AN UNUSUAL DRAINAGE SYSTEM IN AN ANTARCTIC VALLEY

By J. J. LIGHT

ABSTRACT. The drainage system of a small valley on Signy Island in the maritime Antarctic is described. Bathymetric surveys of the three lakes in the valley and observations on ice recession and under-ice streams were made. The highest lake was found to drain through the moraine damming it, and during winter when the inflow is frozen three-quarters of the lake water drained away. The fate of this water is discussed and it seems that the levels of two lower lakes are raised due to an accumulation of ice in their outflows through the winter.

DURING a biological survey in 1970 of lakes on Signy Island (lat. 60° 43′ S., long. 45° 38′ W.) in the South Orkney Islands most of the water of lake 4 was found to drain away in winter. In November 1963, Heywood observed that the ice cover of lake 4 lay broken in radial sectors which dipped below water level in the centre of the lake (Heywood, 1968, p. 30, printed in error as lake 5). The biological implications of these observations promoted a study which was eventually extended to cover past and present drainage systems of the whole valley.

METHODS

Information on drainage patterns within the valley was obtained from maps, photographs and direct observations. A SCUBA diving survey provided information on lake morphology and on the type and distribution of bottom deposits and benthos.

Bathymetric surveys were carried out in early autumn when the lakes were covered with a 3–6 cm. layer of ice. A base line was laid out across the ice using fixed points on the shore. Transects were run from this base line on compass bearings, and holes, made with an ice chisel, were positioned along the transects. The position given for any sounding is estimated to be within $\pm$ 2 m. of its true position in relation to the fixed points on the shore. This method enabled soundings to be made by lead line at rates of up to 40 an hour, and with greater accuracy than by using a boat (Fig. 1). Working on 3–6 cm. thick ice is only possible

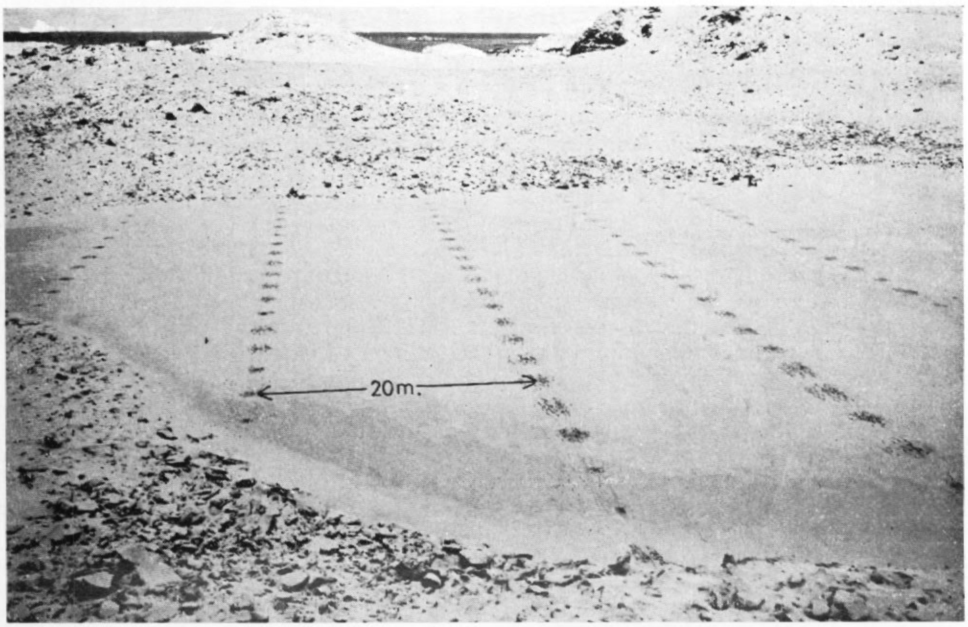

Fig. 1. Part of lake 1 showing the method of bathymetric surveying used. The dark area around each hole is due to disturbance of the snow cover.

when the air temperature is well below freezing and the quality of ice is good. Bathymetric contours were drawn at 1 m. intervals, their areas measured planimetrically, and the volume calculated from the sum of the series of metre-thick elements.

