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HYDROLOGICAL STUDIES OF LAKE NAINI, DISTRICT NAINITAL, UTTAR PRADESH (PART - I)

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PREFACE

The National Institute of Hydrology is a premier institute in the field of Hydrology and Water Resources in the country and undertakes the research related with specific hydrological problems. Keeping in view the importance of natural lakes from water resources point of view, particularly Naini lake which is the only source of drinking water supply in Nainital and major attraction to the tourists, while different kinds of hydrological problems are being increased with this lake, the institute has taken a three years project entitled "Hydrological studies of lake Naini", from Directorate of Environment, Govt. of U.P., Lucknow through Nainital Development Authority. The major problems being recorded in Naini lake are deterioration in water quality, increasing sedimentation rate, reduction in lake water capacity and water input. Besides these, some other related aspects will also be studied like, water balance of lake, and its hydrodynamics. The Institute has the infrastructure to study these aspects of lake using advance techniques, like Nuclear techniques, Remote sensing techniques, advanced instrumentation using data acquisition system and sophisticated/portable equipment for water quality testing. The conventional techniques are also being used to study the sedimentation and other parameters.

The present interim report deals with the theoretical aspects of the techniques to be used and progress made so far. Specifically, the first section is devoted to the methodologies and techniques which will be used for the various hydrological studies of lake Naini. The programme of studies has been divided in three phases and has been mentioned in the second section of the report, including the progress of the work made so far. This interim report has been prepared by a team of scientists comprising Dr. Bhishm Kumar, Dr. C.K.Jain, Sri S. K. Jain and Dr. Rajeev Sinha who are associated with the project on Naini lake. The contribution of Dr. S.V. Navada, Head, Hydrology and tracer section, BARC, Bombay and Sri Saravan Kumar, Sri Suman Sharma, Sri. U. P. Kulkarni and the guidance of Dr. S. M. Rao are significant. The suggestions given by Sri A. K. Bhar scientist E and head of Lake Hydrology Division at NIH have also been incorporated in the report.

I am sure that with the activities proposed to be carried out according to the programme mentioned in this report, the institute will be able to achieve the objectives envisaged in the project.

(S.M.SETH)
Director

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ABSTRACT

Lake Naini (popularly known as Nainital lake) in district Nainital of Kumaun Himalaya region is well known for its importance from tourist point of view in India. It is also the only source of drinking water to the thousands of people living in Nainital town and surrounding area. Unfortunately, due to unscientific use of lake water and improper management, the water availability in lake has been affected with respect to its potability. The sedimentation at a higher rate is reducing the lake water capacity, Many of the subsurface inflow sources, either have been dried or diverted, The lake water is being polluted by different types of human activities. Therefore keeping these in view, to study different aspects of the lake such as water balance, sedimentation, pollution, hydrodynamics and identification of recharge sources/areas from hydrological point of view, the department of Environment, Govt. of U.P. financed a project through Nainital Lake Development Authority to the National Institute of Hydrology, Roorkee.

In the present report, the detailed information like geology, geomorphology of Naini lake have been reported along with the methodology for studying the water balance, sedimentation and pollution aspects etc. of the lake. During the last 7 months i.e. from Feb. to Sept. 1994, study of hydrodynamics of lake along with water quality, including stable isotopic composition of lake water were carried out. The results of these studies are given in this report with the conclusion drawn. The details of instrumentation installed at the lake site and in its catchment have also been mentioned in this report. As this is only an interim report, therefore, much emphasis has been given on the primary part of the studies to be carried out and little about the studies carried out so far. The details of the studies of different process going on with the lake and are being studied by the Institute (for a period of one year, Feb.94 to Feb. 95) using nuclear techniques, remote sensing techniques, chemical techniques and conventional techniques will be given in details in the report which will be brought out in the month of May/June, 1995.

1.0 INTRODUCTION:

Lakes either man made or naturally occurring are constantly used from time immemorial in most of the countries and we are not an exception to it. It is a source of water for a variety of purpose such as irrigation, drinking, hydropower generation, pisciculture and recreation. Further, a lake plays a significant role in shaping the hydrological, ecological, and environmental balance of that region. Lake is also a place for sanctuary for migrating birds, developing flora and fauna and an excellent spot for habitation of aquatic biota which are important for maintaining the ecological and environmental balance and also the hydrological cycle. All the above factors are either directly or indirectly linked up with the overall economic development of the region and the country as a whole. In many parts of the country, lake water is the only dependable source of water on which almost all the activities of the area are based. Any change in the lake water both in quality and quantity which may arise for various reasons, will certainly hamper the development of the area. Impact of degradation may be less in the initial stage, however, the cumulative impact in a longer period would be significant and in many cases, it may be dangerous. Problems are as such very serious and in most of the cases, it has reached at an acute condition in case of Indian lakes. If, the state of the problems and their remedial measures are not looked into, it would be very difficult to save the lakes and therefore, the adjoining areas from an ecological, hydrological and environmental disaster.

The hydrological study of the Naini lake (Fig. 1), in district Nainital of Uttar Pradesh, has been taken up by the N.I.H as a research project sponsored by the Directorate of Environment, Govt. of U.P, through the Nainital Lakes Development Authority (NLDA).

The present report deals with the different kinds of studies carried out on lake Naini in district Nainital during the period from Jan. 1994 to the month of May, 1994. The studies related with hydrodynamics of lake, water quality, sedimentation and hydrometeorological observations carried out using conventional, nuclear and remote sensing techniques have been discussed. In addition to the above, the objectives of the project undertaken, geological & hydrological details of the Naini lake region have been briefly discussed in this report. The details of methodology have also been mentioned briefly in this report.

2.0 NAINI LAKE PROBLEMS AND PROJECT OBJECTIVES:

District Nainital of Kumaun region is well known for its picturesque lakes. It has been observed that due to unscientific use of lake water and improper management, the water availability in lakes is reducing continuously. The sedimentation in the lake and reduction in discharge of the recharge sources of the lakes have adversely affected the storage capacity of lakes, leading to the drying up of springs and/ or lakes. The frequent change of land use pattern and deforestation in the area have affected the zones of recharge to the lakes and ultimately the input to the lake has been reduced accordingly. Due to typical geologic nature, presence of faults and instability of hill slopes lead to frequent land slides and mass movements which ultimately affect the hydrology of the lake. Sedimentation in the lake has reached to an alarming state, the main source of sediments being the debris from the surrounding hills and house-building material.

Further, the Naini lake has been showing signs of accelerated eutrophication due to human interference in the catchment area. Eutrophication is carried when the water of a lake is not able to purify itself because its dissolved oxygen is consumed in oxygen-demanding biochemical processes ,thereby, developing an aerobic condition. The prolific growth due to the presence of phosphate and nitrate nutrients and overcrowding of algae and weeds and their eventual death and decay creates the same situation. One of the major causes of eutrophication of lake is the indian make indiscriminate discharge of untreated domestic waste along with refuse and solid waste through 26 major drainage channels resulting in severe impairment of physical, chemical and biological quality of lake water.

The causes of deterioration of the Naini lake are manifold. The infrastructural facilities such as water supply, sewerage, solid waste disposal, traffic and transportation and tourists facilities have fallen short of requirement. Due to this, the rain water fed channels serve as conduit to carry sewage overflow and also the solid waste, which are dumped into the channels which finally reach the lakes. Some of the springs contributing water to the lakes have dried up, and some are in the process of drying. On the other hand, the need of water is increasing day by day. Therefore, there is a strong need for the study of all aspects related with lakes for better management of lake recharge zones and to restore the health of the lakes in Nainital region.

Keeping in view the above problems, the study has been planned with the following objectives.

(i) To study the hydrological water balance and water availability lake.

(ii) To investigate the causes of sedimentation of lake which is resulting in the reduction of lake capacity.

(iii) To identify the recharge zones for the lake keeping in view the lowering of water table in the catchment area.

iv) To study forest and other management practices and their linkage with water availability and sedimentation.

(v) To suggest measures to augment water availability and reduction of sedimentation.

3.0 DESCRIPTION OF STUDY AREA:

3.1 Background:

The crescent-shaped water body of the Naini lake is surrounded by steep mountain slopes of Nainital hills which is diagonally cut by Nainital fault into northeastern Naina peak - sherka dande ridge made up of the lower krol and southwestern Deepatta-Ayarpatta ridge constituted of the middle and upper krol with the tal (Valdiya, 1988). The lower krol consists of argillaceous limestones and marlites, while the upper krol and tal are made up of dolomite with limestones and black carbonaceous slates (Fig. 2).

The structure of Naini lake basin is characterized by complex tectonic movement related to recurrent movements on the active main boundary thrust and related tear faults (Valdiya, 1981, 1988). The Naini lake is a product of tectonic movement along Nainital fault. The NW-SE trending Nainital fault passing from lake basin and follows belia nala in down side. Quite after the establishment of the drainage of the nature balia nala, subrecent movements of order of 20m to 80m within the lake basin caused uplift of northeastern sherka denda range relative to Ayapatta ridge. The rotational movements was responsible for blockade of stream in its upper reaches, resulting in formation of lake (Valdiya, 1988).

The contributions from precipitation, springs, and streamlets from the surrounding watershed helped in further evolution of the lake. The previous flow of the lake was towards NW through Sariatal region before land slips sealed this channel, shifting the flow to the south through Tallital region. Geological and geomorphological evidences favour the idea of a slide in the southern Sariatal/Khurpatal region.

3.2 Morphometry and Hydrography:

The Naini lake is situated at an altitude of 1937 meters above sea level and is 1433 meters long and 423 meters broad at its widest. The total surface area is about 4.65 hectares (calculated using imageries) and the volume is approximately 8.33 Million cubic meters. The catchment area of the basin is 3.6 km^2 (from the map presented by Valdiya, 1988) ranging in height from 1937m to 2600m. However different figures have been reported by different investigators e.g. NEERI, Nagpur (1989) 11.8 km² and khanka (1991), 5.85 km². The mean hill slope of the area is 19° where large part being confined to the slope group of 20° to 25° and the maximum slope reaching 47° to 49° (Rawat, 1987). The average slope of the snow view - Sherka Danda ridge is 18°, varying between 5° to 35°. At many places the slopes exhibit convex bulges resulting from continuing creep movement. The slopes are locally broken by scarps and fringed at the base by a succession of debris cones and fans. The bathymetric study (Rawat, 1987) reveals that the lake consists of two V-shaped basins, one in the north and the other in the south with maximum depths of 27.3 m and 25.5 m respectively. The depth of lake where the dividing ridge has been observed is 8.6 m. An outlet for draining out excess water is situated at the north-eastern end. The shoreline is steep, except at a few places where the drains have deposited silt and debris.

The annual rainfall is high in the catchment area of the lake and varies between 2245 mm to 2480 mm. The average monthly rainfall is 189.0 mm with a maximum of about 624.8 mm in August and a minimum of about 2.4 mm in March. Besides rainfall, there are occasional snowfalls in and around the lake catchment during the winter, varying between 200 mm to 600 mm in recent years (Khanka, 1991).

4.0 INSTRUMENTATION FOR LAKE STUDIES :

Every field/ laboratory study is conducted with the essential use of different types of instruments. The instruments used for lake studies can be divided in two broad categories.

I. Field instrumentation.
II. Laboratory instrumentation.

The instrumentation for lake studies can be further divided according to the investigations carried out. The details of the required instrumentation for field/ laboratory investigations are given below.

4.1 Water quality instrumentation.
4.2 Hydrological/hydrometeorological instrumentation.
4.3 Remote sensing and nuclear hydrological instrumentation.
4.4 Integrated data acquisition system.
4.5 General instrumentation.

4.1 Water quality instrumentation :

I. Field Instruments

Following instruments are required for different types of water quality investigation in site.

(i) Portable PH meter
(ii) Portable DO meter
(iii)Turbidity meter
(iv) Conductivity Meter
(v) Portable water testing kit

II. Laboratory instruments

(i) Flame photometer.
(ii) Ion-Analyser :
(iii)Total Organic Carbon Analyser :
(iv) Atomic Absorption Spectrophotometer :

III. General Equipment :

General equipment includes BOD Incubator, Becteriological Incubator, Colony counter, Universal Oven, COD Digestor, Distillation plant, Electronic balance, Deep freezer, Water samplers etc.

4.2 Hydrological / hydrometeorological instrumentation :

I. Field instruments :

Following hydrological/hydrometeorological instruments are required to be installed at site for the required observations.

Raingauges, Water level recorders, Stevenson screen consisting of Dry & wet bulb thermometers, Maximum & minimum thermometer and Evaporation pan.

4.3 Remote sensing and nuclear instrumentation :

a. Remote Sensing Instrumentation

Image processing & GIS systems like ERDAS/ILWIS are used to analyse and interpret the remote sensing geographical data.

(i) ERDAS - Earth Resources Data Analysis System

This system is a PC based system having image processing and basic GIS utilities. ERDAS-7.5 software contains a variety of modules that can be used independently or combined. ERDAS programs within each module are accessible through a series of menus.

(ii) ILWIS - Integrated Land and Water Information System

This system has been developed by the International Institute of Aero Space Survey and Earth Science (ITC). The main Characteristics of the system are :

- PC based system
- a tabular, vector and raster data base integrated in one system
- remote sensing capabilities, fully integrated into the GIS and full data format compatibility.

Remote sensing data can be entered into the raster data base from either computer compatible tapes (CCT) or high density floppy disks. Complex modelling procedures can be easily executed through the MAPCALCULATOR, which integrates tabular databases with spatial databases, it includes an easy to use modelling language and the possibilities of using functions and macros. Tabular and spatial databases can be used both independently and on an integrated basis. A versatile program TABLECALCULATOR, provides direct communication between the ILWIS kernal and outside models, statistical packages, raw data files, databases and other systems. ILWIS incorporates conventional image processing capabilities. Pre processing includes several basic image analysis capabilities, such as histogram manipulation, automatic stretch display, user defined filters, transfer function manipulations and other standard functions.

(iii)Digitizors, used to digitize a map to be used in different formats using personal computer.

(iv) Enlargers for studying the imageries in the enlarged form.

(b) Nuclear Instrumentation:

Nuclear instruments are used in field as well as in laboratory. The details of both type of equipment are given below.

i) Geolog rate meter

This equipment is used to measure the discharge of streams/rivers flowing into or out from the lake. The gamma ray emitting radioisotope is used for the measurement of discharge using tracer dilution technique.

This equipment is also used for the measurement of flow of groundwater into the lake or lake water mixing with ground by using the single well dilution technique. Detector with an specific arrangement to inject the radioisotope, mixing and isolation of a desired volume of water, is known as a point dilution probe.

ii) Gamma ray Spectrometer with HPGE detector

This equipment is used in laboratory for the study of sedimentation rate in the lake. The sediment cores from the lake bed are taken up to the desired depth and the analysis of activity of environmental CS-137 and Pb-210 is carried out in the laboratory for the determination of sedimentation rate in the past using dating techniques.

iii) Liquid Scintillation Counter

Two types of liquid scintillation counters are used for specific purposes like normal liquid scintillation counter is used for the studies like turnover rate and flow of groundwater in or out to the lakes using injected radio isotope like tritium while ultra low level liquid scintillation counter is used for the measurement of activity of environmental tritium and carbon-14 for the study of age of groundwater entering into the lake using tritium and carbon-14 dating techniques. The other allied instruments used for dating of the groundwater using above technique are tritium enrichment unit and benzene synthesiser. These all instruments fall under laboratory instrumentation.

iv) Mass Spectrometer for stable isotopes

Mass spectrometer is a very sophisticated laboratory instrument which is used for the analysis of stable isotopes like oxygen-18, deuterium and carbon-13. Oxygen-18 and deuterium stable isotopes are used for the study of thermal stratification, 9 turnover period, identification of recharge sources and recharge zones of waters to the lake C-13 analysis is required for the correct estimation of age of groundwaters in case of C-14 dating.

4.4 Integrated data acquisition system :

This type of system has been designed for acquisition of hydrometeorological data for integrated studies taking different hydrometeorological parameters obtained simultaneously using remote operated sensors. The system is having an electronic console unit to display the data one by one, data storing devices namely memory module. The system can be attached to computer, printer, paper chart recorder for processing and recording the data on paper.

Special features :

(a) Remote operated sensors :

The sensors can be installed away from the central unit (up to 500 m) connected by long cable.

(b) Automatic/manual operation :

The central unit can be operated automatically as well as in manual mode (using 9 v/12v battery) and data can be noted down manually when recorder/ printer/ computer etc are not functioning due to any reason.

(iii)Data simulation facility helps to check the performance of the system easily even in the field.

4.5 General instruments :

Various general instruments are also required to be used for the measurement of some specific parameters for lake studies as per details given below.

(i) Echo-sounder :

For the determination of lake depth, the lake bottom profile i.e bathymetric survey Eco sounder have been used.

(ii) Pigmy current meter :

This instrument is used in water balance studies. It directly gives the velocity of water in the drain which is entering into the lake. So by knowing the area of the drain the total inflow can be calculated.

(iii)Depth water temperature, DO, pH survey equipment :

This is a portable instrument and is used at site to measure the temperature, DO, pH and various other parameters like salinity, conductivity (if provision exists with the equipment) at different depth & positions in the lake. Presently, imported equipment is for this purpose with some depth arrangement to be fabricated according to need as the indigenous equipment available have not be found reliable.

5.0 HYDROLOGICAL WATER BALANCE STUDIES

5.1 General Principles

The water balance of lakes provides very useful information about the availability of water in lakes at any time. In order to proper utilisation of the lake water, the knowledge of different components of water balance of lakes is essential. Also, if the water balance is monitored regularly after a specified period (say yearly or after every 2-5 years depending upon the situation), the information of change in the value of different components of water balance will require important precaution/measure in order to control the required availability of water in the lakes. Unfortunately, the study of various parameters considered for water balance has not been taken so far in case of the Naini lake. The lack of knowledge about input water and water utilised for various agricultural, industrial and domestic purposes and also other natural losses including increased sedimentation and drying/diverting the natural sources of water to the lake have resulted in reducing the lake capacity (Govt. of U.P., 1989).

The water balance equation of a lake can be expressed as follows :

$\Delta S = I_s + I_u + P_l - Q_s - Q_u - E_l$, where

ΔS = change in water storage
I_s = Surface inflow
I_u = Subsurface inflow
P_l = Lake precipitation
Q_s = Surface outflow
Q_u = Subsurface outflow
E_l = Lake evaporation

5.2 Methodology for water balance studies of Naini lake

5.2.1 Lake precipitation (Pl)

Precipitation into a lake can be estimated from the raingauges installed all around the lake, upstream as well as downstream portions and the average values of all the gauges will be taken as the value for lake precipitation.

5.2.2 Surface inflow (Is)

The surface inflow into the Naini lake can be subdivided into inflows from rivers and nalahs and inflows from numerous small basins surrounding the lake. Part of the latter component consists of non-channelized overland flow. Continuous observation of discharge will be carried out in as many inflowing rivers as possible. In case of the perennial rivers, rating curves will be computed for calculating the discharge values for any time period.

To measure the surface inflow from the major nalah (nalah no. 23/26), automatic water level recorder has been installed at the nalah in order to have a continuous record of the discharge. A metallic measuring gauge is also installed near the WLR for manual reading of water depth in the nalah . To compute the discharge from the small and seasonally flowing nails, pigmy type current meters will be used. Further, a relationship between precipitation and discharge through such inflows will also be developed from which discharge can be computed.

Isotopic techniques (Dincer,1968, Allison, et al, 1979;IAEA,1983) can also be used for the measurement of inflow into the lake through visible gullies, nalahs, and springs. Either a gamma ray radioisotope like Br-82 or tritium can mixed at a suitable place in the inflowing channel. The dilution of the radioisotopes can be measured after a certain distance (known as mixing length) by using a rate meter/scaler if gamma ray tracer is injected or by collecting water samples and analysing the diluted activity with the help of liquid scintillation counter, if the tritium is injected.

5.2.3 Lake evaporation (El)

Potential evaporation for the lake can be measured through the evaporation sensor in the Data Logger. A Pan evaporation meter has also been installed at the lake site.

Isotopic methods for estimation of evaporation will involve collection of lake water samples from different depths and at different times and measurement of concentration of ^{18}O or D in each sample. From the variation in the isotopic composition at the surface of the lake, indirect estimates of evaporation will be done through existing empirical relations developed for this purpose

5.2.4 Surface outflow(Qs)

In case of Naini lake, there is no any source of surface runoff in the form of outgoing river streams nalah. Its water is also not used for irrigation for which a regular drain of lake water is required. However, the lake water is being used for the drinking purposes for the whole Nainital city and in the vicinity area including military cantonement. Therefore, the lake water is being within regularly at two sites e.g. one at the Mall road site by the pumping station installed by military personnel and other at Gurudwara site, by number of pumping stations, installed by Jal Nigam. In addition to the above, the lake water is drained by opening the gates installed at Tallital site (near Bus station) whenever the level of lake water rise up to a certain height during the rainy season. Therefore, there are two major source of direct drainage of lake water i.e. pumping for drinking purposes and drainage of water to regulate the lake water level during rainy season.

The volume of water being withdrawn from the Naini lake for different purposes are being collected from concerned authorities which will be used in the water balance equation directly.

5.2.5 Subsurface inflow (Iu) and outflow (Qu)

Keeping in view the formation of Naini lake, the subsurface inflow and outflow is possible only through the faults and fractures. Therefore, the study of stable isotopic composition of lake water at different depths may be helpful in the identification of sources of water i.e. whether, the water belongs to groundwater or surface water, including the mixing percentage. In this respect, the water samples of the different streams emerging out at number of places all around the Naini lake with in the approachable zone, will be collected for the study of stable isotopic composition. The details of the methodology of stable isotopic techniques have been reported by Kumar Bhism and Sinha Rajeev (1994) Zimmerman (1979) in case of artificial lakes.

5.2.6 Storage changes

The storage changes in the lake will be computed from water level fluctuations in the lake, for which the data being recorded by the automatic water level recorders, installed at both ends of the lake will be used.

6.0 SEDIMENTATION IN LAKES

Sedimentation in Naini lakes is an acute problem. The erosion rate has been accelerated from the north-eastern hillside due to indiscriminate house-building, entailing generation of enormous volumes of debris which move down the gutters. This has added to the gradual deterioration of the lake, as evident from the fact that in the period 1960-77 about 0.239 million m^3 of sediments were deposited in the lake at the rate of 0.022 mm^3/yr.(Govt. of U.P.,1989) Judging from this estimate, in about 300 years, the lake will be completely filled up if erosion is not checked.

6.1 Methodology for lake sedimentation studies

6.1.1 Nature and source of sediments:

For an accurate determination of the amount of sediment being carried to a lake by streams, the flow rate and sediment 20
concentration of the inflowing waters just upstream of the lake will be measured. Measurements of fine sediment concentrations would involve collecting a sample of the water-sediment mixture, separating the sediment, and weighing. Measurement of bed load will be made with samplers or sediment traps.

