CHAPTER FOUR

KINGHORN LOCH
AQUEOUS CHEMICAL COMPOSITION
AND ESTIMATION OF LOSSES
TO THE SEDIMENT

4.1. PHYSICAL DESCRIPTION.

Kinghorn Loch is set in a hollow in the basalt bedrock. It is probably underlain by boulder clay although bedrock is exposed along its east and north shores and is close by the south and south-west shores. The north shore is virtually devoid of trees and only a few occur along the east. The shore bordering the Kinghorn to Burntisland road is planted with trees along its length as is the west end which consists of brush and shallow water fronted by a line of dead trees set in the water. The level of the loch was raised in the nineteenth century by the construction of a dam and sluice at the outlet, drowning small parcels of land at the west end behind the dead trees and forming the bay at the point where the north inlet enters the loch. The level was further raised in the 1970's but as this caused flooding of the road the original level was restored.

Figure 4.1. shows a plan of the loch with the sampling station notation superimposed upon it. The sampling grid allows 51 sampling points at 40-60 m intervals and this number was chosen as the largest practical, in order to allow a statistical appraisal of the invertebrate numbers for the 42 sampling points within the body of the loch proper. Permanent onshore features were used as markers for these trancepts wherever possible. Wooden stakes were driven into the ground to within 25 mm of ground-level to mark all other trancepts, with one peg near the shore and another approximately 20 m in trancept line behind it on the hillside. On the east shore this permanent marking was not possible and the remote pegs required removal each Autumn prior to ploughing of this field. The pegs were positioned by use of a theodolite and checked for line by compass to be within 0.009 rad (30') of the desired bearing.

Initially, bouys, which were positioned on the loch by the yachting club, were used to aid trancept location but these were driven off station by strong winds. In consultation with the clubs involved properly anchored buoys were placed in position but these were cut adrift by persons unknown. Similar problems were experienced with the pegs being removed (despite being 0.5 m in length and inserted with a sledge hammer) and continual remedial work was required. Eventually any attempt to use water-based markers was abandoned.

When surveys were conducted, land-survey poles were carefully positioned against the rear of the pegs in order to locate the trancepts from the boat. The accurate positioning of these poles was critical for the correct location of sampling positions on the loch. It is estimated that location of the far (that is south- and west-most) positions was within ±5 m. Several surveys of the loch were carried out, for various purposes, during the period of study. On each occasion a boat was provided by the Estuary Survey Section of the F.R.P.B.; variously a 17ft Dory, Task Force or 12ft inflatable craft fitted with outboard motor.

The initial survey of Kinghorn Loch consisted of a bathymetric profile and the taking of samples for particle size analysis. An attempt was made to use an echo sounder for depth measurements but this proved unreliable due to the incoherent nature of much of the bottom sediment surface. A flat weight on a marked line was used in its stead and Figure 4.1. charts the profile obtained. The maximum depth of the loch proved to be 12.8 m at a point to the south of the geometric centre of the loch. 50% of the area lay at a depth in excess of 4.2 m whilst 50% of the water volume lay below 2.5 m.