Results

The valley is short, less than a mile long and trends north-eastward from a cirque on the north face of Jane Peak in the north-east catchment area of Signy Island (Heywood, 1967). The valley contains three interconnected lakes and is bounded at its head and on the north-west side by icefields (Figs. 2 and 3). Run-off is mainly on the surface and drains into the lakes or the stream that connects them. It is derived from melting snow in late spring and early summer but as the summer progresses an increasing proportion is derived from the icefields.

Lake surveys

The morphometric parameters of the lakes are given in Table I.

Table I. Morphometric parameters of lakes 1, 3 and 4, Signy Island

	Lake 1	*Lake 3*	*Lake 4*
Area (m.^{2})	27,600	8,900	15,500
Mean depth (m.)	4·9	2·4	3·4
Maximum depth (m.)	11·2	5·4	10·4
Volume (m.^{3})	135,000	21,600	52,600

The bottom of lake 1 (Fig. 4) is covered with soft grey-brown mud with an overlying flora of algal felts and some moss (Light and Heywood, 1973). The steep west and north-west sides consist of boulder scree which is still active and free of vegetation. Boulders are also common in shallow water especially near the outflow where they are partially moss-covered. A shelf consisting of glacial debris is present along the south-east shore, and sand and gravel are being deposited by the inflowing stream at the south end of the lake.

Lake 3 has been previously described (Heywood, 1967), but SCUBA and bathymetric surveys (Fig. 5) in 1971 showed it to be more of a regular depression with a poorly developed sub-lacustrine shelf than a steep-sided trough with a wide shelf. The bottom is covered with a fine yellow-grey mud. It is mostly firm and a gloved hand cannot be pushed into it for more than a few centimetres. It is possible that it has been compacted by overlying ice during a former advance of the adjacent icefield, perhaps as recent as 1948. The extent to which this lake has been enlarged by the recent retreat of the icefield since 1964 is shown in Fig. 2. It is not certain whether the lake basin consisted entirely of ice in 1948 or whether the lake was permanently ice- and snow-covered (personal communication from R. M. Laws).

A maximum recorded depth of 5·4 m. was found in 1971 as opposed to 6·4 m. in 1964, suggesting that the outflow was then ice-dammed. There are signs that the lake was ice-dammed to a much greater extent in the past. Evidence of a raised beach, plotted in Fig. 2, has been found on the ground and in air photographs. The outflow is now through a tunnel in the icefield which starts 2–3 m. high and 4–5 m. wide and narrows to 25 cm. high and 1 m. wide after about 100 m.

Lake 4 has a shoreline of scree and large boulders, the latter extending into deep water. The shelf area is very small and the bottom slopes steeply to 10 m. (Fig. 6). Some sand has been deposited on the shore near the inflow. There is little sediment or vegetation above 5 m. depth. Below this a layer of yellow-brown mud, at least 60 cm. thick at the deepest point, is overlain by a luxuriant growth of aquatic mosses and algae (Light and Heywood, 1973).