6.1.2 Computation of sedimentation rate

The periodic bathymetric surveys(Rawat,1987; Khank,1991) of the Naini lake are available which will be used for estimating sedimentation rate in the lake. The amount of sediment accumulated will be essentially computed from the differences. in bed elevations occurring between surveys. Further, digital image processing of high resolution satellite data (SPOT) are also planned for lake sedimentation studies. The information of suspended sediments obtained at different times using this technique will be utilized to predict the deposition or settling rate of sediments in the lake.

Apart from the conventional methods, isotopic studies using environmental isotopes like Cs-137 and Pb- 210 will also be made to compute sedimentation rate in lakes. Cesium-137 is produced in the atmosphere due to the test of nuclear weapons. Since 1954, it has been globally detectable. It emits gamma radiations with the energy peak of 0.662 MeV and has half life of 30.1 years. Cs-137 is strongly adsorbed on fine particles like clay minerals, silts and humic materials. In fact, the variation in the intensity of Cs-137 content of surface soils per unit area is linked with the intensity of fallout, percentage of clay and silt and cation exchange capacity. It follows that all surface soils with an adsorptive capacity will have a Cs-137 content and therefore be able to act as a self tracer. In a catchment, accumulation of a sediment layer in a lake/reservoir is a measure of its trap efficiency. A comparison of Cs-137 content of catchment soils with that of the associated lake/reservoir sediments shows a pronounced build-up of the latter.

Since the nuclear weapons were mainly tested in the northern hemisphere, the fallout of Cs-137 is approximately 4 times greater at comparable northern versus southern latitudes (IAEA,1983) The amount of Cs-137 deposited on the earth has been measured at precipitation stations, many locations installed by IAEA and WMO and the data may be used to determine the cumulative input of Cs-137. Examples of such input have been shown in the reports of measurement from global network of US and UK monitoring stations.

The sedimentation rates will be calculated from the depths of the two principal time horizons i.e. 1955 and 1964, in the Cs-137 concentration profile. The methodology for this would involve collection of undisturbed sediment samples from the bed of the lake with a core cutter up to the depth of 20 to 100 cm. The cores will be cut into 1 cm sections and placed in a polythene bag. The Cs-137 core sections will be analyzed by gamma ray spectrometry using Ge(Li) or intrinsic Germanium detectors (HPGe type).

Grain size information of the lake sediments is also important in predicting erosion, transport, deposition and compaction of sediments. The size distribution of incoming sediment is very important in determining the pattern of deposition in a reservoir. This is one of the most important aspects in the evaluation of the amount of space a given weight or quantity of transported sediment will occupy in a lake. Out of the wide range of sizes of sediment particles being supplied to the lake, the large and intermediate sizes (gravel and sand) can be analysed using standard techniques. The small sizes (clays, silts, and fine sand) are conventionally measured by pipette method based on the settling characteristics of sediments in water. The modern instruments for these analyses include Coulter Counter (Coulter, 1956; Berg,

1957) based on electrical conductivity profile, Laser particle size analyser (Wertheimer et al, 1978; Haverland and Cooper, 1981) based on the intensity and scattering angle of laser light by particles in suspension, SediGraph (Jones et al, 1988) based on the gravitational settling of particles in a small cell etc.

6.1.3 Determination of concentration and density of sediments

The incoming coarse sediments settle quickly at the bed while the finer sediments remain in suspension for a longer period before finally settling down to the lake bed. Therefore, it is necessary to measure the suspended sediment concentration in order to predict the future sedimentation rate.

The conventional techniques to be used for the measurement of suspended sediment concentration have already been mentioned in the section 6.1.1.

The bulk density of a deposited sediment is the dry weight of sediment per unit volume. The bulk density therefore provides a simple and direct conversion from the dry weight of sediment added to the reservoir to the volume of water displaced. The sediment density will be determined by taking core samples from the bottom sediments and measuring the weight and volume of the deposit.

The conventional methods of measuring bulk density by a core sampler is laborious and time-consuming. The modern techniques based on nuclear density probes for measuring density and moisture in boreholes or in core samples has therefore gained wide acceptance. The density of sediment deposited in reservoirs can be easily determined by means of gamma scattering probes.

The most commonly used probe is equipped with a ^{137}Cs source and a gamma scintillation detector. The count rate of the linear rate meter is recorded visually or by a suitable recorder. By reference to a calibration curve using several bentonote/sand or sodium silicate pastes, the bulk density equivalent of the count rate can be derived. A series of such readings through the material allows the construction of a density profile. Measurements on core samples by means of gamma transmission gauges are preferable for measurements of the deposited material in new area. Such nuclear methods are non-destructive and rapid and often give more accurate results than those obtained by other methods.

6.1.4 Determination of sediment types

Sediments of various compositions emit natural radioactivity of different intensities. A technique to trace the sediment transport and to identify sediment types is based on the measurements of gamma radiation of natural uranium, thorium and potassium, which are generally richer in clay than in coarse sediment sizes.

The values of natural sediment radioactivity strongly depend on the position of the gamma scintillation detector with respect to the bottom. The difference between radiation emitted from sand and from clay are due to the mineral composition, whereas between clay and mud the difference may be due to the changes in water content which result in a deeper penetration of the probe into the sediments for soft mud.

Measurement of the radioactivity is made by lowering a gamma probe to the sediment or sliding it over the surface of compact sediment and detecting the gamma radiation by means of a scintillation counter. Signals from the probe are analysed by means of a multi-channel analyser and recorded by a printer or tape. This instrument is very useful for making detailed observations of the composition of sediments at each station, or dragging it along the bottom to observe difference between the natural littoral sand and dredge spoils material. The dredge material often has a different composition from the bed sand and consequently different radiation patterns will be observed. These differences can be utilised to elucidate the extent of the coverage of bottom sediments by the dredge spoils and will show the direction and extent of transport of the spoils by the bottom currents.

6.1.5 Sediment Redistribution Measurements in Lakes

The transport and spatial distribution of sediments entering an impoundment are functions of the balance between the flow velocities, gravitational forces and the secondary forces of flow turbulence. For reservoirs, draw-down procedures can be a very powerful initiator of sediment flows and redistribution while in lakes where the drawdown is negligible, only the inflow velocity and other forces as stated above will control the spatial distribution of incoming sediments.

The Au-198 - a gamma ray radioisotope is mixed with inflowing water body like drains, open springs or channels in order to level the sediments. The Au-198 is adsorbed on the sediment surface and therefore the movement of the suspended sediments as well as the settled bed sediments can be studied by using a gamma ray detecting unit following a method same as for determining the type of sediment. The only difference is that natural gamma ray activity is measured while determining sediment types, whereas in case of sediment redistribution measurements, artificial gamma ray activity is measured.

7.0 LAKE WATER QUALITY ASPECTS

7.1 General Characteristics

The behaviour of lake water is subject to a wide range of influences operating over three dimensions unlike river water which is often virtually unidimensional. A lake may be characterised by morphometric, hydrological, chemical, biological and sedimentological parameters depending on its age, history, climate and water budget. Each lake develop its own response to these combined factors causing major variations of water quality in both time and space. Some of the important factors giving rise to spatial and temporal variations in the distribution of the quality of lake waters are discussed in this chapter.

7.1.1 Water Budget

The composition of the water in the lake is influenced by the water budget, i.e., by the balances between inputs and outputs. However, the water budget is not the sole deciding factor because there is an interchange between sediment and water and a build up of organic matter by biological activity.

The major inputs are usually tributary of rivers and streams which may carry a range of materials of natural and artificial origin. There may be point discharges directly into the lake as well as there will also be diffuse discharges from land drainage influenced by agricultural activities. There may also be sub lacustrine water from underground sources and rainfall which may introduce foreign matter. Of course, the measurement of input from the diffuse sources is difficult.

Most of the outputs are a direct reversal of inputs, along similar pathways. The major output will be the river through which the lake water discharges, and there may be abstractions for public and industrial use. The abstracted water after use may be returned to the lake. There may also be sub- lacustrine movement of water out of the lake into adjoining aquifers. Finally there will be loss of water from evaporation.

The theoretical time for retention or residence time of the lake will be the total water inputs divided bY the lake volume. It can vary from some months for shallow lakes to several decades and more for the greatest and deepest lakes. The residence time is the minimum time taken to reach equilibrium after a major change in input. In practice this rarely occurs unless the lake is fully mixed. The degree of mixing will vary according to the configuration of the lake and the location of the inlets and outlets. Where the lake is elongated or dendritic, with many branches, or consists of a number of basins, lateral mixing will be poor and related variations in water quality will occur. Stratification of the water will also reduce the effective volume of water available for dilution of a changed input.

7.1.2 Stratification and Water Mixing

Another important characteristic of lakes is thermal stratification caused by the influence of temperature on water density.

In temperate regions, during spring and summer the surface layers of the water become warmer and their density decreases. They float upon the colder and denser layer below and there is a resistance to vertical mixing. The warm surface layer is known as the epilimnion and the colder water, which is trapped underneath is the hypolimnion. The epilimnion can be mixed by wind and surface currents and maintains a fairly even temperature. Between the two layers is a shallow zone where the temperature changes from that of the epilimnion to the temperature of the hypolimnion. This zone is called the metalimnion or the thermocline. The hypolimnion does not undergo direct reaeration from the atmosphere and may become depleted of dissolved oxygen if the levels of organic matter are high. Under anoxic conditions reduction of various compounds in the sediments can occur converting them into soluble reduced forms which diffuse into the hypolimnion. Substances produced in this way include ammonia, nitrate, phosphate, sulfide, silicate, iron and manganese compounds.

As the weather becomes cooler, the temperature of the surface layer falls and the thermocline sinks even lower. When the surface layers reach a temperature at which they are denser than the water of the hypolimnion there is an "overturning" of the lake water, which occurs quite quickly and results in a vertical mixing of the lake water.

Thermal stratification does not usually occur in large lakes unless the depth is at least 10 metres and in very deep lakes it may persist throughout the winter. It does not normally arise in small shallow lakes, particularly where there is a high rate of flow through.

If a lake becomes covered with ice an inverse thermal stratification can occur with a layer of colder water on top of the main body at 4^0C. When a lake is frozen over reaeration virtually ceases and anoxic and reducing conditions can arise.

7.1.3 Seasonal and Vertical Variations of Biological Activity

The biota in the lake greatly influence the quality of waters, the effect vary according to the age of the lake. The activity of most immediate consequence is photosynthesis carried out, mainly by phytoplankton, in the upper layer of the lake. This results in an uptake of nutrients such as nitrogen, phosphorus and silica with a production of oxygen and an adsorption of carbon dioxide giving rise to an increase in pH.

In cold climate regions, the photosynthesis cycle follows a marked seasonal pattern with a winter minimum and a summer maximum, while in the tropics the algal productivity, and its influence on water chemistry, is more evenly distributed.

In bottom waters, the bacterial degradation of the algal detritus leads to a regeneration of inorganic nitrogen, phosphorus, an increase of CO2 , a shift towards acidic pH and a decrease in oxygen. This oxygen depletion is directly related to the amount of organic detritus that recycles the bottom waters and inversely linked to the extension of the hypolimnion.

The lake chemistry is therefore more complex than the rivers and groundwaters and results from external (water inputs, chemistry, water balance and evaporation) and internal processes (biological activity, water mixing) which lead to marked temporal and vertical water quality variations.

7.2 Sampling for Water Quality

7.2.1 Sampling Sites

The choice of sampling stations is influenced by the various uses of the water and their location, relative magnitude and importance. There is a need for data collection on the lake characteristics such as volume, surface area, mean depth, water renewal time together with such information as is available on the thermal, bathymetric, hydraulic and ecological characteristics.

Figure 1 illustrate the location of sampling sites for lakes alongwith the criteria for the choice of different sites.

There is usually a high degree of dispersion and dilution of discharges into a lake and sampling stations concerned with specific uses may measure and detect impacts more readily if they are located fairly close to the influent or effluent point. The data from such stations will be restricted to more local uses. If a lake is divided into bays and basins more than one station will be needed. As a guideline, the number of sampling points could be equal to the rounded value of the log of the lake area in km^2.

It is important to note that any information obtained from the survey of a water intake from a lake for drinking water, industry or agriculture cannot reflect the overall quality of this water body which should be determined from vertical profiles.

Lake sampling is normally carried out from a boat. The station is usually identified from a combination of landmarks on the shore and depth profiles with echo sounding. Precise identification of the station each time is not easy but this is usually immaterial because of the good lateral mixing. A number of samples need to be taken at vertical intervals. The following minimum programme is recommended:

- Two depths (surface and bottom) if lake depth does not exceed 10 m;
- Three depths (surface, thermocline and bottom) for lakes not deeper than 30 m;
- Four depths (surface, thermocline, upper hypolimnion, bottom) for lakes of at least 30 m depth
- In lakes deeper than 100 m additional depths may be considered.

Many lakes exhibit the phenomenon of seasonal thermal stratification. When stratification exists a number of samples need to be taken vertically in the lake according to the position of the metalimnion or thermocline. A vertical profile of the stratification may be plotted from a series of vertical temperature measurements. The minimum sampling positions are shown in Figure 2. Samples should be taken:

1. Immediately below the water surface
2. Immediately above the epilimnion
3. Immediately below the epilimnion
4. Mid hypolimnion
5. One metre above the sediment/water interface

For deep lakes additional samples at say 100 m intervals should be taken. When the lake is fully mixed, samples should be taken at least at points 1 and 5 above.

Space coverage of large lakes should be proportional to the lake area. As a guide, the number of sampling points could be equal to the rounded value of the log of the lake area in km2.

7.2.2 Sampling Frequency

In lakes the mass of water and good lateral mixing provide an inertia against any rapid changes resulting from modifications in inputs and outputs. Many lakes exhibit marked seasonal variations due to thermal stratification, overturn and biological activity.

For lake stations the recommendation is to sample five consecutive days during the warmest part of the year and five consecutive days once every quarter.

For impact stations near to use points, where variability is likely to be greater than in the main body of the lake the sampling could be increased. Special cases include temperate-zone lakes that experience stratification. These should be sampled at least six times a year.

7.2.3 Water Quality Parameters

The parameters which characterize water quality may be classified in terms of the kinds of measurements, viz. physical properties (e.g.
temperature, electrical conductivity, colour, turbidity), inorganic chemical components (e.g. dissolved oxygen, chloride, alkalinity, fluoride, phosphorus, nitrogen, metals), organic chemicals (e.g. phenols, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and pesticides), and biological components, both microbiological such as faecal coliforms, and macrobiotic, such as worms, plankton and fish, which can indicate the ecological health of the aquatic environment. Some of the physico-chemical parameters are discussed below.

7.2.3.1 pH:

The pH value of water is an important index of acidity or alkalinity and is the resulting value of the acidic/basic interactions of a number of its mineral and organic compounds. In pure or slightly polluted water, the value of pH is determined mainly by the correlation between the concentration of free carbon dioxide, bicarbonate and carbonate ions. This correlation, in turn depends substantially on the intensity of the process of photosynthesis and the biochemical oxidation of organic substances as well as chemical conversions of some mineral substance.

7.2.3.2 Conductance:

Conductivity is a measurement of water's capacity for carrying electrical current and is directly related to the concentration of ionized substances in the water.

7.2.3.3 Temperature:

The temperature of water is one of the important characteristics which determines to a considerable extent, the trends and tendencies of changes in the quality. Temperature is an important factor affecting ion and phase equilibria, and influencing the rates of biochemical process which accompany the changes of concentration and of content of organic and minerals substances.

7.2.3.4 Dissolved Oxygen:

Dissolved oxygen content in water depends on physical, chemical and biochemical activities in the water body. The analysis of DO is a key test in water pollution studies. The effect of oxidation, the suitability of water fish and other organisms, and the progress of salt purification can also be measured or estimated from the D.O. content.

7.2.3.5 Alkalinity:

Alkalinity refers to the capability of water to neutralize acids. The presence of carbonates, bicarbonates and hydroxides is the most common cause of alkalinity in natural water. Bicarbonates present the major form since they are formed in considerable amount from the action of carbonate upon the basic materials in the soil.

$$CO_2 + CaCO_3 + H_2O = Ca(HCO_3)$$

Natural waters may also contain appreciable amounts of carbonates and hydroxide alkalinities, particularly when water .is blooming with algae. The algae take up carbonate for its photosynthesis activities and raise the pH.

7.2.3.6 Hardness:

Calcium and magnesium ions are the principle causes of formation of hardness although ion, aluminum, manganese, strontium, zinc and hydrogen ions are capable of producing the same effect. High concentrations of the latter ions are not commonly found in natural waters.

7.2.3.7 Chloride:

Chloride is one of the major inorganic anions in water and waste water. Chlorides are present in all potable water supplies and sewage, usually as a metallic salt. When sodium is present in drinking water, chloride concentration in excess of 250 mg/l give a salty taste. The maximum allowable chloride concentration of 250 mg/l in drinking water has been established for reasons of taste rather than as a safeguard against physical hazard.

7.2.3.8 Sulphate:

Sulphate appears in natural water in a wide range of concentrations. Mine water and industrial effluents frequently contain large amounts of sulphate. Sodium and magnesium sulphate exert cathartic action its concentration above 250 mg/l in potable water is objectionable.

7.2.3.9 Nitrogen:

In water and waste water the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitric, ammonia and organic nitrogen. All these forms of nitrogen, as well as nitrogen gas, are biochemically inter convertible and are components of the nitrogen cycle.

Nitrate generally occurs in trace quantities in surface water but may attain high levels in ground water. Drinking waters containing excessive amounts of nitrates can cause infant methemogloinemia (blue babies).

7.2.4 Sample Collection and Preservation

For the pollution survey samples should be collected and stored in clean plastic or glass bottles fitted with screw caps. Plastic containers are generally preferred for inorganic samples and glass is preferred for organic samples. Plastic bottles must not be used for organic samples and certain trace metals because it is known that they introduce interferences and have absorption characteristics.

Deteriorated samples negate all the efforts and cost expended in obtaining good samples. In general, the shorter the time that elapses between the collection of a sample and its analysis, the more reliable will be the analytical results. For certain constituents and physical values, immediate analysis in the field is required in order to obtain reliable results because the composition of the sample almost certainly will change before it arrives at the laboratory. However, some samples can be satisfactorily preserved by chilling or by adding suitable acid, or by other suitable treatment. They may then be allowed to stand for a longer period of time before analysis.

Determination of temperature, pH, specific conductance and turbidity should be made in the field by means of portable meters. For other parameters, samples should be preserved by adding an appropriate reagent. The preserved samples should be stored at $4^{O}C$ in sampling kits and brought to the laboratory for detailed analysis. Some common preservation techniques and time allowed between sample collection and analysis is presented in Table 1.

7.2.5 Measurement and Methods

Temperature, pH, electrical conductance and turbidity should be determined in the field at the time of sample collection using portable meters. Chemical analysis of the samples is carried out as per Standard Methods(APHA, 1961) for the analysis of Water and Wastewater. A brief description about some of the most commonly used parameters is given below.

Solids are determined by gravimetric method. Chloride is estimated by argentometric method in the form of silver chloride. Acidity / alkalinity is determined by titrimetric method using phenolphthalein and methyl orange indicators.

Total hardness and calcium hardness are determined by EDTA titrimetric method while magnesium hardness is calculated by deducting calcium hardness from total hardness. Calcium (as Ca^{++}) may be calculated by multiplying calcium hardness with 0.401 while magnesium (as Mg^{++}) by

Table 1: Summary of Analytical Methods

Parameter	Analytical method	Equipment used
pH	Electrometric	pH meter
Conductivity	Wheatstone bridge	Conductivity meter
Temperature	Thermometric	Thermometer
Turbidity	Photometric	Turbidity meter
Solids	Gravimetric	-
Acidity	Titrimetric	-
Alkalinity	Titrimetric	-
Hardness	Titrimetric	-
DO	Iodometric	-
BOD	Dilution	BOD Incubator
COD	Dichromate	COD Digestion System
Calcium	Titrimetric	-
Magnesium	Titrimetric	-
Chloride	Mercuric nitrate	-
Sulphate	Turbiditimetric	Turbidity meter
Phosphate	Ascorbic acid	Spectrophotometer
Ammonia-nitrogen	Ion-selective electrode	Ion-Analyser
Nitrate-nitrogen	Ion-selective electrode	Ion-Analyser
Nitrite-nitrogen	Ion-selective electrode	Ion-Analyser
Sodium	Flame-emission	Flame photometer
Potassium	Flame emission	Flame photometer
Trace elements	Atomic absorption	AAS

multiplying magnesium hardness with 0.243.

Nitrogen in the form of ammonia, nitrate and nitrite is determined by using ion-specific electrodes or spectrometric methods.

Sodium and potassium are determined by flame-emission method using flame photometer or by atomic absorption spectrometry.

Phosphate is estimated by Stannous chloride method in the form of molybdenum blue while sulphate by turbidimetric method in the form of barium sulphate crystals.

Trace elements are determined by atomic absorption or atomic emission methods.

The summary of analytical methods used for some common parameters is given in Table -1.

7.3 Sediment Sampling

Sediment plays an important role in water quality. Part of the assimilative capacity of natural water systems for metals, pesticides and herbicides is the ability of the sediment to bind these substances, thus removing them from the water. On the other hand, many toxic substances stored in the sediment are released to the surrounding waters by a variety of chemical and biochemical reactions, thus making them available to the organisms living in these waters. Lake and stream sediments often reflect recent additions of heavy metals before elevations of such elements are detectable in the overlying water. While water analysis may therefore indicate no elevated concentrations in the soluble phase, a water body may still be heavily polluted with organic and inorganic material in sediments. The possibility of sedimented material into the water, owing to physical, chemical or biological processes in natural situations, always exists. Also, with bottom-feeding organisms, sediments may be more important than water as a source of organic and inorganic substances.

To collect valid suspended sediment samples, samplers and sampling procedures must be designed to represent accurately the water/sediment systems being studied. The methodology and the equipment used for sampling suspended sediments are different from those required for sediment deposits.

7.3.1 Sample Collection

Suspended sediment samples are collected to determine the quantity as well as the physical and chemical characteristics of those sediments in suspension. In the other hand, bottom sediments are sampled to provide the physical and chemical characteristics of those particles that make up the bed of the system being studied at specific locations.

Samplers used for suspended sediments must allow the collection of a sample representative of the water-sediment mixture at the sampling point or sampling zone at the time of sampling. Samples are of three general types:

1. Integrating samples
2. Instantaneous or grab samplers, and
3. Pumping samplers

7.3.2 Sample Handling and Preservation

Procedure for handling and preserving sediments samples depend on the specific analysis needed and on whether the sample is from the suspended or bottom environment. Samples for trace metal analyses require special precautions to prevent contamination and also require preservation. Collection bottles should be precleaned by thorough washing.

As soon as possible after collection the sample should be filtered. The filtrate can then be used for measuring the dissolved constituents.

Suspended sediment sample analysis are often limited on account of the difficulty in obtaining sufficient sediment for the many subsamples required for different analysis. Composite of a large number of representative samples may be necessary.