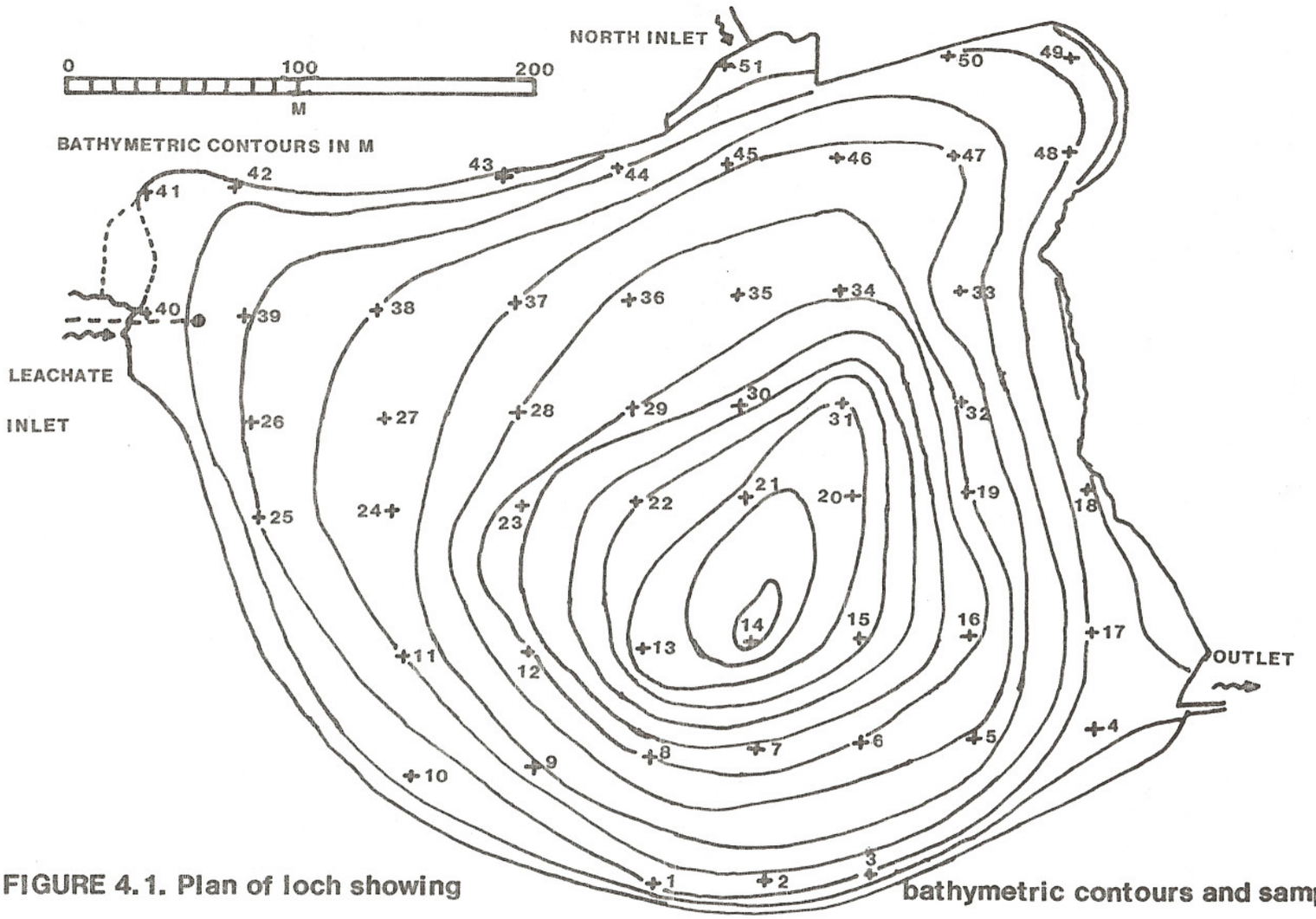

FIGURE 4.1. Plan of loch showing bathymetric contours and sampling stations.

Figure 4.2. illustrates the accumulated volume of the loch and shows that a normal summer draw down via the penstock by 1.4 m reduces the water volume to 70% of capacity. Figure 4.3 illustrates water levels found in the loch during the period of study and shows that the loch was not drawn any further than this, although previously extra draw down has been accomplished by pumping over the spillway. Exceptionally, in 1976, the loch surface was drawn down by 4.3 m indicating a reduction to 27% of capacity and exposing 50% of the bottom sediments.

4.2. DEVELOPMENT OF THE POLLUTED STATE.

The natural chemistry of Kinghorn Loch would be that of the north inlet waters. The loch should be phosphorus deficient and thereby oligotrophic. Over a period from the mid-1970's up until May 1983 the loch regularly suffered from excessive phytoplanktonic activity at a level seen in very few water bodies in this country. Additionally, the mean pH of 9.94 was prohibitively high for the survival of fish and most invertebrates. The loch had the dubious distinction of possessing by far the highest level of dissolved arsenic of any waterbody in the United Kingdom[18], a level of 500 ug l^{-1} as against a level in most waters of less than 5 ug l^{-1}. Figure 4.4. charts the pH of the loch over the period 1954 to 1985 and vividly illustrates the onset of significant pollution in 1961 and the ever increasing pH up until the removal of the leachate. It also shows the surprising rapidity of the improvement in water quality that followed. Pre-1981 data for compiling this figure were obtained from F.R.P.B. records and from BA Chemicals Ltd.