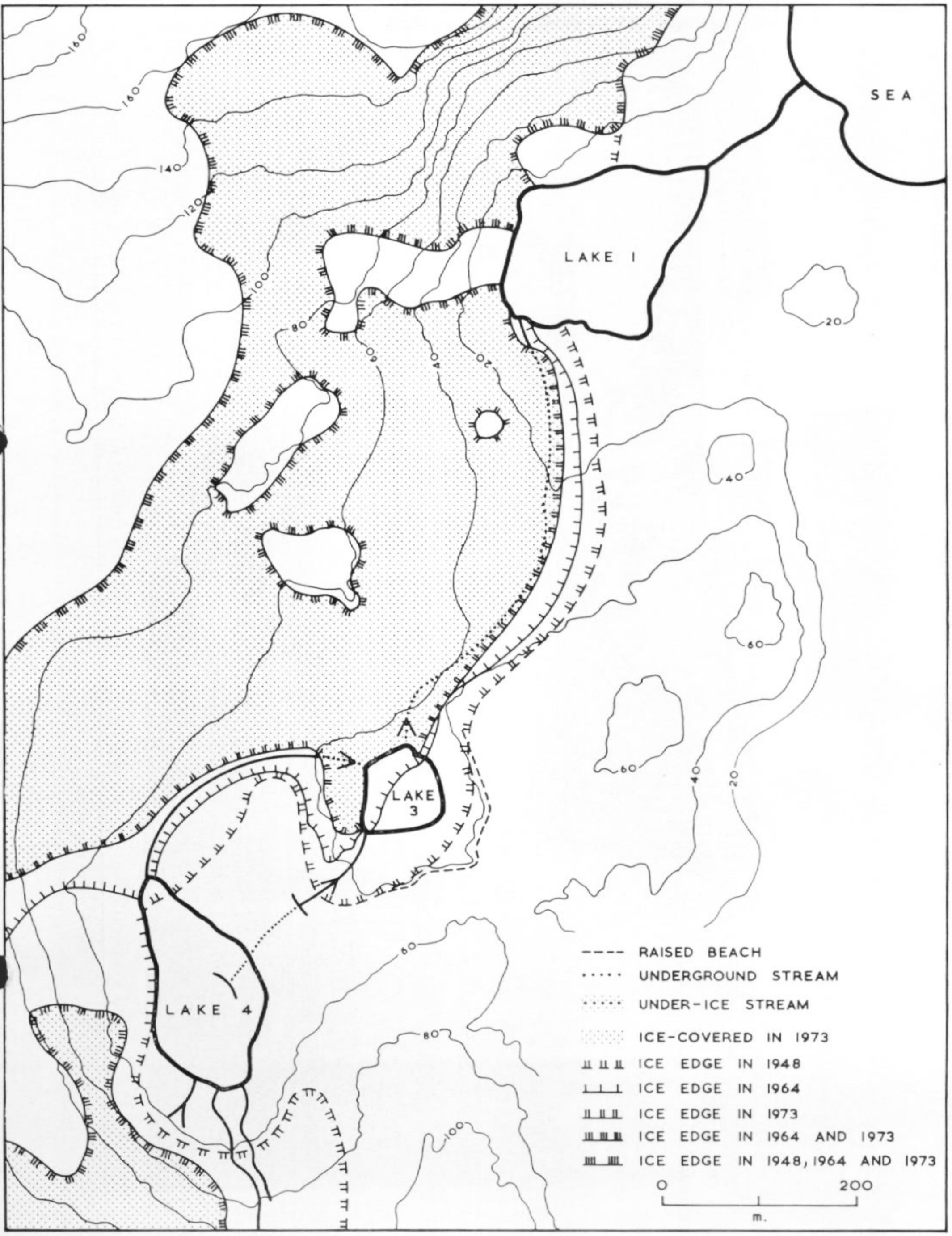

Fig. 2. Map of the valley containing lakes 1, 3 and 4 in the north-east catchment area of Signy Island. Ice edge in 1948 from map of Signy Island, South Orkney Islands (F.I.D.S. Misc. 14, 4th edition (R.D.F.O., August 1959)) Ice edge in 1964 largely from a photograph by R. B. Heywood.