7.4 Remote sensing application in water quality studies:

Some of the hydrological aspects of the lake will be analyzed through remote sensing techniques. Remote sensing of water quality has certain advantages in identifying source of water pollution, dispersion and dilution pattern in a water body. Remote sensing data are the measure of reflectance or emitted energy from the surface or near surface of water bodies such as lake. Various remote sensing missions provide data from variety of sensors operating in different regions of electromagnetic radiation (EMR). Remote sensing data from satellite is based on interaction of EMR from sun with various surface features, which interact in different fashion with the incident EMR and hence give rise contrast in the remotely sensed data. However, these are limitations of remote sensing data with respect to the scale and spatial resolution which restrict their usage particularly for water quality parameters.

Satellite images of water bodies readily reflect turbidity which is caused by high concentration of algae, silt and other suspended materials in water. Remote sensing of reflected solar radiation can provide timely and repeated information regarding flow pattern of suspended sediments in lakes. The preciseness of turbidity as a water quality indicator is based on the light attenuation in water by suspended sediment and organic material. Turbidity is not a uniform parameter, either spatially or temporally. Turbidity estimated from satellite data is useful for tracking the movement of water masses within large lake.

Due to the strong contrast between water and surrounding surface afforded by satellite reflective infrared observation, mapping and monitoring of surface water spread of lakes can be obtained with very good degree of accuracy. In reflective infrared region, incident radiation is absorbed by water whereas surrounding land and vegetation reflect. Because of this phenomena, surface water appears black on reflective infrared images and digital mean values are lower than the surrounding land features. Because of the non-availability of real-time spectral data corresponding to the date of imagery, such an exercise has not been carried out in Nailtal lake so far. However, in future it is porposed to carry out this.

8.0 IDENTIFICATION OF RECHARGE ZONES/SOURCES USING STABLE ISOTOPES

The ground water originates as precipitation, therefore, the amount of recharge to ground water system is related to the storage capacity of a system and thus determines the maximum available resources for exploitation. However, in many cases, the recharge and water flow are rather complex and more information of the actual process is desirable. The environmental isotopic methods provide a valuable approach to understand these complex phenomena as well as to test the validity of the alternative hypothesis.

Methodology using stable isotopes

The use of environmental isotopes for the identification of recharge sources/area and origin of ground water is based on the temporal and spatial variability of the isotope content of water(Zimmerman and Ehhalt, 1970; Gat, 1970). These effects are summarised below in brief.

a) Altitude effect

Ground water originating from precipitation at high altitude either directly or by rivers draining high altitude catchment basins can be distinguished from recharge originating from low altitude precipitation. This effect is most useful in regimes having orographic precipitation, where there is a regular relationship between land surface altitude and condensation temperature of precipitation.

The observed range of variation of $\delta^{18}O$ ‰ per 100 m is between -0.16 and -0.7 with an average value of -0.25.

b) Latitude effect

The environmental stable isotope content of precipitation shows a marked dependence on latitude, thus ground water replenished by rivers spanning significant latitude zones can be distinguished from local recharge.

c)Deuterium Excess

The change in the evaporation rate due to the geographic effect result in the excess contents of stable isotopes thus the different relationship of D - ^{18}O is obtained i.e.,

$$\delta D = 8\delta^{18}O + 22$$

which is quite different from the general relationship observed in northern hemisphere i.e.,

$$\delta D = 8\delta^{18}O + 10$$

This difference can be used in the border areas of climatic zones where precipitation on the coastal mountains can be mediterranean or oceanic origin.

d) Fractionation effect

The open water evaporation creates a fractionation in the contents of D and ^{18}O which effectively labels surface reservoirs. The application of this effect can be best understood by taking the studies related with surface water and ground water interactions.

e) Seasonal Recharge

The isotopic content of ground water may indicate the seasonal dependency of recharge due to occurrence of precipitation on seasonal basis and variations of temperature accordingly. A number of studies have been carried out by various scientists for mediterranean karstic systems.

f) Modern Recharge

In order to identify the period of recharge (modern), the tritium content can be analyzed as its half life is short (12.43 yrs.) and because of its high levels in the atmosphere since the beginning of atmospheric testing of thermonuclear devices in 1952. The availability of tritium in water samples indicate the presence of some component of modern recharge. However, now a days, due to ban on the testing of nuclear devices and long period (about 40 yrs.) passed, the tritium contents analysis of water samples may not be that much effective in prediction of modern recharge.

The modern recharge may also be defined as the meteoric waters i.e. the ground water which derived directly from precipitation or from fresh surface waters, usually by recharge through an unsaturated soil zone. The isotopic composition of the meteoric ground waters generally matches that of local precipitation, at least in the humid climate zone.

Keeping in view the above changes which occur in the composition of environmental isotopes with respect to the origin and areas/zones of the water resources, the altitude etc can be predicted. The predictions made by using the isotope techniques regarding the altitude and position of recharge sources can be further confirmed by using remote sensing techniques.

SECTION II : PROGRESS OF THE STUDIES

9.0 PRELIMINARY SURVEY AND GENERAL OBSERVATIONS:

A general survey of the Naini lake was carried out to assess the general condition of the lake, its water quality and major sources of pollution. The following observations were made:

(i) The lake water is green, probably due to a high content of algal material. Large algae growth was also seen at a few places.

(ii) There are a large number of nalahs (around 82 as per an old report) flowing into the lake.Most of them were perhaps designed to flush out water and sediment discharge due to rain in the lake catchment area. However some of them were carrying domestic waste also.

(iii)The quantity of debris brought in through these nalahs is really huge and this is indeed the main reason of siltation in the lake. Apparently, these debris choke the nalahs at times, following which a cleaning operation is undertaken by the concerned agency. But, instead of removing the material from the site, they pile it by the side of nalahs and the entire debris ultimately slips into the lake.

(iv) Some of the nalahs are directly flowing from the restaurants around the lake (e.g. capital hotel near the Municipality office) bringing the entire kitchen waste into the lake.

(v) The nalahs near the Naina temple (nalah no.23/26) seems to be heavily polluted with domestic waste. Some unconfirmed sources informed that it sometimes contain sewer waste also due to leakage in sewer lines at some places.

(vi) One of the main reasons identified for heavy debris flow is the construction of unauthorised houses on the hill slopes. There are also reports of illegal housings (as the construction is now prohibited on the hills) Which do not have proper sewer connections.

(vii)A large quantity of plastic waste (mainly polythene bags and packets of food stuff) was observed floating in the lake.

In addition to the above visible survey, sample collection survey and in-situ measurement survey were also carried out as per the details given below.

(a) In a preliminary survey of lake Naini, water samples were collected from four representative locations which were later on analyzed in laboratory at NIH, Roorkee for water quality analysis.

(b) The second water quality and pollution survey was carried out in the month of feb. 1994 under which six water samples were collected and brought to laboratory for various types of analysis. The temperature survey of lake was also carried out at 10 locations with respect to depth.

(c) Third time, the water samples were collected in the month of May, 1994 from 11 locations and D. O., temp. and conductivity survey was carried out at 22 locations and at different depths.

The results of water quality analysis and temp., D. O. and conductivity survey have been discussed under the heading water quality aspects (section 8.0).

10.0 IDENTIFICATION OF LAKE CATCHMENT AREA:

For carrying out different analyses such as water quality and land use classification of the lake, digital data of the SPOT satellite with the resolution of 20 m and 10 m have been procured. At NRSA, Hyderabad SPOT data available was of 27 Nov. 1987 (MLA) and March 1989 (PLA). False colour composite of MLA data is shown in fig.- 3a. The base map of Naini lake catchment was prepared using survey of India toposheet N0.530/7 and the catchment map provided in Valdiya (1988). The Naini lake catchment area is about 3.6 sq km^2. The digital satellite data have been processed & analyzed in a GIS environment using the ILWIS and the ERDAS software packages available at N.I.H. The Naini lake boundary and a map of the lake catchment were digitized using the digitizer connected to the ILWIS. The lake area and shore line computed from the digitized map are 0.456 sq km and 3458 m respectively (Fig.-3b).The SPOT data of 27 Nov. 1987, was registered to the catchment map and the catchment area was extracted from the satellite data. Further,using the ERDAS system,the lake and it's surrounding catchment area was classified into fine classes viz. forest, water body, barren area,shadow & built-up area using supervised classification approach (Fig.-3c). The percentage coverage of these five classes as computed from the classified map are as follows :-

CLASS	Percentage
Water body	10.4
Forest	48.4
Barren	18.3
Built up	19.3
Shadow	3.6

Other analyses particularly in relation to water quality aspects e.g. extent of algae are also planned using the satellite data.

11.0 HYDROLOGICAL WATER BALANCE STUDIES:

The water balance of lakes provides very useful information about the availability of water in lakes at any time. In order to properly utilise the lake water, the knowledge of different components of water balance of lakes is essential. Also, if the water balance is worked out regularly after a specified period (say yearly or after every 2-5 years depending upon the situation), the information on the change in different components of water balance will help in taking appropriate measures in order to maintain the water availability in the lakes. Unfortunately, the study of various parameters considered for water balance has not been taken so far in case of the Naini lake. The lack of knowledge about input water and water utilized for various agricultural, industrial and domestic purposes and also other natural losses have resulted in mismanagement of the lake.

In order to study the water balance of lake Naini, following data are being collected.

(i) Precipitation at four locations in the catchment area.

(ii) Evaporation rate.

(iii) Change in storage i.e water level monitoring at both ends of the lake.

(iv) Surface outflow - The data of lake water which is being drawn for irrigation purposes and the water which is taken out to regulate the water level in the lake during the rainy season.

The details of total water which is being pumped from the lake for drinking and other purpose (excluding the pumping from natural springs) are given below:

i)	Mechanical filter	3.5 million litre/day
(ii)	Pressure filter	2.0 million litre/day
(iii)	Tube well	3.0 million litre/day

Efforts are also being made to monitor/determine the inflow to the lake due to surface inflow and sub surface inflow. However, due to some reasons, if it will not be possible to determine the inflow by direct means, the indirect methods will be used to calculate the same. With the present, data, it is not possible to compute the water balance of lake, therefore, the efforts are being made to collect the other required data.

12.0 SEDIMENTATION IN NAINI LAKE:

Sedimentation in Naini lake is an acute problem. The accelerated rate of erosion in the north-eastern hillside has risen due to indiscriminate house-building, entailing generation of enormous volumes of debris which move down the gutters. This has added to the gradual deterioration of the lake, as evident from the fact that in the period 1960-77 about 0.239 million m^3 of sediments were deposited in the lake at the rate of 0.022 m^3/yr. Judging from this estimate, in about 300 years, the lake will be completely filled up if erosion is not checked. Recently, the bathymetric survey of Naini lake was carried out by NIO in collaboration with Dr. K.S. Valdiya of Kumaun University, during the year 1992. The map indicating the depth of lake at various location is shown in fig. -4.

In order to study the sedimentation of lake through the nalahs (drains) meeting to the lake, the water samples are being collected regularly from the continuously flowing nalahs.The variation of suspended sediments load entering in to the lake through various drains have been shown in fig. 5for the period from Feb.94 to June 94.The data is also being collected to compute the suspended sediment load in lake. Ten indigenously designed devices were installed in the lake to monitor the suspended sediment load at various locations in lake. But, due to problems disturbance created by tourists, these devices were removed temporarily. Further studies are in progress to study the suspended as well as bed sediments in order to compute the present sedimentation rate in lake Naini. Efforts are also being made to study the sedimentation rate in Naini lake in older period using isotope dating techniques.

13.0 WATER QUALITY ASPECTS:

The behaviour of lake water is subject to a wide range of influences operating over three dimensions unlike river water which is often virtually unidimensional. A lake may be characterized by morphometric, hydrological, chemical, biological and sedimentological parameters depending on its age, history, climate and water budget. Each lake develop its own response to these combined factors causing major variations of water quality in both time and space.

13.1 Physico - Chemical characteristics of Lake Water

For the pollution survey of the lake, water samples are being collected from various locations and depths (Fig. 6)using a standard water sampler of two litre capacity and subjected to various physico-chemical tests. The samples thus collected were stored in clean plastic bottles fitted with screw cups. Some parameters like temperature, pH, electrical conductance and dissolved oxygen were measured on the spot by means of portable kits. For other parameters, samples were preserved by adding an appropriate regent. The samples thus preserved were stored at 4 ^{0}C in sampling kits and brought to the laboratory for detailed analysis. Results of the analysis are discussed below.

pH:

The pH value found at various locations in the lake varies from 7.2 to 8.6 during the period under report indicating the alkaline character of the lake water.

Conductance:

The conductance value observed during the period under report varies from 350 to 660 with minimum values in the month of Feb. 94 and maximum values in May 1994 . The lower values in Feb. 94 may be due to dilution by rain in February, 1994.

Temperature:

Temperature values observed from various depth indicate decreasing trend with the depth. The details are discussed under the special features and remarks.

Dissolved Oxygen:

DO content in the lake was found in the range 8-9 mg/l during Feb. 94 at almost all location except near the area of Naina Devi drain. Near Naina devi drain the DO content was of the order of 5-6 mg/l while the same was found in the range 3-5 mg/l in the drain itself.However, during an another survey which was carried out in the month of May 1994, it has been observed that D. O. declines very rapidly after 3m depth and after 3m it becomes almost constant i. e. 1mg/l through out the depth till bottom. Also at surface, the value of D. O. was observed less than 6mg/l at most of the locations except near the Jal Sansthan pumping station where the pumped water was feeding back to the lake causing an increase in D. O. values. The contours of D. O. values at different depths have been shown in fig.- 13 to 19.

Alkalinity:

Alkalinity values during the Feb, 94 survey were found of the order of 250-300 mg/t while somewhat lower values were observed during May, 94. The higher values of alkalinity in Feb, 94 may be attributed due to surface runoff during rains.

Hardness:

Hardness values were found in the range 330-360 mg/l at the surface during Feb, 94. A higher value of about 460 mg/l was found during the same survey near the area of Naina Devi drain. Due to the domestic waste coming out through the drain. Hardness values were found in the range of 340-400 mg/l during May, 94 due to dry weather conditions.

Chloride:

In Naini lake chloride concentration was found of the order of 5-10 mg/l which is an indication of natural sources available to purify the water. However, further studies may reveal some interesting results in this respect.

Sulphate:

The concentration of sulphate in lake water is found well within the range allowed for drinking water.

Nitrogen:

In lake water samples, in most of the cases, the nitrate contents could not be measured due to some problems with the measuring equipment. But in cases of few springs/drains meeting to Naini lake, where the nitrate contents were measured, high values ranging from 1.5 to 2.85 mg/l in Naina Devi drain and 2.9 to 3.5 mg/l in Pardadhara have been found.

Further investigations on pollution studies are under progress. However, the investigations carried out during the period under report, revealed that drains near Naina devi temple and Tallital Rickshaw stand are the main source of pollution of the lake water. These findings are yet to be confirmed with the help of stable isotopic compositions of water samples of respective drains and lake

14.0 HYDRODYNAMICS OF NAINI LAKE:

In order to study the hydrodynamics of lake Naini, the in-situ temperature survey was carried out at 22 locations and 154 points distributed all over the lake along different sections. An imported portable temperature cum DO meter was used to measure the correct temperature of the lake water at different points in the lake. Prior to used DO cum temperature meter for lake water measurements, it was duly tested in laboratory to ensure the satisfactory work of the instrument.

The temperature contours at different depths have been shown in fig. 7 to 13 while the variation of temp. with respect to depth have been shown in fig.- 20 to 25. The results clearly indicate that Naini lake is thermally active only with in the depth of 6m and after it the temp. variation is almost negligible. The further studies reveal the behavior of lake from temp. variation point of view in different seasons.

Isotopic Investigations:

Water samples for stable isotope composition were also collected from different depths and locations in a similar pattern as followed in case of samples collected for water quality analyses. The analysis for $\delta^{18}O$ in these samples were carried out by the BARC scientists at their laboratory at Bombay. The results of $\delta^{18}O$ also indicate more or less similar pattern of variation as observed in caseof temperature and D.O. variation.

The results of chemical analyses, physical parameters measured at lake site and ^{18}O composition of lake water samples have been shown in tables 2, 3a, 3b and 4.

15.0 HYDROMETEOROLOGICAL OBSERVATIONS:

In order to study the nature of variation of various hydrometeorological parameters, one data acquisition system with 13 sensors have been installed at the Naini lake site. Some of these sensors have been installed inside the lake using a buoy (drum type). The details of the data acquisition system and sensors installed are given below while the installation of the sensors etc have been shown in fig. 26 and 27.

The data acquisition system has been designed for the acquisition of hydrometeorological data for integrated studies using remote operated sensors. The system consists of 16 sensors which are installed at different locations/positions to sense the respective hydrometeorological parameters. An electronic console unit which can be operated manually to display the data one by one and can also store the data in automatic mode using the memory module Computer, Printer, Paper chart recorder etc. can be attached with the DAS for retrieving and processing the data.

The various sensors attached with the DAS are as follows .

(i) Water level (A) 10 m
(ii) Water level (B) 30 m
(iii) Sedimentation (Gm)
(iv) Relative humidity (%)
(v) Rainfall (mm)
(vi) Evaporation (mm)
(vii) Water temperature (Deg. Cent.)
(viii) Under water solar radiation
(ix) Air temperature (Deg. Cent.) (A)
(x) Air temperature (Deg. Cent.) (B)
(xi) Wind velocity (Km/ph)
(xii) Wind direction (Degree)
(xiii) Solar radiation (W/m^2)

15.1 Sensors installed in the lake :

The following sensors have been installed in the Lake with the help of buoy.

(i) Water level (A) & (B) sensors :

The two water level sensors can be installed up to a maximum of 10m & 30 m below the water surface respectively. But for this study, these are placed at 2 m & 11 m below the water surface respectively.

(ii) Sedimentation sensor : This sensor is having a bucket for weighting the sediment deposited on that bucket. It is placed at 12m. depth from water surface. The capacity of the bucket is to collect the 1 kg of sediments. Therefore, the bucket will be cleaned after every 6 months or so.

(iii)Water temperature sensor :

This sensor is attached with the buoy & is kept at 0.5m below the water surface to get the surface water temperature continuously in order to use this data for calculating the evaporation of lake water using the change in isotopic composition.

(iv) Under water solar radiation sensor :

This sensor is also placed at 0.5m depth under the water surface attached with a MS rod, which is fitted to the buoy. It is used for water quality.

(v) Soil moisture sensor :

The soil moisture sensor is installed near the Lake shore on the ground by digging two holes 1 m apart & 1 feet deep & placing the sensor plates in it for continuous record of soil moisture.

One air temperature sensor is placed just above the Lake water surface near the Lake shore to get a continuous record of air temperature above the Lake water surface.

The position of various sensors installed in the lake has been shown in fig.-26.

15.2 Sensors installed at lake bank and in lake catchment:

The following sensors are fitted on a pole 6m high from the Lake water surface at the Jal Sansthan office.

(i) Wind velocity (Km/ph) sensor

(ii)Wind direction sensor

These two sensors are mounted on the pole to get the nature of wind in the Lake catchment. Following three sensors have also been mounted on the same pole, to get continuous record of the concerned parameters.

(iii) Relative humidity sensor

(iv) Air temperature sensor

(v) Solar radiation sensor :

The rainfall sensor has been connected with the data acquisition system at the Lake shore, just 3m above the Lake water surface, to get precipitation data along with the evaporation sensor.

One screen has been fitted with dry bulb and wet bulb thermometer and maximum - minimum thermometer. It has been installed at the Jal Sansthan Pump House roof. The installation is as per IS specifications. One stevenson screen and one evaporation pan are kept for installation at Khurpa Tal, which has been chosen as a reference Lake for Naini Lake. The position of various sensors mounted at the pole are shown in fig.-27.

In addition to the above sensors, following equipment have also been installed at various location in the lake catchment.

(a) Automatic water level recorders:

Two water level recorders have been installed on both ends of the Lake to get Lake water fluctuations for water balance studies. One water level recorder is fixed at the western end of the Lake behind the Gurudwara, Mallictal. The other one at the eastern end of the Lake near the bus stand, Tallital. The third water level recorder is fixed at the Naini drain (nalah No.23) with a measuring gauge nearby to get the total inflow in the Lake through the drain.

(b) Raingauge network:

Three raingauges (SRRGs) have been installed in the Naini Lake catchment. Sites were selected on the basis of subcatchments, slopes and safety of equipment and accessibility of sites. Standards set by IS codes have been followed in site selection.

Out of the three SRRGs, RG1 has been installed at Ratan Cottage near Birla Vidya Mandir, RG2 at Alma Cottage and RG 3 at ATI Building in the Ardwell Camp.

The hydrological and hydrometeorological data is being collected regularly and are being processed for getting some useful information.

16.0 SPECIAL FEATURES AND REMARKS:

The observations of temperature, D.O. and oxygen-18 (stable isotope) at various locations and at different depths leads to some very interesting features as per details given below.

1. There is a small variation of temperature (2.4°C) of the surface water in lake during the month of May i.e. it varies between 19°C and 21.4°C, through out the lake which is a normal feature and governed by various factors like direction of sun movement, surrounding formation and depth of lake at different locations. However, it is interesting to note that the temperature variation even at the surface indicates the differential behavior of the lake in two distinct parts.

2. The variation of lake water temperature is also very less (from 18°C to 20°C) at 3 m depth but as we move downwards, the difference in temperature among different points, in the same

lake level increases i.e., at 6m depth, the lake water temp. varies from 12.4°C to 18°C , at 9m depth the temp. varies from 10°C to 18°C, at 12m depth from 8.5°C to 17.5°C , at 15m depth, from 9°C to 16°C, at 18m depth from 8.8°C to 15.6°C, at 21 m, it varies from 9.2°C to 17.2°C and at 22m, the late water temp. varies from 9.4°C to 18.2°C.

3. It is very clear from the above data that the lower side of the temp. at different depth decreases very rapidly after 3m depth while the higher side decrease very slowly with depth at different locations. Therefore, it can be concluded that the lake is thermally active only up to the depth of 6m and below it the temp. of lake is almost constant (vary between 9 - 10°C. The reason of higher temp. observed at few depths may be understood, if we consider that ground water streams are emerging at those depths. However, the variation of this temperature may also be due to leakage of water in the depth water sampler during sample collection . But, at certain depths, where visibly more clear water was observed during the collection of water sample may not be suspected for leakage of water.

4. At 9m depth, there is an indication of underground stream emerging at the ridge (section 6-15). Similarly, the second ground water stream is suspected at boat house side near the section 10-11. Similarly, two ground water streams are suspected to emerge under the lake at 12 m depth along sections 3-18 and 6-15 (at ridge). The another possibility of a ground water stream at 15 m depth along the Mallital side of the ridge. Therefore, it is suspected that a number of ground water streams are issuing out from the ridge inside the lake at different depths. In addition to the above, the fresh water streams are also suspected at 18m depth along section 2-19 , near to the Rajbhawan pumping station. A number of ground water streams are also suspected to emerge from the bottom of the lake at 21m and 22m, in the Northern part of the lake. Here, it is important to note that most of the suspected ground water stream lies along the major fault and fractures as shown in fig. 2 (map).The further studies will enable to specifically pinpoint the existence and location of ground water streams in the Naini lake.

