CS (AR)-1/1999-2000

WATER QUALITY STUDIES OF LAKE NAINITAL AND SURROUNDINGS

आपो हि ष्ठा मयोभुव

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (INDIA)

PREFACE

The water quality of Lake Nainital is influenced not only by the complex nature of the catchment geology but also by the anthropogenic activities. Several thousands of tourists visit the Lake each year. Apart from the tourism related activities the need for drinking water supply has put the lake to undue stress that is reflected in the deteriorating water quality.

The investigations conducted during the period 1994 to 1996, as part of the comprehensive hydrologocal studies of Lake Nainital included water quality and eutrophication aspects of the lake besides the sedimentation and water balance studies. Apart from the physical parameters like temperature and electrical conductivity, major ions like calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chlorine; and trace elements like strontium, lead, zinc, boron and iron were monitored in the lake as well as surrounding springs and wells regularly. Due to some unavoidable reasons the biological aspects of lake pollution could not be studied and therefore the details of the biological studies conducted earlier by other investigators have been summarised in the report.

In this report the sampling strategy adopted, the analytical techniques followed at the laboratory, accuracy of the results are presented along with a comprehensive discussion on the sources and behaviour of selected elements in the lake. The causes for the hypereutrophic state of the lake, the limiting factor, and probable measures to check the eutrophication process have also been presented.

This report has been prepared by Dr. Bhishm Kumar and Mr. Rm. P. Nachiappan with the assistance of Mr. Vinod Kumar, Mr. B. C. Dungarakoti and Mr. Y. S. Rawat who have worked under the Nainital Lake Project in various capacities. The water samples were analysed at the Nuclear Hydrology and Water Quality Laboratories of NIH, Department of Earth Sciences and USIC, University of Roorkee, Roorkee.

I hope, this report will provide the useful information about the status of water quality of the Nainital and groundwater (including springs) and measures for improving the lake water quality to the interested investigators, authorities associated with lake and water supply management.

S. M. SETH
DIRECTOR

CONTENTS

List of Figures

List of Tables

ABSTRACT

The water quality aspects of Lake Nainital were investigated during the period 1994-1996. The investigations were conducted as part of the project "Hydrological studies of Lake Nainital, Uttar Pradesh" sponsored by Department of Environment, Government of Uttar Pradesh. Although quite a few water quality investigations have already been conducted by other researchers, they were more focused on the biological aspects and did not include hydrological aspects. Further, not all of the earlier studies on Nainital included the quality aspects of the surrounding groundwater. The later information is very much essential to establish the background values that can be ascribed to the geology of the region. Only after establishing the background values, the pollution levels can be assessed.

During the investigations, the major ions namely calcium, magnesium, sodium, potassium, bicarbonate, sulfate and chloride were analysed in addition to the in-situ phyico-chemical parameters such as temperature, pH and electrical conductivity. To assess the pollution levels during different seasons, the dissolved oxygen content of the lake water were monitored regularly at different depths and at different locations of the lake. Trace elements such as iron, manganese, lead, boron, zinc and copper were also analysed.

The results indicate that the lake water is hard in nature, and the hardness exceeds the desirable limit prescribed in the IS:10500 standards of BIS. However, all the springs and groundwater drawn through wells located within the lake basin are also hard and therefore the hardness is due to the local geology, that is characterised mainly by calcareous rocks, such as calcareous slates, limestones and dolomites. Lead content in lake as well as surrounding springs also exceed the IS:10500 standards. The source of the lead could also be ascribed to the local geology. This report presents complete details of the investigations carried out, the sampling strategy adopted and the analytical procedures followed including the accuracy of measurements / analyses. The report also discusses the possible sources of different ions in aquatic environment, the temporal variation in the concentrations of different ions in the lake water, surrounding springs as well as inflow nalahs. The eutrophication level of the lake has reached an advanced stage and the lake has been classified as hypereutrophic. The Nainital is the most eutrophic among all the lakes of the Kumaun region. The limiting factor in the eutrophication of the Lake Nainital is phosphorous. The external load of soluble reactive phosphorous can be reduced substantially if the inflow through the nalahs are diverted during non-monsoon season. In this report possible methods that can be adopted for amelioration of lake water quality have also been suggested.

1.0 INTRODUCTION

The water quality of a lake depends upon various parameters which are influenced by a wide range of natural and man made operations. A lake may be characterized by morphometric, hydrological, chemical, biological and sedimentological parameters depending on its age, history, climate and water budget. Each lake develops its own response to these combined factors causing major variations of water quality in both time and space. The physico-chemical characteristics of a lake provide a first hand information about the state of the quality of the lake water. These characteristics include the measurement of pH, conductance, temperature, dissolved oxygen, dissolved inorganic carbon, turbidity, transparency, alkalinity, hardness, chloride, sulphate and nitrogen etc. The present report deals with the study of water quality aspects of Nainital including its characterisation and comparison with other lakes in Kumaun region.

The behaviour of Lake Nainital is subjected to a wide range of influences operating over three dimensions like in other lakes. The water quality of the Nainital lake is mostly governed by the sub-surface inflow and flow that takes place through major drains including sediments. However, the continuous supply of various major and minor trace elements have created the deposits of these elements at the bottom which circulates every year during winter mixing. The circulation of these elements make the concentration of few elements beyond the permissible limits. Further, the Nainital 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 and chemical processes, thereby, developing anaerobic 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 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 Nainital 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 the lake for better management of lake recharge zones and to restore the health of the Lake Nainital.

The investigations conducted during the period 1994 to 1996 included water quality and eutrophication aspects of the lake besides the sedimentation and water balance studies. In this report the sampling strategy adopted, the analytical techniques followed at the laboratory, accuracy of the results are presented along with a comprehensive discussion on the sources and behaviour of selected elements in the lake. The causes for the hypereutrophic state of the lake, the limiting factor, and probable measures to check the eutrophication process have also been presented.

1.1 Study Area

Lake Nainital is one among a group of lakes occurring in the southern fringe of the Kumaun Lesser Himalaya (Fig. 1). The maximum length of the lake is 1.4 km, maximum width 0.45 km, maximum depth 27.32 m and mean depth 18.5 m. The surface area of lake is 0.46 Km^2. It is subdivided into two sub-basins by 100 m wide transverse underwater ridge, 7 m to 20 m below the lake surface while volume of the lake is 8.3 Mm^3. The average annual rainfall in the basin is 203 mm. The catchment area of the lake is 4.9 km^2. The landuse pattern is 48.4% forest, 18.3% barren, 19.3% built land and 10.4% water bodies.

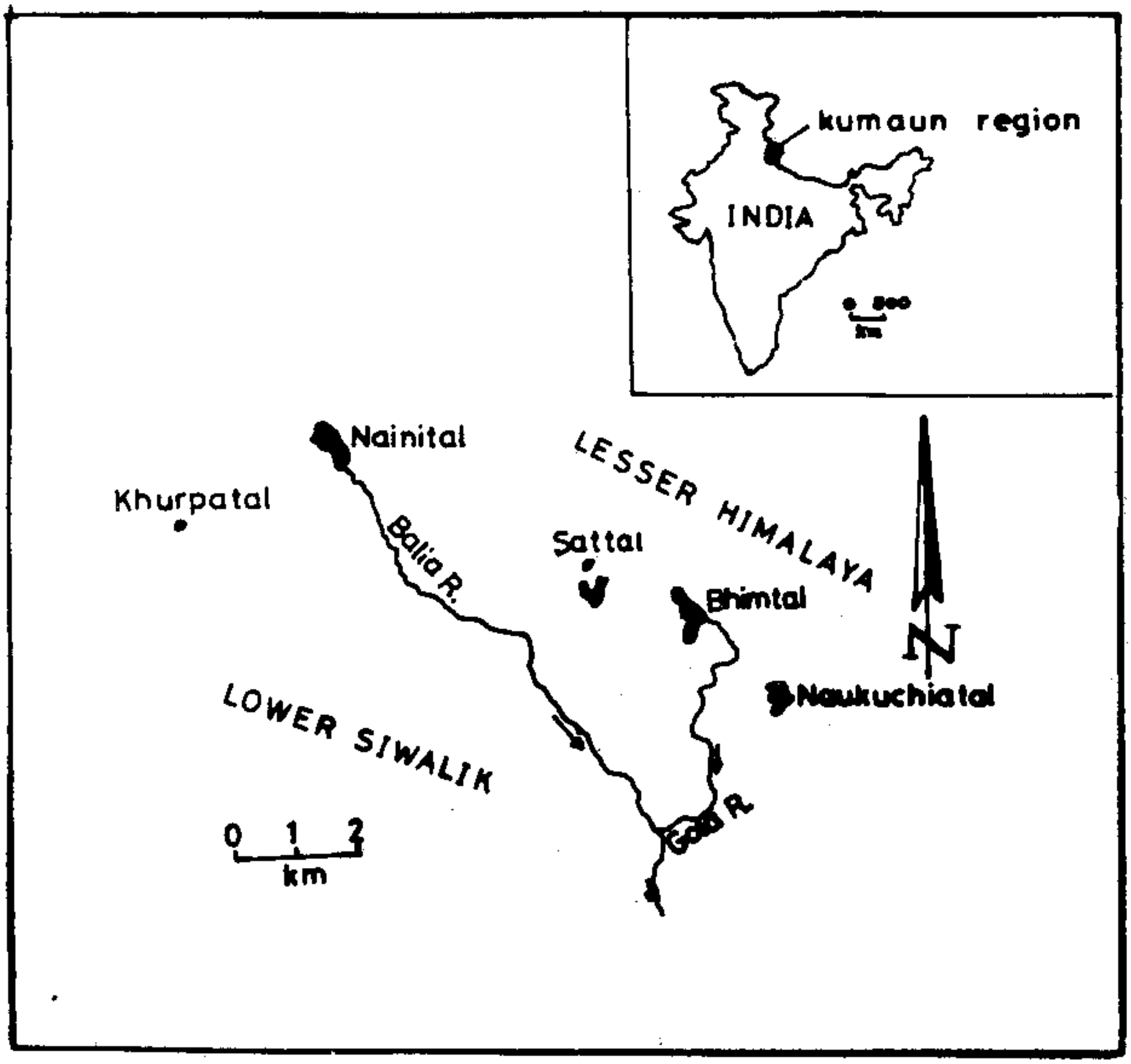


Fig. 1 Location map of Lake Nainital and other lakes of Kumaun Lesser Himalayas

2.0 EARLIER STUDIES

2.1 Biological Characteristics

Biological analysis in Lake Nainital, have been carried out by various workers from time to time. In these studies, noticeable amount of phytoplankton, zooplankton, macrobenthos, fungi, actinomycetes, nematodes, insects, bacteria and photozoons have been isolated during different seasons. The colour of lake vary from light green to dark blue depending upon the population of phytoplankton and zooplankton. Algal blooming has become very common in Nainital lake which clearly indicates its eutrophication level.

Pant et al. (1981) observed various species of phytoplankton among these microcystis species and others, which undergo blooming during summer and autumn months. The occurrence of oedogonium species and anabacna spiroides towards the upper end (north-west) of the lake as well as near the mouths of the two perennial open drains, suggested the existence of concentrated zone of pollution in the lake. The higher population density of plankton was encountered during the late spring and early autumn months.

Certain zooplanktons, such as bodo species, bursaria species, oxytricha species, spirostomum species, epistylis species, brachionus species and keratella species have been observed in appreciable numbers near and around the inlets of nalahs into the lake. The benthonic fauna was mainly constituted by low-oxygen tolerant and pollution-tolerant organism such as chironomus plumosus, tubifex tubifex, glossiphonia and weberi etc. They also observed population of 6105 indiv/m^3 of tubificid worms in certain months which could be taken as evidence of pollution.

· The marked pollution of Nainital lake (Pant, et al., 1980) was also reflected by the absence of macrobenthic organisms below a depth of 7m. It could be attributed to the completely anoxic conditions in the bottom water overlying the sediments for greater part of the year, to accumulation of organic matters at the bottom with sediments are responsible for the production of toxic substances like (NH_3, CH_4, and H_2S) in the lake.

Sharma et al. (1982) observed the growth of phytoplankton often forming visual algal blooms except during the winter. The algal density becomes higher during March and August. The phytoplankton community was mainly constituted by green algae, with relatively lower proportions of diatoms and blue green algae. Thus the phytoplankton community in Nainital is truly characterized by blooms of blue green algae.

Purohit and Singh (1985) observed submerged macrophytes upto 6 m water depth in Nainital lake. Potamogeton pectinatus reached the maximum depth in Nainital lake and show high rate of production from April to May . Other species like hydrilla verticillata during rainy season and P. crispus during February-March (Late winter) have been observed in the lake. Besides species of many higher flung including Epicoccum, Cheetomium, Fusarium, Humicola, Lemonmiera, Lunulospora, Tetracladium, Triscelophorus and Tubercularia have been isolated from various decomposing domestic wastes present in drains and lake water (Khulbe et al., Khulbe and Bhargava, 1981; Khulbe, 1980). They have also isolated different kinds of bacteria from the lake water. Depending upon the colour, colonies pattern and shape of the bacteria, the sample showed 10 types of bacteria. Their number varied from 45 to 240/ml of lake water. They have also noticed that tap water which supplied after filtration and chlorination by Water Works Department also show a considerable number of bacteria Escherichia coli and Salmonella sp. that have been identified from the water samples which clearly indicate faecal (sewer) pollution.

2.2 Physico-chemical characteristics

Gupta and Pant (1983) carried out experiments for a period of 12 months from October 1977 to September 1978. They studied the variations of the contents of lake organic matters, phosphorous, nitrate- nitrogen (NO_3-N), cations (Ca, Na & K), trace metals (Mn, Cu, Zn & Co), pH and redox potential (Eh) including sediments in the water samples collected from different depths of Nainital lake including mud-water interface. Their findings are: 1)With depth, clay, organic metals, cations redox potential go on increasing rapidly upto 9 m depth and almost negligible after 9 m depth, 2) Dissolved O_2 decreases while phosphate and NO_3-N increase with depth and much in hypolimnetic sample of overlying water and 3) Trace metals decrease with depth.

The sources of organic matter in the lake are (a) disposal of domestic wastes (including sewage) through open drains, (b) biologically derived organic matter (dead plankton, microphytes or dead fishes etc.) settling at bottom (c) randomly deposited faecal matters, broken tree leaves etc. falling into lake through surface runoff during rains by wind.

Pant et al. (1985), carried out some important investigations related with Physico-chemical limnology of Nainital. They found that transparency is poor in the lake with lowest in March and highest in June. Poor transparency is because of suspended regime matter (Mccombic) biological productivity in the form of algal blooming and in the form of plankton and in winter because of lake mixing. Also because of silting and low sunshine in rainy seasons. More recently Gupta and Shukla (1997) have tried to relate the changes in physico-chemical and biological properties of Lake Nainital to human interference. But none of the above studies have taken into account the role of hydrology in the lake's present water quality status.

3.0 SAMPLING STRATEGY AND PROCEDURES

The water quality aspects of the Lake Nainital was monitored between February 1994 and July, 1996. Sampling was carried out during February, May, October and December, 1994; February, March, May, June August, September, November and December, 1995; January, April and July, 1996. The number of samples collected from the lake varied from a minimum of 6 (June, 1995) and a maximum of 37 (March, 1995). However, keeping in view the need for control points, the centre points of North and South basins (C2 and H2) were sampled regularly during all the sampling periods. Sampling at any point in the lake was carried out, generally, at three different depths viz., the surface, middle and bottom of the lake. During some sampling periods, sampling was carried out at every three meter depth interval, starting from surface to the bottom.

Apart from the analyses of lake waters as noted above other water sources in the surrounding region were also studied, since the lake has to be studied as part of the total ecosystem of the catchment rather than as an isolated water body. The samples of upstream springs considered to be representative of the local groundwater were also collected and analysed for establishing background water quality. To study the human impact on the lake environment it is imperative to have the knowledge of the quality of water that flows into the lake through the nalahs. Keeping this in view, apart from the lake, Springs located in the upstream side of lake and within the catchment, springs located on the downstream side of lake and outside the catchment, nalahs draining into the lake and the tube wells and open well located around the lake were also sampled. The water quality information on downstream springs issuing outside the catchment will give information on the possible links with the lake. The details of samples collected during the study period is given below:

Month	Lake	Nalahs	U/s Springs	D/s Springs	Wells	Total
Feb.,94	4	1	1	-	-	6
May, 94	9	1	1	-	-	11
Oct.,94	28	11	-	1	2	42
Dec.,94	11	1	1	6	1	20
Feb.,95	26	1	-	4	3	34
Mar.,95	37	2	7	4	1	51
May, 95	18	2	6	7	4	37
Jun.,95	6	-	-	7	-	13
Aug.,95	20	7	3	4	3	37
Sep.,95	20	6	4	5	5	40
Nov.,95	20	2	3	4	4	33
Dec.,95	19	-	2	2	2	25
Jan.,96	20	2	3	4	4	33
Apr.,96	27	2	3	4	5	41
Jul.,96	8	1	3	2	1	15
Total	**273**	**39**	**37**	**54**	**35**	**438**

In the year 1994, sampling was carried out during 4 months, which was considered to be representative of the four different seasons. However, realising the dynamics and the possible short hydraulic residence time of the lake water, the sampling was carried out during 8 months (as shown in the table) in the year 1995. In the last year of the investigations i.e. 1996, sampling was carried out in January, April and July with a view to complement the available information on the lake's quality.

The samples from the lake were collected using a depth sampler (Hydrobios make) of 2 L capacity with a built in thermometer of 0.2°C least count. The electrical conductivity (E.C.) and pH were measured in-situ using a 5-parameter field water testing kit. In the early stages the dissolved oxygen was also measured in the field. But later comparison with laboratory data showed the non-reliability of the field DO values. Hence, the in-situ measurements were restricted only to temperature, pH and E.C.

As stated above samples were collected from fixed points (Fig. 2). To understand the hydrodynamics of the lake and also the spatial variation of the water characteristics within the lake, samples were collected at every three meter depth, starting from the surface upto the bottom. The collected samples were mainly utilised for three different aspects, viz. a) In-situ measurement of phsico-chemical characteristics, b) Isotope composition and c) water quality aspects. While insitu measurements and samples for isotope characteristics were made every three meters, samples for water quality of aspects were made only at three or four different depths viz. Epilimnion (0 m), Mesolimnion (6 - 9 m, depending on the season) and hypolimnion (1 to 4 m above the bottom, depending on the season).

The samples collected for the water quality aspects were first filtered using an 0.45 μm Whatman filter and preserved. Three different bottles were filled. The first one (1 L) was unpreserved for alkalinity, chloride and Orthophosphate - phosphorus determination. The second one (1 L) was preserved with Concentrated sulphuric acid for total hardness, and calcium hardness determinations. The third one (60 mL) was preserved with concentrated nitric acid for trace elements, Na, K and sulphate determinations. The samples were then transported to the National Institute of Hydrology laboratory at Roorkee, and were immediately analysed

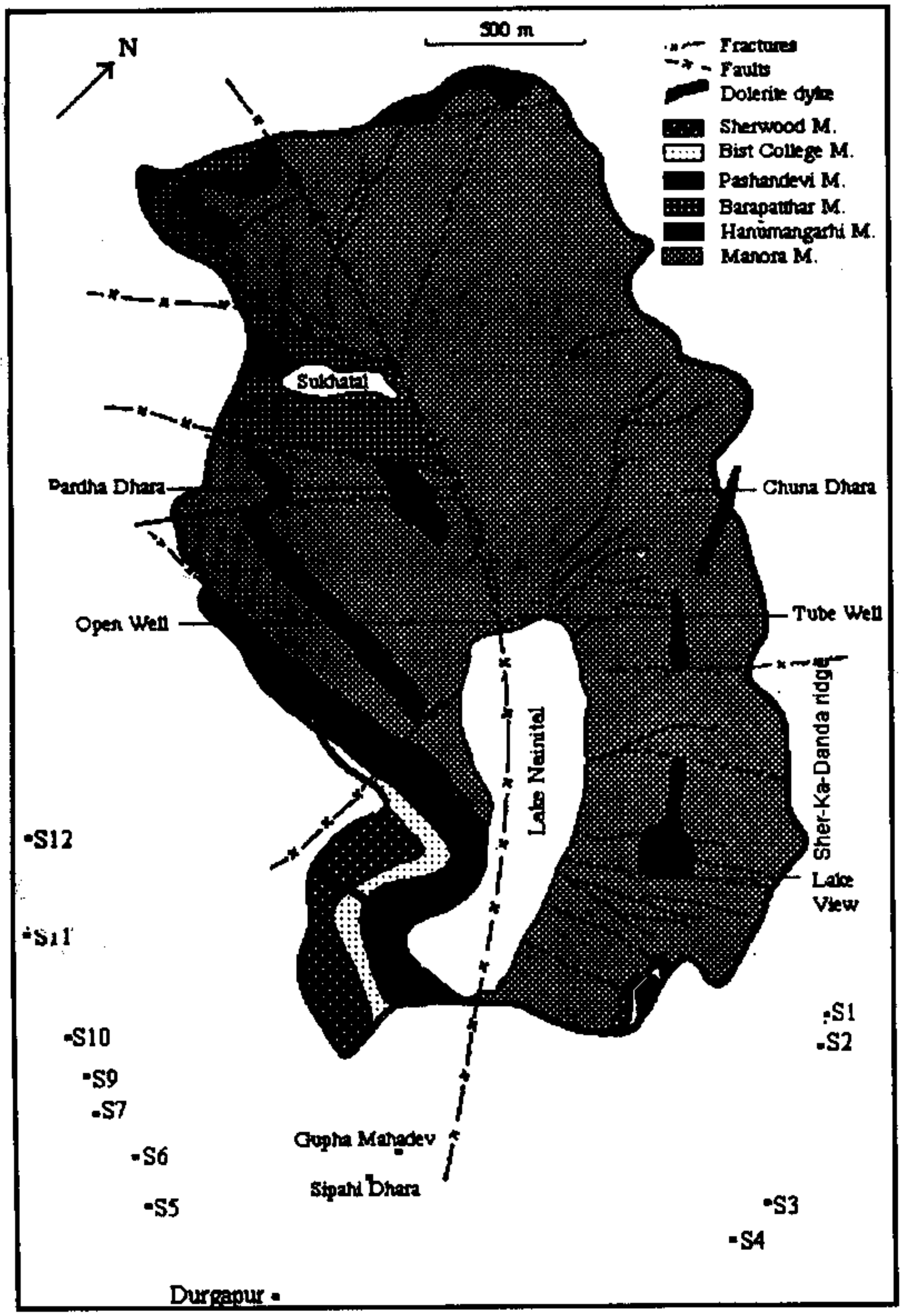


Fig. 2. Map of Lake Nainital catchment showing sampling locations

giving priority to those parameters that are to be determined using the unpreserved samples. Other parameters were analysed within a weeks time.

Apart from the above three bottles, one sample was collected from each sampling point for dissolved oxygen determination. The DO bottle of 300 mL capacity was filled upto the brim and preservatives were added according to winkler's method.

3.1 Laboratory Procedures

The samples for stable isotope analyses were collected at every three meters depth in 20 mL plastic vials and tightly sealed with tapes and were transported to Bhabha Atomic Research Centre (BARC), Mumbai. Samples were also collected for environmental tritium analyses and sent to BARC, during the month of December, 1994. The physico-chemical parameters that were analysed in the water samples include:

Field parameters	-	Temp., pH and E.C.
Major ions	-	Ca, Mg, Na, K, HCO_3, SO_4 and Cl
Trace elements	-	Sr, B, Pb, Mn, Zn and Fe
Nutrients	-	PO_4-P and NO_3-N
Others	-	DO, BOD, COD and Suspended solids
Stable isotopes	-	Oxygen-18 and Deuterium
Radio-isotopes	-	Environmental tritium

The methods followed at the NIH water quality laboratory for analyses of different parameters discussed above are as follows:

Chloride was estimated by argentometric method in the form of silver chloride. Alkalinity was determined by titrimetric method using phenolphthalein and methyl orange indicators. Total hardness and calcium hardness were 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 multiplying magnesium hardness with 0.243. Sodium and potassium were determined by flame-emission method using flame photometer.

Nitrogen in the form of nitrate was determined by using spectrometric methods. Phosphate was 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 were determined by atomic absorption or atomic emission methods.

4.0 ANALYSES OF DATA AND ACCURACY

It is established that the sampling techniques, preservation methods and length of storage time before analysis have certain effect on the accuracy of the results. Under optimum conditions the results for major constituents of the water have an accuracy of ± 2% to ±10 %. Solutes present in concentrations above 100 mg/L generally can be determined with an accuracy of better than ± 5%. For solutes present in concentration below 1 mg/L, the accuracy is not better than ± 10% and can be poorer.

One way of determining the accuracy of major dissolved constituent values in a reasonably complete chemical analysis of a water sample can be accomplished by checking anion - cation balance. Though this concept is chemically sound, in some waters it may be difficult to ascertain the forms of some of the ions reported in the analysis. Solutions that are strongly coloured, for example, commonly have organic anions that form complexes with metals and the usual analytical procedures will not give results that can be balanced satisfactorily.

Another procedure for checking the accuracy is possible using specific conductivity and dissolved solids determinations. The total of milliequivalents per litre of either anions or cations multiplied by 100 usually agrees approximately with the electrical conductivity in μmhos/cm.

A simple screening procedure for evaluating analyses for the same or similar source is to compare the results with one another. Groups of analyses from the same or similar sources in which all magnesium concentrations are similar but the calcium concentrations have a rather wide range may indicate the calcium and bicarbonate were lost by precipitation of calcite. This can occur during storage and also in the water circulation system before sampling.

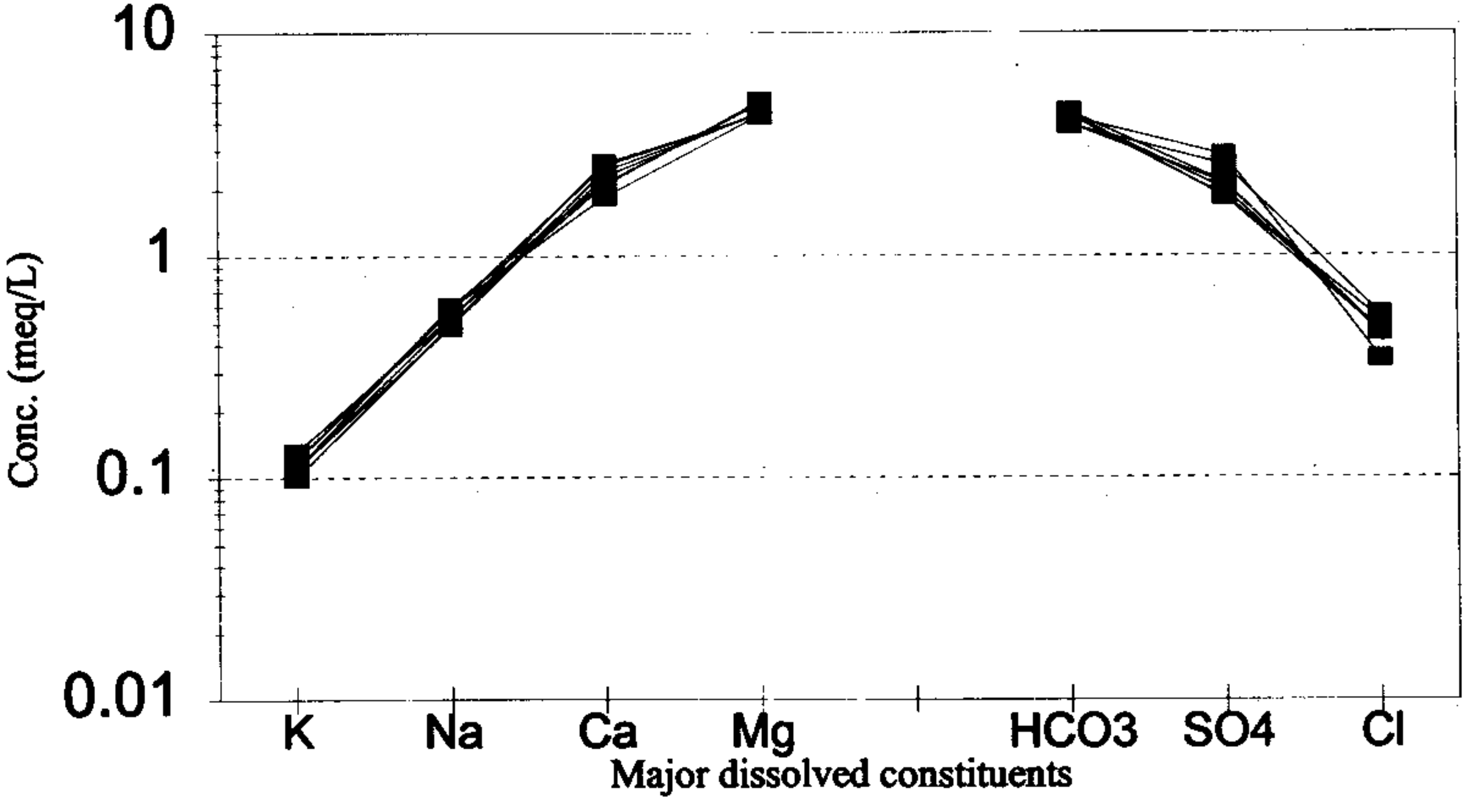
Considering the results of the repeat analysis and duplicate analysis of samples and electro-neutrality for estimating analytical accuracy, it is found that the overall accuracy of the analyses is within ± 5% error limit.

