# SPATIAL DISTRIBUTIONS OF MELTWATER IN AN ICE COVERED LAKE

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Fluorescent dye (sodium fluoroscein), and natural background fluorescence were used to trace the terrestrial snowmelt inputs within an ice-covered lake (Plastic Lake, southern Ontario). Streamwater and direct terrestrial drainage water were found to mix in the nearshore littoral zones to a depth of 1m and then layer out in a thin tongue adjacent to the underside of the ice without mixing with the main body of the lake. The highly fluorescent runoff water was strongly associated with low pH and high conductance water as opposed to the lower fluorescing, higher pH and lower conductance lake water. As lake ice-melt began, a three-layer system was established with lake-ice meltwater superimposed over the runoff meltwater and resident lake water. Initial results indicate that Plastic Lake's actual flushing time may be longer than predicted as a result of this incomplete mixing.

## STUDY AREA

The following is largely taken from Girard et al 1985. Plastic Lake ($45^{o}N$, $78^{o}W$) is a small (32.14 ha), Precambrian Shield headwater lake (Fig. 1). The 95.5 ha basin is covered by a thin (<2m), discontinuous layer of basal till; exposed gneissic bedrock of igneous origin is common. Organic deposition is occurring in bog areas and weakly developed podzolic or brunisolic soils have developed on the thin basal tills. The forest is dominated by conifers, most notably Pinus strobus L. and Tsuga canadiensis (L.) Carr with Picea mariana (Mill.) B.S.P. found in boggy areas. Hardwoods (Acer sp. and Betula sp.) are common on slopes with slighter deeper till deposits. The lake is fed by one perennial stream (Plastic 1), and four dominant ephemeral streams (Plastic 2,3,5 and 6). A single, large sphagnum-conifer bog occupies the south-central portion of the Plastic One watershed and outflows at the southern end through a shallow, one metre wide bedrock based channel which is continuously gauged by the Ontario Ministry of Environment (OME), before draining into Plastic Lake.

## METHODS

A forty point stratified random sampling grid was established on the ice surface of Plastic Lake during the January-April period of 1985. Holes were drilled through the ice surface at each point and plastic collars were frozen in place to inhibit surface water drainage into the sampling holes (Kingsbury 1984). A 1.5m tube sample was collected weekly at each point and analysed for fluorescence, pH and specific conductance. Fluorescence was determined on site with a generator-powered Turner MkIII Automatic Fluorometer utilizing a Kodak 47b and 2A primary filter combination for a maximum excitation of 490 nm and a secondary 2A-12 filter for a maximum emission of 520 nm (Smart and Laidlaw 1977). pH was determined on site with a Fisher Acumet model 602 pH meter, standardized to buffers of pH 4 and pH 7. Specific conductance was determined on site with a Barnstead Hind Conductivity Bridge and corrected to $25^{o}C$ (Edwards et al 1975). During the spring of 1986 several sampling transects were established on Plastic Lake running from the lake margin towards the lake centre. A hole was established at each site and samples for fluorescence and conductance were taken at 50 cm intervals to bottom with a peristaltic pump. In situ conductivity and temperature profiles were obtained with a YSI conductivity/temperature meter. A 250g sodium fluoroscein dye addition was added to Plastic Inflow 6 and traced under the ice cover. Water was sampled at depth with a peristaltic pump and dye presence was determined on site with the above mentioned fluorometerfilter combination and reported as arbitrary units of fluorescence.

## RESULTS

Plastic inflows 1,6 and 5 were found to be particularly high in background fluorescence (29-90 units), in relation to Plastic Lake Water (2-4 units). Lake ice, snow and soil water seeps were clear and characterized by a low fluorescence (0-10 units). We were able to trace the stream snowmelt runoff water under the ice for several tens of metres (Fig. 2). The runoff water initially appears to push and displace the relatively stagnant lake water out into the lake until, buoyancy forces, as a result of thermal density differences, become sufficient to arrest the inflow (Fischer et al 1979). At this point the cold, lighter snowmelt water flows over the warmer lake water in a very thin tongue adjacent to the underside of the ice cover.