5. The D.O. of lake water sharply decline after 3m depth which clearly indicate the poor mixing of lake water. It has been noticed that during rainy season, the D.O. of the lake water increases, up to the 3m depth in comparison to summer. But as the time passes and lake water level reduce, D.O. value also reduces and reach the required minimum level or even less than that of the epilimnion.Therefore, this is enough to conclude that if this trend persist for longer period, the lake water pollution will increase especially during summer period. And therefore it will not be possible to use the lake water for drinking purposes without proper treatment.

6. The water quality analysis of lake water samples from different locations and depths indicates that the following parameters show some definite trend with depth. While in the northern part Temperature, D.O., COD, SS and SO_4 show an decreasing trend; Ca, TS and hardness show an increasing trend and Mg is almost constant. This is in contradiction to the southern part of the lake where, COD, SS and TS show an increasing trend, hardness indicates decreasing trend. Ca is higher at the bottom than the surface. Temp., D.O. are less in the bottom than the surface. Mg is showing mixed trend and its content is lesser at the bottom. PO_4 is noted only at bottom in the southern part. In the northern part of the lake, PO_4 content is higher at the bottom. The noticeable point is that, at surface, PO_4 is observed only in the northern part and not in the southern part, which indicates that there is poor mixing between the epilimnions. This aspect is to be further studied with the help of stable isotopic composition of water from different sources.

However, in order to confirm the above results and to get some specific information further, studies are in progress.

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Table- 2

Chemical analysis data of water samples collected from Naini lake during the month of Feb. 1991. (Collected 09/10, Feb., 1991)

Parameters	3-18 1.0 m Point 5	3-18 20.0 m Point 5	8-13 1.0 m Point 5	8-13 20.0 m Point 5	Naina Devi Drain	Pardha Dhara
D.O., mg/l						
Temperature, °C	10.0	8.5	9.2	8.75	-	-
pH	7.5	8.6	8.1	-	8.1	-
Conductivity, µS/cm	385	366	401	416	455	520
Alkalinity, mg/l	260	285	272		290	-
Hardness, mg/l	386	338	352	336	420	356
Cl^-, mg/l	8.0	-	9.0	-	2.8	-
SO_4^{2-}, mg/l						
PO_4^{3-}, mg/l	nil	0.19	0.20	-	0.02	-
NO_3-N, mg/l	ND	ND	ND	ND	2.85	3.5
NH_3-N, mg/l						
Na, mg/l						
K, mg/l						
Ca, mg/l	67.0	53.0	56.0	51.0	69.0	58.0
Mg, mg/l	51.0	32.0	52.0	51.0	60.0	52.0
COD, mg/l	19.2	19.2	19.2	19.2	131.1	19.2
BOD, mg/l						
Turbidity, NTU	7	6	6	7	9	-
δ D, %.	-10.8	-53.0	-56.0	-56.0	-	-57.0
δ $_{18}$O, %.	-7.79	-8.69	-8.6	-7.5	-	-8.2

Table- 3a

Chemical analysis data of water samples collected from Naini lake during the month of May, 1991. (Collected 20/21, May, 1991)

Parameters	3-18 Surface Point 5	3-18 12.0 m Point 5	3-18 21.0 m Point 5	8-13 Surface Point 7	8-13 12.0 m Point 7	8-13 21.0 m Point 7
D.O., mg/l	5.6	0.8	3.9	5.1	0.9	0.8
Temperature, °C	19.9	9.8	17.2	18.6	10.1	9.2
pH	8.6	7.2	8.0	8.6	7.6	8.0
E. C., µS/cm	600	660	610	600	650	660
Alkalinity, mg/l	133	117	110	132	111	130
Hardness, mg/l	372	370	311	365	379	391
Cl^-, mg/l	1.0	1.0	1.0	1.0	1.0	3.0
SO_4^{2-}, mg/l	110	93	110	112	111	78
PO_4^{3-}, mg/l	nil	0.16	0.08	0.02	0.28	0.10
NO_3-N, mg/l	ND	ND	ND	ND	ND	ND
NH_3-N, mg/l	ND	ND	ND	ND	ND	ND
Na, mg/l	9.9	10.2	10.2	10.0	9.6	10.1
K, mg/l	1.5	1.1	1.6	1.8	1.8	1.7
Ca, mg/l	16.1	80.2	51.1	15.7	56.1	58.5
Mg, mg/l	62.5	11.3	50.8	60.9	58.1	59.5
COD, mg/l	150	206	337	56	75	37
BOD, mg/l	50	60	2	1	30	70
TDS, mg/l	331	311	330	318	385	370
SS, mg/l	17	27	51	22	23	13
Total Solids, mg/l	318	371	381	310	108	383
$\delta\ ^{18}O$, ‰	-	-	-7.8	-6.3	-7.8	-7.1

Chemical analysis data of water samples collected from Naini lake during the month of May, 1994. (Collected 20/21, May, 1994)

Parameters	6-15 Surface Point 6	6-15 7.0 m Point 6	1-17 22.0 m Point 6	Naina Devi Drain	Pardha Dhara
D.O., mg/l	5.1	0.7	2.7	2.8	5.7
Temperature, °C	19.6	11.6	16.3	ND	ND
pH	8.5	7.9	7.2	7.5	8.1
Conductivity, µS/cm	600	630	610	1010	815
Alkalinity, mg/l	128	113	118	202	150
Hardness, mg/l	373	375	310	512	178
Cl^-, mg/l	5.0	3.0	3.0	9.0	6.0
SO_4^{2-}, mg/l	119	96	101	173	177
PO_4^{3-}, mg/l	0.01	0.22	0.29	0.18	nil
NO_3-N, mg/l	ND	ND	ND	1.5	2.9
NH_3-N, mg/l	ND	ND	ND	ND	ND
Na, mg/l	9.1	9.5	10.3	10.1	8.6
K, mg/l	1.6	1.3	1.8	9.3	3.0
Ca, mg/l	18.9	50.1	52.9	86.2	85.8
Mg, mg/l	61.0	60.8	50.5	79.5	61.2
COD, mg/l	nil	nil	393	56	131
BOD, mg/l	2	10	23	8	1
TDS, mg/l	351	365	370	361	120
SS, mg/l	66	12	38	13	6
Total Solids, mg/l	120	377	108	377	126
$\delta^{18}O$, ‰	-6.6	-	-6.1	-7.9	-

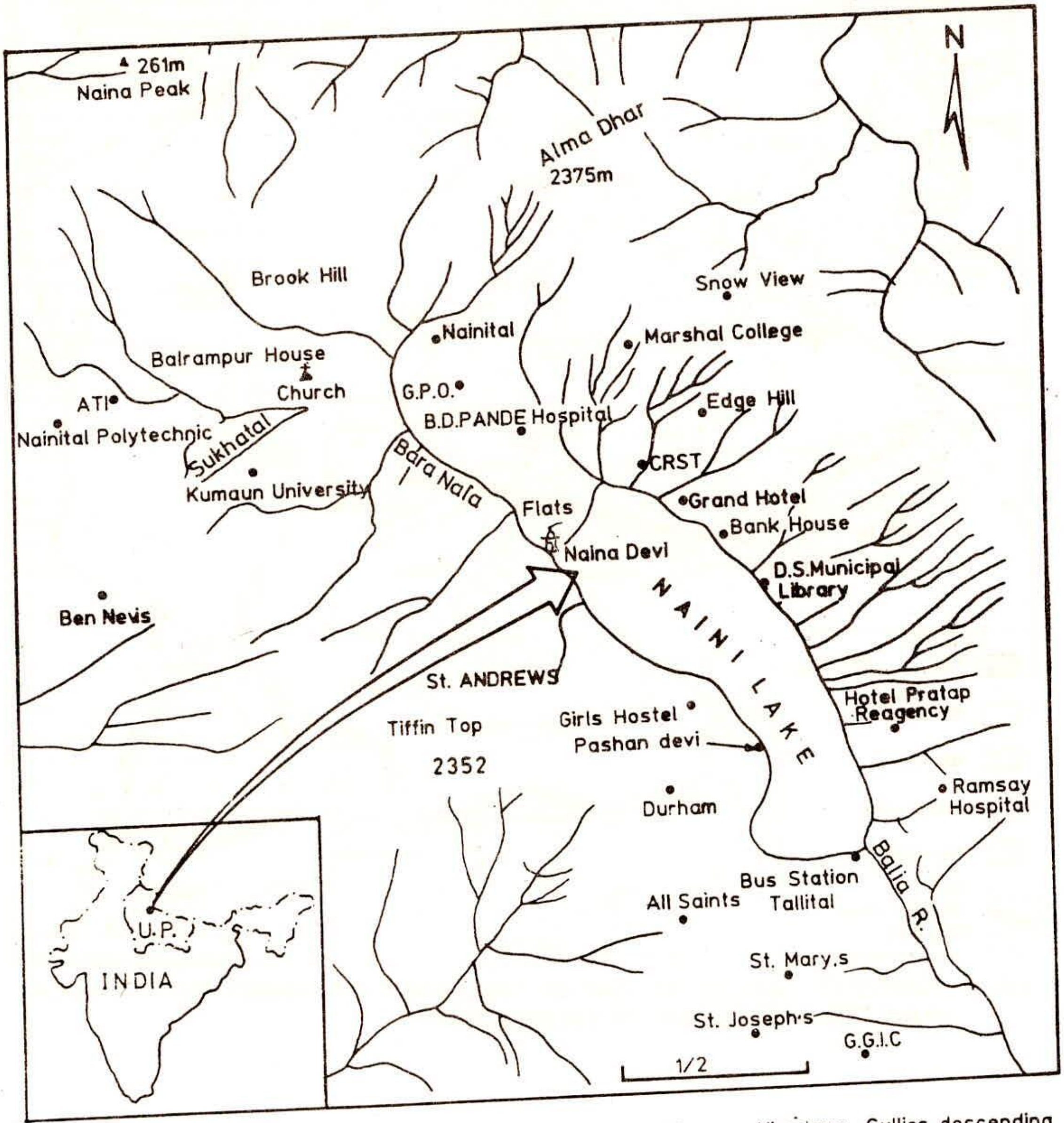

Fig 1 - Location of the Naini Lake in the frontal range of the Kumaun Himalaya. Gullies descending transversely and the Bara Nala have been dumping sediments with pollutants of all grades in large quantities (After Valdiya,1988)

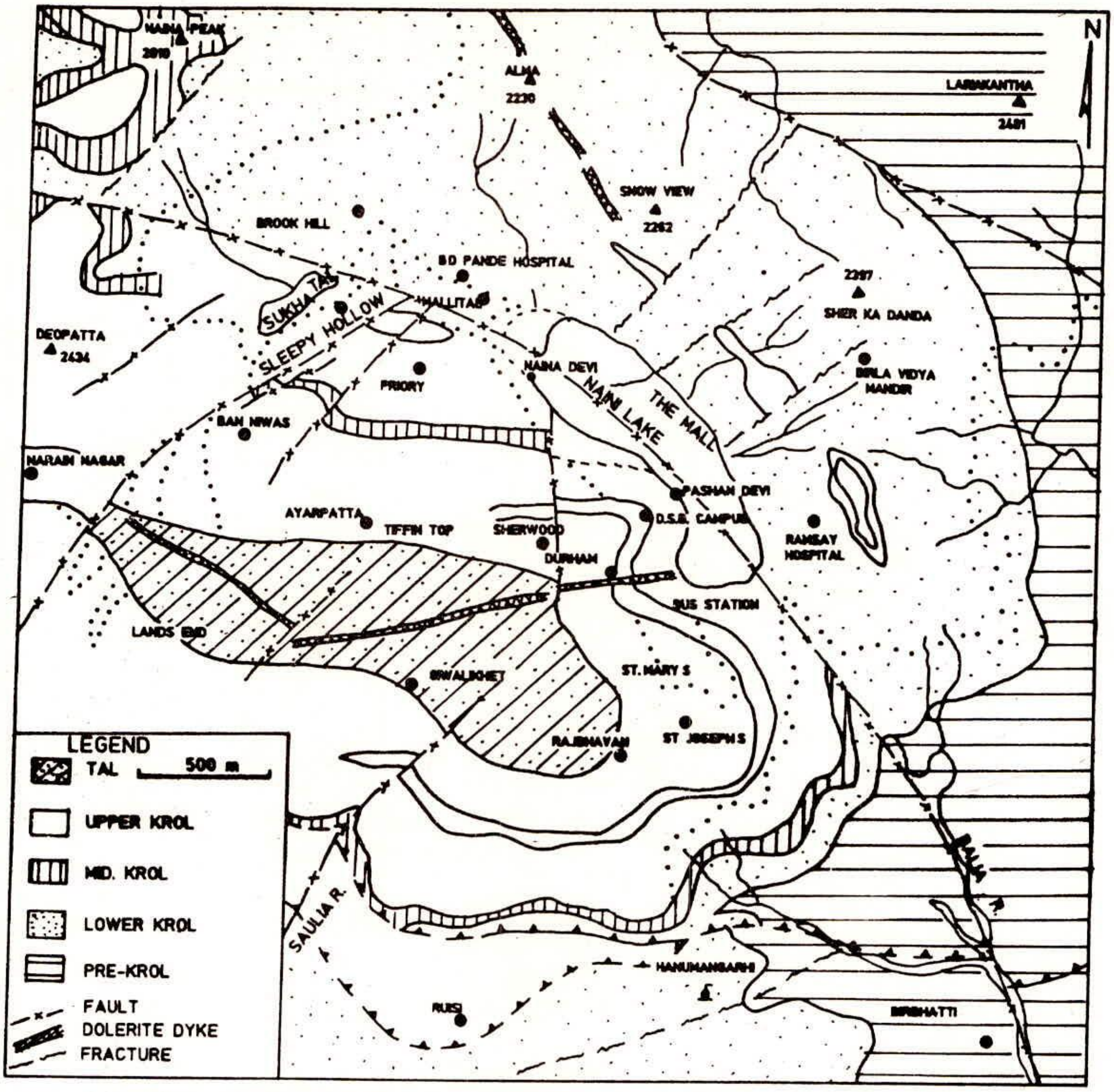

FIG. 2 SIMPLIFIED GEOLOGICAL MAP OF THE NAINI BASIN BRINGS OUT ITS MUCH FAULTED NATURE (AFTER VALDIYA, 1988)

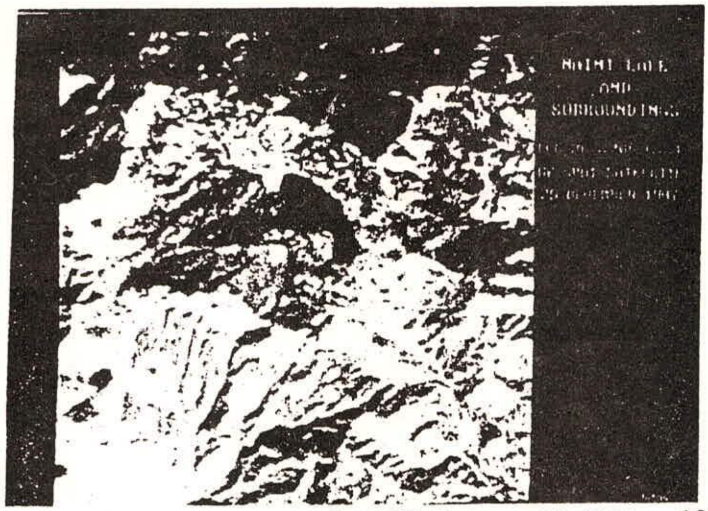

Fig. 3a FCC of bands 3,2,1 of SPOT data , 25 Nov., 1987

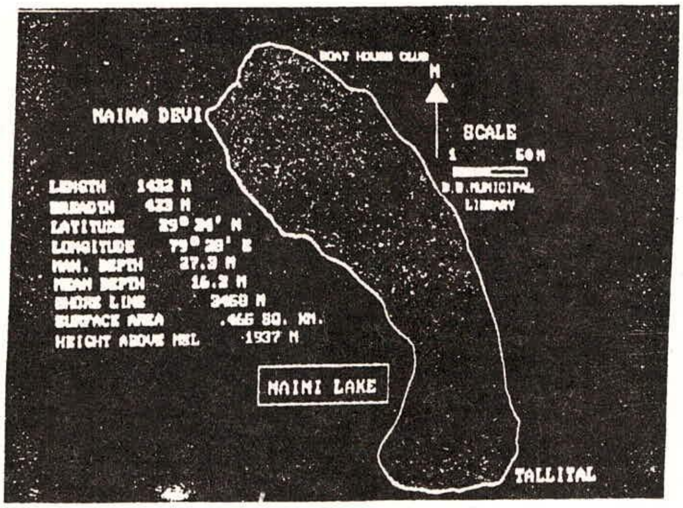

Fig. 3b Naini Lake

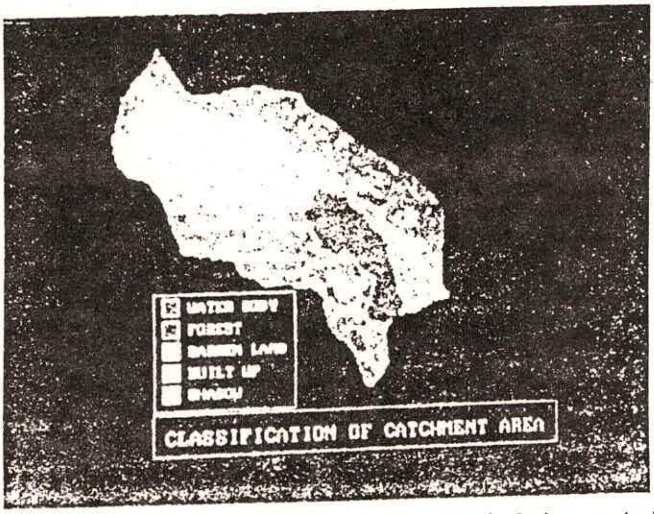

Fig. 3c Supervised classification of Naini lake catchment

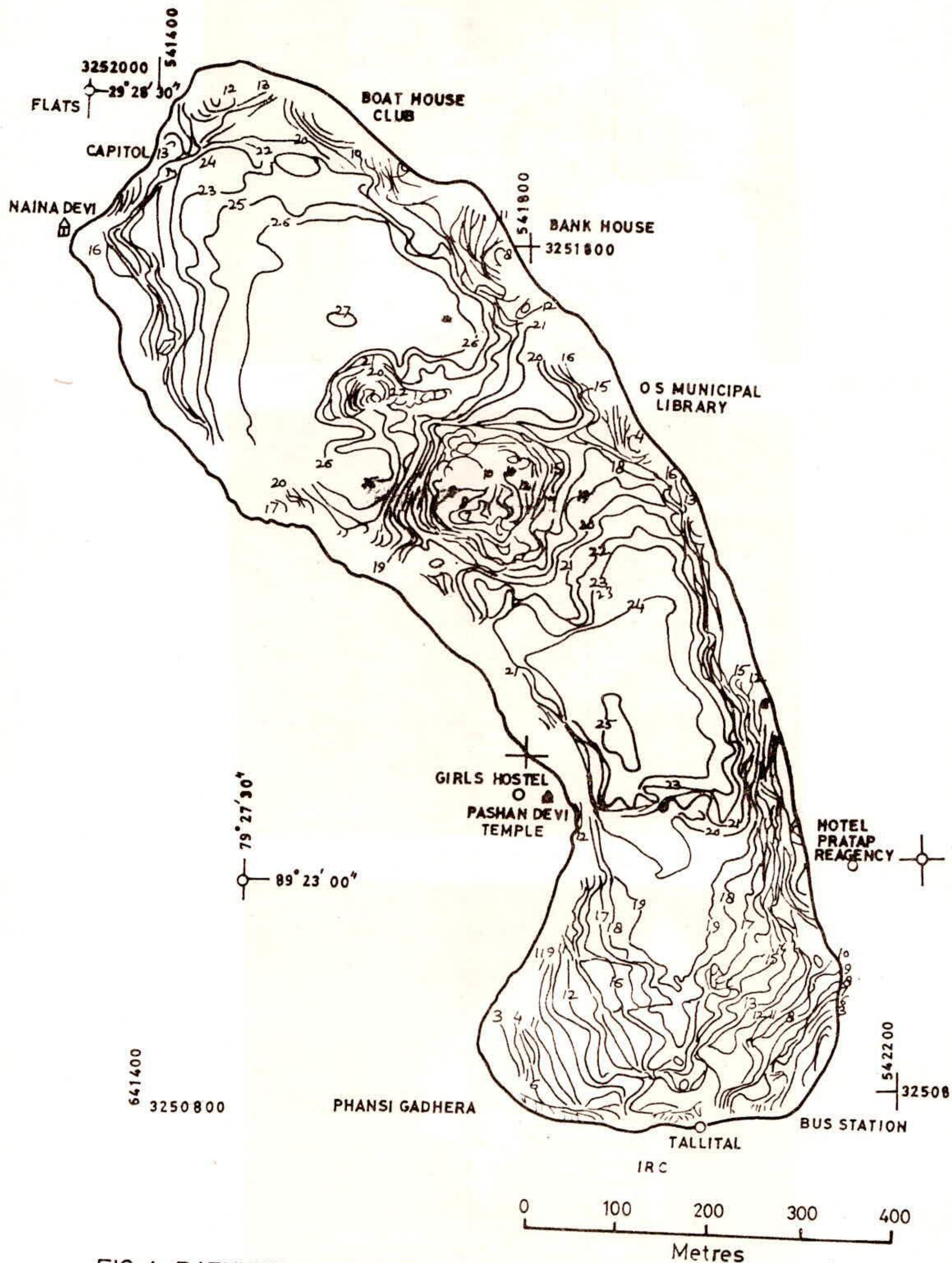

FIG. 4–BATHYMETRIC MAP OF NAINI LAKE

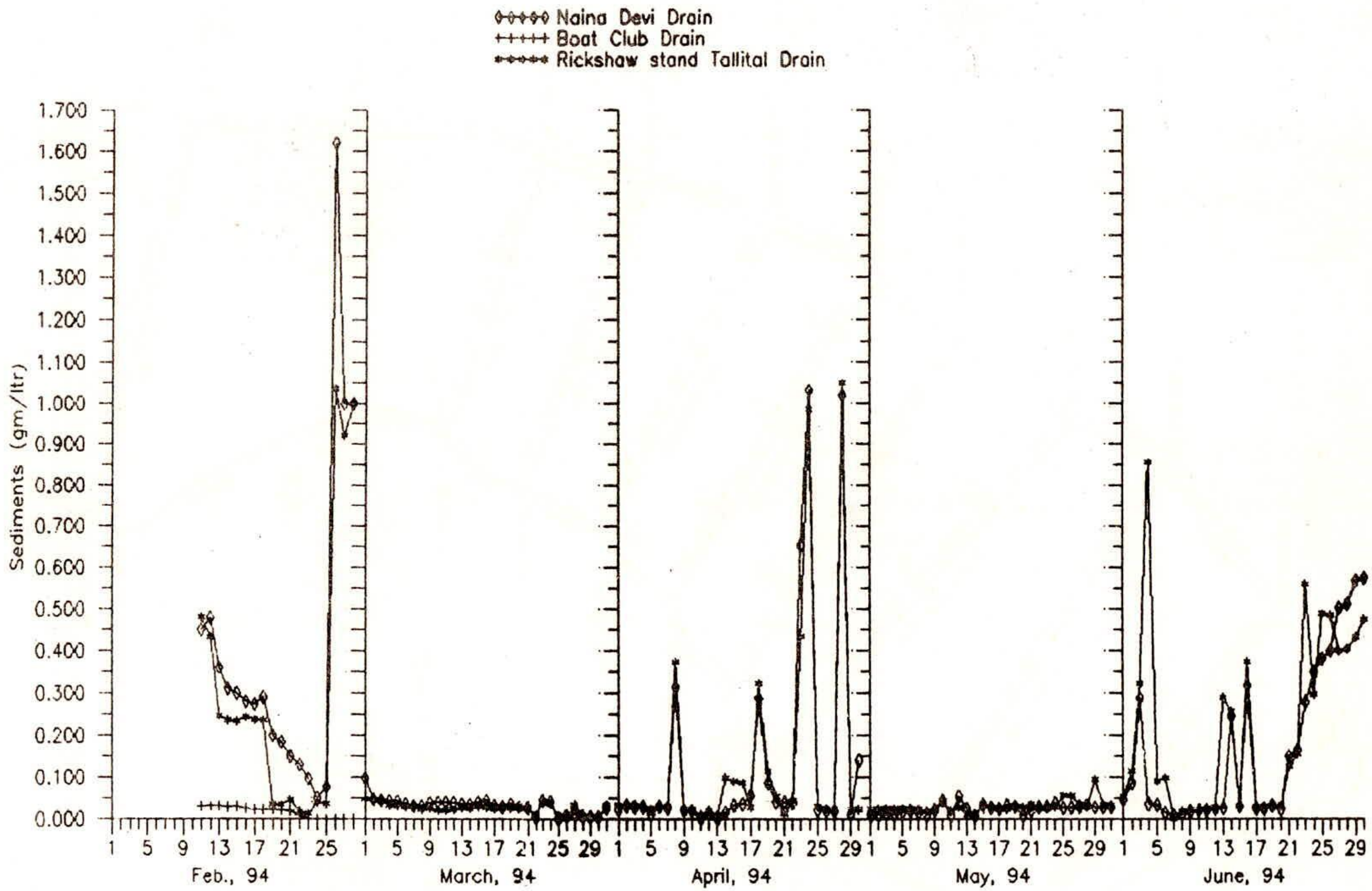

Fig. 5 Variation of suspended **sediment** load in gm/ltr. with time during the months from Feb. to **June 1994** in major drains meeting to lake Naini, district Nainital, U.P **(India)**