5.0 RESULTS

The results have been organised and presented in two different formats. The first set (Table 1 to Table 14b) gives sampling campaign wise results of the all the samples from different sources. The second set (Table 15 to Table 26) gives the results of samples collected from selected sources viz., the north and south basins of the lake (includes epilimnion and hypolimnion), Naina devi mandir drain, well located on the north bank of the lake, upstream springs (issuing from dolomite rock - Pardha dhara, from shales - alma spring, Chuna dhara or doctor house spring, and lake view spring), downstream springs (Gupha mahadev mandir spring or Sipahi dhara, and springs that issue outside the catchment). The second set of results are presented in a more comprehensive manner so that temporal variations can be assessed easily.

The results show that all the water sources in the study area are closely related and that they reflect the local geology. Since the study area is very small (less than 5 km^2) no significant variations in the water chemistry can be expected. This is reflected in the fingerprint plots for the lake (Fig. 3a to Fig 3h) that all the samples behave in a similar fashion (with a little deviations due to the analytical errors). However, the springs that issue in the Kailakhan side, in Ratighat and Krishnapur show a slightly different characteristic than other springs (Fig. 4a to Fig. 4h), in that they have sulfate as the major anionic constituent rather than bicarbonate, which is the case with all other sources that were studied in the area.

Fig. 3a. Lake Nainital - Fingerprint plot (Mar., 95)



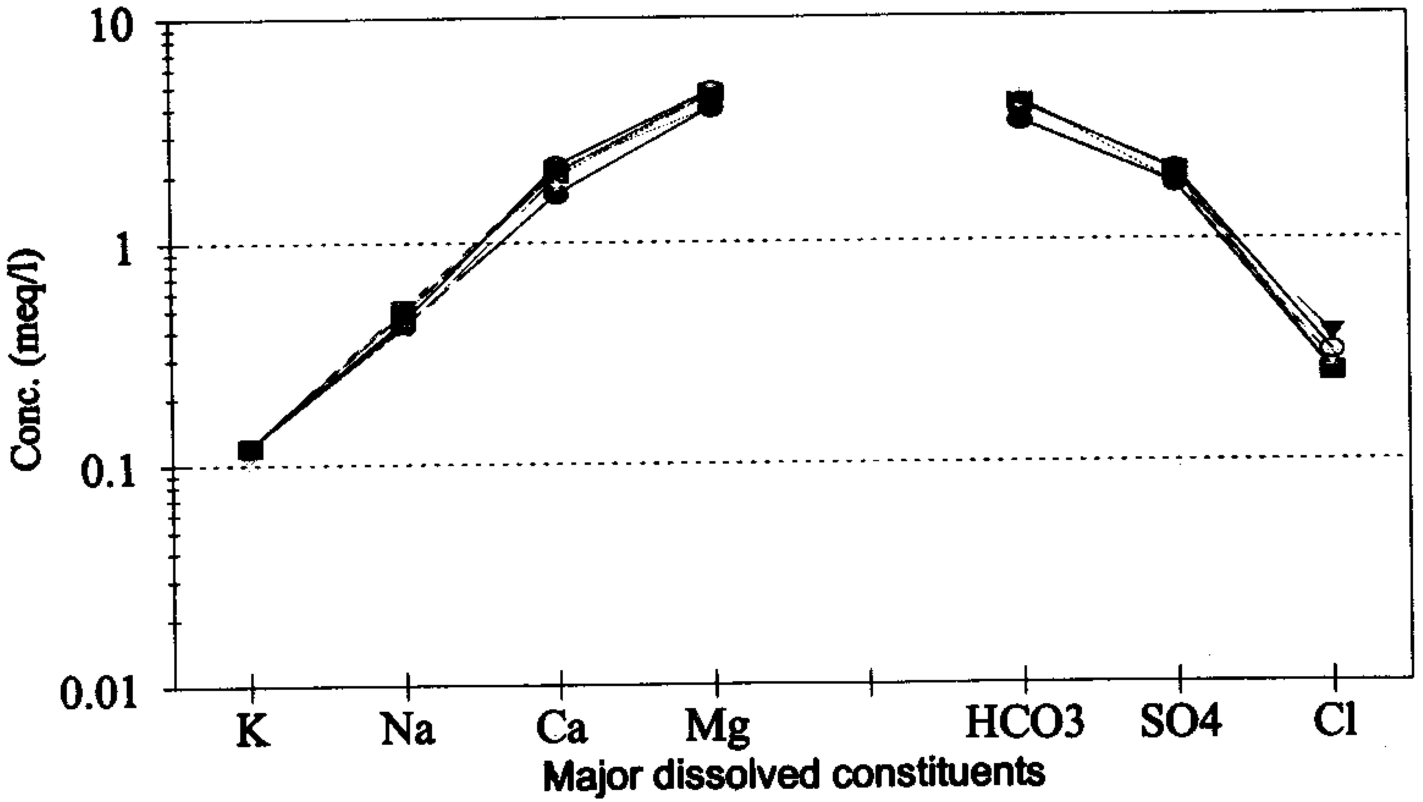


Fig. 3b. Lake Nainital - Fingerprint plot (May, 95)

Fig. 3c. Lake Nainital - Fingerprint plot (Jun., 95)

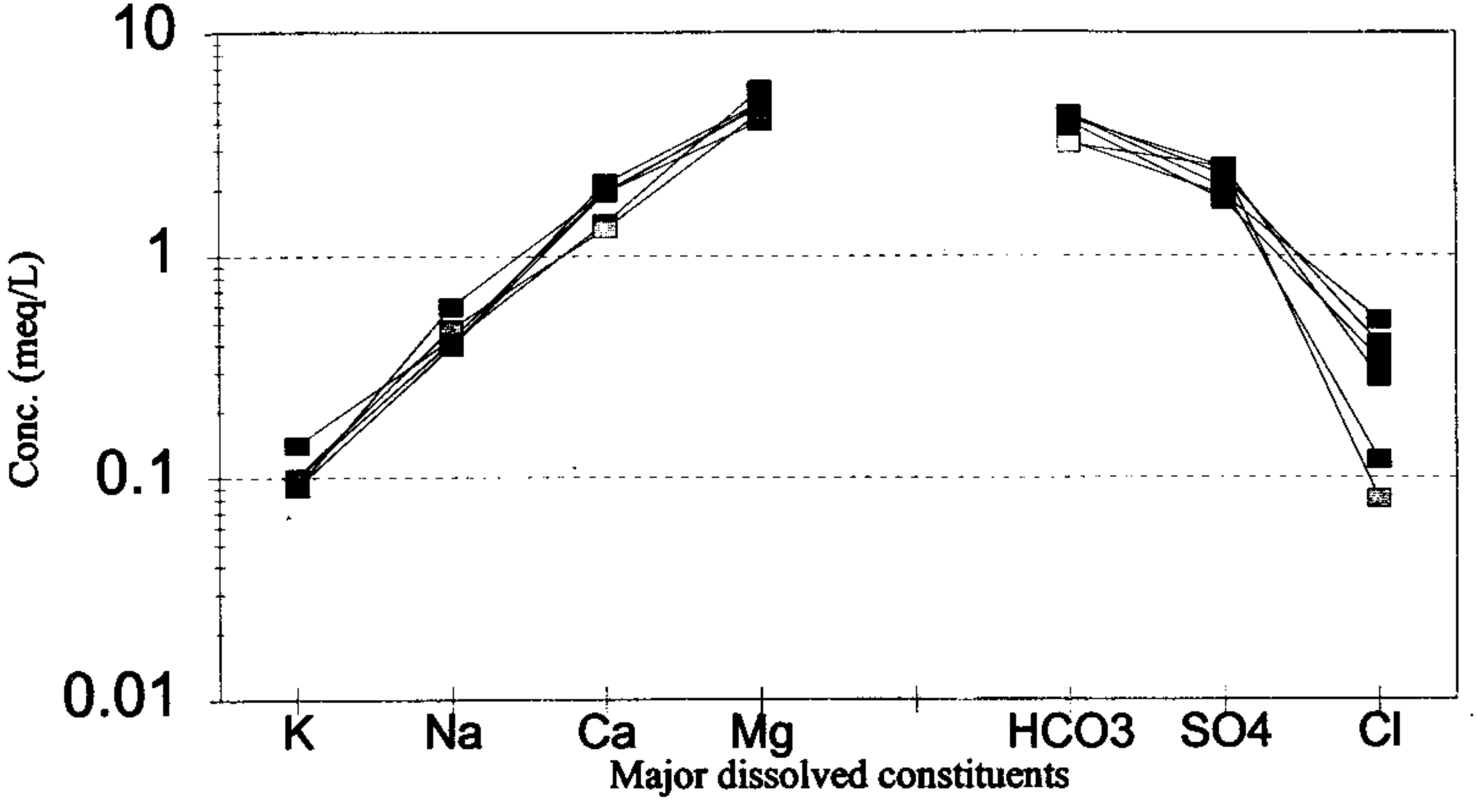


Fig. 3d. Lake Nainital - Fingerprint plot (Aug., 95)

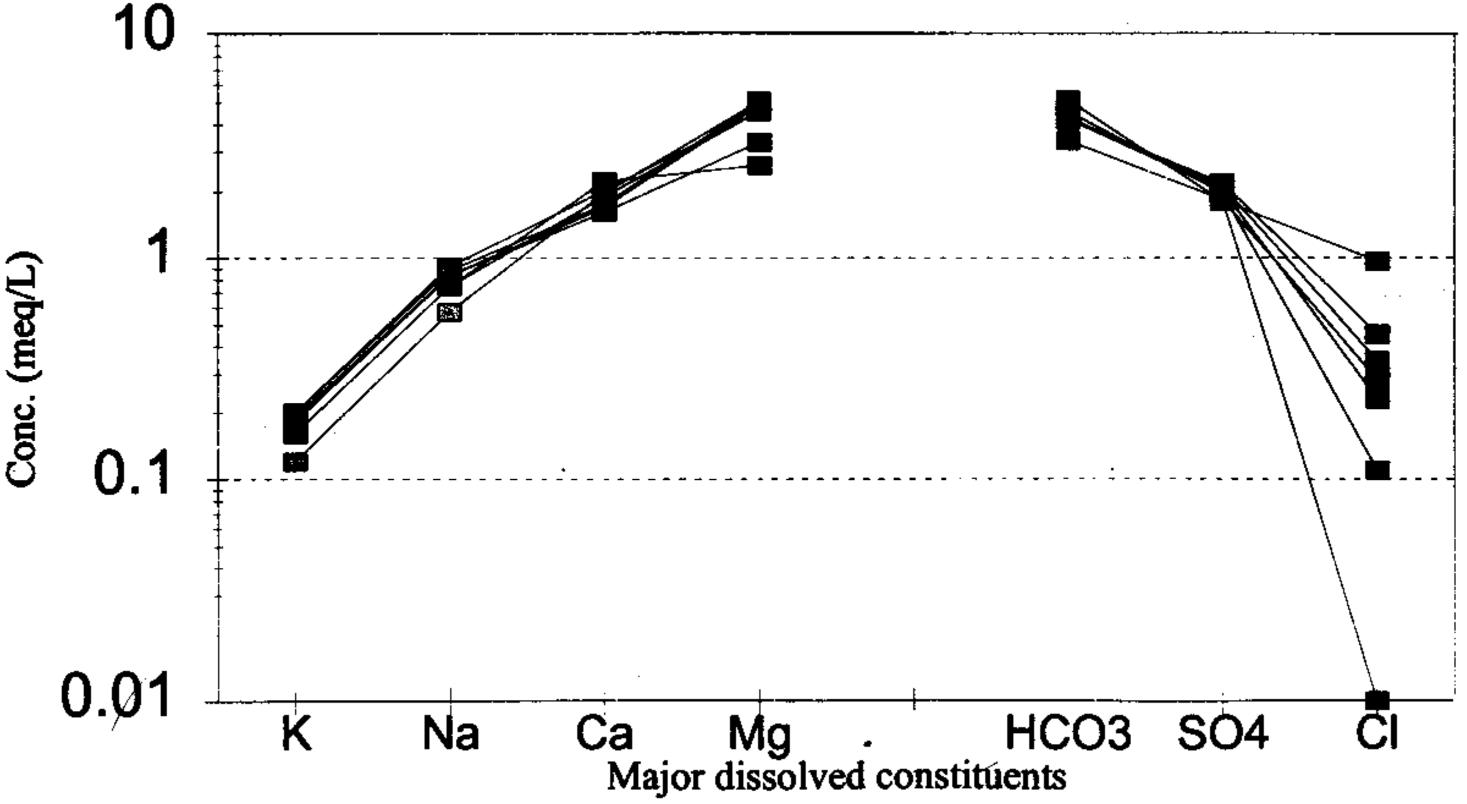


Fig. 3e. Lake Nainital - Fingerprint plot (Sep., 95)

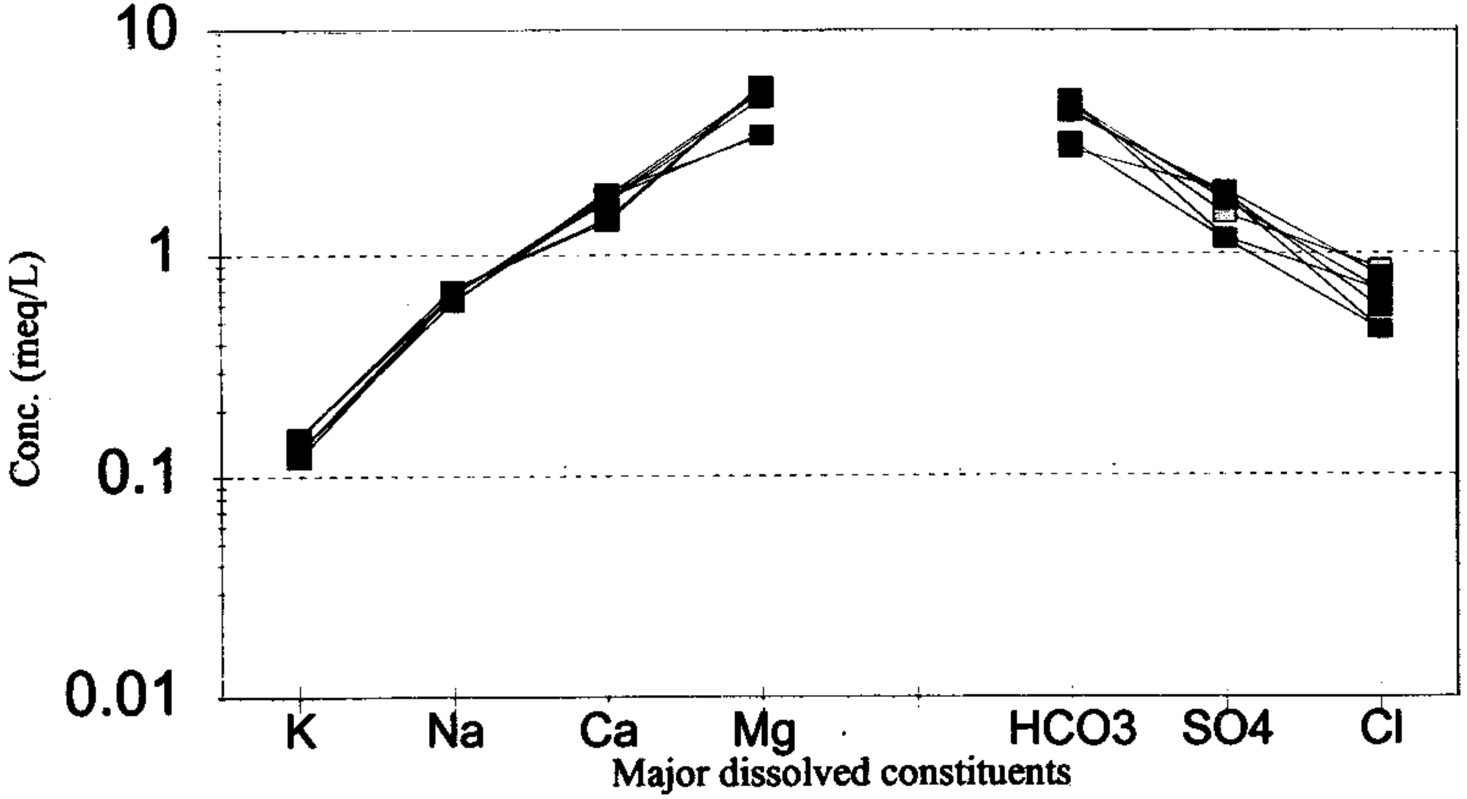


Fig. 3f. Lake Nainital - Fingerprint plot (Nov., 95)

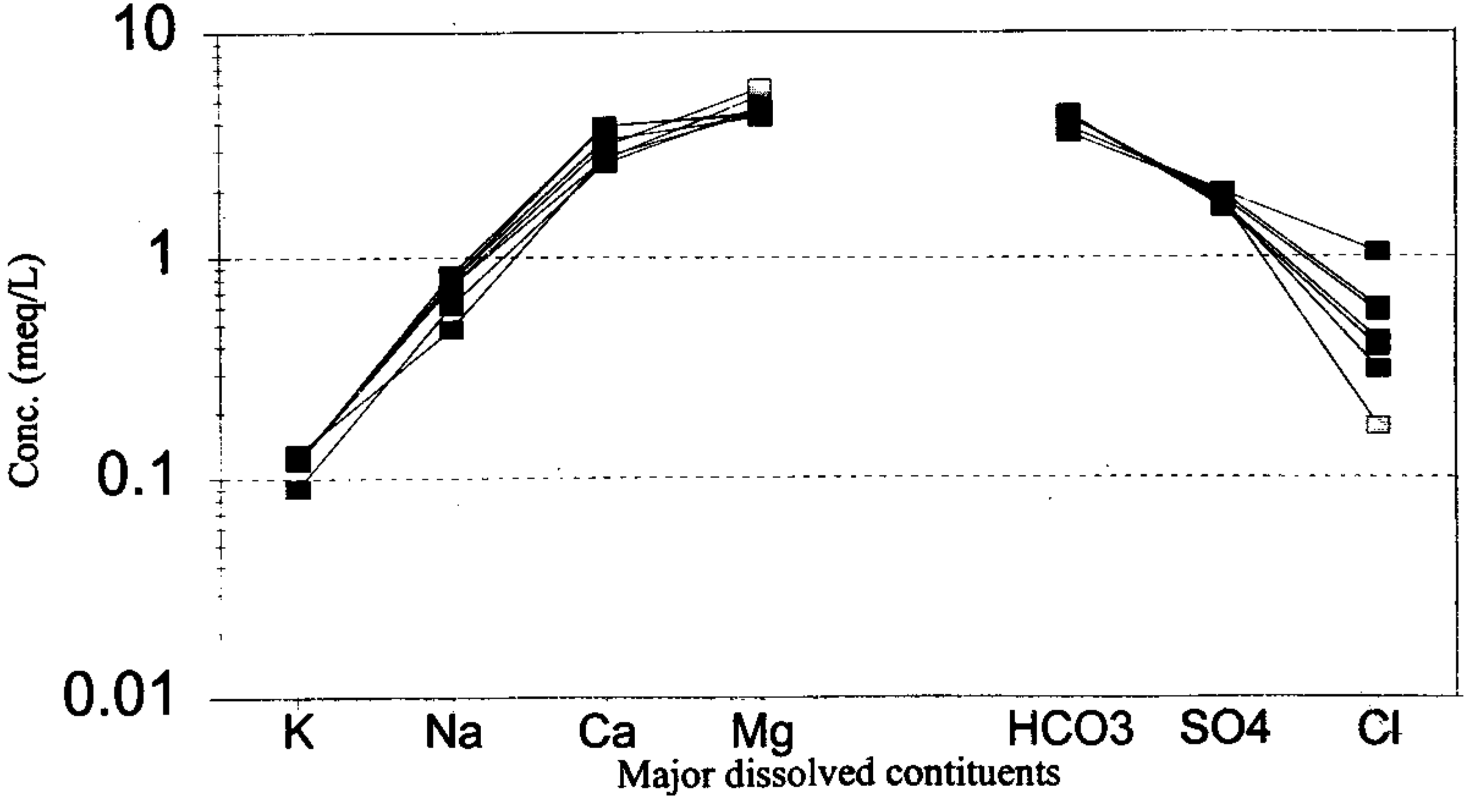


Fig. 3g. Lake Nainital - Fingerprint plot (Dec., 95)

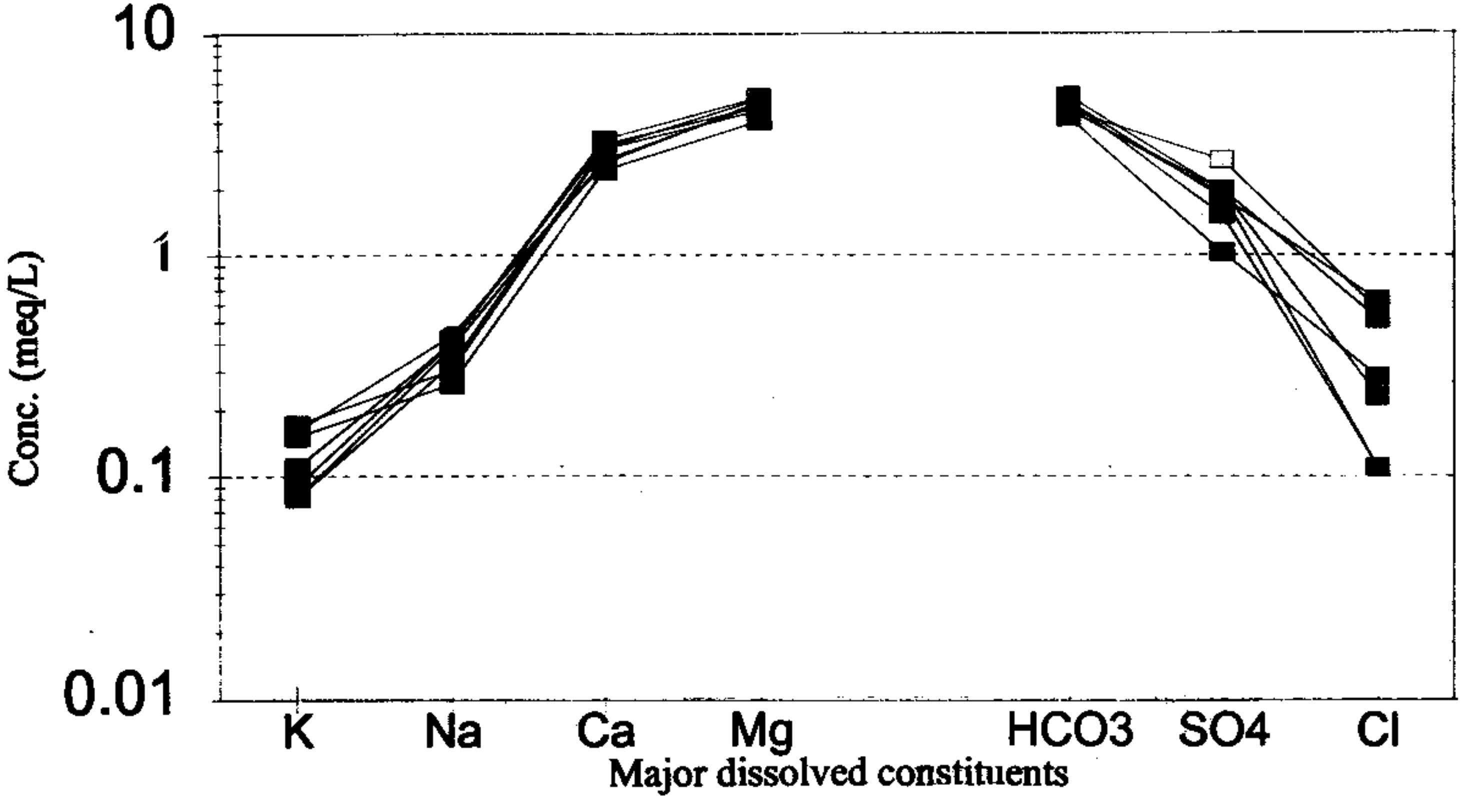


Fig. 3h. Lake Nainital - Fingerprint plot (Jan., 96)

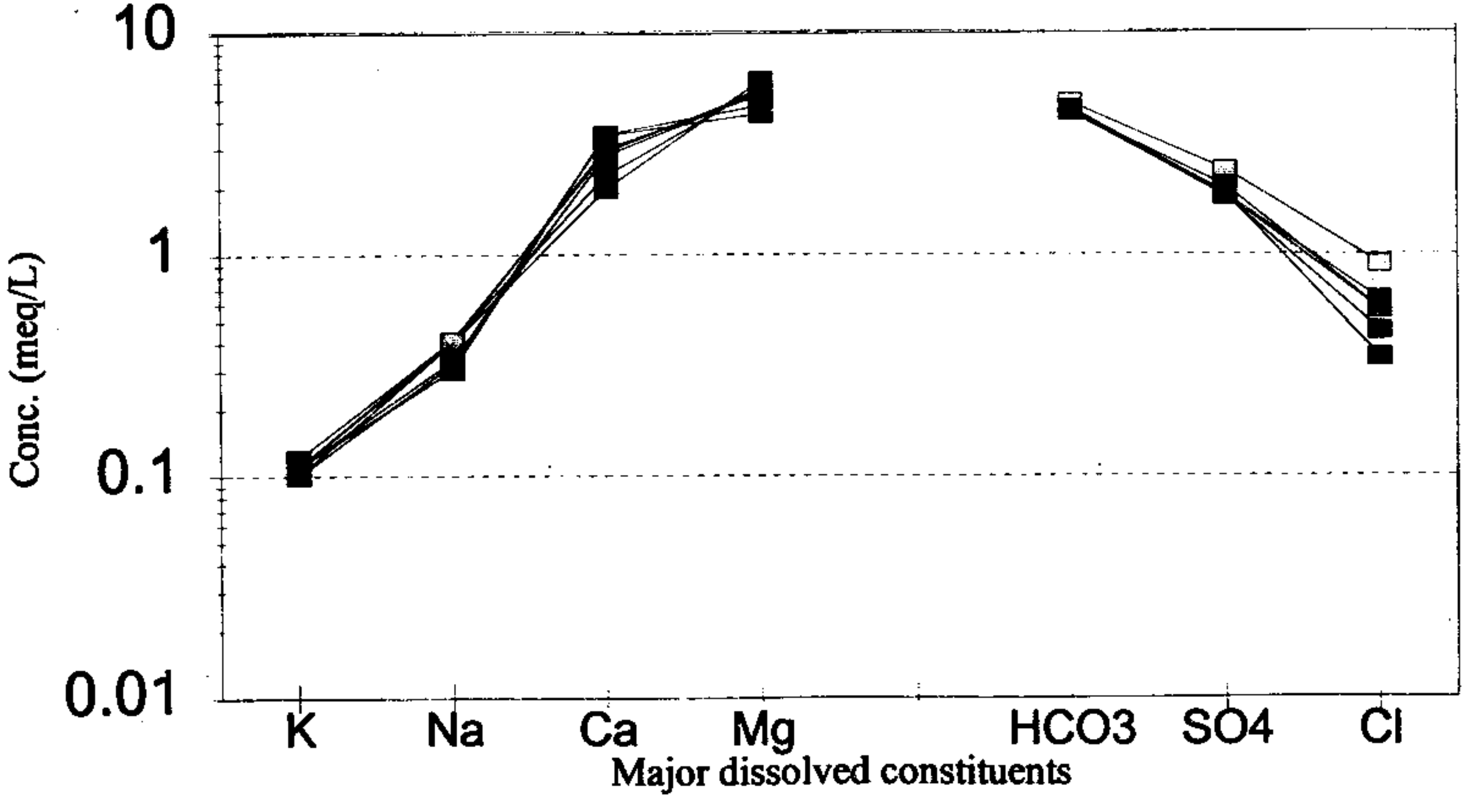


Fig. 4a. Springs - Fingerprint plot (Mar, 95)