Coincident sampling of pH and conductivity generally indicated that lower pH and higher conductance water is associated with this runoff water (Fig. 2). Isopleths of fluorescence over time indicate a general increase of fluorescence of Plastic Lake's surface water. Fluorescence decreases as one moves outward from the main stream inputs towards the lake centre (Fig. 3). A green fluorescent dye (sodium fluorescein) was added to the Plastic 6 inflow on April 27 at a flow of 24 1/sec. The dye generally followed the same pattern as that indicated by the natural fluorescent patterns obtained in presampling. An average horizontal velocity of .24 m/min was obtained in the direction of the main flow while a much lower .08 m/min lateral velocity was obtained over a three hour period. As lake ice melt proceeded, a three-layer system was established with surface ice meltwater superimposed above the terrestrial runoff water and resident lake water. A dye addition to the ice surface percolated down to the lake water, layering directly under the ice over the terrestrial runoff water within 1/2 hour of application.

**DISCUSSION**

The major source of fluorescence in natural waters is believed to be a yellow organic substance, likely a carboxylic acid (Shapiro 1957). Christian and Glassemi (1966) believed the substance to be similar in nature to a fulvic acid. The high background fluorescence found in the stream meltwater in the Plastic Lake basin is likely a result of meltwater contact and export of fulvic acids from organic soils. The difference in fluorescence between the incoming meltwater and the resident lake water enabled us to trace the path of the meltwater under the ice cover. Once entering Plastic Lake, meltwater generally displaced lake water for a short horizontal distance in the littoral zone before been forced into a thin ( 50cm), horizontal tongue which flowed over the resident lake water without mixing with the main water body of the lake. This incomplete mixing of under-ice inputs increases the theoretical flushing time of Plastic Lake as defined by Hutchinson (1975),

$$FT(yrs) = \text{Lake Volume } (m^3)/\text{Annual Outflow Volume } (m^3)$$

Higher acidity and conductance were generally associated with higher fluorescence, but not always. Soil seepage and snow and ice meltwater are generally dominated by mineral acid complexes rather than organic acid complexes and therefore have a low fluorescence and often a high acidity (Lazerte and Dillon 1984, Allan unpublished data). Fluorescent dye-tagged streamwater was found to follow the same pattern as indicated by background fluorescence presampling. Flow rates under the ice were found to be fairly rapid (up to .24m/min over 43m), at least initially before horizontal dispersion slowed forward momentum. Natural fluorescence has been used as a conservative parameter to determine open water mass changes in the past (Spain et al 1967 and Spain and Andrews 1970). This study indicates that background fluorescence of coloured streams can also be used to determine under-ice mixing patterns of those stream inputs. The technique can be performed in the field and with the installation of a flowthrough door on the fluorometer, the measurements are quite rapid. In headwater lakes with low stream energy, inputs and thin soil horizons, runoff water appears to be confined to the upper stratum and nearshore areas. Because of this incomplete mixing, the theoretical flushing time underestimates the real flushing time of Plastic Lake. A thin under-ice layer appears to exchange quite rapidly with runoff inputs. Because Plastic Lake's outflow appears to draw mainly from its epilimnion and thus this rapidly exchanging layer, downstream chemistry will be influenced much more rapidly than would be expected if the runoff inputs mixed completely with the lake.

