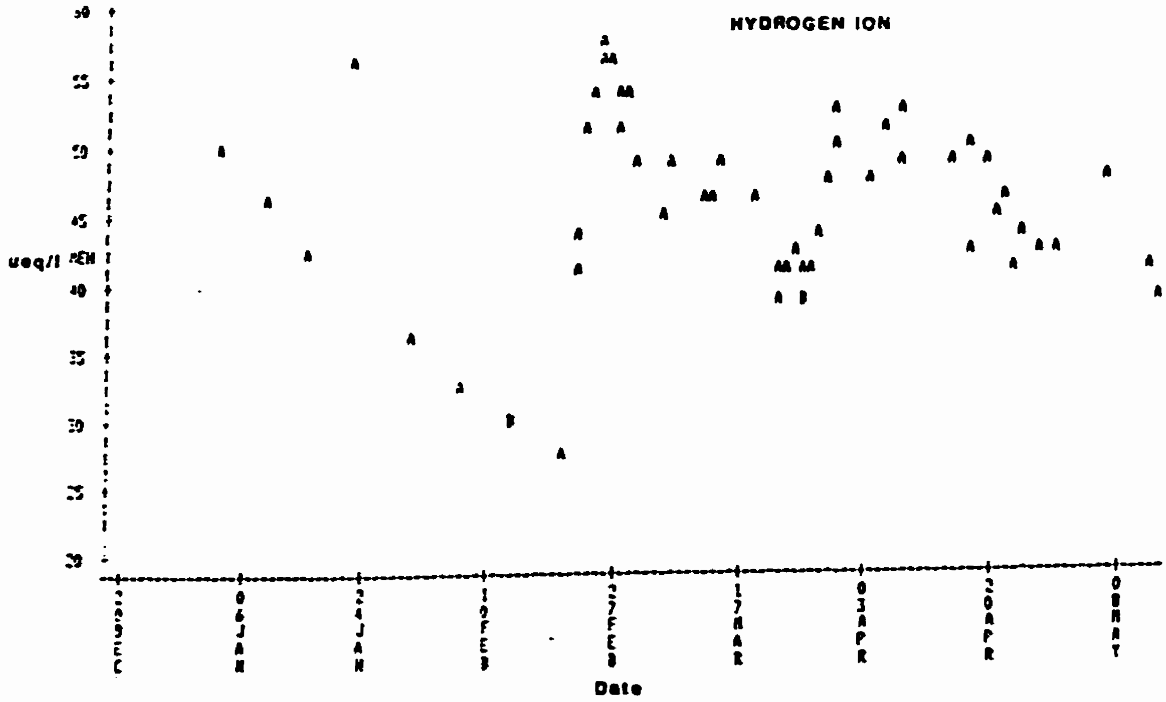


Fig. C2b

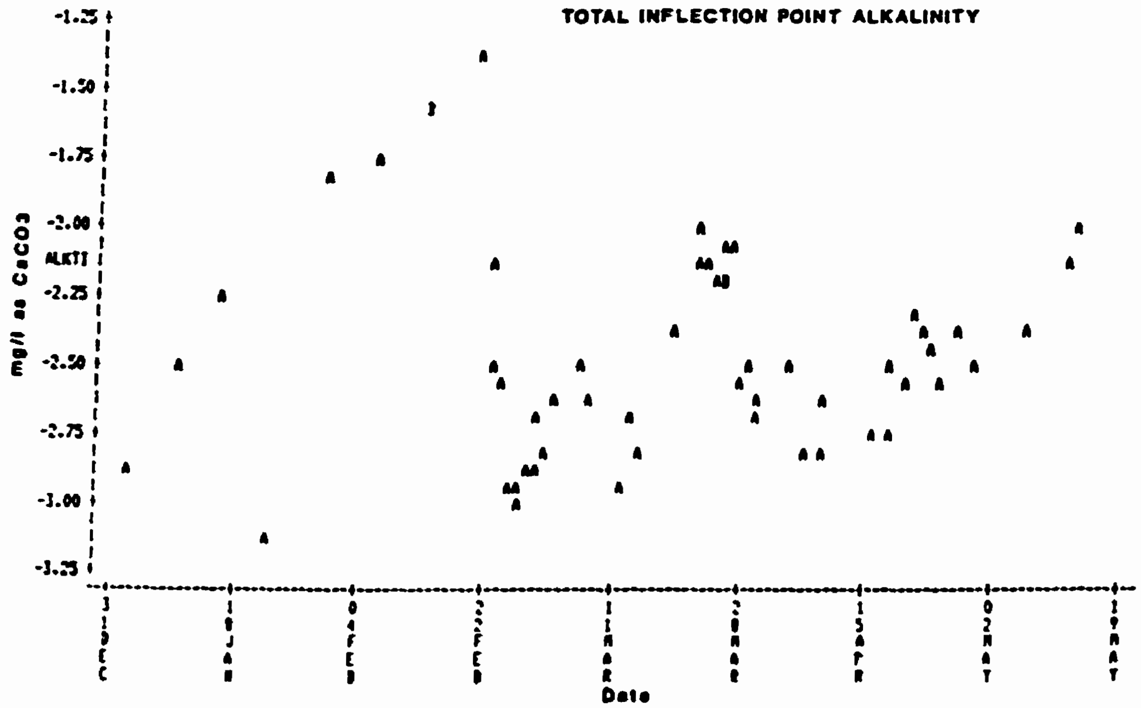


Fig. C2c

1985 Plastic Inflow 1 Chemistry Jan–May

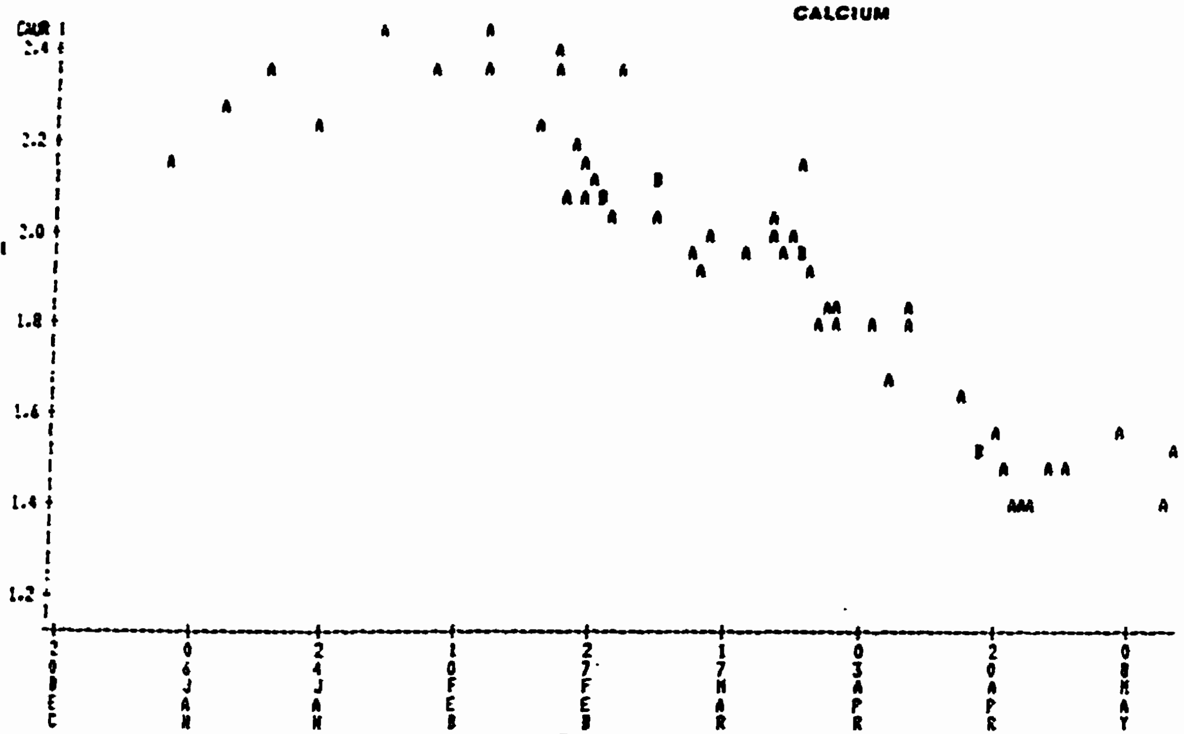


Fig. C2d

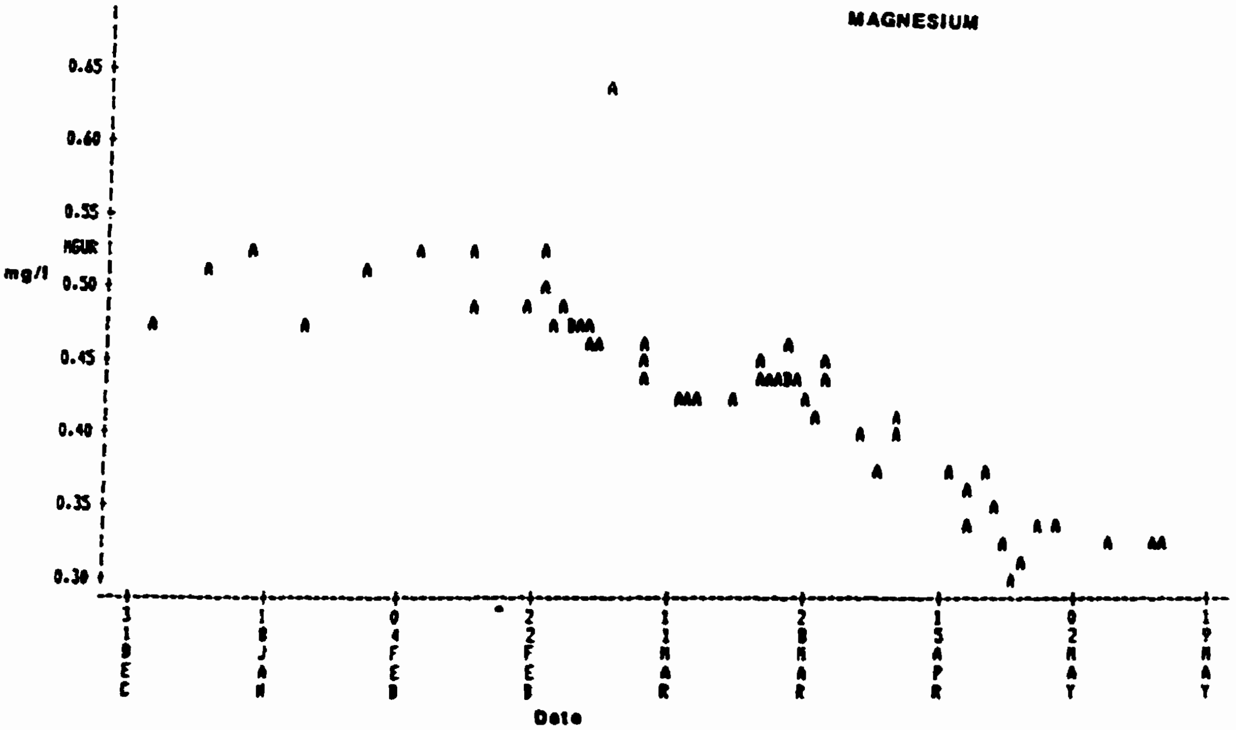


Fig. C2e

**1985 Plastic Inflow 1 Chemistry Jan-May**

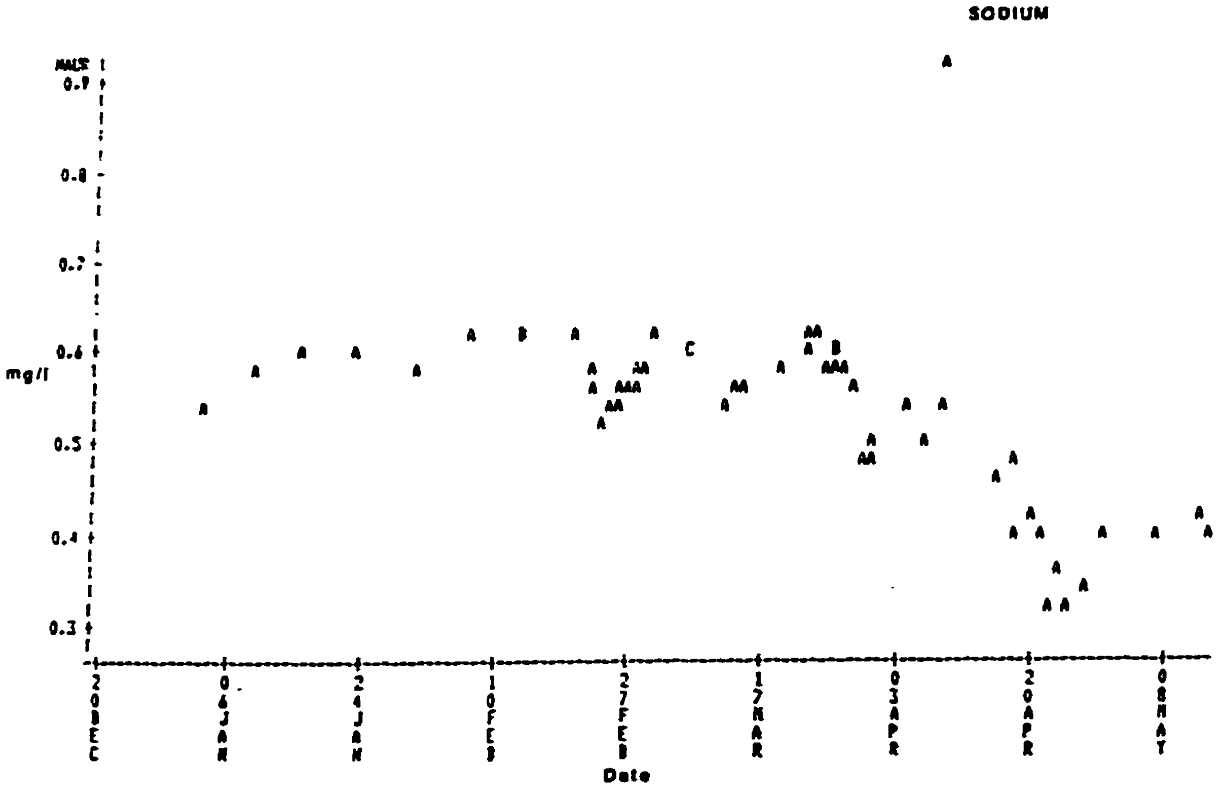


Fig. C2f

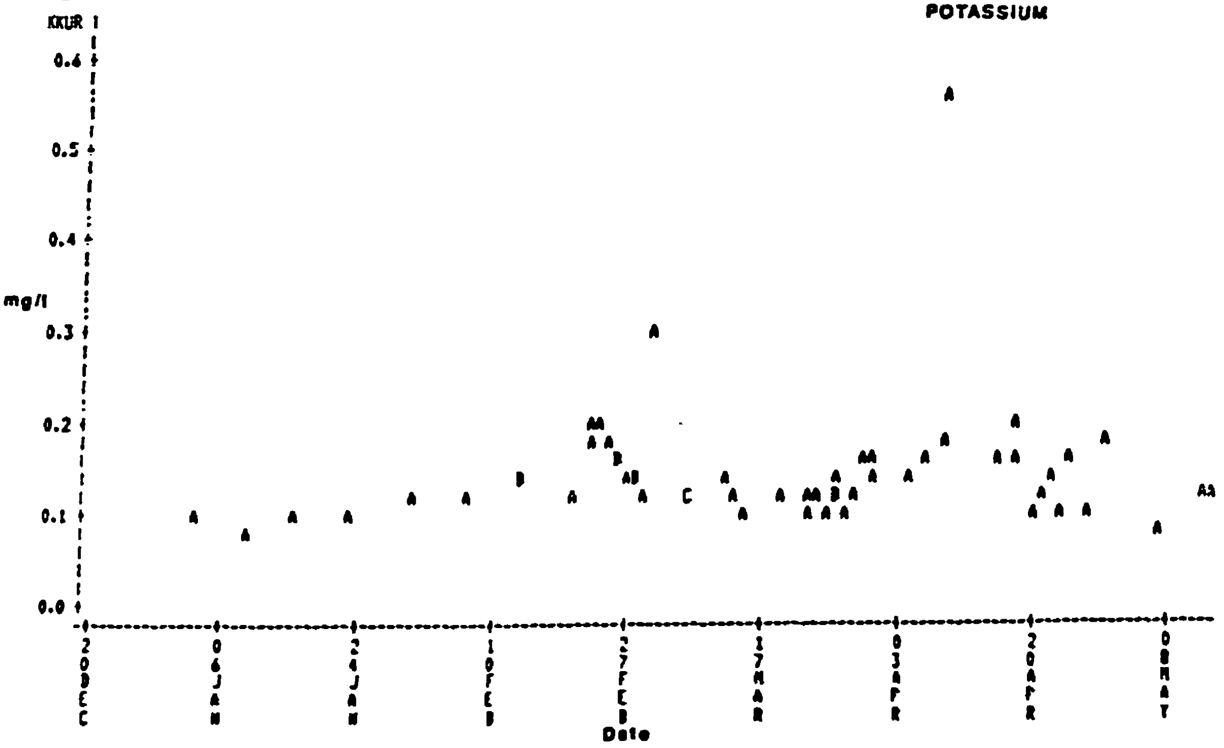


Fig. C2g

1985 Plastic Inflow 1 Chemistry Jan-May

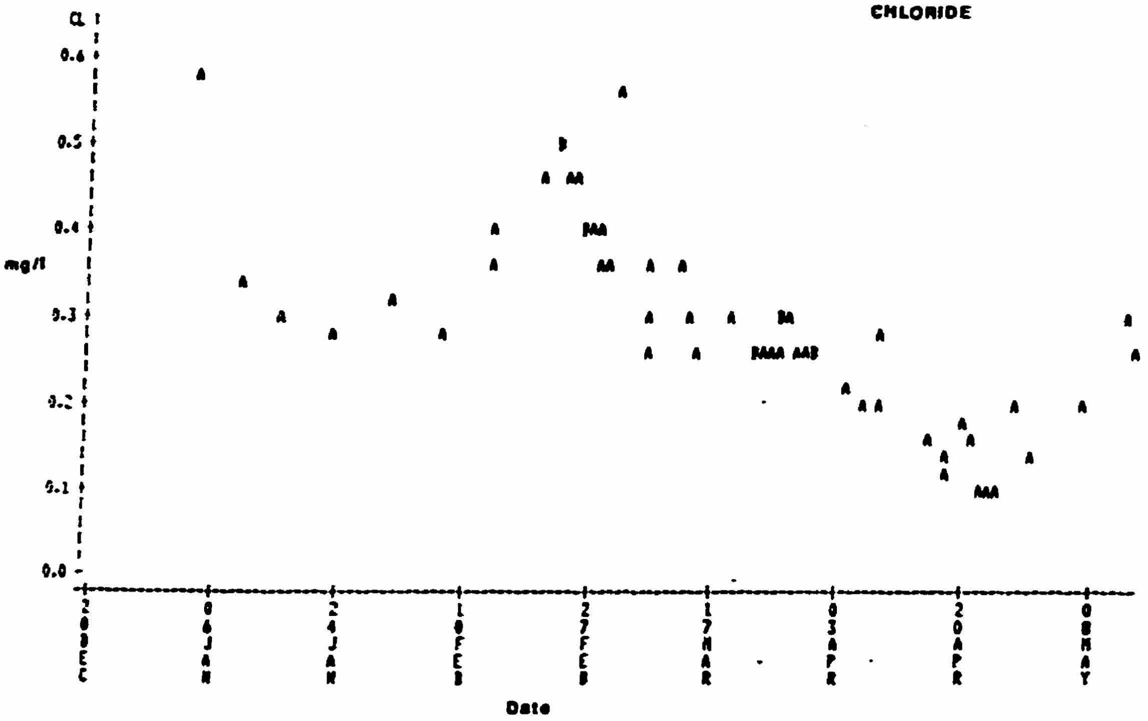


Fig. C2h

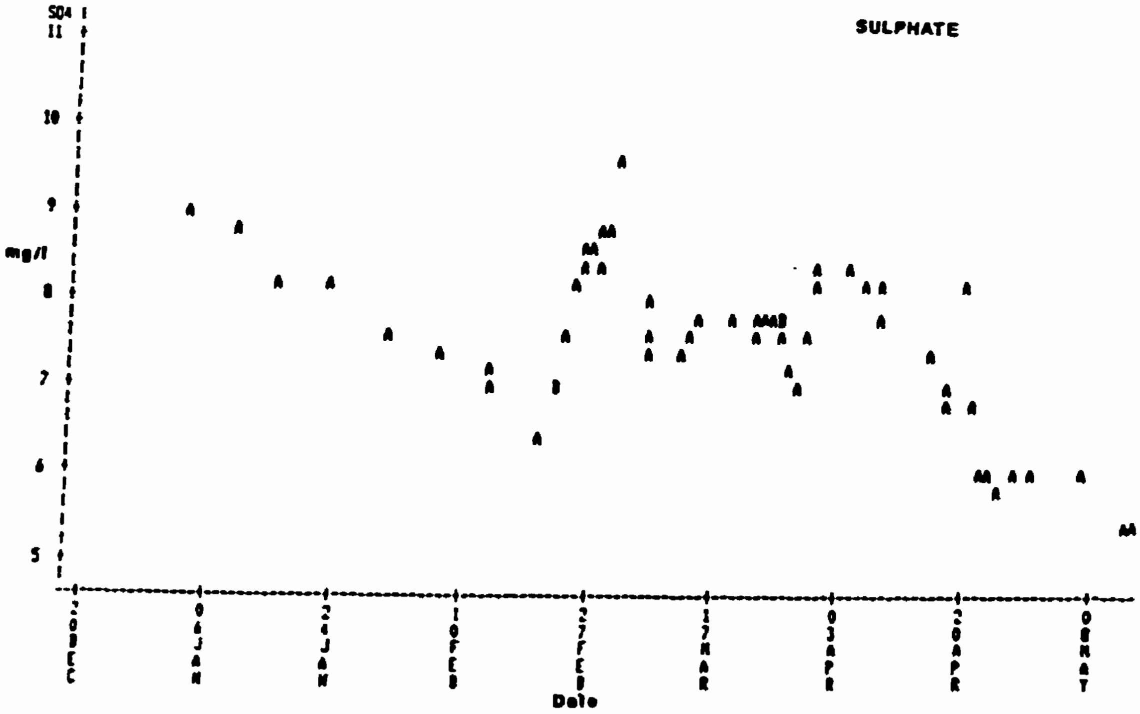


Fig. C2i

**1985 Plastic Inflow 1 Chemistry Jan-May**

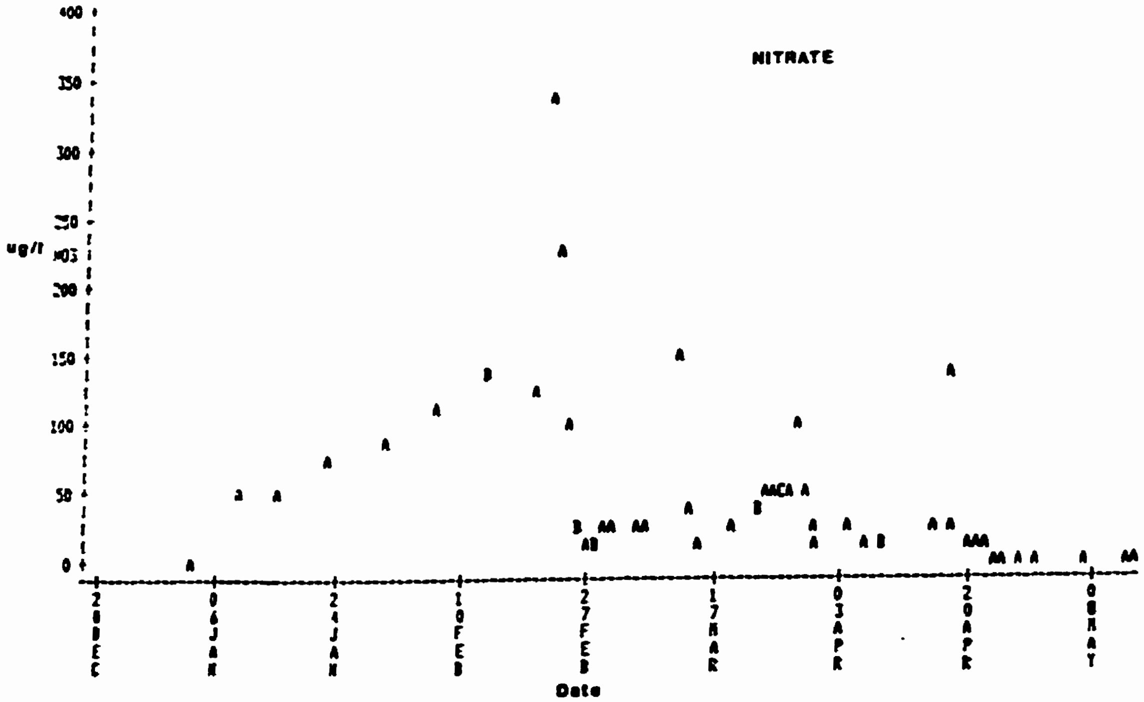


Fig. C2j

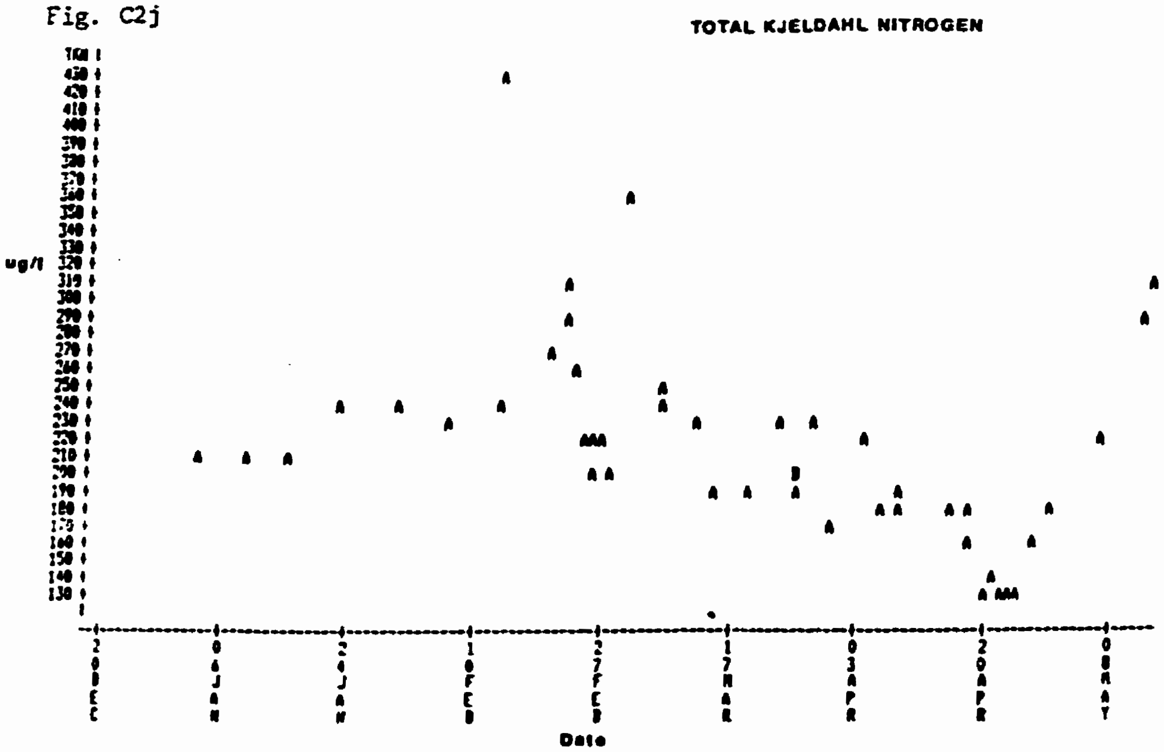


Fig. C2k

1985 Plastic Inflow 1 Chemistry Jan-May

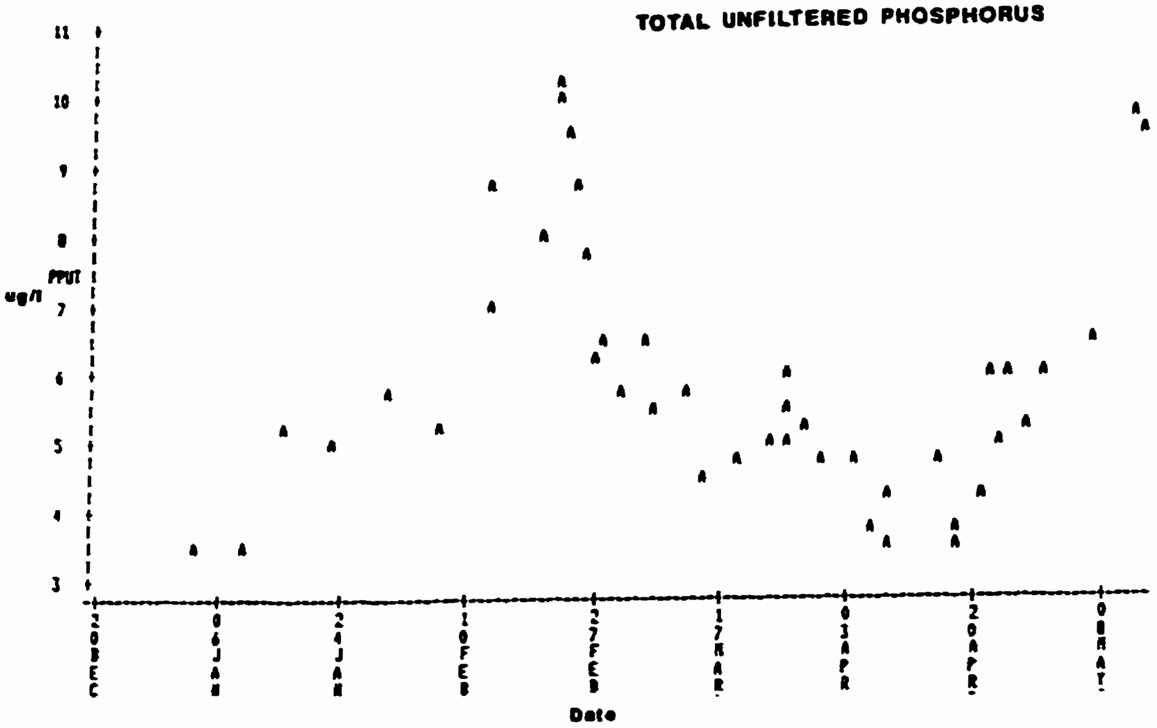


Fig. C2l

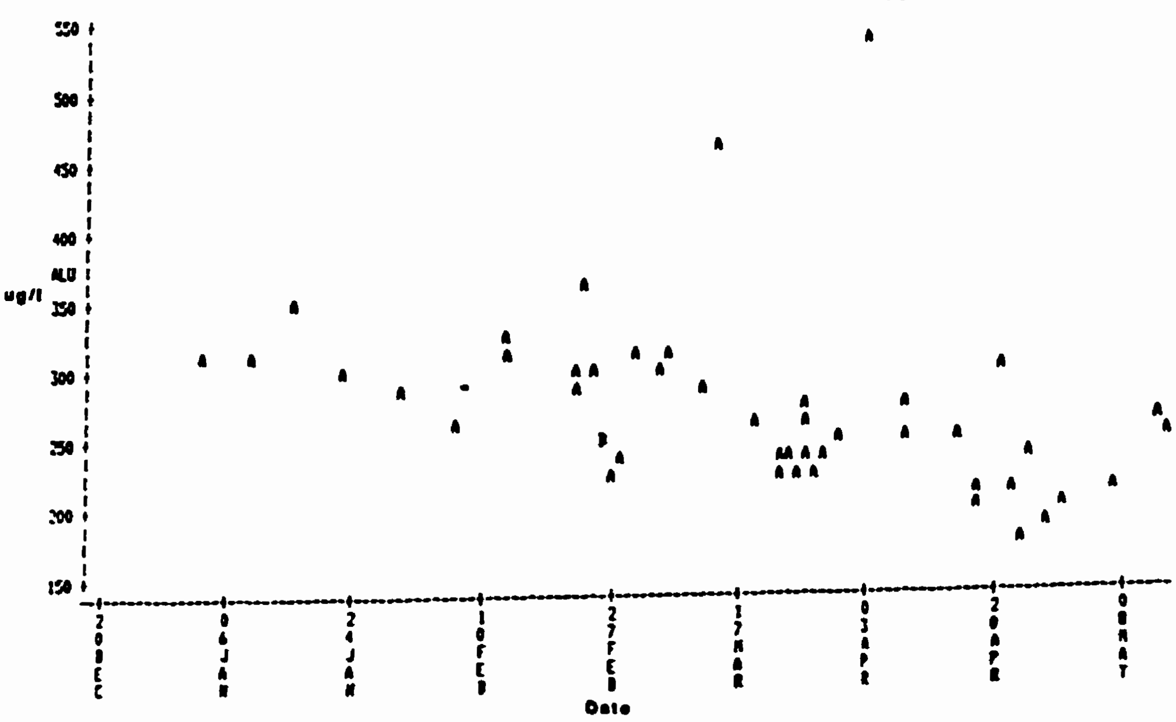


Fig. C2m

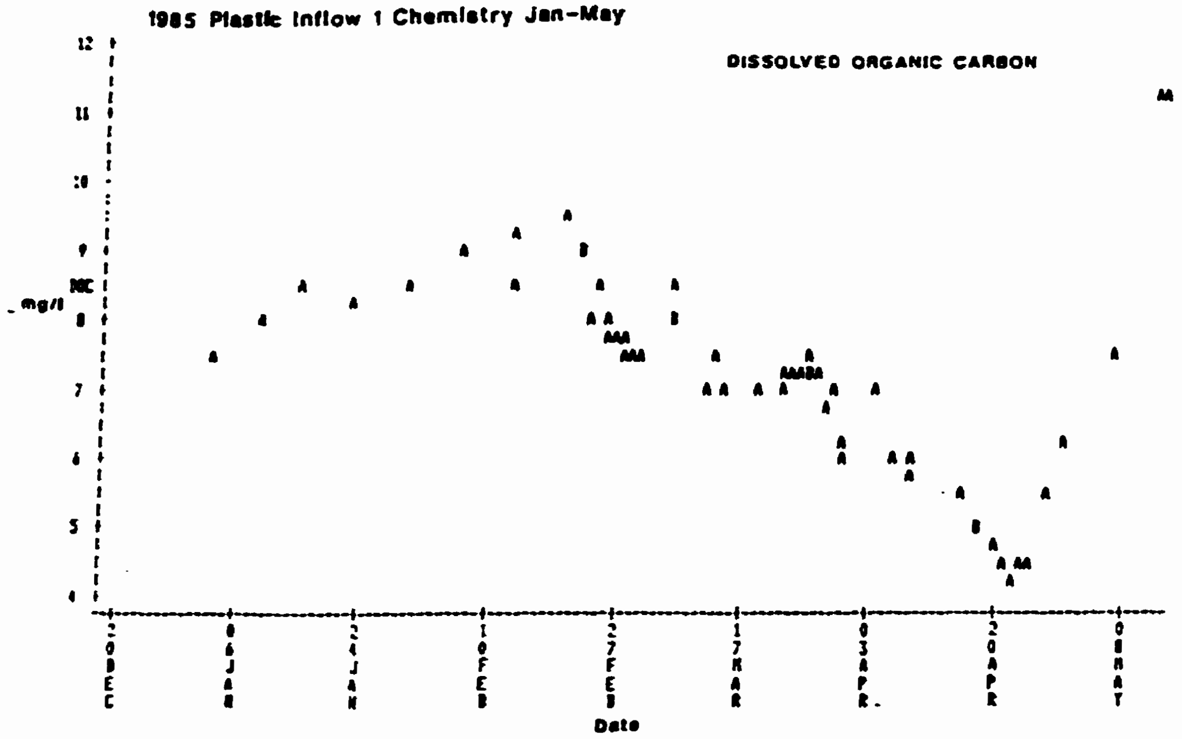


Fig. C2n

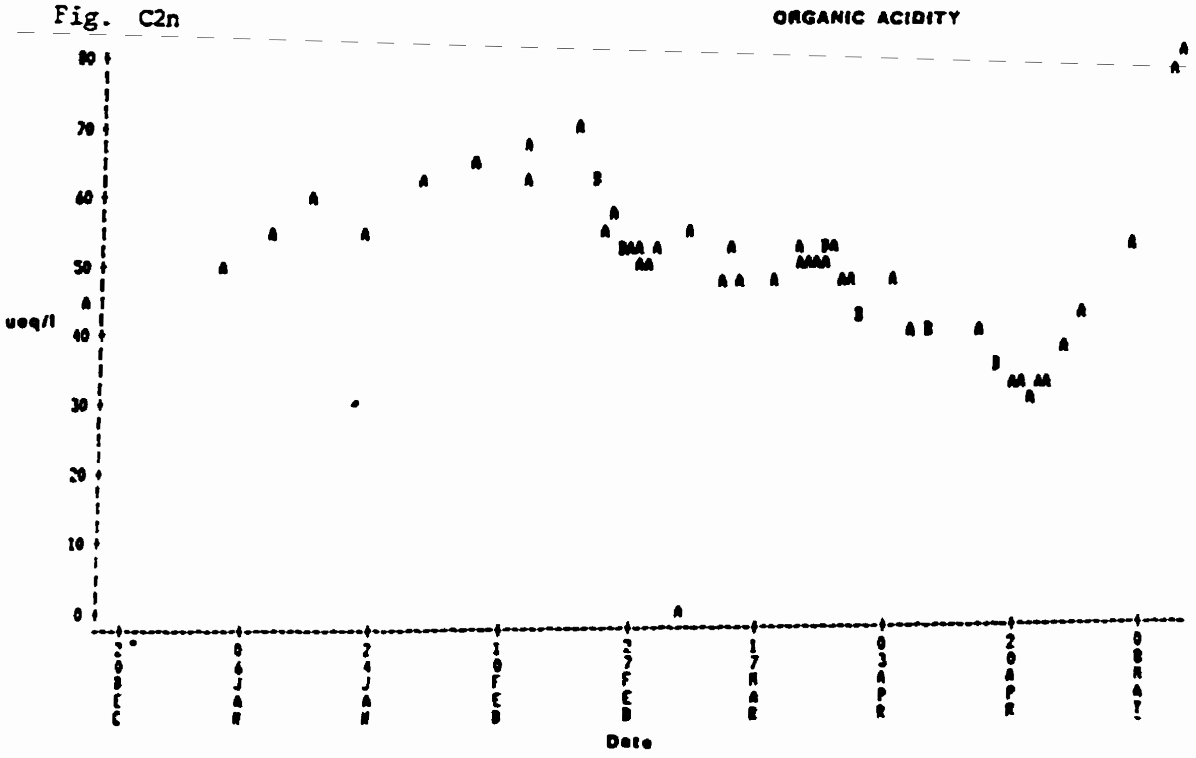


Fig. C2o

1985 Plastic Inflow 1 Chemistry Jan-May

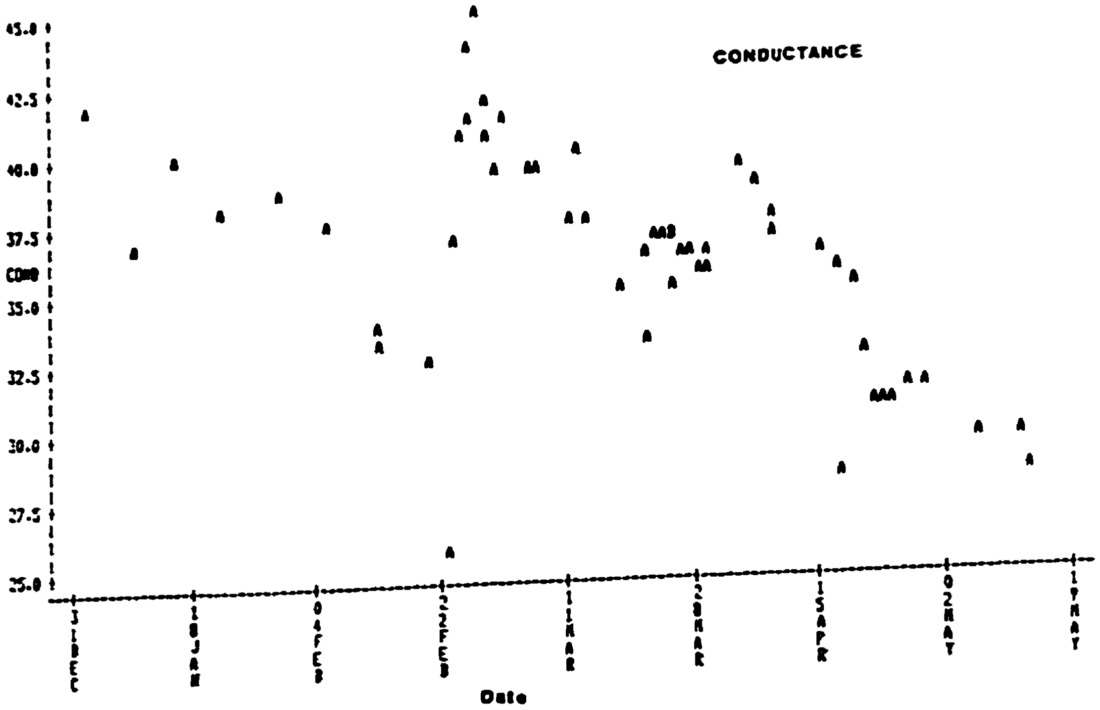


Fig. C2p

COLOUR

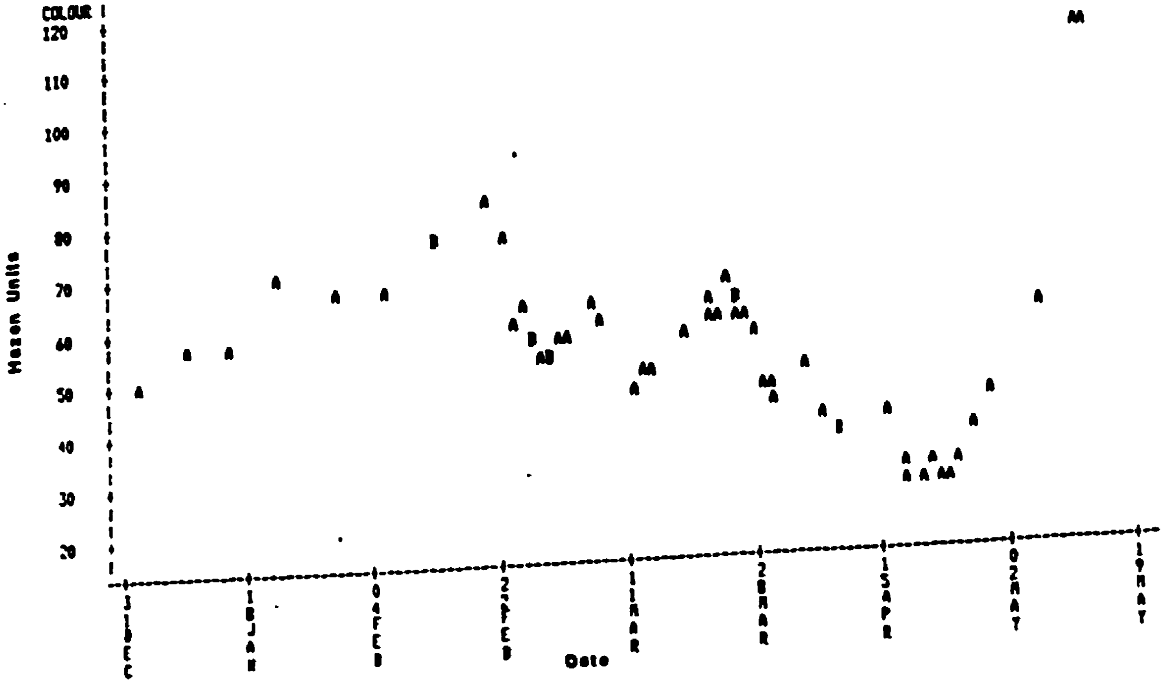


Table C3

1985 Plastic Lake Outflow mean daily discharge (l/sec.)*

| | Jan | Feb | Mar | Apr |
|---|---|---|---|---|
| 1 | | 14.70 | 32.30 | 54.10 |
| 2 | | 14.10 | 31.40 | 58.10 |
| 3 | 53.50 | 13.90 | 27.50 | 50.00 |
| 4 | 49.60 | 13.60 | 29.40 | 43.60 |
| 5 | 45.60 | 12.80 | 47.20 | 71.30 |
| 6 | 41.70 | 12.50 | 40.30 | 133.00 |
| 7 | 37.80 | 12.30 | 32.60 | 111.00 |
| 8 | 33.90 | 12.30 | 29.00 | 77.80 |
| 9 | 29.90 | 11.70 | 24.90 | 56.80 |
| 10 | 26.00 | 11.20 | 22.80 | 49.40 |
| 11 | 24.80 | 11.20 | 22.20 | 49.40 |
| 12 | 23.70 | 11.50 | 35.50 | 39.40 |
| 13 | 22.50 | 12.80 | 43.60 | 34.20 |
| 14 | 21.40 | 13.90 | 40.80 | 31.00 |
| 15 | 20.20 | 13.60 | 35.90 | 45.90 |
| 16 | 19.90 | 13.90 | 34.60 | 99.40 |
| 17 | 19.60 | 14.10 | 35.50 | 122.00 |
| 18 | 19.30 | 13.90 | 30.60 | 139.00 |
| 19 | 18.90 | 15.00 | 27.10 | 137.00 |
| 20 | 18.60 | 14.70 | 24.20 | 126.00 |
| 21 | 18.30 | 13.30 | 22.50 | 165.00 |
| 22 | 18.00 | 15.50 | 20.80 | 283.00 |
| 23 | 15.50 | 16.70 | 22.80 | 319.00 |
| 24 | 15.40 | 26.40 | 18.30 | 259.00 |
| 25 | 15.40 | 31.80 | 18.00 | 184.00 |
| 26 | 15.30 | 31.00 | 17.30 | 130.00 |
| 27 | 15.20 | 36.30 | 18.00 | 91.60 |
| 28 | 15.20 | 34.60 | 31.00 | 66.60 |
| 29 | 15.10 | | 61.60 | 50.60 |
| 30 | 15.10 | | 64.40 | 33.00 |
| 31 | 15.00 | | 62.30 | |
| Mean | 24.15 | 16.76 | 32.40 | 103.67 |
| Max | 53.50 | 36.30 | 64.40 | 319.00 |
| Min | 15.00 | 11.20 | 17.30 | 31.00 |

*P. Dillon and L. Scott unpublished data.

Table C4
1985 Plastic Lake Outflow Chemistry (P. Dillon unpublished studies)

| Date:time | pH | ALKTI* | DIC | $HCO_3^-$ | $Ca^{+2}$ | $Mg^{+2}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{-2}$ | $NH_4^+$ | $NO_3^-$ | TKN | PPUT | TAL | DOC | Cond | C | Anions | Cations | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | | | | | | | | | ug/l | | | | | mg/l | uS·cm | Hu | ueq/l | | % |
| Jan03:15:55 | 5.47 | 0.24 | 0.78 | .0076 | 2.02 | .50 | .50 | .24 | .58 | 7.59 | 2 | 10 | 200 | 6.33 | 47 | 2.4 | 26.7 | 5 | 182.7 | 170.0 | -7.2 |
| Jan10:13:30 | 5.42 | 0.29 | 0.88 | .0077 | 2.19 | .54 | .52 | .24 | .38 | 7.78 | 42 | 50 | 180 | 4.20 | 53 | 2.5 | 26.2 | 10 | 184.0 | 185.5 | 0.8 |
| Jan15:11:51 | 5.46 | 0.32 | 0.84 | .0080 | 2.18 | .55 | .53 | .25 | .36 | 7.14 | 40 | 55 | 190 | 4.77 | 48 | 2.4 | 27.0 | 7 | 170.7 | 186.3 | 8.7 |
| Jan22:15:24 | | | 0.97 | | 2.04 | .50 | .50 | .23 | .32 | 7.32 | 47 | 60 | 200 | 3.97 | 52 | 2.3 | 25.7 | 8 | 165.7 | | |
| Jan30:15:48 | 5.49 | 0.42 | 0.98 | .0099 | 2.12 | .49 | .49 | .22 | .32 | 6.64 | 40 | 65 | 200 | 4.47 | 40 | 2.3 | 25.5 | 8 | 161.8 | 175.9 | 8.3 |
| Feb06:15:07 | 5.44 | 0.35 | 1.00 | .0091 | 2.14 | .50 | .48 | .23 | .29 | 6.45 | 41 | 60 | 160 | 3.83 | 40 | 2.3 | 24.8 | 6 | 155.9 | 177.6 | 13.0 |
| Feb13:15:25 | 5.47 | 0.40 | 1.12 | .0109 | 2.23 | .50 | .47 | .23 | .35 | 6.78 | 47 | 65 | 340 | 5.63 | 32 | 2.1 | 24.9 | 8 | 166.5 | 182.1 | 8.9 |
| Feb21:10:00 | 5.46 | 0.35 | 0.99 | .0094 | 2.14 | .50 | .47 | .22 | .35 | 6.20 | 36 | 50 | 180 | 4.77 | 40 | 1.7 | 24.7 | 7 | 151.9 | 176.6 | 15.0 |
| Feb24:15:05 | 5.34 | 0.28 | 1.23 | .0091 | 2.18 | .51 | .45 | .24 | .35 | 7.10 | 43 | 130 | 180 | 4.80 | 56 | 2.5 | 25.8 | 14 | 176.1 | 179.5 | 1.9 |