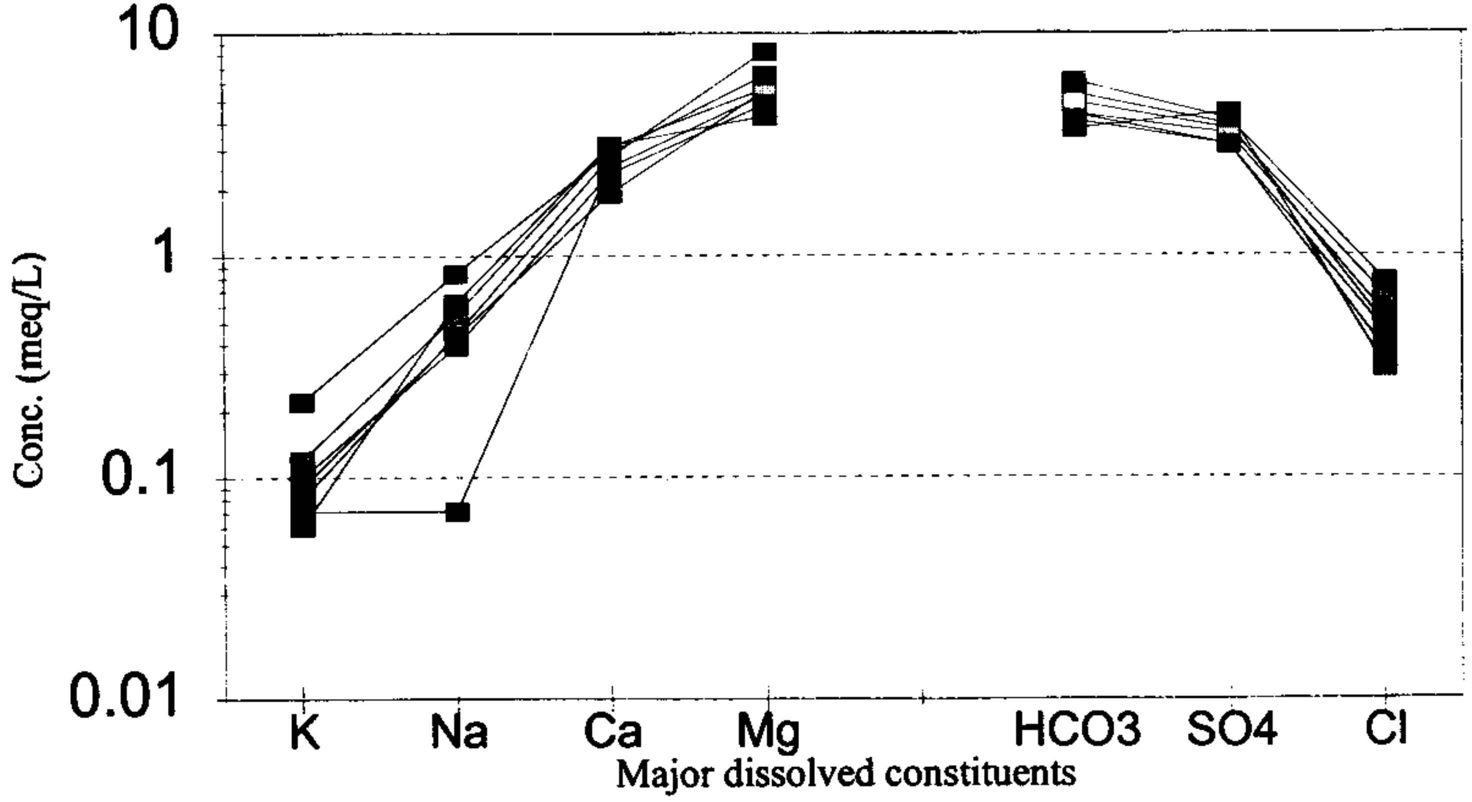


Figure 4b. Springs - Fingerprint plot (May, 95)

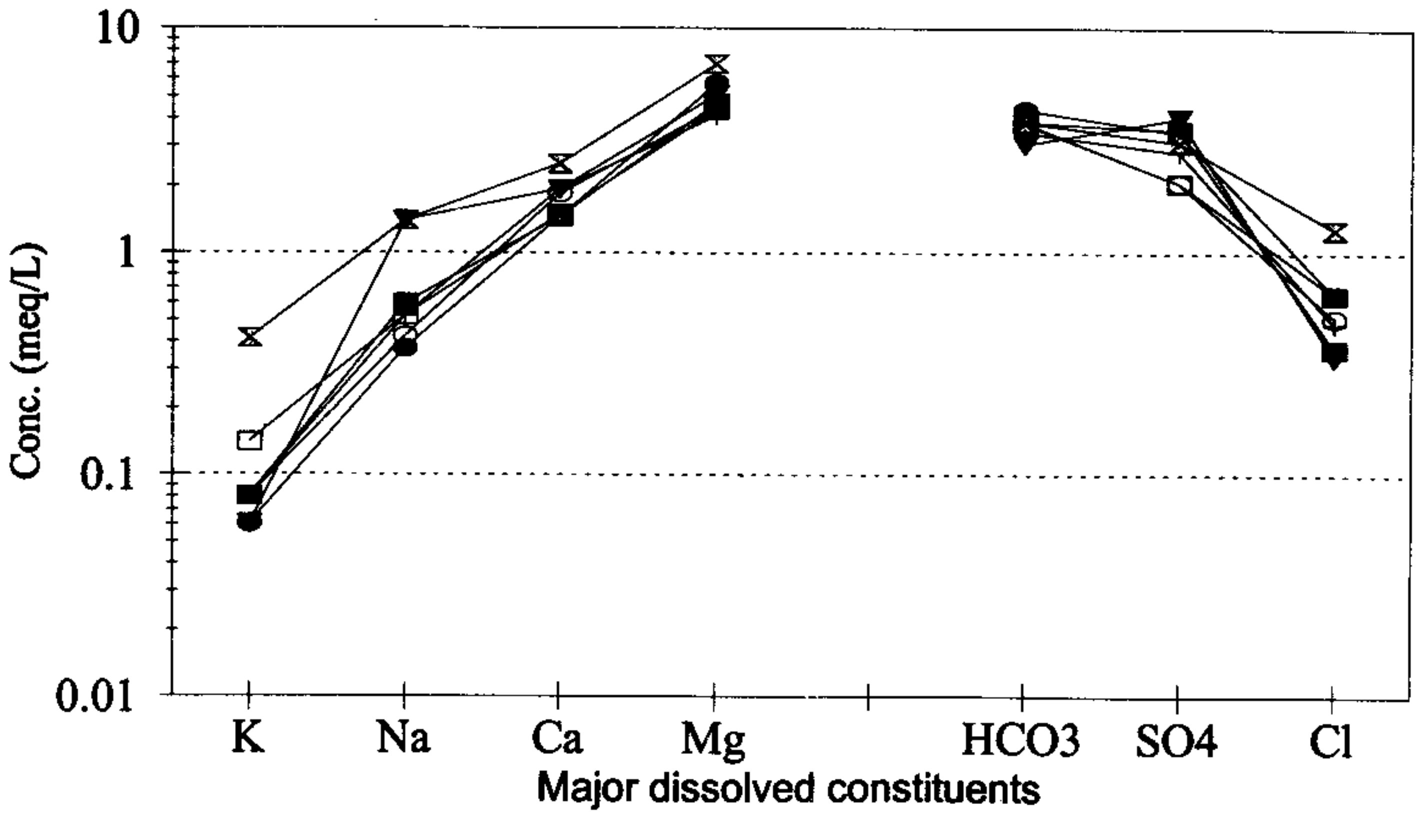


Fig. 4c. Springs - Fingerprint plot (Jun, 95)

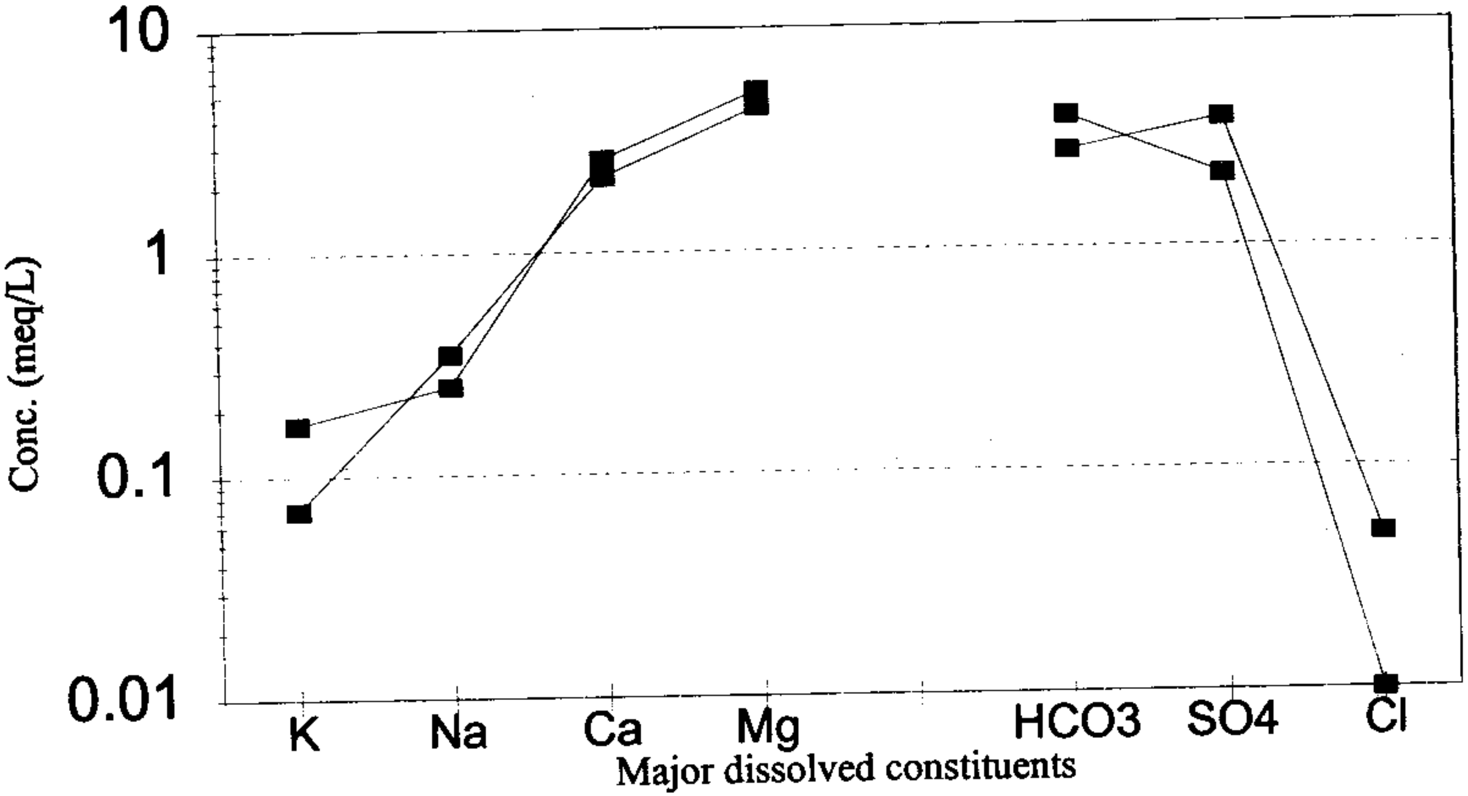
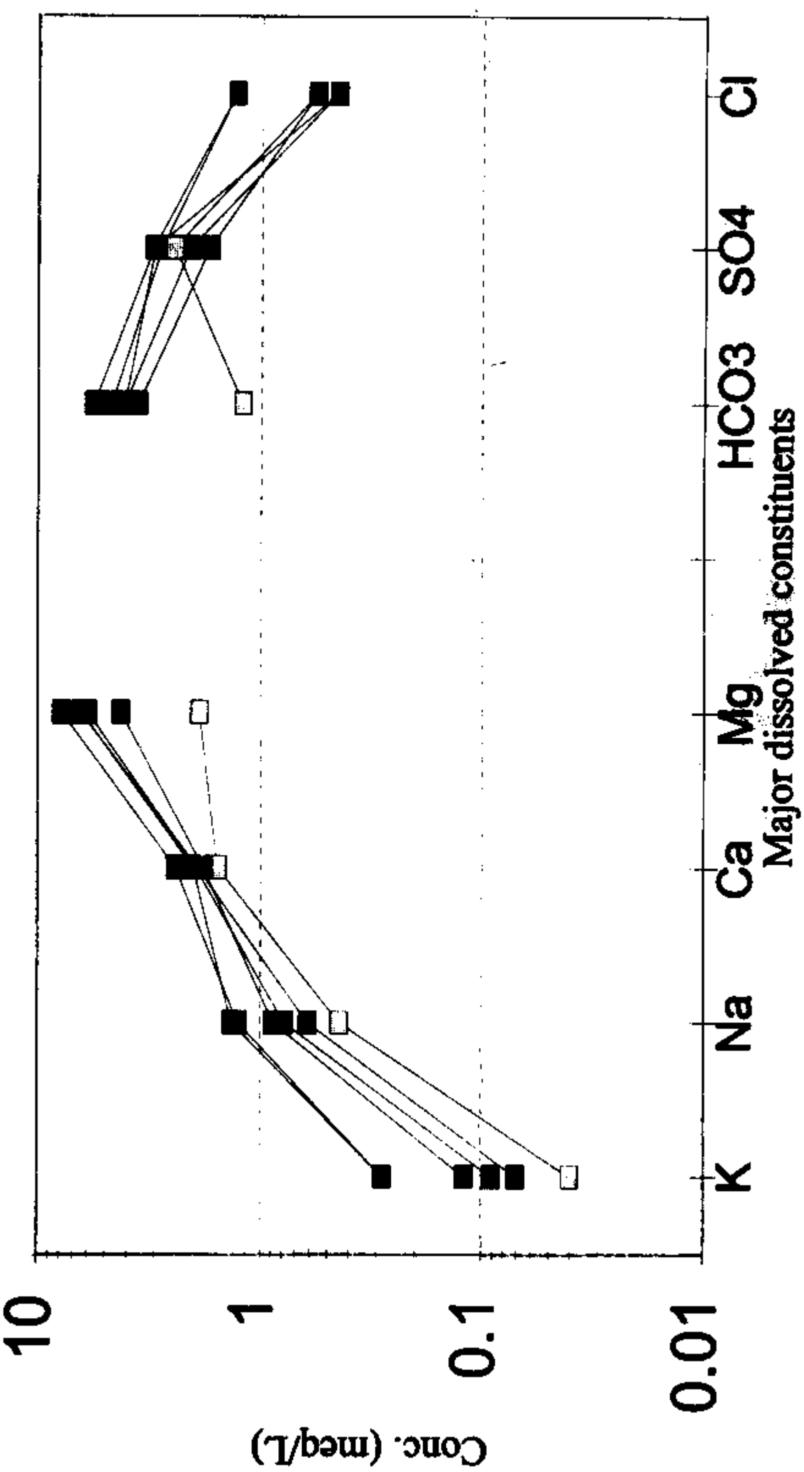


Fig. 4d. Springs - Fingerprint plot (Aug., 95)



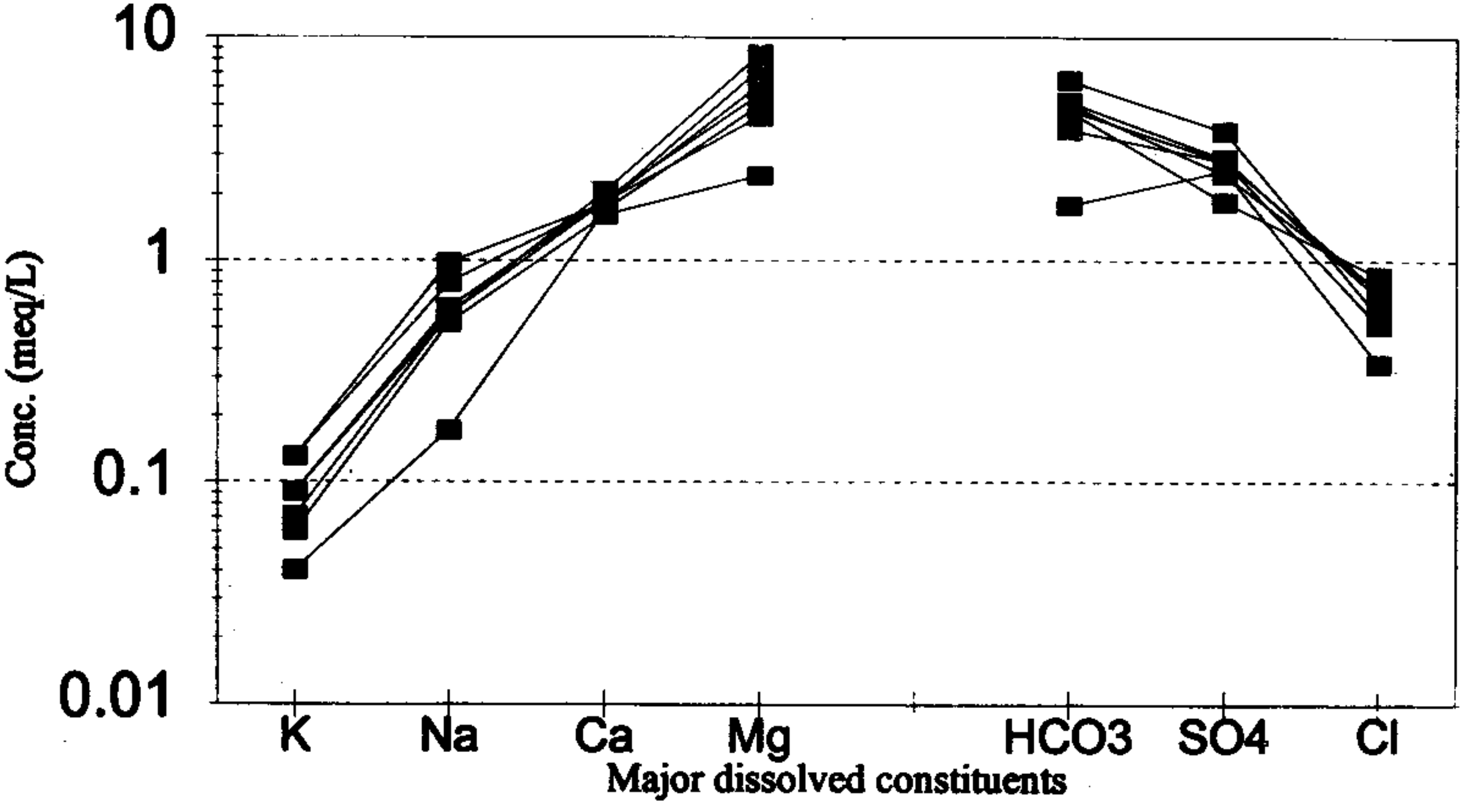


Fig. 4e. Springs - Fingerprint plot (Sep., 95)

Fig. 4f. Springs - Fingerprint plot (Nov., 95)

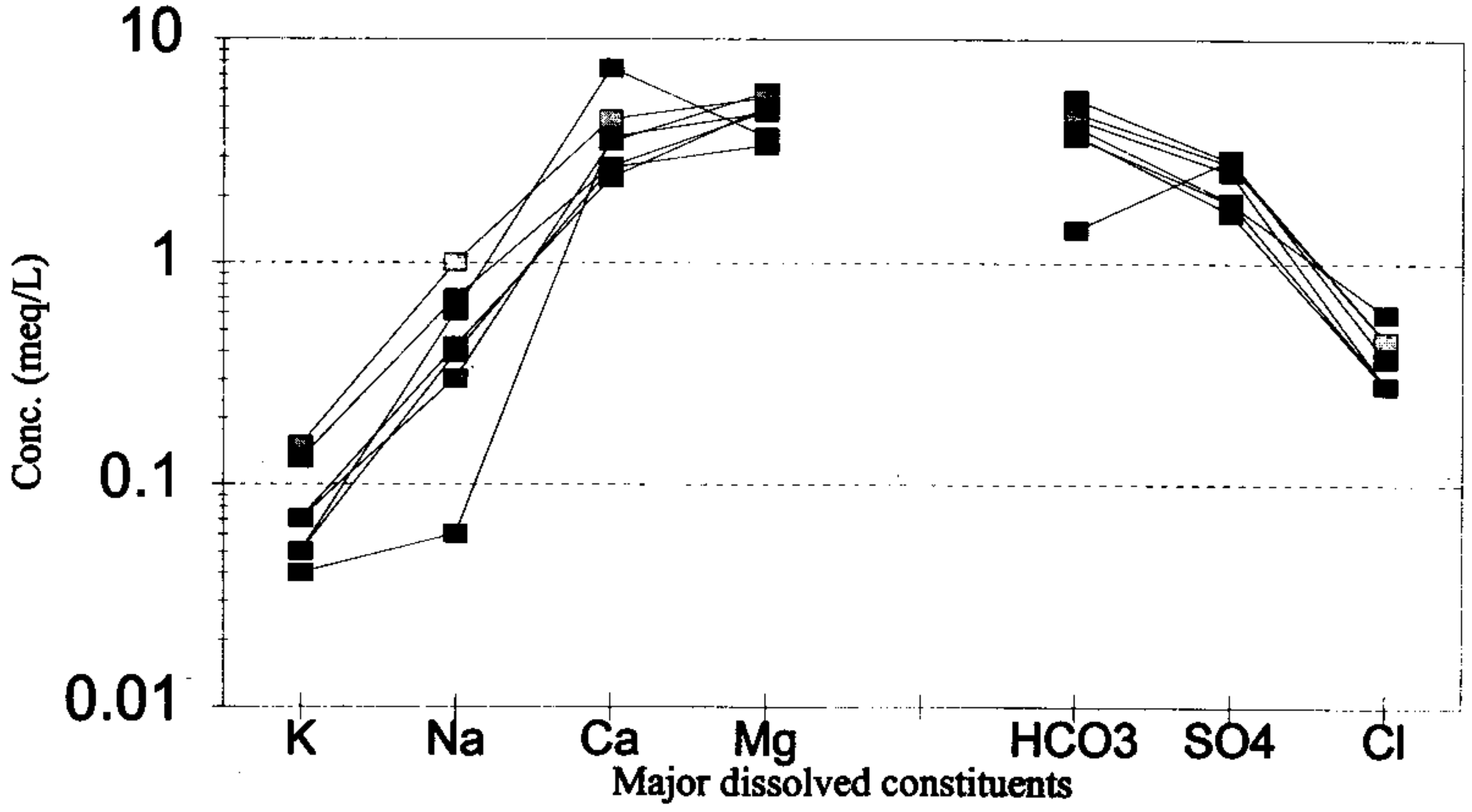


Fig. 4g. Springs - Fingerprint plot (Dec., 95)

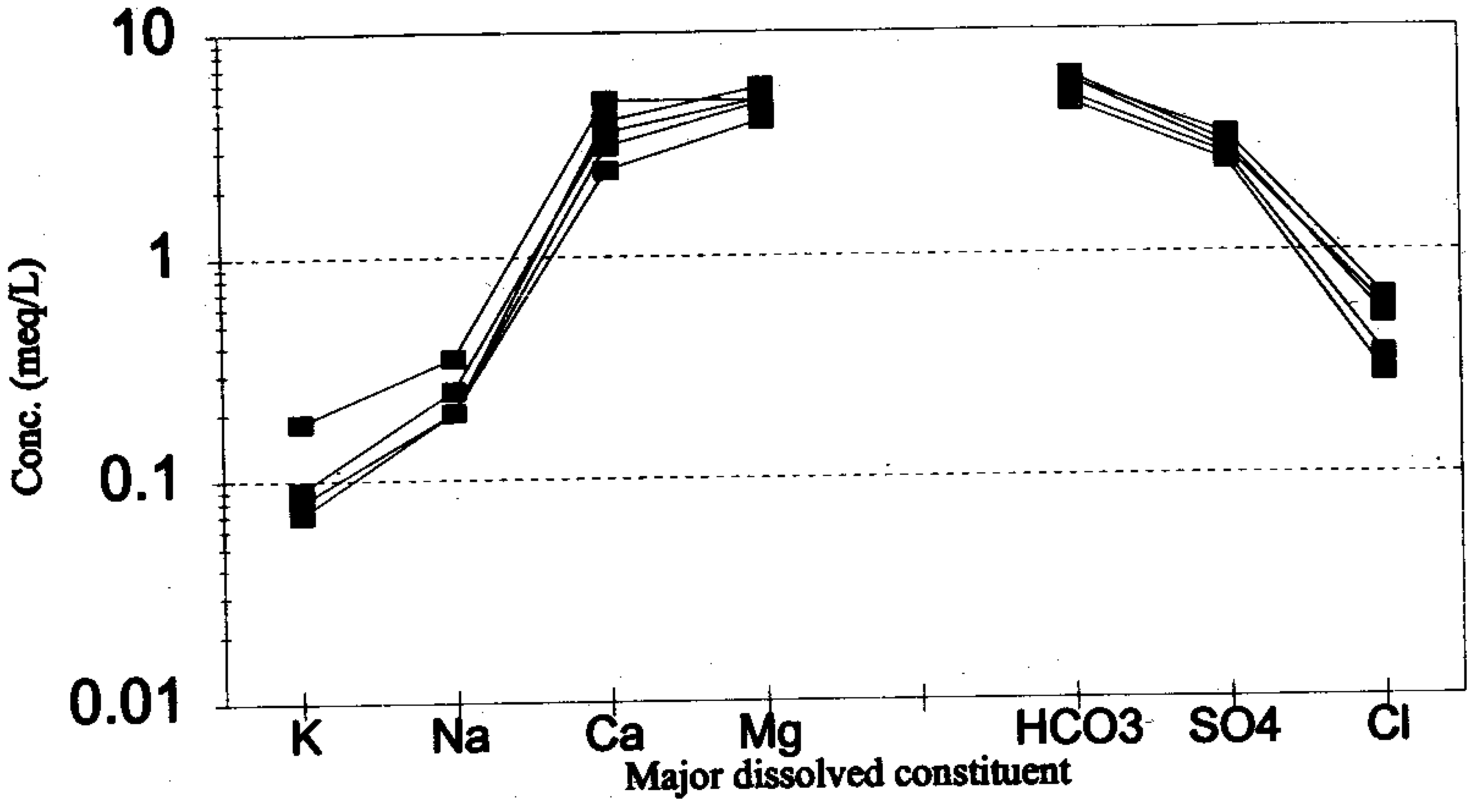


Fig. 4h. Springs - Fingerprint plot (Jan., 96)