**ACKNOWLEDGEMENTS**

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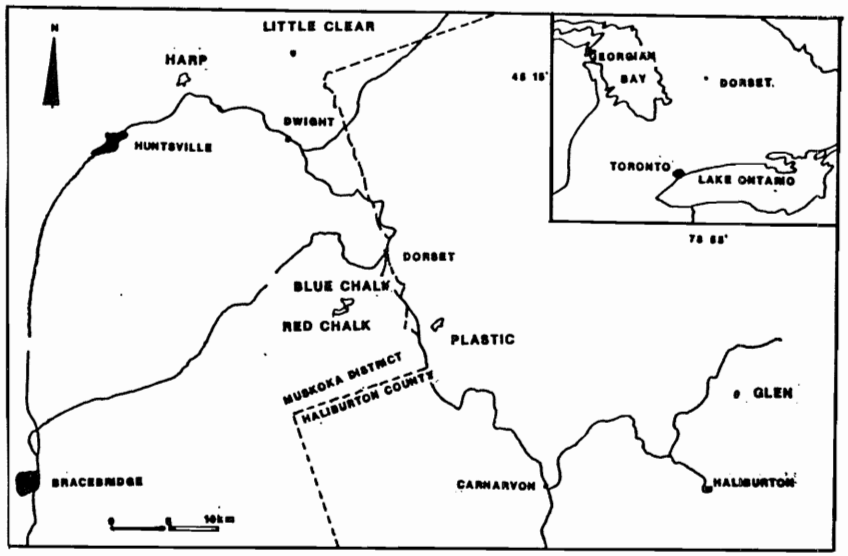
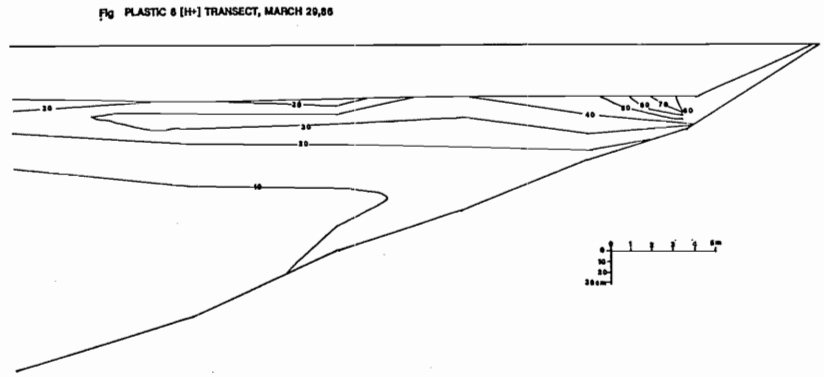
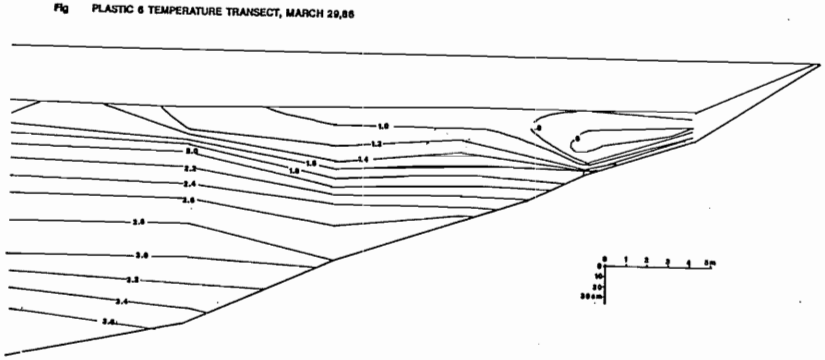
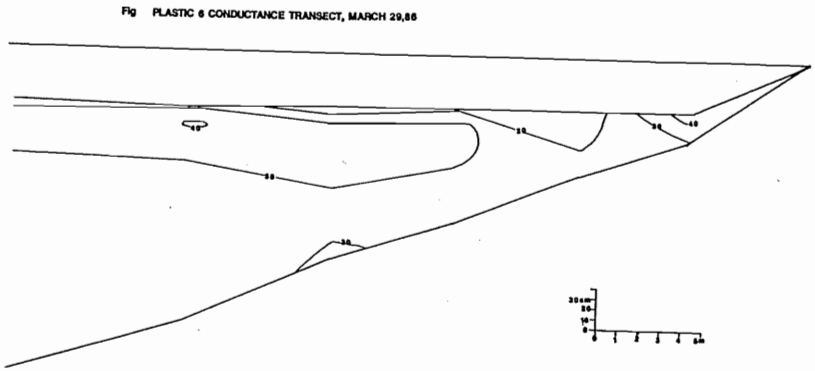


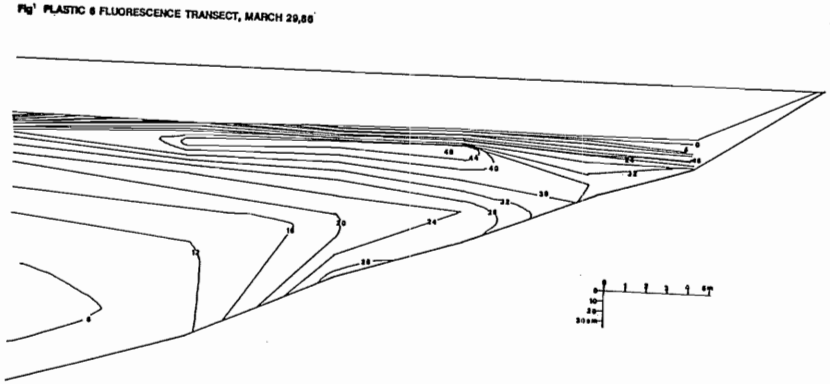

Fig. 1 (above) Dorset Study Area.