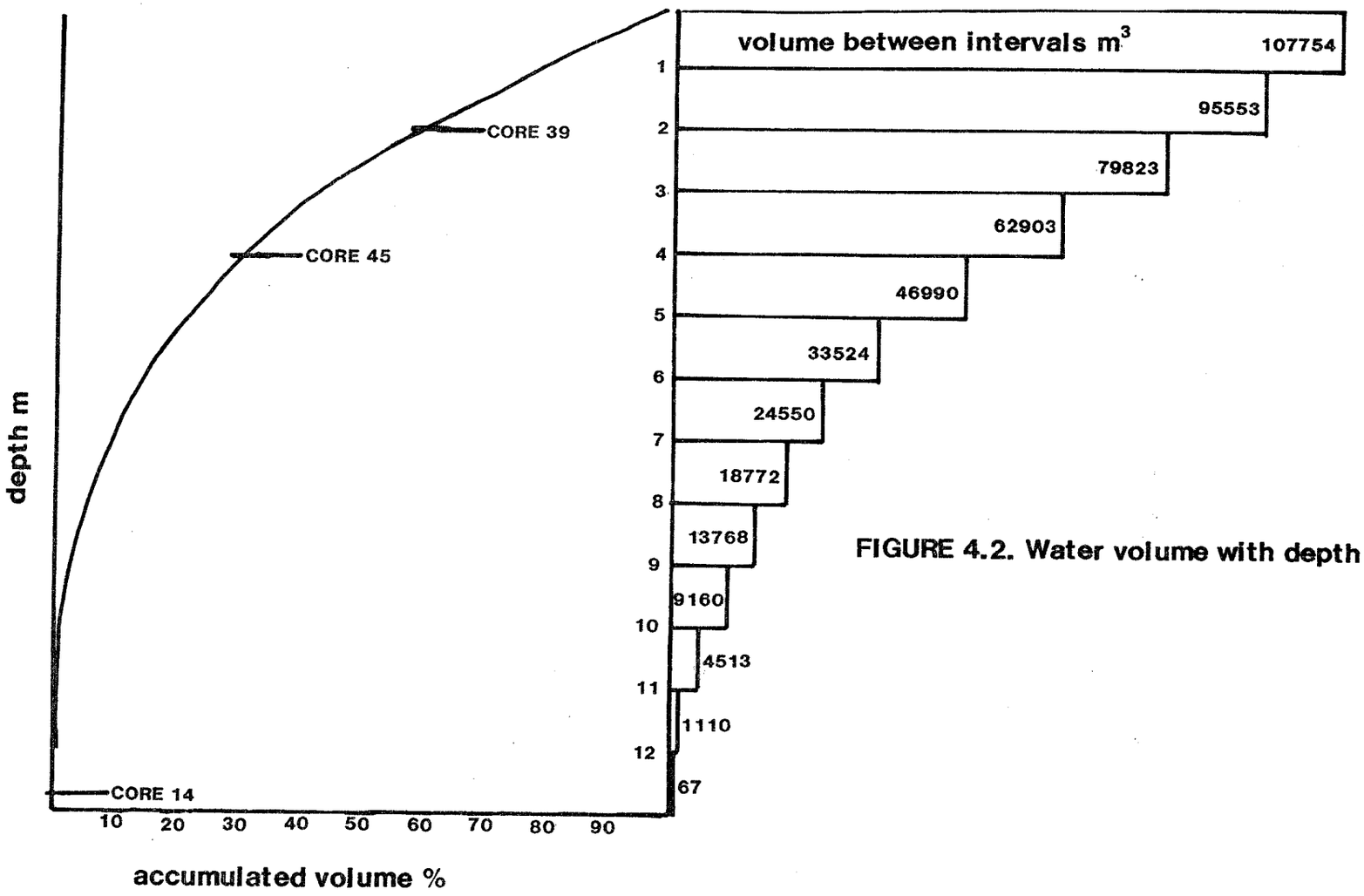

FIGURE 4.2. Water volume with depth

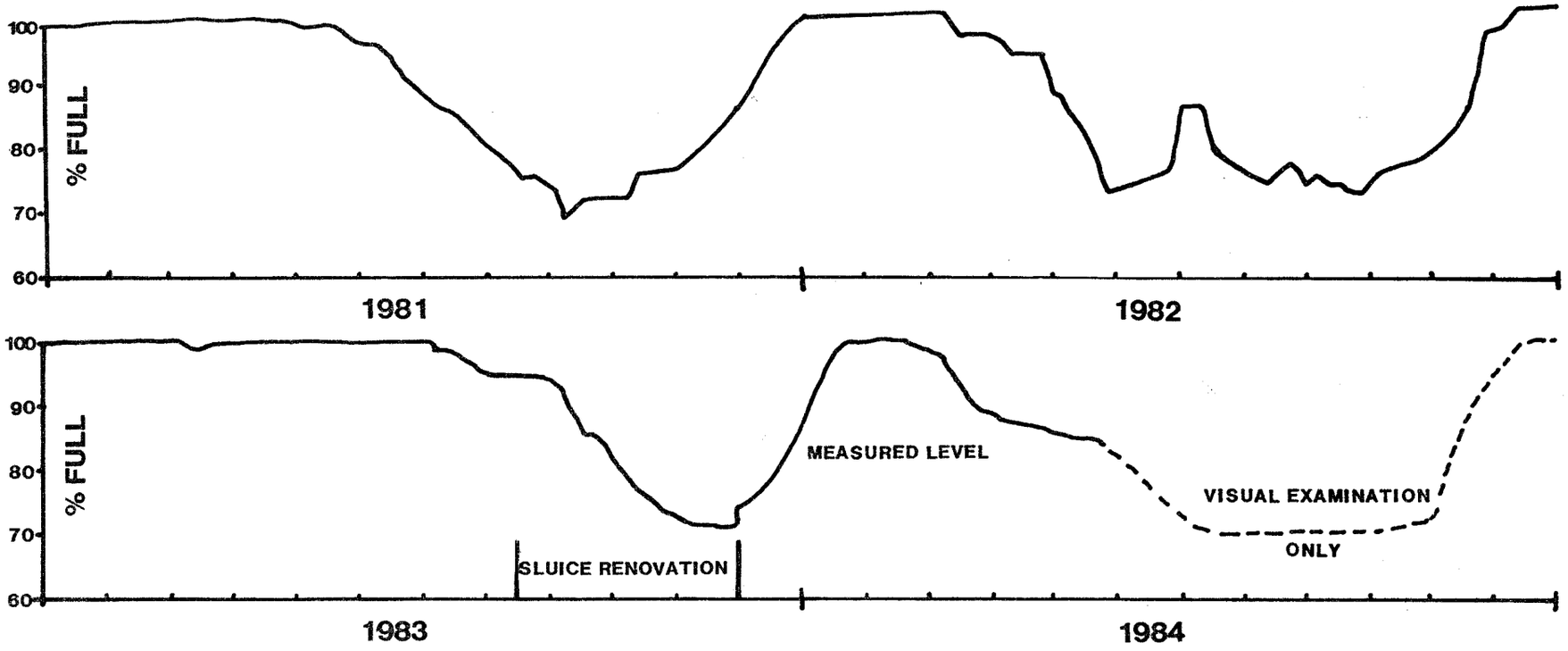

FIGURE 4.3. Water level

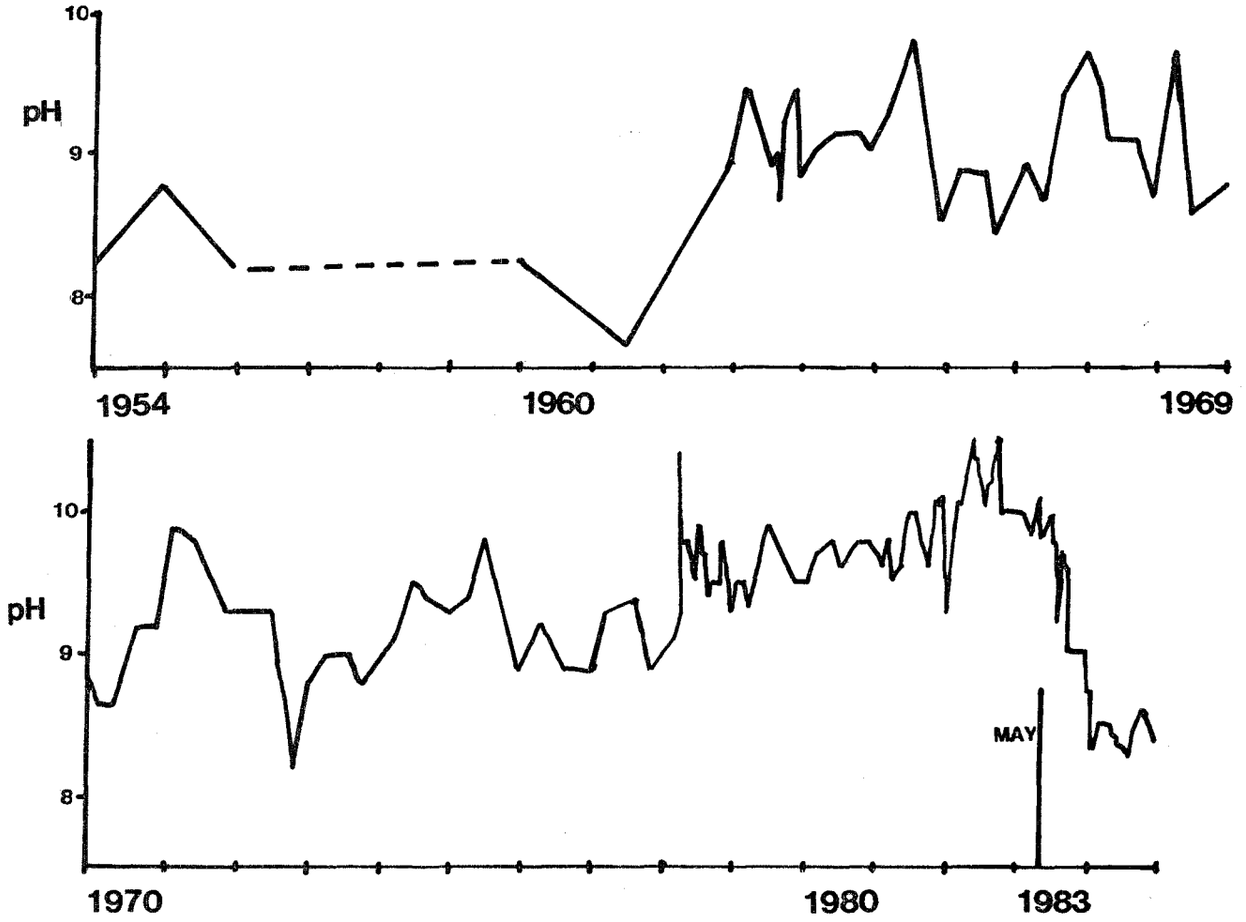

FIGURE 4.4. pH of Kinghorn Loch at outlet

4.3. CHEMICAL COMPOSITION.

Table A.5. of Appendix A.3 collates data for the analysis of the loch over the period up to May 1983 and Table A.6. illustrates its subsequent recovery. The data contained in these tables were obtained from a sampling station near the outlet and need not be representative of the water body as a whole. The loch is relatively deep for its size and may be expected to be thermally and chemically stratified. Several surveys were carried out during calm weather, between February and October 1981 in order to ascertain whether any such stratification would occur and to estimate the homogeneity of mixing and chemical reaction throughout the loch. The results of these surveys, each covering a three dimensional grid of up to 48 samples, are displayed in Tables A.7. to A.11. of Appendix A.3. These surveys include two taken during prolonged calm weather in October. It is evident that the chemistry of the loch water was surprisingly homogeneous over three dimensions. Given this general observation, station 39, which will be seen from Figure 4.1. to be close to where the pipe carrying the leachate entered, showed a very slightly elevated causticity, although on one occasion this station showed pH 11.1, 1.2 pH units above loch mean. Similarly a slight elevation of calcium level is indicated within the bay of the north inlet. These effects are marginal and the transition into general loch body chemistry is rapid.