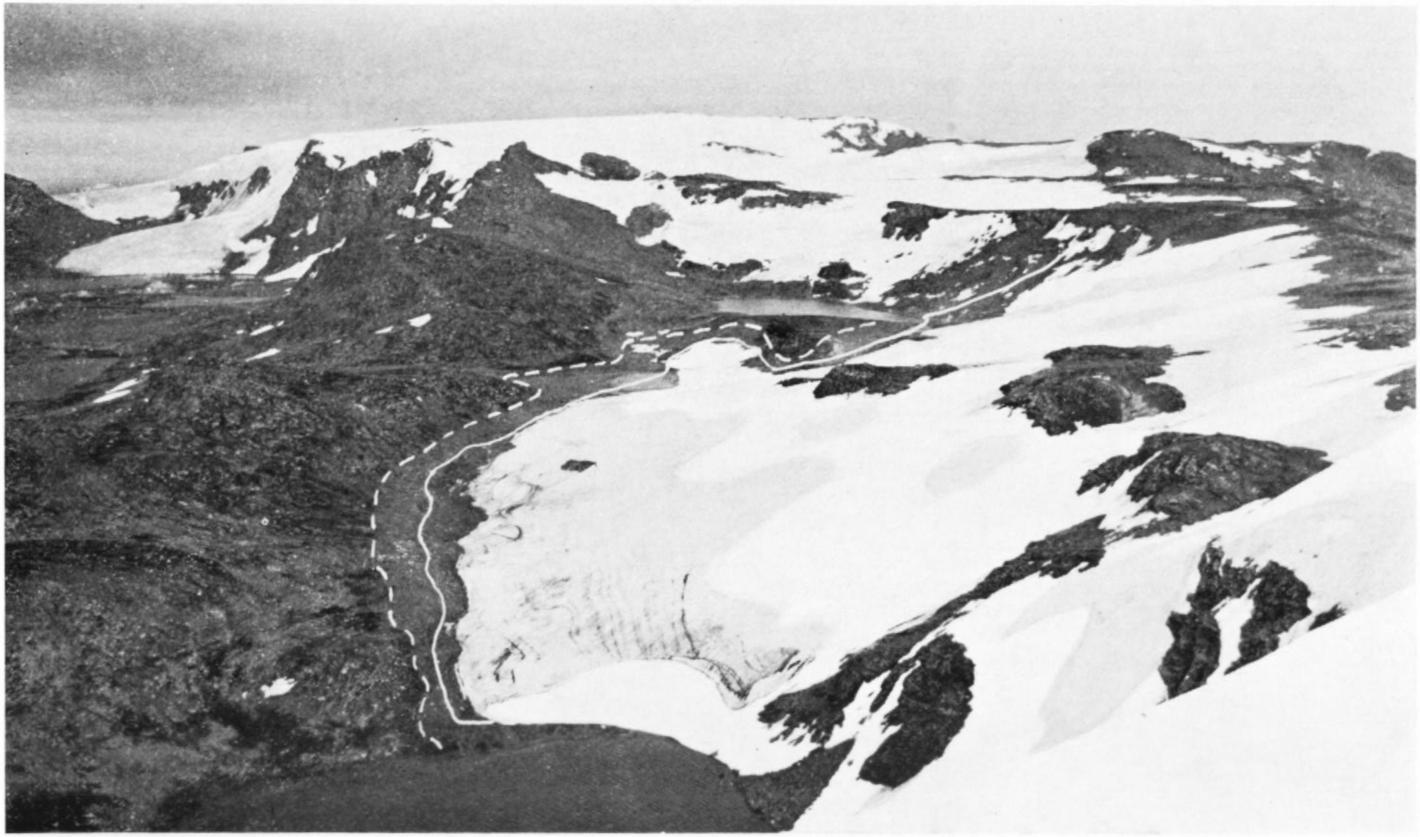

Fig. 3. View southward from Robin Peak in 1973 showing lake 1 (part in foreground), lake 3, lake 4 and the valley containing them. The extent of the icefields in previous years is shown: the solid line for 1964, the pecked line for 1948.