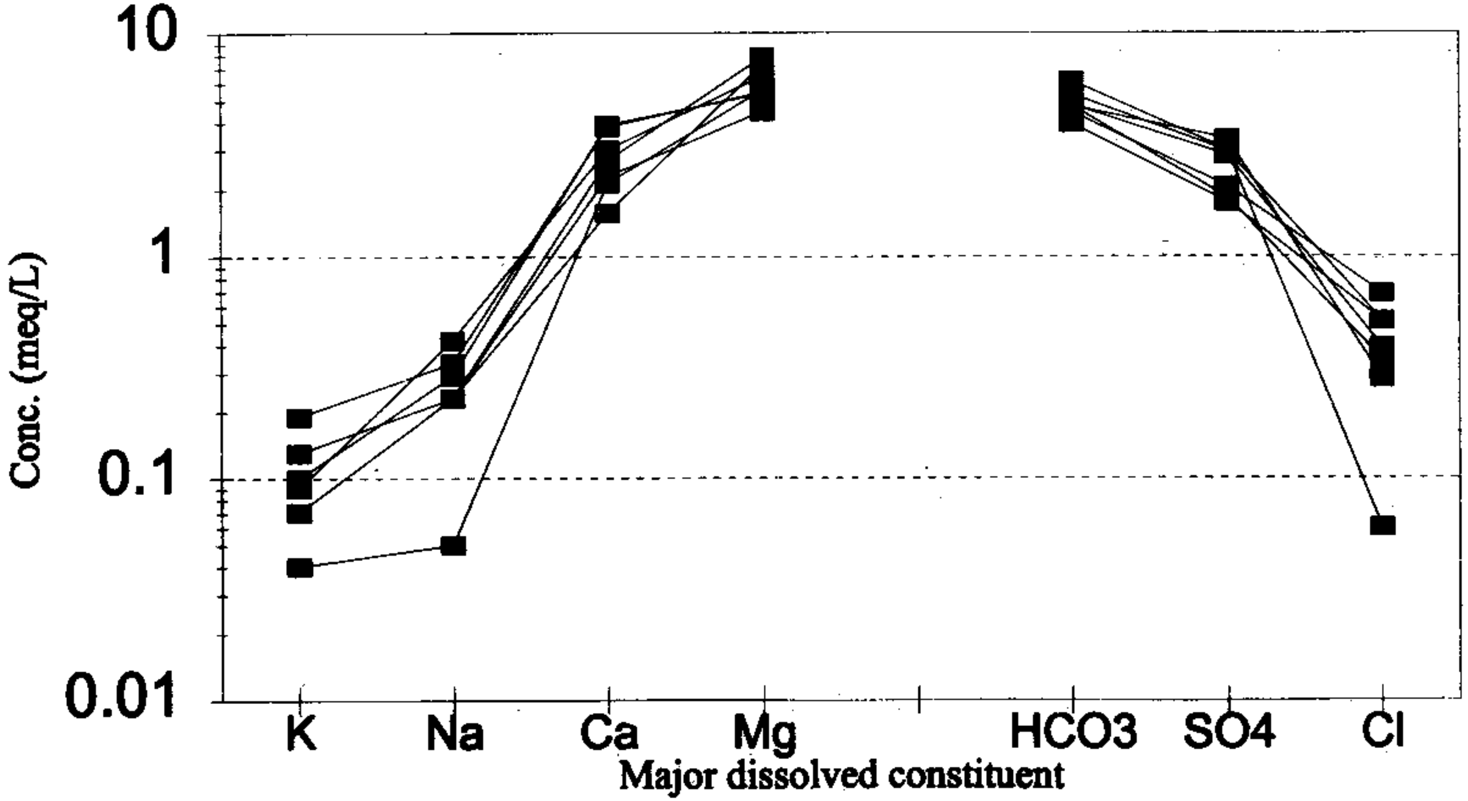


Table :1 Collected :9-10, Feb, 1994

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
C21	1		10	7.5	385	260	386	8		0	0			67	54
C28	20		8.5	8.6	366	285	338			0.19	0			53	32
H21	1		9.2	8.1	404	272	352			0.2	0			56	52
H28	20		8.8		416		336				0			51	51
DRAINS															
Naina D				8.1	455	290	420	2.8		0.02	2.85			69	60
SPRINGS															
Pardha S					520		356				3.5			58	52

Table :2 Collected :20-21, May, 1994

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
C21	0.00	5.60	19.90	8.60	600.00	133.00	372.00	1.00	110.00	0.00	0.00	9.90	4.50	46.10	62.50
C24	12.00	0.80	9.80	7.20	660.00	147.00	370.00	1.00	93.00	0.16	0.00	10.20	4.40	80.20	41.30
C28	21.00	3.90	17.20	8.00	610.00	140.00	344.00	1.00	110.00	0.08	0.00	10.20	4.60	54.10	50.80
E27	22.00	2.70	16.30	7.20	610.00	148.00	340.00	3.00	101.00	0.29	0.00	10.30	4.80	52.90	50.50
F21	0.00	5.10	19.60	8.50	600.00	128.00	373.00	5.00	119.00	0.04	0.00	9.40	4.60	48.90	61.00
F24	7.00	0.70	14.60	7.90	630.00	143.00	375.00	3.00	96.00	0.22	0.00	9.50	4.30	50.10	60.80
H21	0.00	5.40	18.60	8.60	600.00	132.00	365.00	4.00	112.00	0.02	0.00	10.00	4.80	45.70	60.90
H24	12.00	0.90	10.10	7.60	650.00	144.00	379.00	1.00	111.00	0.28	0.00	9.60	4.80	56.10	58.10
H28	21.00	0.80	9.20	8.00	660.00	130.00	391.00	3.00	78.00	0.10	0.00	10.10	4.70	58.50	59.50
DRAINS															
Naina D		2.80		7.50	1040.00	202.00	542.00	9.00	173.00	0.48	1.50	10.40	9.30	86.20	79.50
SPRINGS															
Pardha S		5.70		8.10	845.00	150.00	478.00	6.00	177.00	0.00	2.90	8.60	3.00	85.80	64.20

Table :3a Collected :03-05, Oct., 1994

parame	Depth	DO mg/l	Temp	pH	EC	Alk	Hardnes	Cl	Sulfate	P(PO-4)	N(NO-3)	Na	K	Ca	Mg
units	m (bws)	mg/l	°C		mic. mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
LAKE															
A16				7.10	652.00	266.00	280.00	12.00		0.40	2.30			45.70	40.30
A25				7.70	634.00	242.00	274.00	11.00		0.30	2.40			42.50	40.80
A35				7.70	620.00	220.00	318.00	11.00	98.00	0.17	1.70			48.10	48.10
C21	0.00	9.50	20.10	8.20	506.00	189.00	254.00	13.00	76.60	0.00	0.40			26.50	45.70
C22	3.00		19.60	8.20	520.00	188.00	252.00	14.00	78.20	0.00	0.30			28.10	44.20
C23	6.00		18.60	7.80	559.00	213.00	274.00	15.00	74.10	0.00	0.40			36.10	44.70
C24	9.00		13.50	7.30	629.00	247.00	326.00	13.00	79.00	0.25	1.60			52.10	47.60
C25	12.00	0.00	10.80	7.20	656.00	260.00	328.00	14.00	67.50	0.18	2.90			50.50	49.10
C26	15.00		10.00	7.10	662.00	242.00	330.00	13.00	77.40	0.10	3.20			52.10	48.60
C27	18.00		9.90	7.10	658.00	265.00	324.00	11.00	77.40	0.20	3.50			52.10	47.10
C28	21.00		10.20	8.30	673.00	258.00	330.00	11.00	72.40	0.10	3.70			52.90	48.10
C29	23.75	0.00	10.00	7.10	683.00	284.00	430.00	16.00		0.40	0.00			80.20	55.90
C39	23.50		9.90	6.90	669.00	260.00	282.00	13.00		0.40	3.10			49.70	38.40
D39				6.90	660.00	258.00	290.00	13.00		0.40	2.00			49.70	40.30
F21	0.00	9.60		8.10	521.00	180.00	252.00	13.00	117.70	0.00	0.20			27.30	44.70
F24	7.00	0.90		7.50	581.00	218.00	302.00	13.00	76.60	0.10	0.70			42.50	47.60
H110	24.52		9.60	6.80	946.00	200.00	518.00	16.00		0.10	2.30			120.30	52.90
H21	0.00	8.50	20.50	8.20	521.00	178.00	248.00	15.00	86.40	0.00	0.30			26.50	44.60
H22	3.00		20.20	8.10	505.00	174.00	244.00	14.00	84.80	0.02	0.40			30.50	40.80
H23	6.00		18.10	7.70	571.00	214.00	274.00	14.00	81.50	0.04	0.40			39.30	42.80
H24	9.00		12.90	7.80	657.00	246.00	320.00	16.00	76.60	0.30	1.80			54.50	44.70
H25	12.00		10.90	7.20	664.00	250.00	316.00	17.00	82.30	0.14	2.50			55.30	43.20
H26	15.00	0.00	10.00	7.20	667.00	260.00	314.00	15.00	76.60	0.20	3.30			55.30	42.80
H27	18.00		10.00	7.10	661.00	252.00	320.00	13.00	79.80	0.20	3.50			55.30	44.20
H28	21.00		9.80	7.20	683.00	266.00	322.00	13.00	83.10	0.20	4.30			55.30	44.70
H29	24.00	0.00		7.10	711.00	270.00	332.00	13.00	45.30	0.12	7.00			59.30	44.70
H210	26.05		9.70	6.90	772.00	270.00	400.00	14.00		0.60	0.00			80.20	48.60
H310				7.10	701.00	274.00	326.00	12.00	74.90	0.10	5.10			59.30	43.20

Table :3b Collected :03-05, Oct., 1994

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Nala 1				7.40	909.00	310.00	408.00	6.00	45.30	0.80	4.00			80.20	50.50
Nala 4				8.20	916.00	350.00	400.00	26.00	139.10	0.30	2.30			86.60	44.70
Nala 11				8.20	845.00	296.00	376.00		152.30	0.30	2.00			52.10	59.80
Nala 13				8.10	775.00	242.00	422.00	11.00	158.10	0.00	1.40			52.90	70.50
Nala 16				8.10	663.00	280.00	286.00			0.02	2.70			43.30	43.20
Naina D-u		7.40		7.70	807.00	290.00	408.00	14.00	84.80	0.10	3.20			43.30	72.90
Naina D-d				7.80	802.00	288.00	420.00	15.00	158.20	0.10	3.05			33.70	81.60
Alka				8.20	478.00	140.00	220.00	13.00	87.30	0.20	0.00			23.20	39.40
Stream 1				5.90	58.00	26.00	14.00	4.00	4.12	0.20	0.00			4.80	0.50
Stream 2				7.10	171.00	38.00	40.00	21.00	11.50	0.00	0.20			11.20	2.90
Stream 3				8.10	610.00	260.00	300.00	15.00	11.50	0.00	0.00			46.50	44.70
SPRINGS															
Suriya S				8.00	606.00	228.00	290.00	5.00	99.60	0.00	0.00			50.50	39.80
GW															
O. Well		1.80		7.50	640.00	238.00	210.00	15.00	70.80	0.11	1.80			62.60	13.10
Pump H				7.40	671.00	266.00	278.00		86.40	0.10	2.00			44.90	40.30

Table :4 Collected :14-20, Dec., 1994

parame	Depth	DO mg/l	Temp	pH	EC	Alk	Hardnes	Cl	Sulfate	P(PO-4)	N(NO-3)	Na	K	Ca	Mg
units	m (bws)	mg/l	°C		mic. mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
LAKE															
A35	11.50	0.00	10.60	7.80	601.00	260.00	404.00	12.00		0.55	0.00	14.00	3.60	70.00	56.00
C21	0.00	2.20	11.40	8.00	547.00	240.00	316.00	6.00		0.16	0.75	12.00	4.40	47.00	49.00
C24	7.50	0.70	11.00	8.10	547.00	230.00	306.00	10.00		0.21	0.80	11.80	4.20	43.00	48.00
C26	15.00	0.00	10.40	7.50	630.00	298.00	344.00	6.00		0.53	0.00	13.60	4.80	53.00	52.00
C29	22.80	0.00	10.00	7.70	652.00	324.00	356.00	8.00		0.90	0.00	11.60	3.60	63.00	49.00
F21	0.00	1.40	11.00	7.90	553.00	242.00	316.00	10.00		0.14	0.70	11.60	4.40	48.00	48.00
F24	7.00	3.00	10.80	7.90	550.00	244.00	314.00	6.00		0.19	0.70	14.00	4.40	47.00	48.00
H21	0.00	1.30	11.60	8.10	553.00	234.00	310.00	4.00		0.13	0.65	11.20	4.10	46.00	48.00
H24	7.50	0.90	10.90	8.10	562.00	164.00	314.00	8.00		0.18	0.65	11.20	4.20	46.00	49.00
H26	15.00	0.00	10.40	7.60	614.00	302.00	350.00	8.00		0.55	0.00	13.80	4.50	57.00	51.00
H210	25.00	0.00	9.80	7.60	680.00	350.00	354.00	8.00		0.15	0.00	11.60	4.50	51.00	55.00
DRAINS															
Naina D		5.30		7.60	822.00	328.00	434.00	4.00		0.43	2.00	12.20	7.40	71.00	62.00
SPRINGS															
Pardha S		4.90		7.70	716.00	174.00	320.00	6.00		0.06	3.30	13.60	3.60	71.00	35.00
S-3 S		8.10		8.20	654.00	228.00	384.00	8.00		0.00	0.00	12.80	1.50	83.00	43.00
S-5 S		7.70		8.10	288.00	174.00	168.00	0.00		0.01	0.00	6.40	0.70	34.00	20.00
S-9 S		6.60		7.90	562.00	268.00	348.00	0.00		0.03	0.15	5.20	1.70	55.00	52.00
S-12 S				8.30	1066.00	208.00	592.00	0.00		0.00	0.00	8.40	4.80	129.00	66.00
Gupha S		7.70		8.30	547.00	230.00	302.00	6.00		0.02	2.20	8.80	2.70	49.00	44.00
Sipahi S		6.40		8.10	560.00	238.00	310.00	6.00		0.03	2.30	9.20	3.00	46.00	48.00
GW															
Pump H		2.00		7.70	726.00	294.00	370.00	6.00		0.05	2.35	14.60	4.40	44.00	63.00

Table : 5 Collected :22-26, Feb., 1995

parame units	Depth m (bws)	DO mg/l mg/l	T °C	pH	EC mic. mho	Alk mg/l	H mg/l	Cl mg/l	S mg/l	P mg/l	N mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00	6.60	8.60	6.90	493.00		330.00	11.00	61.30	0.22	0.40	11.60	4.40	49.70	50.10
A35	12.00	3.40	7.90	7.10	504.00		328.00	13.00	102.10	0.23	0.50	12.40	4.60	54.50	46.70
C21	0.00	5.60	9.20	6.80	516.00		322.00	11.00	72.00	0.27	0.20	11.60	4.60	51.30	47.10
C25	12.00	5.00	8.20	6.90	503.00		324.00	1.00	90.10	0.29	0.60	11.20	4.70	48.90	49.10
C29	22.75	4.90	8.00	7.00	496.00		310.00	3.00	74.90	0.26	0.70	11.00	4.60	48.90	45.70
F11	0.00	7.00	10.20	6.80	532.00		316.00	11.00	94.30	0.25	0.00	11.20	4.60	49.70	46.70
F15	12.00	4.80	8.00	6.80	511.00		300.00	13.00	96.70	0.24	0.40	11.00	4.50	47.30	44.20
F17	18.50	3.50	8.00	6.80			318.00	2.00	92.60	0.22	0.40	13.40	4.80	48.10	48.10
H21	0.00	4.80	8.40	6.60	553.00		324.00	1.00	85.20	0.19	1.00	14.00	4.40	50.50	48.10
H25	12.00	5.40	8.00	6.70	511.00		326.00	9.00	87.70	0.16	0.50	14.40	4.30	46.50	51.00
H29	24.00	3.60	8.00	6.80	501.00		318.00	9.00	95.90	0.19	0.30	11.60	4.20	46.50	49.10
J11	0.00	5.10	8.30	6.60	507.00		330.00	27.00	63.40	0.25	0.60	11.20	4.70	48.90	50.50
J12	3.00	5.00	8.20	6.50	517.00		348.00	13.00	103.30	0.24	0.60	11.00	4.70	49.70	54.40
J13	6.00	5.30	8.20	6.40	516.00		354.00	19.00	113.20	0.28	0.60	9.20	4.60	48.90	56.40
J14	9.00	5.00	8.10	6.50	507.00		334.00	9.00	105.80	0.24	0.70	11.80	4.50	48.90	51.50
J15	12.00	4.90	8.20	6.50	506.00		334.00	19.00	105.40	0.25	0.60	11.10	4.60	44.90	54.00
J16	15.00	4.70	8.10	6.50	503.00		324.00	3.00	98.80	0.24	0.60	11.80	4.60	45.70	51.00
J17	16.00	5.10	8.10	6.40	503.00		322.00	15.00	99.60	0.26	0.60	14.20	4.50	47.30	49.60
DRAINS															
Naina D		6.00	11.00	7.00	490.00		350.00	22.00	125.10	0.35	2.90	15.20	6.40	20.10	72.90
SPRINGS															
S3 S		8.80					398.00	25.00	137.90	0.14	0.00	12.60	1.60	58.60	61.20
S5 S		7.70	15.00	6.90	300.00		234.00	15.00	142.80	0.00	0.00	4.30	0.40	36.90	34.50
Sariya S							366.00	7.00	81.50	0.00	0.50	2.70	2.20	59.30	52.90
km 11 S							334.00	5.00	117.30	0.00	0.00	7.00	1.40	40.90	56.40
GW															
O. Well		2.50	12.70	6.70	757.00		436.00	13.00	73.20	0.04	3.00	12.80	5.00	64.90	66.60
Pump							400.00	15.00	13.60	0.24	2.30	11.20	4.40	65.00	57.80
N Pump							428.00	17.00	26.70	0.06	3.80	11.00	5.90	68.20	62.70

Table :6a Collected :22-23, March, 1995

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00	14.10	16.00	9.40	751.00	252.00	332.00	15.00	93.80	0.10	0.00	11.60	4.10	46.70	52.30
A32	3.00		12.00	9.00	741.00	268.00	340.00	15.00	95.50	0.16	0.00	11.60	4.10	48.10	53.60
A33	6.00		10.40	8.60	747.00	254.00	333.00	17.00	95.50	0.13	0.50	11.60	4.20	48.30	51.60
A34	9.00	0.46	8.40	8.10	709.00	270.00	343.00	18.00	101.30	0.23	1.30	12.60	4.20	52.00	51.90
A35	12.00	1.20	8.20	8.00	698.00	270.00	341.00	16.00	102.10	0.20	1.00	12.00	4.20	52.30	51.20
C21	0.00	11.10	16.00	9.40	888.00	260.00	326.00	16.00	95.50	0.16	0.00	13.60	4.20	42.40	58.40
C22	3.00		12.20	9.00	830.00	262.00	366.00	21.00	90.60	0.09	0.00	11.80	4.20	41.90	63.50
C23	6.00		9.40	8.30	795.00	260.00	343.00	16.00	105.40	0.18	1.15	12.20	4.20	47.40	54.50
C24	9.00	1.50	8.60	8.10	760.00	248.00	346.00	16.00	93.80	0.15	1.15	11.60	4.30	50.50	53.50
C25	12.00		8.20	8.10	773.00	268.00	335.00	16.00	88.10	0.19	1.25	11.00	4.20	45.70	53.70
C26	15.00		8.20	8.10	723.00	256.00	324.00	15.00	96.30	0.16	1.15	11.20	4.20	46.80	55.10
C27	18.00		8.20	8.00	772.00	252.00	345.00	12.00	88.90	0.19	1.25	10.20	4.20	47.50	55.10
C28	21.00		8.20	8.00	769.00	264.00	338.00	16.00	102.90	0.15	1.15	11.20	4.20	49.60	52.20
C29	22.50	0.36	8.20	8.10	711.00	260.00	337.00	18.00	88.90	0.19	1.05	11.20	4.10	48.30	52.70
F11	0.00		14.90	9.20	760.00	260.00	344.00	15.00	74.90	0.15	0.00	12.80	4.40	47.90	54.70
F12	3.00		12.60	8.80	766.00	278.00	349.00	17.00	76.60	0.15	0.00	12.60	4.50	52.50	53.10
F13	6.00		9.30	8.90	739.00	272.00	346.00	16.00	100.40	0.19	1.00	12.60	4.40	50.60	53.30
F14	9.00	1.70	8.60	8.50	717.00	272.00	335.00	16.00	93.80	0.22	1.25	12.60	4.50	45.70	53.70
F15	12.00		8.30	8.20	726.00	276.00	334.00	17.00	88.90	0.21	1.15	12.60	4.50	48.90	51.40
F16	15.00		8.20	8.00	716.00	272.00	337.00	17.00	105.40	0.20	1.30	12.20	4.50	47.20	53.30
F17	20.00	1.30	8.20	8.20	721.00	256.00	338.00	18.00	86.40	0.24	1.25	12.60	4.50	48.60	52.40
H21	0.00	15.50	15.40	9.10	740.00	236.00	306.00	16.00	101.30	0.16	0.00	13.40	4.50	37.00	52.00
H22	3.00		12.40	9.10	761.00	262.00	349.00	14.00	99.60	0.14	0.00	13.40	4.70	46.70	56.60
H23	6.00		9.60	8.70	721.00	254.00	330.00	14.00	98.60	0.19	0.70	14.60	4.60	49.20	50.30
H24	9.00		8.60	8.50	701.00	262.00	338.00	17.00	101.30	0.21	0.50	12.60	4.40	46.00	54.20
H25	12.00	1.80	8.30	8.30	751.00	256.00	343.00	12.00	135.00	0.21	0.70	13.00	4.50	51.20	52.40
H26	15.00		8.20	7.90		252.00	345.00	16.00	131.70	0.23	1.15	12.40	4.50	42.80	58.00
H27	18.00		8.20	7.80	723.00	286.00	349.00	13.00	102.10	0.22	1.10	12.60	4.50	45.90	57.10
H28	21.00		8.20	8.30	746.00	268.00	350.00	18.00	94.70	0.23	1.10	13.00	5.10	43.90	58.40
H29	24.00	1.40	8.20	8.40	861.00	236.00	352.00	19.00	121.80	0.26	1.15	12.20	5.20	41.70	60.20
J11	0.00	14.50	16.00	9.30	892.00	260.00	368.00	15.00	96.30	0.16	0.00	11.60	4.40	51.50	58.30
J12	3.00		12.30	8.80	752.00	262.00	342.00	15.00	102.90	0.13	0.00	15.20	4.60	59.10	47.20
J13	6.00		10.00	8.70	766.00	268.00	344.00	15.00	97.10	0.19	0.30	11.60	4.20	54.10	50.80
J14	9.00	2.10	8.80	8.40	757.00	250.00	335.00	16.00	87.30	0.19	0.45	14.60	4.30	52.10	49.60
J15	12.00		8.30	8.20	740.00	264.00	341.00	16.00	79.90	0.21	1.00	13.60	4.40	48.90	53.10
J16	15.00		8.20	8.20	744.00	278.00	337.00	16.00	73.70	0.21	1.05	13.60	4.40	50.20	51.50
J17	16.50	1.90	8.20	8.10	711.00	260.00	338.00	17.00	76.60	0.22	0.15	12.80	4.40	49.70	52.00

Table :6b Collected :22-23, March, 1995

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/t	Ca mg/l	Mg mg/l
DRAINS															
Naina D		3.40			999.00	366.00	464.00	27.00	194.30	0.10	2.35	19.00	8.70	57.50	77.90
Riksha D		4.10			1147.00	350.00	485.00	44.00	189.30	0.22	0.45	27.60	16.00	71.90	74.40
SPRINGS															
Pashan S		5.40			800.00	290.00	427.00	19.00	174.50	0.00	1.70	12.60	5.50	69.00	61.90
Arch S		6.80			871.00	268.00	413.00	18.00	180.30	0.00	2.80	10.20	3.80	65.50	60.70
Pardha S		4.60			818.00	296.00	432.00	23.00	176.20	0.03	4.15	12.40	4.50	61.10	67.90
L. View S					806.00	322.00	546.00	17.00	184.40	0.02	0.95	10.20	3.10	55.10	99.20
S2 S						254.00	264.00	17.00	106.20	0.03	0.40	9.60	2.60	42.00	38.80
S3 S						224.00	366.00	11.00	208.30	0.07	0.00	14.00	2.20	62.60	51.10
S5 S						182.00	185.00	9.00	84.80	0.03	0.00	3.40	1.00	36.70	22.70
Sariya S					806.00	260.00	387.00	16.00	149.80	0.05	0.00	1.60	2.60	49.60	64.00
Rais S					657.00	250.00	329.00	26.00	117.70	0.08	4.30	14.80	5.50	44.67	52.80
Sipahi S						244.00	354.00	13.00	149.80	0.00	2.10	9.00	3.80	46.40	57.90
Gupha S						236.00	328.00	16.00	133.20	0.03	2.10	10.60	3.00	45.90	57.90
GW															
Sukha					840.00	262.00	367.00	19.00	167.90	0.05	3.60	9.80	3.50	37.90	66.30