| Feb25:12:00 | 5.37 | 0.22 | 1.03 | .0081 | 2.16 | .50 | .45 | .21 | .35 | 6.75 | 35 | 100 | 170 | 4.30 | 53 | 2.2 | 32.8 | 67 | 165.7 | 176.4 | 6.2 |
| Feb26:10:47 | 5.33 | 0.19 | 0.93 | .0068 | 2.11 | .50 | .44 | .20 | .35 | 6.55 | 28 | 80 | 190 | 5.13 | 51 | 2.4 | 25.8 | 8 | 158.7 | 172.7 | 8.4 |
| Feb28:10:32 | 5.37 | 0.22 | 0.93 | .0073 | 2.16 | .50 | .46 | .21 | .35 | 6.40 | 33 | 90 | 180 | 5.00 | 46 | 2.5 | 26.5 | 7 | 156.9 | 176.7 | 11.9 |
| Mar07:14:30 | 5.28 | 0.06 | 0.92 | .0060 | 2.15 | .49 | .48 | .23 | .35 | 6.70 | 25 | 85 | 220 | 4.33 | 48 | 2.3 | 26.2 | 7 | 161.4 | 176.2 | 8.7 |
| Mar12:11:47 | 5.29 | 0.10 | 0.97 | .0065 | 2.17 | .50 | .48 | .25 | .35 | 6.95 | 30 | 120 | 210 | 4.27 | 53 | 2.4 | 26.2 | 10 | 169.6 | 178.8 | 5.3 |
| Mar14:12:00 | 5.38 | 0.22 | 0.85 | .0068 | | | | | | | 28 | 85 | | 4.07 | 46 | | 25.9 | 8 | | | |
| Mar19:14:00 | 5.28 | 0.38 | 0.87 | .0057 | 2.19 | .50 | .48 | .21 | .35 | 6.75 | 27 | 100 | 190 | 4.23 | 58 | 2.2 | 25.9 | 7 | 163.2 | 178.6 | 9.0 |
| Mar26:13:50 | 5.29 | 0.04 | 0.91 | .0061 | 2.15 | .51 | .52 | .23 | .35 | 7.40 | 23 | 105 | 170 | 3.50 | 52 | 2.2 | 26.3 | 5 | 177.5 | 179.4 | 1.1 |
| Mar28:10:07 | 5.25 | 0.06 | 0.99 | .0061 | 2.15 | .51 | .52 | .23 | .35 | 7.00 | 35 | 160 | 210 | 4.00 | 47 | 2.2 | 27.2 | 10 | 173.1 | 180.2 | 4.0 |
| Mar31:19:05 | 5.19 | -0.12 | 0.85 | .0046 | 2.29 | .51 | .45 | .21 | .38 | 7.52 | 52 | 150 | 230 | 4.00 | 56 | 2.2 | 27.4 | 7 | 182.6 | 191.3 | 4.7 |
| Apr04:09:20 | 5.00 | -0.35 | 0.85 | .0030 | 2.15 | .49 | .49 | .20 | .40 | 7.64 | 57 | 200 | 370 | 3.57 | 55 | 2.3 | 29.4 | 8 | 187.7 | 188.1 | 0.2 |
| Apr07:10:14 | 5.06 | -0.37 | 0.78 | .0032 | 2.01 | .47 | .45 | .18 | .33 | 7.49 | 52 | 150 | 200 | 3.90 | 58 | 2.4 | 28.3 | 10 | 179.1 | 175.6 | -2.0 |
| Apr09:09:11 | 4.92 | -0.59 | 0.80 | .0024 | 2.11 | .49 | .92 | .64 | .36 | 7.37 | 58 | 180 | 210 | 6.13 | 76 | 2.6 | 28.9 | 7 | 178.8 | 218.2 | 19.8 |
| Apr16:09:29 | 4.92 | -0.54 | 0.97 | .0029 | 2.01 | .46 | .47 | .23 | .29 | 7.12 | 50 | 180 | 200 | 4.10 | 71 | 2.4 | 28.2 | 8 | 172.2 | 180.1 | 4.5 |
| Apr18:11:58 | 4.92 | -0.59 | 0.97 | .0029 | 1.95 | .42 | .44 | .39 | .27 | 6.83 | 52 | 140 | 200 | 4.13 | 83 | 2.5 | 26.6 | 10 | 162.7 | 185.4 | 13.0 |
| Apr20:09:27 | 4.76 | -0.80 | | | 1.84 | .44 | .43 | .17 | .29 | 6.97 | 50 | 155 | 180 | 4.33 | | 2.6 | 28.7 | 10 | 164.4 | 172.0 | 4.5 |
| Apr21:10:01 | 4.73 | -0.98 | 1.10 | .0021 | 1.79 | .42 | .42 | .17 | .29 | 6.67 | 47 | 140 | 210 | 5.13 | 127 | 2.7 | 28.2 | 20 | 159.2 | 168.5 | 5.7 |
| Apr23:10:37 | 4.91 | -0.53 | 1.12 | .0033 | 1.71 | .43 | .40 | .18 | .25 | 6.34 | 23 | 50 | 150 | 5.83 | 83 | 2.5 | 25.1 | 17 | 145.9 | 156.7 | 7.1 |
| Apr25:10:13 | 4.86 | -2.70 | 0.90 | .0023 | 1.49 | .35 | .32 | .16 | .16 | 5.32 | 21 | 50 | 140 | 4.30 | 111 | 2.4 | 23.5 | 14 | 121.2 | 136.5 | 11.8 |
| Apr28:08:57 | 5.26 | -0.13 | 0.91 | .0057 | 1.70 | .43 | .42 | .24 | .42 | 6.16 | 16 | 40 | 160 | 5.60 | 49 | 2.0 | 23.3 | 7 | 148.7 | 145.8 | -2.0 |
| Apr30:09:22 | 5.36 | -0.02 | 0.98 | .0076 | 2.23 | .45 | .41 | .20 | .34 | 6.25 | 16 | 50 | 150 | 6.20 | 41 | 2.2 | 22.8 | 7 | 150.9 | 172.4 | 13.3 |
| | 5.15 | -0.12 | 0.95 | .0060 | 2.06 | .48 | .48 | .24 | .34 | 6.87 | 37 | 98 | 199 | 4.57 | 58 | 2.3 | 26.5 | 11 | 176.5 | 165.3 | 7.4 |
| | 4.43 | 0.63 | 0.11 | .0029 | 0.19 | .04 | .10 | .09 | .07 | 0.55 | 14 | 50 | 49 | 0.75 | 21 | 0.2 | 2.0 | 11 | 14.3 | 14.0 | 4.8 |
| | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 30 | 30 | 29 | 29 | 29 | 29 | 30 | 30 | 29 | 28 | 28 |

*mg/l as $CaCO_3$
** Colour in Hazen Units
*** pH sd in ueq/l H+

Fig. C3

1985 PLASTIC LAKE OUTFLOW DISCHARGE JAN-APR

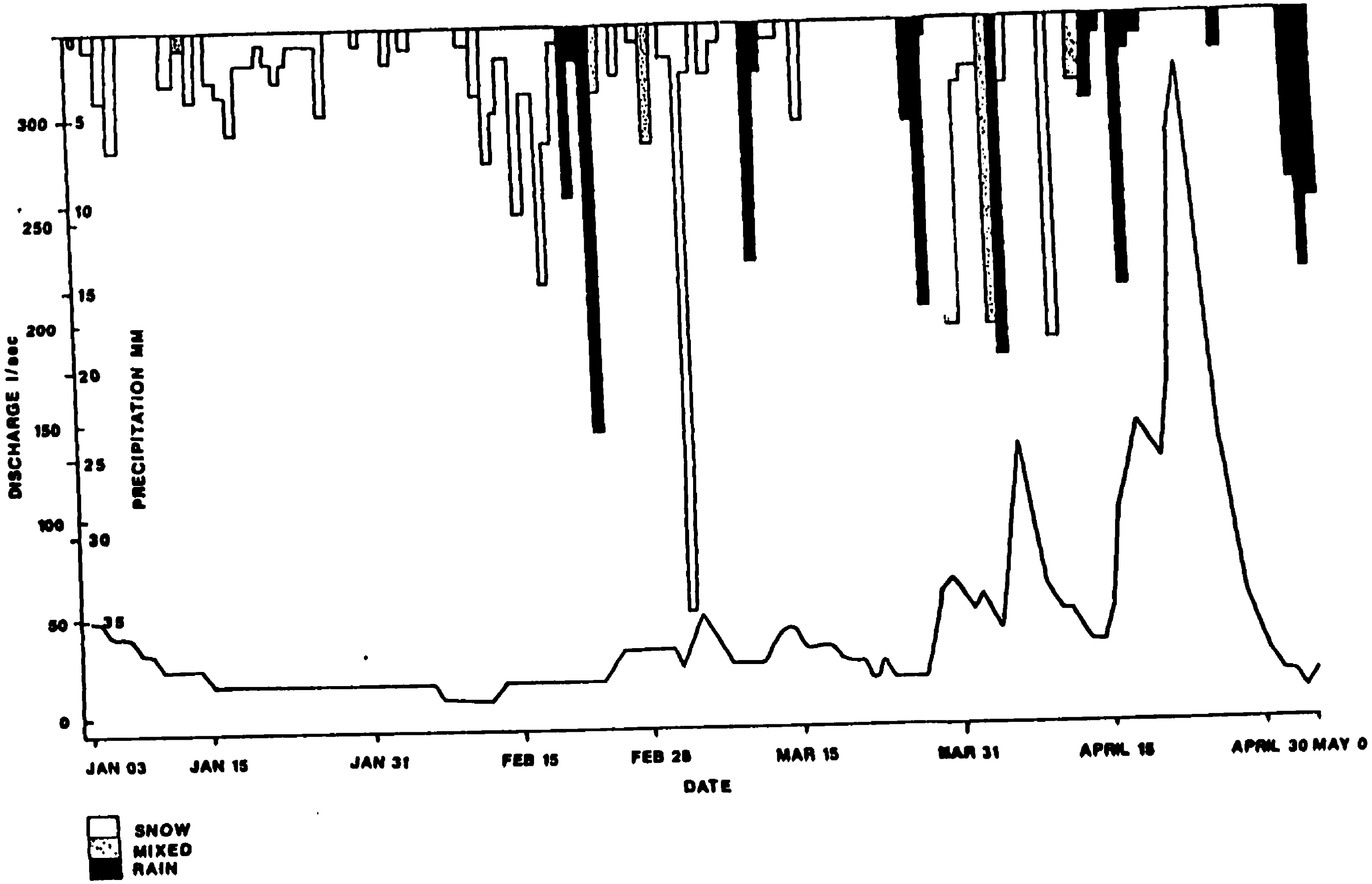
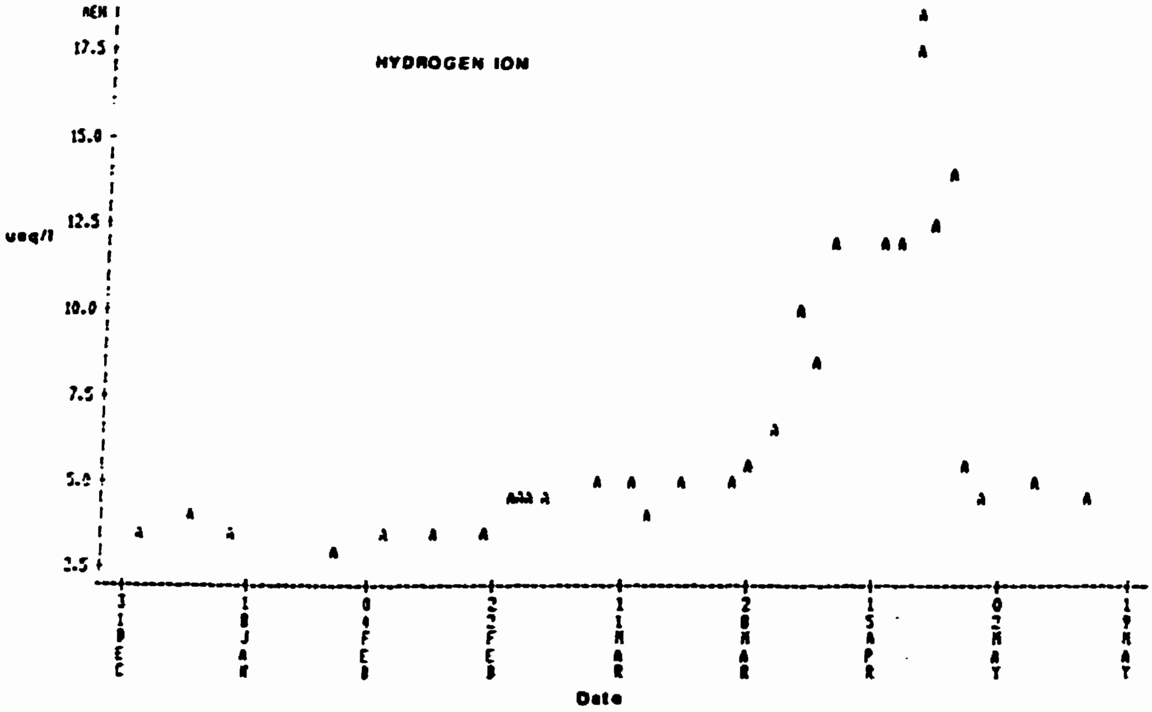


Fig. C4a

**1985 Plastic Lake Outflow Chemistry Jan-May**



**TOTAL INFLECTION POINT ALKALINITY**

Fig. C4b

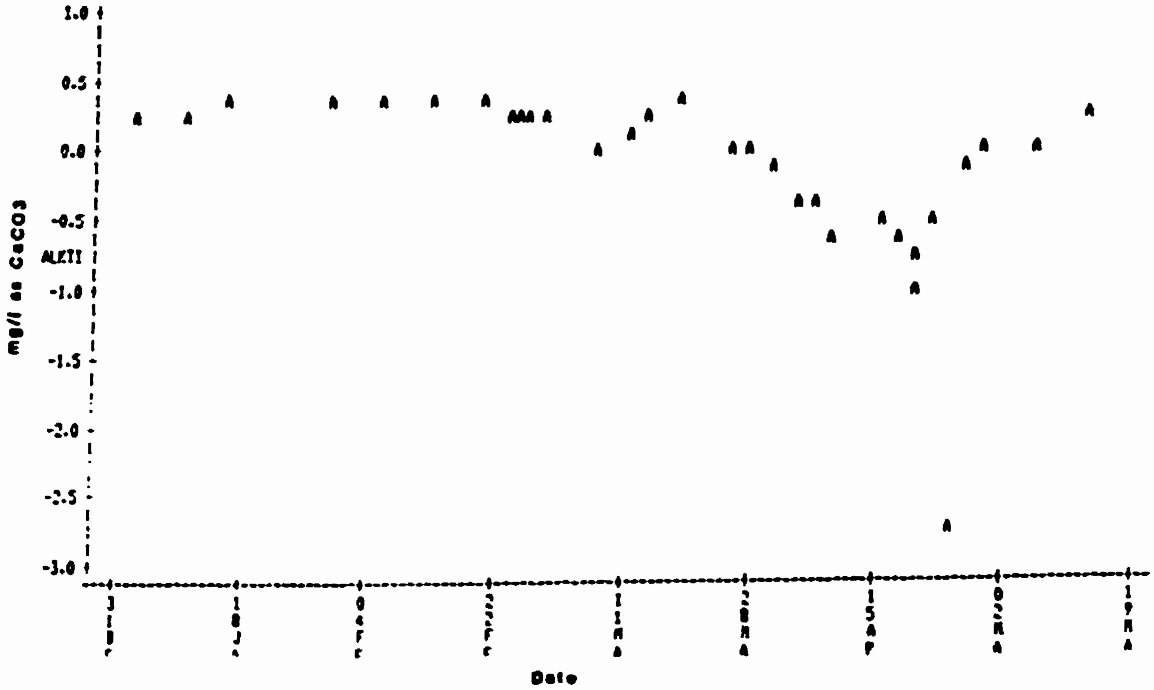


Fig. C4c

1985 Plastic Lake Outflow Chemistry Jan-May

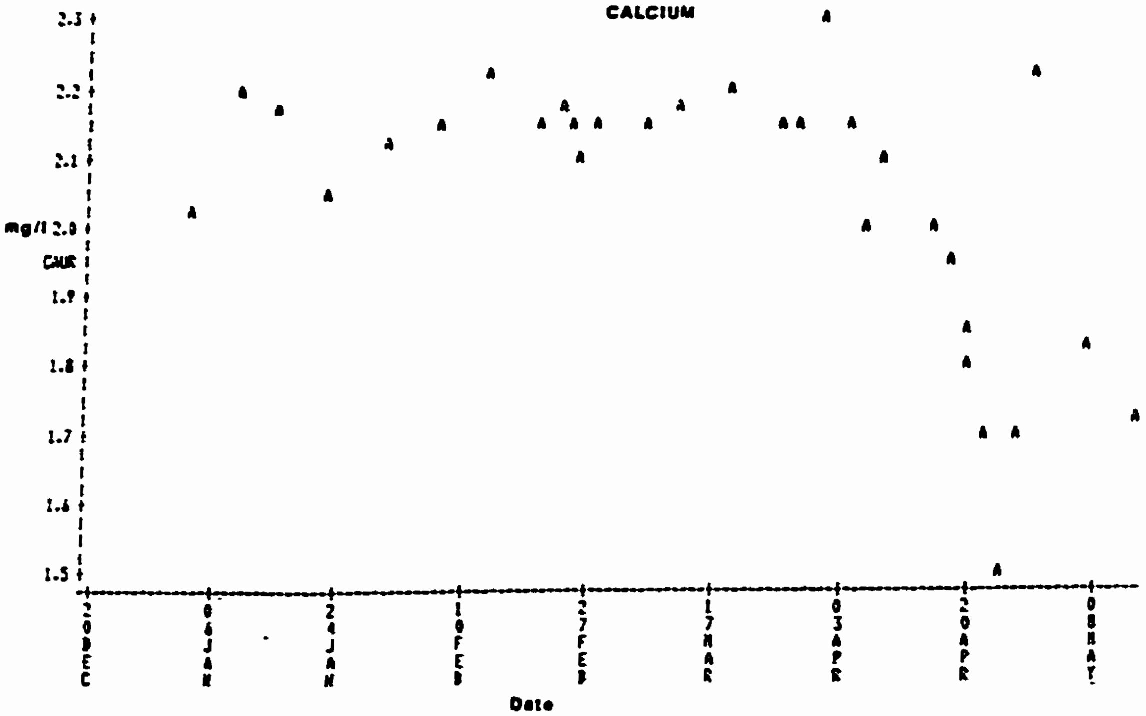
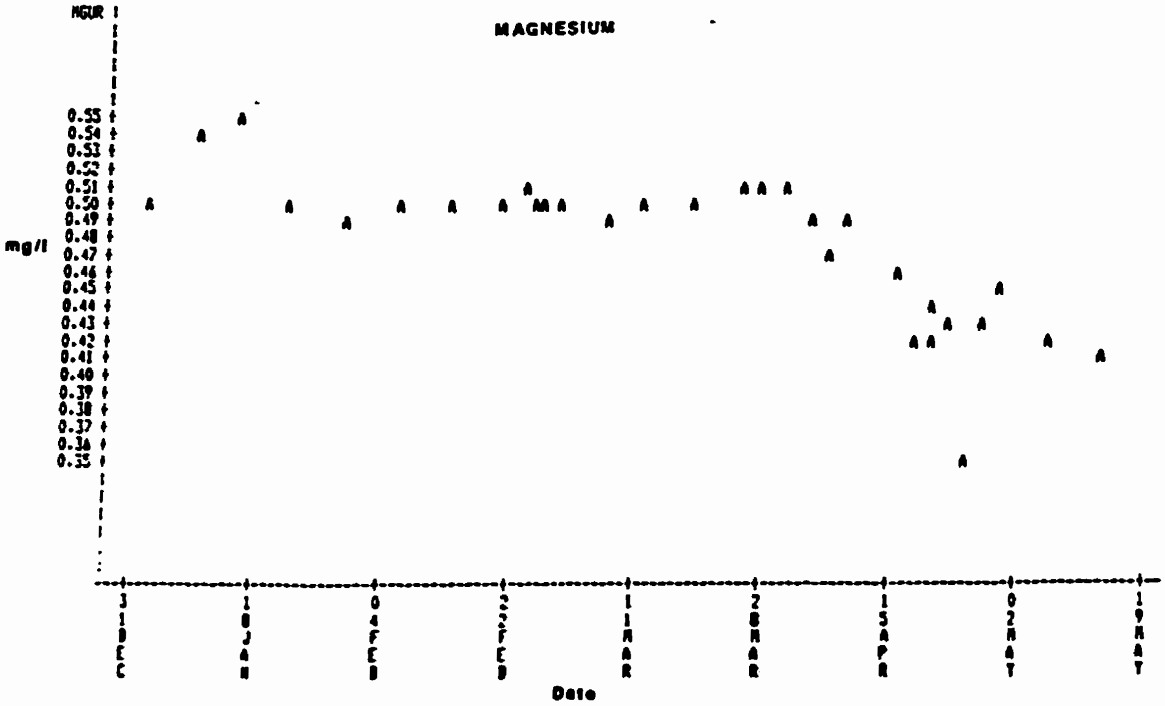


Fig. C4d



1985 Plastic Lake Outflow Chemistry Jan-May

Fig. C4e

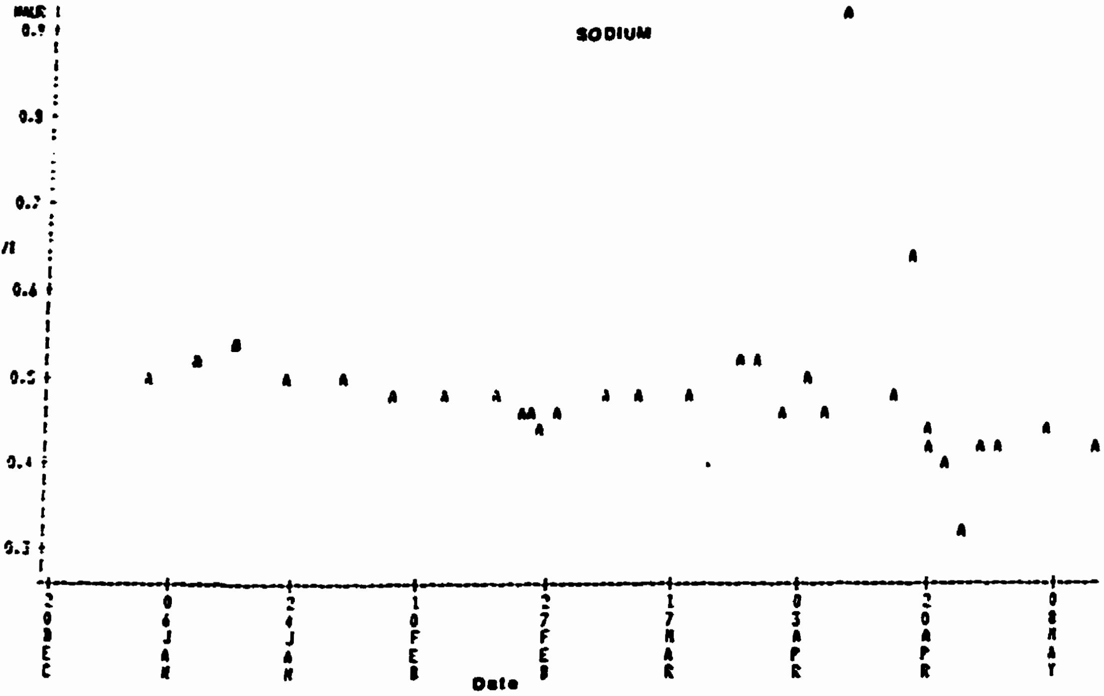
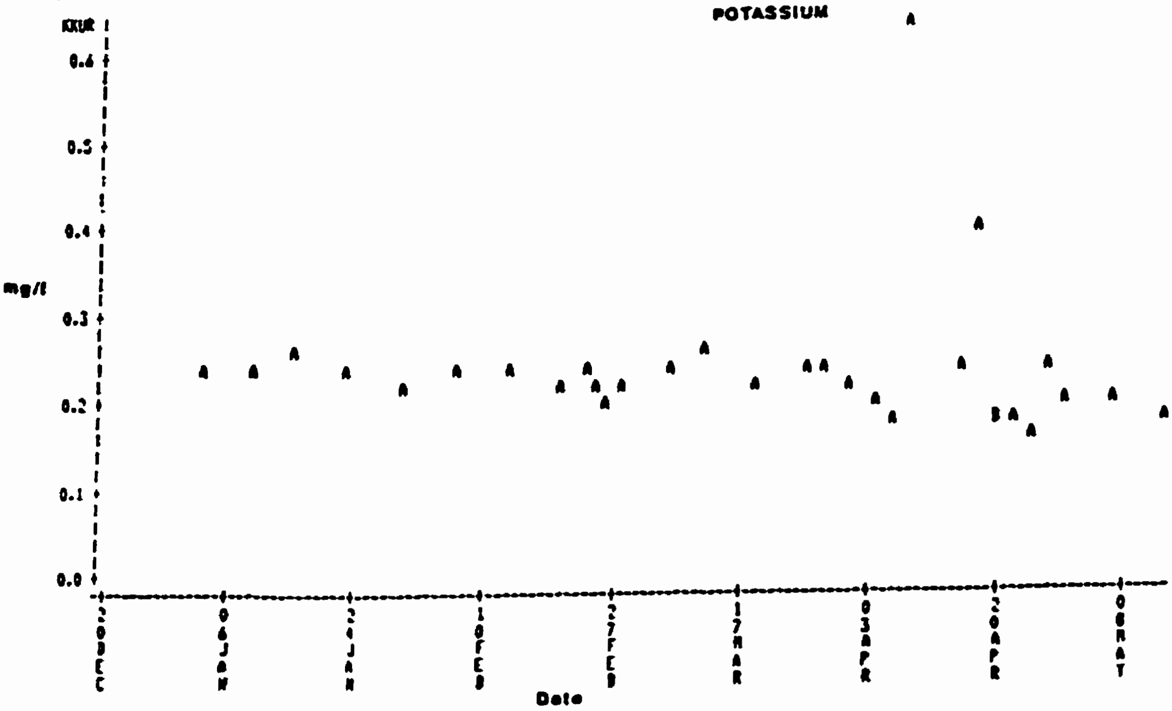


Fig. C4f



1985 Plastic Lake Outflow Chemistry Jan-May

Fig. C4g

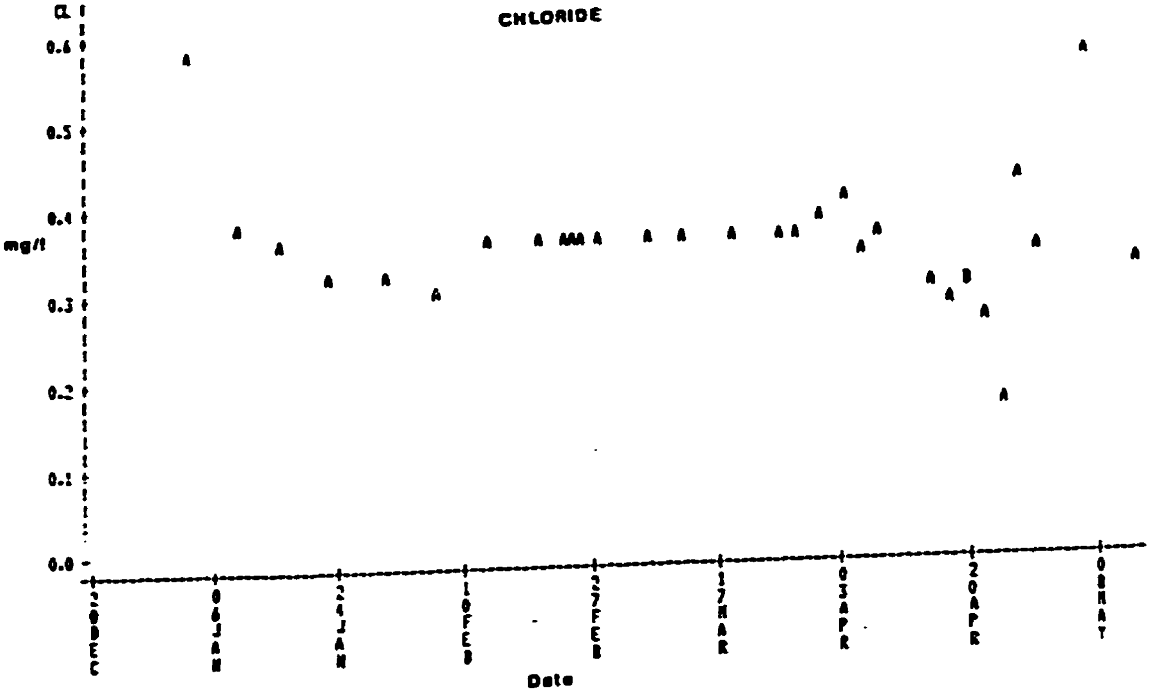
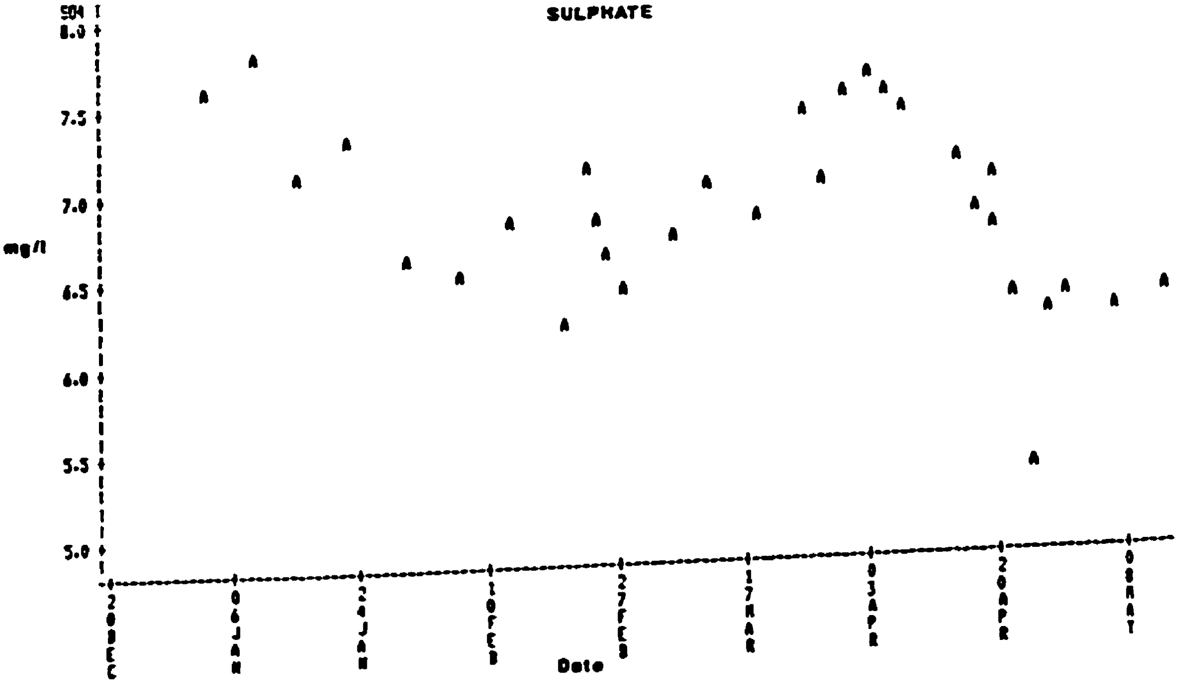