Fig. 2 (below and to right) Cross sectional coincident sampling of fluorescence, conductance, temperature and hydrogen ion from a near shore area near Plastic 6 inflow, during spring runoff April, 1986.



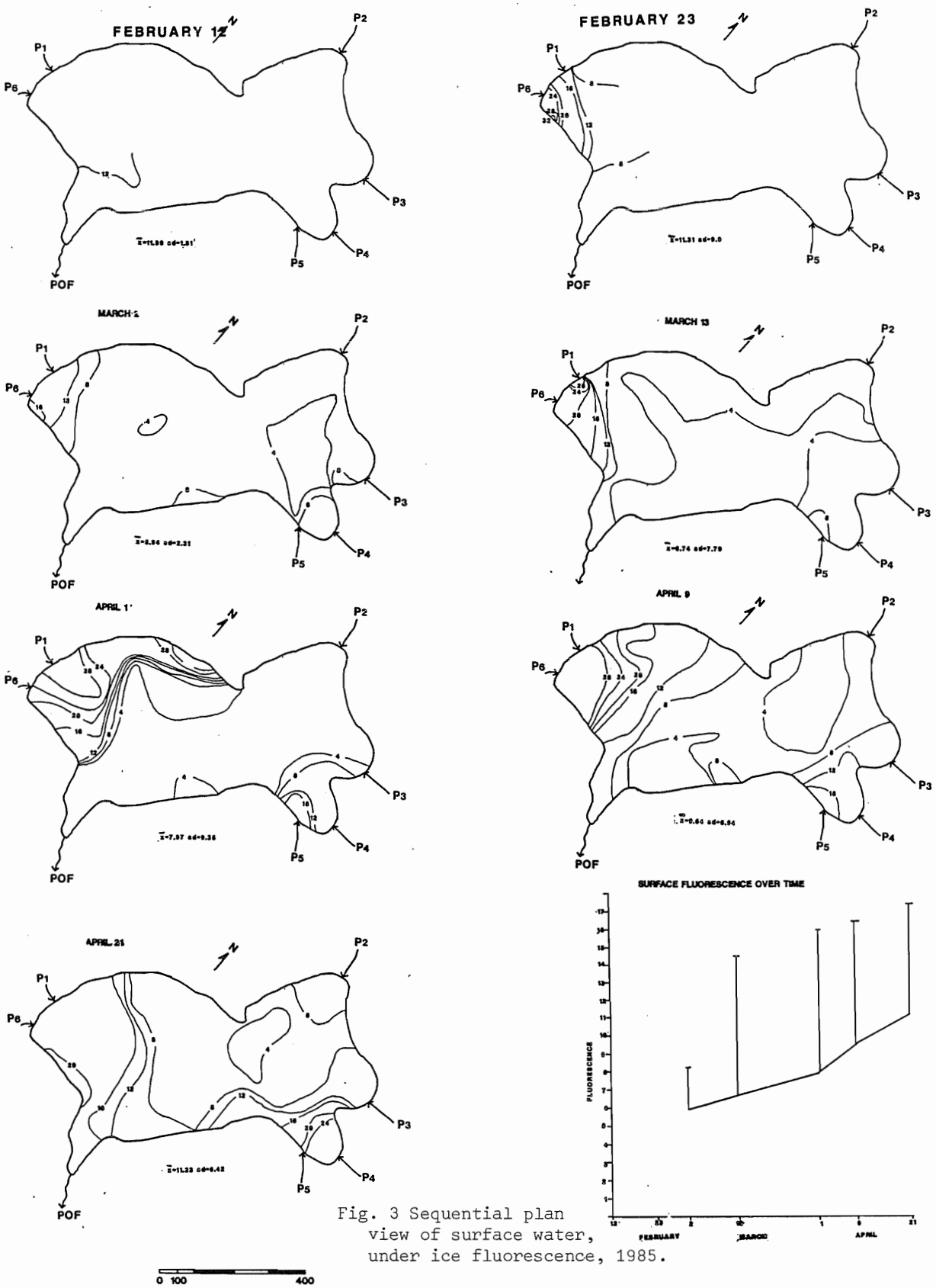



Fig. 3 Sequential plan view of surface water, under ice fluorescence, 1985.