Table :7 Collected :29-31, May, 1995

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00	15.00	21.30	7.80	567.00	209.00	280.00	21.00	126.00	0.10		11.60	4.40	37.70	45.20
A34	9.00	1.70	10.00	7.60	637.00	245.00	340.00	11.00	97.00	0.40		9.60	4.70	40.10	58.30
A35	11.50	2.80	10.20	7.60	646.00	252.00	326.00	10.00	92.00	0.37		9.20	4.00	36.90	56.90
C21	0.00	13.90	21.10	7.80	570.00	206.00	280.00	9.00	85.00	0.12		9.60	4.60	32.90	48.10
C24	9.00	1.90	8.90	7.80	648.00	260.00	326.00	10.00	85.00	0.39		9.40	4.50	39.30	55.40
C29	21.85	0.00	8.50	7.40	649.00	253.00	332.00	9.00	97.00	0.78		11.00	4.60	40.90	55.90
E11	0.00	14.20	21.00	8.00	569.00	197.00	294.00	12.00	100.00	0.11		11.60	4.60	32.90	51.50
E14	9.00	4.90	9.20	7.50	639.00	254.00	336.00	11.00	90.00	0.42		12.40	4.80	40.10	57.30
E18	19.50	1.40	8.40	7.60	651.00	255.00	336.00	11.00	93.00	0.41		8.00	4.60	36.10	59.80
F11	0.00	13.40	21.00	7.80	570.00	229.00	304.00	15.00	90.00	0.12		11.20	9.00	34.50	52.90
F14	9.00	2.50	8.80	7.50	633.00	253.00	338.00	10.00	97.00	0.36		12.40	4.80	40.90	57.30
F18	20.00	3.40	9.00	7.40	640.00	252.00	334.00	15.00	86.00	0.42		10.00	4.70	44.10	54.40
H21	0.00	10.80	20.30	8.00	583.00	209.00	304.00	13.00	86.00	0.09		11.60	4.50	42.50	48.10
H25	12.00	2.50	8.60	7.20	647.00	248.00	346.00	11.00	99.00	0.49		10.20	4.50	44.10	57.30
H29	23.00	1.80	8.40	7.30	642.00	251.00	356.00	12.00	92.00	0.53		10.00	4.60	48.50	56.90
J11	0.00	5.50	20.50	7.80	568.00	208.00	286.00	17.00	93.00	0.13		12.20	4.80	33.70	49.10
J14	9.00	4.90	9.00	7.60	647.00	259.00	334.00	13.00	93.00	0.40		10.60	4.80	40.10	56.90
J17	15.90	10	8.50	7.40	644.00	234.00	358.00	17.00	94.00	0.29		11.00	4.40	42.50	61.20
DRAINS															
Riksha D		0.00	14.50	7.10	1549.00	360.00	504.00	82.00	126.00	0.68		72.00	35.00	38.50	99.10
Naina D		0.70	19.50	7.10	1054.00	234.00	472.00	45.00	150.00	1.71		32.00	16.00	49.70	84.60
SPRINGS															
Pardha S		15.30	15.00	7.30	821.00	234.00	304.00	13.00	170.00	0.03		13.60	3.30	28.90	56.40
Chuna S			14.50	7.50	943.00	231.00	356.00	21.00	170.00	0.06		13.00	5.60	32.10	67.10
Pashan S		3.30	16.00	7.30	722.00	252.00	324.00	18.00	176.00	0.11		11.60	3.90	32.10	59.30
Dr. H S			15.00	7.90	652.00	200.00	280.00	24.00	100.00	0.07		9.60	2.30	33.70	47.60
Sipahi S				7.70	632.00	230.00	312.00	18.00	99.00	0.07		9.60	3.00	36.90	53.50
Gupha S				8.00	602.00	159.00	246.00	11.00	130.00	0.03		8.00	2.50	34.50	38.90
S3 S				7.60	885.00	187.00	350.00	12.00	192.00	0.07		32.00	2.50	38.50	61.70
S4 S			15.00	7.10	525.00	83.00	248.00	20.00	150.00	0.09		10.80	2.90	35.30	38.90
S5 S			18.50	7.70	339.00	162.00	170.00	6.00	135.00	0.04		5.20	0.50	30.50	22.80
Sher S			19.50	7.60	443.00	209.00	270.00	12.00	123.00	0.01		1.40	0.70	32.10	46.20
L View S			14.50	7.60	851.00	266.00	356.00	23.00	165.00	0.04		8.60	2.30	28.90	69.00
Sariya S		1.10	16.80	7.50	698.00	217.00	314.00	15.00	126.00	0.03		2.00	2.10	30.50	57.80
Mangoli				7.80	347.00	123.00	126.00	6.00	10.00	0.23		4.50	2.20	28.90	13.10
GW															
O. Well		4.70	15.20	7.30	734.00	262.00	330.00	15.00		0.16		14.00	4.50	36.90	57.80
T. Well 1				7.60	799.00	210.00	312.00	16.00	134.00	0.04		13.60	4.60	30.50	57.30
T. Well 3				7.50	745.00	231.00	292.00	23.00	99.00	0.09		12.00	5.60	29.60	52.90
Sukha		5.60	13.50	7.40	764.00	210.00	300.00	17.00	135.00	0.03		12.00	3.20	38.50	49.60

Table :8 Collected :30, June, 1995

Parame	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic.mho	Alk mg/l	Hardness mg/l	Cl mg/l	SO-4 mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
C21	0.00	12.50	22.40	7.60	600.00	199.00	289.00	18.00	90.00	0.22		13.60	3.40	35.70	48.60
C24	9.00	0.80	9.40	7.70	666.00	243.00	330.00	12.20	85.00	0.37		9.70	5.60	38.90	56.60
C28	21.00	0.00	8.60	7.70	734.00	263.00	348.00	14.20	110.00	0.19		9.40	4.00	28.10	67.60
H21	0.00	10.50	23.60	7.80	608.00	194.00	285.00	3.00	120.00	0.12		10.80	3.80	26.50	53.20
H25	12.00	0.60	8.80	8.60	620.00	252.00	334.00	10.00	120.00	0.54		9.00	3.60	38.50	57.80
H29	23.00	0.00	8.60	8.20	717.00	262.00	348.00	4.20	97.00	0.80		9.00	3.60	42.50	58.80
SPRINGS															
Sipahi				8.20	676.00	236.00	327.00	0.00	100.00	0.06		8.00	2.60	43.30	53.20
Gupha				7.80	657.00	230.00	325.00	0.00	115.00	0.21		7.70	1.20	50.00	48.60
Durga 1				8.60	589.00	155.00	275.00	0.00	165.00	0.06		6.00	5.60	19.30	55.20
Durga 2				8.00	775.00	164.00	390.00	1.80	180.00	0.05		5.80	6.70	52.10	63.20
Ratigat1				7.00	777.00	105.00	96.00	11.00	22.00	0.26		5.00	2.00	24.10	8.80
Ratigat2				8.00	202.00	97.00	80.00	6.60	4.00	0.03		9.20	0.50	14.00	10.90
Sheel H				8.40	687.00	252.00	337.00	10.60	22.00	0.45		10.00	4.00	50.10	51.50
LAKE KHURPATAL															
Khurpa 0	0.00			8.00	409.00	166.00	182.00	6.60	45.00	0.10		3.70	1.30	20.10	32.10
Khurpa 1	1.00			8.50	384.00	170.00	198.00	1.40	45.00	0.07		3.50	2.30	19.70	36.20

Table :9a Collected :17-21, Aug.,1995

Parame	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic.mho	Alk mg/l	Hardness mg/l	Cl mg/l	SO-4 mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00		21.60	9.40	383.00	204.00	244.00	28.00	87.30	0.12	0.00	16.00	6.80	35.30	37.90
A34	9.00		11.70	7.70	535.00	258.00	322.00	0.00	101.00	0.42	1.70	18.00	7.50	44.10	51.50
A35	12.00		9.20	7.50	536.00	256.00	350.00	8.00	97.00	0.45	2.10	13.00	4.50	39.30	61.20
C21	0.00	18.40	21.60	8.90	392.00	204.00	240.00	10.00	97.30	0.14	0.00	17.00	6.10	44.10	31.60
C24	9.00	0.00	11.60	7.00	538.00	259.00	320.00	12.00	101.00	0.36	1.20	17.00	6.40	37.70	54.90
C27	18.00	0.00	9.00	7.10	541.00	256.00	316.00	32.00	98.40	0.51	2.00	20.00	7.60	33.70	56.40
C29	23.00		8.80	7.60	553.00	276.00	326.00	4.00	94.20	0.46	0.00	21.00	7.70	40.10	54.90
E11	0.00		21.20	9.60	394.00	190.00	256.00	2.00	97.30	0.09	0.00	16.00	7.50	45.70	34.50
E14	9.00		11.80	9.10	531.00	254.00	318.00	4.00	99.80	0.36	1.50	16.00	5.80	34.50	56.40
E17	18.00		8.80	8.00	540.00	258.00	332.00		106.70	0.30	2.20	14.00	5.20	31.30	61.70
F11	0.00		21.60	9.10	397.00	204.00	246.00	0.00	87.30	0.13	0.00	14.00	4.90	39.30	35.90
F14	9.00		12.20	7.30	534.00	286.00	324.00	32.00	103.90	0.32	1.20	18.00	6.90	36.10	56.90
F17	18.00		9.00	7.50	536.00	264.00	324.00	34.00	97.00	0.45	3.30	18.00	6.80	35.30	57.30
H21	0.00	17.10	22.20	8.90	392.00	204.00	248.00	0.00	87.30	0.15	0.00	19.00	7.20	32.10	40.10
H24	9.00	0.00	11.00	8.10	530.00	252.00	236.00	16.00	103.90	0.35	1.40	19.00	7.60	33.70	58.80
H27	18.00	0.00	8.80	7.60	542.00	262.00	326.00	44.00	97.00	0.40	2.40	19.00	7.90	32.30	59.30
H29	24.00		8.40	7.10	566.00	312.00	338.00	34.00	86.00	0.45	0.00	20.00	7.70	34.50	61.20
J11	0.00		23.80	9.60	390.00	202.00	252.00	20.00	87.30	0.22	0.00	17.00	7.80	21.60	48.10
J14	9.00		10.20	8.80	546.00	258.00	304.00	32.00	101.00	0.41	1.80	21.00	8.10	34.50	52.90
J17	17.00		8.00	9.40	542.00	268.00	316.00	38.00	97.00	0.43	0.00	20.00	7.80	40.10	52.50

Table :9b Collected :17-21, Aug.,1995

Parame	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic.mho	Alk mg/l	Hardness mg/l	Cl mg/l	SO-4 mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Riksha D		6.70				278.00	388.00	42.00	144.00	0.56	6.00	27.00	11.90	36.90	71.90
Naina D		8.30				292.00	396.00	10.00	146.70	0.13	4.80			34.50	75.30
Phansi D									72.10	0.18	0.00	12.00	3.70		
Drain-4						344.00	432.00	40.00	124.60	0.11	4.60	21.00	22.00	40.10	80.20
Drain-6						346.00	492.00	18.00	199.20	0.09	3.30	20.00	5.90	15.20	110.30
D-10						326.00	450.00	18.00	157.80	0.20	3.90	26.00	12.00	36.90	87.00
D-20						288.00	418.00	46.00	134.30	0.20	7.40	31.00	11.10	40.10	77.30
SPRINGS															
Gupha						228.00	304.00	30.00	87.30	0.08	4.20	14.00	2.80	36.10	52.00
Sipahi						218.00	302.00	20.00	81.80	0.05	4.50	20.00	4.50	36.10	51.50
S4						74.00	172.00	20.00	117.70	0.09	1.30	10.00	1.50	31.30	22.80
S5						166.00	152.00	0.00	14.00	0.03	0.00	4.00	0.30	32.90	17.00
Pardha						250.00	396.00	16.00	144.00	0.09	4.60	18.00	3.70	39.30	72.40
Dr. H						208.00	302.00	28.00	86.00	0.04	3.50	12.00	2.20	33.70	52.90
L.View S						250.00	418.00	16.00	99.80	0.09	1.80	14.00	2.60	38.50	78.20
GW															
Pump						268.00	414.00	36.00	149.50	0.06	3.20	25.00	5.90	43.30	74.30
O. Well		5.00				284.00	416.00	46.00	120.50	0.18	4.20			44.10	74.30
Wel 3 JN						346.00	510.00	46.00	145.50	0.03	7.00	29.00	10.90	48.10	94.80

Table :10a Collected :26-28, Sept.,1995

parame units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC mi.mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00		20.40	8.50	430.00	200.00	260.00	16.00	63.20	0.16	0.00	15.10	5.50	29.70	45.20
A34	9.00		13.20	7.60	500.00	242.00	384.00	72.00	89.90	0.26	1.29	15.10	5.60	32.10	73.90
A35	12.00		9.80	7.60	520.00	286.00	366.00	30.00	72.10	0.49	0.00	15.10	5.80	36.90	66.60
C21	0.00	14.00	20.20	8.40	440.00	196.00	264.00	16.00	55.40	0.02	0.00	14.10	4.90	36.10	42.30
C24	9.00	0.70	12.40	7.80	500.00	304.00	336.00	24.00	56.40	0.35	1.50	15.10	5.20	34.50	60.80
C27	18.00	0.00	9.20	7.80	480.00	318.00	344.00	30.00	95.40	0.69	0.00	15.10	7.20	31.30	64.60
C29	23.00		9.00	8.70	490.00	268.00	360.00	16.00	87.50	0.11	3.76	16.10	6.00	28.90	69.90
E11	0.00	16.20	20.00	5.60	450.00	208.00	268.00	24.00	95.40	0.13	0.00	15.10	5.30	27.30	48.60
E14	9.00	0.20	13.40	4.10	530.00	260.00	362.00	30.00	90.10	0.14	1.22	16.10	5.20	32.10	68.50
E17	16.00	0.00	9.00	5.90	560.00	266.00	348.00	26.00	80.10	0.11	0.26	15.10	5.00	28.90	67.10
F11	0.00		21.60	9.10	397.00	190.00	348.00	22.00	93.80	0.12	0.00	15.10	4.70	25.70	44.70
F14	9.00		12.20	7.30	534.00	258.00	334.00	18.00	95.80	0.21	1.39	16.10	4.60	31.40	62.20
F17	18.00		9.00	7.50	536.00	174.00	338.00	6.00	89.10	0.39	0.00	16.10	5.10	25.70	66.60
H21	0.00	16.30	20.20	8.50	440.00	180.00	266.00	28.00	92.70	0.36	0.00	14.10	5.00	38.50	41.30
H24	9.00	0.40	11.70	5.70	510.00	260.00	356.00	20.00	90.00	0.22	2.34	15.10	4.80	35.30	65.10
H27	18.00	0.00	9.40	5.00	490.00	282.00	352.00	12.00	93.40	0.13	3.34	16.10	5.50	32.10	66.10
H29	25.00		8.90	7.10	510.00	290.00	354.00	24.00	82.50	0.11	2.30	16.10	5.70	28.10	69.00
J11	0.00		21.20	8.90	470.00	170.00	248.00	14.00	92.70	0.23	0.00	15.10	4.50	28.90	42.70
J14	9.00		12.20	7.00	560.00	262.00	350.00	12.00	96.20	0.26	1.55	17.10	4.80	31.30	66.10
J17	18.00		9.70	6.00	540.00	266.00	360.00	26.00	88.00	0.34	2.67	17.10	5.10	26.50	71.40

Table :10b Collected :26-28,Sept.,1995

parameter units	Depth m (bws)	DO mg/l mg/l	Temp °C	pH	EC micromho	Alk mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	Phosphat mg/l	Nitrate mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Riksha D		3.00				306.00	418.00	32.00	125.30	0.24	3.74	36.60	12.60	33.30	81.40
Boat D						306.00	464.00	24.00	170.60	0.15	5.15	34.50	10.10	31.30	93.80
Alka D						362.00	480.00	30.00	162.80	0.16	1.59	27.40	8.70	36.90	94.30
Church D						354.00	468.00	24.00	135.60	0.27	2.60	23.30	7.90	48.90	84.10
Library D						290.00	402.00	30.00	136.90	0.03	1.62	17.10	4.60	35.30	76.30
Naina D		3.90				306.00	398.00	26.00	116.60	0.13	3.57	18.20	5.00	36.10	74.80
SPRINGS															
Dr. House						240.00	358.00	20.00	69.70	0.06	3.61	12.00	2.90	39.30	63.20
Takula		7.20				186.00	174.00	24.00	69.60	0.09	0.00	4.80	0.70	32.10	22.80
L-view						392.00	524.00	20.00	183.60	0.02	0.26	13.00	2.90	40.90	102.50
S-3						108.00	200.00	12.00	122.10	0.07	0.80	12.00	2.30	32.10	29.20
Chuna						330.00	476.00	24.00	149.90	0.02	4.32	22.30	7.80	40.10	91.40
Sariya						286.00	334.00	30.00	88.20	0.07	0.23	3.80	1.60	33.70	60.80
Pardha						290.00	372.00	26.00	134.40	0.04	3.57	14.10	3.70	37.70	67.60
Sipahi						236.00	314.00	18.00	134.30	0.08	3.79	13.00	3.50	36.90	53.90
Gupha		4.90				220.00	298.00	28.00	76.50	0.04	3.96	13.00	3.30	32.10	52.90
GW															
T-Well-1						314.00	452.00	24.00	138.20	0.09	4.86	22.30	5.20	36.10	87.90
Open						238.00	320.00	22.00	101.80	0.14	3.13	21.20	7.50	36.90	55.40
Jal San						268.00	368.00	24.00	113.60	0.13	3.06	18.20	5.30	36.10	67.50
T-Well-2						280.00	400.00	16.00	115.40	0.16	3.21	20.20	5.20	34.50	76.30
T-Well-3						358.00	468.00	46.00	113.80	0.05	3.58	37.60	13.40	33.70	93.30

Table :11a Collected :24-25, Nov.,1995

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00	9.14	14.00	7.50	579.00	234.00	376.00	10.00	96.00	0.00	0.50	14.80	3.60	57.70	56.40
A34	9.00	8.80	13.10	7.50	573.00	235.00	416.00	8.00	91.00	0.00	0.57	14.80	3.80	51.30	70.00
A35	12.00	0.00	10.50	7.20	624.00	263.00	442.00	6.00	86.00	0.29	2.48	16.90	4.60	63.30	69.00
C21	0.00	9.78	14.20	8.80	567.00	233.00	366.00	37.00	94.00	0.59	0.14	13.80	3.50	52.90	56.90
C25	12.00	0.00	10.20	7.50	644.00	258.00	410.00	20.00	88.00	0.41	0.00	17.90	4.50	77.80	52.50
C28	9.30	0.00	9.30	7.40	660.00	263.00	402.00	15.00	82.00	0.47	0.61	16.90	4.70	55.30	64.10
E11	0.00	9.17	13.60	8.10	583.00	230.00	382.00	14.00	92.00	0.56	0.65			54.50	59.80
E15	12.00	0.00	10.20	6.90	643.00	257.00	398.00	5.00	85.00	0.42	2.26	16.90	4.10	77.80	49.60
E17	18.00	0.00	9.20	7.30	633.00	254.00	428.00	12.00	84.50	0.53	2.99			75.40	58.30
F11	0.00	8.03	13.60	7.60	586.00	227.00	374.00	6.00	93.50	0.13	0.55	39.80	4.90	52.10	59.30
F15	12.00	0.00	10.00	6.80	650.00	266.00	420.00	8.00	91.50	0.30	2.46	16.90	4.70	69.80	59.80
F17	18.00	0.00	10.90	7.00	626.00	249.00	380.00	21.00	88.50	0.27	1.97	39.80	4.90	72.20	48.60
H21	0.00	9.26	13.60	7.80	580.00	219.00	364.00	21.00	92.00	0.01	0.52	39.80	4.90	56.90	53.90
H25	12.00	0.00	9.80	7.20	638.00	264.00	380.00	11.00	83.50	0.39	2.41	17.90	4.70	67.40	51.50
H28	21.00	0.00	9.20	6.90	654.00	267.00	414.00	14.00	79.50	0.49	4.18	19.00	4.80	77.80	53.50
J11	0.00		13.80	8.00	578.00	227.00	410.00	23.00	95.00	0.00	1.09	19.00	3.90	56.10	65.60
J15	12.00		10.00	6.80	652.00	266.00	430.00	17.00	85.50	0.33	2.50	25.20	4.90	77.80	57.30
J17	17.50		9.30	6.70	650.00	248.00	414.00	17.00	83.00	0.46	3.63	19.00	5.00	68.90	58.80

Table :11b Collected :24-25, Nov.,1995

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Riksha D				7.15	821.00	279.00	514.00	35.00	127.20	0.45	3.39	41.80	8.70	83.00	74.60
Naina D				6.98	796.00	288.00	495.00	16.00	132.60	0.23	4.20	23.10	5.80	88.60	66.60
SPRINGS															
Pardha S				8.00	701.00	269.00	467.00	10.00	122.00	0.00	3.29	20.00	2.90	70.20	70.90
Alma S				7.20	788.00	323.00	512.00	30.00	121.20	0.00	0.42	15.90	3.40	91.80	68.80
Lake S				8.30	834.00	332.00	555.00	16.00	137.40	0.13	0.84	13.80	2.10	149.20	44.50
S-4				8.60	475.00	86.00	302.00	13.00	140.40	0.00	0.69	31.50	1.80	53.70	40.80
Sipahi				8.50	582.00	228.00	370.00	10.00	80.50	-8.00	2.50	9.70	2.60	48.10	60.80
Gupha				8.60	566.00	222.00	347.00	9.00	82.50	0.03	2.93	10.70	2.30	49.30	54.40
Sariya S				7.40	586.00	249.00	419.00	10.00	90.50	-8.00	0.19	0.90	1.50	73.40	57.30
GW															
O. Well				7.10	708.00	237.00	439.00	19.00	111.50	0.15	2.85	15.90	3.50	70.60	63.90
Suk Wel				6.90	679.00	241.00	453.00	9.00	121.20	0.09	3.14			68.60	68.50
Jal Nigam				6.90	594.00	224.00	376.00	21.00	89.50	0.22	0.00	15.90	4.90	54.50	58.30
Jal Sans				7.50	693.00	270.00	423.00	21.00	104.50	0.12	1.97	16.90	3.60	56.10	68.80

Table :12 Collected :29-30, Dec,1995

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00		10.00	8.70	448.00	252.00	366.00	20.00	106.00	0.16	0.94	6.50	3.20	40.90	64.20
A34	9.00		9.80	8.30	469.00	254.00	358.00	28.00	93.50	0.16	0.87	9.20	3.80	52.10	55.40
A35	12.00		9.30	8.10	494.00	272.00	390.00	20.00	128.50	0.54	3.83	9.30	3.60	63.40	56.40
C21	0.00		10.60	8.10	450.00	254.00	372.00	10.00	49.00	0.17	0.92	8.80	3.10	53.70	57.80
C24	9.00		9.80	8.10	468.00	272.00	404.00	18.00	94.50	0.20	1.10	7.40	3.20	60.90	61.20
C28	21.00		9.40	7.70	497.00	300.00	422.00	22.00	87.00	0.58	4.99	9.20	4.40	66.60	62.20
E11	0.00		10.00	8.10	454.00	276.00	406.00	20.00	94.50	0.18	0.88	8.40	4.00	59.30	62.70
E17	18.00		9.80	8.10	458.00	272.00	338.00	20.00	90.50	0.11	0.89		3.30	44.10	55.40
F11	0.00		10.40	8.50	464.00	288.00	366.00	10.00	74.00	0.24	1.17	8.00	4.30	49.70	58.80
F14	9.00		9.80	8.30	464.00	276.00	356.00	14.00	76.50	0.17	0.94	8.10	5.80	52.90	54.40
F17	18.00		9.00	7.60	558.00	320.00	392.00	6.00	83.00	0.92	3.58	9.70	5.20	73.80	50.50
H21	0.00		10.00	8.20	457.00	316.00	376.00	8.00	93.50	0.14	0.93	9.80	6.20	52.10	59.80
H24	9.00		9.80	8.10	453.00	276.00	320.00	4.00	90.50	0.17	0.93	5.90	5.80	48.10	48.60
H27	18.00		9.00	7.80	522.00	300.00	374.00	4.00	72.50	0.80	3.21	6.80	6.70	60.20	54.40
J21	0.00		10.40	8.20	462.00	284.00	360.00	8.00	90.00	0.15	0.98	6.70	4.70	52.90	55.40
J24	9.00		10.00	8.00	459.00	284.00	318.00	12.00		0.19	0.89	6.50	4.80	41.70	52.00
J27	18.00		9.40	7.90	500.00	296.00	346.00	4.00	87.00	0.48	3.74	7.10	5.50	58.50	48.60
Y-TOP			10.00	8.10	463.00	288.00	368.00	8.00	90.50	0.32	1.89	5.40	3.60	52.90	57.30
Y-BOTT			9.80	8.00	449.00	276.00	332.00	10.00	96.00	0.15	1.84	6.30	4.30	45.70	52.90
SPRINGS															
Chuna S				8.20	625.00	360.00	498.00	22.00	162.00	0.06	3.28	8.00	7.00	100.30	60.30
L. View S				8.40	629.00	380.00	486.00	18.00	148.00	0.05	0.39	4.70	2.70	81.00	69.00
Sipahi S				8.30	434.00	288.00	324.00	10.00	122.00	0.04	2.25	4.60	3.20	48.90	49.10
Gupha S				8.30	468.00	280.00	350.00	16.00	75.00	0.04	2.46	4.30	2.90	46.50	56.90
GW															
Sukha				8.80	530.00	312.00	398.00	12.00	131.00	0.03	3.08	4.70	3.00	62.60	58.80
O. Well				8.00	548.00	364.00	432.00	20.00	138.50	0.07	2.33	5.80	3.60	72.20	61.20

Table :13a Collected :12-15,Jan, 1996

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31		0.00	9.80		454.00	260.00	402.00	20.00	94.50	0.16	0.95	7.10	4.70	60.90	60.80
A34			9.40		487.00	258.00	392.00	18.00	96.00	0.19	0.99	8.30	3.90	64.20	56.40
A35			9.20		502.00	292.00	414.00	32.00	114.00	1.47	1.88	9.50	4.20	57.70	65.60
C21		2.40	9.60		432.00	276.00	394.00	12.00	90.50	0.19	0.92	9.40	4.50	44.90	68.50
C24		2.90	9.20		462.00	264.00	398.00	20.00	88.00	0.18	1.07	9.20	4.30	39.30	72.90
C27		1.20	9.20		492.00	270.00	408.00	20.00	88.00	0.22	0.99	9.20	3.90	59.40	63.20
C29			9.20		515.00	284.00	412.00	12.00	118.00	0.50		9.90	3.60	28.10	96.00
E11		2.90	9.50		459.00	256.00	400.00	14.00	99.50	0.30	1.17	9.70	3.90	61.80	59.80
E14		2.80	9.40		464.00	264.00	376.00	12.00	102.50	0.16	0.95	9.20	3.70	61.80	53.90
E17		0.60	9.20		489.00	278.00	376.00	30.00	93.50	0.23	1.04	7.70	4.00	59.40	55.40
F11			9.60		471.00	268.00	392.00	20.00	98.50	0.16	1.26	7.90	5.00	50.50	64.60
F14			9.20		479.00	266.00	396.00	28.00	94.50	0.19	1.03	8.00	4.50	60.20	59.80
F17			9.20		485.00	280.00	420.00	14.00	106.00	0.21	0.16	7.90	4.50	56.60	66.60
H21		2.00	9.40		456.00	284.00	404.00	22.00	88.00	0.20	0.87	6.90	4.30	68.90	56.40
H24		1.80	9.20		473.00	266.00	402.00	20.00	97.00	0.15	0.89	7.70	4.20	55.30	64.20
H27		0.00	9.20		483.00	272.00	384.00	16.00	87.00	0.32	1.74	7.40	4.00	68.20	52.00
H29			9.20		515.00	314.00	400.00	22.00	116.50	0.70	3.62	7.40	5.20	73.00	52.90
J11		1.40	9.60		465.00	260.00	366.00	32.00	84.00	0.20	0.91	8.20	4.30	61.80	51.50
J14		2.60	9.20		460.00	266.00	364.00	30.00	145.00	0.21	1.02	7.40	3.90	53.70	55.90
J17		1.00	9.20		480.00	268.00	388.00	30.00	87.00	0.28	1.06	7.80	4.00		

Table :13b Collected :12-15,Jan, 1996

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Riksha D		8.60				298.00	502.00	24.00	94.50	0.56	4.18	9.60	6.60	47.30	93.30
Naina D		5.80				324.00	466.00	18.00	142.50	0.54	6.23	7.60	7.60	77.80	66.10
SPRINGS															
Chuna S						334.00	494.00	18.00	171.00	0.07	3.46	9.60	7.00	32.10	100.60
Pardha S						290.00	460.00	12.00	88.00	0.05	3.34	6.70	4.00	77.80	64.60
L. View S						374.00	522.00	2.00	144.00	0.04	0.69	5.20	5.20	53.70	94.30
Gupha S		8.40				240.00	356.00	14.00	97.00	0.07	2.27	4.70	2.90	46.50	58.30
Sipahi S						240.00	336.00	18.00	84.00	0.08	2.63	5.30	2.70	45.70	54.00
Sariya S						270.00	382.00	24.00	98.50	0.03	0.14	1.20	1.50	42.50	67.10
S5 S						204.00	202.00	6.00	15.00	0.03	0.00	2.10	0.00	36.90	26.70
GW															
O. Well		3.30				290.00	432.00	14.00	133.50	0.09	2.61	6.80	3.50	71.40	61.70
T. Well						332.00	462.00	22.00	122.00	0.08	3.40	5.00	5.30	77.80	65.10
T. Well 2						288.00	470.00	10.00	162.00	0.05	2.21	9.70	3.40	60.20	77.80
Sukha W						292.00	432.00	14.00	136.00	0.08	3.40	5.20	5.20	31.30	87.20