Fig. C4h



## 1985 Plastic Lake Outflow Chemistry Jan-May

Fig. C4i

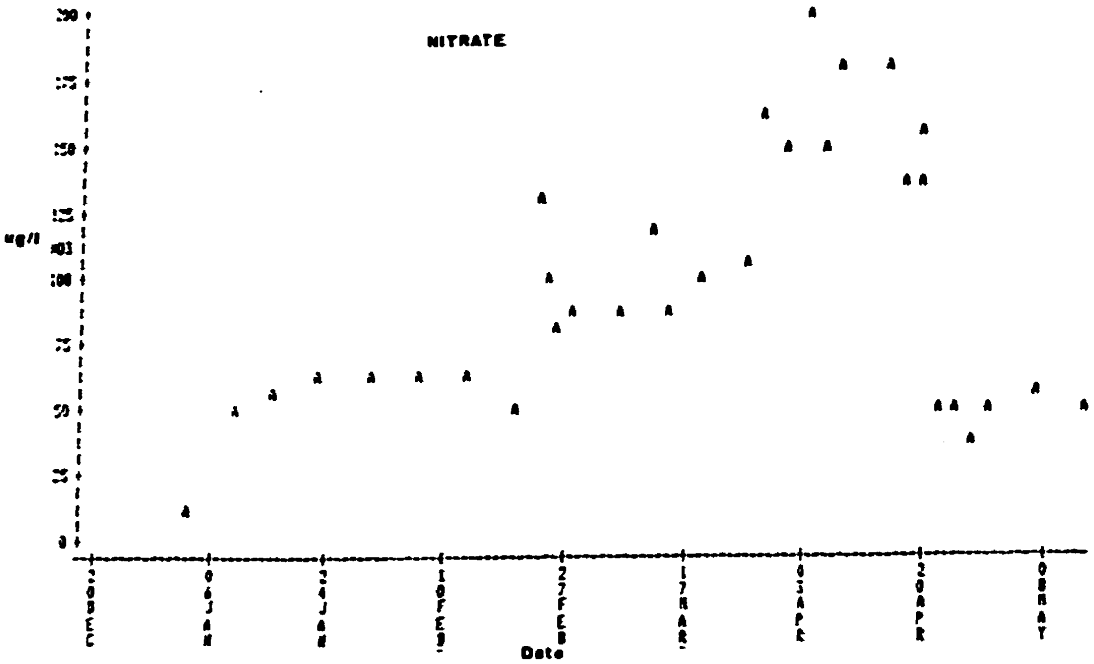


Fig. C4j

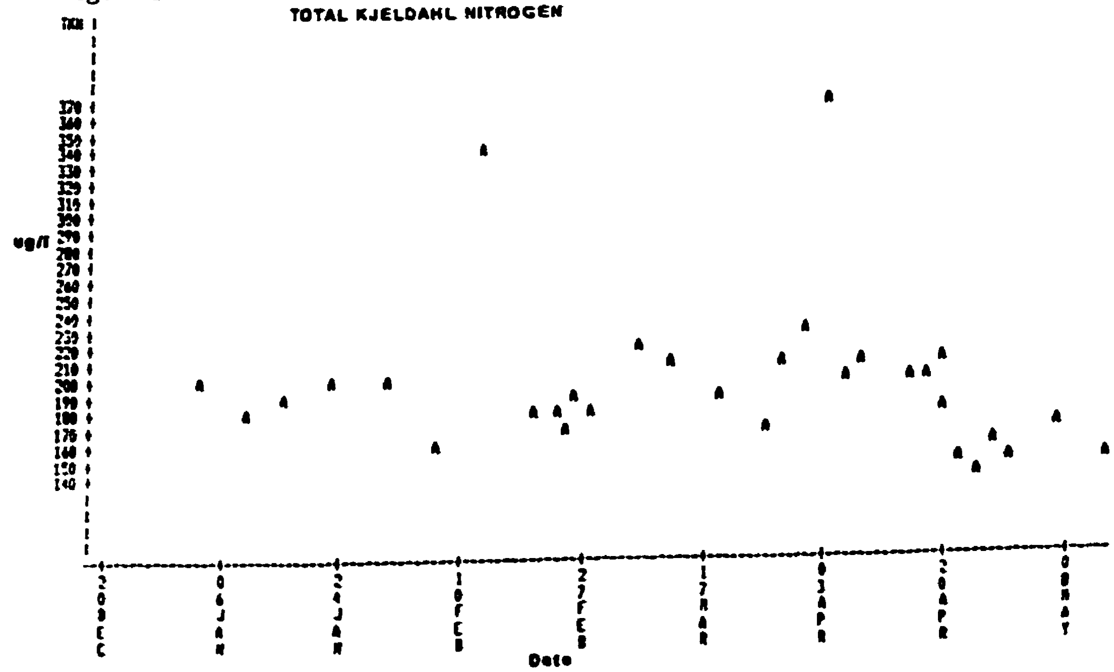


Fig. C4k

**1985 Plastic Lake Outflow Chemistry Jan–May**

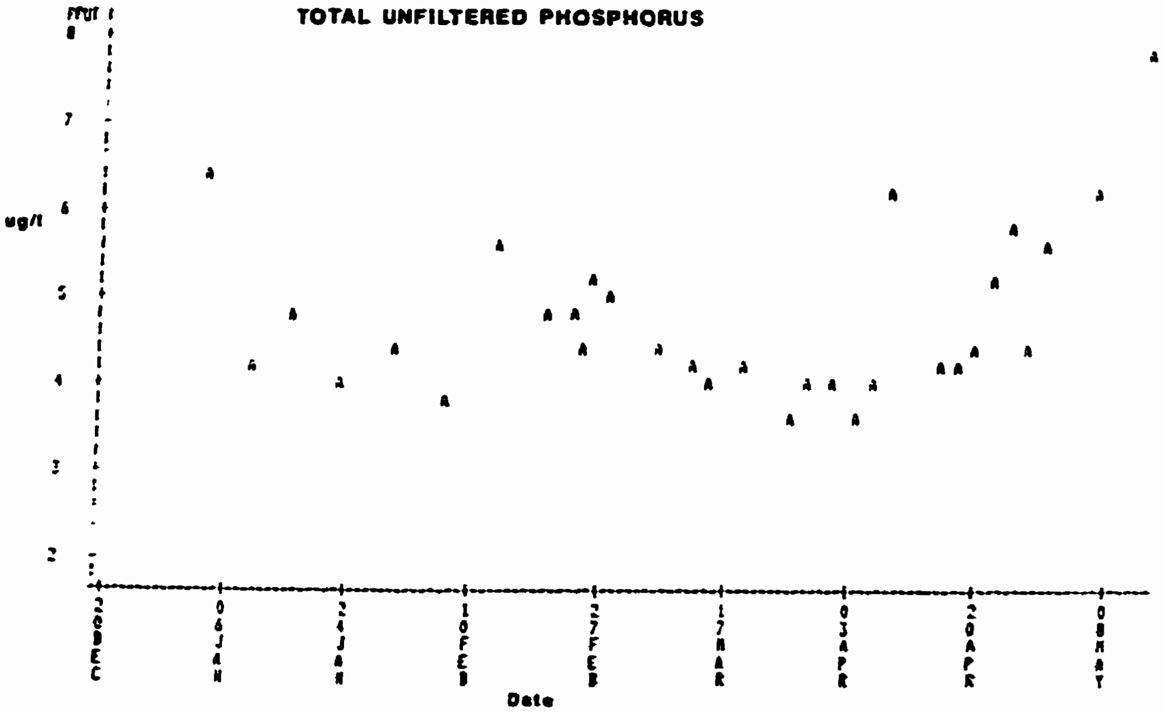
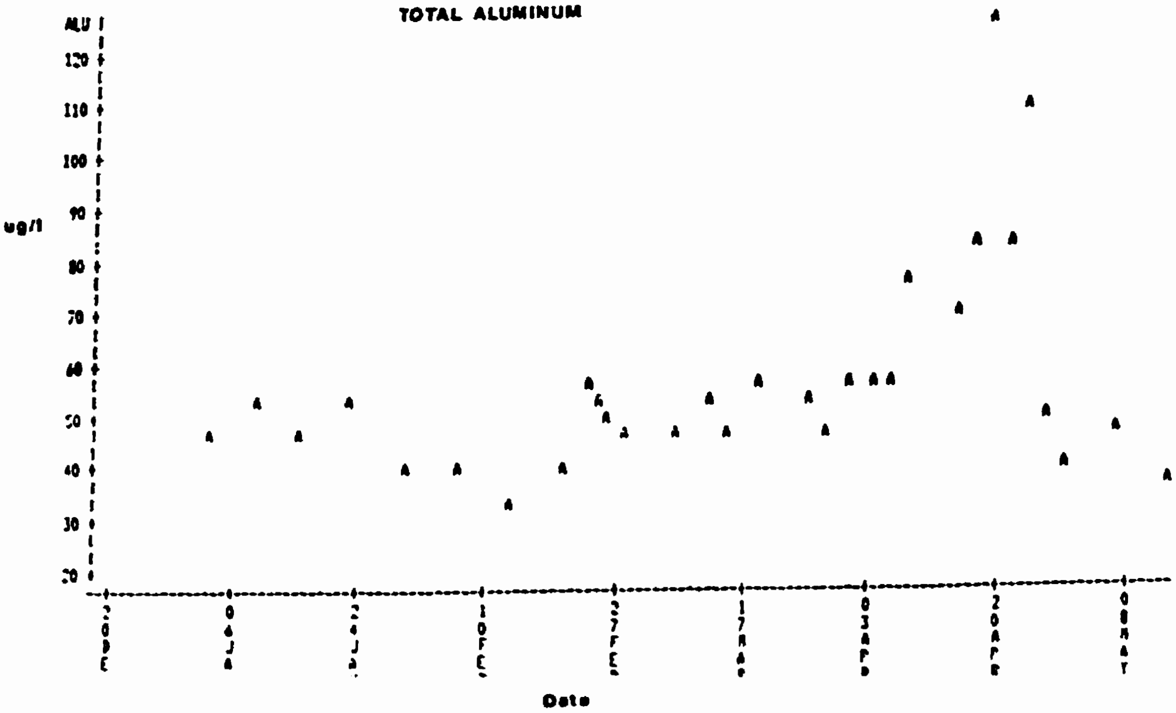


Fig. C41



## 1985 Plastic Lake Outflow Chemistry Jan-May

Fig. C4m

DISSOLVED ORGANIC CARBON

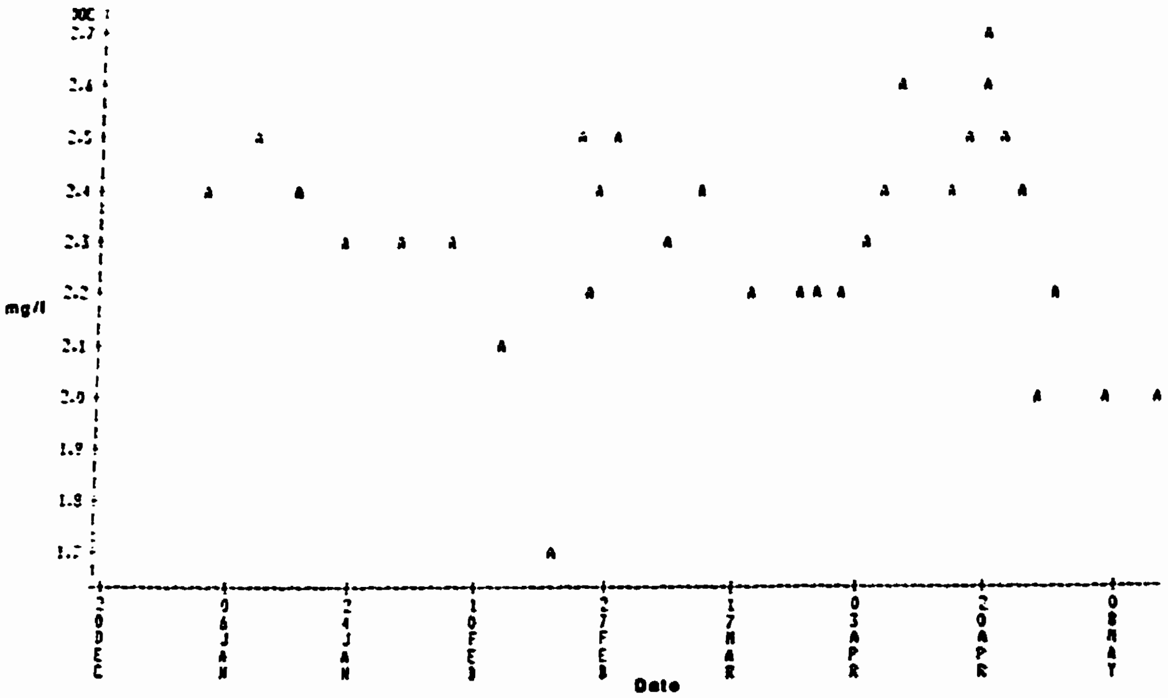
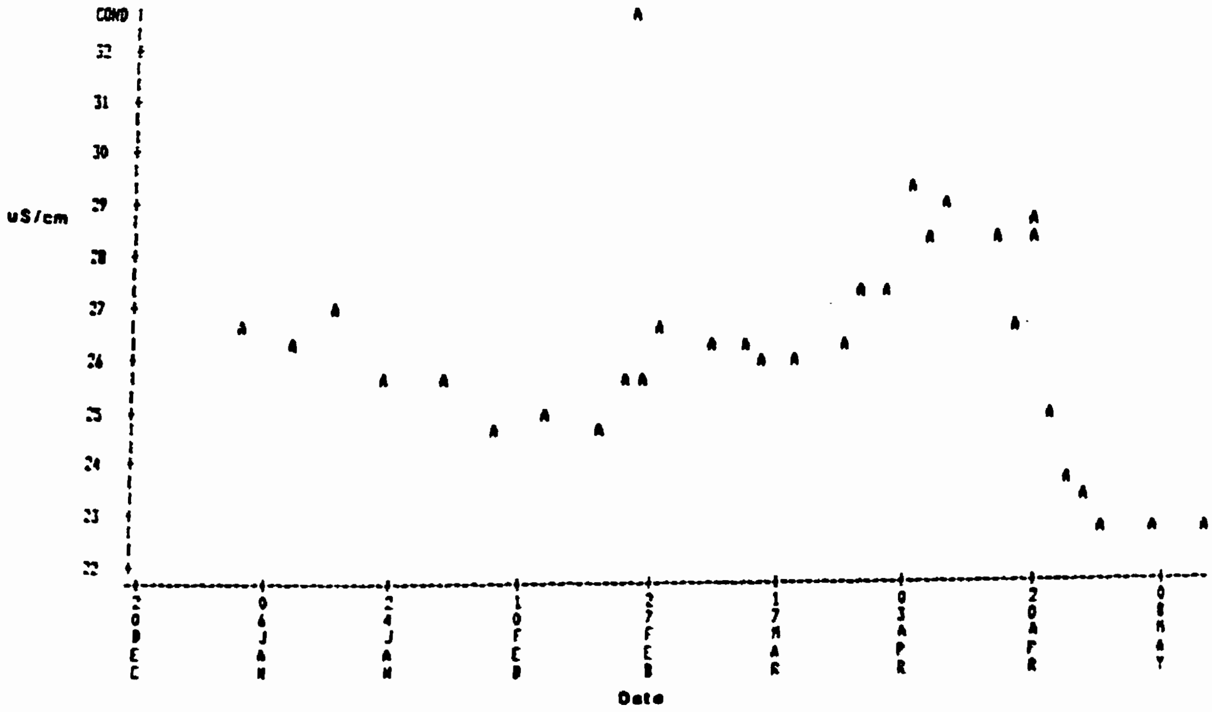


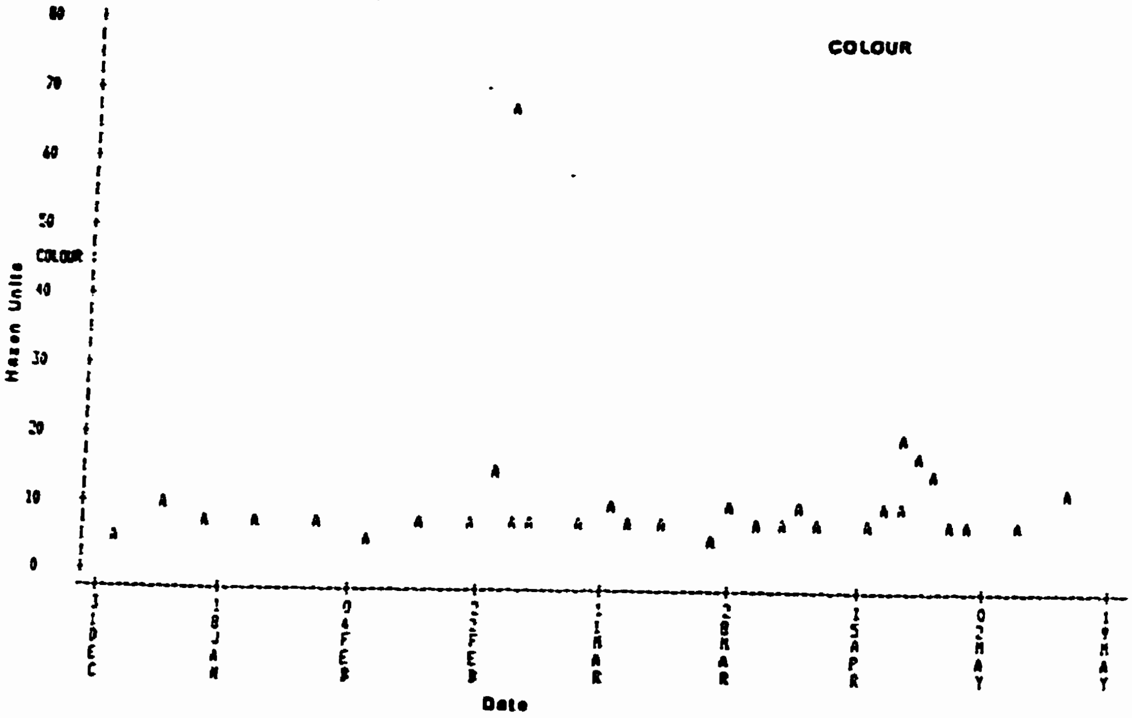
Fig. C4n

CONDUCTANCE



## 1985 Plastic Lake Outflow Chemistry Jan-May

Fig. C40



# Appendix 4 Plastic Lake chemistry and temperature data

Table D1
1985 Plastic Lake integrated "deep hole" chemistry (P. Dillon unpublished studies)

| Date | pH | ALKTI* | DIC | $HCO_3^-$ | $Ca^{+2}$ | $Mg^{+2}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{-2}$ | $NH_4^+$ | $NO_3^-$ | TKN | PPUT | TAL | DOC | Cond | C | Anions | Cations | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | | | | | | | | | mg/l | | | | | mg/l | uS·cm | Hu | ueq/l | | % |
| Jan28 | 5.64 | .40 | 0.64 | .0087 | 2.07 | .48 | .46 | .21 | .26 | 6.43 | 32 | 20 | 190 | 5.27 | 35 | 2.1 | 23.7 | 8 | 151.3 | 170.4 | 11.9 |
| Feb25 | 5.52 | .32 | | | 2.12 | .49 | .43 | .20 | .35 | 6.50 | 35 | 30 | 170 | 3.70 | 32 | 2.0 | 23.7 | 7 | 147.3 | 172.4 | 15.7 |
| Mar20 | 5.50 | .28 | 0.92 | .0095 | 2.17 | .49 | .45 | .20 | .40 | 6.30 | 34 | 40 | 210 | 3.73 | 37 | 2.2 | 24.3 | 7 | 154.8 | 175.7 | 12.7 |
| Apr18 | 5.32 | .20 | 1.06 | .0075 | 2.16 | .48 | .55 | .26 | .33 | 6.46 | 41 | 65 | 170 | 3.80 | | 2.2 | 24.7 | 7 | 156.0 | 180.8 | 14.7 |
| May06 | 5.45 | .16 | 0.89 | .0082 | 1.98 | .46 | .43 | .19 | .31 | 6.09 | 35 | 55 | 180 | 5.00 | 36 | 1.9 | 22.5 | 7 | 147.8 | 162.7 | 9.6 |
| x | 5.47 | .27 | 0.88 | .0085 | 2.10 | .48 | .46 | .21 | .33 | 6.36 | 35 | 42 | 184 | 4.30 | 35 | 2.1 | 23.8 | 7 | 151.4 | 172.4 | 12.9 |
| sd | 9.17 | .10 | 0.17 | .0008 | 0.08 | .01 | .05 | .03 | .05 | 0.17 | 3 | 18 | 17 | 0.77 | 2 | 0.1 | 0.8 | .4 | 4.0 | 6.7 | 2.4 |
| N | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 |

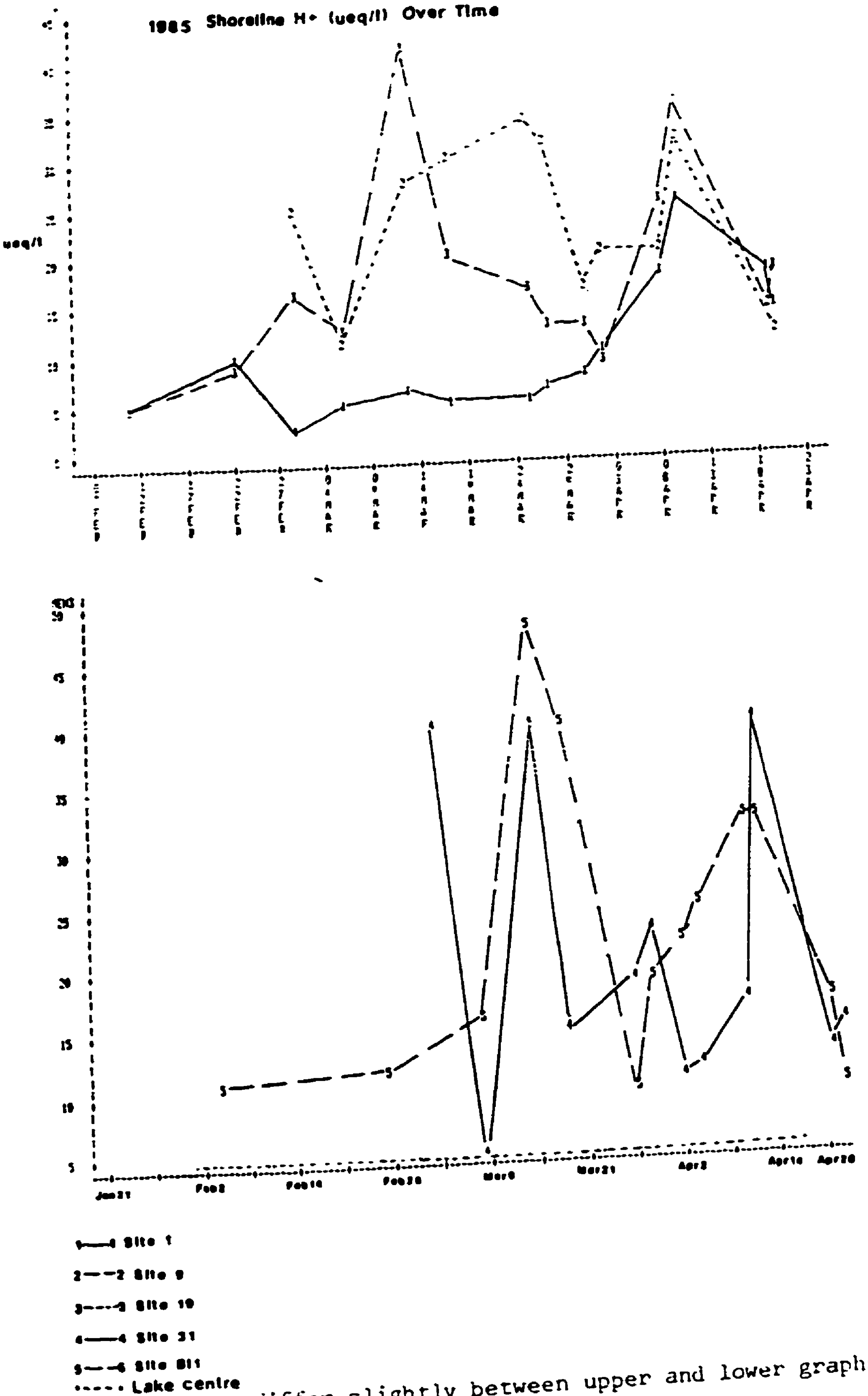
*mg/l as $CaCO_3$

Table D2
1985 Plastic Lake Shoreline Chemistry

| Date | Cond | pH | $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{=}$ | DOC | Ã | Fluor | TAL | ALKTI | PO4T | TKN | $NO_3^{-}$ | Cations | Anions | Imbalance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | µS | | | | | mg/l | | | | µg/l | ru | µeq/l | mg/l* | | mg/l | | | µeq/l | % |
| Site 1 | | | | | | | | | | | | | | | | | | | |
| Feb02 | [illegible] | 5.33 | | | | | | | | | 10 | | | | | | | | |
| Feb23 | 21.9 | 5.01 | | | | | | | | | 6 | | | | | | | | |
| Mar02 | 21.2 | 5.60 | | | | | | | | | 6 | | | | | | | | |
| Mar07 | [illegible] | 5.32 | 2.20 | .50 | .56 | .22 | .35 | 6.05 | [illegible] | 0 | | | 0.15 | [illegible] | .21 | .090 | 180.9 | 154.8 | 15.6 |
| Mar11 | [illegible] | [illegible] | 2.10 | .50 | .50 | .18 | .35 | 6.75 | [illegible] | 0 | 6 | 45 | 0.03 | .008 | .19 | .065 | 178.1 | 155.0 | 13.8 |
| Mar18 | [illegible] | 5.10 | | | | | | | | | | | | | | | | | |
| Mar26 | [illegible] | 5.29 | 2.15 | .48 | .70 | .18 | .39 | 6.98 | [illegible] | 0 | | 45 | 0.09 | .01? | .16 | .140 | 185.9 | 166.3 | 11.1 |
| Mar28 | 21.0 | 5.21 | | | | | | | | | | | | | | | | | |
| Apr01 | 25.1 | 5.11 | | | | | | | | | 3 | | | | | | | | |
| Apr03 | 25.7 | 4.98 | 2.35 | .51 | .64 | .26 | .61 | 8.37 | [illegible] | [illegible] | 6 | 65 | -0.49 | [illegible] | .37 | .215 | 189.2 | 206.8 | -8.9 |
| Apr09 | 24.1 | 4.77 | | | | | | | | | 7 | | | | | | | | |
| Apr11 | [illegible] | 4.60 | 2.20 | .48 | .66 | .30 | .57 | 7.45 | [illegible] | 0 | 7 | 22 | -0.55 | .01? | .33 | .170 | 210.8 | 181.1 | 13.9 |
| Apr20 | [illegible] | 4.76 | 1.55 | .35 | .32 | .05 | .27 | 5.05 | [illegible] | 0 | 16 | 98 | -0.61 | .007 | .20 | .065 | 146.9 | 129.9 | 12.1 |
| Apr21 | 25.8 | 4.87 | | | | | | | | | 18 | | | | | | | | |
| x | 24.4 | 5.01 | 2.04 | .48 | .56 | .22 | .42 | 6.98 | [illegible] | 0 | 9 | 55 | [illegible] | .010 | .28 | .124 | 182.0 | 166.0 | 12.6 |
| sd | [illegible] | 6.4 | 0.25 | .02 | .14 | .10 | .14 | 0.70 | [illegible] | 0 | 5 | 28 | [illegible] | .003 | .08 | .061 | 20.7 | 26.5 | 2.4 |
| n | 14 | 14 | 6 | 6 | 6 | 6 | 6 | 6 | [illegible] | 6 | 10 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Site [illegible] | | | | | | | | | | | | | | | | | | | |
| Mar02 | 36.1 | 4.60 | | | | | | | | | 8 | | | | | | | | |
| Mar07 | 24.8 | 4.76 | 2.00 | .50 | .56 | .26 | .50 | 6.75 | [illegible] | 0 | | | -0.20 | .014 | .47 | .035 | 182.9 | 157.1 | 15.2 |
| Mar11 | 29.5 | 4.56 | 1.80 | .45 | .46 | .12 | .35 | 5.35 | 2.6 | 0 | 10 | 59 | -1.40 | .006 | .26 | .295 | 177.5 | 154.8 | 13.6 |
| Mar18 | 31.4 | 4.51 | | | | | | | | | | | | | | | | | |
| Mar26 | 34.3 | 4.47 | 2.25 | .48 | .68 | .12 | .52 | 8.15 | [illegible] | 0 | | 50 | -0.88 | .005 | .40 | .395 | 223.4 | 216.7 | 3.0 |
| Mar28 | 26.7 | 4.50 | | | | | | | | | | | | | | | | | |
| Apr01 | 27.3 | 4.78 | | | | | | | | | 20 | | | | | | | | |
| Apr03 | 22.9 | 4.70 | 2.05 | .50 | .60 | .31 | .47 | 7.42 | 4.1 | 32.9 | 28 | 101 | -0.95 | .008 | .30 | .070 | 197.4 | 205.6 | -4.1 |
| Apr09 | 14.6 | 4.70 | | | | | | | | | 18 | | | | | | | | |
| Apr11 | 27.4 | 4.50 | 1.95 | .45 | .66 | .11 | .40 | 7.43 | [illegible] | 0 | 15 | 111 | -0.89 | .007 | .26 | .065 | 202.6 | 170.6 | 17.1 |
| Apr20 | 20.7 | 4.87 | 1.50 | .41 | .22 | .16 | .27 | 5.18 | 2.5 | 0 | 22 | 107 | -0.56 | .005 | .20 | .075 | 135.7 | 120.8 | 11.6 |
| Apr21 | 24.4 | 4.94 | | | | | | | | | 18 | | | | | | | | |
| x | [illegible] | 4.65 | 1.93 | .47 | .53 | .25 | .42 | [illegible] | [illegible] | [illegible] | 17 | 86 | [illegible] | .008 | .32 | .156 | 186.6 | 170.9 | 10.8 |
| sd | [illegible] | 8.3 | 0.25 | .04 | .17 | [illegible] | .10 | 1.14 | [illegible] | 11.4 | 6 | 29 | 0.40 | .003 | .10 | .151 | 29.7 | 35.4 | 5.6 |
| n | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | [illegible] | [illegible] | 8 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Site 2[illegible] | | | | | | | | | | | | | | | | | | | |
| Feb02 | 24.7 | 5.28 | | | | | | | | | 14 | | | | | | | | |
| Feb23 | 31.7 | 5.05 | | | | | | | | | 32 | | | | | | | | |
| Mar02 | 26.0 | 4.80 | | | | | | | | | 15 | | | | | | | | |
| Mar07 | 24.7 | 4.90 | 2.20 | .55 | .56 | .22 | .40 | 6.85 | 3.5 | 1 | | | -0.38 | .008 | .25 | .060 | 197.6 | 158.2 | 22.2 |
| Mar11 | 33.9 | 4.39 | 1.90 | .45 | .50 | .10 | .30 | 6.35 | 4.5 | 1 | 20 | 134 | -1.50 | .005 | .25 | .265 | 196.9 | 159.6 | 20.9 |
| Mar18 | 26.9 | 4.71 | | | | | | | | | | | | | | | | | |
| Mar26 | 26.1 | 4.80 | 2.20 | .52 | .78 | .32 | .50 | 7.96 | 4.2 | 11.6 | 22 | 107 | -0.63 | .008 | .31 | .075 | 210.3 | 219.8 | -4.4 |
| Mar28 | 24.2 | 4.89 | | | | | | | | | | | | | | | | | |
| Apr01 | 25.3 | 4.92 | | | | | | | | | 19 | | | | | | | | |
| Apr03 | 25.8 | 5.03 | 2.15 | .49 | .76 | .18 | .34 | 7.63 | 3.4 | 0 | 29 | 170 | -0.26 | [illegible] | .27 | .085 | 194.7 | 174.5 | 13.5 |
| Apr09 | 34.0 | 4.60 | | | | | | | | | | | | | | | | | |
| Apr11 | 28.9 | 4.45 | 2.10 | .48 | .72 | .30 | .75 | 7.98 | 4.4 | 32.4 | 22 | 204 | -0.91 | .013 | .27 | .065 | 218.8 | 224.3 | -2.5 |
| Apr20 | 22.6 | 4.55 | 1.45 | .43 | .30 | .06 | .26 | 5.54 | | | 20 | 130 | -0.68 | .007 | .23 | .085 | 136.4 | 128.7 | 5.8 |
| Apr21 | 25.8 | 4.75 | | | | | | | | | 20 | | | | | | | | |
| x | 27.2 | 4.76 | 2.00 | .49 | .60 | .23 | .43 | 7.05 | 3.8 | 13.4 | 21 | 149 | -0.73 | .008 | .26 | .106 | 193.3 | 177.5 | 11.6 |
| sd | 3.6 | 10.0 | 0.29 | .04 | .19 | .13 | .18 | 0.98 | 0.5 | 18.4 | 6 | 38 | 0.44 | .008 | .03 | .079 | 29.1 | 37.6 | 8.6 |
| N | 14 | 14 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 5 | 10 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Site31 | | | | | | | | | | | | | | | | | | | |
| Mar02 | 39.7 | 4.40 | | | | | | | | | 6 | | | | | | | | |
| Mar07 | 23.1 | 5.34 | 2.20 | .50 | .50 | .20 | .50 | 6.75 | 2.4 | 0 | | | 0.21 | .015 | .39 | .080 | 177.8 | 160.4 | 10.3 |
| Mar13 | 34.2 | 4.40 | 1.90 | .45 | .50 | .08 | .30 | 6.65 | 2.4 | 0 | 8 | 140 | -1.10 | .007 | .23 | .285 | 195.4 | 167.3 | 15.5 |
| Mar18 | 28.3 | 4.81 | | | | | | | | | | | | | | | | | |
| Mar26 | 28.9 | 4.72 | | | | | | | | | | | | | | | | | |
| Mar28 | 24.4 | 4.64 | | | | | | | | | | | | | | | | | |
| Apr01 | 25.6 | 4.96 | | | | | | | | | 10 | | | | | | | | |
| Apr03 | 29.7 | 4.93 | 2.10 | .49 | .62 | .21 | .32 | 7.50 | 2.5 | 0 | 12 | 155 | -0.43 | .006 | .23 | .120 | 189.2 | 173.7 | 8.5 |
| Apr09 | 33.7 | 4.76 | | | | | | | | | 12 | | | | | | | | |
| Apr11 | 27.4 | 4.40 | 1.95 | .46 | .56 | .20 | .55 | 7.28 | 2.3 | 0 | 16 | 176 | -0.63 | .007 | .23 | .155 | 204.4 | 178.2 | 13.7 |
| Apr20 | 21.3 | 4.87 | 1.50 | .41 | .04 | .08 | .24 | 5.18 | 1.9 | 0 | 22 | 93 | -0.66 | .004 | .21 | .185 | 125.9 | 127.8 | -1.6 |
| Apr21 | 24.0 | 4.81 | | | | | | | | | 8 | | | | | | | | |
| | 28.4 | 4.68 | 1.93 | .46 | .44 | .15 | .38 | 6.67 | 2.3 | 0 | 12 | 141 | -0.52 | .008 | .26 | .165 | 178.5 | 161.5 | 9.[illegible] |
| . | 5.3 | 12.3 | .27 | .04 | .23 | .07 | .13 | 0.91 | 0.2 | 0 | 5 | 35 | 0.48 | .004 | .07 | .078 | 31.0 | 20.0 | 5.4 |
| | 12 | 12 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 8 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Site B11 | | | | | | | | | | | | | | | | | | | |
| Feb02 | 26.3 | 4.94 | | | | | | | | | 22 | | | | | | | | |
| Feb23 | 23.5 | 4.92 | | | | | | | | | 20 | | | | | | | | |
| Mar07 | 27.8 | 4.79 | 2.60 | .50 | .60 | .20 | .50 | 7.30 | 4.9 | 40.0 | 14 | | -0.77 | .008 | .28 | .045 | 218.3 | 209.4 | 4.2 |
| Mar11 | 40.2 | 4.32 | 1.90 | .45 | .50 | .08 | .30 | 6.10 | 1.9 | 0 | 31 | 132 | -1.60 | .005 | .27 | .275 | 203.5 | 155.1 | 27.0 |
| Mar18 | 36.0 | 4.40 | | | | | | | | | | | | | | | | | |
| Mar26 | 25.3 | 4.99 | 2.25 | .49 | .70 | .27 | .33 | 7.15 | 3.3 | 0 | | 124 | | | .24 | | 200.2 | | |
| Mar28 | 31.7 | 4.72 | | | | | | | | | | | | | | | | | |
| Apr01 | 33.6 | 4.65 | | | | | | | | | 30 | | | | | | | | |
| Apr03 | 28.4 | 4.60 | 2.05 | .45 | .82 | .30 | .61 | 8.17 | 5.0 | 18.5 | 24 | 179 | -1.10 | .006 | .26 | .055 | 200.8 | 229.7 | -10.0 |
| Apr09 | 36.9 | 4.50 | | | | | | | | | 28 | | | | | | | | |
| Apr11 | 29.8 | 4.49 | 2.05 | .48 | .76 | .36 | .83 | 7.72 | 4.4 | 12.8 | 24 | 185 | -1.10 | .008 | .25 | .055 | 216.4 | 220.9 | -2.1 |
| Apr20 | 20.4 | 4.76 | 1.30 | .35 | .24 | .14 | .25 | 4.57 | 2.4 | 0 | 16 | 88 | -0.80 | .004 | .21 | .100 | 125.1 | 109.3 | 13.4 |
| Apr21 | 23.4 | 4.98 | | | | | | | | | 16 | | | | | | | | |
| x | 29.6 | 4.64 | 2.02 | .45 | .60 | .22 | .47 | 6.84 | 4.1 | 18.6 | 22 | 142 | -1.07 | .006 | .25 | .106 | 195.2 | 184.9 | 11.3 |
| sd | 6.0 | 12.0 | 0.43 | .05 | .21 | .10 | .22 | 1.31 | 0.9 | 20.4 | 6 | 40 | .33 | .002 | .02 | .097 | 35.1 | 51.2 | 9.8 |
| N | 13 | 13 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 10 | 5 | 5 | 5 | 6 | 5 | 6 | 5 | 5 |

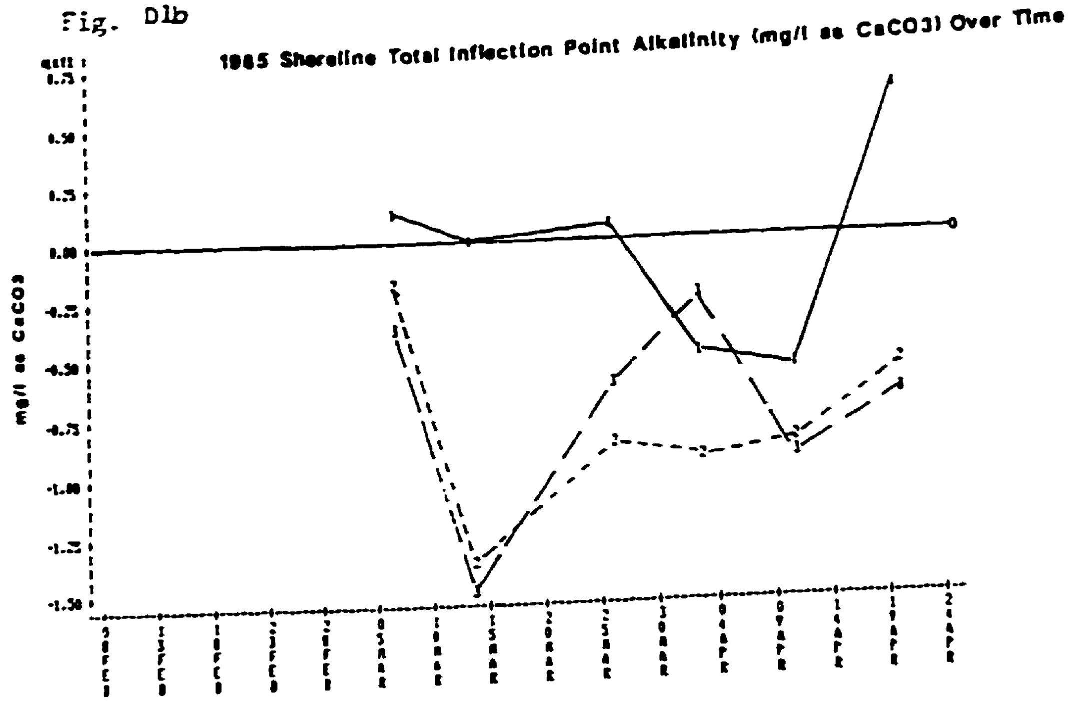
*mg/l as $CaCO_3$

Fig. D1a



* Note scales differ slightly between upper and lower graphs.