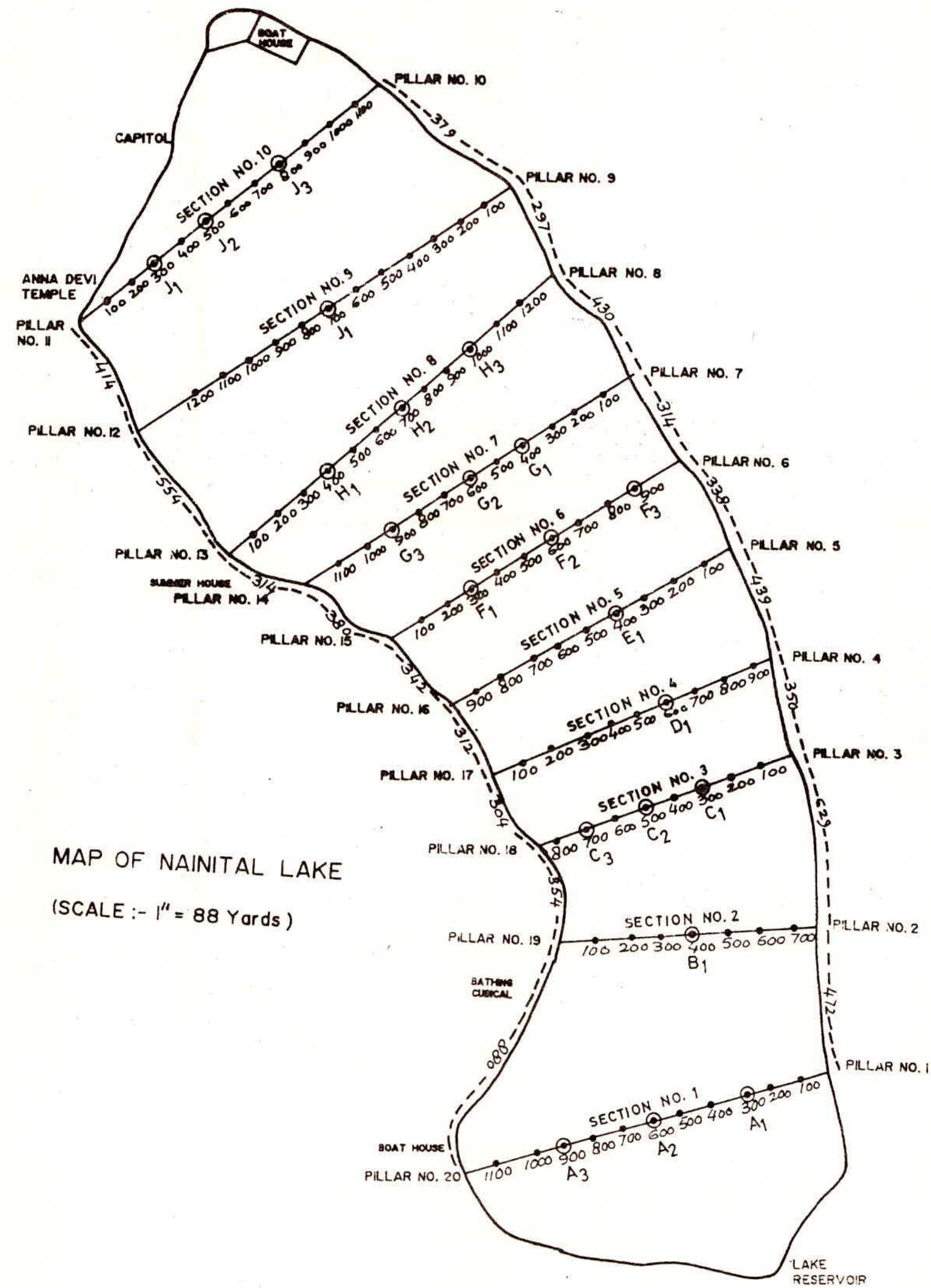

FIG. 6 LOCATION OF STUDY / WATER SAMPLING POINTS

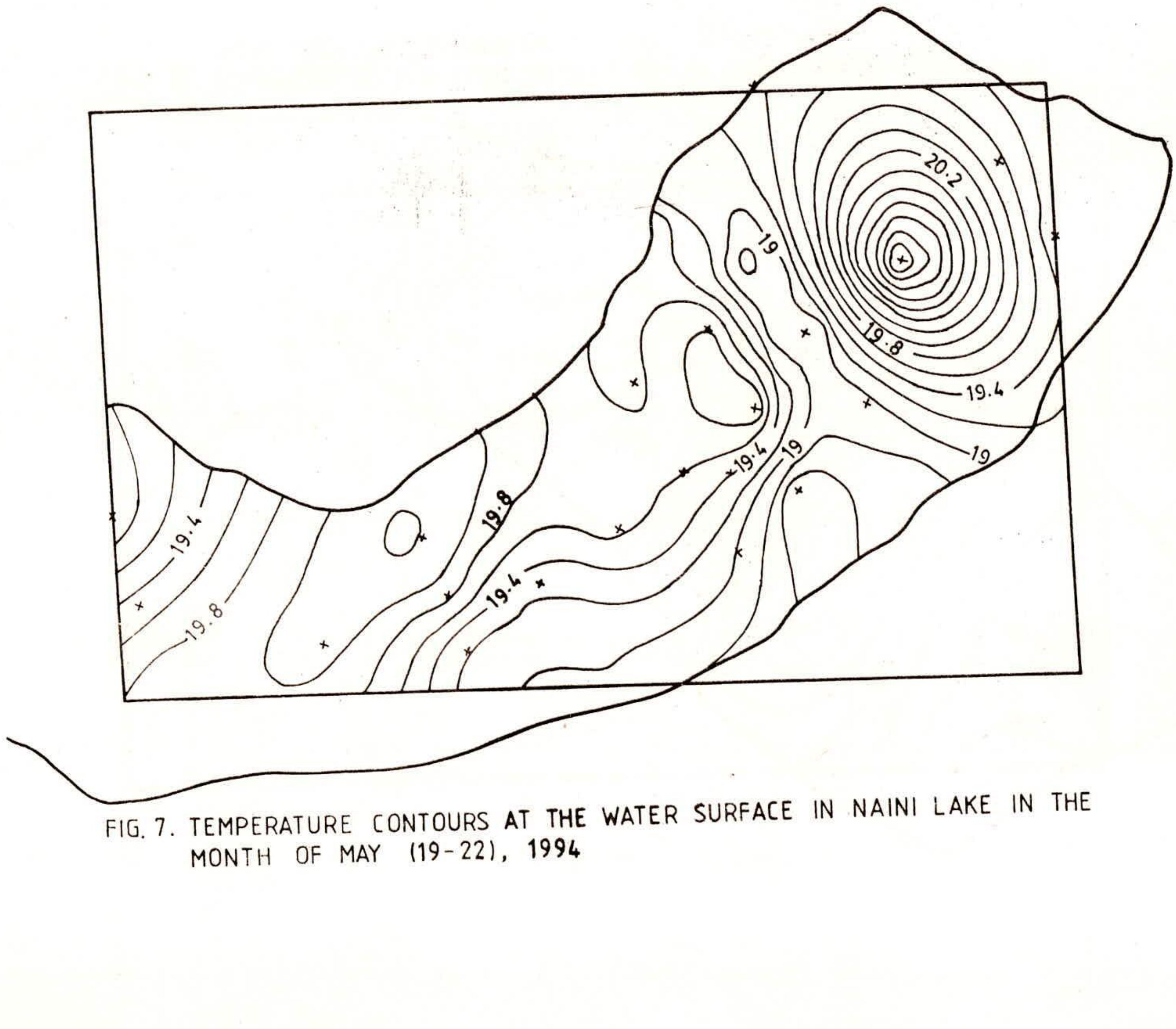

FIG. 7. TEMPERATURE CONTOURS AT THE WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994

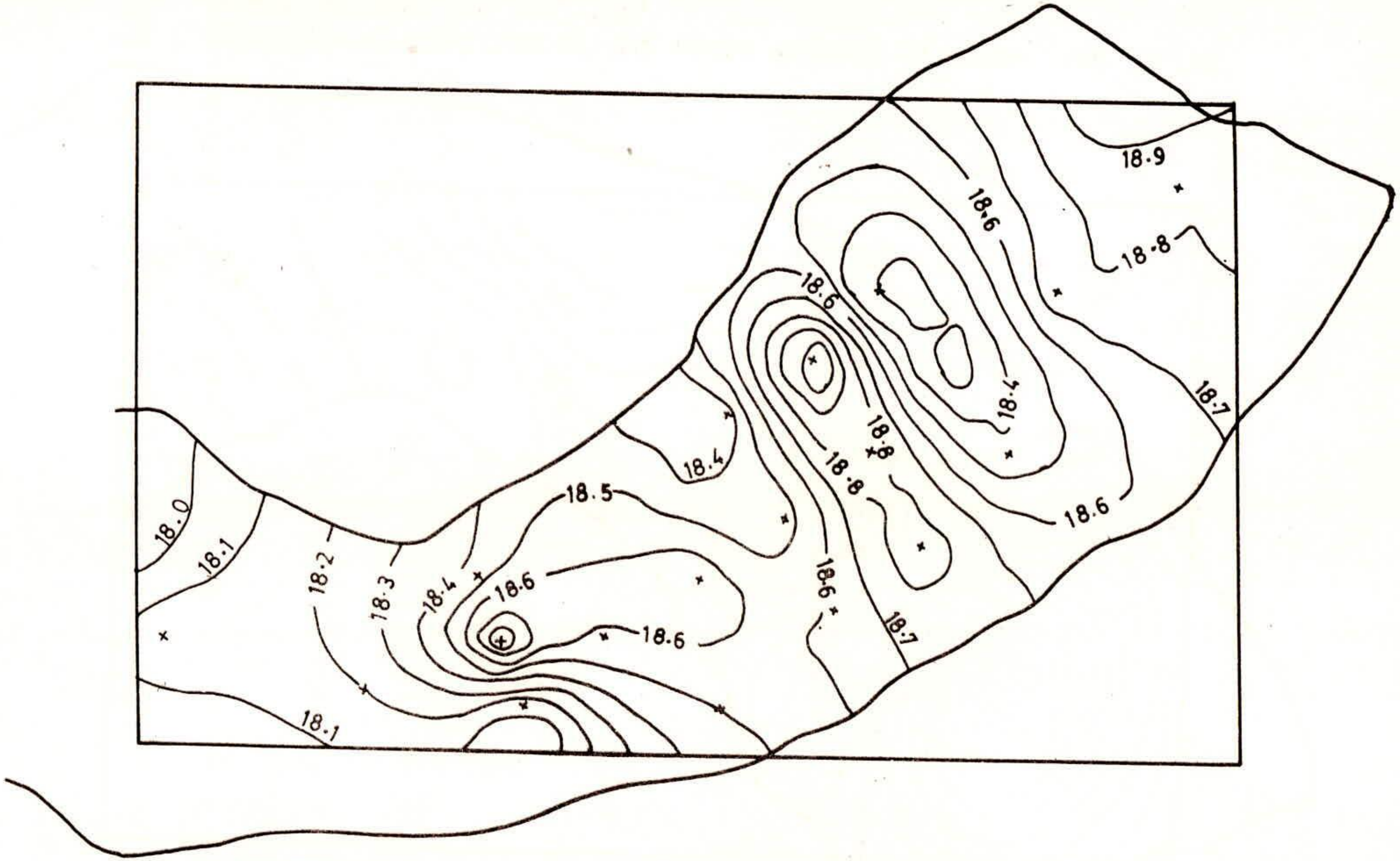

FIG. 8. TEMPERATURE CONTOURS AT 3·0m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994

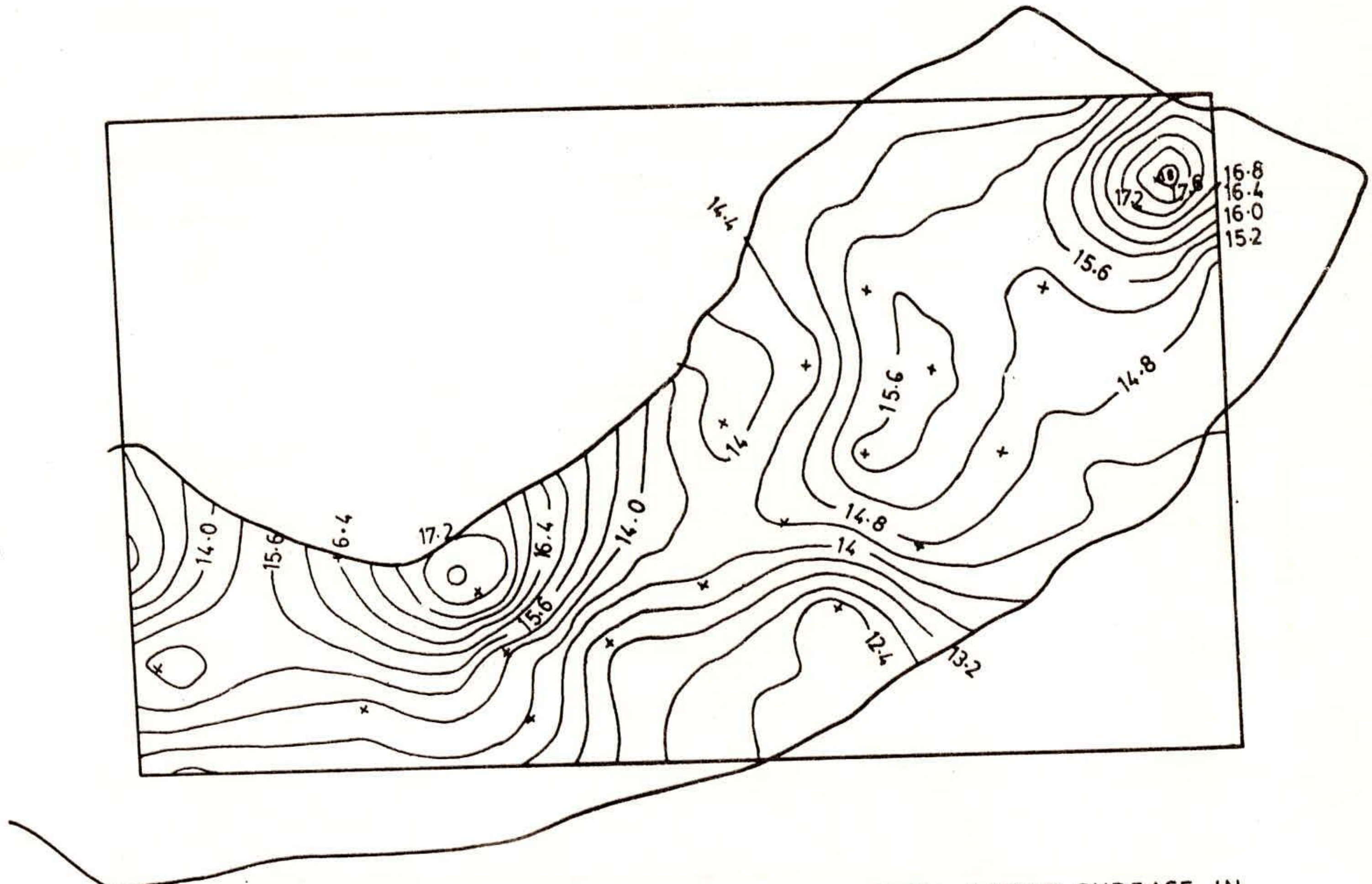

FIG. 9. TEMPERATURE CONTOURS AT 6·0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22) 1994

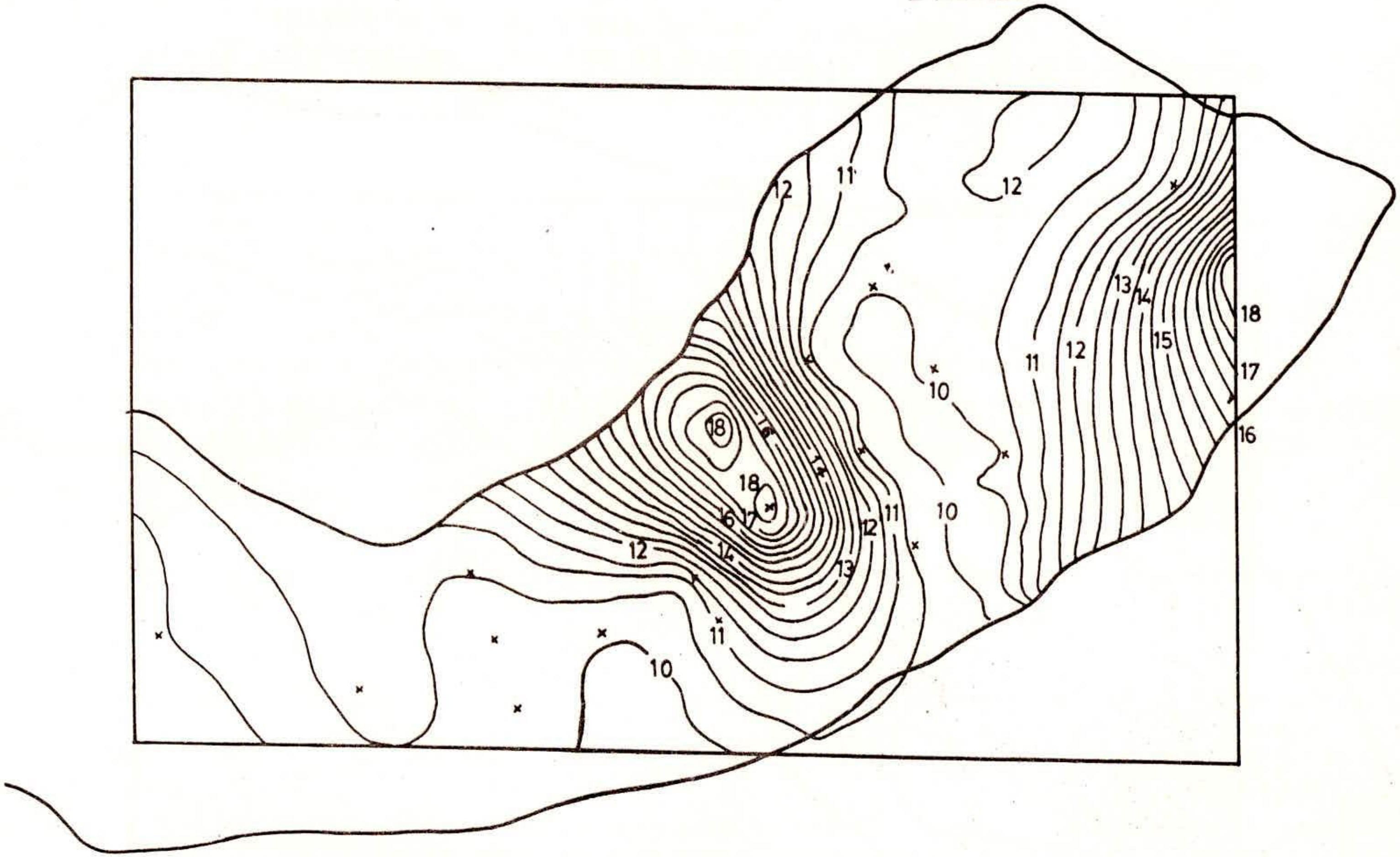

FIG.10. TEMPERATURE CONTOURS AT 9.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22) 1994