Of more interest however, though again of very local effect, are the reductive and re-solution processes that evidently occur at or near the mud-water interface of the deeper stations. The situation is characterised by low dissolved oxygen saturation and high electrical conductivity, dissolved calcium, magnesium, aluminium and iron,

elevated alkalinity and the presence of free sulphide. Unfortunately arsenic was not determined for these surveys. These processes have only been observed very locally and disappear rapidly within the body of the loch water. Reductive processes within the sediment will be discussed in Chapter 5.

The chemical surveys were supplemented on other occasions over this period by the instrumental measurement of temperature and dissolved oxygen down the profile of station 21 and the findings are summarised in Figure 4.5. It is evident that, although thermal stratification did not occur to any significant extent, in calm weather the mud-water interface was often anoxic. The summer of 1981 proved to be a time of relatively low phytoplanktonic activity (see Figure 7.5) and the data should be compared with those for July 1983 (see Figure 4.6) when extremely high phytoplanktonic activity was observed. The figure shows that on 10th July 1983 the loch was thermally stratified and that the high phytoplankton content of the upper waters was having a dramatic effect on the dissolved oxygen profile below 2 m to the extent that the mud-water interface was anoxic. The pH profile showed little variation with depth. This day was completely taken up with the taking of sediment cores by divers of Fife Sub-Aqua Club and so no further investigations were possible. Unfortunately the calm weather had broken before a boat was available for more intensive sampling of the anoxic zone.

The reductive processes appeared to occur only locally within the water body itself and any metals taken into solution were redeposited. Arsenic may however be lost to the atmosphere either as arsine or organoarsenicals (see Chapter 4.7.6). Overall, these