Table :14a Collected :27-30,Apr, 1996

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
LAKE															
A31	0.00	4.90	19.00		440.00	268.00	364.00	26.00	68.00					41.70	63.20
A34	9.00	2.60	10.00		410.00	304.00	340.00	14.00	72.00					38.50	52.30
A35	11.00	1.70	9.50		410.00	286.00	368.00	6.00	72.00					43.70	58.80
C21	0.00	4.70	19.00		440.00	242.00	336.00	10.00	73.00					37.70	58.80
C24	9.00	2.90	9.80		390.00	260.00	352.00	12.00	67.00					56.10	51.50
C27	18.00	2.00	9.00		370.00	256.00	348.00	18.00	70.00					52.10	53.00
C29	23.00		9.00		380.00	254.00	350.00	12.00	122.00					56.90	50.50
E11	0.00	2.90	19.80		460.00	244.00	326.00	12.00	73.00					56.90	44.70
E14	9.00	2.80	9.80		370.00	244.00	344.00	12.00	69.00					50.50	53.00
E17	18.00	0.60	9.00		360.00	256.00	360.00	18.00	71.00					57.70	52.50
F11	0.00		18.80		480.00	252.00	334.00	18.00	73.00					43.30	54.90
F14	9.00		9.80		420.00	268.00	350.00	12.00	69.00					62.60	47.10
F17	17.50		9.00		400.00	248.00	344.00	22.00	66.00					60.20	47.10
H21	0.00	4.10	18.80		490.00	260.00	348.00	16.00	69.00					46.50	56.40
H22	3.00		17.80		480.00	234.00	340.00	16.00	75.00					50.50	52.00
H23	6.00		12.40		440.00	258.00	354.00	10.00	69.00					52.90	53.90
H24	9.00	3.20	9.80		410.00	260.00	364.00	14.00	67.00					49.70	58.30
H25	12.00		9.20		400.00	254.00	344.00	16.00	65.00					47.30	54.90
H26	15.00		9.00		400.00	258.00	340.00	14.00	66.00					68.20	41.30
H27	18.00	1.60	9.00		400.00	252.00	346.00	14.00	65.00					52.90	52.00
H29	23.50	0.90	9.00		420.00	270.00	350.00	16.00	115.00					60.90	48.10
J11	0.00	4.60	19.30		490.00	244.00	346.00	14.00	68.00					40.10	59.80
J14	9.00	2.70	9.80		420.00	250.00	344.00	14.00	71.00					57.70	48.60
J17	16.00	2.00	9.20		410.00	250.00	328.00	20.00	64.00					41.70	54.40

Table :14b Collected :27-30,Apr, 1996

Parame units	Depth m (bws)	DO mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
DRAINS															
Riksha D		8.20				362.00	480.00	46.00	128.80					92.20	60.80
Naina D		7.40				392.00	440.00	56.00	108.40					38.50	83.40
SPRINGS															
Chuna S						308.00	514.00	28.00	167.50					99.40	64.60
Pardha S						260.00	414.00	18.00	128.80					60.20	64.20
L. View S						334.00	522.00	22.00	132.00					61.00	69.00
Gupha S		8.40				224.00	324.00	24.00	83.70					36.90	56.40
Sipahi S						224.00	314.00	20.00	88.00					45.70	48.60
Sariya S						242.00	360.00	14.00	89.00					52.90	[illegible]5.40
S5 S						174.00	204.00	18.00	21.50					38.50	26.20
GW															
O. Well		4.20				262.00	372.00	28.00	70.80					63.40	52.00
Pump 1						300.00	394.00	30.00	108.40					35.30	74.40
Pump 3						292.00	408.00	26.00	99.80					56.10	65.10
T.Well 3						278.00	398.00	26.00	131.00					36.90	74.40
Sukha W						268.00	424.00	18.00	126.70					51.30	71.90

Table: 15 Lake South Basin - Epilimnion

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94		10.0	7.5	385	260	386	8		0.00	0.00			67.0	54.0
May-94	5.60	19.9	8.6	600	133	372	1	110	0.00	0.00	9.9	4.5	46.1	62.5
Oct-94	9.50	20.1	8.2	506	189	254	13	77	0.00	0.40			26.5	45.7
Dec-94	2.20	11.4	8.0	547	240	316	6		0.16	0.75	12.0	4.4	47.0	49.0
Feb-95	5.60	9.2	6.8	516		322	11	72	0.27	0.20	11.8	4.6	51.3	47.1
Mar-95	11.10	16.0	9.4	888	260	326	16	96	0.16	0.00	13.6	4.2	42.4	58.4
May-95	13.90	21.1	7.8	570	206	280	9	85	0.12		9.6	4.6	32.9	48.1
Jun-95	12.50	22.4	7.6	600	199	289	18	90	0.22		13.6	3.4	35.7	48.6
Aug-95	18.40	21.6	8.9	392	204	240	10	97	0.14	0.00	17.0	6.1	44.1	31.6
Sep-95	14.00	20.2	8.4	440	196	264	16	55	0.02	0.00	14.1	4.9	36.1	42.3
Nov-95	9.78	14.2	8.8	567	233	366	37	94	0.59	0.14	13.8	3.5	52.9	56.9
Dec-95		10.6	8.1	450	254	372	10	49	0.17	0.92	8.8	3.1	53.7	57.8
Jan-96	2.40	9.6		432	276	394	12	91	0.19	0.92	9.4	4.5	44.9	68.5
Apr-96	4.70	19.0		440	242	336	10	73	0.03				37.7	58.8
Jul-96	13.80		7.1	542	186	260	14						32.1	43.7

Table: 16 Lake South Basin - Hypolimnion

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94		8.5	8.6	366	285	338			0.19	0.00			53.0	32.0
May-94	3.90		8.0	610	140	344	1	110	0.08	0.00	10.2	4.6	54.1	50.8
Oct-94		9.9	6.9	669	260	282	13		0.40	3.10			49.7	38.4
Dec-94	0.00	10.0	7.7	652	324	356	8		0.90	0.00	11.6	3.6	63.0	49.0
Feb-95	4.90	8.0	7.0	496		310	3	75	0.26	0.70	11.0	4.6	48.9	45.7
Mar-95	0.36	8.2	8.1	711	260	337	18	89	0.19	1.05	11.2	4.1	48.3	52.7
May-95	0.00	8.5	7.4	649	253	332	9	97	0.78		11.0	4.6	40.9	55.9
Jun-95	0.00	8.6	7.7	734	263	348	14	110	0.19		9.4	4.0	28.1	67.6
Aug-95		8.8	7.6	553	276	326	4	94	0.46	0.00	21.0	7.7	40.1	54.9
Sep-95		9.0	8.7	490	268	360	16	88	0.11	3.76	16.1	6.0	28.9	69.9
Nov-95	0.00	9.3	7.4	660	263	402	15	82	0.47	0.61	16.9	4.7	55.3	64.1
Dec-95		9.4	7.7	497	300	422	22	87	0.58	4.99	9.2	4.4	66.6	62.2
Jan-96		9.2		515	284	412	12	118	0.50		9.9	3.6	28.1	96.0
Apr-96		9.0		380	254	350	12	122	0.03				56.9	50.5
Jul-96	0.00		7.2	847	274	356	4						62.6	48.6

Table: 17 Lake North Basin - Epilimnion

parame	DO mg/l	Temp	pH	EC	Alkalinity	Hardness	Cl	Sulfate	P(PO-4)	N(NO-3)	Na	K	Ca	Mg
units	mg/l	°C		mic. mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Feb-94		9.2	8.1	404	272	352			0.20	0.00			56.0	52.0
May-94	5.40	18.6	8.6	600	132	365	4	112	0.02	0.00	10.0	4.8	45.7	60.9
Oct-94	8.50	20.5	8.2	521	178	248	15	86	0.00	0.30			26.5	44.6
Dec-94	1.30	11.6	8.1	553	234	310	4		0.13	0.65	11.2	4.1	46.0	48.0
Feb-95	4.80	8.4	6.6	553		324	1	85	0.19	1.00	14.0	4.4	50.5	48.1
Mar-95	15.50	15.4	9.1	740	238	306	16	101	0.16	0.00	13.4	4.5	37.0	52.0
May-95	10.80	20.3	8.0	583	209	304	13	86	0.09		11.6	4.5	42.5	48.1
Jun-95	10.50	23.6	7.8	608	194	285	3	120	0.12		10.8	3.8	26.5	53.2
Aug-95	17.10	22.2	8.9	392	204	248	0	87	0.15	0.00	19.0	7.2	32.1	40.1
Sep-95	16.30	20.2	8.5	440	180	266	28	93	0.36	0.00	14.1	5.0	38.5	41.3
Nov-95	9.26	13.6	7.8	580	219	364	21	92	0.01	0.52	39.8	4.9	56.9	53.9
Dec-95		10.0	8.2	457	316	376	8	94	0.14	0.93	9.8	6.2	52.1	59.8
Jan-96	2.00	9.4		456	264	404	22	88	0.20	0.87	6.9	4.3	68.9	56.4
Apr-96	4.10	18.8		490	260	348	16	69	0.03				46.5	56.4
Jul-96	16.70		6.9	651	198	252	10						33.7	40.8

Table: 18 Lake North Basin - Hypolimnion

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94		8.8		416		336				0.00			51.0	51.0
May-94	0.80	9.2	8.0	660	130	391	3	78	0.10	0.00	10.1	4.7	58.5	59.5
Oct-94	0.00		7.1	711	270	332	13	45	0.12	7.00			59.3	44.7
Dec-94	0.00	9.8	7.6	680	350	354	8		0.15	0.00	11.6	4.5	51.0	55.0
Feb-95	3.60	8.0	6.8	501		318	9	96	0.19	0.30	11.6	4.2	46.5	49.1
Mar-95	1.40	8.2	8.4	861	236	352	19	122	0.26	1.15	12.2	5.2	41.7	60.2
May-95	1.40	8.4	7.6	651	255	336	11	93	0.41		8.0	4.6	36.1	59.8
Jun-95	0.00	8.6	8.2	717	262	348	4	97	0.80		9.0	3.6	42.5	58.8
Aug-95		8.4	7.1	566	312	338	34	86	0.45	0.00	20.0	7.7	34.5	61.2
Sep-95		8.9	7.1	510	290	354	24	83	0.11	2.30	16.1	5.7	28.1	69.0
Nov-95	0.00	9.2	6.9	654	267	414	14	80	0.49	4.18	19.0	4.8	77.8	53.5
Dec-95		9.0	7.8	522	300	374	4	73	0.80	3.21	6.8	6.7	60.2	54.4
Jan-96		9.2		515	314	400	22	117	0.70	3.62	7.4	5.2	73.0	52.9
Apr-96	0.90	9.0		420	270	350	16	115	0.04				60.9	48.1
Jul-96	0.00		7.1	825	284	394	8						61.8	58.3

Table: 19 Naina devi mandir drain

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94			8.1	455	290	420	3		0.02	2.85			69.0	60.0
May-94	2.80		7.5	1040	202	542	9	173	0.48	1.50	10.4	9.3	86.2	79.5
Oct-94	7.40		7.7	807	290	408	14	85	0.10	3.20			43.3	72.9
Dec-94	5.30		7.6	822	328	434	4		0.43	2.00	12.2	7.4	71.0	62.0
Feb-95	6.00	11.0	7.0	490		350	22	125	0.35	2.90	15.2	6.4	20.1	72.9
Mar-95	3.40			999	366	464	27	194	0.10	2.35	19.0	8.7	57.5	77.9
May-95	0.70	19.5	7.1	1054	234	472	45	150	1.71		32.0	16.0	49.7	84.6
Jun-95														
Aug-95	8.30				292	396	10	147	0.13	4.80			34.5	75.3
Sep-95	3.90				306	398	26	117	0.13	3.57	18.2	5.0	36.1	74.8
Nov-95			7.0	796	288	495	16	133	0.23	4.20	23.1	5.8	88.6	66.6
Dec-95														
Jan-96	5.80				324	466	18	143	0.54	6.23			77.8	66.1
Apr-96	7.40				392	440	56	108					38.5	83.4
Jul-96			7.8	1090	300	444	16						87.4	54.9

Table: 20 Well located on North bank of Lake Nainital

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alk mg/l	Hardnes mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/i	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94														
May-94														
Oct-94	1.80		7.5	640	238	210	15	71	0.11	1.80			62.6	13.1
Dec-94	2.00		7.7	726	294	370	6		0.05	2.35	14.6	4.4	44.0	63.0
Feb-95						400	15	14	0.24	2.30	11.2	4.4	65.0	57.8
Mar-95														
May-95	4.70	15.2	7.3	734	262	330	15		0.16		14.0	4.5	36.9	57.8
Jun-95														
Aug-95					268	414	36	150	0.06	3.20	25.0	5.9	43.3	74.3
Sep-95					238	320	22	102	0.14	3.13	21.2	7.5	36.9	55.4
Nov-95			7.1	708	237	439	19	112	0.15	2.85	15.9	3.5	70.6	63.9
Dec-95			8.0	548	364	432	20	139	0.07	2.33			72.2	61.2
Jan-96	3.30				290	432	14	134	0.09	2.61			71.4	61.7
Apr-96	4.20				262	372	28	71					63.4	52.0
Jul-96			7.6	692	216	268	10						44.1	38.4

Table: 21 Well located in Sukhatal

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94														
May-94														
Oct-94														
Dec-94														
Feb-95														
Mar-95				840	262	367	19	168	0.05	3.60	9.8	3.5	37.9	66.3
May-95	5.60	13.5	7.4	764	210	300	17	135	0.03		12.0	3.2	38.5	49.6
Jun-95														
Aug-95														
Sep-95														
Nov-95			6.9	679	241	453	9	121	0.09	3.14			68.6	68.5
Dec-95			8.8	530	312	398	12	131	0.03	3.08			62.6	58.8
Jan-96					292	432	14	136	0.08	3.40			31.3	87.2
Apr-96					268	424	18	127					51.3	71.9
Jul-96														

Table: 22 Pardha Dhara (U/s Spring) located near Nainital water works

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94				520		356				3.50			58.0	52.0
May-94	5.70		8.1	845	150	478	6	177	0.00	2.90	8.6	3.0	85.8	64.2
Oct-94														
Dec-94	4.90		7.7	716	174	320	6		0.06	3.30	13.6	3.6	71.0	35.0
Feb-95														
Mar-95	4.60			818	296	432	23	176	0.03	4.15	12.4	4.5	61.1	67.9
May-95	15.30	15.0	7.3	821	234	304	13	170	0.03		13.6	3.3	28.9	56.4
Jun-95														
Aug-95					250	396	16	144	0.09	4.60	18.0	3.7	39.3	72.4
Sep-95					290	372	26	134	0.04	3.57	14.1	3.7	37.7	67.6
Nov-95			8.0	701	269	467	10	122	0.00	3.29			70.2	70.9
Dec-95														
Jan-96					290	460	12	88	0.05	3.34			77.8	64.6
Apr-96					260	414	18	129					60.2	64.2
Jul-96														

Table: 23 U/s Springs issuing from calcareous shales (near Alma cottage, Chuna dhara or Doctor house)

parame	DO mg/l	Temp	pH	EC	Alkalinity	Hardness	Cl	Sulfate	P(PO-4)	N(NO-3)	Na	K	Ca	Mg
units	mg/l	°C		mic. mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Feb-94														
May-94														
Oct-94														
Dec-94														
Feb-95														
Mar-95														
May-95		14.5	7.5	943	231	356	21	170	0.06		13.0	5.6	32.1	67.1
Jun-95														
Aug-95					208	302	28	86	0.04	3.50	12.0	2.2	33.7	52.9
Sep-95					330	476	24	150	0.02	4.32	22.3	7.8	40.1	91.4
Nov-95			7.2	788	323	512	30	121	0.00	0.42	15.9	3.4	91.8	68.8
Dec-95			8.2	625	360	498	22	162	0.06	3.28			100.3	60.3
Jan-96					334	494	18	171	0.07	3.46			32.1	100.6
Apr-96					308	514	28	168					99.4	64.6
Jul-96			8.1	923	340	408	2						73.0	54.9

Table: 24 Lake view (U/s) spring (issuing from shales)

parame	DO mg/l	Temp	pH	EC	Alkalinity	Hardness	Cl	Sulfate	P(PO-4)	N(NO-3)	Na	K	Ca	Mg
units	mg/l	°C		mic. mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Feb-94														
May-94														
Oct-94														
Dec-94														
Feb-95														
Mar-95				806	322	546	17	184	0.02	0.95	10.2	3.1	55.1	99.2
May-95		14.5	7.6	851	266	356	23	165	0.04		8.6	2.3	28.9	69.0
Jun-95														
Aug-95					250	418	16	100	0.09	1.80	14.0	2.6	38.5	78.2
Sep-95					392	524	20	184	0.02	0.26	13.0	2.9	40.9	102.5
Nov-95														
Dec-95			8.4	629	380	486	18	148	0.05	0.39			81.0	69.0
Jan-96					374	522	2	144	0.04	0.69			53.7	94.3
Apr-96					334	522	22	132					61.0	69.0
Jul-96			7.9	1050	326	470	6						97.0	55.4

Table: 25 S3 (D/s) spring (issuing in Kailakhan side)

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94														
May-94														
Oct-94														
Dec-94	8.10		8.2	654	228	384	8		0.00	0.00	12.8	1.5	83.0	43.0
Feb-95	8.80					398	25	138	0.14	0.00	12.6	1.6	58.6	61.2
Mar-95					224	366	11	208	0.07	0.00	14.0	2.2	62.6	51.1
May-95			7.6	885	187	350	12	192	0.07		32.0	2.5	38.5	61.7
Jun-95														
Aug-95					74	172	20	118	0.09	1.30	10.0	1.5	31.3	22.8
Sep-95					108	200	12	122	0.07	0.80	12.0	2.3	32.1	29.2
Nov-95			8.6	475	86	302	13	140	0.00	0.69	31.5	1.8	53.7	40.8
Dec-95														
Jan-96														
Apr-96														
Jul-96														

Table: 26 Sipahi Dhara (D/s) spring (issuing from dolomites)

parame units	DO mg/l mg/l	Temp °C	pH	EC mic. mho	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulfate mg/l	P(PO-4) mg/l	N(NO-3) mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Feb-94														
May-94														
Oct-94														
Dec-94	6.40		8.1	560	238	310	6		0.03	2.30	9.2	3.0	46.0	48.0
Feb-95														
Mar-95					244	354	13	150	0.00	2.10	9.0	3.8	46.4	57.9
May-95			7.7	632	230	312	18	99	0.07		9.6	3.0	36.9	53.5
Jun-95			8.2	676	236	327	0	100	0.06		8.0	2.6	43.3	53.2
Aug-95					218	302	20	82	0.05	4.50	20.0	4.5	36.1	51.5
Sep-95					236	314	18	134	0.08	3.79	13.0	3.5	36.9	53.9
Nov-95			8.5	582	228	370	10	81	-8.00	2.50	9.7	2.6	48.1	60.8
Dec-95			8.3	434	288	324	10	122	0.04	2.25	4.6	3.2	48.9	49.1
Jan-96					240	336	18	84	0.08	2.63	5.3	2.7	45.7	54.0
Apr-96					224	314	20	88					45.7	48.6
Jul-96			7.9	789	238	348	8						68.2	43.3

5.1 Characterisation of Waters

In general all the springs that issue within the catchment, the water flowing in the nalahs and the Nainital water are of Magnesium-Bicarbonate type. However, the springs that issue outside the catchment, particularly S2, S3 and S4 located in the kailakhan side (Fig. 2) which were thought to be as leakages from the lake based on topography and stable isotope data (refer section on stable isotopes) are not of the same type of water as in Nainital. These spring waters are of Magnesium-Sulphate type. This may be considered as indicative of the fact that the sources of these springs may not be the lake. Fürther, the springs that issue at Durgapur power house are also Magnesium-sulfate type. However, the springs Sipahi dhara, Gupha mahadev, Rais hotel (Reserve police lines), Sariyatal, Takula spring are all of magnesium bicarbonate type, same as the lake water.

The following table summarises the water types of different sources:

Sl. No.	Source / Location	Water type
1.	Lake : Nainital	Magnesium Bicarbonate
2.	Spring: Pardha Dhara	Magnesium Bicarbonate
3.	Drain : Naina Devi	Magnesium Bicarbonate
4.	Spring: Alma Cottage	Magnesium Bicarbonate
5.	Spring: Lake View	Magnesium Bicarbonate
6.	Spring: Chuna Dhara	Magnesium Bicarbonate
7.	Spring: Sipahi Dhara	Magnesium Bicarbonate
8.	Spring: Gupha Mahadev	Magnesium Bicarbonate
9.	Spring: Rais Hotel	Magnesium Bicarbonate
10.	Spring: S2 Kailakhan	Magnesium Sulfate
11.	Spring: S3 Kailakhan	Magnesium Sulfate
12.	Spring: S4 Kailakhan	Magnesium Sulfate
13.	Spring: S5 Takula vil	Magnesium Bicarbonate

14.	Spring: Durgapur	Magnesium Sulfate
15.	Spring: Ratighat	Calcium Bicarbonate
16.	Spring: Sariyatal	Magnesium Bicarbonate
17.	Lake : Khurpatal	Magnesium Bicarbonate
18.	Well : Sukhatal	Magnesium Bicarbonate
19.	Well : Mallital	Magnesium Bicarbonate

5.2 Temporal Variation in the Water Quality

To study the temporal variation in the water quality of lake, let us consider the two key parameters that reflect the overall conditions viz. the electrical conductivity and the hardness. Total hardness ranges from a minimum of 292 mg/L to a maximum of 396 mg/L. In general the hardness was higher during winter (November to January) and lower during rainy season. It is also noted that during the months of significant inflow to the lake (March, July, August and October) the lake shows a reduction in hardness. This is possible if the rainfall related surface runoff has a low runoff time, and the runoff is loaded with comparatively less ions that causes the hardness.

Further, significant inflow to the lake during October (during which period there was no rainfall) is from lake Sukhatal, the water of which finds its way to Nainital through the fault controlled subterranean pathway. It is possible that this process also does not allow the water to interact with the rock system to be significantly loaded with hardness causing ions.

Apart from these two sources the lake also receives inflow from the surrounding aquifers, that is high in hardness. Therefore, the hardness in the lake is due to natural process, since the catchment is dominated by dolomites and calcareous shales. The weathering and related physical and chemical erosion leads to dissolution of these rock types and thereby enriches the associated water in Calcium and Magnesium. It is also interesting to note that the hardness of the lake water has not changed significantly, atleast for the past 45 years. This is observed from the hardness data presented by Pant et al. (1980) [Data Source: Nainital water works]. The data is given below:

Year	No. of Samples	Hardness (mg/L)
1954	12	300
1955	9	300
1956	16	320
1957	14	312
1958	14	300
1959	12	320
1960	10	305
1961	13	302
1962	12	300
1963	14	340
1964	13	336
1965	9	344
1966	14	340
1967	11	343
1968	10	349
1969	13	347
1970	15	345
1971	17	337
1972	17	348
1973	24	368
1974	23	380
1975	24	400
1994 ✣	11	326
1995 ✣	40	306
1996 ✣	14	330

✣ Data collected under the present study that pertains only to surface waters

The above data can not be considered as representative of the whole lake, as the data pertains only to the surface waters. It however, gives an idea that the hardness has not significantly varied, during the past several years. This could be due to the reason that the residence time of lake waters is very low (refer section on water balance).

6.0 DISCUSSION

6.1 Electrical Conductance

Electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. Specific electrical conductance is the conductance of a body of unit length and unit cross section at a specified temperature. This term is synonymous with volume conductivity and is the reciprocal of volume resistivity. The American Society for Testing and Materials defined electrical conductivity of water as the reciprocal of the resistance in mhos measured between opposite faces of a centimetre cube of an aqueous solution at a specified temperature. This definition further specifies that units for reporting conductivity shall be micromhos per centimetre at t°C. Because the definition already specifies the dimensions of the cube to which the measurement applies, the added precaution of including the length in the unit may not be essential and is often omitted in practice. The standard temperature for laboratory measurements is 25°C, but because other standard temperatures were used in the past it is important that the temperature of measurement be specified. Under the International System of Units (SI) the unit of conductivity is Siemens. The microsiemens (μS) is numerically the same as the micromho.

The specific conductance of the purest water that can be made would approach 0.5 μmho/cm, but ordinary single-distilled water or water passed through a deionizing exchange unit normally has a conductance of at least 1.0 μmho/cm. Carbon dioxide from the air in the laboratory dissolves in distilled water that is open to the air, and the resulting bicarbonate and hydrogen ions impart most of the observed conductivity.

Rain water has ample opportunity before touching the Earth to dissolve gases from the air and also may dissolve particles of dust or other airborne material. As a result, rain may have a conductance much higher than distilled water, especially near the ocean or near sources of atmospheric pollution.

The conductance of surface and ground waters has a wide range, of course, and in some areas may be as low as 50 μmho/cm where precipitation is low in solutes and rocks are resistant to attack. In other areas, conductances of 50,000 μmho/cm or more may be reached; this is the approximate conductance of seawater. Brine associated with halite may contain as much as ten times the dissolved-solids concentration of seawater.

The accuracy of field measurements of conductivity made with good portable equipment and proper attention to temperature effects should be about the same as the accuracy of laboratory measurements if the temperature is near 25°C. Conductivity devices that have been permanently installed in the field require periodic maintenance to prevent electrode fouling and (or) other interferences that may cause erroneous readings and loss of record.

The EC in the lake waters vary from a minimum of 412 μS/cm to a maximum of 742 μS/cm. EC shows a larger temporal variation than hardness, and cannot easily be related to any hydrological process. However a first look indicates that the EC during the spring, summer and early part of the monsoon is controlled by surface runoff inputs and during later part of monsoon and winter by subsurface inputs. The higher EC and hence the total dissolved solids (TDS) in the month of March may be due to heavy snowfall during the preceding months and resultant melt water flowing into the lake, as sub-surface and also as interflow. Since the groundwater (lake view spring) is also high in TDS (with an EC of 800 μS/cm to 1050 μS/cm), the lake may infact be reflecting the characteristics of its major source. The epilimnion is low in EC in both the sub-basins when compared to the hypolimnion. The lake waters show a comparatively low EC during the late winter period (February), which incidentally is the well mixed period. The EC ranges between 400 and 450 μS/cm. As noted above the EC is high during March (Spring season) and October and November (post monsoon) with an EC range of 700 to 800 μS/cm.

The Pardha dhara spring that issues from dolomite, in the Lake fault zone, has an average EC of 740 μS/cm (520 μS/cm to 850 μS/cm). This mean and range of EC closely resembles that of Sukhatal well. The springs that issue from calcareous shales (Alma spring, Chuna dhara and Doctor House spring) as well as Lake view spring has a mean of 825 μS/cm (625 μS/cm to 1050 μS/cm). This may be indicative of the fact that the aquifer that feed the springs in the shales which is recharged by natural infiltration process has a relatively higher EC. On the other hand the Pardha dhara which is thought to be having its source as the infiltrated waters of Sukhatal lake, a seasonal lake in upstream side shows comparatively lower EC.