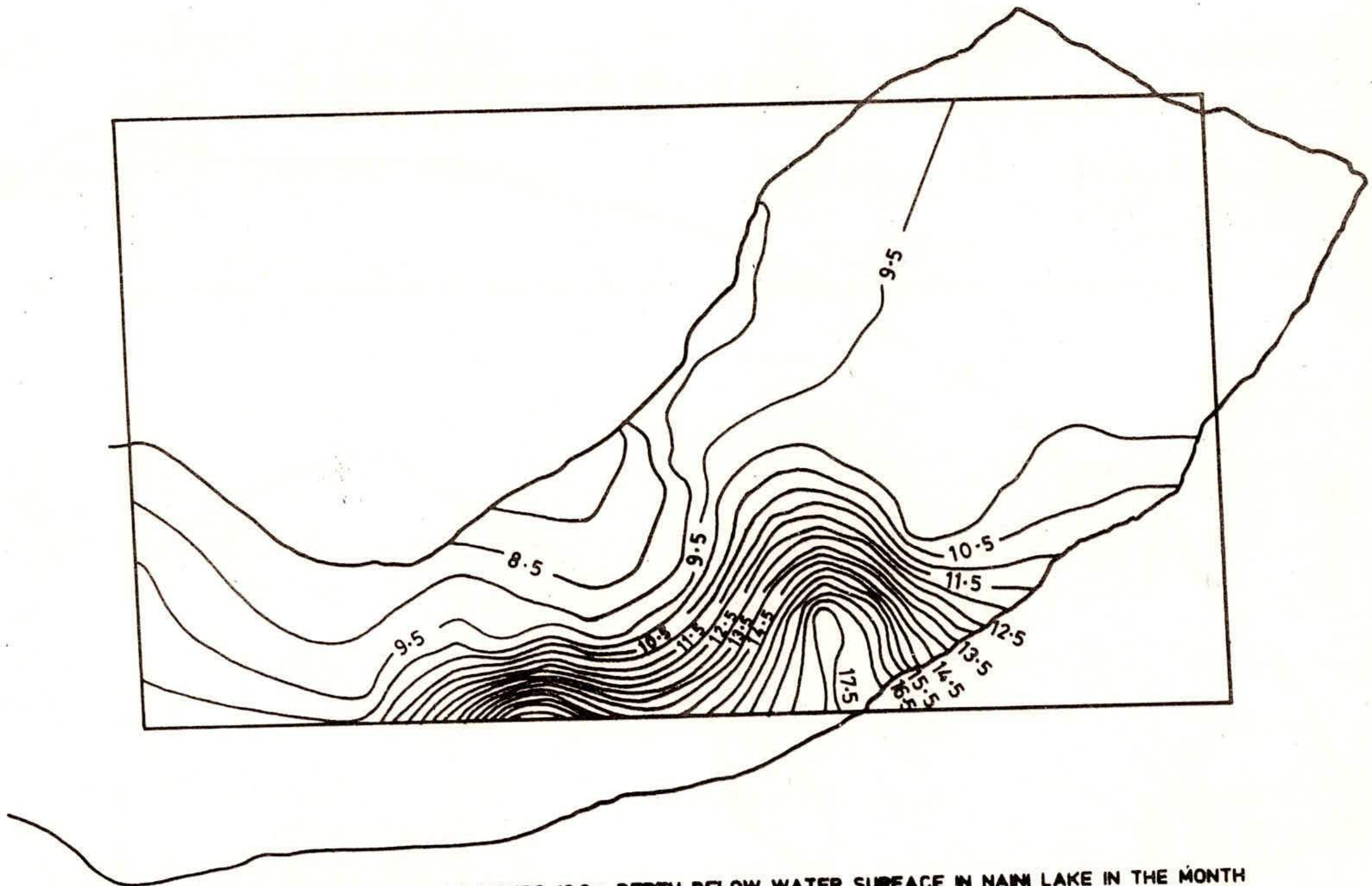

FIG. 11 TEMPERATURE CONTOURS 12.0m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22),1994

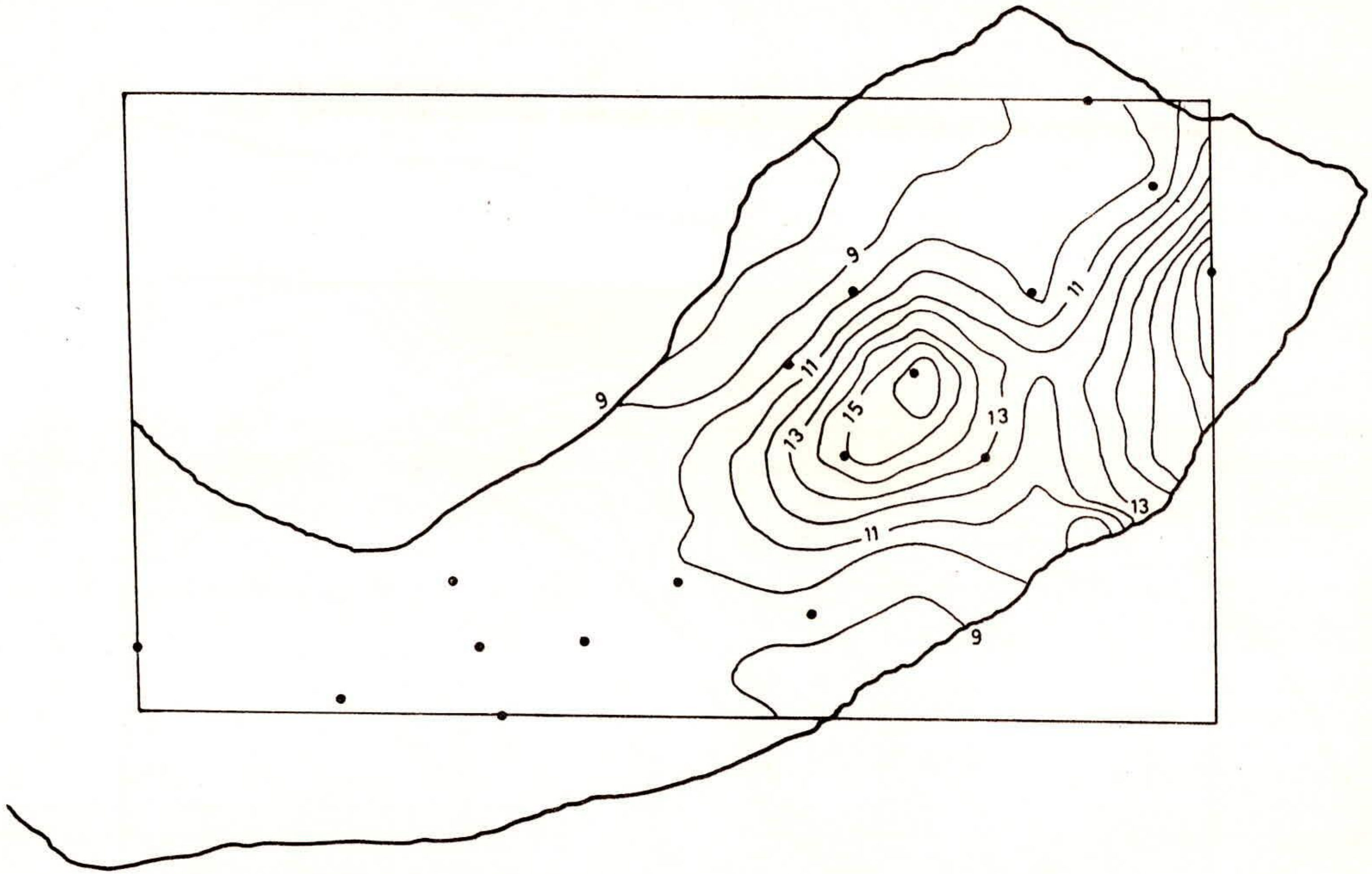

FIG. 12 TEMPERATURE CONTOURS AT 15.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22),1994.

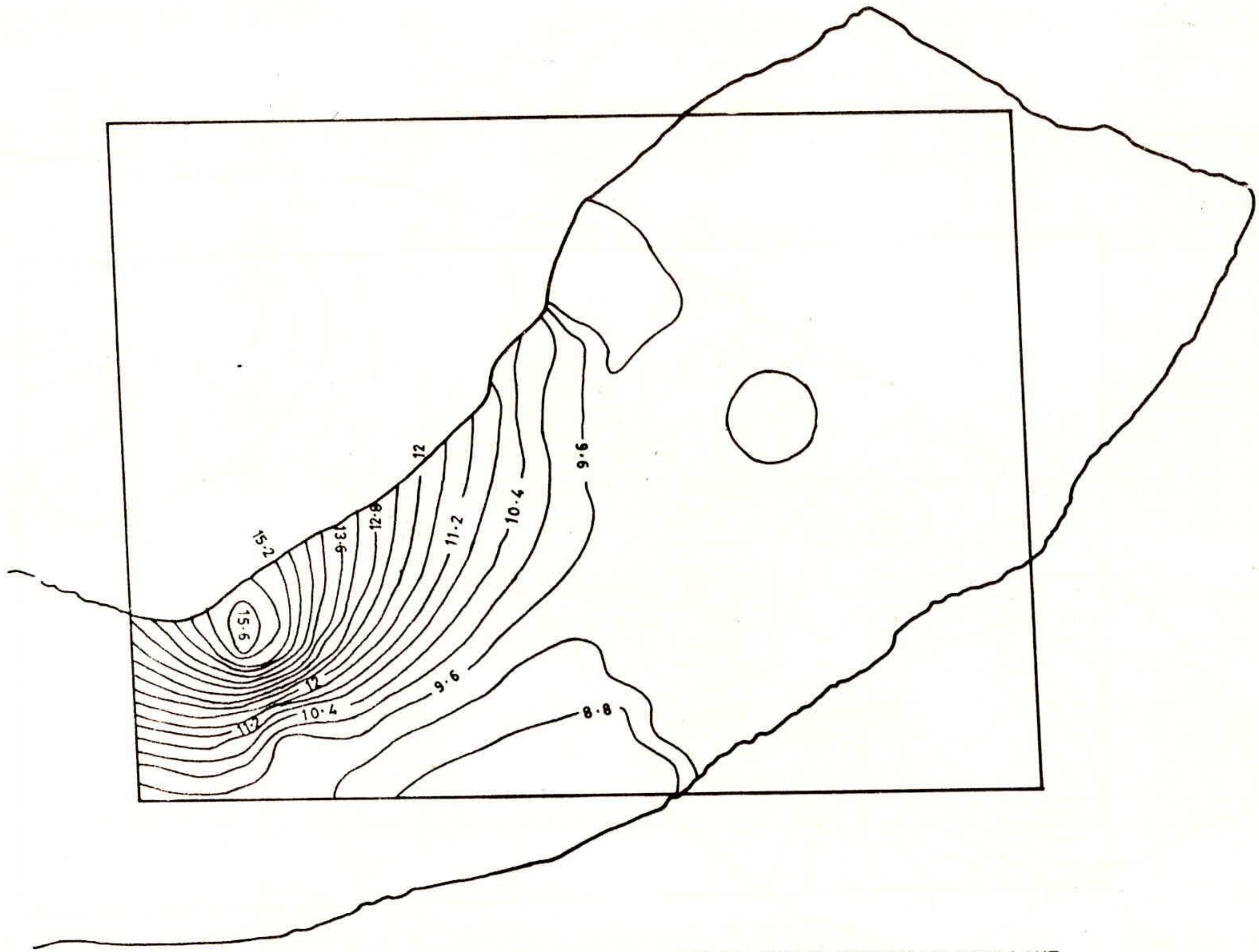

FIG. 13 TEMPERATURE CONTOURS AT 18.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22) 1994.

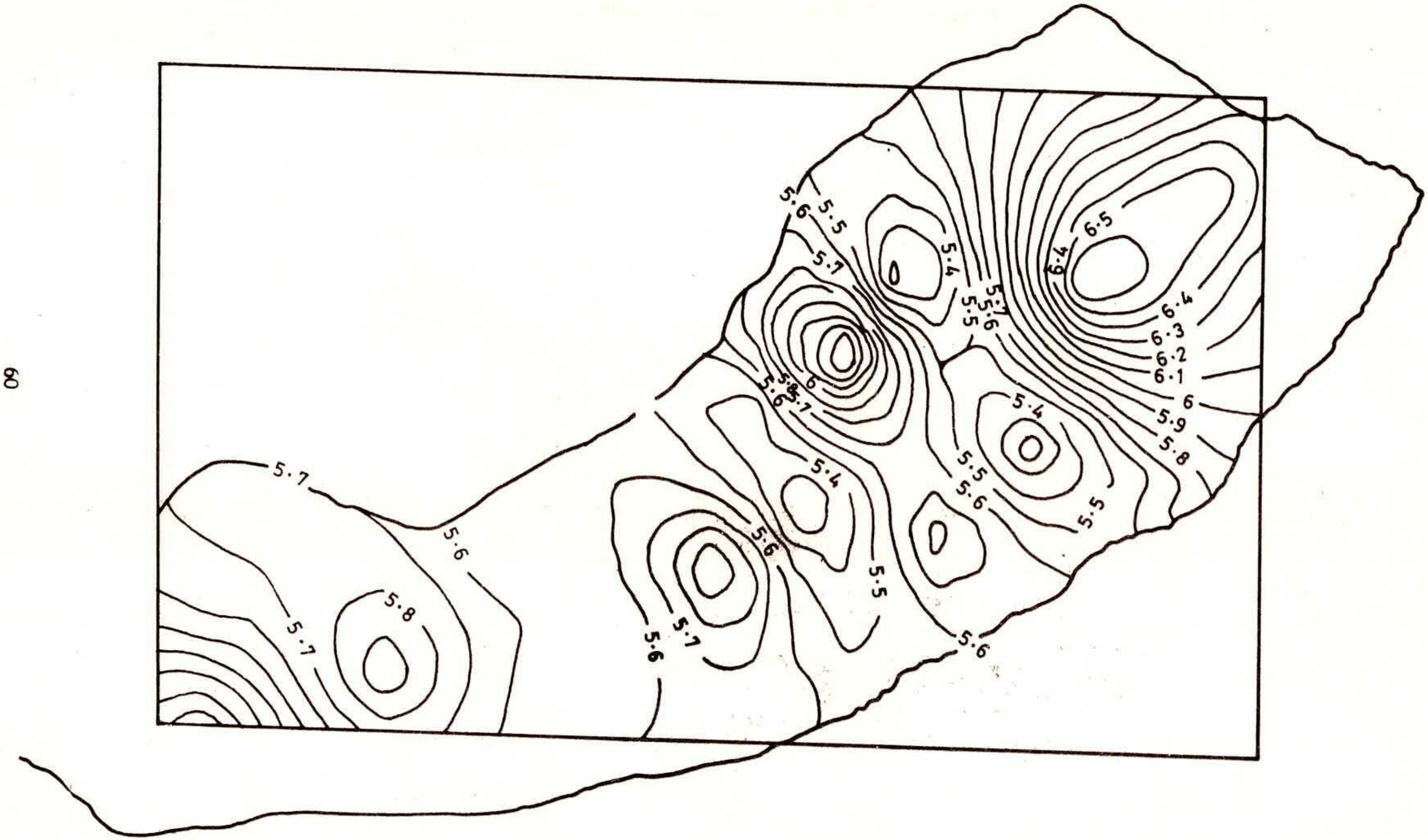

FIG. 14 D.O. CONTOURS AT WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994

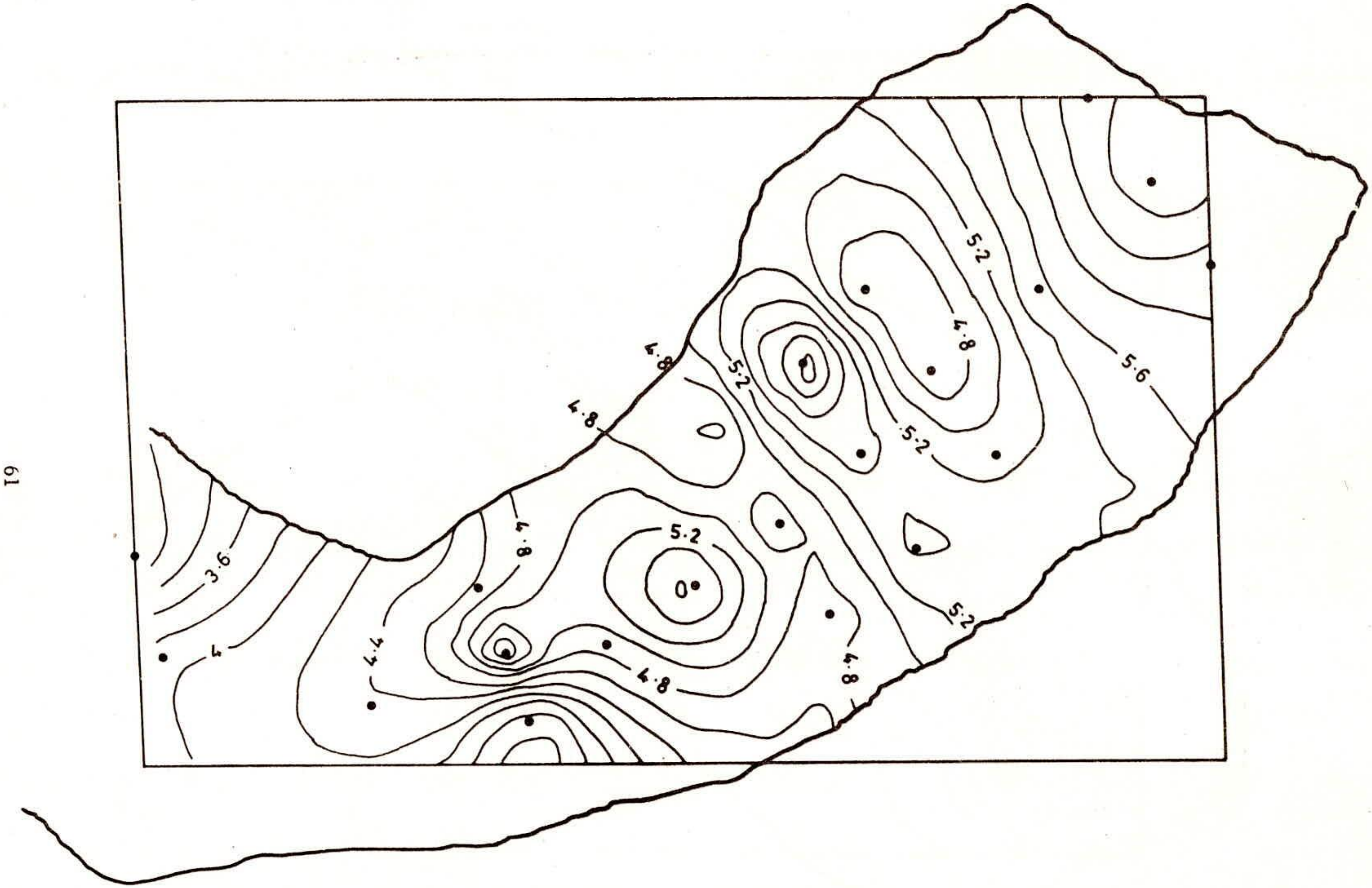

FIG. 15 D.O CONTOUR AT 3.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22),1994.

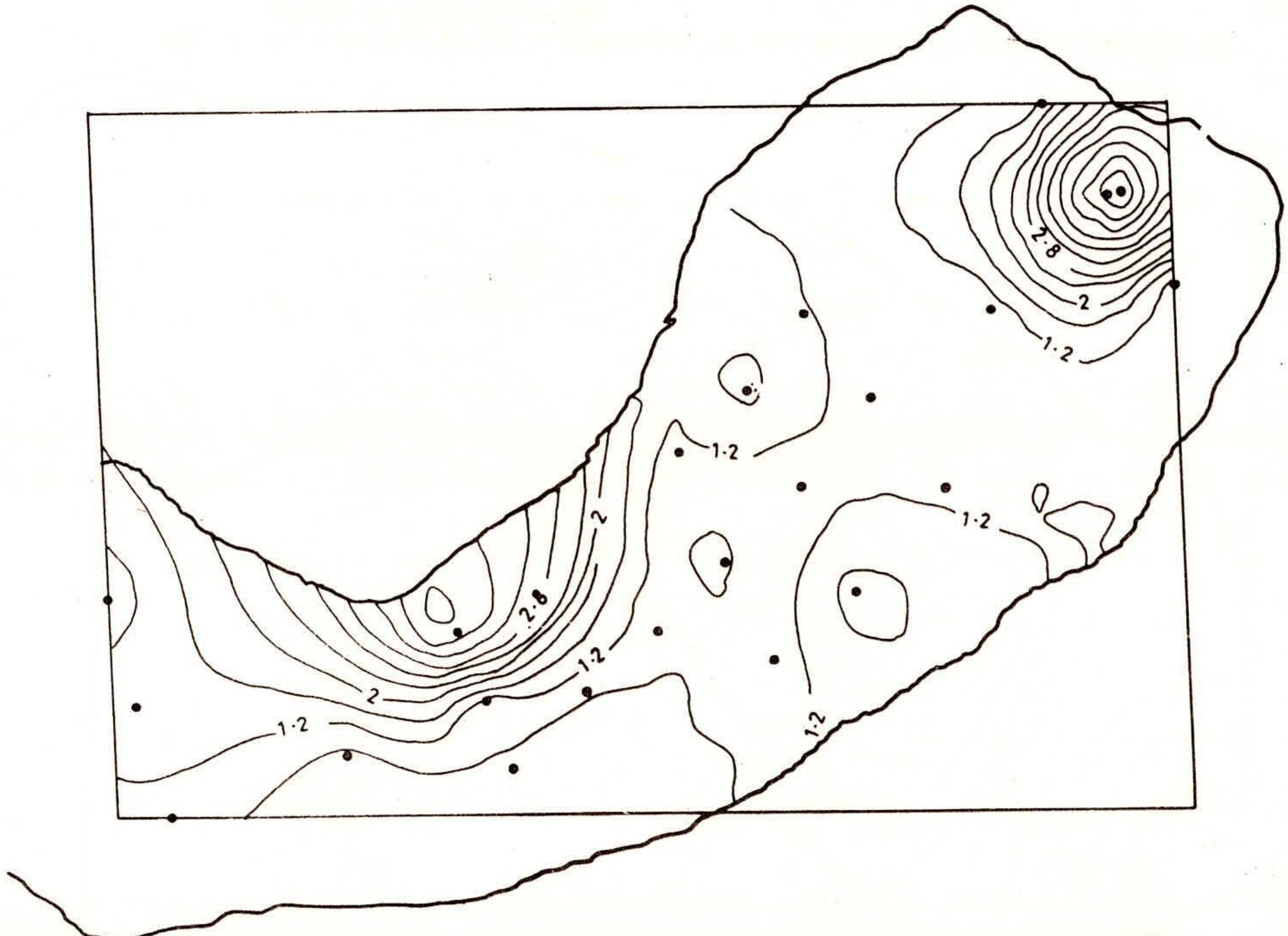

FIG. 16 D.O CONTOURS AT 6.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994

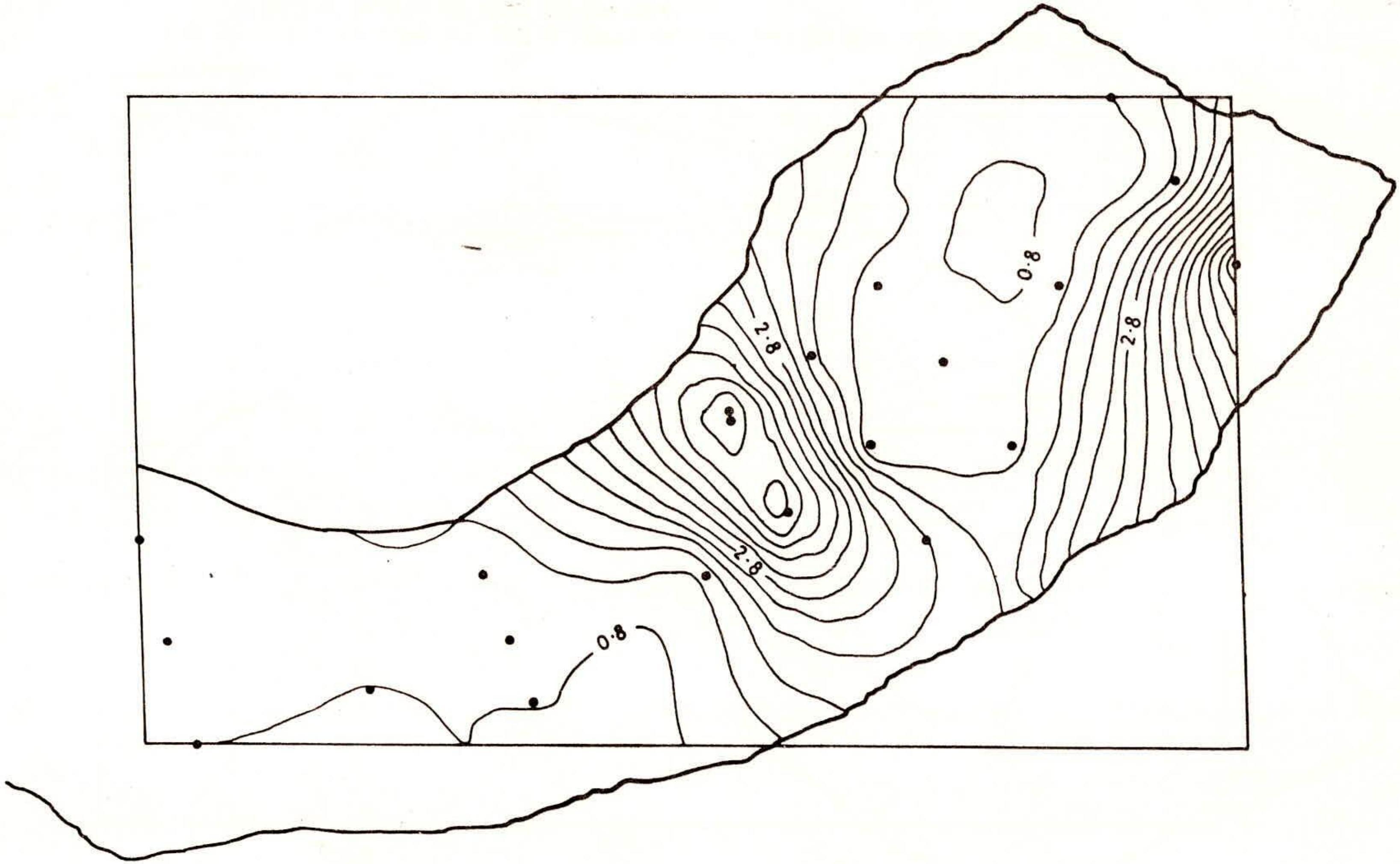

FIG. 17 D.O CONTOURS AT 9.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994.