Fig. D1b



1985 Shoreline Total Inflection Point Alkalinity (mg/l as CaCO3) Over Time

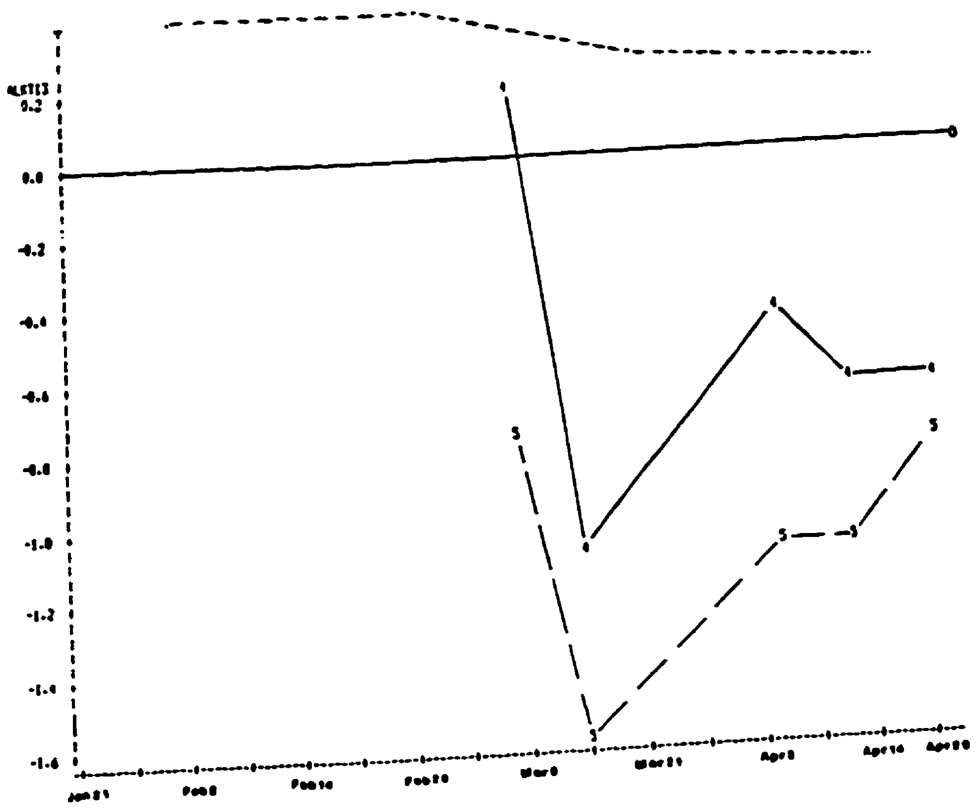


Fig. D1c

**1985 Shoreline Conductance (uS/cm) Over Time**

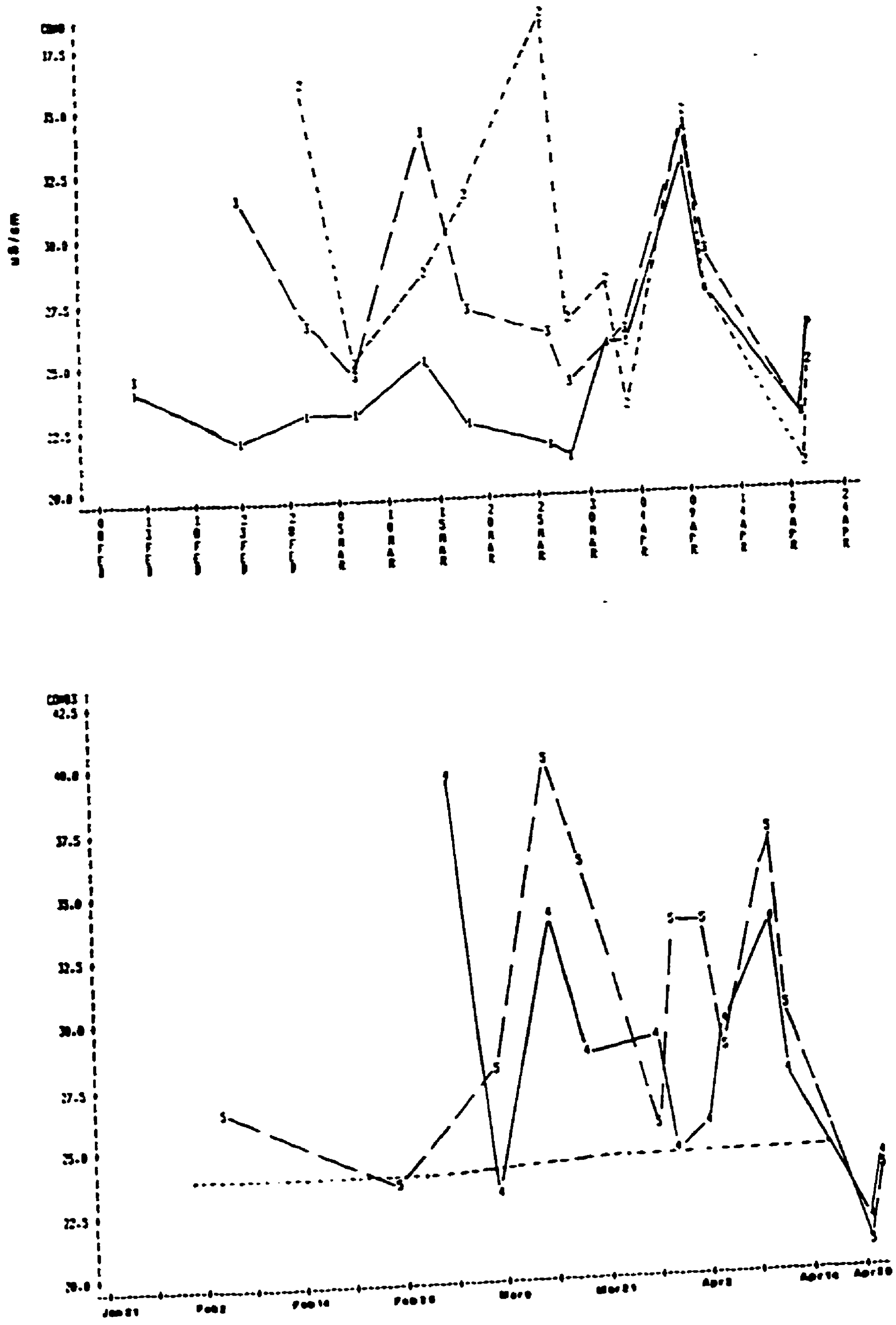


Fig.D1d

1985 Shoreline Ca (mg/l) Over Time

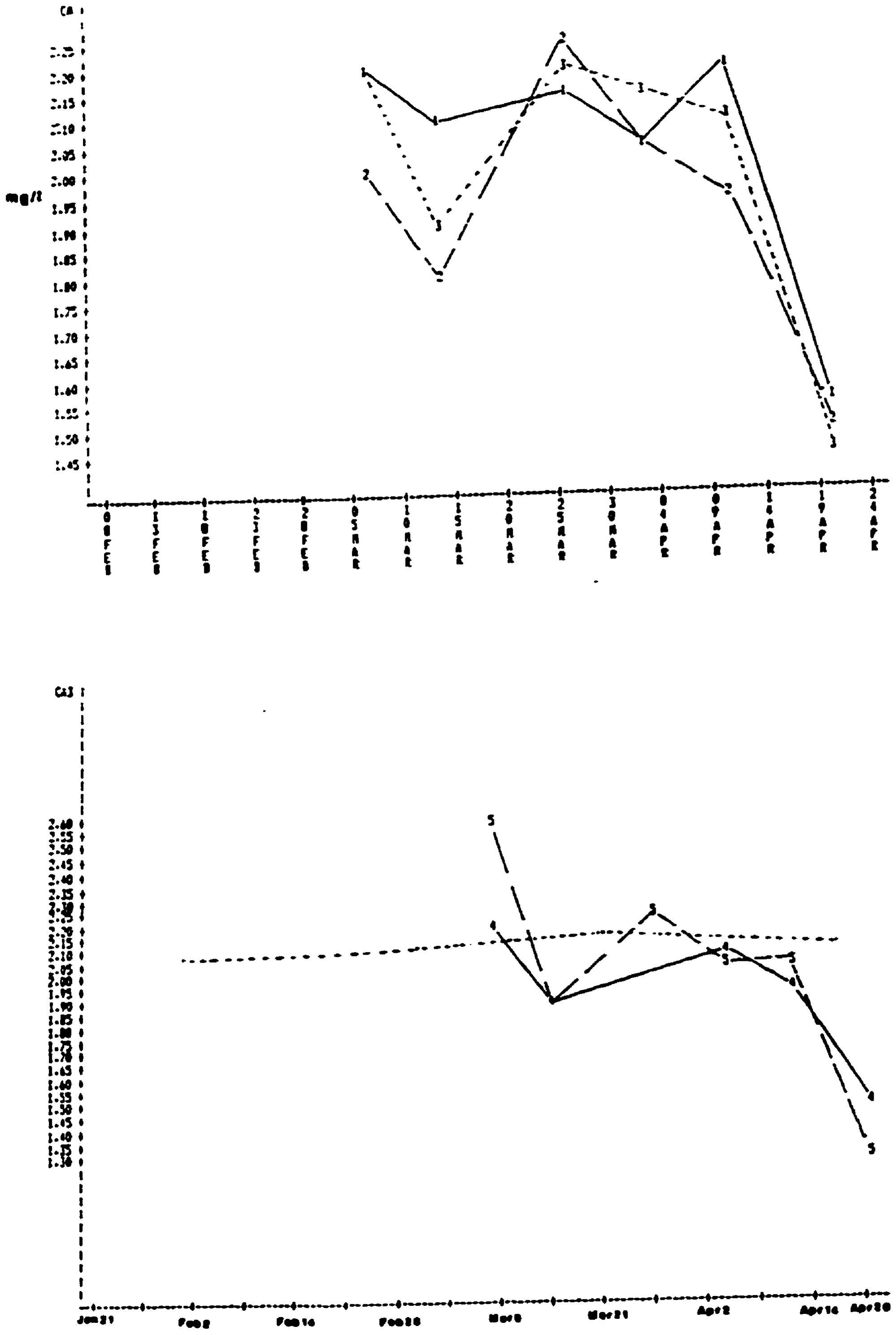


Fig. D1e

1985 Shoreline Mg (mg/l) Over Time

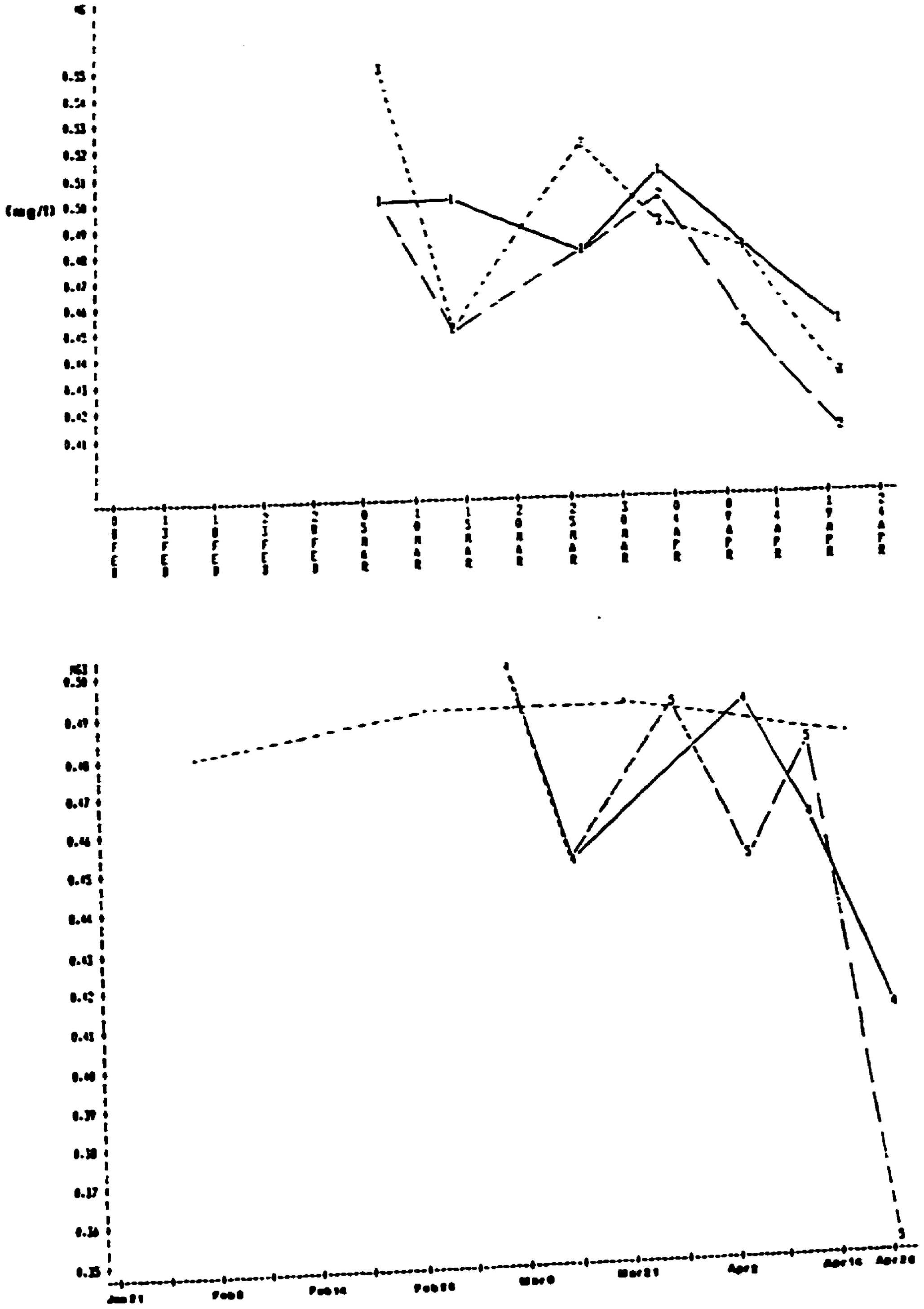
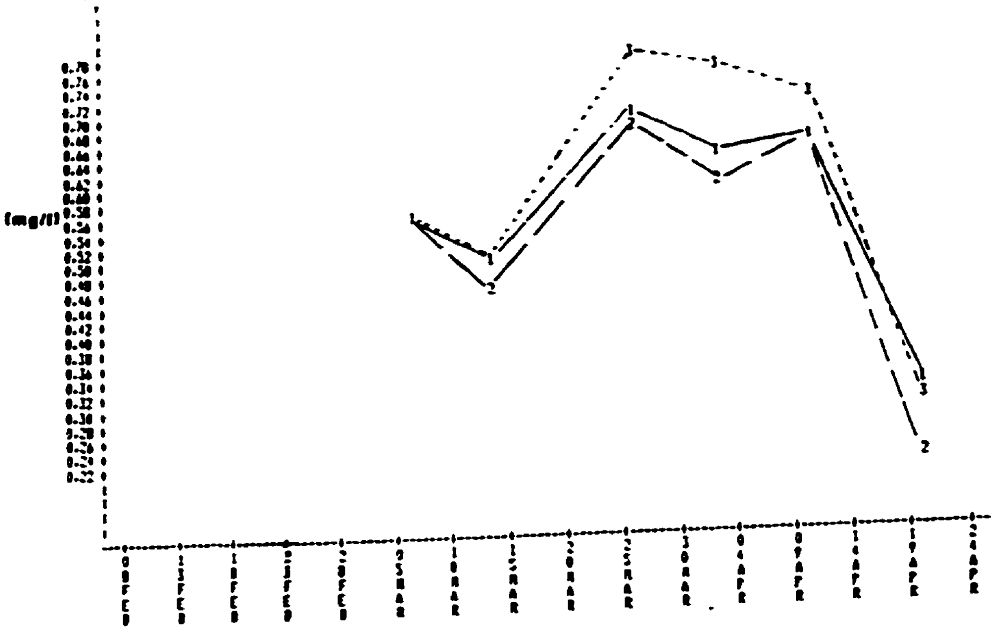


Fig. D1f



W85 Shoreline Na (mg/l) Over Time

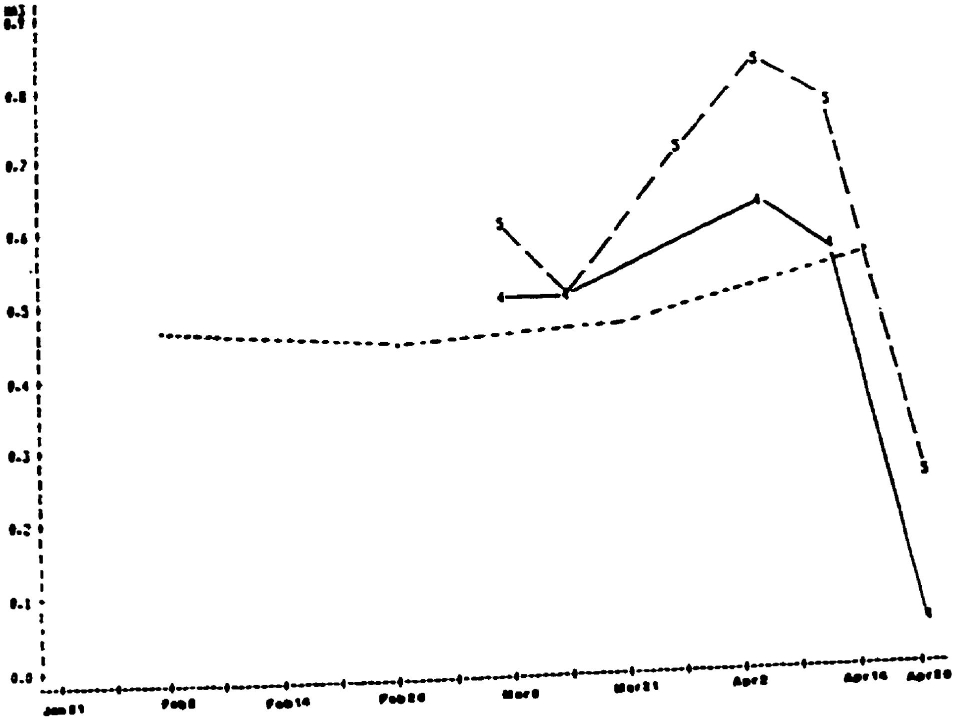
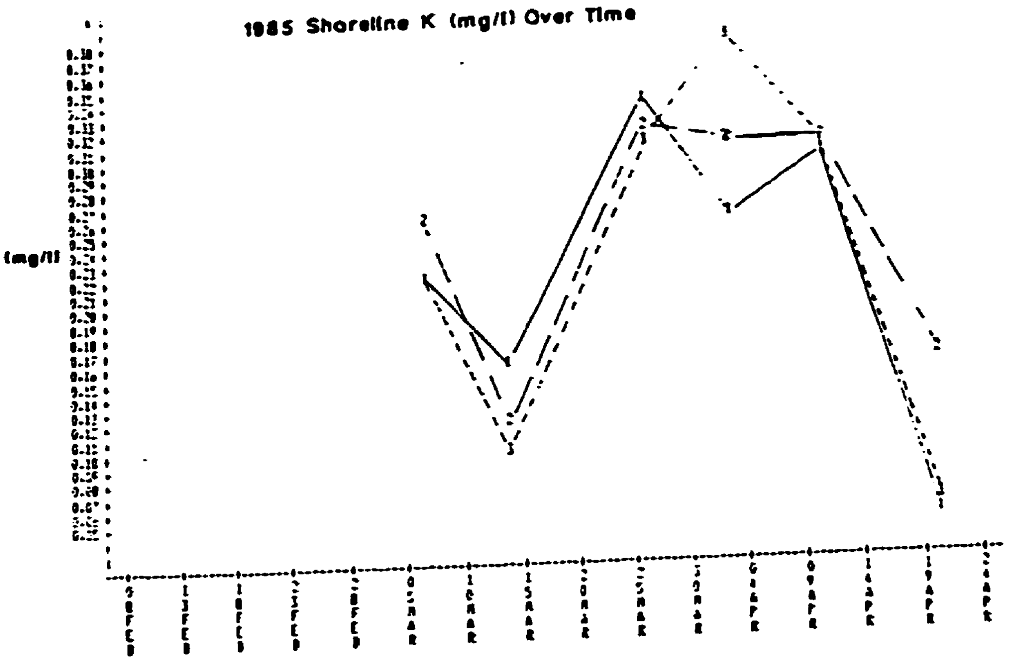
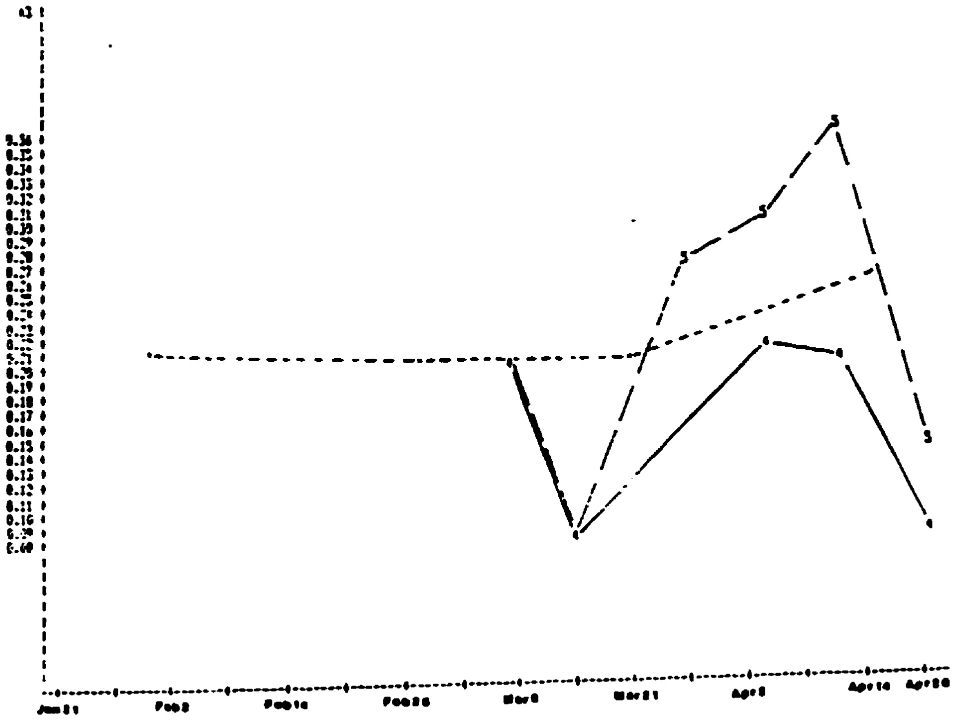


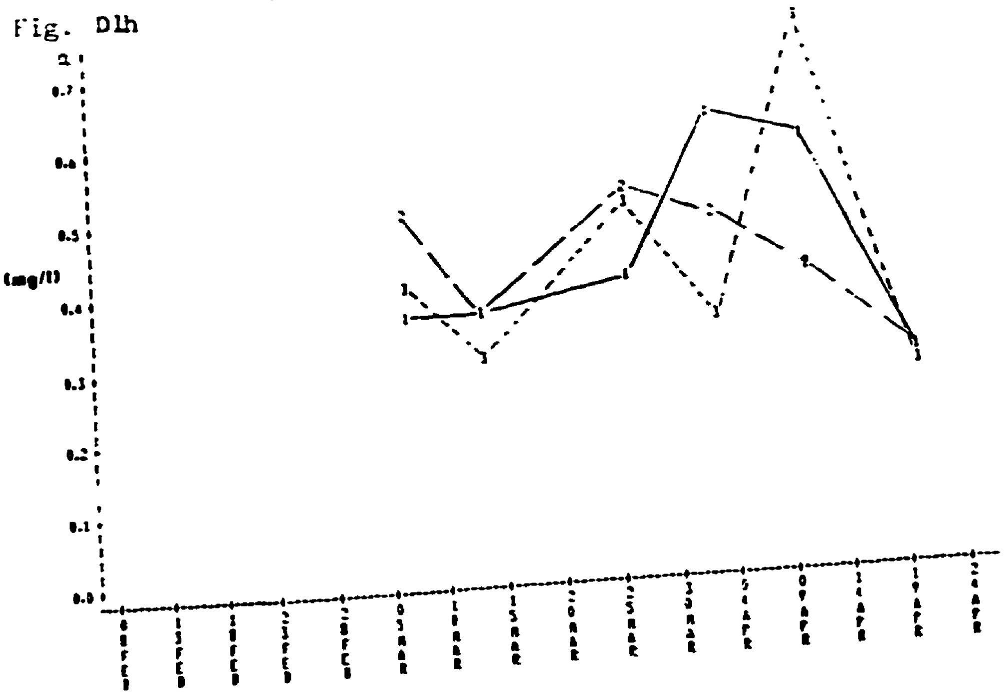
Fig. D1g


1985 Shoreline K (mg/l) Over Time
(mg/l)
10MAR
15MAR
20MAR
25MAR
30MAR
09APR
14APR
19APR
24APR



1985 Shoreline Cl (mg/l) Over Time

Fig. D1h



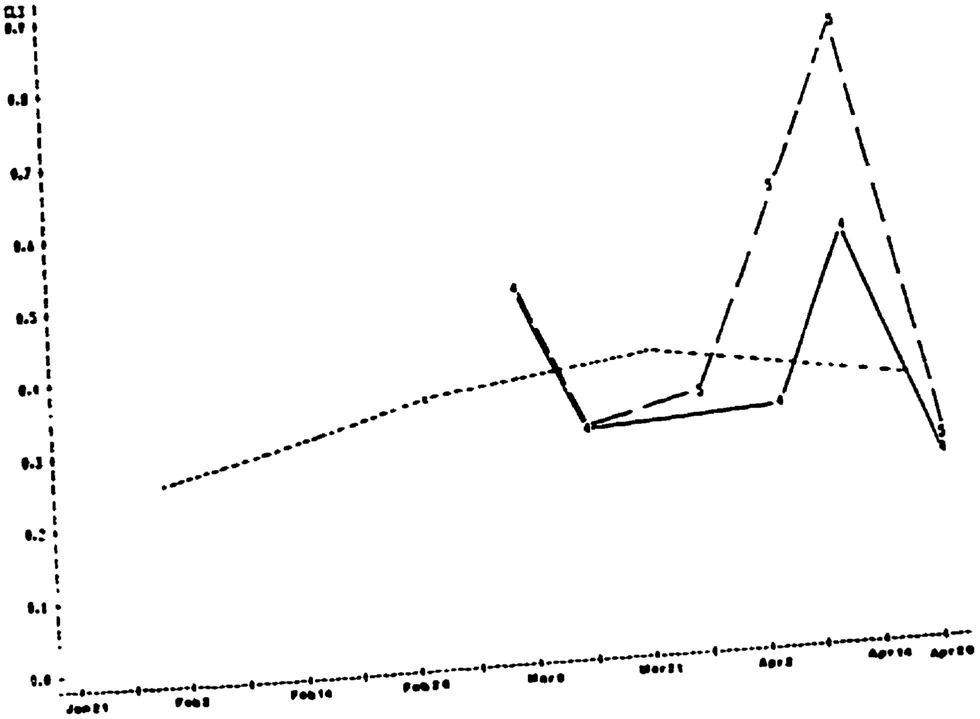
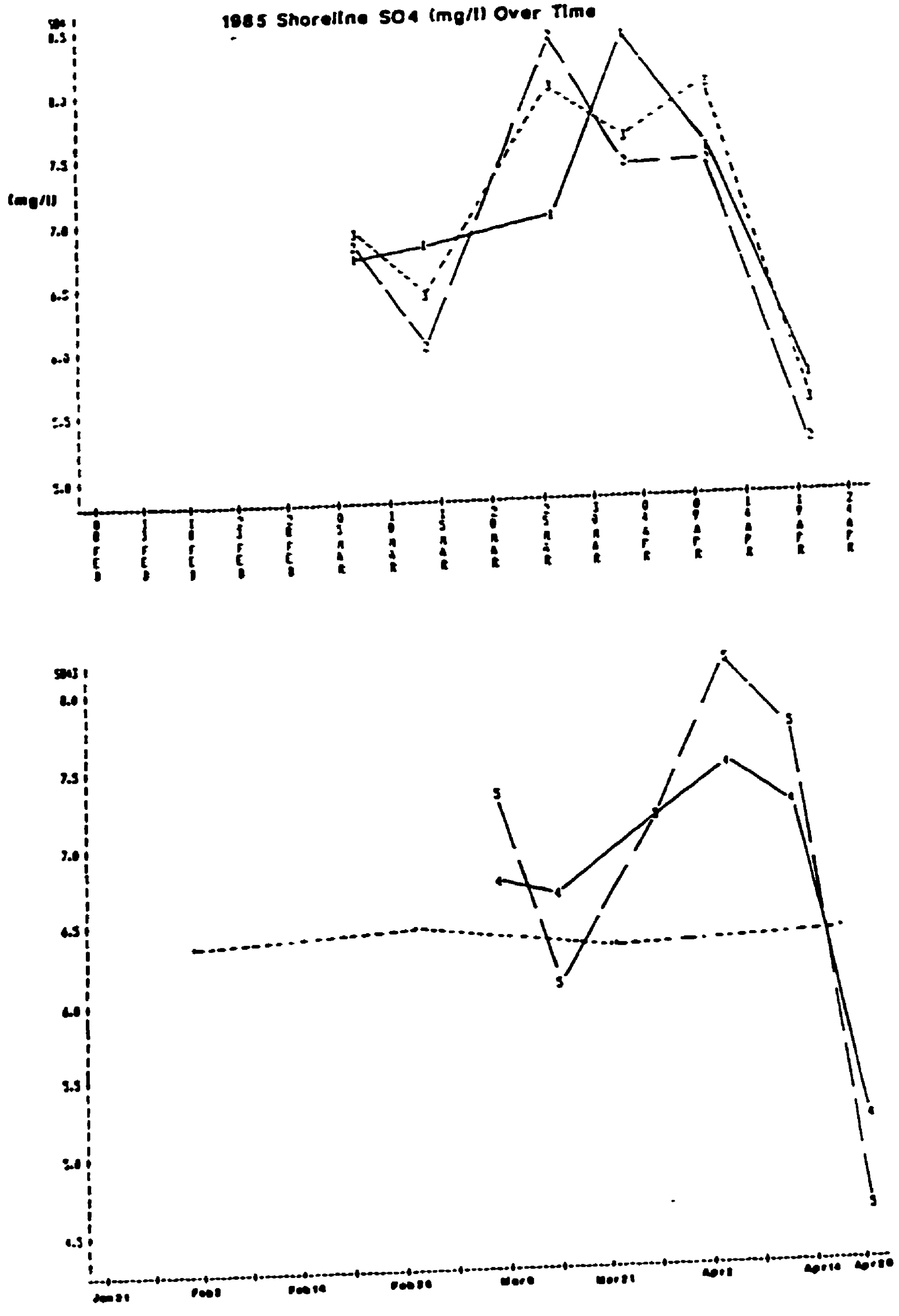