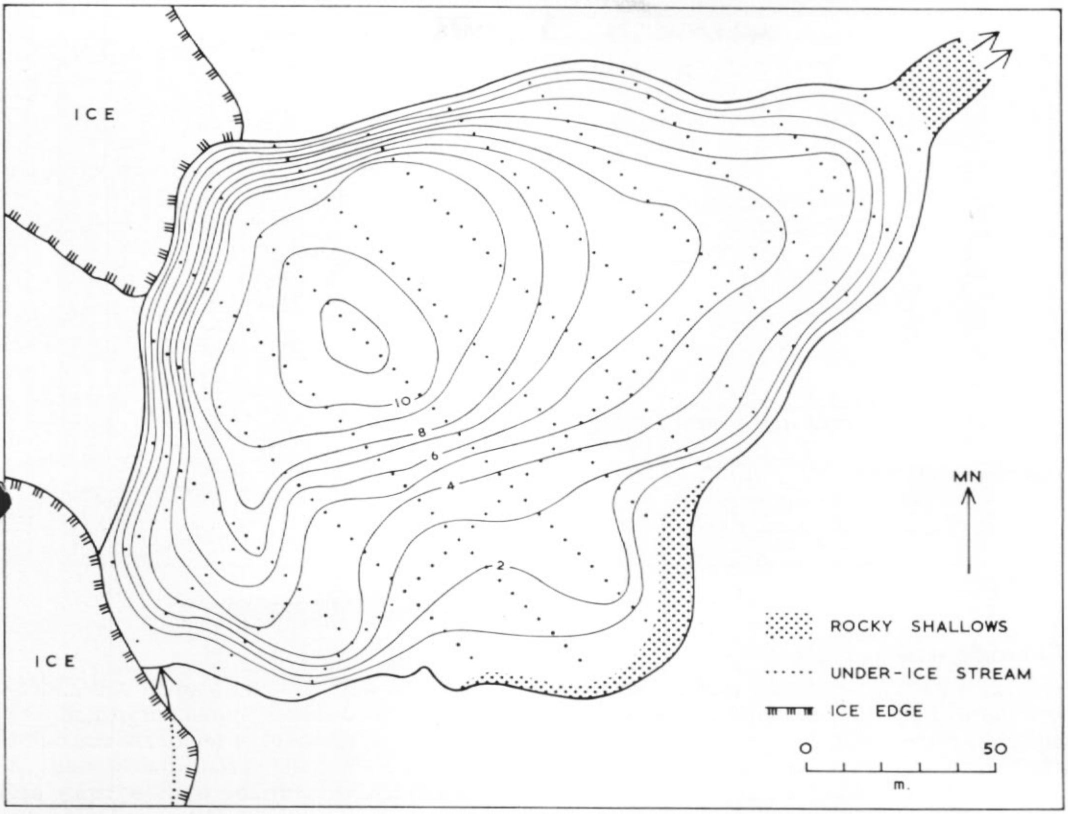

Fig. 4. Bathymetric survey of lake 1, Signy Island. Contours are in metres.

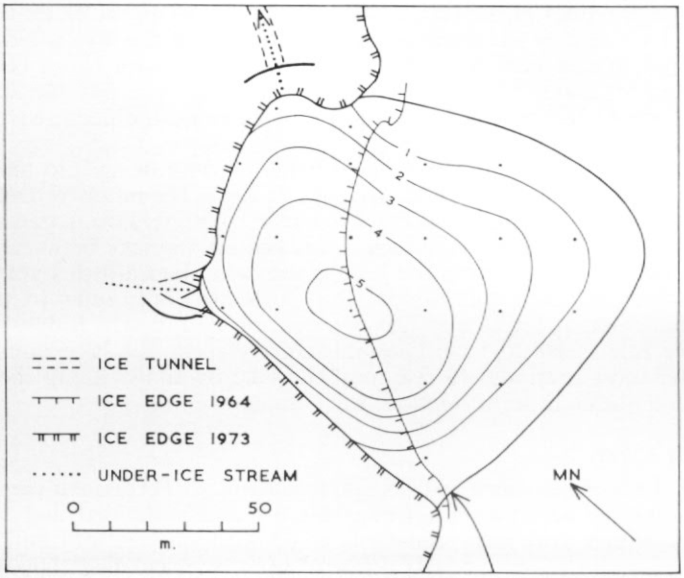

Fig. 5. Bathymetric survey of lake 3, Signy Island. Contours are in metres.