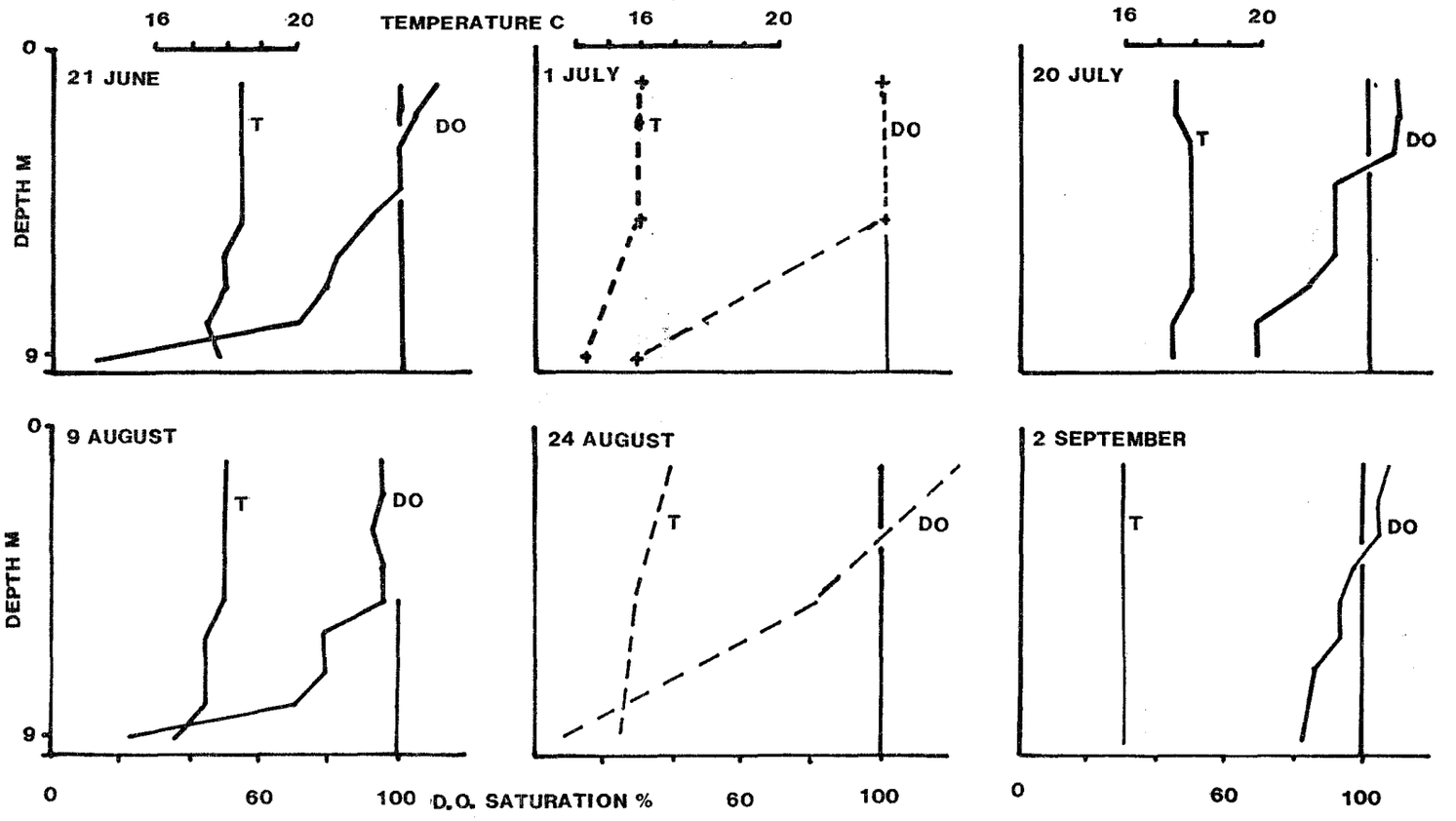

FIGURE 4.5. Daytime temperature and oxygen profiles for Station 21 (June - September 1981)

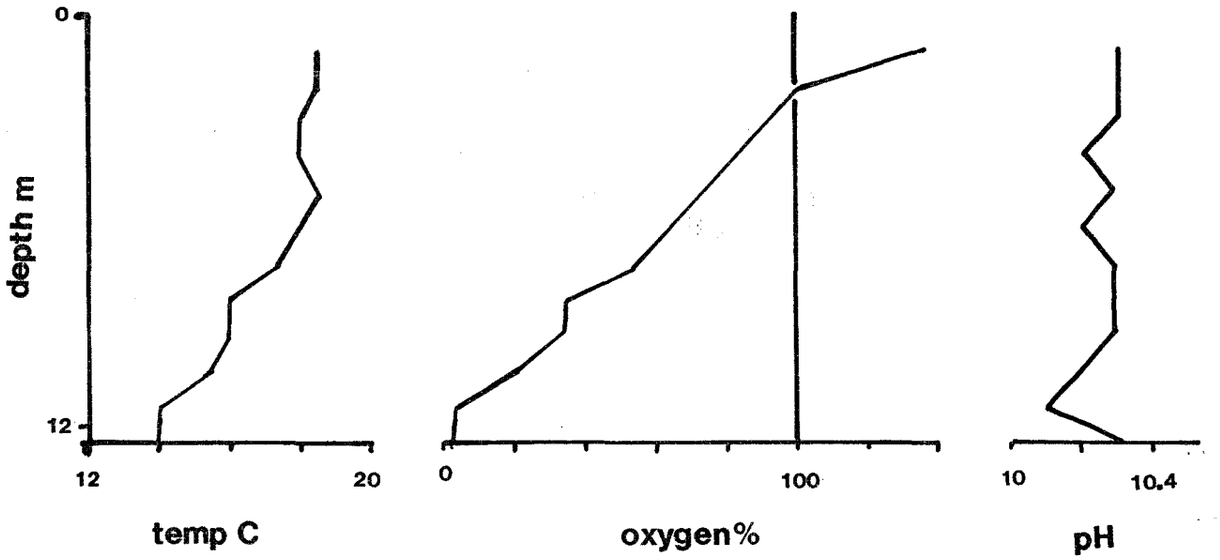

FIGURE 4.6. Daytime profiles for Station 14 , July 10, 1983

processes will have had only a minor effect in determining the gross deposition rate. They do however indicate likely conditions within the sediments and are therefore of vital interest in determining the broader relationships within the whole water body-sediment system.

The concentration of determinands found in the loch were affected by two major processes both of which caused irretrievable loss of material to the sediments. The first process was the chemical reaction of the leachate and the inlet waters to form carbonate and aluminosilicate minerals and the second was the phytoplanktonic productivity within the loch which grossly affected the nutrients present. These processes would be reflected by similar variability of related determinands with time. A significant correlation between two determinands will therefore indicate joint participation in such processes and the following section was set out to identify these relationships.