Fig. D1i



1985 Shoreline SO4 (mg/l) Over Time

Fig. D1j

1985 Shoreline NO3 (mg/l) Over Time

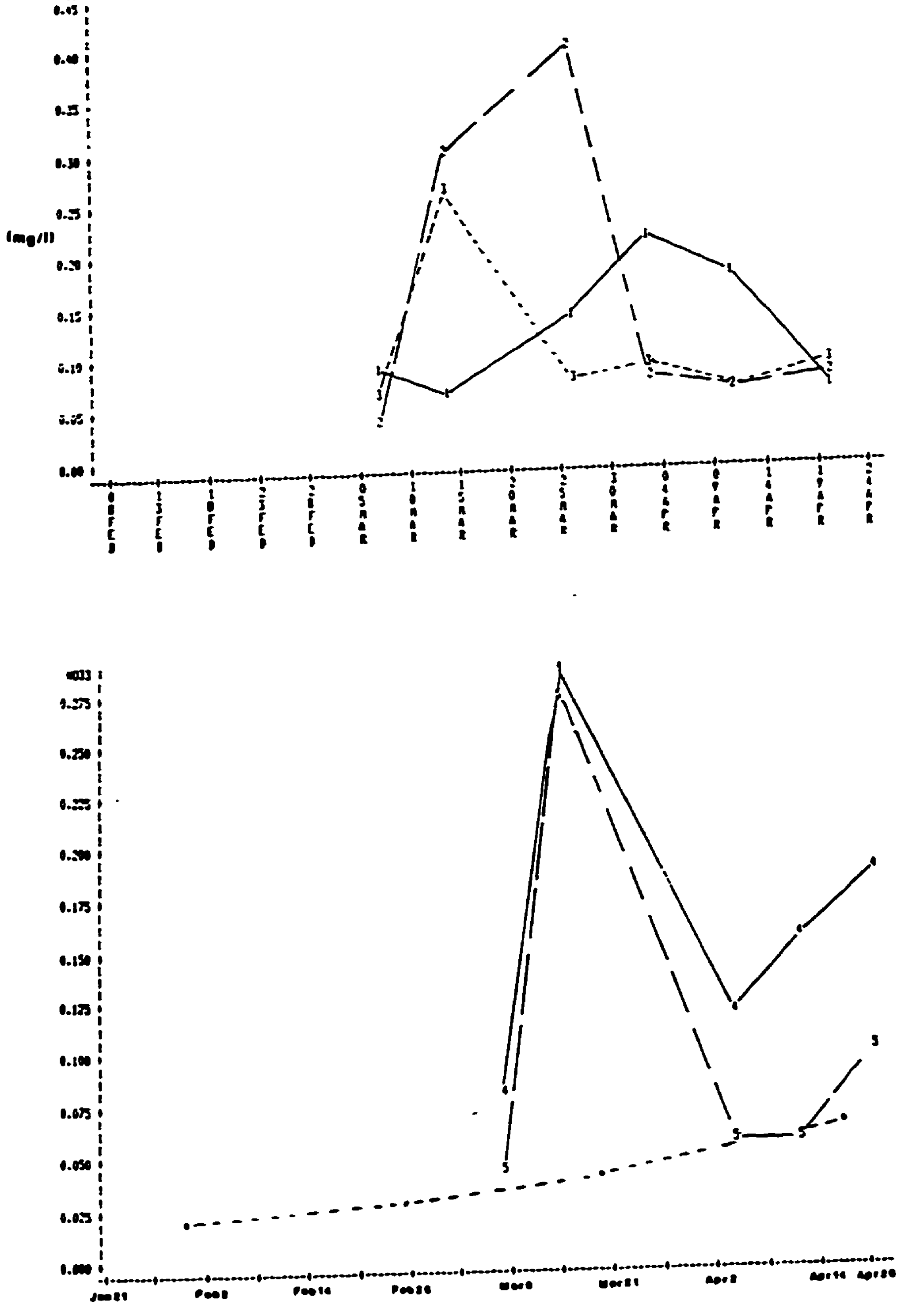


Fig. D1k

1985 Shoreline Total Unfiltered Phosphorus (mg/l) Over Time

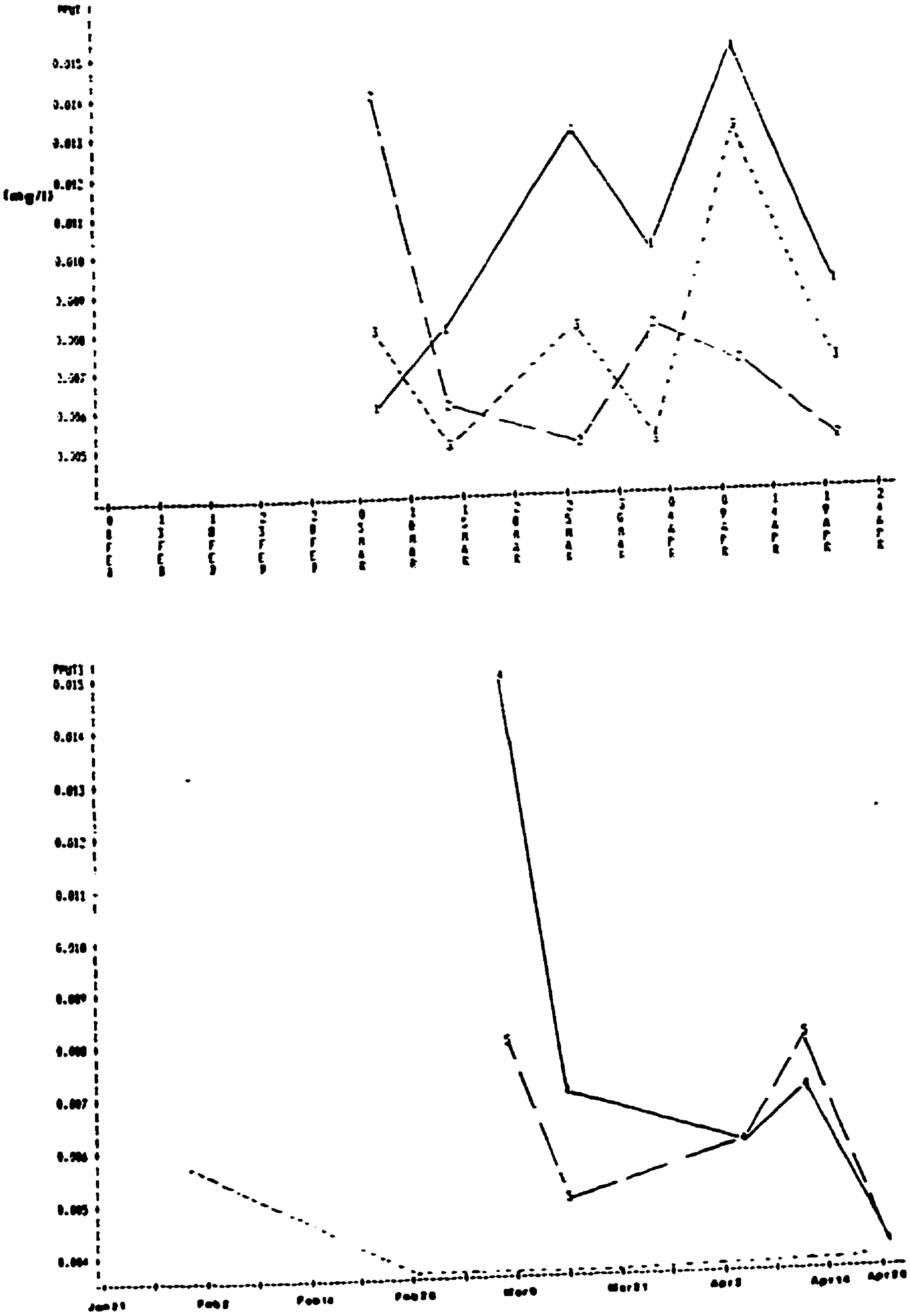


Fig. D11

1985 Shoreline Total Kjeldahl Nitrogen (mg/l) Over Time

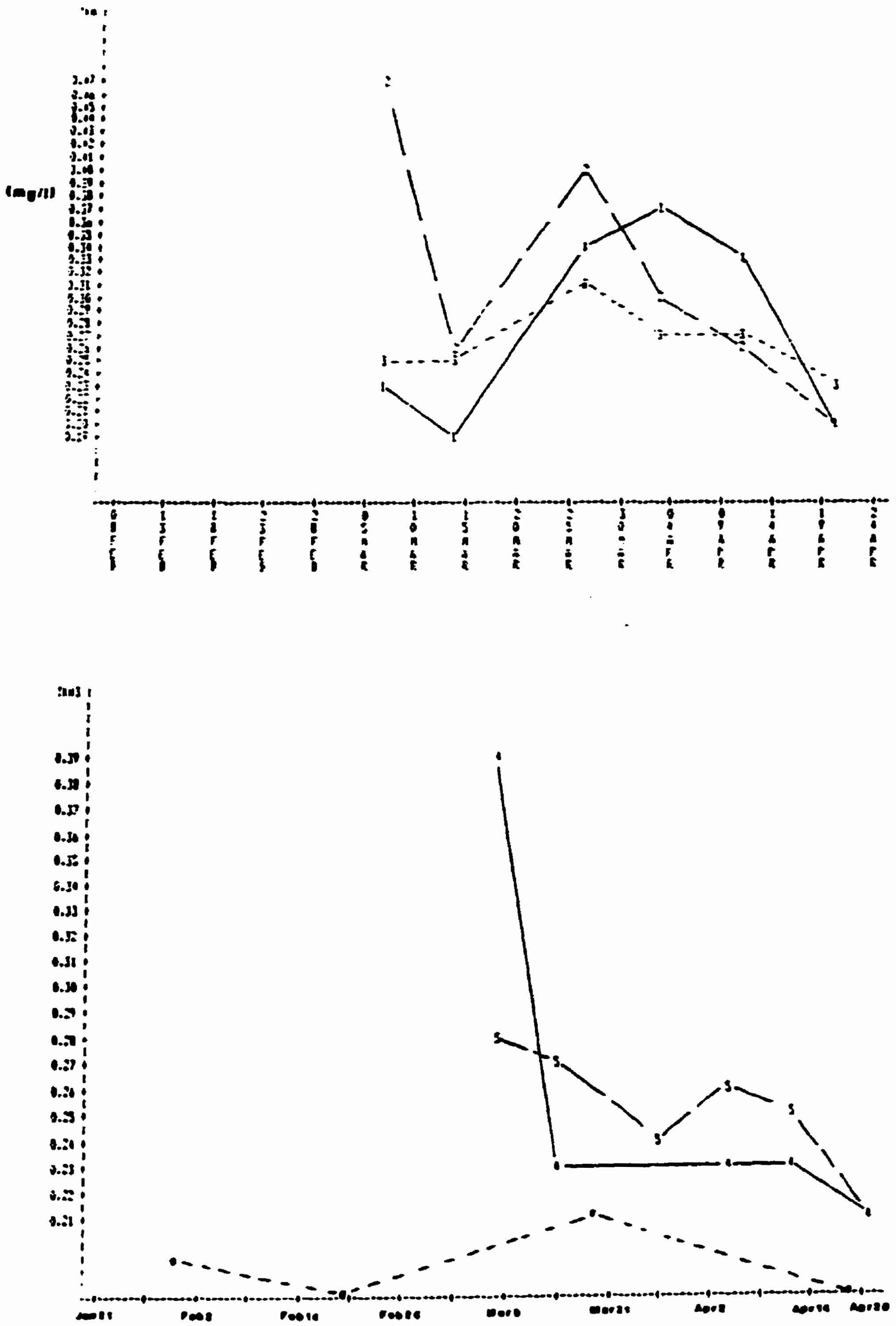
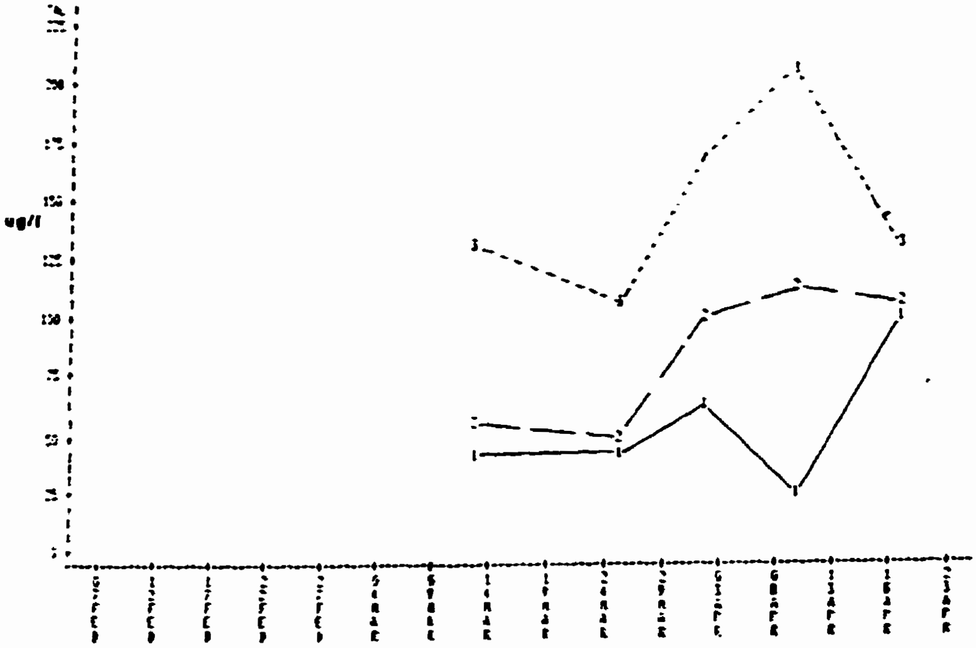
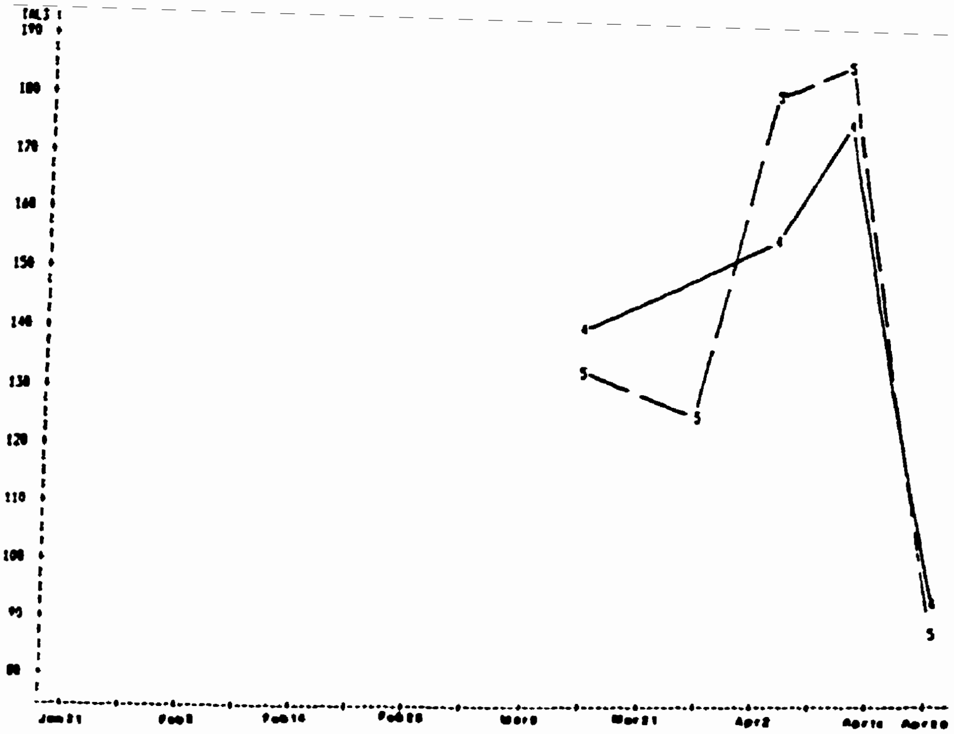


Fig. D1m

1985 Shoreline Total Aluminum (ug/l) Over Time





* Integrated lake center TAL values were 32-37 ug/l

Fig. D1n

**1985 Shoreline Dissolved Organic Carbon (mg/l) Over Time**

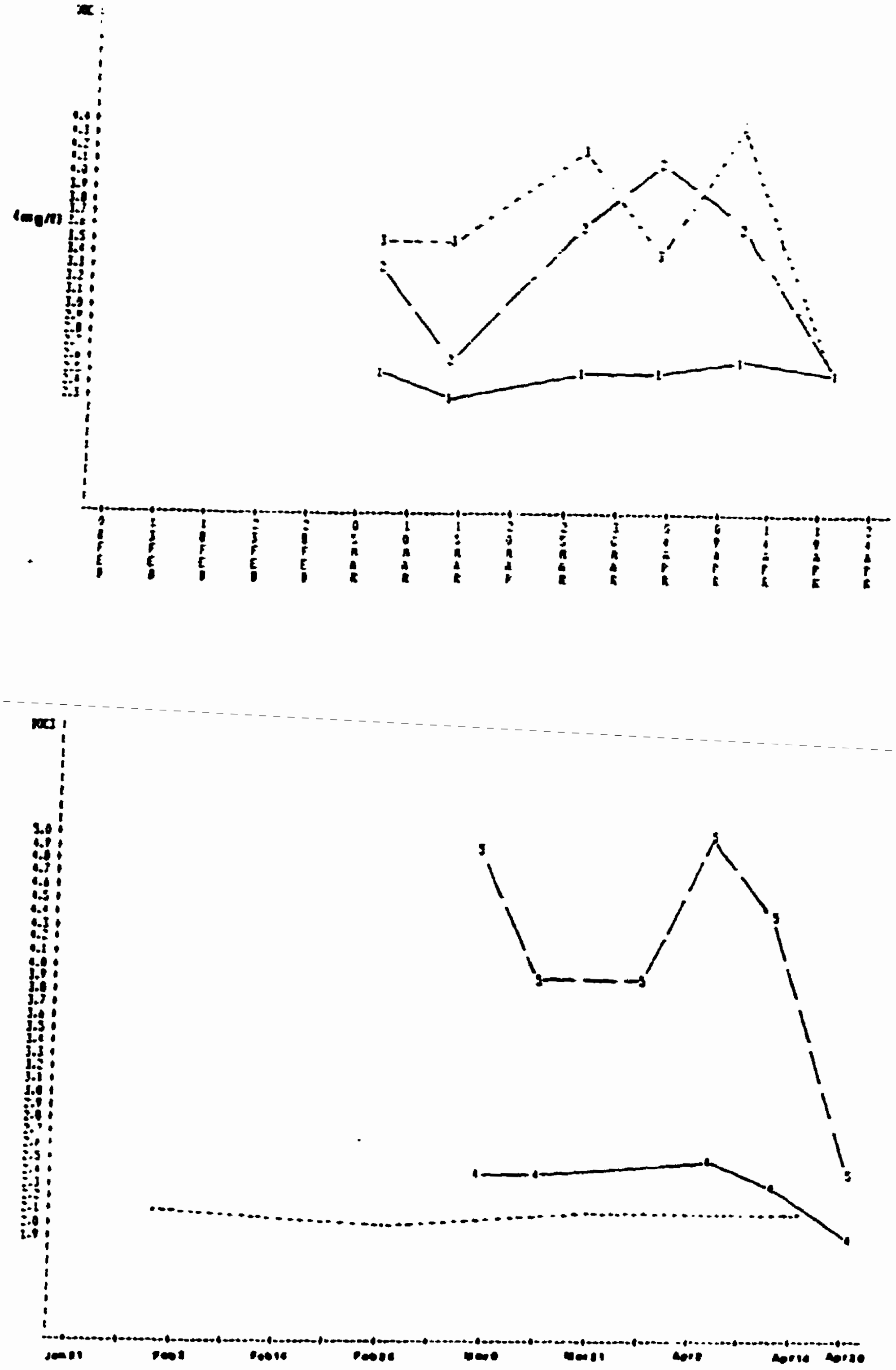
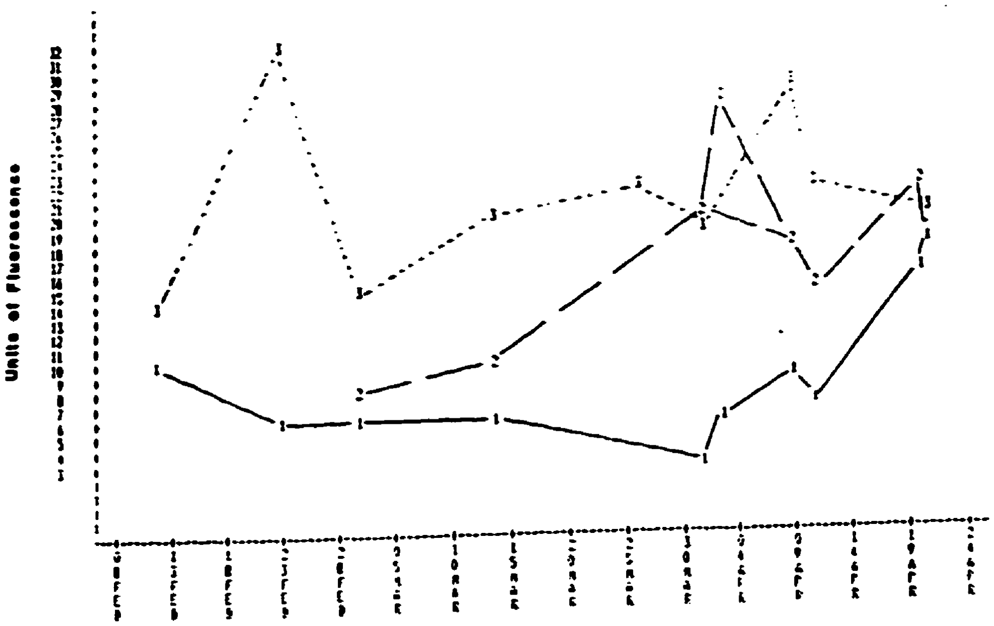
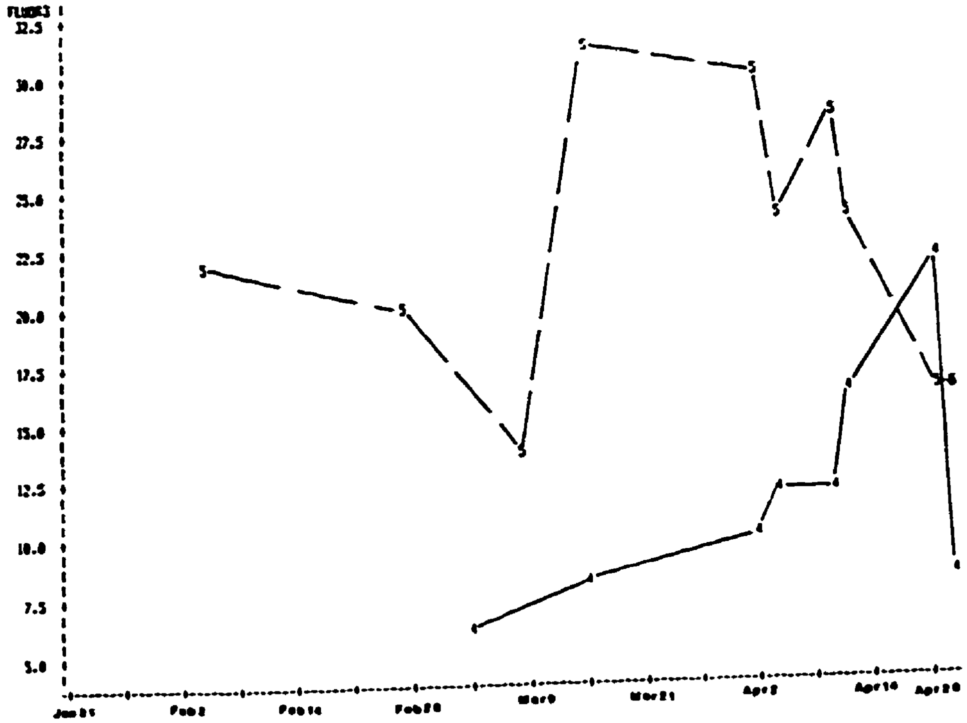


Fig. Dlo





* Lake centre natural fluorescence averaged 4 fluorescent units

Fig. D2a

SITE 19 TEMPERATURE (°C) OVER TIME

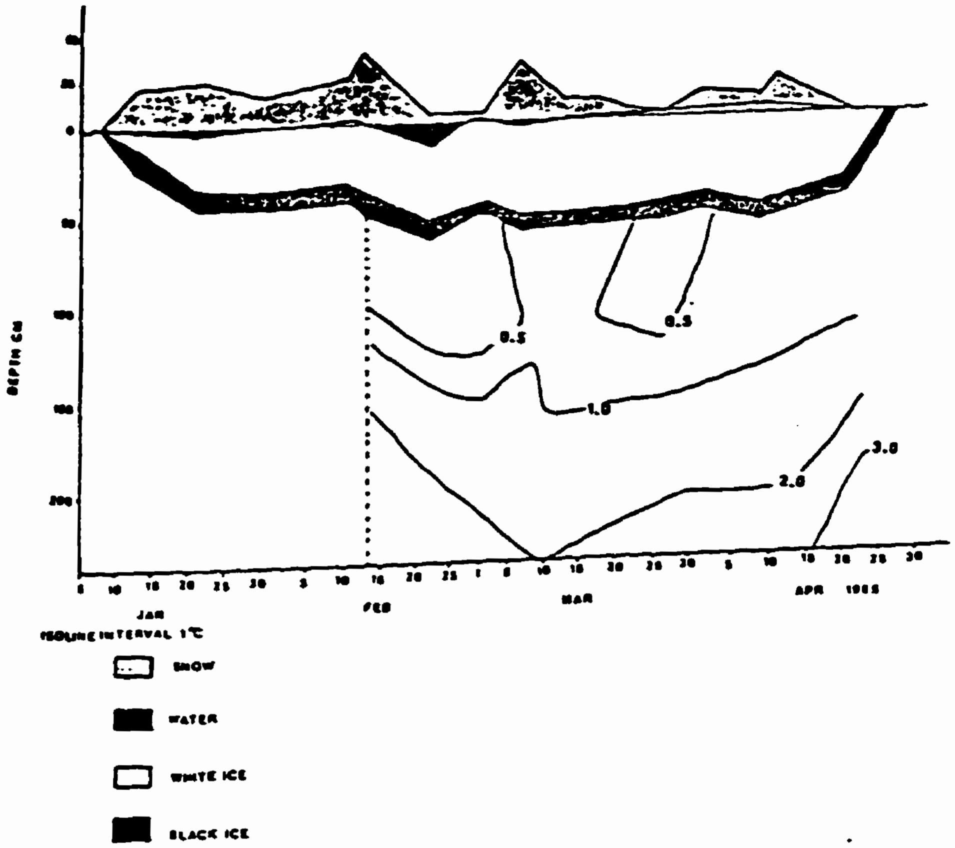


Fig. D2b

SITE 1 TEMPERATURE (°C) OVER TIME

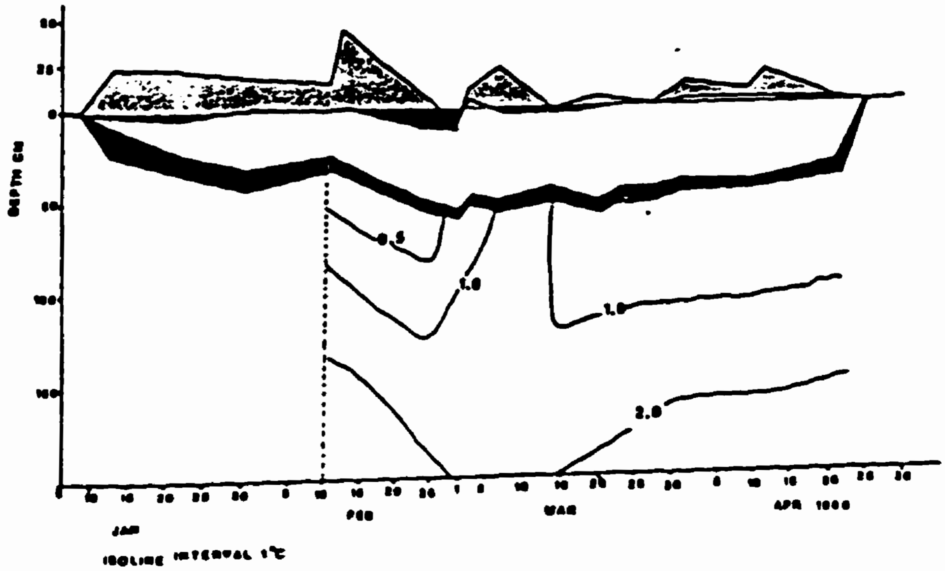


Fig. D2c SITE 31 TEMPERATURE (°C) OVER TIME

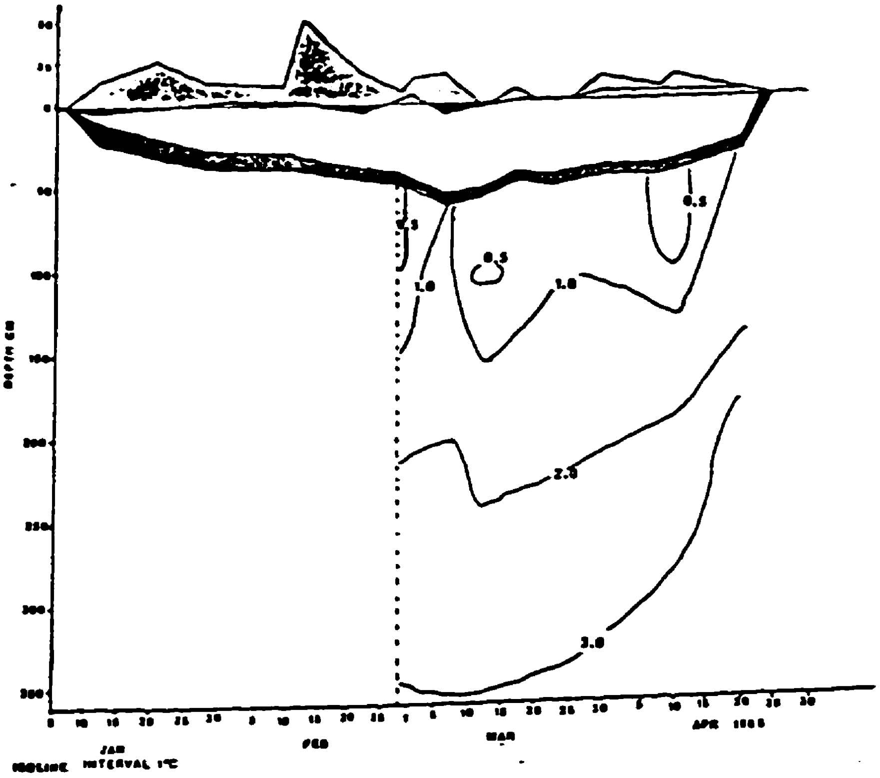


Fig. D2d SITE 311 TEMPERATURE (°C) OVER TIME

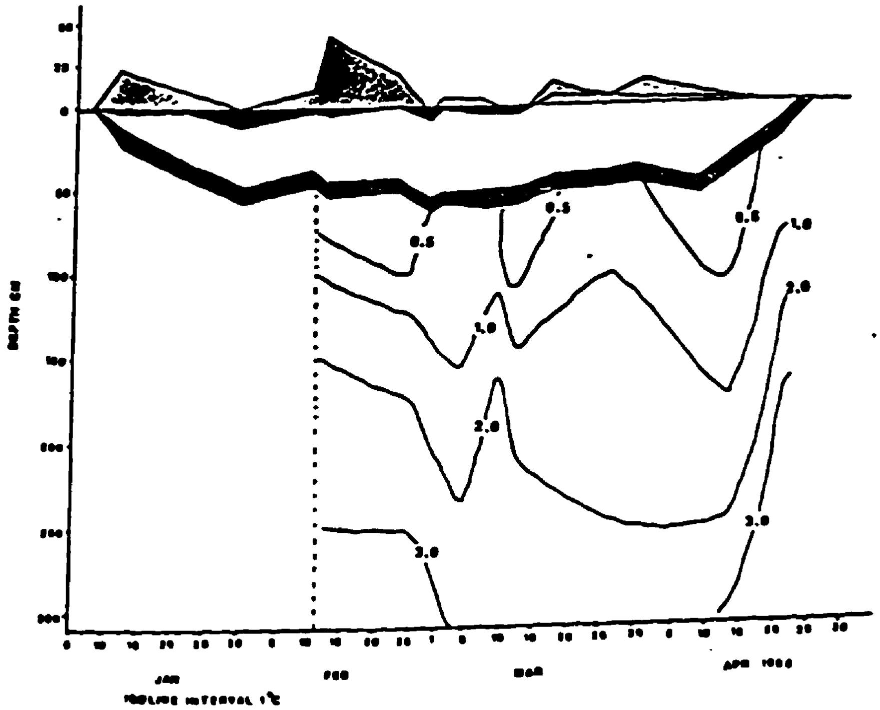


Fig. D2e

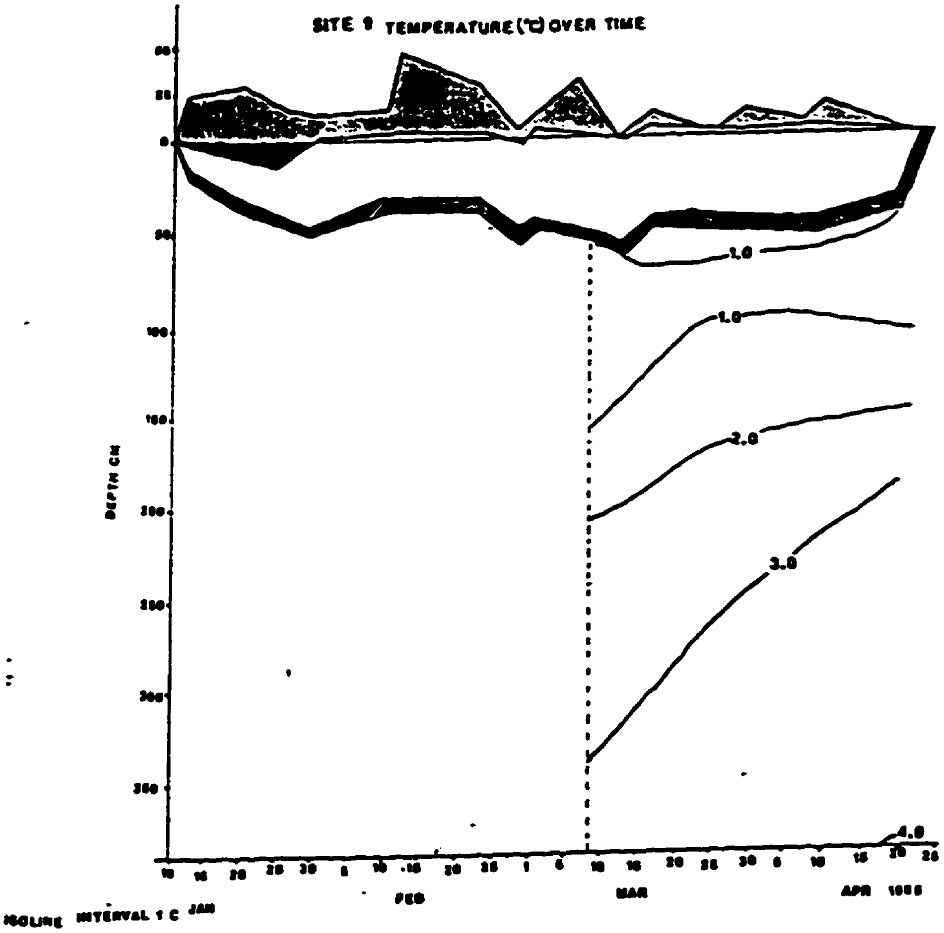

SITE 9 TEMPERATURE(°C) OVER TIME
DEPTH CM
50
25
0
50
100
150
200
250
300
350
1.0
1.0
2.0
3.0
4.0
10
15
20
25
30
5
10
15
20
25
1
5
10
15
20
25
30
5
10
15
20
25
JAN
FEB
MAR
APR 1985
ISOLINE INTERVAL 1 C

Fig. D3a SITE 19 ACIDITY(ueq) OVER TIME

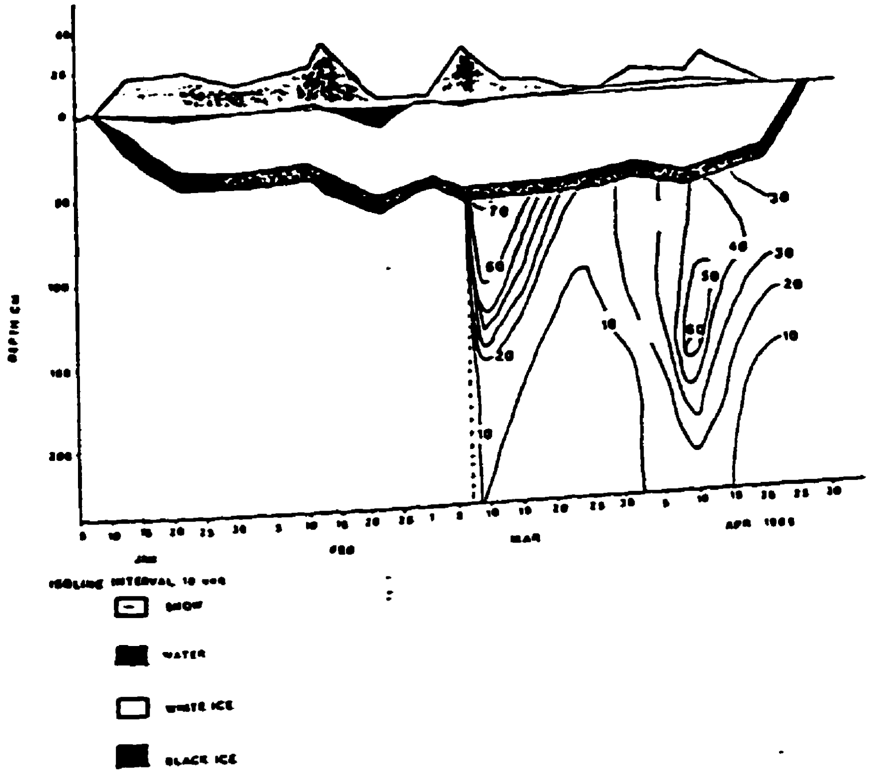


Fig. D3b SITE 1 ACIDITY (ueq)OVER TIME

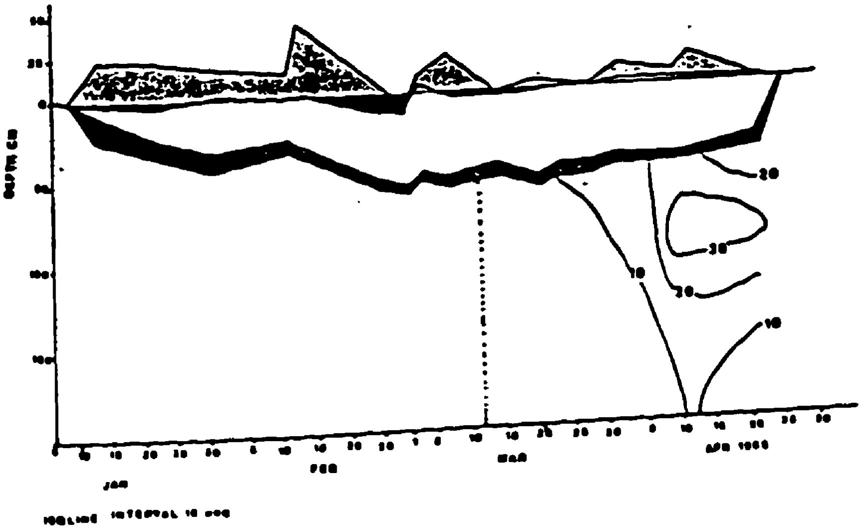


Fig. D3c SITE 31 ACIDITY(ueq)OVER TIME

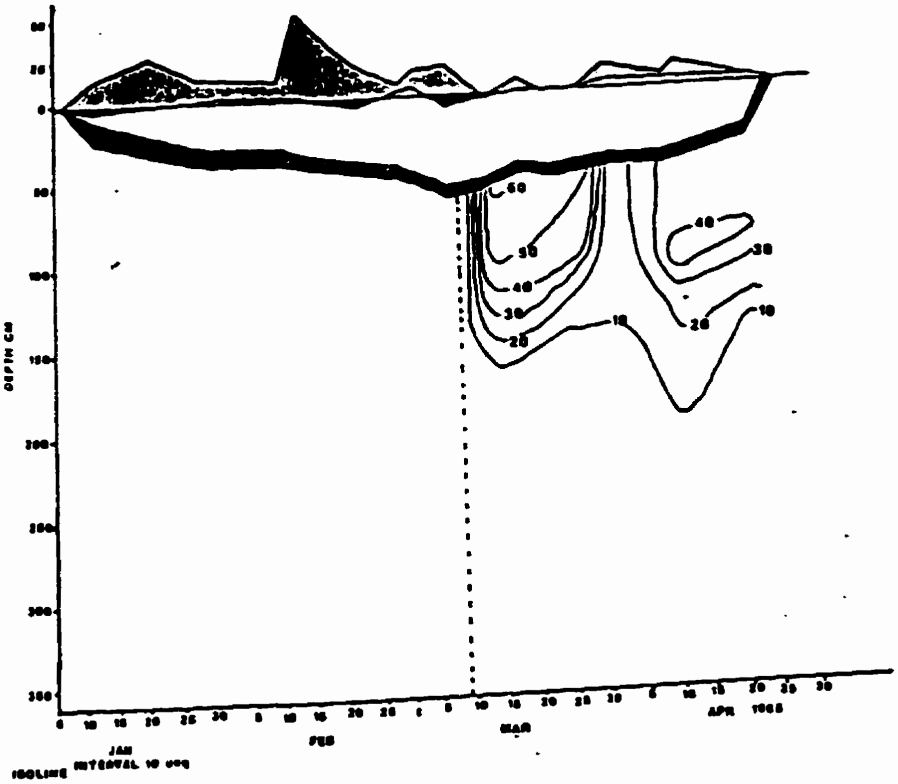


Fig. D3d SITE B11 ACIDITY(ueq)OVER TIME

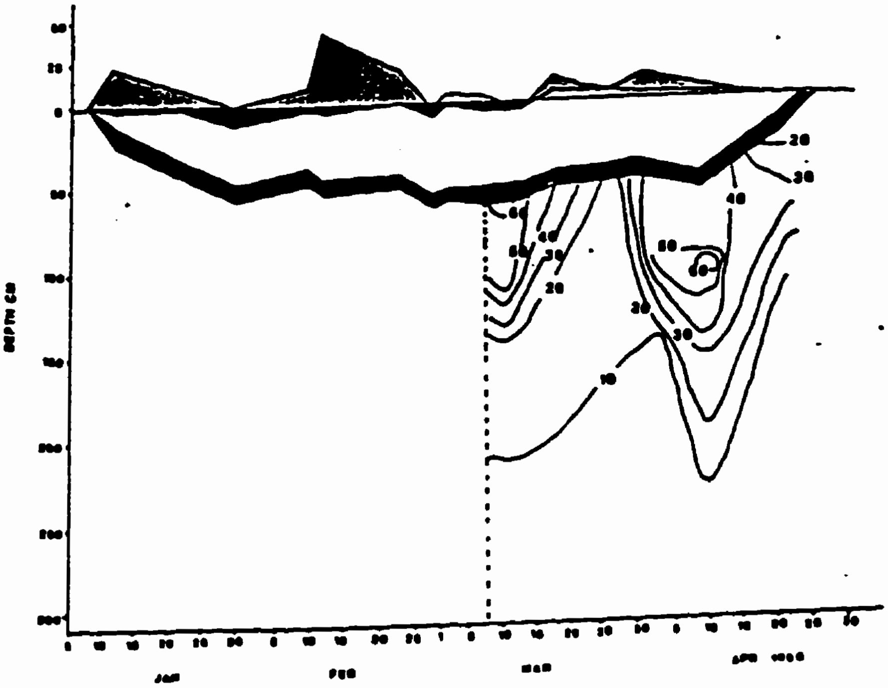


Fig. D3e

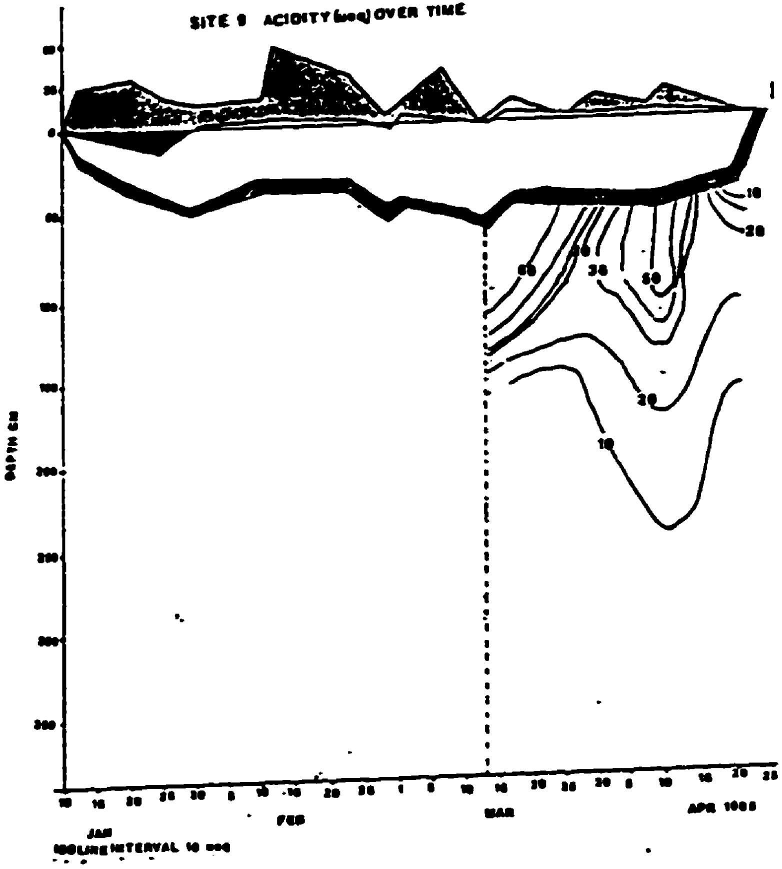

SITE 9 ACIDITY (ueq) OVER TIME
DEPTH CM
0
50
100
150
200
250
300
350
10
20
60
40
30
50
20
10
10
15
20
25
30
5
10
15
20
25
1
5
10
15
20
25
30
5
10
15
20
25
JAN
FEB
MAR
APR 1985
ISOLINE INTERVAL 10 ueq