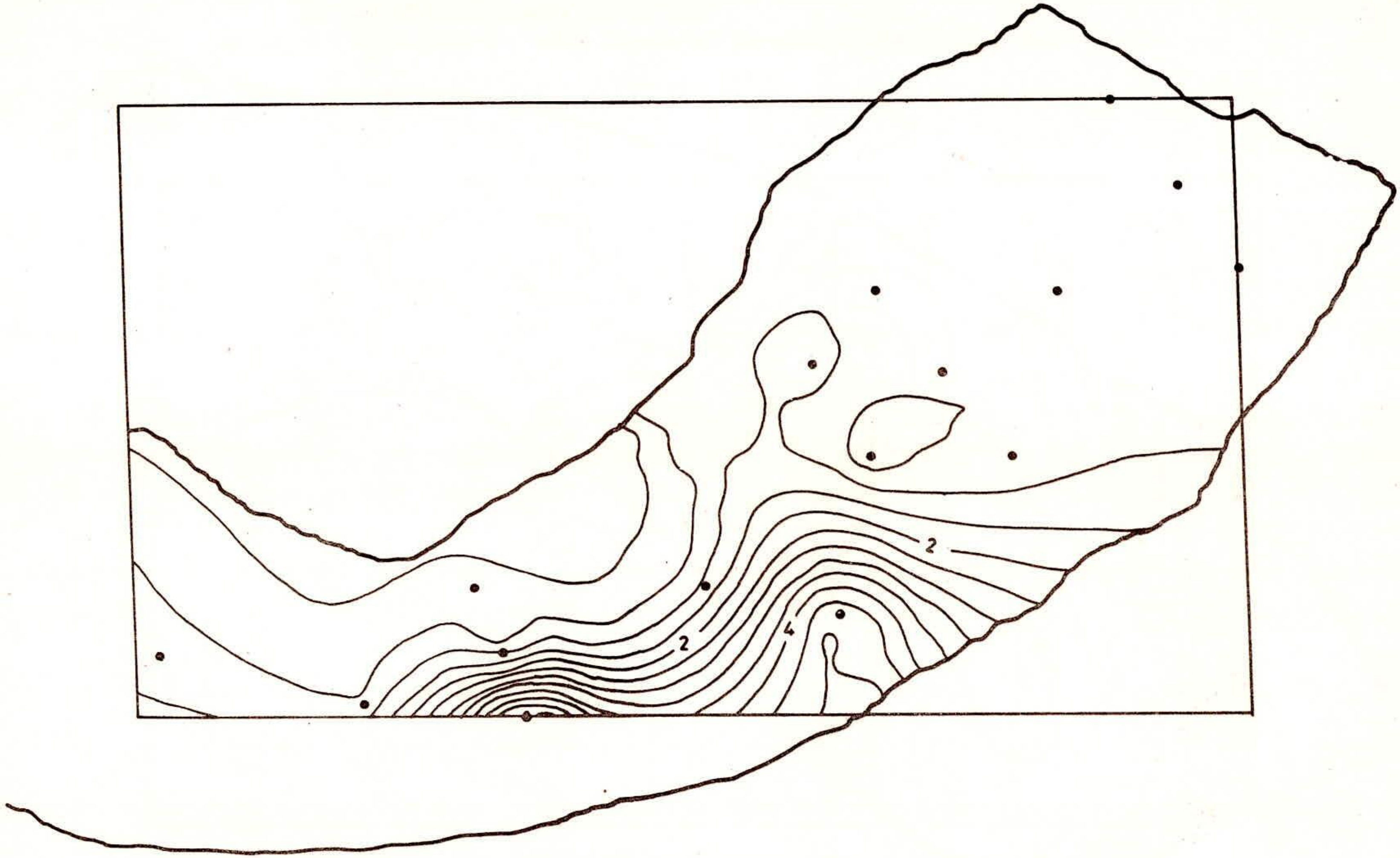

FIG. 18. D.O CONTOURS AT 12.0 m DEPTH BELOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19-22), 1994