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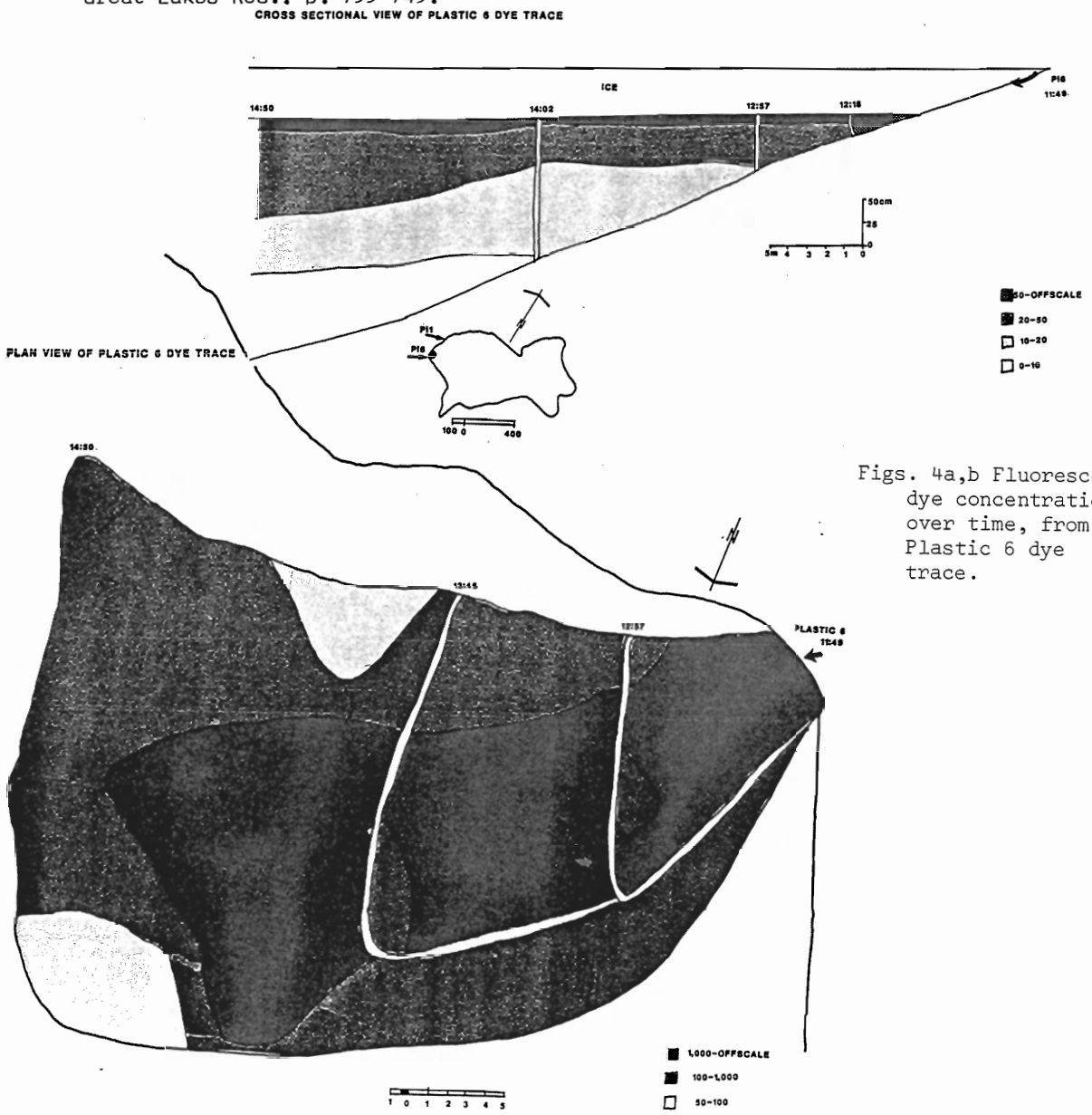


Figs. 4a,b Fluorescent dye concentrations over time, from Plastic 6 dye trace.