Fig. D4a SITE 19 SPECIFIC CONDUCTANCE(µS) OVER TIME

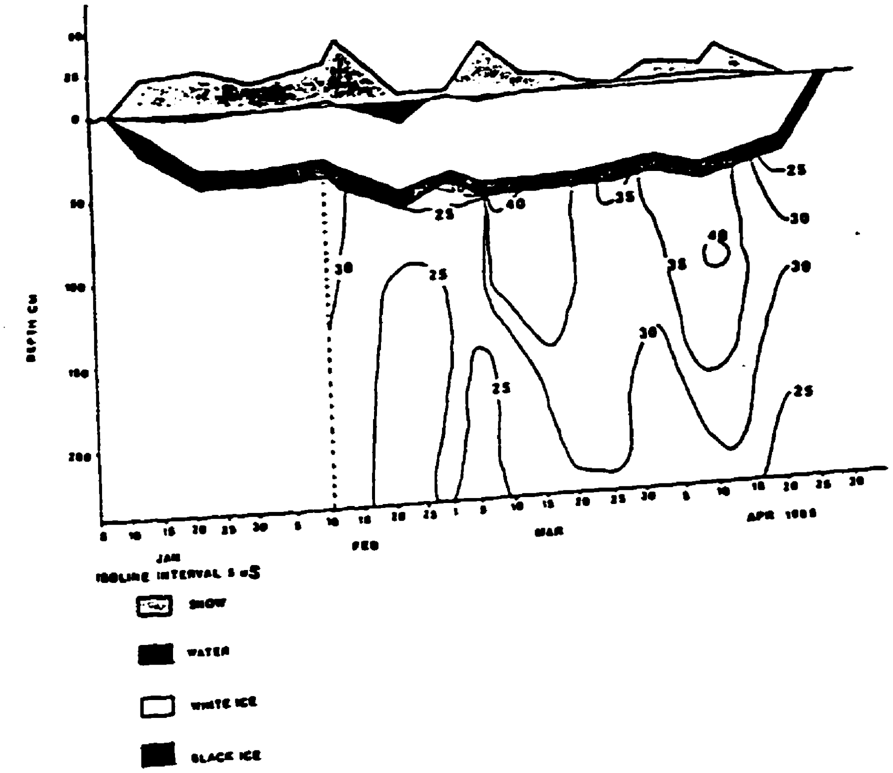


Fig. D4b SITE 1 SPECIFIC CONDUCTANCE(uS)OVER TIME

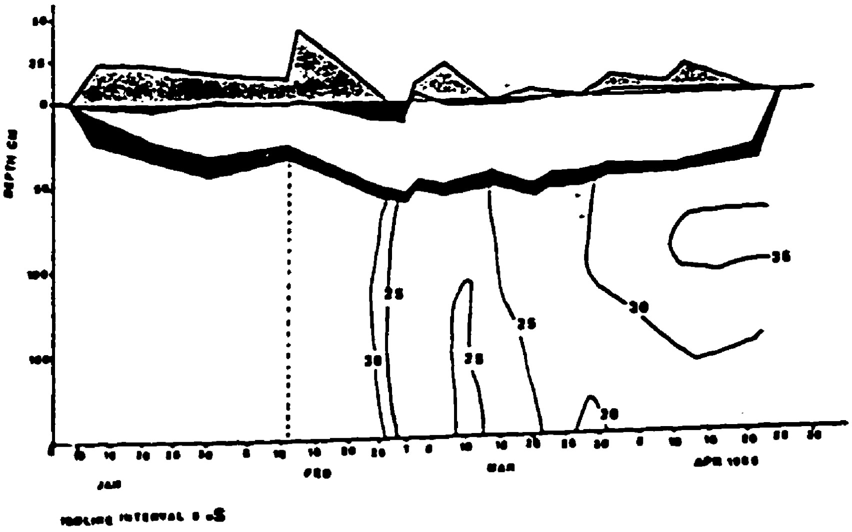


Fig. D4c SITE S1 SPECIFIC CONDUCTANCE (uS) OVER TIME

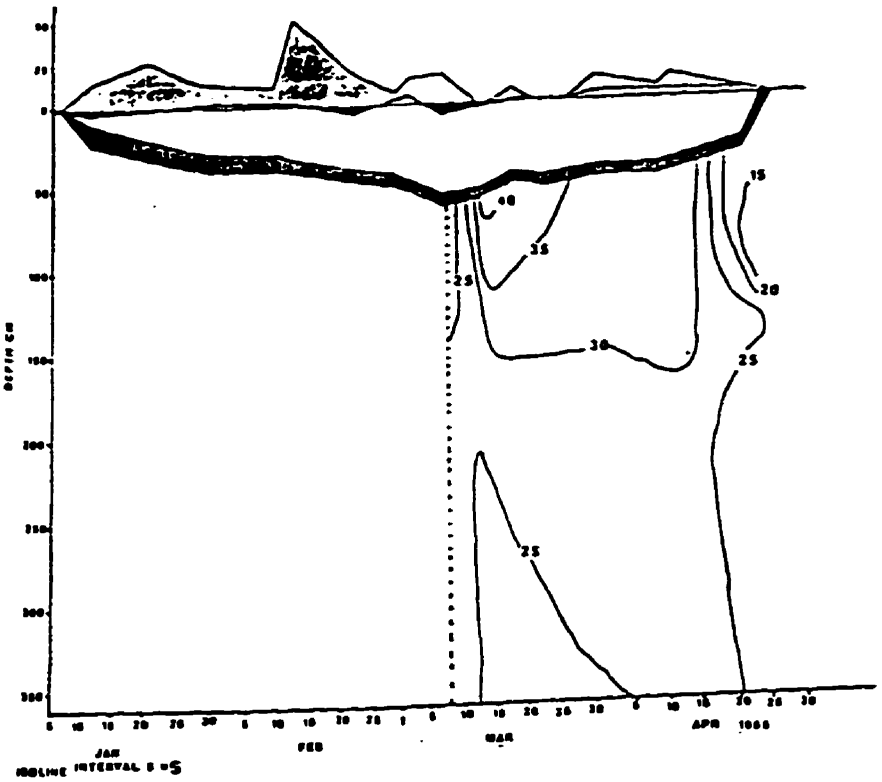


Fig. D4d SITE S11 SPECIFIC CONDUCTANCE (uS) OVER TIME

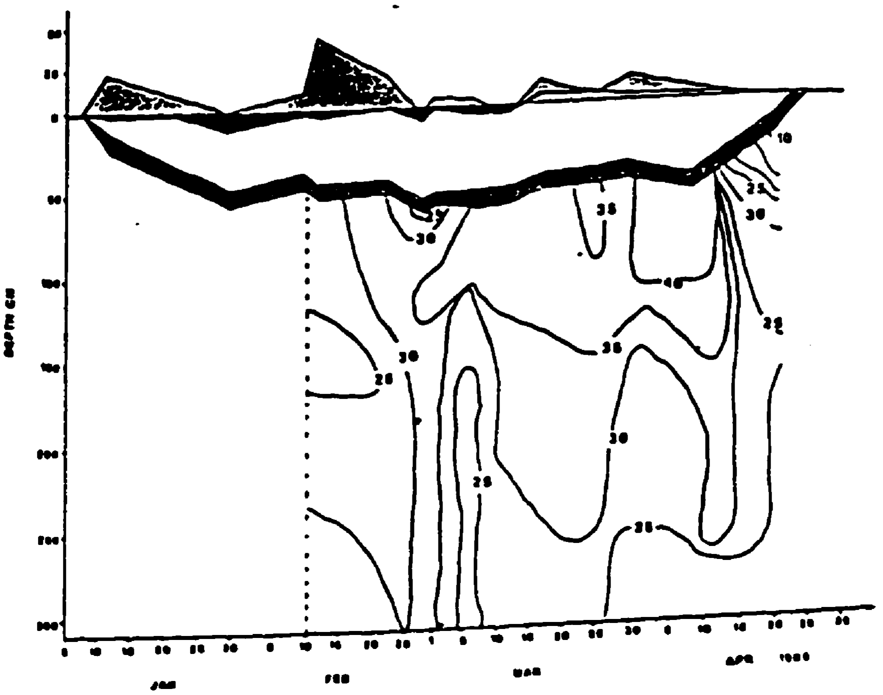


Fig. D4e

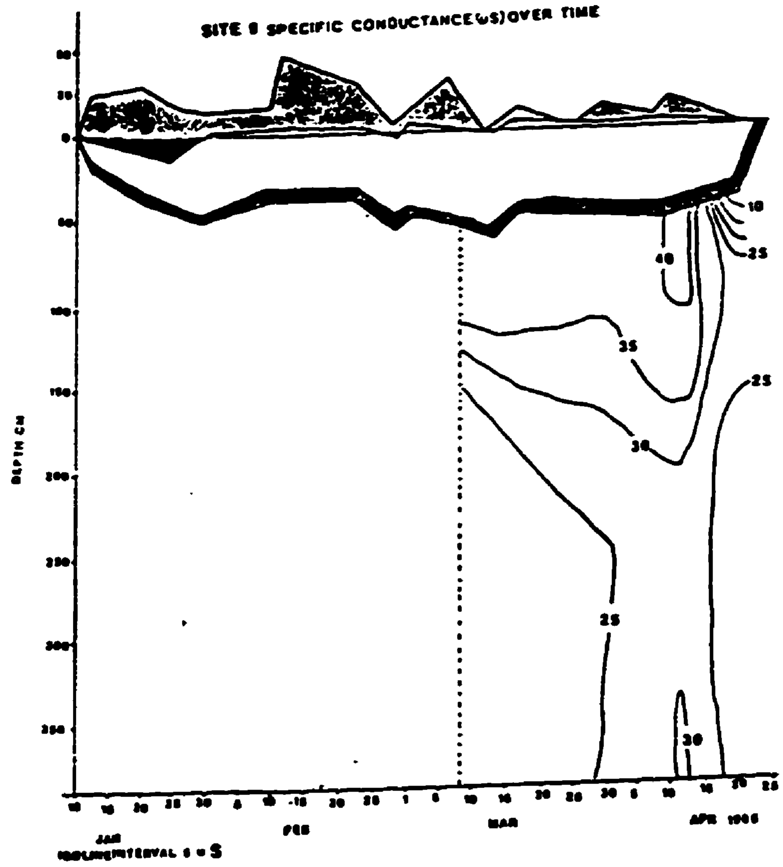

SITE 8 SPECIFIC CONDUCTANCE(uS) OVER TIME
50
25
0
50
100
150
200
250
300
350
DEPTH CM
10
25
40
25
35
30
25
25
30
10
15
20
25
30
5
10
15
20
25
1
5
10
15
20
25
30
5
10
15
20
25
JAN
FEB
MAR
APR 1985
ISOLINE INTERVAL = 5

Fig. D5a

SITE 19 NATURAL FLUORESCENCE (fluorescence units) OVER TIME

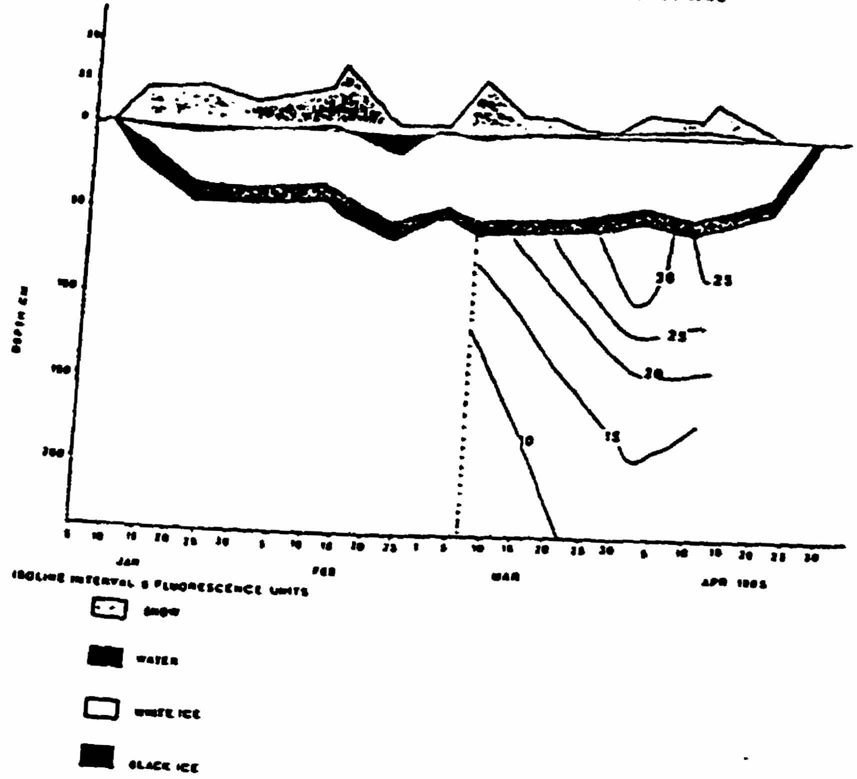


Fig. D5b

SITE 1 NATURAL FLUORESCENCE (fluorescence units) OVER TIME

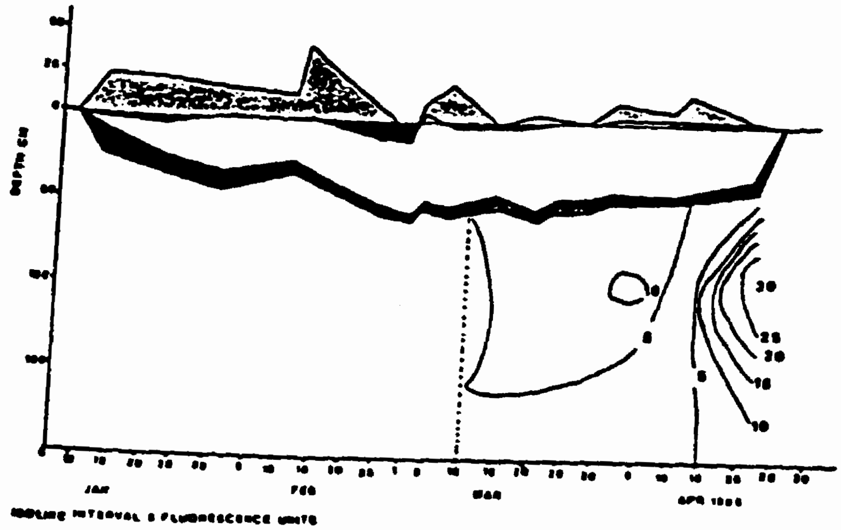


Fig. D5c SITE 31 NATURAL FLUORESCENCE (fluorescence units) OVER TIME

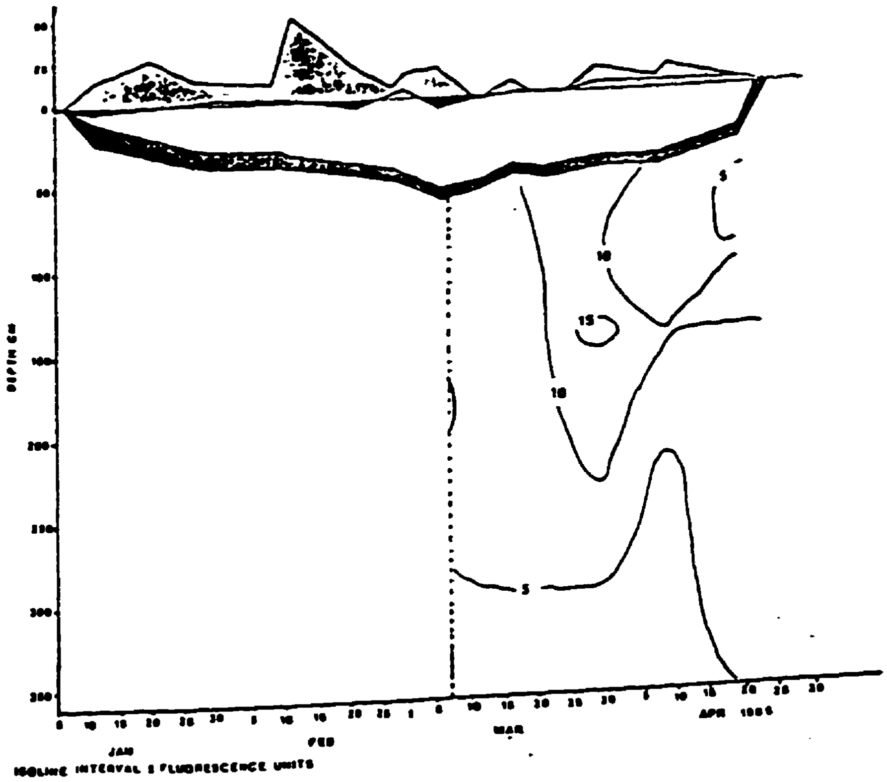


Fig. D5d SITE B11 NATURAL FLUORESCENCE (fluorescence units) OVER TIME

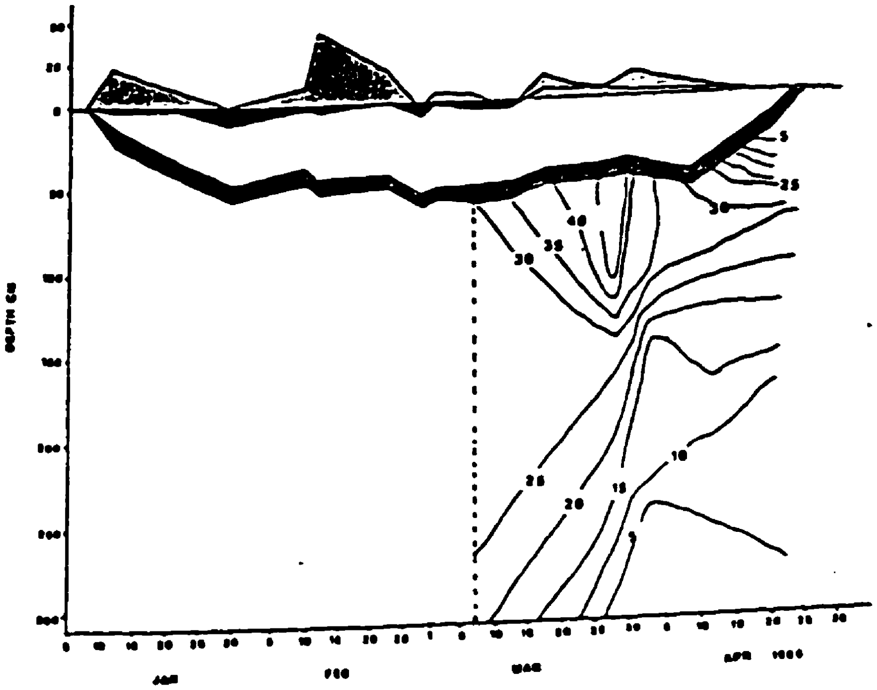


Fig. D5e

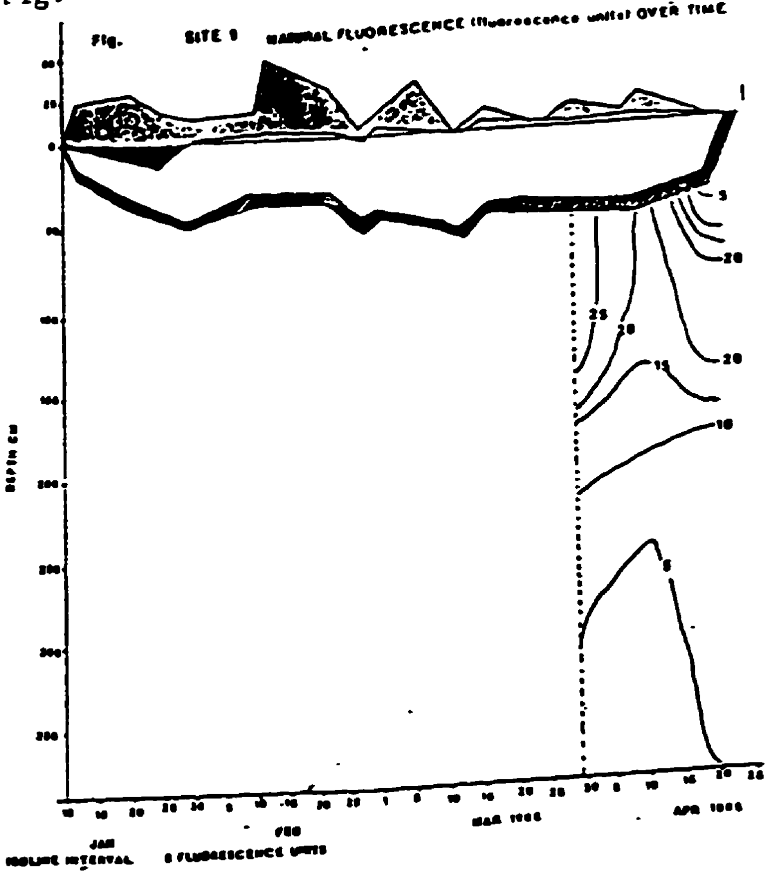


Fig. SITE 1 NATURAL FLUORESCENCE (fluorescence units) OVER TIME
DEPTH CM
0
50
100
150
200
250
300
350
1
5
20
25
20
20
15
10
5
10 15 20 25 30 5 10 15 20 25 1 5 10 15 20 25 30 5 10 15 20 25
JAN
FEB
MAR 1986
APR 1986
ISOLINE INTERVAL 5 FLUORESCENCE UNITS

Fig. D6a

# 1985 Plastic Lake Surface Acidity (ueq/l)

FEB 12

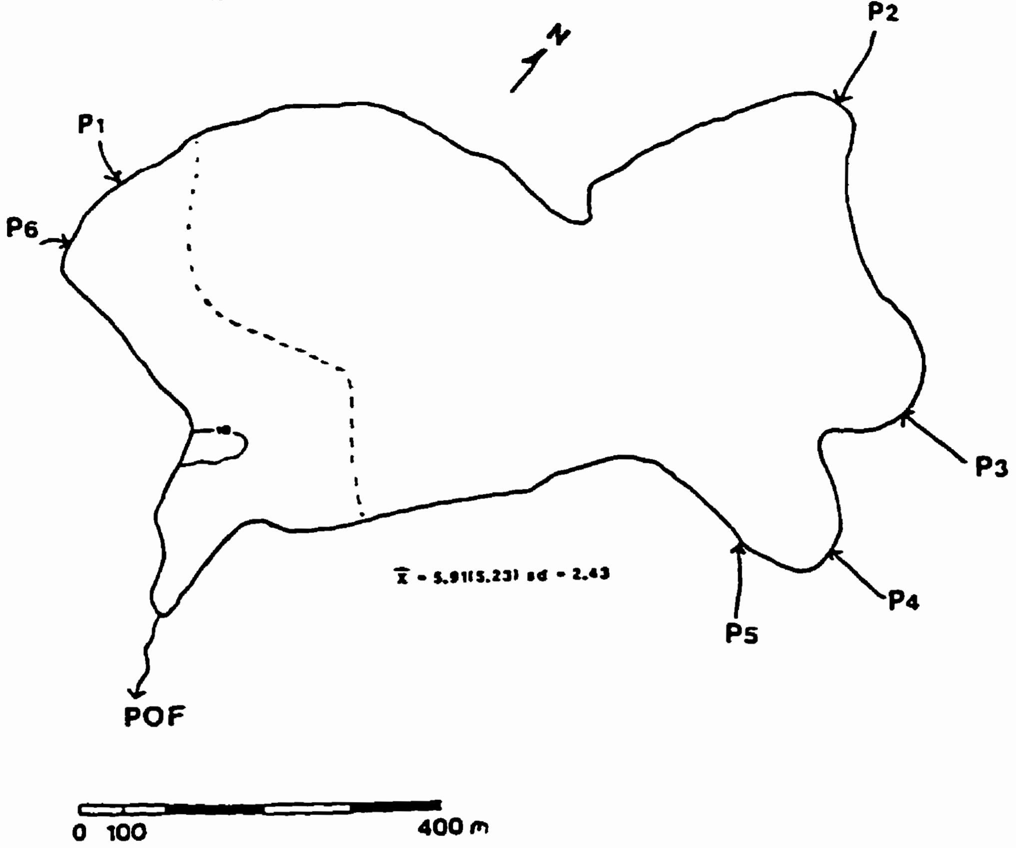
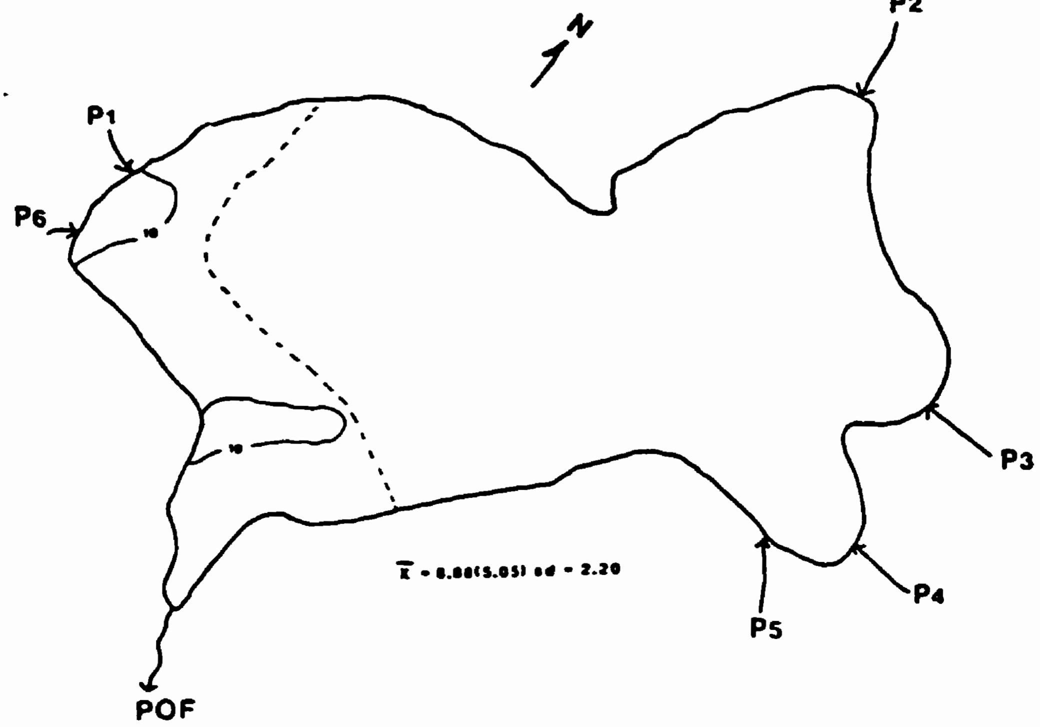


Fig. D6b

FEB 23



isoline interval 10 ueq/l

## 1985 Plastic Lake Surface Acidity (ueq/l)

·Fig. D6c MAR 2

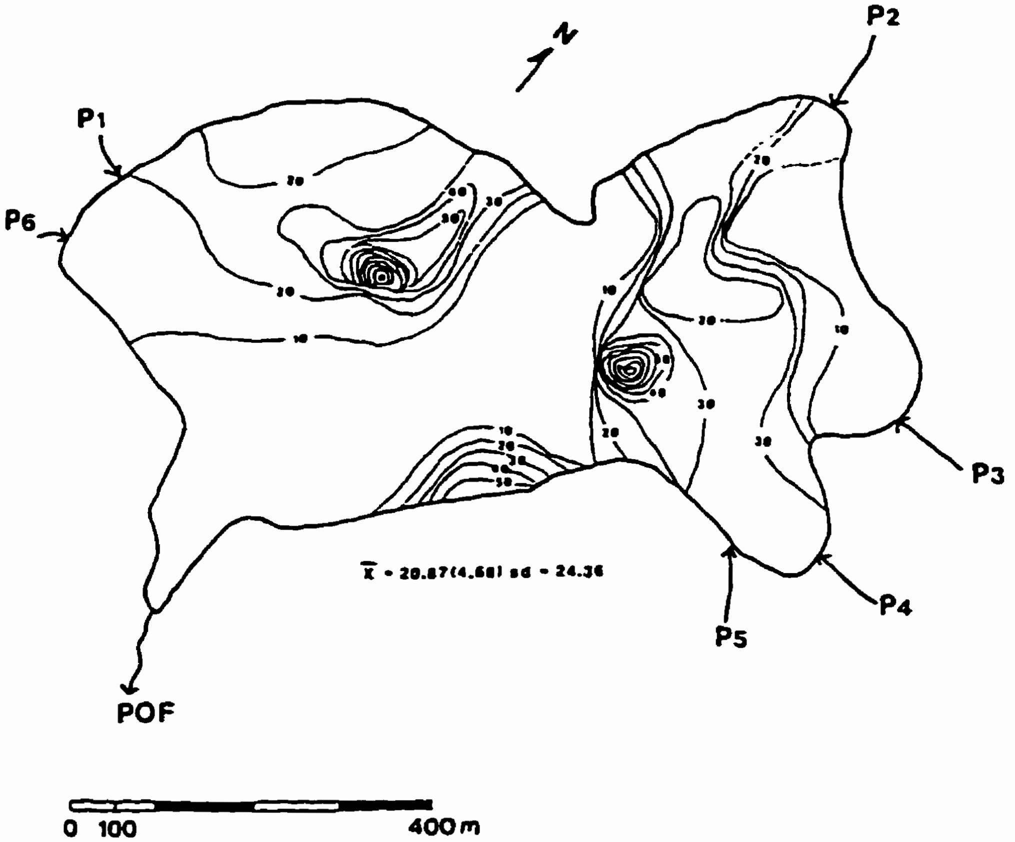


Fig. D6d MAR 13

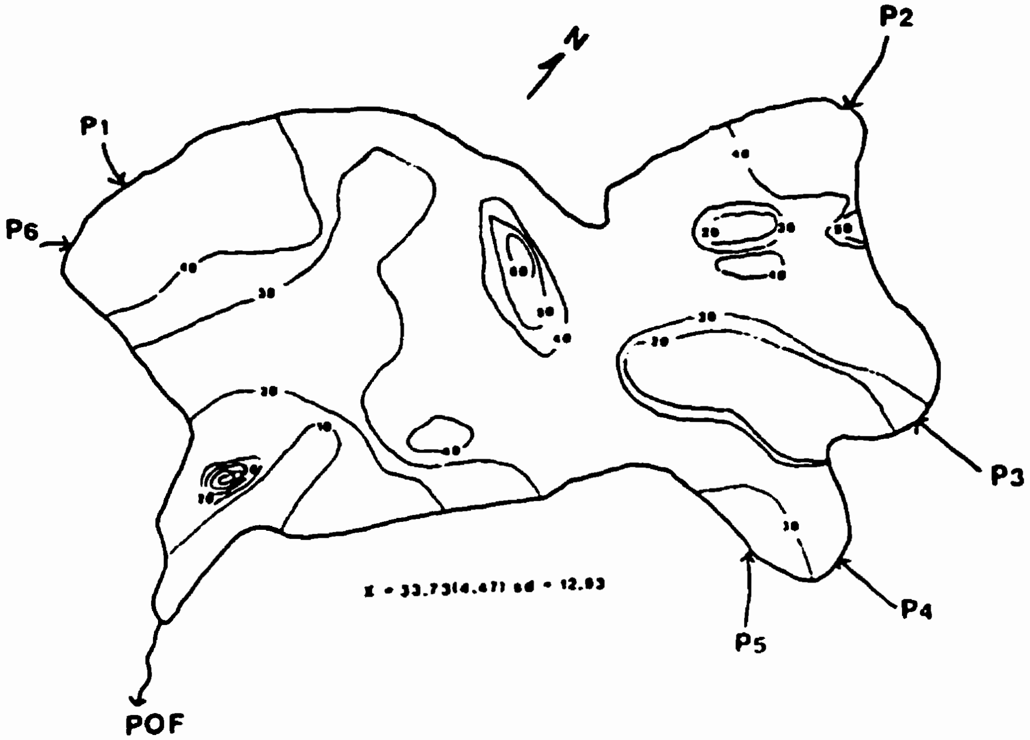


Fig. D6e

# 1985 Plastic Lake Surface Acidity (ueq/l)

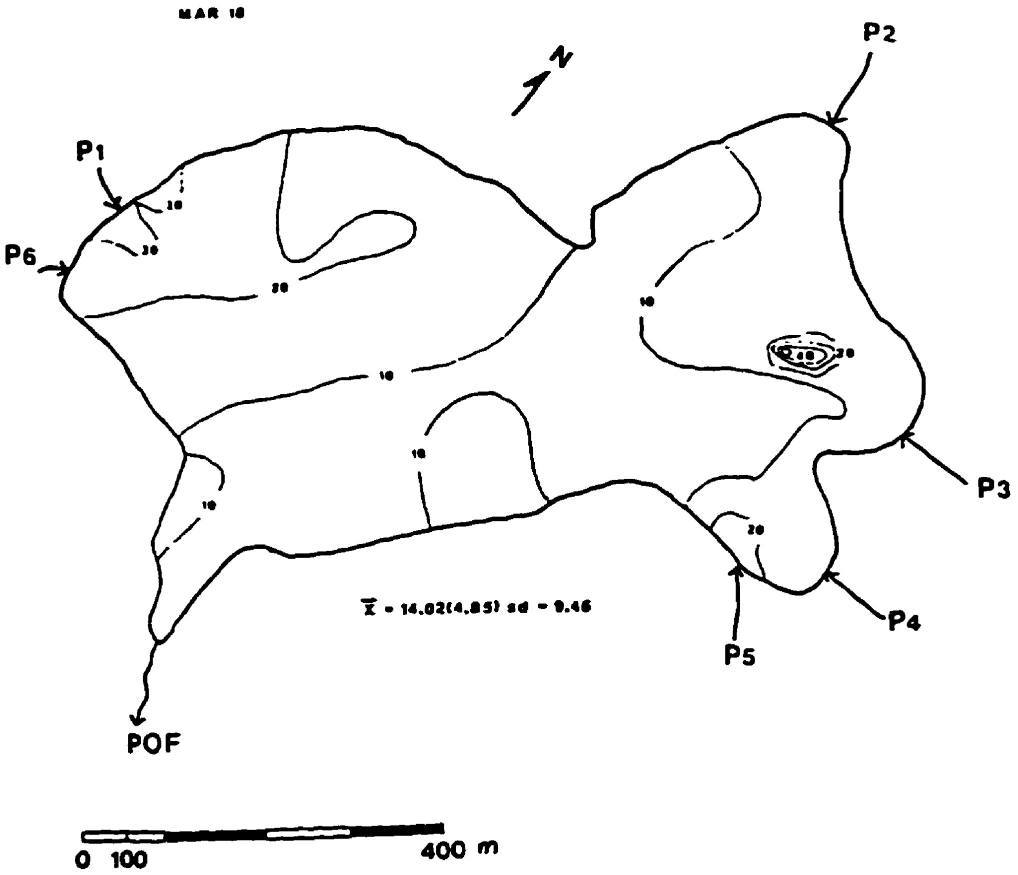


Fig. D6f

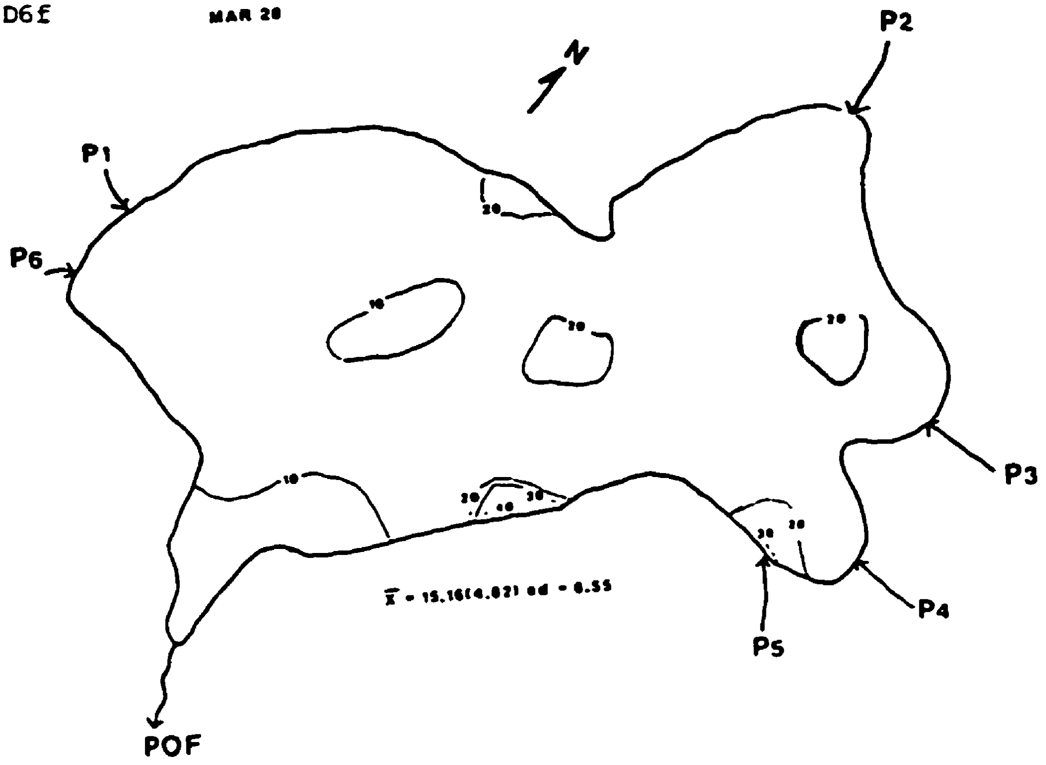


Fig. D6g

# 1985 Plastic Lake Surface Acidity (ueq/l)

APRIL 1

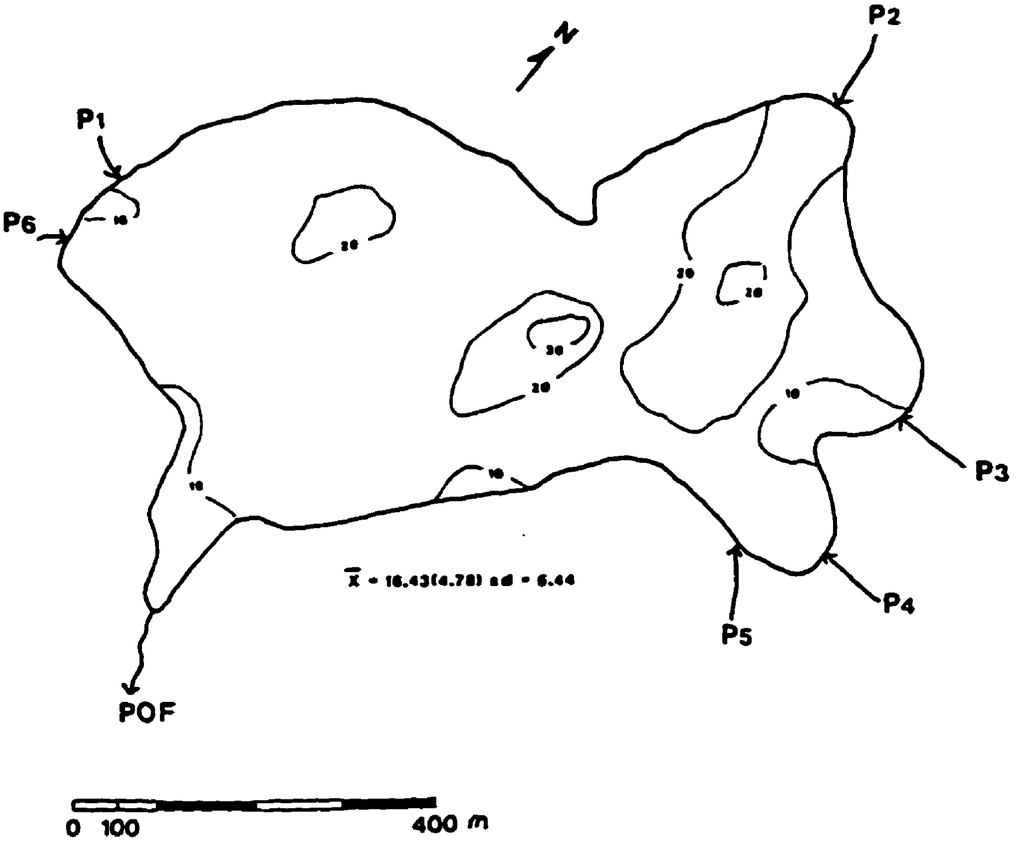
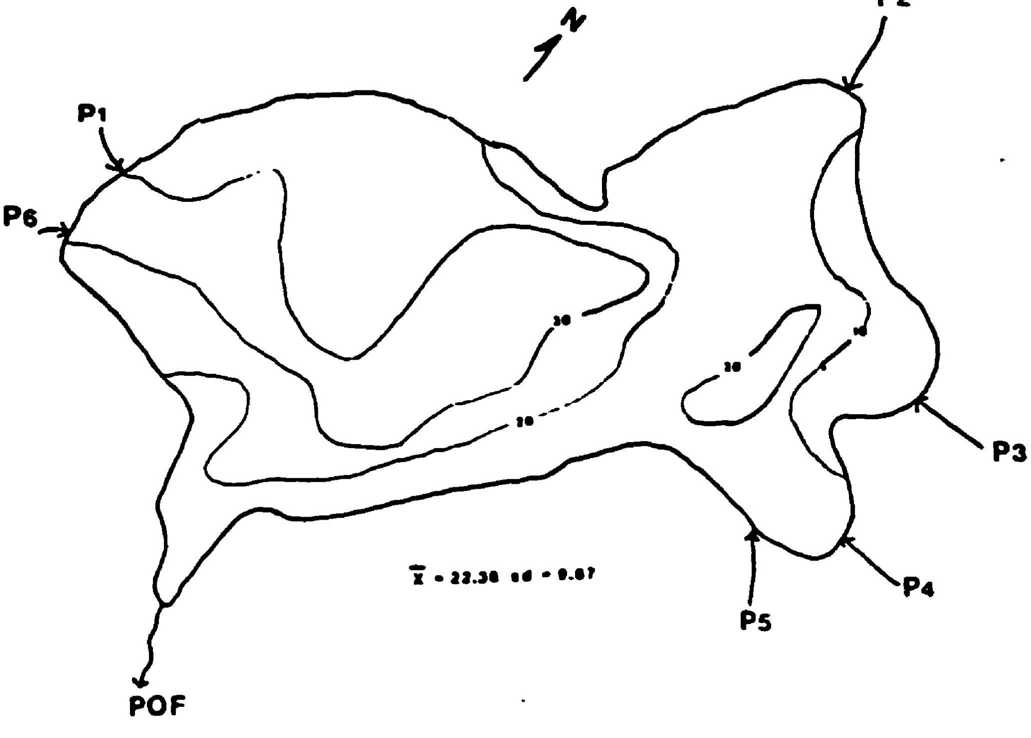