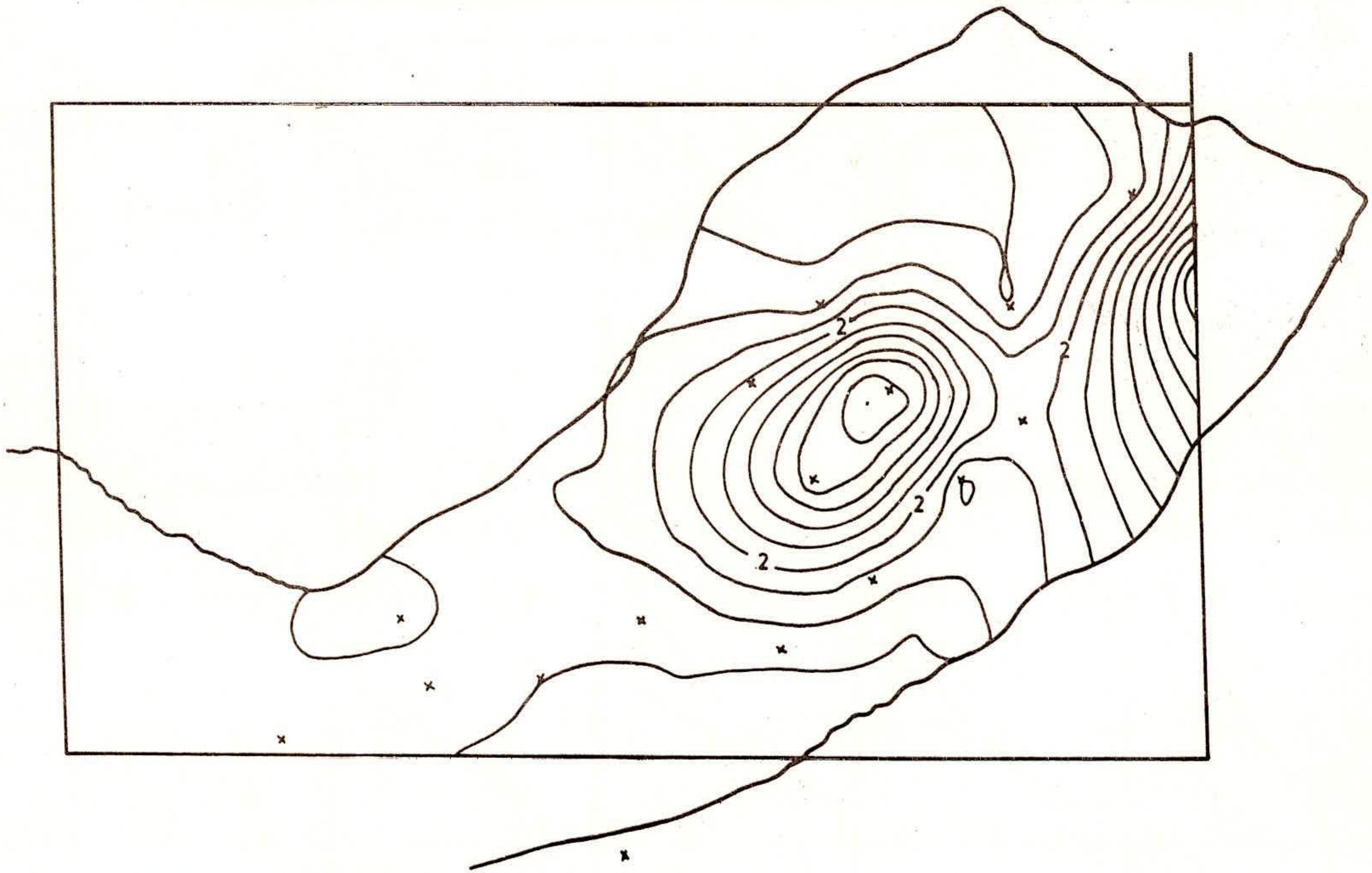

FIG.19. D.O. CONTOURS AT 15·0 m DEPTH BEWOW WATER SURFACE IN NAINI LAKE IN THE MONTH OF MAY (19 22),1994

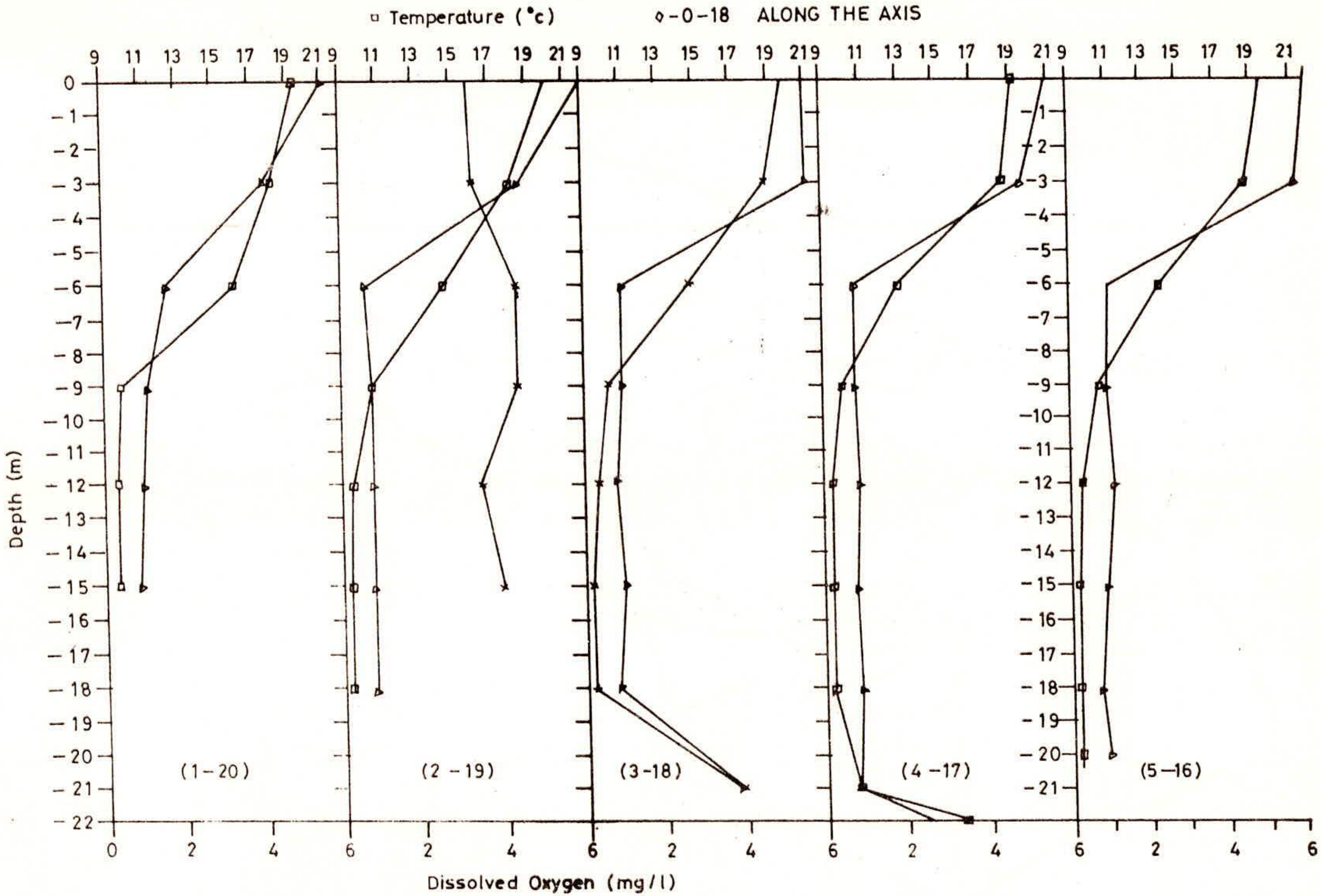

FIG. 20 VARIATION OF TEMPERATURE, D.O AND OXYGEN-18 COMPOSITION OF WATER WITH DEPTH AT DIFFERENT LOCATION IN NAINI LAKE

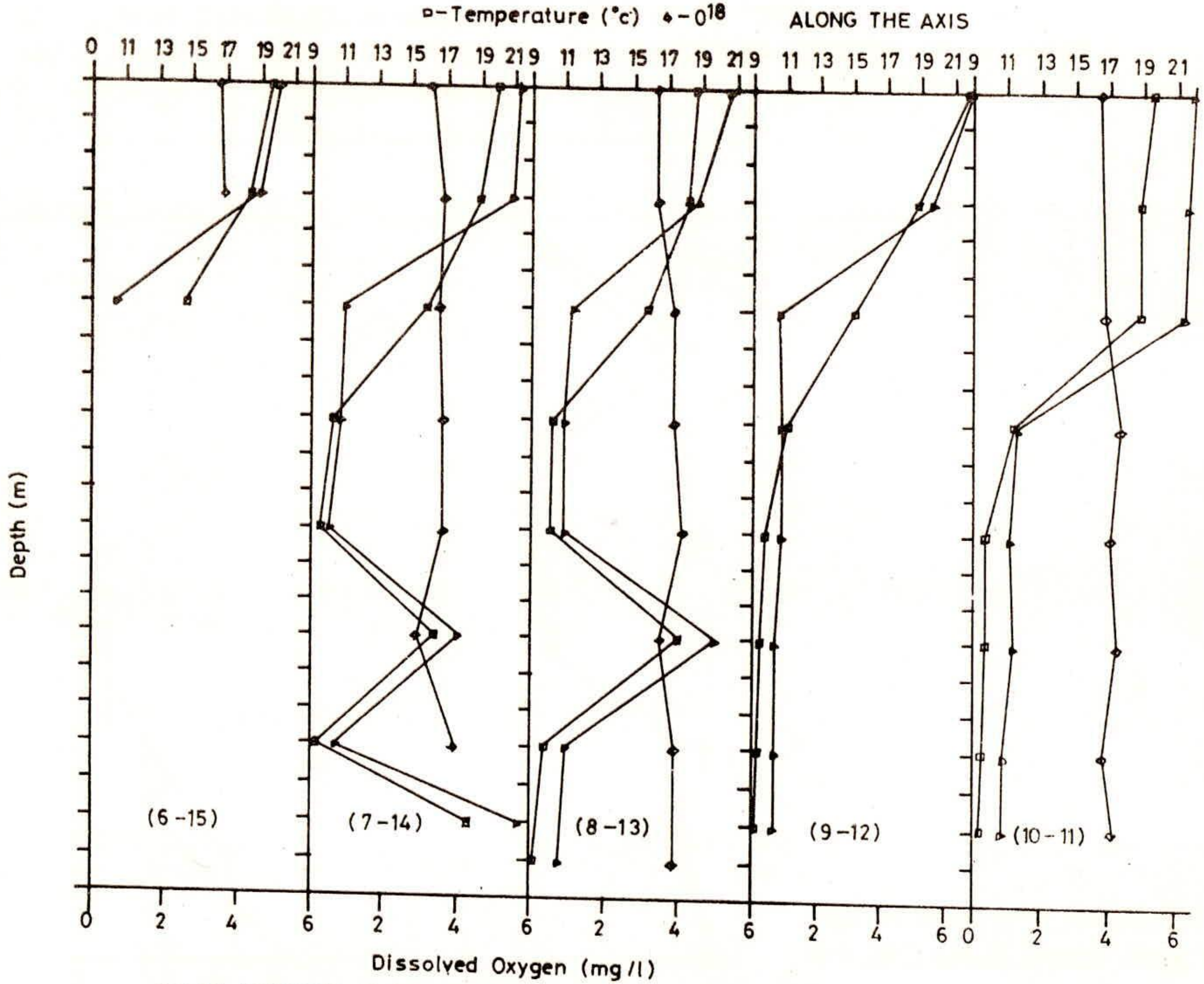

FIG. 21 VARIATION OF TEMPERATURE, D.O. AND OXYGEN-18 COMPOSITION OF WATER WITH DEPTH AT DIFFERENT LOCATION IN NAINI LAKE

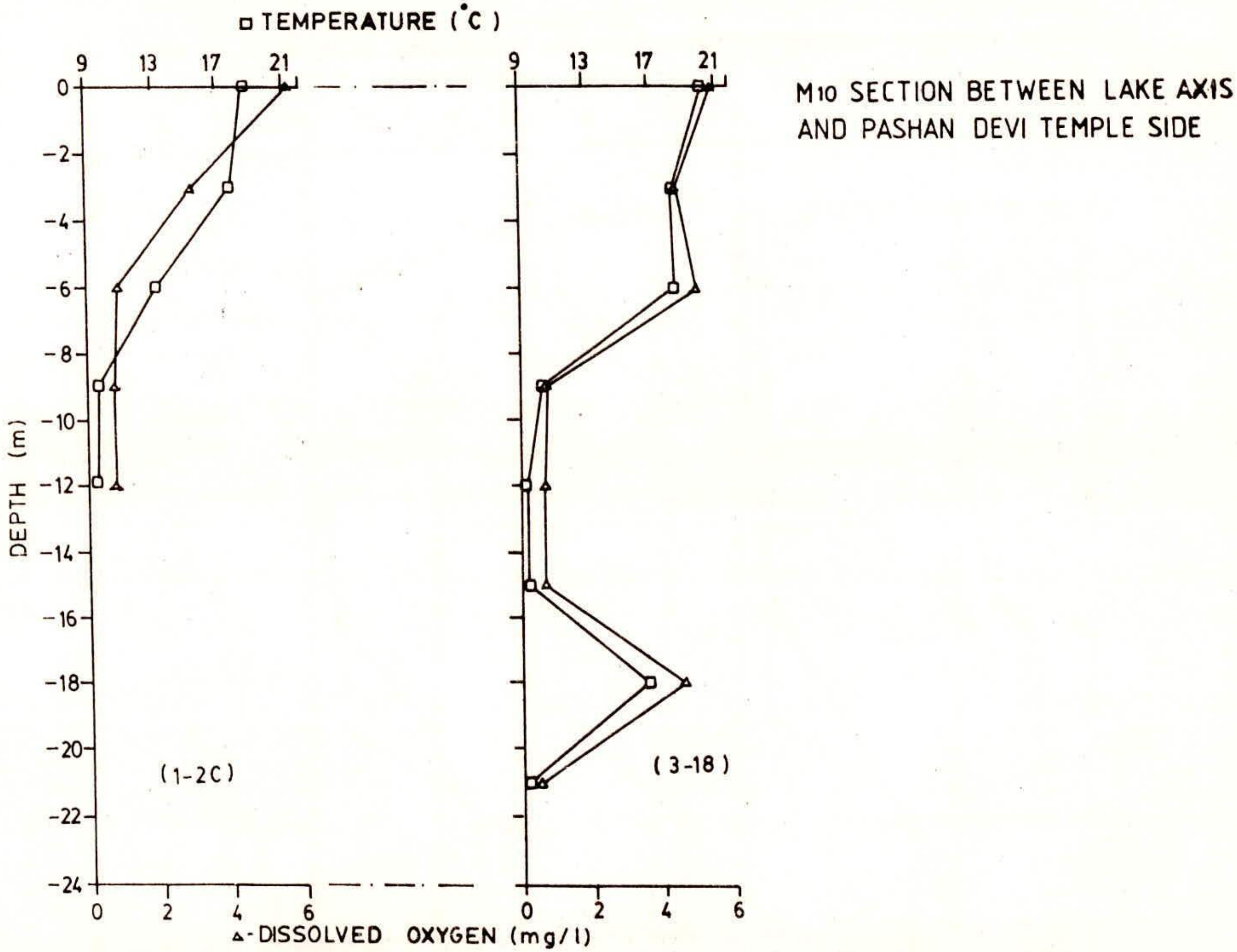

FIG.22. VARIATION OF TEMPERATURE, D.O. AND OXYGEN 18 COMPOSITION OF WATER WITH DEPETH AT DIFFERENT LOCATIONS NAINI-LAKE

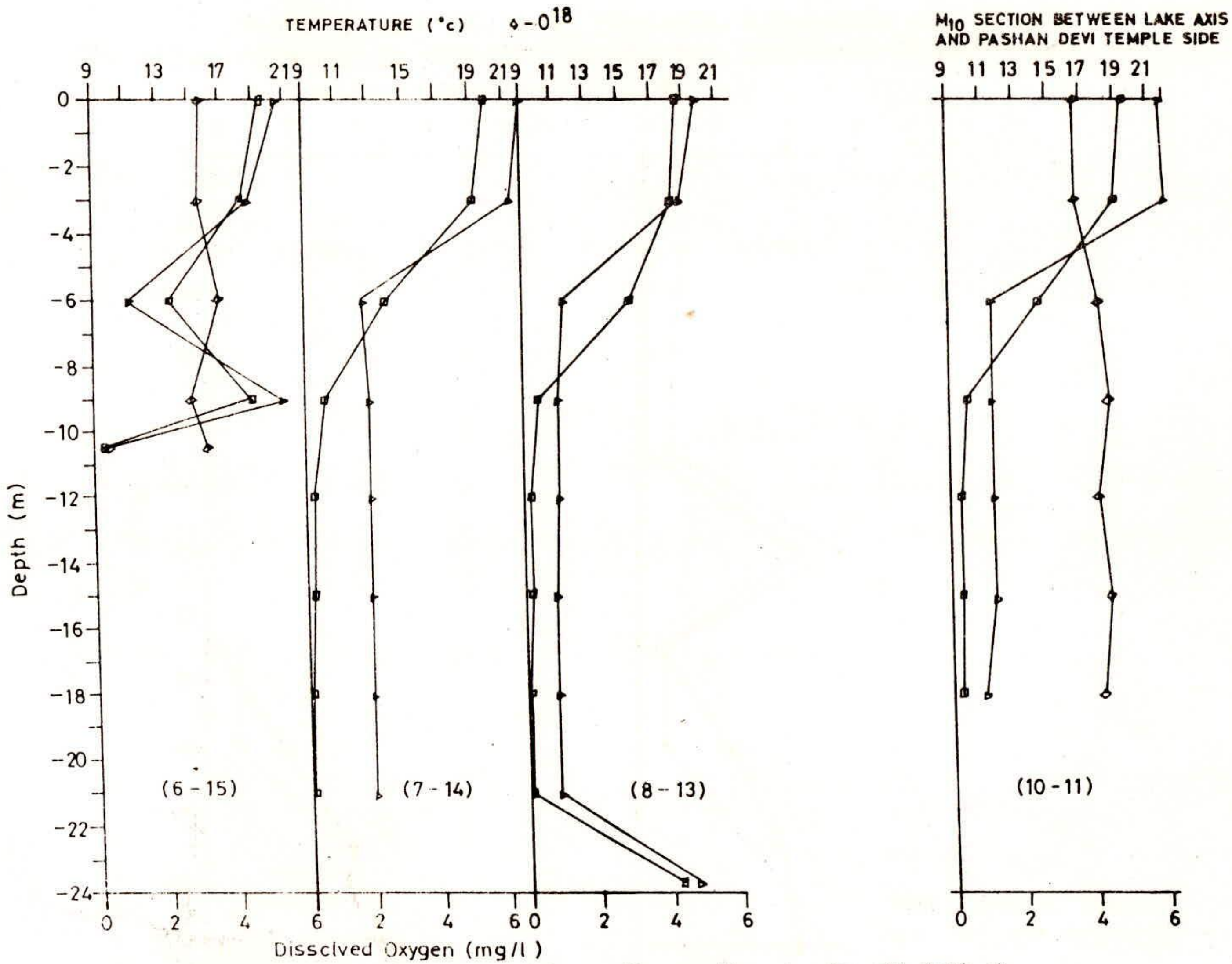

Fig.23 Variation of Temperature, D.O. and Oxygen-18 composition of water with depth at different location in Naini Lake

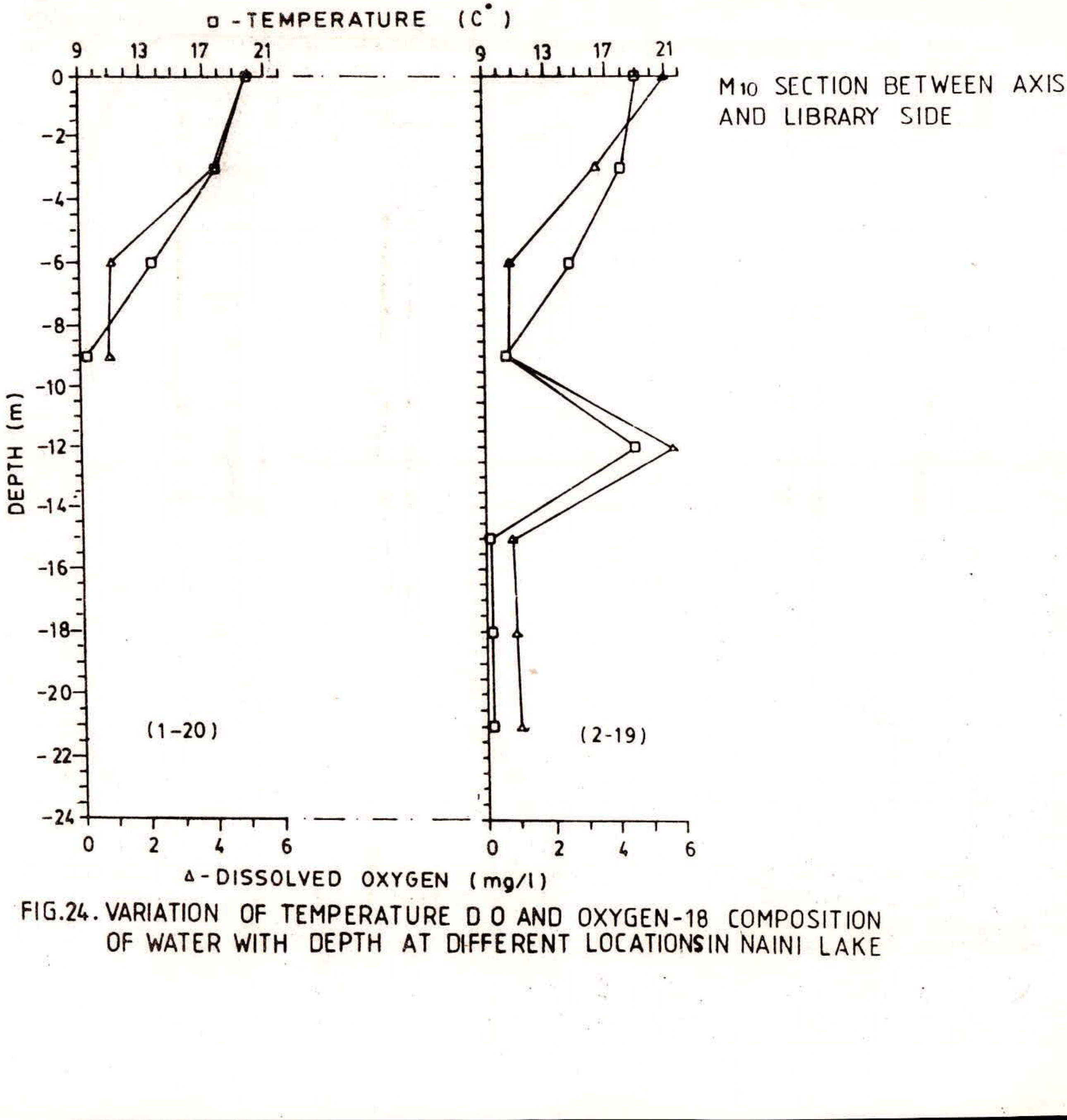

FIG.24. VARIATION OF TEMPERATURE D O AND OXYGEN-18 COMPOSITION OF WATER WITH DEPTH AT DIFFERENT LOCATIONS IN NAINI LAKE

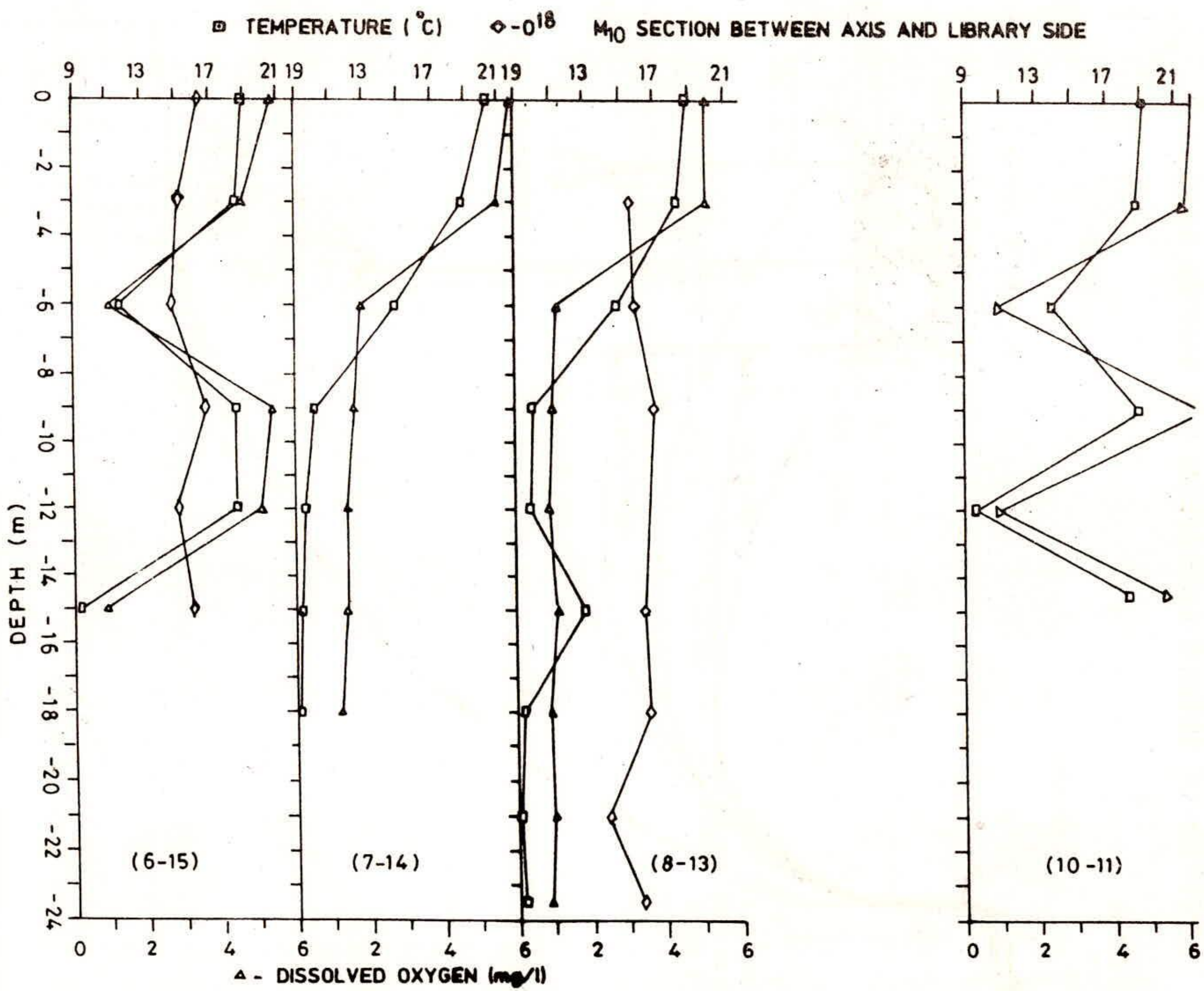

FIG. 25 VARIATION OF TEMPERATURE, D.O. AND OXYGEN-18 COMPOSITION OF WATER WITH DEPTH AT DIFFERENT LOCATION IN NAINI LAKE.

POSITION OF VARIOUS SENSORS IN THE NAINITAL LAKE

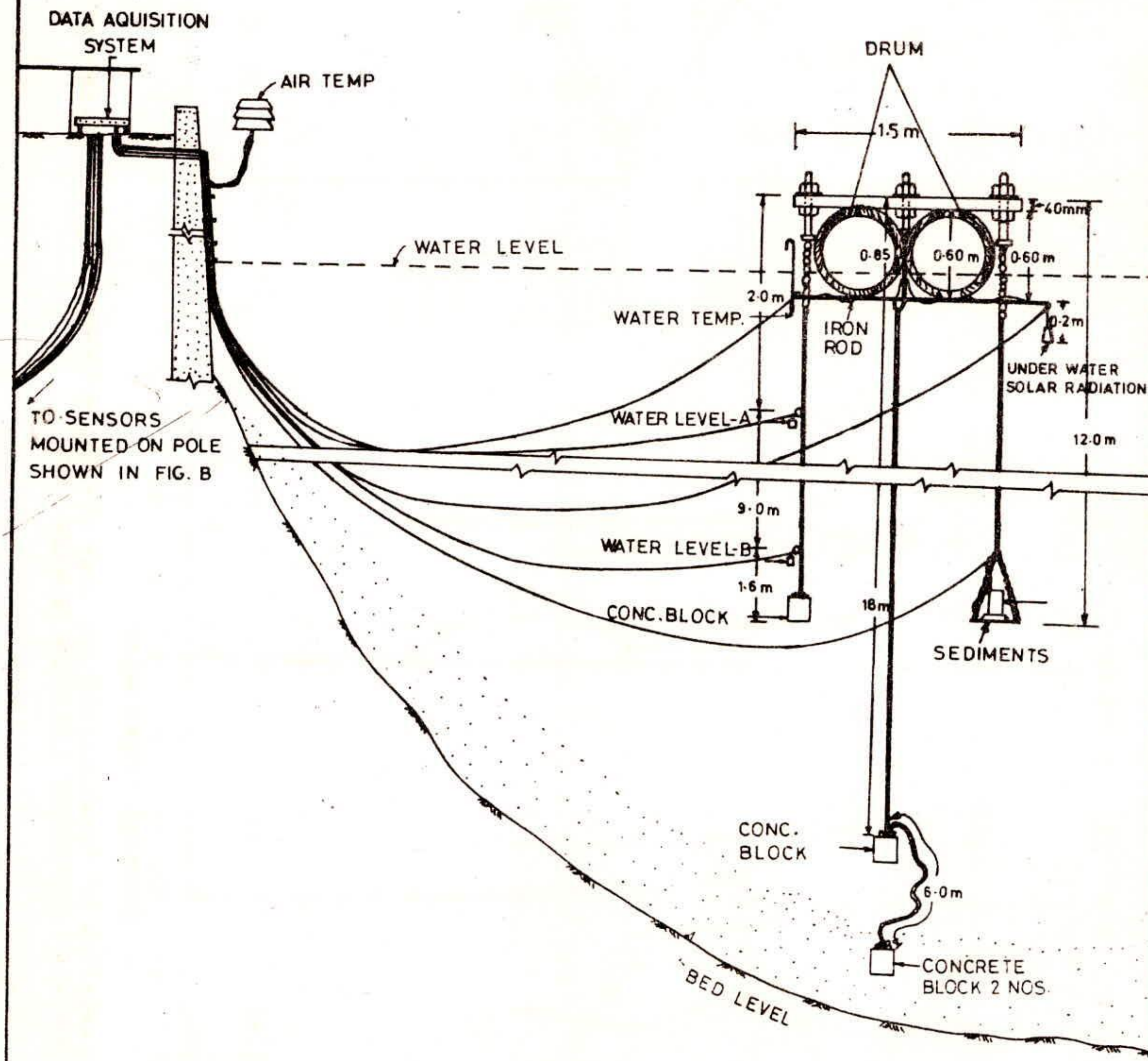

FIG. 26

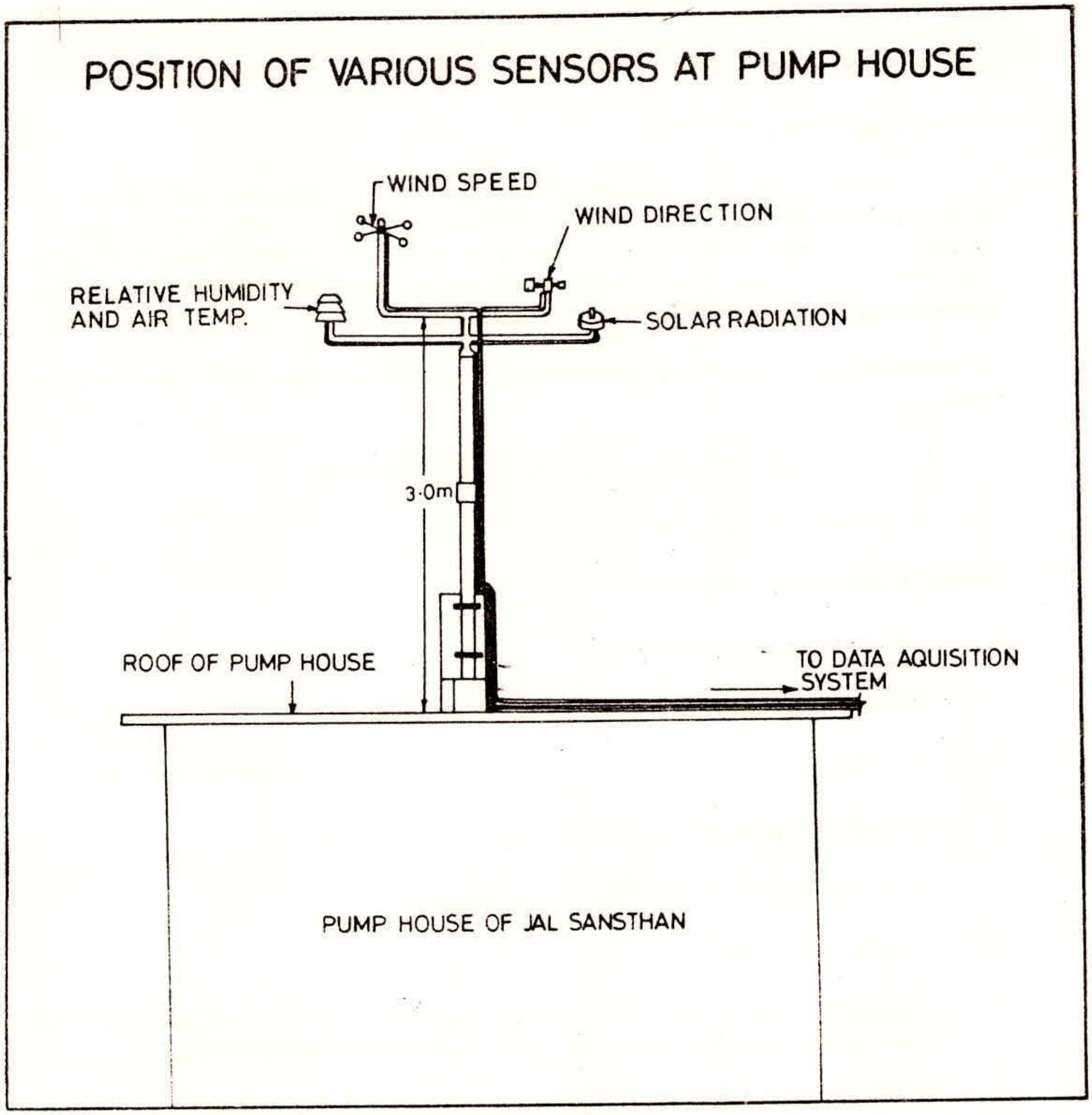
POSITION OF VARIOUS SENSORS AT PUMP HOUSE
WIND SPEED
WIND DIRECTION
RELATIVE HUMIDITY
AND AIR TEMP.
SOLAR RADIATION
3·0m
ROOF OF PUMP HOUSE
TO DATA AQUISITION
SYSTEM
PUMP HOUSE OF JAL SANSTHAN

FIG. 27

PROGRAMME OF PROJECT WORK :

The project involves various techniques of geological and geomorphological mapping, remote sensing, isotope hydrology and water quality aspects. It was planned to carry out the project in different phases, the details of which are outlined below with specific comments about the progress made so far.

PHASE I (July 1993 - June 1994)

In the first phase, mostly the procurement of the equipment their installation, appointment of project staff and preliminary field survey and laboratory work was envisaged. The details of the work carried out in the first phase have been given in the section "Progress of the work". The details of procurement of equipment, project staff appointed and budget utilized are given in appendix I, II and III respectively.

The following team of scientists is engaged in order to complete the work related with this project.

- i) Dr. Bhishm Camber, Sc. E & Project Coordinator
- ii) Dr. C.K. Jain, Sc. C
- iii) Mr. S.K. Jain, Sc. C

PHASE II (July 1994 - June 1995)

i) Remote sensing investigations:

The following investigations will be carried out using remote sensing data.

a) Identification of lake catchment area using SPOT data and available imageries.

b) Geomorphology of lake.

c) Water spread area and turbidity level mapping.

ii) Detailed field programme.

a) Collection of data on water level, rainfall, evaporation, discharge, suspended load and other water quality parameters including seepage loss measurements.

b) Detailed bathymetric survey of the lake to define the configuration of the lake.

c) Detailed temperature variations of different water layers in lakes in order to study the hydrodynamics of lake.

d) Detailed and systematic sampling for testing water quality and lake response with respect to pollutant distribution and mixing.

e) Detailed sampling for isotopic analysis in order to study the evaporation loss from lake surface, origin of lake waters and lake dynamics.

iii) Laboratory Work:

a) Water samples will be subjected to the following analysis in the laboratory:

i) 2H and ^{18} O stable isotope analysis.
ii) Environmental tritium and ^{14} C analysis.
iii) Water quality analysis including pollutants.

b) The rainwater sample and water samples of the stream and nalas meeting to the lake will also be subjected to similar analyses.

c) The toposheets, imageries, and digital remote sensing data will be studied and analysed in the laboratory.

d) The hydrometeorological data will be collected for the study area.

iv) Data compilation and interpretation

All the data collected through different field trips and laboratory analyses ill be compiled, interpreted and presented in the form of a report.

PHASE III (July 1995 - 1996)

i) Water balance studies using conventional and isotopic techniques including remote sensing techniques.

ii) Studies on rates of sedimentation and age of lake water using conventional, remote sensing and isotopic techniques.

iii) Identification of recharge sources using isotopic and remote sensing techniques.

iv) Detailed study of lake water pollution with respect to the sources of pollution and its distribution/mixing with lake water using chemical/conventional, isotopic and remote sensing techniques.

v) Compilation and analysis of data collected with the help of the equipment installed at the lake site and in the lake catchment area.

vi) Analysis of the data collected during phase II to derive meaningful interpretation through an integrated approach.

vii) Preparation of final report with possible suggestions for the overall improvement of the Naini lake.

DIRECTOR : Dr. S.M SETH

Dr. Bhishm Kumar
Scientist E & Project Coordinator

Dr. C.K Jain
Scientist C & Member

Shri Sanjay Jain
Scientist C & Member

Dr. Rajeev Sinha
Scientist B & Member
(Presently at IIT, Kanpur)

Shri Rm.P Nachiappan
Senior Research Assistant

PROJECT STAFF

Shri Sanjay Bansal
Project Officer
(Presently left the Project)

Shri S P Rai,
Project Officer

Shri Vinod Kumar
Technical Assistant

Shri B.C Dungrakoti
Junior Technical Assistant

Shri Sanjay Bharti
Junior Technical Assistant