The perennial drain, the nalah that flows near the Naina devi mandir, shows an average EC of 840 μS/cm (460 μS/cm to 1090 μS/cm). The large range of EC is due to the fact that the nalah during February shows a strikingly lower EC, than other months. Hence the average is close to the higher side of the EC range. In general the nalah waters are high in EC. This is because of disposal of domestic effluent and the effluent from the mushrooming hotel industry into these nalahs. The common bathing facility constructed by the side of Nainital water works also leads to the increase in pollutants, which will be discussed in the lake eutrophication section.

The EC in the well waters (wells located on the northern bank of Nainital), unfortunately, have not been measured regularly. However, the available data indicates that the variation in EC of well waters follow the pattern of lake epilimnion. This is also indicative of the fact that the water drawn through these wells are dominated by the seepage from the lake. These wells have an average EC of 675 μS/cm (640 μS/cm to 740 μS/cm). The well located on Sukhatal has an average EC. of 700 μS/cm (530 μS/cm to 840 μS/cm). While the average EC of the waters from both well groups are very close, the range of EC differs significantly.

6.2 Dissolved Oxygen

The equilibrium concentration of dissolved oxygen (DO) in water in contact with air is a function of temperature and pressure, and to a lesser degree, of the concentration of other solutes. At 5°C in freshwater the equilibrium DO value is 12.75 mg/L. Values for DO in water analyses may be given in milligrams per litre or as a percentage of saturation at the temperature of measurement.

The higher forms of aquatic life require oxygen for survival, and the DO determination is used widely in evaluations of the biochemistry of streams and lakes. The DO concentration may be depleted by processes that consume dissolved, suspended, or precipitated organic matter, and values above equilibrium can be produced in systems containing actively photosynthesizing biota. The extent to which a supply of oxygen can be maintained in a polluted stream or lake depends in part on the hydraulic properties that influence rates at which atmospheric oxygen can be supplied in the water column; the stream can assimilate more organic or other oxidizable material without significant degradation when the rate is rapid than when it is slow.

Oxygen is supplied to ground water through recharge and by movement of air through unsaturated material above the water table. This oxygen reacts with oxidizable material encountered along the flow path of the water. Water containing measurable amounts of dissolved oxygen may penetrate long distances into the system if little reactive material is available. The principal reacting species are organic materials and reduced inorganic minerals such as pyrite and siderite. As time passes the oxidizable material in the aquifer will be removed or altered for long distances from the point of recharge.

For various reasons, determining dissolved oxygen in ground water has not been a standard practice. The dissolved-oxygen concentration of a ground water could not be used as an indicator of organic pollution. Nor would it be significant in evaluating the usability of the water for ordinary purposes. The determination would require special sampling equipment and care and would normally need to be completed immediately after sampling.

There is a general impression that most ground waters contain little or no dissolved oxygen. Actually, the water that enters ground-water systems as recharge can be expected to contain oxygen at concentrations similar to those of surface water in contact with the atmosphere, unless the recharge has encountered oxidizable material below the land surface. Buried organic matter or oxidizable minerals are plentiful enough in some systems to deplete oxygen quickly. It seems likely that significant concentrations of dissolved oxygen occur in ground water in many areas.

The epilimnion of Lake Nainital showed varying degrees of dissolved oxygen contents. In the winter and summer months the DO is much less than the saturated values and during the monsoon it is much higher than the saturated DO. The observed DO values above the saturated values during monsoon months could be related to the excessive biotic activities. This has also been reported by earlier workers (Pant et al., 1980; Gupta and Shukla, 1997). The Hypolimnion waters, on the other hand, was generally devoid of dissolved oxygen. DO in the bottom waters was observed only during late winter and early summer. The DO in February was 30%, and during March, April and May ranged between 7 and 12 %. Between June and January, DO was virtually absent and anoxic conditions prevailed in the bottom waters. This seriously hampers the decay of dead organic matter that settles to the bottom and also creates a reducing condition leading to release of unwarranted matter from the sediments.

6.3 Calcium

Calcium is the most abundant of the alkaline-earth metals and is a major constituent of many common rock minerals. It is an essential element for plant and animal life forms and is a major component of the solutes in most natural water. Calcium has only one oxidation state, Ca^{2+}. Its behaviour in natural aqueous systems is generally governed by the availability of the more soluble calcium-containing solids and by solution-and gas-phase equilibria that involve carbon dioxide species, or by the availability of sulfur in the form of sulfate. Calcium also participates in cation-exchange equilibria at aluminosilicate and other mineral surfaces. Solubility equilibrium models have been used widely in studying the chemical behaviour of calcium. The most common forms of calcium in sedimentary rock are carbonates. The two crystalline forms, calcite and aragonite, both have the formula $CaCO_3$, and the mineral dolomite can be represented as $CaMg(CO_3)_2$. Limestone consists mostly of calcite with admixtures of magnesium carbonate and other impurities. A carbonate rock is commonly termed dolomite if the magnesium is present in amounts approaching the theoretical 1:1 mole ratio with calcium. Other calcium minerals common in sediments include the sulfates gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$), and, more rarely, the fluoride, fluorite (CaF_2). Calcium is also a component of some types of zeolite and montmorillonite.

In sandstone and other detrital rocks, calcium carbonate commonly is present as a cement between particles or a partial filling of interstices. Calcium also is present in the form of adsorbed ions on negatively charged mineral surfaces in soils and rocks. Because divalent ions are held more strongly than monovalent ions at surface charge sites, and because calcium is generally the dominant divalent in solution, most such sites are occupied by calcium ions in the usual river or ground-water system.

Generally calcium is the predominant cation in river water. The pH of river water is influenced by many factors, especially by photosynthesizing organisms. These organisms commonly cause diurnal and seasonal fluctuations, with higher pH values on summer days and lower values at night and during other periods of low photosynthetic activity. The measured pH in river water is generally not well correlated with calcium and bicarbonate activities. Rivers in more arid regions, especially where some of the more soluble rock types are exposed, tend to have much higher dissolved-calcium concentrations.

When river water is impounded in a storage reservoir, changes may occur in calcium content as a result of calcium carbonate precipitation. The increased pH near the water surface, caused by algae and plankton, may bring about supersaturation, and precipitation can occur on solid surfaces around the edges of the water body. The fresh water deposit called marl, which is formed in many lakes, is made up partly of calcium carbonate.

In closed basins, water can escape only by evaporation, and the residual water can be expected to change in composition after a fairly well defined evolutionary pattern. The less soluble substances, including calcium carbonate, are lost first, followed by calcium sulfate.

Equilibrium solubilities can be expected to control calcium concentrations in many ground-water systems. Unfortunately, many published chemical analyses of such waters are unsuitable for rigorous testing of calcite-solubility models owing to lack of accurate on site measurements for pH and alkalinity. However, if the acceptable uncertainty in saturation index calculations is broadened, the application of calcite equilibria to some of the ground-water analyses may be useful. Approximations of this kind often are of value in water-analysis interpretation.

Equilibrium with respect to gypsum is obviously to be expected in ground water from a gypsiferous aquifer. As the amount of other solutes increases, the solubility of gypsum will tend to increase owing to greater ionic strength and smaller activity coefficients. In a solution containing 2,500 mg/L of chloride and about 1,500 mg/L of sodium, the equilibrium concentration of calcium would be near 700 mg/L. These calculations presuppose nearly equivalent concentrations of calcium and sulfate. Frequently, this does not occur in natural water. When the solution is in equilibrium with gypsum, however, any increase in sulfate activity would be matched by a decrease in calcium as $CaSO4$ precipitates.

Water that has been trapped underground for a long time could be altered from its original composition by selective permeability of strata for different solutes, by the bacterial reduction of sulfate and other dissolved ions, and by adsorption or desorption of dissolved ions, as well as by chemical solution or precipitation of minerals. Water that is strongly influenced by irrigation return flow may approach simultaneous equilibrium with both calcite and gypsum.

The calcium content in both top and bottom waters of Lake Nainital show a seasonal variation. It ranges from a minimum of around 30 mg/L during late summer (June) and a maximum of around 60 mg/L during winter. This could probably be related to the precipitation of calcite during summer months, when the lake shows a steady reduction in Ca content. The increase in Ca during the advent of winter may be linked to either dissolution of precipitated calcium carbonate (which is highly unlikely) or a large subsurface inflow which is high in Ca.

The calcium content in Nalah inflow waters is in general low during February, August and September. This indicates that the surface inflow during the snow melt period and during monsoon season is low in Ca content. The Ca content ranges from a minimum of 20 mg/L to a maximum of 90 mg/L.

6.4 Magnesium

Magnesium is an alkaline-earth metal and has only one oxidation state of significance in water chemistry, Mg^{2+}. It is a common element and is essential in plant and animal nutrition.

In some aspects of water chemistry, calcium and magnesium may be considered as having similar effects, as in their contributions to the property of hardness. The geochemical behaviour of magnesium, however, is substantially different from that of calcium. Magnesium ions are smaller than sodium or calcium ions and can be accommodated in the space at the centre of six octahedrally coordinated water molecules, an arrangement similar to that described for aluminium. The hydration shell of the magnesium ion is not as strongly held as that of aluminium ions, but the effect of hydration is much greater for magnesium than for the larger ions of calcium and sodium. The tendency for precipitated crystalline magnesium compounds to contain water or hydroxide is probably related to this hydration tendency.

Sedimentary forms of magnesium include carbonates such as magnesite and hydromagnesite, the hydroxide brucite, and mixtures of magnesium with calcium carbonate. Dolomite has a definite crystal structure in which calcium and magnesium ions are present in equal amounts.

The magnesium ion, Mg2+, will normally be the predominant form of magnesium in solution in natural water. It has been shown that the complex MgOH+ will not be significant below about pH 10. The ion pair MgSO4(aq) has about the same stability as the species $CaSO_4$(aq), and magnesium complexes with carbonate or bicarbonate have approximately the same stability as the similar species of calcium. The sulfate ion pair and the bicarbonate complex will be significant if the solution contains more than 1,000 mg/L of sulfate or bicarbonate. Before it reaches saturation with respect to either dolomite or calcite, a water passing through dolomite should dissolve equal molar amounts of calcium and magnesium.

Magnesium content of the surface waters of Lake Nainital varies from a minimum of 30 mg/L to a maximum of 60 mg/L. The minimum values are associated with higher surface inflow during monsoon season. the maximum values are associated with winter overturn process. The bottom waters are slightly higher in its Mg content. It ranges from 45 mg/L to 70 mg/L. The minimum values are observed during winter season, most probably related to the lake's winter overturn process, as noted above. The maximum values in the hypolimnion are observed during late monsoon period. This could probably be associated with the large subsurface inflow from the dolomite aquifers.

The magnesium content in Nalah inflow waters is minimum during winter. The Mg content ranges from a minimum of 60 mg/L to a maximum of 85 mg/L.

6.5 Sodium

Sodium is the most abundant member of the alkali-metal group of the periodic table. The other naturally occurring members of this group are lithium, potassium, rubidium, and cesium. In igneous rocks, sodium is slightly more abundant than potassium, but in sediments, sodium is much less abundant. The amounts of sodium held in evaporite sediments and in solution in the ocean are an important part of the total. All the alkali metals occur in the 1+ oxidation state and do not participate in redox processes. Sodium ions have a radius somewhat greater than 1 angstrom and are not strongly hydrated.

When sodium has been brought into solution, it tends to remain in that status. There are no important precipitation reactions that can maintain low sodium concentrations in water, in the way that carbonate precipitation controls calcium concentrations. Sodium is retained by adsorption on mineral surfaces, especially by minerals having high cation-exchange capacities such as clays. However, the interaction between surface sites and sodium, and with monovalent ions generally, is much weaker than the interactions with divalent ions. Cation-exchange processes in fresh water systems tend to extract divalent ions from solution and to replace them with monovalent ions.

According to an estimate, about 60 % of the body of igneous rock in the Earth's outer crust consists of feldspar minerals. The feldspars are tectosilicates, with some aluminium substituted for silica and with other cations making up for the positive-charge deficiency that results. The common feldspars are orthoclase and microcline and the plagioclase series ranging in composition from albite to anorthite. Some sodium may be present, substituting for potassium in orthoclase and microcline.

Potassium feldspar is resistant to chemical attack. However, species containing sodium and calcium are somewhat more susceptible to weathering; they yield the metal cation and silica to solution and commonly form a clay mineral with the aluminium and part of the original silica.

Human activities can have a significant influence on the concentrations of sodium in surface water and ground water. The use of salt for deicing highways in winter and the disposal of brine pumped or flowing from oil wells, for example, have had direct, noticeable regional effects. Somewhat less directly, the reuse of water for irrigation commonly leaves a residual that is much higher in sodium concentration than was the original water. Pumping of ground water, which alters hydraulic gradients, can induce lateral movement of seawater into fresh-water coastal aquifers. Water associated with evaporite formations generally has a very high sodium concentration. Anthropogenic effects on sodium concentrations are demonstrated by high sodium concentration of residual drainage.

The Na ion is not a major constituent in the Lake Naintal, when compared to Ca and Mg. The Na ranges from 10 mg/L to 20 mg/L. There is single well defined peak during the monsoon season. However the rising limb of the peak in surface waters is less sharply defined than that of the bottom waters.

The Na^+ content of the Nalah waters, ranges between 13 mg/L to 33 mg/L. The peak observed during summer (in the month of May) may be a resultant of polluted sewage flow. The effluent from the nearby hotel industry could be probable reason for this spike during May.

6.6 Potassium

Potassium is slightly less common than sodium in igneous rock but more abundant in all the sedimentary rocks. In the ocean the concentration of potassium, though substantial, is far less than that of sodium. Sodium tends to remain in solution rather persistently once it has been liberated from silicate-mineral structures. Potassium is liberated with greater difficulty from silicate minerals and exhibits a strong tendency to be reincorporated into solid weathering products, especially certain clay minerals. In most natural water, the concentration of potassium is much lower than the concentration of sodium.

Another important factor in the hydrochemical behaviour of potassium is its involvement in the biosphere, especially in vegetation and soil. Potassium is an essential element for both plants and animals. Maintenance of optimum soil fertility entails providing a supply of available potassium. The element is present in plant material and is lost from agricultural soil by crop harvesting and removal as well as by leaching and runoff acting on organic residues.

The principal potassium minerals of silicate rocks are the feldspars orthoclase and microcline, the micas, and the feldspathoid leucite. The potassium feldspars are resistant to attack by water. Presumably they are altered to silica, clay, and potassium ions by the same process as other feldspars, only more slowly.

In sediments, the potassium commonly is present in unaltered feldspar or mica particles or in illite or other clay minerals. Evaporite rocks may locally include beds of potassium salts and constitute a source for high potassium concentration in brines.

Average content of potassium in living plants is near 0.3 percent. Concentrations in dry plant material and in ash are substantially greater. Wood ashes have been used by humans as a potash source for many centuries. In dilute natural waters in which the sum of sodium and potassium is less than 10 mg/L, it is not unusual for the potassium concentration to equal or even exceed the sodium concentration.

However, in most other fresh-water aquifers, if the sodium concentration substantially exceeds 10 mg/L the potassium concentration commonly is half or a tenth that of sodium. Concentrations of potassium more than a few tens of milligrams per litre are decidedly unusual except in water having high dissolved-solids concentration or in water from hot springs.

The K^+ content in surface waters of the Lake ranges from 3.5 mg/L to 7 mg/L. As in the case of Na^+ ions, the K^+ content also shows a peak in monsoon season. The south basin is comparatively low in K^+ content, and the North basin is slightly higher. This could be due to the reason that most of the surface inflow is through the Nalahs draining the larger part of the catchment. In the hypolimnion, the picture is not too different from that of Epilimnion, in K content, except that the range of variation is slightly larger, i.e., it ranges from 4 mg/L to 8 mg/L. In the bottom waters also the K^+ shows a definite peak during monsoon season. The potassium content is, in general, one third to one fourth of the sodium content.

The K^+ content of the Nalah waters varies from a minimum of 4 mg/L to maximum of 16 mg/L. The peak, as in the case of sodium, is observed during the May, the month of maximum tourist influx.

6.7 Alkalinity

The properties of alkalinity and acidity are important characteristics of natural and polluted waters and are almost always included in the chemical determinations. However, these properties differ in important ways from most of the other determinations reported in the analysis. Both are defined as capacity functions - that is, the capacity of the solution to neutralize acid or base. Both properties may be imparted by several different solute species.

and both are evaluated by acid-base titration, to appropriate end points. Systems having these properties are commonly referred to by chemists as buffered systems.

Most quantities determined in chemical analyses are intensity functions-that is, they are actual concentrations of a particular dissolved species at the time of analysis. The measurement of pH provides values of concentrations of H+ and OH- in solution. These species contribute, of course, to acidity or alkalinity, but within in pH range commonly seen in natural water they are minor constituents. The principal solutes that constitute alkalinity are imparted to natural water during its passage in liquid form through the hydrologic cycle. They reflect the history of the water, as an imprint left by these encounters. The properties of alkalinity or acidity also evaluate the potential of the solution for some kinds of water-rock interaction or interaction with other material the water may contact.

Most natural waters contain substantial amounts of dissolved carbon dioxide species, which are the principal source of alkalinity and can conveniently be evaluated by acid titrations. Undissociated dissolved carbon dioxide contributes to acidity rather than to titratable alkalinity and can also be determined by titration using a basic solution.

The alkalinity of a solution may be defined as the capacity for solutes it contains to react with and neutralize acid. The property of alkalinity must be determined by titration with a strong acid, and the end point of the titration is the pH at which virtually all solutes contributing to alkalinity have reacted. The end-point pH that should be used in this titration is a function of the kinds of solute species responsible for the alkalinity and their concentrations. However, the correct titration end point for a particular solution can be identified from the experimental data when the species involved are unknown. It is the point at which the rate of change of pH per added volume of titrant acid is at a maximum. The best values for the end points for a particular sample depend on ionic strength and temperature. Analytical procedures may specify a pH value between 5.1 and 4.5, or that of the methyl-orange end point (about pH 4.0-4.6). Sometimes, however, an alkalinity above the phenolphthalein end point (about pH 8.3) is also specified. Thus one may find terms such as methyl-orange alkalinity, or its equivalent, total alkalinity, and phenolphthalein alkalinity.

Several different solute species contribute to the alkalinity of water as defined above, and titration with acid does not specifically identify them. The property of alkalinity can be expressed in quantitative terms in various ways. The most common practice is to report it in terms of an equivalent amount of calcium carbonate. It could also be expressed in milliequivalents per litre, where meq/L is 1/50 times mg/L $CaCO_3$. In almost all natural waters the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate, and the end points mentioned above were selected with this in mind. Analyses in current geochemical literature, follow the convention of reporting titrated alkalinity in terms of the equivalent amount of bicarbonate and carbonate.

The more important noncarbonate contributors to alkalinity include hydroxide, silicate, borate, and organic ligands, especially acetate and propionate. Rarely, other species such as NH4OH or HS- may contribute significantly to alkalinity. If alkalinity is expressed in milliequivalents per litre, or as $CaCO_3$, the contributions from these species will affect the cation-anion balance of the analysis only if some of them are determined by other methods and are thus included in the balance computation in two places.

Except for waters having high pH (greater than about 9.50) and some others having unusual chemical composition, especially water associated with petroleum and natural gas or water having much dissolved organic carbon, the alkalinity of natural waters can be assigned entirely to dissolved bicarbonate and carbonate without serious error. The principal source of carbon dioxide species that produce alkalinity in surface or ground water is the CO_2 gas fraction of the atmosphere, or the atmospheric gases present in the soil or in the unsaturated zone lying between the surface of the land and the water table. The CO_2 content of the atmosphere is near 0.03 percent by volume. Soil-zone and unsaturated-zone air can be substantially enriched in carbon dioxide, usually owing to respiration by plants and the oxidation of organic matter.

In some natural systems there may be sources of carbon dioxide other than dissolution of atmospheric or soil-zone CO_2. Possible major local sources include biologically mediated sulfate reduction and metamorphism of carbonate rocks.

Carbon dioxide species are important participants in reactions that control the pH of natural waters. Reactions among the alkalinity-related species, aqueous CO_2, H_2CO_3(aq.), HCO_3^-, and CO_3^{2-}, and directly pH related species, OH^- and H^+, are relatively fast and can be evaluated with chemical equilibrium models. Rates of equilibration between solute species and gaseous CO_2 across a phase boundary are slower, and water bodies exposed to the atmosphere may not be in equilibrium with it at all times. The oceans are a major factor in maintaining atmospheric CO_2 contents. It may be of interest to note that carbonic acid, H_2CO_3, is conventionally used to represent all the dissolved undissociated carbon dioxide. In actuality, only about 0.01 percent of the dissolved carbon dioxide is present in this form. We will use the H_2CO_3 convention in discussing these systems, however, as the choice of terminology has no practical effect on final results.

In more calcareous environments, the circulation of water rich in carbon dioxide may produce solutions that are highly supersaturated with respect to $CaCO_3$ when exposed to air. Such solutions may deposit large quantities of calcium carbonate as travertine near their points of discharge.

The bicarbonate concentration of natural water generally is held within a moderate range by the effects of carbonate equilibria. The concentration in rainwater commonly is below 10 mg/L and sometimes is much less than 1.0 mg/L, depending on pH. Most surface streams contain less than 200 mg/L, but in ground waters somewhat higher concentrations are not uncommon. Concentrations over 1,000 mg/L occur in some waters that are low in calcium and magnesium, especially where processes releasing carbon dioxide (such as sulfate reduction) are occurring in the ground-water reservoir.

The alkalinity in the surface waters of the Lake Nainital ranges from 180 to 300 mg/L, and in general is higher during winter. The hypolimnion waters have alkalinity ranging from 240 to 320 mg/L. In this layer also the alkalinity is higher during winter, and a small peak is also observed during monsoon season.

6.8 Sulfur

The chemical behaviour of sulfur is related strongly to redox properties of aqueous systems. In the most highly oxidized form, the effective radius of the sulfur ion is only 0.20 angstrom and it forms a stable, four-coordinated structure with oxygen, the SO_4^{2-} anion. The reduced ion, S^{2-}, forms sulfides of low solubility with most metals. Because iron is common and widely distributed, the iron sulfides have a substantial influence on sulfur geochemistry. The element is essential in the life processes of plants and animals.

Sulfur is widely distributed in reduced form in both igneous and sedimentary rocks as metallic sulfides. Concentrations of these sulfides commonly constitute ores of economic importance. When sulfide minerals undergo weathering in contact with aerated water, the sulfur is oxidized to yield sulfate ions that go into solution in the water. Hydrogen ions are produced in considerable quantity in this oxidation process. Pyrite crystals occur in many sedimentary rocks and constitute a source of both ferrous iron and sulfate in ground water.

Oxidation of pyrite and other forms of sulfur also is promoted by humans: the combustion of fuels and the smelting of ores are major sources of sulfate for natural water. Organic sulfides also may undergo oxidation in natural soil processes or in organic waste treatment. Sulfate occurs in certain igneous-rock minerals of the feldspathoid group, but the most extensive and important occurrences are in evaporite sediments. Calcium sulfate as gypsum, $CaSO_4.2H_20$, or as anhydrite, which contains no water of crystallization, makes up a considerable part of many evaporite-rock sequences. Barium and strontium sulfates are less soluble than calcium sulfate but are relatively rare. Sodium sulfate is formed in some closed-basin lakes, as noted in the discussion of sodium occurrence.

Moderately low sulfate concentrations are typical of rainfall in relatively unpolluted areas. Although sulfur oxides are probably a major factor in producing rainfall having a low pH, the correlation between acidity and sulfate concentration is not always close. In some areas nitrogen oxides may be more important contributors.

Sulfate concentrations below the level expected in present-day rainfall occur in ground waters that have undergone sulfate reduction. Sometimes such waters contain noticeable concentrations of dissolved hydrogen sulfide, but in many places they do not. Waters showing the effects of sulfur gases are common in some geothermal areas. Effects of pyrite oxidation on ground waters is sometimes more subtle, as the iron so released may be precipitated or lost by cation exchange and the sulfate may be reduction as the water moves through the aquifer.

When an area of low rainfall and accumulated solutes is reclaimed by irrigation, the increased water supply tends to leach away the solutes, and they appear in drainage water or return flow. The process is an acceleration of natural leaching and will increase the dissolved-solids concentrations and loads in the residual water of the affected area for a considerable period. Even where the soil is fairly free from soluble salts, the sulfate concentrations and chloride concentrations of the residual water draining from an irrigated area are generally much higher than they were in the original water supply, owing to water lost by evapotranspiration.

The sulfate in the epilimnion watersof Lake Nainital range from 40 to 100 mg/L. The south basin shows a large variation and no definite seasonal trend. On the other hand the north basin shows a single peak during June. And generally the SO_4 content is around 90 mg/L. In the hypolimnion waters the SO_4 ranges from 70 to 120 mg/L. In the south basin the peak is observed during June and in the north basin the main peak is observed during March and subsidiary peak during August. These are probably related to inflows.

The sulfate content in Nalah waters varies between 120 mg/L to 200 mg/L. The maximum value is observed in the month of March, and minimum during monsoon season.

6.9 Chloride

The element chlorine is the most abundant of the halogens. Others in this group of elements are fluorine, bromine, and iodine. The geochemical behaviour of chlorine reflects the volatility of the element and the fact that compounds of chlorine with common metallic elements, alkali metals, and alkaline earth metals are readily soluble in water. Although chlorine can occur in various oxidation states ranging from Cl^{1-} to Cl^{7+}, the chloride form is the only one of major significance in water exposed to the atmosphere.

A significant fact illustrating the geochemical behaviour of this element is that more than three-fourths of the total amount present in the Earth's outer crust, atmosphere, and hydrosphere is in solution in the ocean as Cl^- ions. Chloride forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh waters. They may be of more significance in seawater and brine.

Chlorine gas dissolves readily in water and has a somewhat stronger and more rapid oxidizing effect than does dissolved oxygen. The element has long been used as a disinfectant or biocide in purification of water supplies. Organic solutes are attacked also, as are other easily oxidized species, and the biological sterility of the solution after the reactions have been completed is readily ascertainable by testing for the presence of free chlorine. It is common practice in water-supply technology to maintain a few hundred micrograms per litre residual of free chlorine in solution throughout the distribution system.

Although some of the oxidized chlorine species, once formed, are fairly stable, they are not found in significant concentrations in any natural water. The presence of chlorine residuals in treated water may influence laboratory tests for some other ions, however. Chloride is present in the various rock types in concentrations lower than any of the other major constituents of natural water. Among the chloride-bearing minerals occurring in igneous rock are the feldspathoid sodalite and the phosphate mineral apatite. Minerals in which chloride is an essential component are not very common, and chloride is more likely to be present as an impurity.

On the whole, it must be concluded that igneous rocks cannot yield very high concentrations of chloride to normally circulating natural water. Considerably more important sources are associated with sedimentary rocks, particularly the evaporites. Chloride may be present in resistates as the result of inclusion of connate brine and in cementing material and is to be expected in any incompletely leached deposit laid down in the sea or in a closed drainage basin. When porous rocks are submerged by the sea at any time after their formation, they become impregnated with soluble salts, in which chloride plays a major role. Fine-grained marine shale might retain some of this chloride for very long periods. In all these rock types, the chloride is mostly present either as sodium chloride crystals or as a solution of sodium and chloride ions.

The behaviour of chloride in the hydrosphere can be represented by a cycle, one considerably simper than the cycles of carbon and sulfur. Chloride is present in rain and snow owing primarily to physical processes that entrain marine solutes in air at the surface of the sea. Some of the entrained chloride also reaches the land and its fresh water by dry fallout. Leaching of evaporites and return of connate water to circulating ground water are important routes by which marine chloride is returned to the sea. Humans use salt in many ways, and the return of this material to the sea by various routes can have important local effects on natural-water composition.

The chemical behaviour of chloride in natural water is tame and subdued compared with the other major ions. Chloride ions do not significantly enter into oxidation or reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles. The circulation of chloride ions in the hydrologic cycle is largely through physical processes. Chloride ions move with the water through most soils with less retardation or loss than any of the other tracers (such as tritium) that had actually been incorporated into the water molecules. This conservative behaviour should not be expected where movement is through compacted clay or shale, however.