Fig. D6h

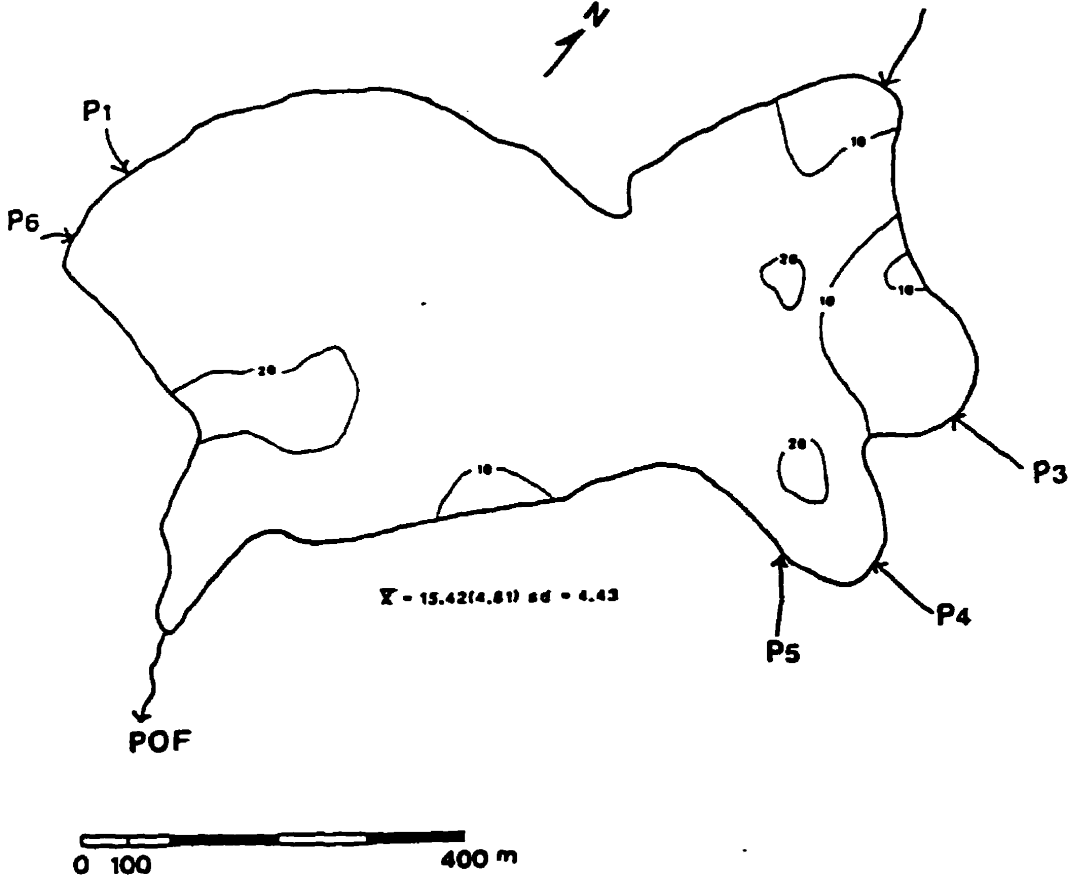
APRIL 9/10



# 1985 Plastic Lake Surface Acidity

Fig. D6i

APRIL 21



$\bar{X}$ = 15.42(4.81) sd = 4.43

# 1985 Plastic Lake Surface Conductance (uS/cm)

Fig. D7a FEB 12

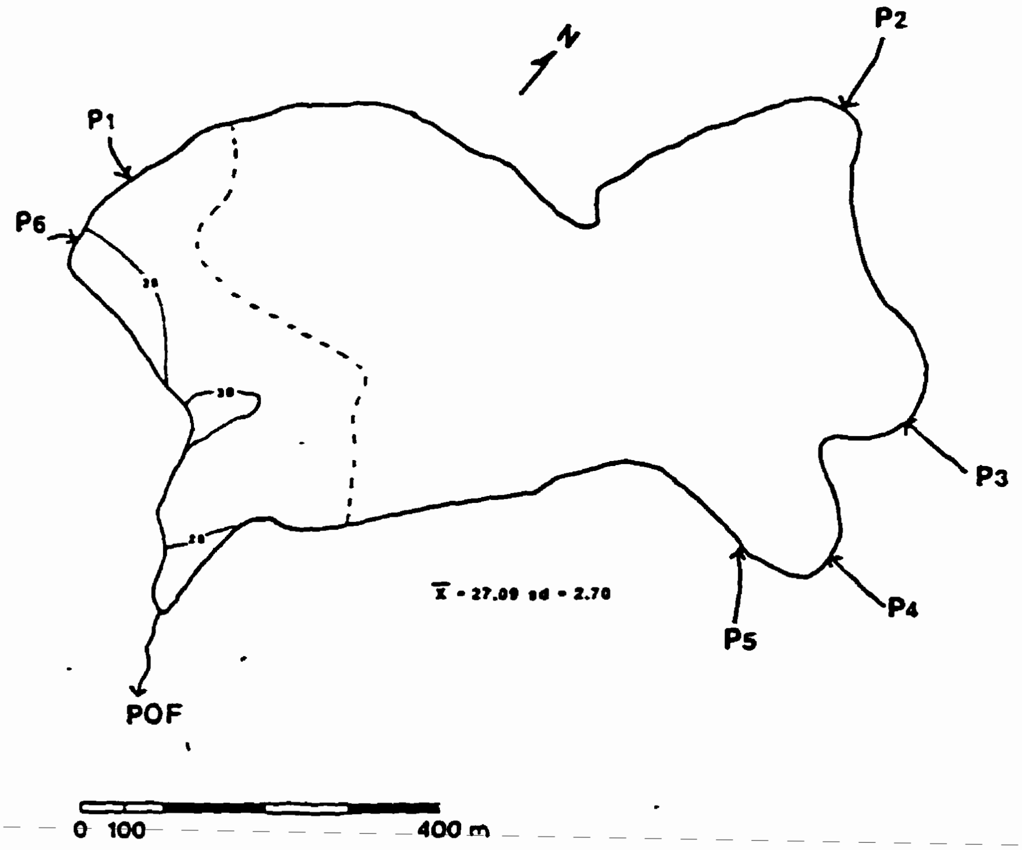
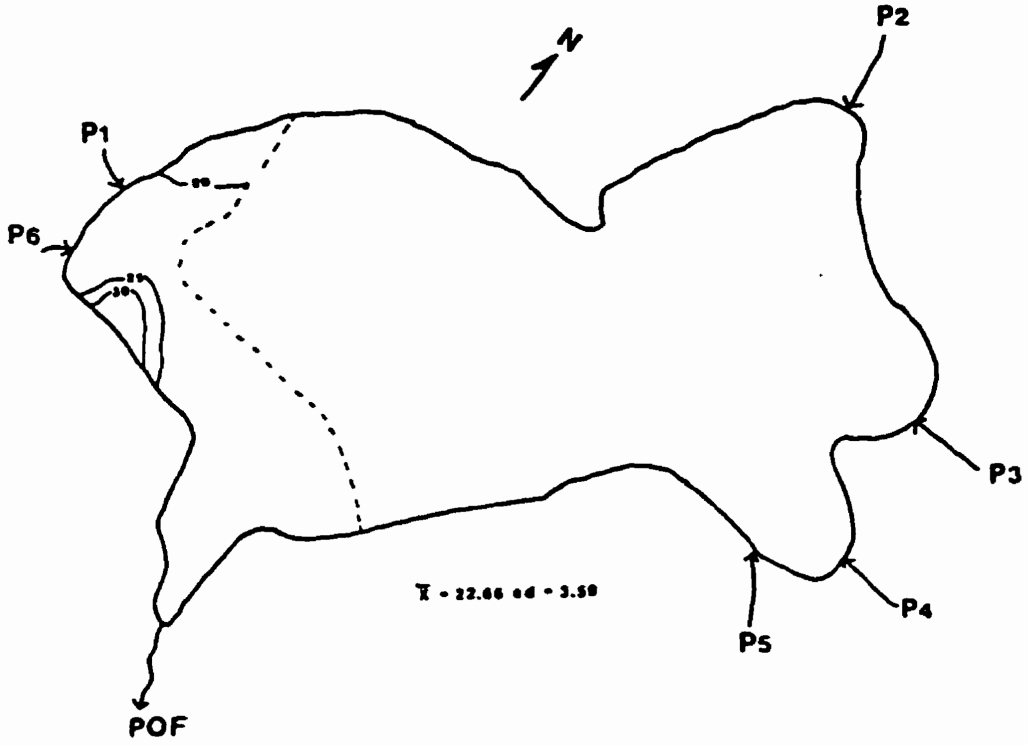


Fig. D7b FEB 23



isoline interval 5 uS/cm

## 1985 Plastic Lake Surface Conductance (uS/cm)

Fig. D7c MAR 2

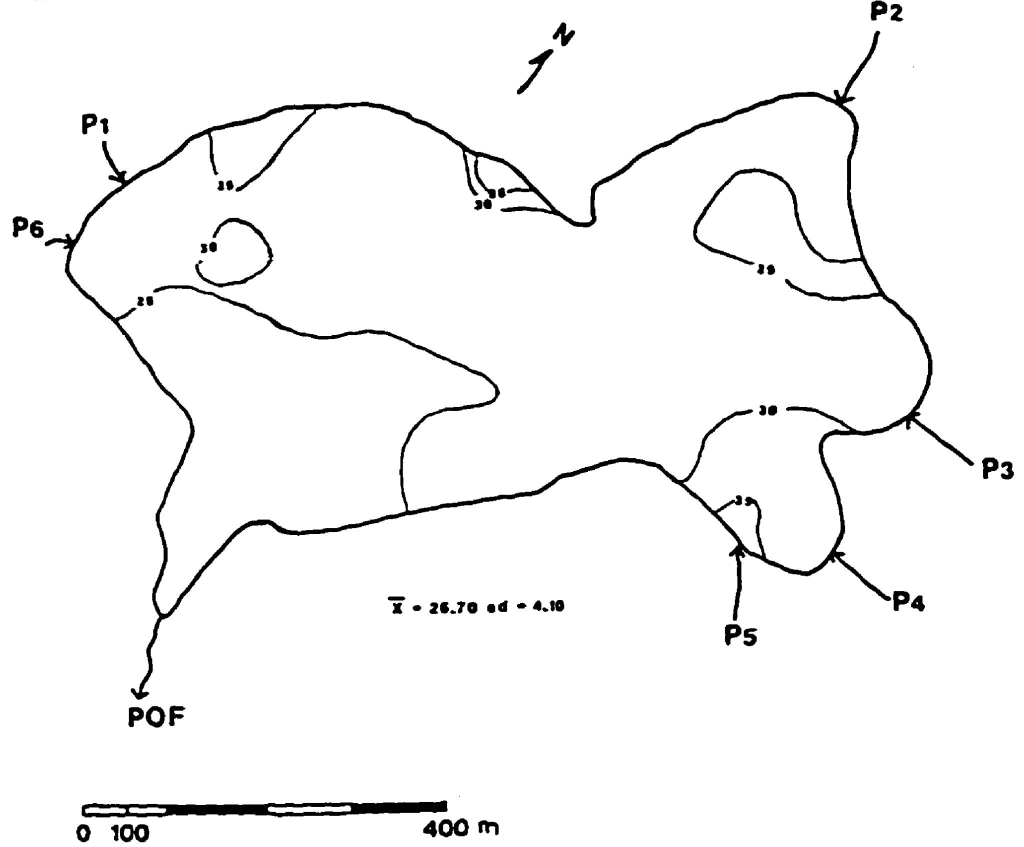
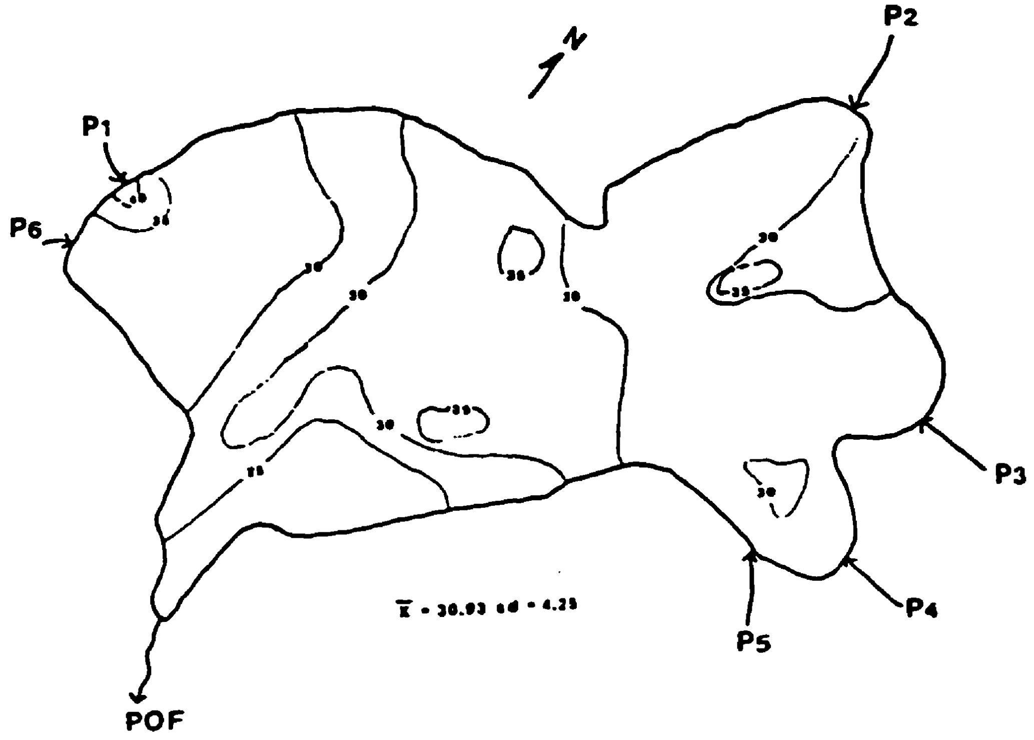


Fig. D7d Mar 13



# 1985 Plastic Lake Surface Conductance (uS/cm)

Fig. D7e MAR 28

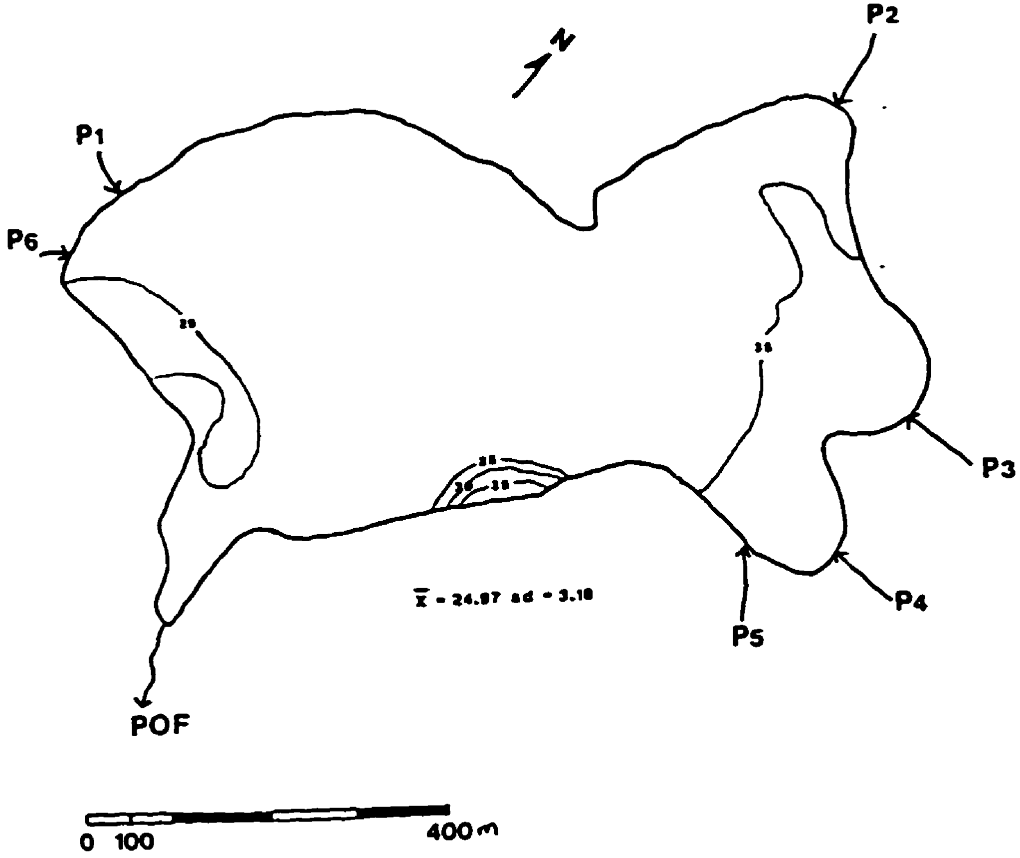
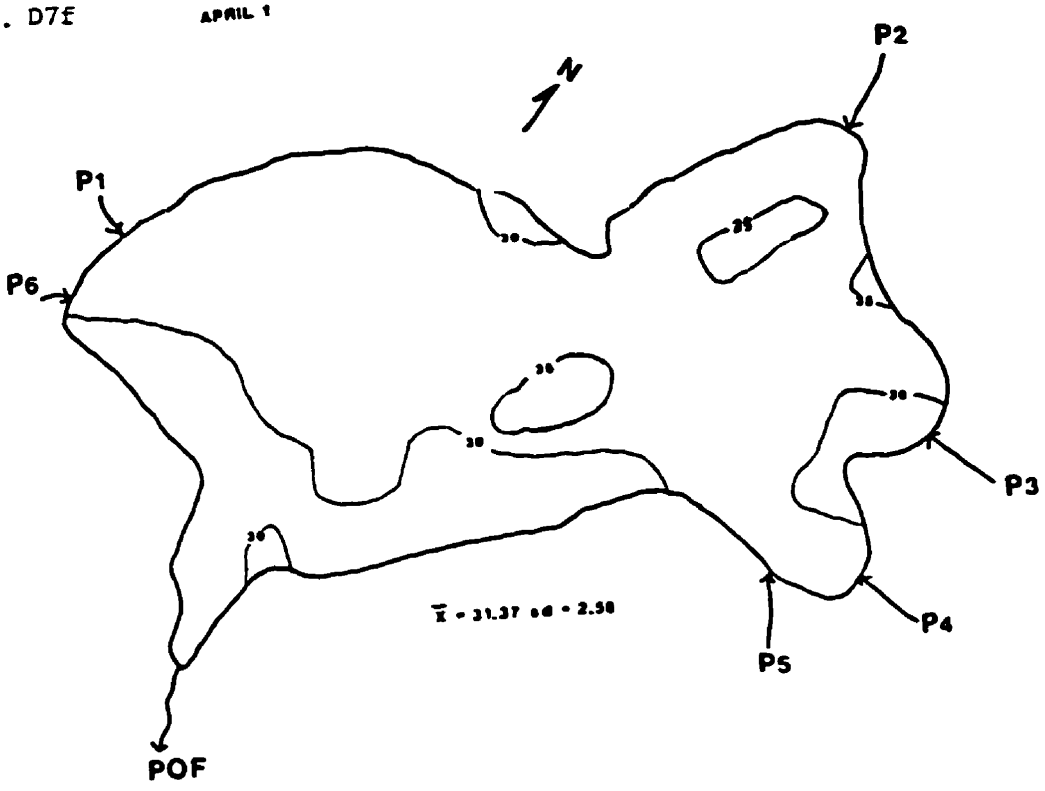


Fig. D7f APRIL 1



# 1985 Plastic Lake Surface Conductance (uS/cm)

Fig. D7g APRIL 9/11

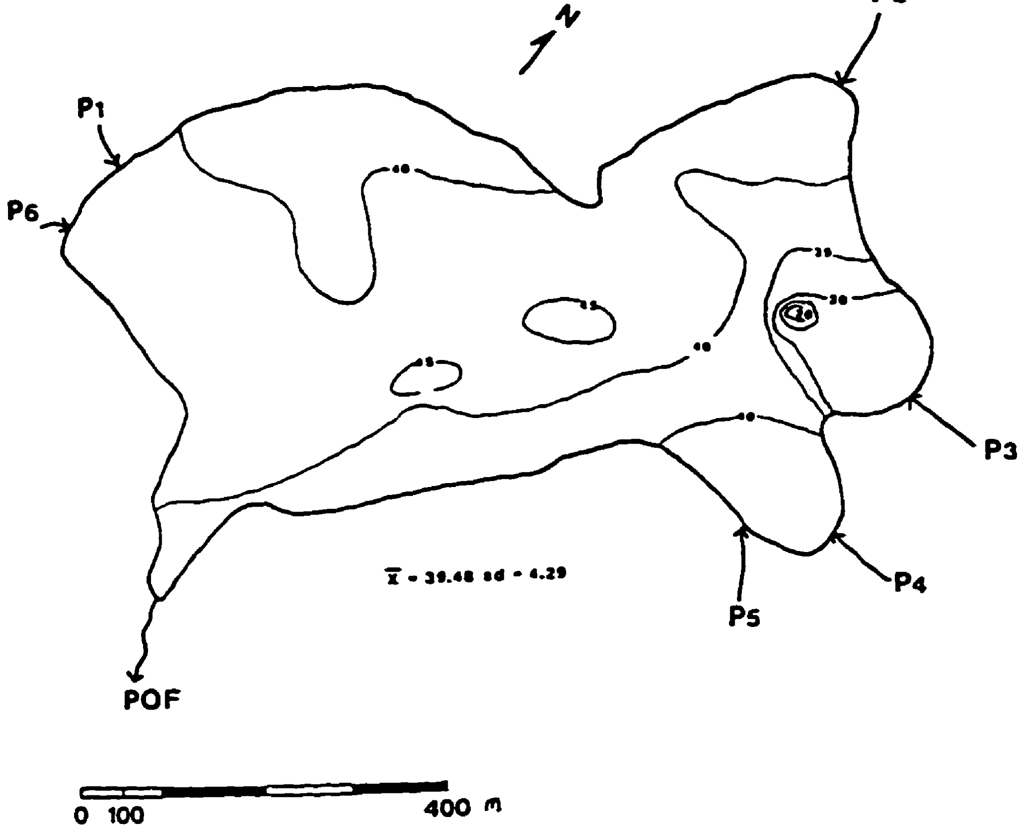
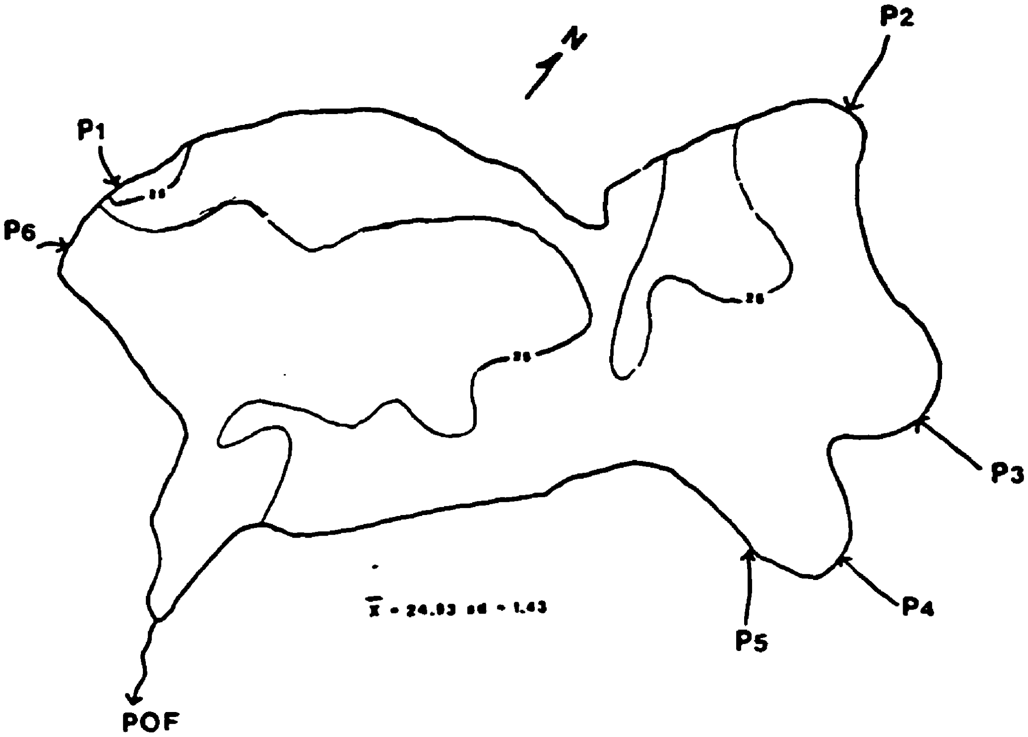


Fig. D7h APRIL 21



## 1985 Plastic Lake Surface Natural Fluorescence (fluorescence units)

Fig. D8a FEBRUARY 12

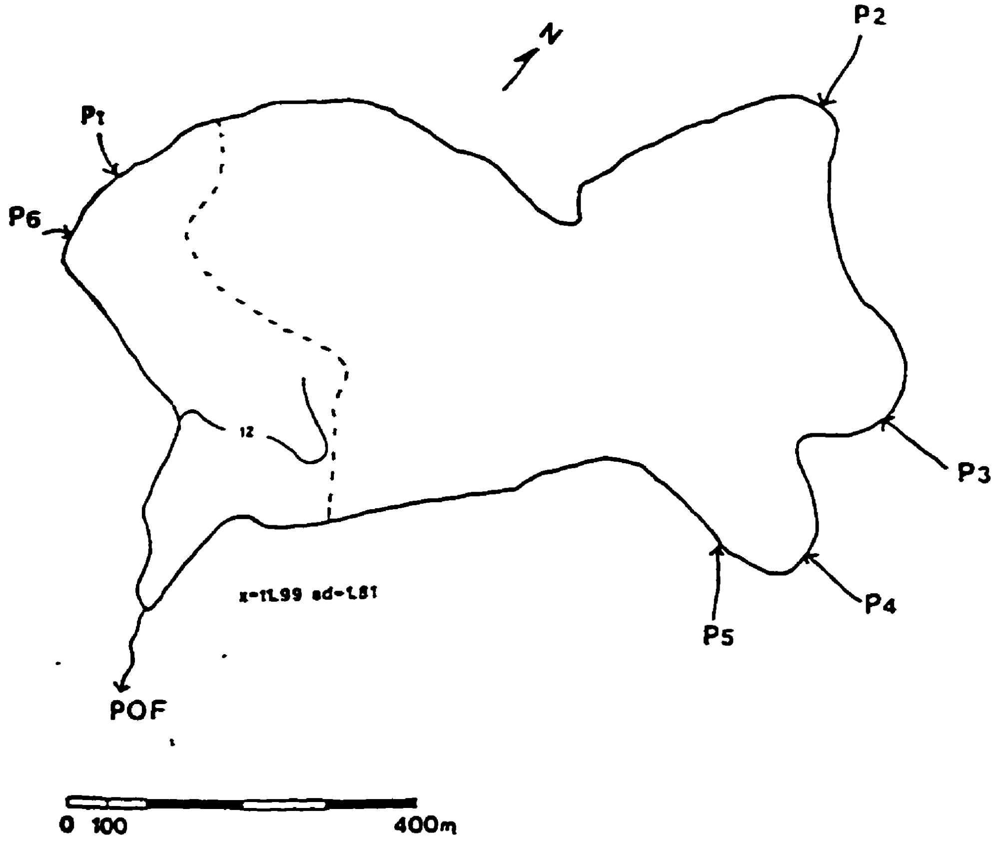
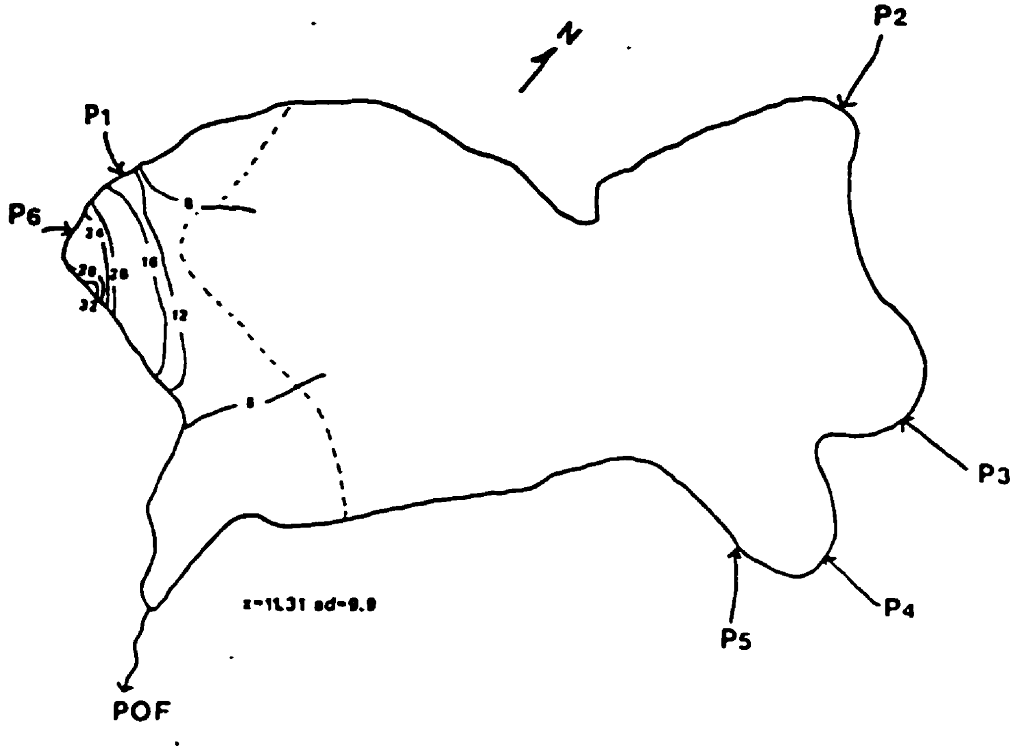


Fig. D8b FEBRUARY 23



## 1985 Plastic Lake Surface Natural Fluorescence (fluorescence units)

Fig. D8c MARCH 2

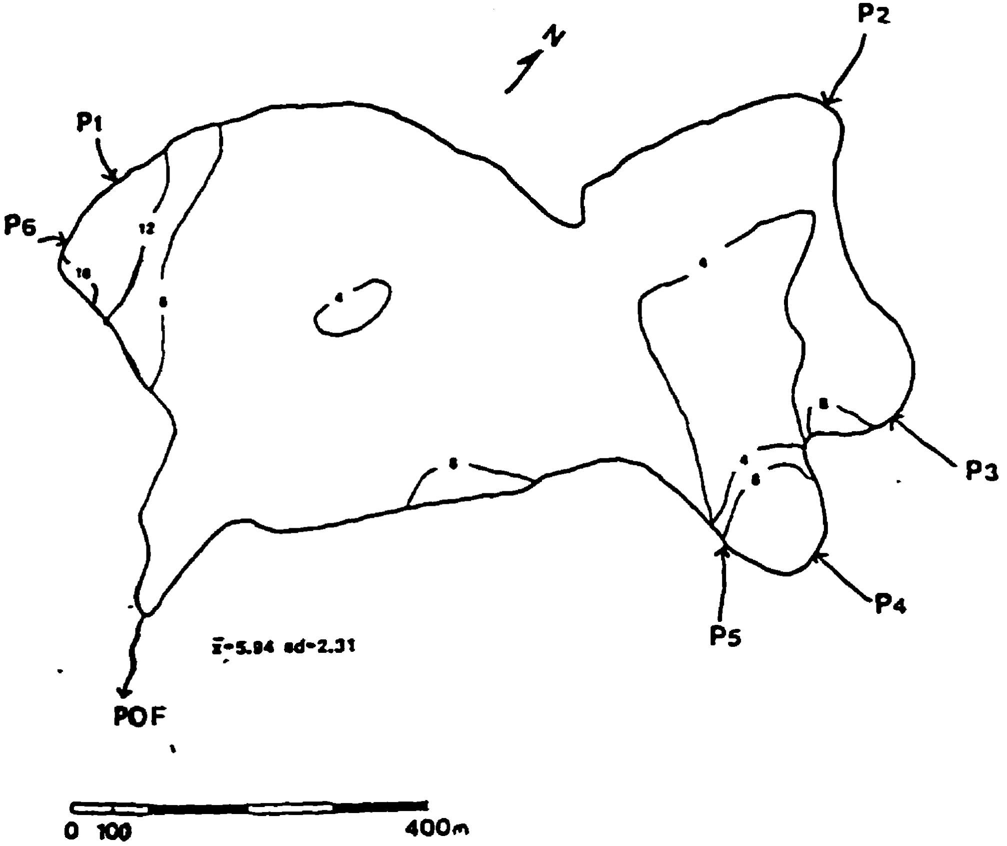
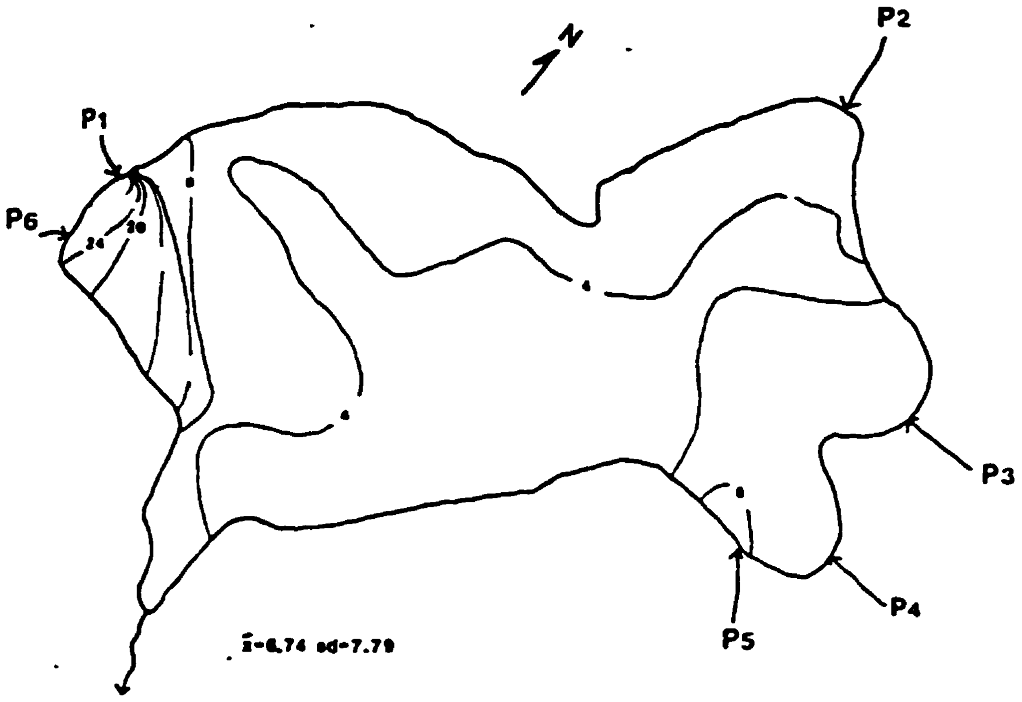


Fig. D8d MARCH 13



* isoline interval 4 units of fluorescence

# 1985 Plastic Lake Surface Natural Fluorescence (fluorescence units)

Fig. D8e **APRIL 1**

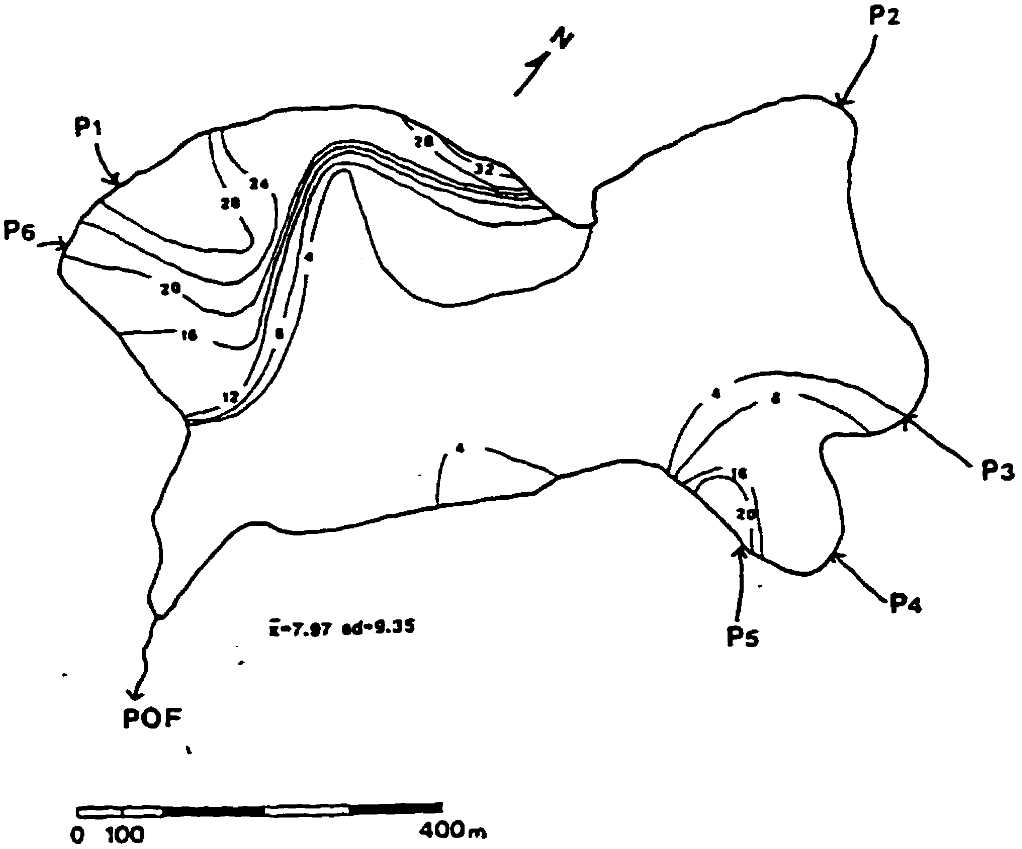
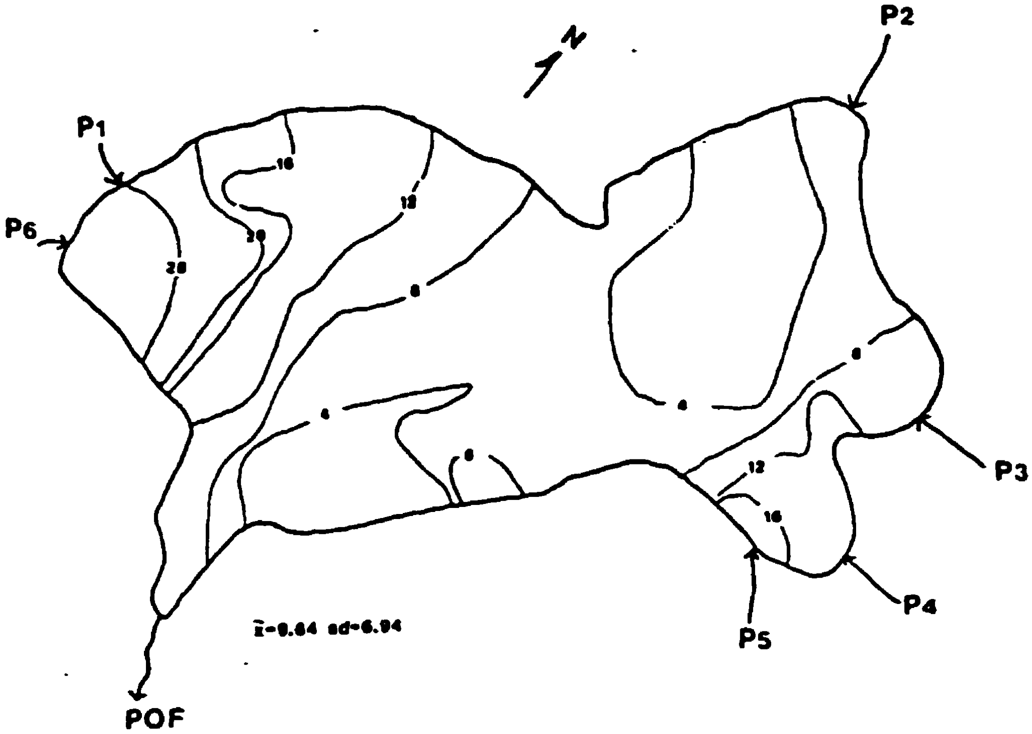