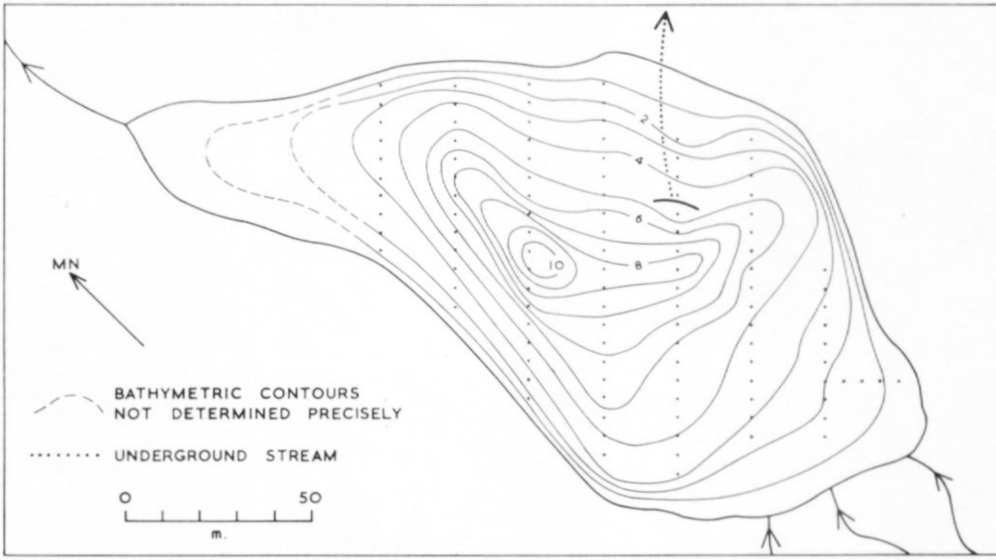

Fig. 6. Bathymetric survey of lake 4, Signy Island. Contours are in metres.

Drainage system of lake 4

Lake 4 has two outflows, one on the surface at the north-west end and a small one underground through the surrounding moraine (Fig. 6). Both flow to lake 3, the underground one coming to the surface some way above it. In summer the water level is relatively constant, the surface outflow compensating for any change in inflow. When the surface inflow stops in autumn, March–April (it is assumed all inflow is surface), the surface outflow dries up. However, the underground outflow continues slowly, and the ice surface falls steadily as the autumn and winter progress. The ice thickens on the lake and progressively thicker slabs of ice are stranded on the sides of the lake basin. By August, when the water level stops falling, it is about 4 m. below that of the summer, and the volume of the lake is reduced to less than one-quarter of that in summer. An area of coarse moraine with holes between the stones was seen at a depth of about 5 m. in summer. This is most probably the start of the underground outflow. Due to the porous nature of the moraine on the north-east side of the lake, seepage also occurs at other points.

The lake level remains low until spring melt water starts flowing into the lake basin; this was in early September in 1970 and in late October in 1971. The inflow of melt water increases and, as the lake fills, the ice splits and cracks. Large pieces remain frozen to the shore and become submerged. A zone of disturbed ice forms around the lake between the summer and winter shorelines. Radiation entering the lake is increased beneath this zone as ice and any spring snow become saturated with water; this probably contributes to the early melting of ice in the zone. A moat forms and leaves a central ice raft which does not melt in cold summers. The ice raft seems to have been misinterpreted as the lake outline in air photographs. The water level continues to rise until the lake overflows along the surface outflow and the water level varies little throughout the summer.

Ice changes in the valley

The retreat of the icefields since 1948 is shown in Fig. 2. Permanent ice still extends into lake 3, although the ice wall overhangs considerably and is divided into small underwater caves and gullies. Much drift snow accumulates beneath this ice wall and in most years it does not melt entirely. In February 1971 a floe of snow and ice about 200 m^2 in area broke away from this point and floated across the lake. It grounded in 3 m. of water and later froze in this position. The lake remained frozen the following summer and the ice floe was still in position 18 months later.

In lake 1 permanent ice and snow appear to extend into the water but in fact stop a few centimetres short forming a large horizontal roof. Presumably this ice is melted by the lake water in summer as it creeps lower.

In 1964 permanent ice also bordered lake 4 but it may not actually have extended into the water. In 1971 it had receded many metres from the lake edge and uncovered the surface outflow from lake 4 for all but the last 50 m. of its length to lake 3.