Fig. D8f **APRIL 9**



## 1985 Plastic Lake Surface Natural Fluorescence (fluorescence units)

Fig. D8g **APRIL 21**

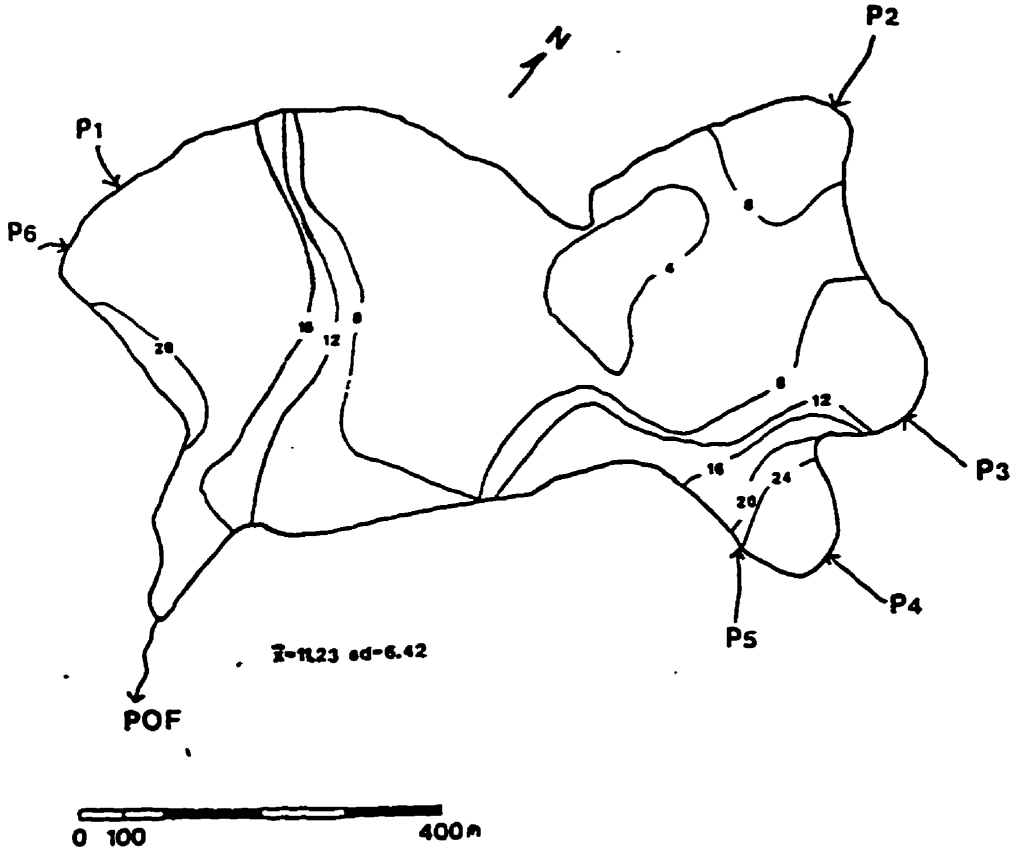


Fig. D9a

Little Clear Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles

April 16,1985

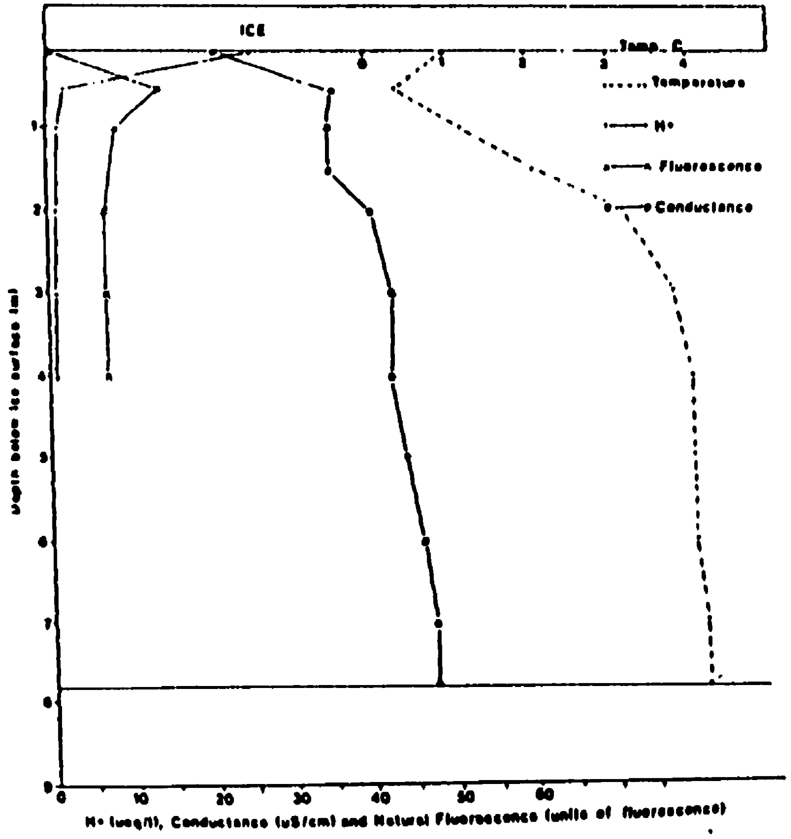


Fig. D9b

Harp Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles

April 18,1985

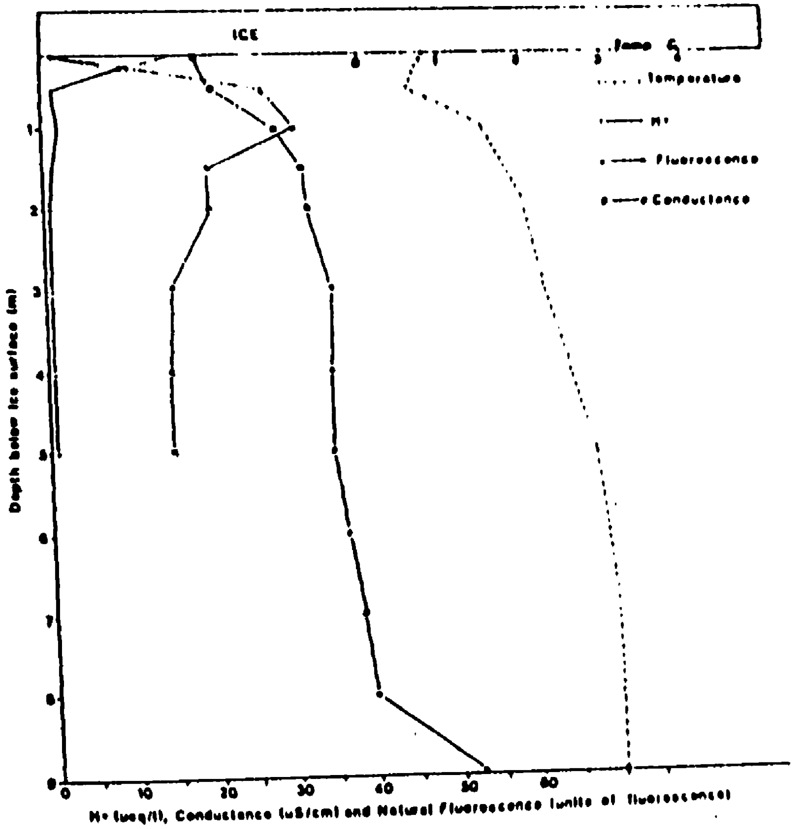


Fig D9c

**East Red Chalk Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles**

**April 17,1985**

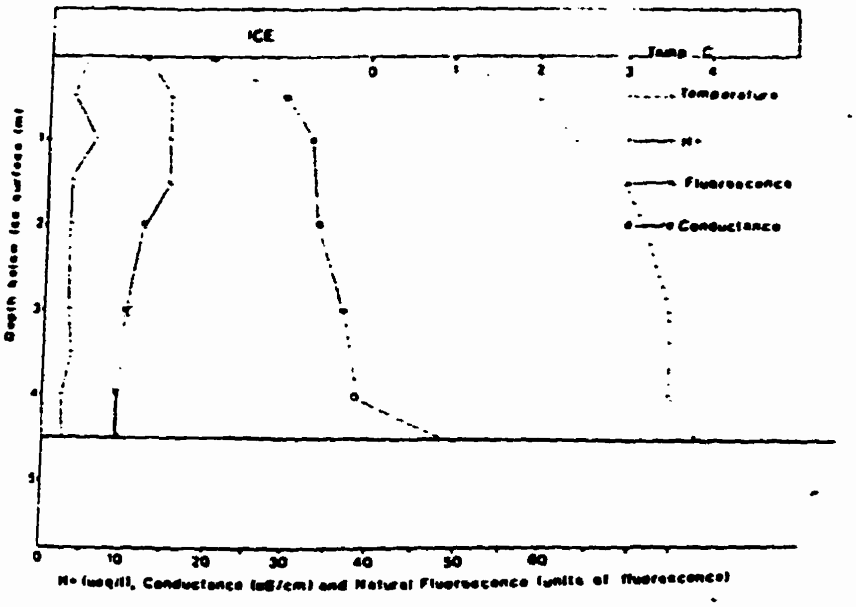


Fig D9d

**Blue Chalk Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles**

**April 17,1985**

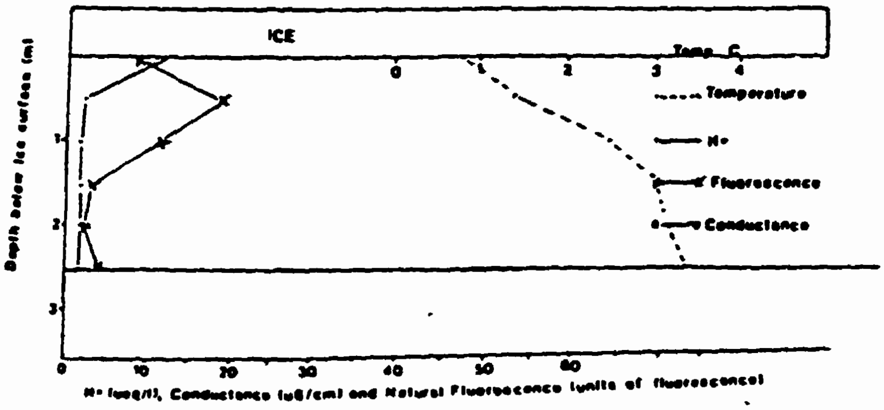


Fig. D9d

Red Chalk Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles

April 17,1985

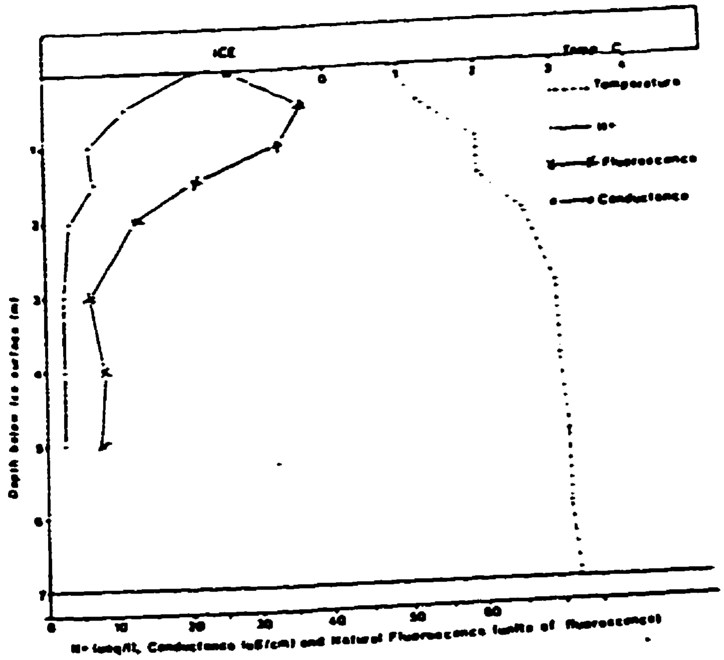
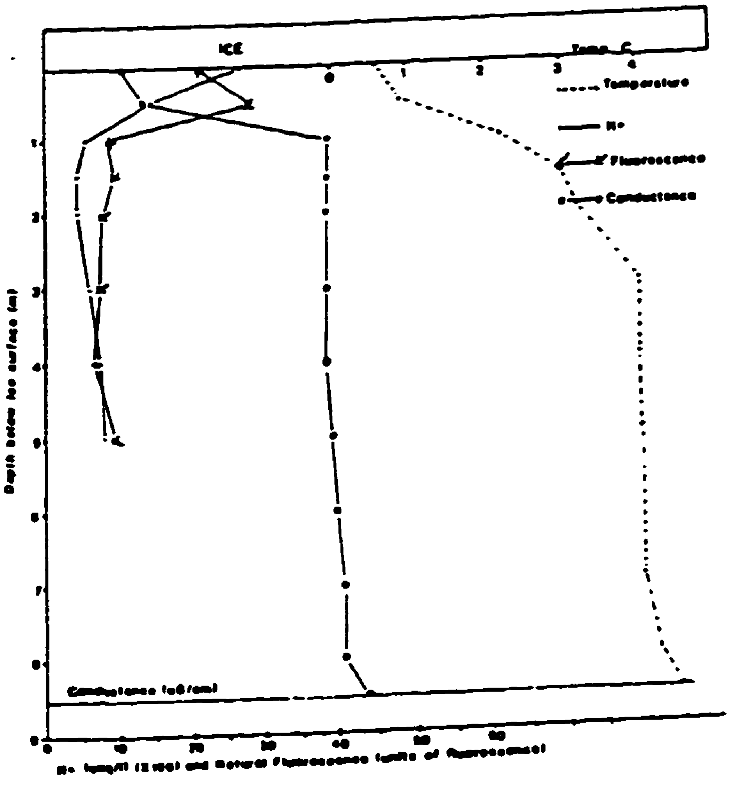


Fig. D9e

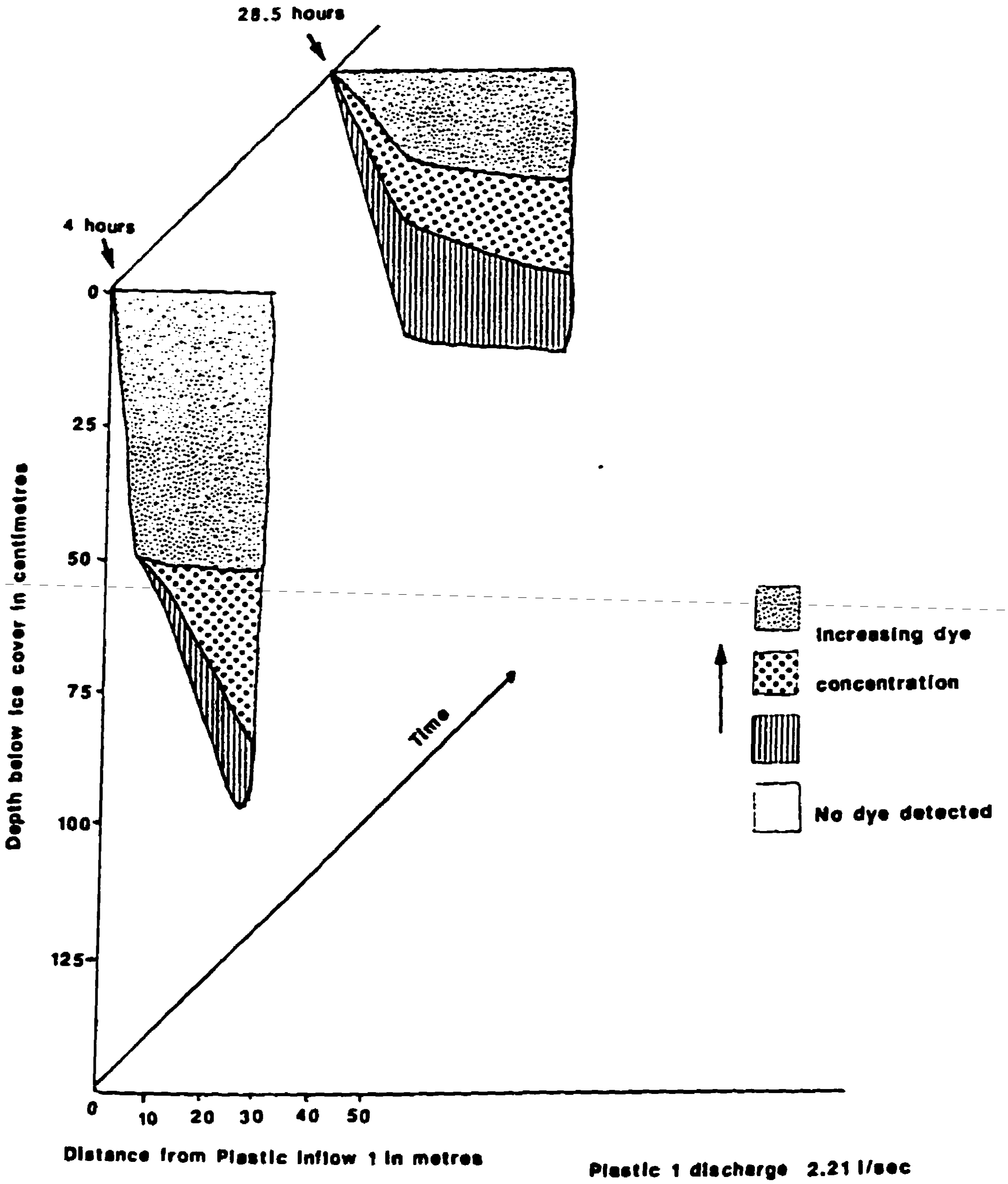
Glen Lake Temperature, Conductance, H+ and Natural Fluorescence Profiles

April 21,1985



# Appendix 5 Plastic Lake dye trace results

Fig. E1 Plastic 1 dye trace, March 8, 1985

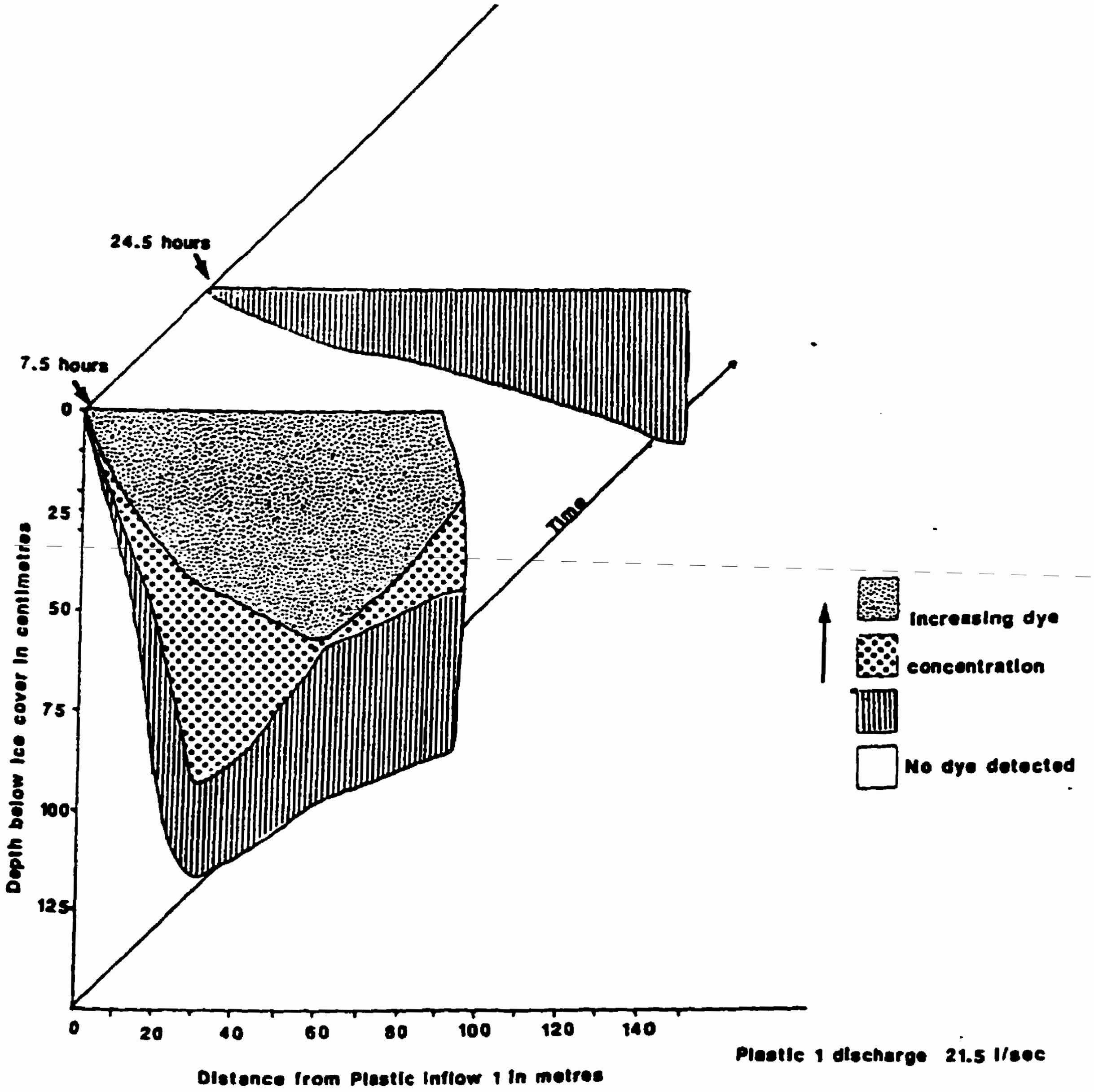


Plastic 1 discharge 2.21 l/sec

Vertical exaggeration 100X

$\bar{x}$ dye velocity 30m/4hrs=.125m/min

Fig. E2 Plastic 1 dye trace, March 29, 1985

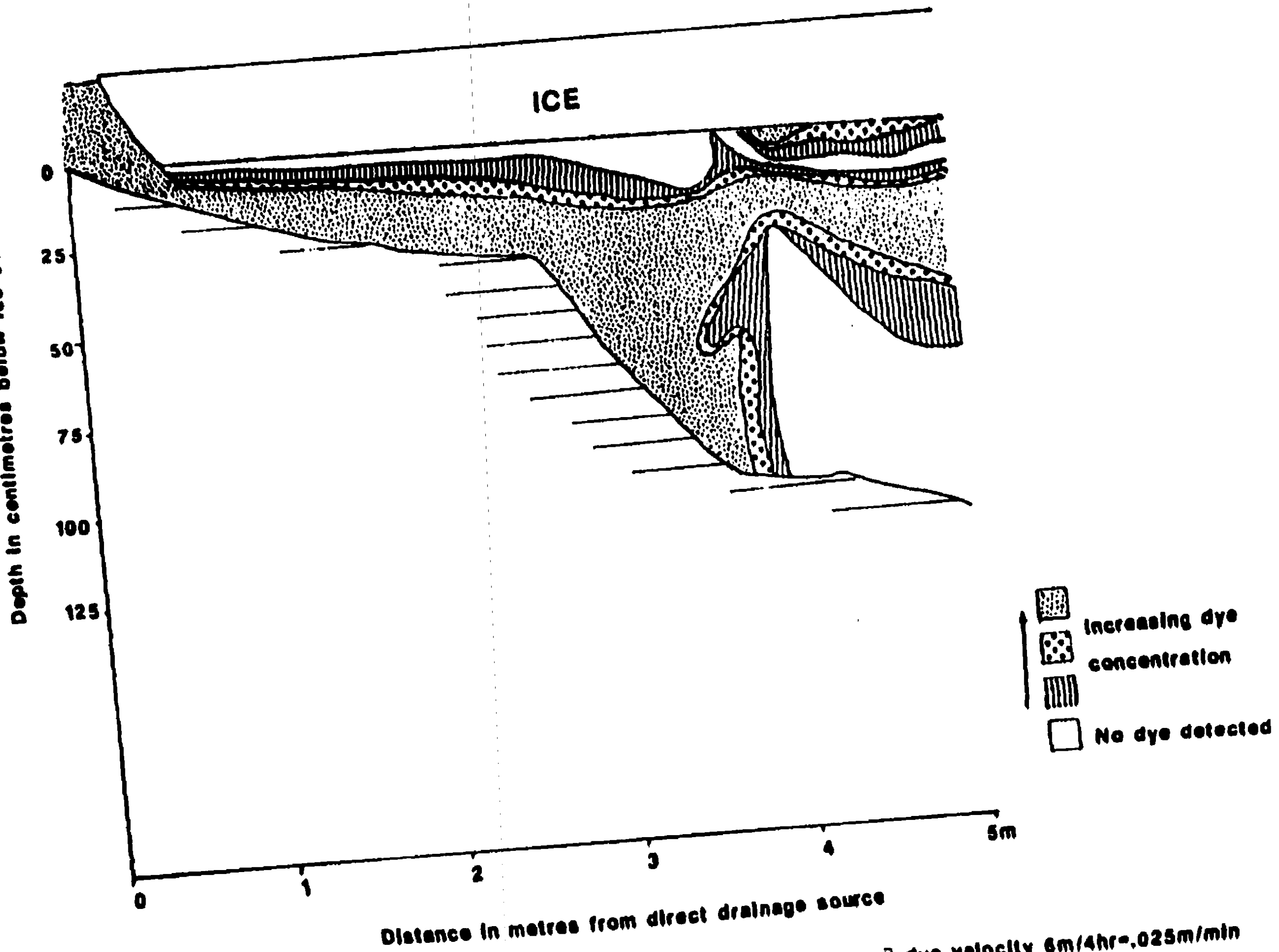


Plastic 1 discharge 21.5 l/sec

$\bar{x}$ dye velocity 30m/4hrs=.214m/min

Vertical exaggeration 111x

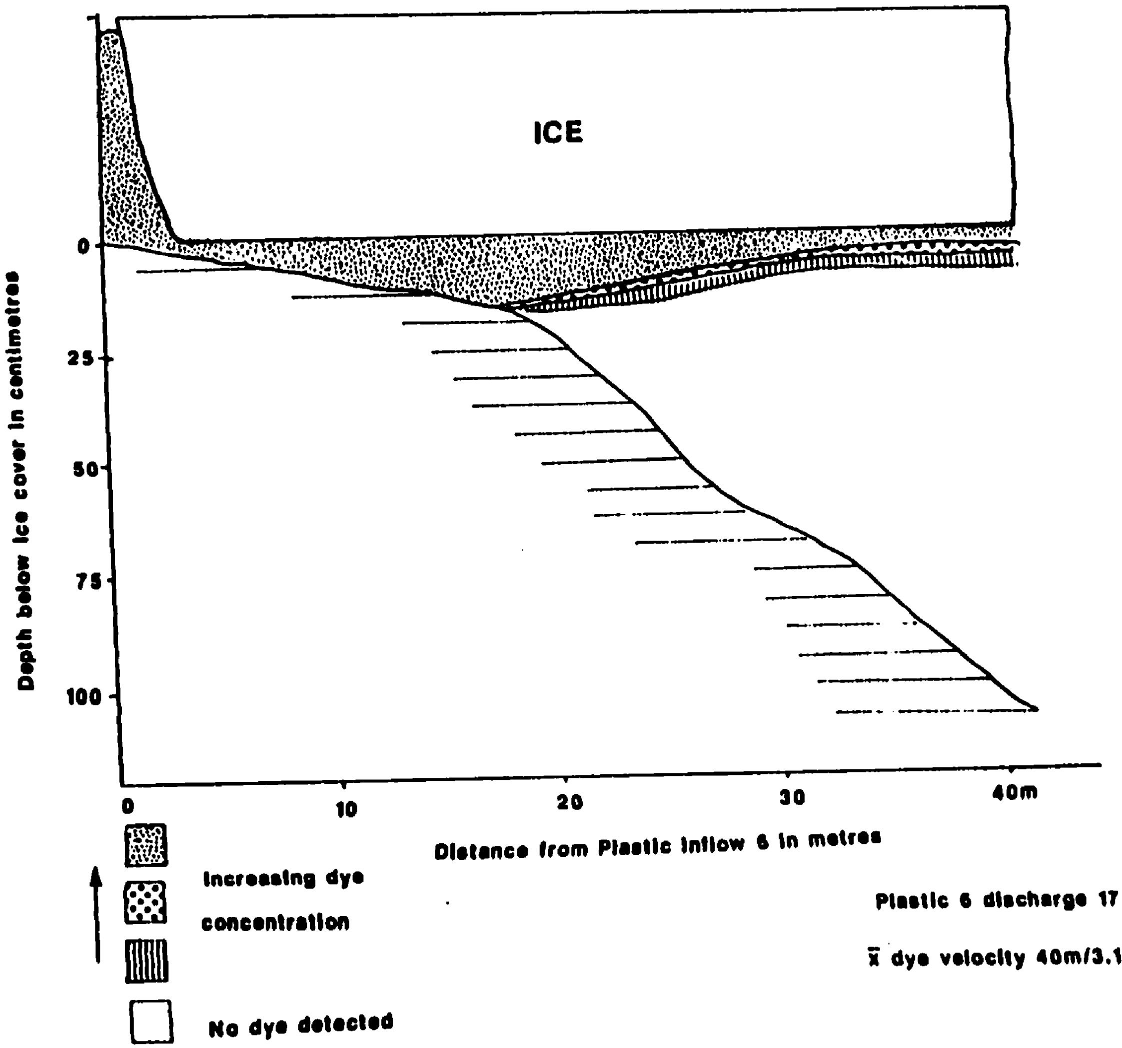
Fig. E3 Plastic seep 3 dye trace, March 31, 1986



x̄ dye velocity 6m/4hr=.025m/min

Vertical exaggeration 2X

Fig. E4 Plastic 6 dye trace, April 1, 1986



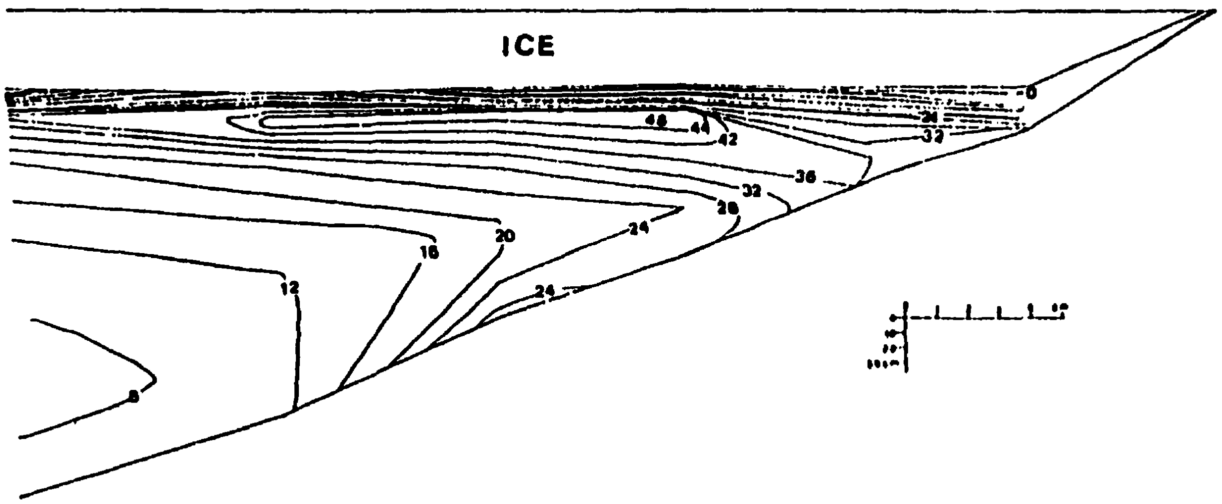
Plastic 6 discharge 17.9 l/sec

$\bar{x}$ dye velocity 40m/3.1hrs.=.22m/min

Vertical exaggeration 20X

Fig. E5 Plastic 6 inflow natural fluorescence, $H^+$, temperature and conductance cross-sectional profiles.

PLASTIC 6 FLUORESCENCE TRANSECT, MARCH 29,88



PLASTIC 6 TEMPERATURE TRANSECT, MARCH 29,88

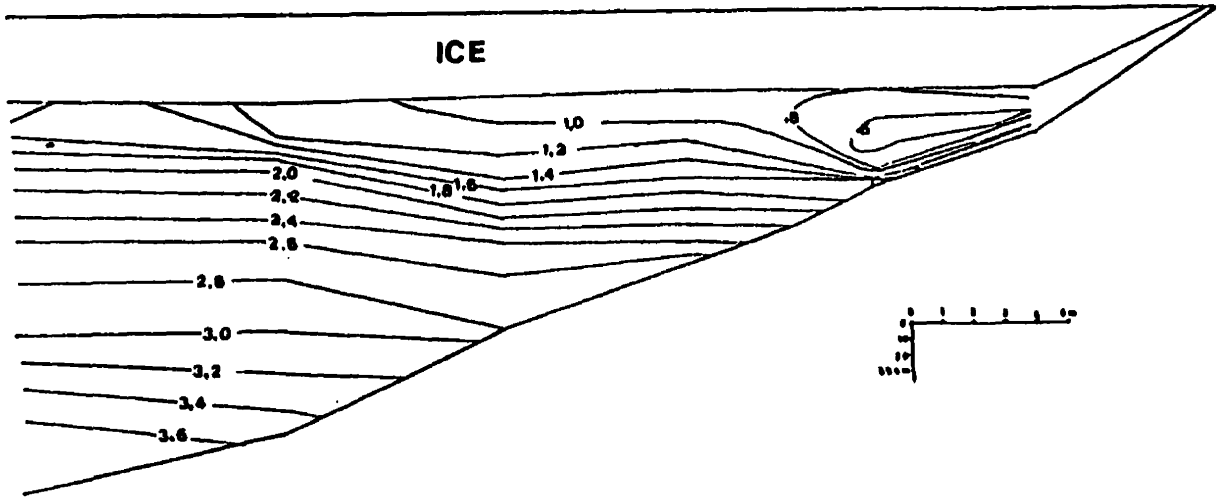
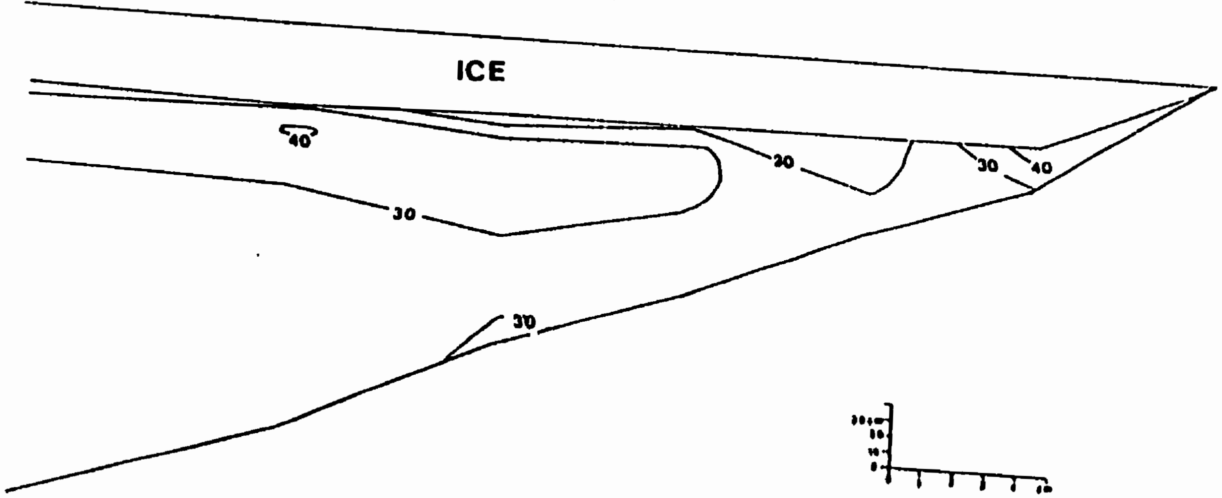
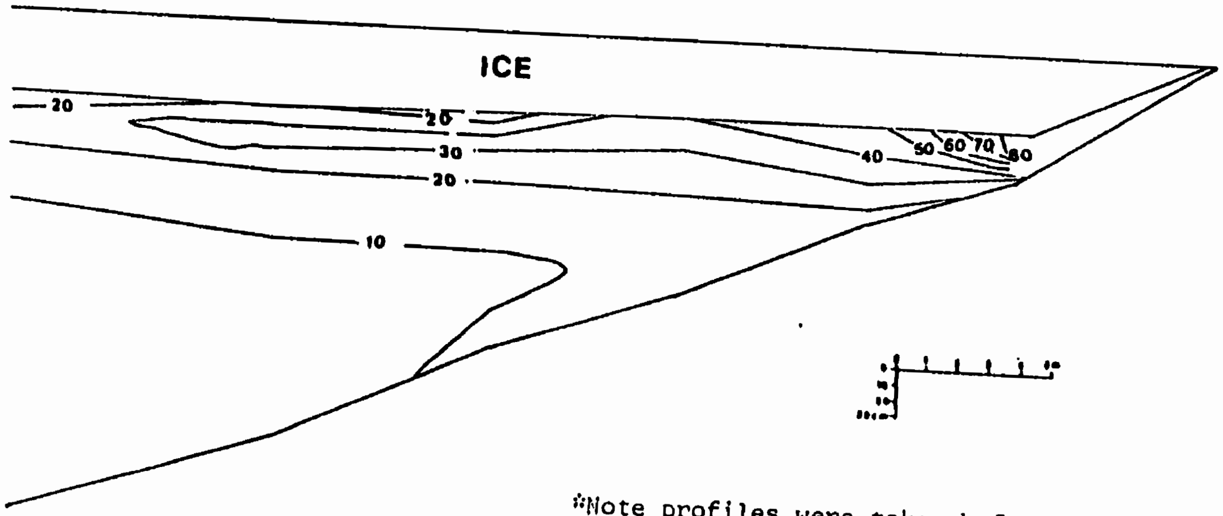


Fig. 18 cont'd.

PLASTIC 8 CONDUCTANCE TRANSECT, MARCH 29,88



PLASTIC 8 [H+] TRANSECT, MARCH 29,88



*Note profiles were taken before March, 30 dye addition.