Discussion

There is little doubt that there has been a considerable recession in the permanent ice-cover in the area around lakes 1, 3 and 4 during the last two and a half decades. The overhang of the icefields in lakes 1 and 3 suggests that heat input to the ice is greater via lake water than via air, where the icefields border the lakes.

In cold snowy years the icefield bordering lake 3 probably increases from the snow accumulation at its leeward edge to such an extent that the lake is considerably reduced in size. The snow floe described is an example of part of this process.

The general drainage pattern described would seem to be a regular annual cycle, and the cause of the phenomenon in 1963. The winter loss of water from lake 4 has been observed during the three winters since 1971.

The extent and nature of the splitting of the ice cover on lake 4 in early spring and the development of the moat probably depend on how well the ice freezes to the sides during the August to spring melt period. This will probably be governed by the severity of the winter and the start of the spring melt. Heywood's observations in 1963 differ in this respect from those in 1970 and 1971. The winter of 1963 was a cold one, whereas the winters of 1970 and 1971 were mild, thus supporting this suggestion.

The loss of water from lake 4 is about 75 per cent of its volume or 40,000 m.^{3}. The fate of this water is of interest as surface water is normally frozen from April to October, and the sub-surface is generally considered to be impermeable due to permafrost. There are several possibilities:

i. The water may have flowed on to the ice surface of lake 3, frozen and increased the ice thickness. There was 1·6 m. of ice on lake 3 in September 1970, whereas other lakes with lesser snow covers, and therefore less insulation, had no more than 1 m. of ice (solar heating had not started to reduce ice thickness at this time). The ice surface of lake 3 also appeared to rise a little through the winter but drift snow hid most surface features and the rise was not measured by sounding. If the rise had been greater than about 1·5 m. it would have been obvious. In any case a 1·5 m. rise could not account for more than 20,000 m.^{3} of water.

ii. The outflow from lake 3, being under ice for its whole length to lake 1, probably does not freeze quickly in autumn, so some water probably leaves the lake 3 basin and flows to lake 1. In March 1974 the ice tunnel containing this outflow was discovered and there was evidence of accumulation of water ice from the previous winter in the form of a rim of ice 0·5 m. up along each wall. The ice accumulation in this tunnel could only account for a maximum of 1,000 m.^{3} of water, but it does support the suggestion that the level of lake 3 rises in winter.

iii. In 1970 and 1971 the ice surface of lake 1 rose by 0·5–1 m. through the winter, but this rise, and possibly that of lake 3, may have been due, at least in part, to melt water from heavy thaws at midwinter. This was seen to flood lakes 2, 5 and 6 in 1971 and it probably flooded other lakes. This melt water then froze, effectively raising lake ice surfaces by up to 0·5 m. So probably the level of lake 1 rose about 0·5 m. due to the loss from lake 4. This would account for about 16,000 m.^{3} of water.

iv. There is also the possibility that some water seeps out of lake 1 during the winter and freezes as it flows to the sea. Some evidence for this was obtained in November 1971 when the outflow from the lake had cut a channel through a mass of ice which filled the very wide stream bed. This was up to 2 m. thick but its volume was difficult to estimate.

v. Some lake water may even reach the sea and it would be of interest to know whether this occurs during the Antarctic winter. Salinity measurements and studies of the sea ice beside the outflow from lake 1 would probably provide the answer. Recent evidence (personal communication from D. Weller) suggests this can occur but for an entirely different reason. On 24 September 1973 an avalanche flowed on to lake 1, breaking and depressing the metre-thick ice cover. The next day a large area of the sea ice in Stygian Cove was flooded probably by water expelled from lake 1 by the avalanche.

Conclusions

The evidence suggests that the loss of water from lake 4 results in an increase in the winter surface levels of lakes 1 and 3, and in an accumulation of ice in their outflows.

The biological consequences of this water loss are considerable. The sparsity of benthic vegetation in lake 4 in the zone between high- and low-water levels is almost certainly due to this. The effects on the plankton and water chemistry are more difficult to predict but the results of the current long-term monitoring programme may reveal what they are.

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