Chloride is present in all natural waters, but mostly the concentrations are low. In most surface streams, chloride concentrations are lower than those of sulfate or bicarbonate. Exceptions occur where streams receive inflows of high-chloride ground water or industrial waste or are affected by oceanic tides.

Rainwater close to the ocean commonly contains from one to several tens of milligrams per litre of chloride, but the concentrations observed generally decrease rapidly in a landward direction. Air masses containing sodium chloride particles may move inland and drop out salt by mechanisms other than by washing out in rainfall.

The most common type of water in which chloride is the dominant anion is one in which sodium is the predominant cation. Waters of this type range from dilute solutions influenced by rainfall near the ocean to brines near saturation with respect to sodium chloride. The determination of chloride is commonly assumed to be one of the simplest and most dependable procedures in water analysis. However, a commonly used procedure, the Mohr titration, which uses a standard silver nitrate solution with chromate to indicate the end point, has fundamental limitations that have not always been adequately recognized. The optimum range of concentration for this procedure is from about 20 to about 5,000 mg/L. Accuracy and precision of the Mohr procedure are inadequate for determining concentrations of chloride below about 10 mg/L unless the sample is concentrated by evaporation of a large aliquot, and this entails a risk of contamination.

The Cl^- in Lake Nainital has a range from 3 to 7 mg/L, in the epilimnion. The chloride shows a distinct single peak during August, and reduces during post monsoon period. This is probably indicative of outflow, since Cl^- is conservative in nature. The bottom waters have Cl^- ranging from 2.5 mg/L to 30 mg/L. The variation is more pronounced in the south basin rather than the north. There are two distinct peaks observed in the north basin, during March and during August.

The Cl- content in Nalah waters ranges from 5 mg/L to 45 mg/L. The maximum value is observed during May. This behaviour is similar to the cations Na+ and K+.

6.10 Nitrogen

Aqueous geochemical behaviour of nitrogen is strongly influenced by the vital importance of the element in plant and animal nutrition. It is present in the atmosphere, hydrosphere, and biosphere at oxidation states covering the full range from N^{3-} to N^{5+}. Most of the Earth's atmosphere is nitrogen gas.

The crustal rocks of the Earth contain about one-fourth of the total nitrogen present in the crust, atmosphere, hydrosphere, and biosphere and that nearly three-fourths in the atmosphere. Amounts in the hydrosphere and biosphere are much smaller. A much larger quantity may be present in the mantle at depths below 16 km. Amounts there are not known with certainty, nor are they significant in the biochemical cycle of the element.

Chemical and biological processes that transfer nitrogen to and from the lithosphere, atmosphere, hydrosphere, and biosphere represent the nitrogen cycle. A very large amount of scientific investigation of the nitrogen cycle has been done, and the related literature is voluminous. The importance of these processes in governing concentrations, form, and behaviour of nitrogen in water is obvious, and they merit brief consideration.

Processes by which N_2 gas is changed in oxidation state and converted to chemical compounds containing nitrogen are referred to in general as nitrogen fixation. A substantial energy input is required because the two atoms in molecular N_2 are very strongly bound to each other. Biological fixation is accomplished by blue-green algae and certain related organisms that have the capacity of photosynthesis, and by certain species of bacteria that use other organic material as energy sources. The latter may grow symbiotically on roots of some species of higher plants, notably legumes. Inorganic fixation occurs naturally in the atmosphere, but amounts produced in this way are small. Lightning discharges produce nitric oxides and were thought at one time to be a major factor in producing nitrate nitrogen in rainwater.

Man's influence on the nitrogen cycle includes production and use of synthetic fertilizers such as ammonia and other nitrogen compounds. Some of this fixed nitrogen escapes to the hydrosphere. Nitrogen in reduced or organic forms is converted by soil bacteria into nitrite and nitrate. This process is commonly termed nitrification. The nitrogen used by plants is largely in the oxidized form. Nitrate in anaerobic systems can be reduced by other strains of bacteria to nitrous oxide or nitrogen gas. Biochemists refer to this process as denitrification.

Nitrogen oxides are present in the atmosphere, in part, from combustion of fossil fuel. Coal and petroleum generally contain about 1 percent nitrogen. A part of this is converted to nitrogen oxides on burning and escapes to the atmosphere. Gasoline and diesel engines and most other combustion devices also emit nitrogen oxides that are synthesized by high-temperature fixation of atmospheric nitrogen. Nitrogen oxides in the atmosphere undergo various chemical alterations that produce h+ and finally leave the nitrogen as nitrate. These processes can lower the pH of precipitation in the same way sulfur oxides do. Ammonia nitrogen is generally present in rainfall also.

Nitrogen occurs in water as nitrite or nitrate anions (NO_2^- and NO_3), in cationic form as ammonium (NH_4^+), and at intermediate oxidation states as a part of organic solutes. Some other forms such as cyanide (CN^-) may occur in water affected by waste disposal. The differences in chemical properties among these species obviously is substantial. Ammonium cations are strongly adsorbed on mineral surfaces. Anionic species such as nitrate are readily transported in water and are stable over a considerable range of conditions. Above a pH of 9.20 the form of most dissolved ammonium ions will be $NH_4OH(aq)$, an uncharged species. The nitrite and organic species are unstable in aerated water and are generally considered to be indicators of pollution through disposal of sewage or organic waste. The presence of nitrate or ammonium might be indicative of such pollution also, but generally the pollution would have occurred at a site or time substantially removed from the sampling point. Ammonium and cyanide ions form rather strong soluble complexes with some metal ions, and certain types of industrial waste effluent may contain such species.

Excessive concentrations of nitrate in drinking water may cause methaemoglobinaemia in small children. Concentrations in excess of 20 mg/L, equivalent to 88 mg/L of NO_3^- evidently present this hazard (IS:10500). Occurrence of nitrate and nitrite in water has been studied rather extensively because of the public health relationship.

Concentrations of nitrate that approach or exceed 44 mg/L NO_3^- are not uncommon in many rural water-supply wells. This nitrate is attributed to drainage from nearby septic tanks and cesspools. Farm animals produce considerable amounts of nitrogenous organic waste that tends to concentrate in places where large number of animals are confined.

The sources of reduced forms of nitrogen in natural water presumably are similar to the sources of nitrate, and the state of oxidation of nitrogen probably is controlled by biochemical processes. Although the reduced forms normally would be transformed to nitrate in most surface-water environments, there is considerable evidence that a significant amount of reduced nitrogen is present in many ground waters.

The nitrate nitrogen in the surface waters of Lake Nainital range from 0 to 1 mg/L. The most striking feature of NO3-N is that it is totally absent in the epilimnion during all seasons except winter. In the hypolimnion, on the other hand NO3-N is present in significant amounts ranging from 0 to 5 mg/L, showing no definite seasonal effect.

The NO_3-N in Nalah waters varies from 2 mg/L to 6.75 mg/L. There is no definite seasonal trend. The nalah water is highly loaded in NO_3-N and is detrimental to the lake water quality.

6.11 Phosphorus

Phosphorus is a rather common element in igneous rock. It is also fairly abundant in sediments, but concentrations present in solution in natural water are normally no more than a few tenths of a milligram per litre. Major features of phosphorus chemistry that govern its behaviour include the low solubility of most of its inorganic compounds and its use by biota as a nutrient.

Phosphorus is in the same group in the periodic table as nitrogen. It can occur at oxidation states ranging from P^{3-} to P^{5+}, but the fully oxidized (phosphate) form is the only one of significance in most natural-water systems. The most common mineral form is apatite, which is a calcium phosphate with variable amounts of OH, Cl, and F (hydroxychloro-, or fluoro-apatite) and various impurities. Some other phosphate minerals contain aluminium or iron. Phosphorus that is released into seawater by marine biota can be precipitated as phosphorite, an impure calcium phosphate.

Phosphate mining, concentrating, and processing are sources of phosphate in river water in some areas. The use of phosphate fertilizers has a potential for increasing the phosphorus content of drainage, but this seems generally to be a rather minor factor as phosphates are not very mobile in soils or sediments. Soil erosion, however, may add considerable amounts of suspended phosphate to streams.

Phosphorus is a component of sewage, as the element is essential in metabolism, and it is always present in animal metabolic waste. The increased use of sodium phosphate as a builder to increase the cleaning power of household detergents tends to increase the output of phosphate by sewage-disposal plants. Indian public is not aware of the role of phosphorus as a nutrient for aquatic biota and the implication of phosphorus as a major cause of eutrophication problems in lakes. Actions are to be taken by political units, detergent manufacturers, and consumers to limit the use of phosphate in detergents. However, domestic and industrial sewage effluent probably remain important sources of phosphorus in surface water.

Reduced forms of phosphorus are present in certain synthetic organic chemicals, including some that are used in insecticides. These compounds are unstable in aerated water but may persist in reducing environments long enough to be of some significance. Organic phosphate species synthesized by plants and animals constitute a significant fraction of the dissolved and particulate phosphorus in many natural water bodies. The orthophosphate ion ($PO_4{}^{3-}$) is the final dissociation product of phosphoric acid, H_3PO_4. The dissociation of the acid occurs in steps, and four solute species are possible: $H_3PO_4(aq)$, $H_2PO_4^-$, $HPO_4{}^{2-}$, and PO_4^{3-}. The orthophosphate species are the most thermo-dynamically stable of the $P5+$ forms likely to occur in natural water, and the most commonly used analytical procedures aim to convert all the phosphorus present to that form. Final results are reported as total phosphorus, without indicating species. Phosphorus associated with particulate material in a surface water is of interest in evaluating potential effects on aquatic biota, and a total or total extractable value for phosphorus is commonly reported. Such numbers have little or no relationship to solution composition. Data in the literature or stored in data banks may not distinguish clearly between dissolved and dissolved-plus-particulate status for phosphorus.

The Soluble Reactive Phosphorus (SRP) or orthophosphate in the surface waters of Lake Nainital ranges from 0 to 600 μg/L. The SRP in the two basins differs significantly. The reason for very low or trace amount of SRP during certain months in the surface water is most probably due to uptake by the aquatic biota. The PO_4-P in the bottom waters ranges from 100 to 900 μg/L. The presence of PO_4-P in bottom waters is very significant in Winter, May and to a less extent in August. The higher quantity of SRP in the bottom waters during winter is probably due to release from the sediments during winter overturn.

The minimum SRP content in the nalahs is 200 μg/L. The maximum value is a whopping 1750 μg/L. The maximum value is observed during May. The main source of this SRP is then the anthropogenic activities, such as washing and bathing, etc. along the nalah, particularly near the Nainital water works.

6.12 Lead

Lead is comparable in abundance to cobalt and is rather widely dispersed in sedimentary rocks. Its natural mobility is low, however, owing to the low solubility of lead hydroxy carbonates and phosphate. The adsorption of lead on organic and inorganic sediment surfaces and the coprecipitation of lead with manganese oxide also tend to maintain low concentration levels in surface and ground water.

Certain of the uses of load by humans have tended to disperse the element widely through the environment. In the 1920's, addition of tetraethyl lead was found to promote more efficient combustion of gasoline used in automobile engines. Leaded petrol permitted a higher compression of the fuel-air mixture, which in turn increased the power output. The lead content of the fuel is emitted as an aerosol in exhaust gases, and the quantities so dispersed increases greatly as the number of automobiles in use grow.

Lead pipe once was commonly used to convey drinking water and is still present in many old buildings. Water that has a pH below neutrality or is poorly buffered may dissolve considerable amounts of lead from such pipe, and may also obtain lead from solder used to join copper pipe and fittings. The extent of these effects is not well known, because few chemical analyses are available for water taken from consumer taps. The upper limit for lead in drinking water in India is 100 μg/L (IS:10500).

Concentrations of lead in rain and snow range from 100 μg/L or more in areas subject to substantial air pollution down to 1.0 μg/L or less in more remote areas. Dry fallout and rainout of particulate lead is probably a factor of major importance in the circulation of the element, especially in areas of heavy automobile traffic. Washing of this material into streams during runoff events is a potential source of dissolved lead in river water. Occasional concentrations of dissolved lead in excess of 10 μg/L have been reported at many river-sampling stations elsewhere in the developed countries but the records indicate that most of the lead that was present was in particulate form.

The lead content in the Lake Nainital is above the limit prescribed in the ISI standards. It ranges from 120 μg/L to 160 μg/L. Though this is unhealthy for human consumption, this may not be treated as pollution related, as the background concentration in the area is also above 100 μg/L. The upstream springs representing the local groundwater also have lead values comparative to that of lake waters. This could be probably from dissolution of certain lead bearing minerals present in the catchment rock formations (upto 100 μg/L) and anthropological activities.

6.13 Manganese

The chemistry of manganese is somewhat like that of iron in that both metals participate in redox processes in weathering environments. Manganese, however, has three possible valence states in such environments rather than two (2^+,3^+, and 4^+) and can form a wide variety of mixed-valence oxides. The 3^+ species are unstable in that they may disproportionate. That is, two Mn^{3+} ions may interact spontaneously to produce one Mn^{2+} and one Mn^{4+} ion, and these products are more stable thermo-dynamically than the original Mn^{3+} species. This ability has a number of interesting ramifications in the chemistry of the element in natural water.

Manganese is an undesirable impurity in water supplies, mainly owing to a tendency to deposit black oxide stains. The recommended upper limit for manganese in public water supplies in India is 500 μg/L (IS:10500). It is an essential element for both plant and animal life forms. Small amounts commonly are present in dolomite and limestone, substituting for calcium.

When divalent manganese is released to aqueous solution during weathering, it is somewhat more stable toward oxidation than is ferrous iron. Generally, however, if it is in contact with the atmosphere, it will be precipitated, at sites where pH is high enough, as a crust of manganese 4^+ oxide. These encrustations generally contain a substantial quantity of coprecipitated iron and, under some conditions, significant amounts of other metal ions as well, especially cobalt, lead, zinc, copper, nickel and barium. A particularly favourable substrate for manganese oxide precipitation is a previously existing manganese oxide surface. Thus the deposit may become thicker with time and form nodules around some central nucleus, as on the bottoms of certain lakes and at many localities on the ocean bottom. Small, discrete particles of oxide or coatings on other particles are widely distributed in stream sediments and soils. Coatings of manganese oxides in streambeds occur in many places. These coatings generally do not become very thick, owing to mechanical erosion and changes in water properties. In some areas manganese oxide may accumulate with other material in the form of a bog.

In lakes and reservoirs where thermal stratification develops, the bottom sediments may become anoxic and manganese oxide previously deposited may be reduced and dissolved. Water drawn from the deeper part of the supply reservoir may at times contain significant concentrations of dissolved Mn^{2+}. Reduction of manganese oxides at depth in buried sediment may be a factor in accumulations of manganese nodules in many environments. Diffusing Mn^{2+} can be redeposited as oxide when it reaches the surface of the sediment layer and encounters oxygenated water.

Manganese is an essential element in plant metabolism, and it is to be expected that organic circulation of manganese can influence its occurrence in natural water. Specific mention of manganese accumulation in tree leaves appears in published literature. Some species of trees are much more effective accumulators than others. Aquatic plants are noted to be accumulators of manganese. Manganese in plant parts that die back or are shed becomes available for solution in runoff and soil moisture. The importance of this source of manganese in river water is not completely known, although some studies show the effects of fallen leaves on the water quality of a small streams could be important at times.

The Mn content in Lake Nainital waters hovers around the limit as per Indian Standards for domestic water supply. The Mn has been observed to exceed during the months of April (550 μg/L) and July (650 μg/L) and very close to the maximum limit during November and December. The Mn values are below the limits during January (300 μg/L), during which period the Chuna dhara, an upstream spring was very high in Mn content (5.7 mg/L). Some other sources which was high in Mn content during this period are Sukhatal groundwater well (1.56 mg/L), Sipahi dhara, a downstream spring (2.32 mg/L) and Sariyatal (2.79 mg/L).

7.0 EUTROPHICATION

The process of eutrophication is defined as the loading of inorganic and organic dissolved and particulate matter to lakes at rates sufficient to increase the potential for high biological production that leads to a decrease in the capacity of the lake. The above definition is a holistic and accurate one against the general description where eutrophication is referred as loading of inorganic plant nutrients (such as Phosphorous and Nitrogen) and the high production of algae that may occur as a consequence of increased nutrient concentration.

Lakes are considered to undergo a process of ageing which has been characterized by three qualitatively defined conditions. The initial condition of a lake is termed oligotrophic and is normally associated with deep lakes, where the waters at the bottom of the lake are cold and have relatively high levels of dissolved oxygen throughout the year. The waters and bottom sediments of the lake usually contain only small amounts of organic matter. Productivity in terms of the population levels of phytoplankton, rooted aquatic plants, zooplankton, and fish is usually low. Species diversity is often quite high and chemical water quality is good.

The eutrophic condition of a lake represents the opposite end of the ageing process. Eutrophic lakes may be either shallow or deep. They are characterized by high concentrations of suspended organic matter in the water column and by relatively large sediment depths with high organic contents particularly in the upper layers of the sediment. Biological productivity is high and the diversity of biological populations may be somewhat limited. Coarse (non-game) fish may predominate due to elevated bottom water temperatures and/or depressed water quality. Dissolved oxygen concentrations of bottom waters are usually depressed and in extreme cases of eutrophication may reach zero during summer periods. Generally water quality is low and can result in impairment of beneficial water usages such as water supply, contact recreation, and/or boating.

The characteristics of a eutrophic lake is that it will have frequent blue-green algal blooms, coloured water (green/brown), very low or absence of dissolved oxygen in the bottom waters and fairly high fish productivity. Silt is a major source of sorbed nutrients and organic matter in a eutrophic lake and silt loading directly contributes to reduction of lake's capacity. It is important to note that the term eutrophic does not mean bad, but it is only a descriptive of the state or condition of the lake. The problems of potable water treatment and its safety are directly related to the degree of eutrophication of the lake. According to Martin (1993) some organic molecules either loaded to or produced within the lake, produce mutagenic or carcinogenic compounds when chlorinated for drinking purposes. Surface water with a blue-green algal bloom may be unfit for human consumption as they may contain toxins released form algae. These toxins are lethal to cattle and have been shown to produce human gastro-intestinal problems.

A third lake condition is mesotrophic which is defined as an intermediate state between oligotrophic and eutrophic. Mesotrophic lakes have intermediate levels of biological productivity and can have some reductions in bottom dissolved oxygen levels. Lakes in this category generally have water quality which is adequate for most beneficial uses but may be deteriorating toward the eutrophic state.

The boundaries between the three stages are not rigidly defined and may vary with regions of the nation and with beneficial uses of lake waters. Therefore, attempts have been made to establish a trophic state index (TSI) as a function of commonly measured water quality variables. The different trophic classification schemes are shown below which are largely followed (US EPA-NES trophic state delineation).

Water Quality Variable	Oligotrophic	Mesotrophic	Eutrophic
Total phosphorus ($\mu g/l$)	<10	10-20	>20
Chlorophyll ($\mu g/l$)	<4	4-10	>10
Secchi depth (m)	>3.7	2-4	<2
Hypolimnetic oxygen (% saturation)	>80	10-80	<10

7.1 Basic Processes

7.1.1 Loads

Nutrient levels in lakes are controlled by external sources to the lake and in-lake processes. External sources of nutrients include municipal and industrial point sources, stream inputs, atmospheric sources, urban drainage, groundwater, agricultural drainage, and other non-point sources surrounding the lake. In-lake processes include sediment release, biological recycling, and nitrogen fixation.

Municipal and industrial point sources may discharge both nitrogen and phosphorus directly into lakes or to streams that eventually drain into lakes. Existing monitoring data should be used or a monitoring network should be developed to provide reliable estimates of nutrient inputs. Source strength of municipal discharges can vary diurnally and seasonally. Total municipal load usually tends to increase over the years due to population growth.

Stream inputs are the most significant source of nutrients to most lakes. As such, these inputs should be carefully estimated. Estimates can often be obtained by sampling on two to four week intervals and during major storm events. It should be noted that significant increases in nutrient inputs may occur during wet weather flows. Consequently, it is necessary to collect sufficient dry weather flow and concentration data, so as not to overestimate load contributions during dry-weather periods. Nutrient input can then be estimated by multiplying average flow by the flow-weighted concentration, or by a regression equation of phosphorus input on flow. The availability of these nutrients would depend on upstream activities responsible for the nutrient concentrations.

Atmospheric sources to lakes include precipitation and dry deposition; these sources are frequently considered together as bulk precipitation. Because nutrient forms in precipitation are generally soluble and those in dry deposition generally insoluble, the availability of nutrients from bulk precipitation varies from year-to-year, site-to-site, and storm-to-storm. Nutrient quantities also vary with respect to these parameters. Because nutrient inputs from bulk precipitation are generally small, literature values, despite their limitations, are frequently used for loading estimates. If literature data indicate bulk precipitation inputs are relatively large, a sampling program may be necessary.

Making reliable estimates of groundwater nutrient input to lakes is difficult. Because of the spatial and seasonal non-uniformity of groundwater nitrogen and phosphorus concentrations, it is necessary to catalog potential sources of nutrients to surrounding groundwaters. The nutrient forms reaching lakes from groundwater sources would, of course, be soluble and readily available for phytoplankton incorporation. Agricultural drainage may contribute significantly to the lake nutrient budget. In most cases, agricultural drainage would be estimated as part of the stream input.

Sediments release nutrients in soluble forms readily available for algal uptake, although the density structure of the lake may hinder immediate uptake. Although this release from sediments is not well understood, laboratory and field investigations have produced numerical estimates of nutrient loss which can be used to compare sediment release to other lake inputs. Biological decomposition occurs throughout the water column to make the nutrients laced in organic detritus available for phytoplankton. In addition, phytoplankton and zooplankton secrete and excrete soluble and insoluble nutrient forms.

Nitrogen fixation may be a significant source of nitrogen in lakes with limiting concentrations of nitrogen. During nitrogen fixation, blue-green algae and some macrophytes are able to reduce molecular nitrogen to nitrogen at the ammonia oxidation level. The ability of selected algae and macrophytes to fix nitrogen is frequently cited as one of the reasons due to which phosphorus is considered to be the limiting nutrient in most lakes.

7.1.2 Nutrients

As mentioned above, the two nutrients of greatest concern are nitrogen and phosphorus. In addition to these nutrients, phytoplankton require carbon dioxide and a host of minor elements (potassium, sodium) and trace elements (iron, manganese, cobalt, copper, zinc, boron, and molybdenum) and organic growth factors. Silica is an important nutrient for diatoms, as it forms the basis for their skeletal structure.

Phosphorus in lake inputs and the lake itself can be found in dissolved inorganic and/or organic and particulate forms. Dissolved inorganic forms include the free orthophosphate and the condensed phosphates (pyro, meta, and poly). Orthophosphate is immediately available to phytoplankton growth. Dissolved organic phosphorus includes nucleic acids, nucleotides, and phospholipids, among others. The phosphate part of these molecules must be cleaved by exoenzymes to release phosphorus for uptake. Particulate phosphorus includes algae, bacteria, detritus, and silt, etc. Analytical testing for phosphorus in water can identify orthophosphate, dissolved and particulate condensed phosphates, and dissolved and particulate organic phosphorus. Total phosphorus is just the sum of all phosphorus species. Levels of total phosphorus in lakes can range from as low as a few μg/l to as high as a few mg/l. These levels are usually reported for elemental phosphorus; in some instances data are reported as phosphates and appropriate conversion is required. Levels of dissolved orthophosphate expressed in terms of elemental phosphorus range from below detection limits to a few hundred μg/l.

Nitrogen can exist in several different forms in lakes and their inputs. Nitrogen in its most reduced state is found in ammonia and various organic nitrogen forms such as purines, pyrimidines, nucleic acids, etc. Ammonia is immediately available for phytoplankton uptake. Organic nitrogen forms (both dissolved and particulate) may need to be broken down to ammonia for uptake. Some amino acids are immediately available. Other common nitrogen forms include the more oxidized and soluble, nitrate and nitrite. Nitrate is immediately available for uptake but requires the organism to expend more energy to employ this source of nitrogen than for utilization of ammonia.

Measurements of nitrogen compounds are usually reported in terms of elemental nitrogen. In lakes, the sum of the oxidized forms of nitrogen and ammonia may range from 10 μg/l and above. The concentration of organic nitrogen may range up to several mg/l.

7.1.3 Phytoplankton

The specific growth rate of phytoplankton is controlled by the levels of important nutrients, light and temperature. Overall phytoplankton growth in an area is controlled by this specific growth rate and the effects of death, respiration, settling, zooplankton grazing, and vertical and horizontal transport.

Phytoplankton are one of two main primary producers found in lakes. Primary producers are able to utilize light, carbon dioxide and nutrients to synthesize new organic material. The other primary producers are the rooted or floating aquatic plants (macrophytes). These plants are generally restricted to shallow waters. Phytoplankton are free-floating and transported by currents. In most cases, phytoplankton are more important than are rooted aquatic vegetation in the basic food production of the lake ecosystem, although their relative importance depends on the specific characteristics of the pond/lake in question.

Phytoplankton can be characterized in terms of species, size, composition, growth rates, and pigmentation, among others. Groups of phytoplankton species include diatoms, green algae, nitrogen-fixing blue-green algae and non-nitrogen-fixing blue-green algae. The standing crop of phytoplankton in lakes has been characterized in terms of overall cell counts, individual species counts, mass, and chlorophyll a. Phytoplankton mass has also been characterized after drying, ashing, and weighing. A problem with this determination is that all biomass in a lake water sample, including bacteria, detritus and zooplankton, will also be measured as phytoplankton. Other processes affecting phytoplankton levels are respiration and death. Respiration is a biochemical process that occurs continuously day and night and results in consumption of some portion of the photosynthetically fixed carbon in the system. Hydrolysis of the phytoplankton cell follows death.

Factors affecting phytoplankton growth in a particular volume include advective and dispersive transport, settling, and zooplankton grazing. There are a number of factors that can limit phytoplankton growth. For the purposes of modifying the productivity of a lake, it is important to identify those limiting factors which can be controlled. Very little can be done to control the intensities or concentrations of light, temperature and the various trace elements and organic growth factors. Because some control can be exerted over the concentrations of nitrogen and phosphorus in lakes, considerable effort has been exerted to define the effects of these nutrients. While nitrogen contributions from point sources are controllable, the greater solubility of nitrogen compounds in non-point sources makes control difficult. The ability of blue-green algae to fix nitrogen from the atmosphere also reduces the importance of nitrogen control. In addition, control of nitrogen alone may cause a shift from green to blue-green algae, thereby reducing the effectiveness of control. As inorganic phosphorus compounds are much less soluble than inorganic nitrogen compounds and tend to absorb onto natural surfaces, control of phosphorus point sources can be more effective. One method to determine the limiting nutrient is the algal bioassay. In this procedure lake water samples are spiked with incremental additions of the nutrient(s) being investigated. A number of samples with different levels of nutrient(s) are then incubated in the laboratory or in-situ for a specified period of time under specified conditions. Considerable controversy still exists over the role of rooted aquatic plants in eutrophication dynamics. The area of controversy revolves around the origin of nutrients used by these primary producers. Bole and Allan (1979) reported levels of phosphorus that control the source (sediment or water) of nutrient uptake by aquatic weeds. In addition macrophyte growth was found to increase in response to steadily increasing nitrogen and phosphorus concentrations in waters of the Goczalkowice river. On the other hand, Carignan and Kalff (1979) showed that mobile phosphorus in sediments closely matched the phosphorus uptake by macrophytes.

Other investigations have found that aquatic plants were limited only by light and space requirements. For instance, Sheldon and Boylen (1977) found that the density of aquatic plants decreased linearly as the depth of the sampling location from the shore increased. Jupp and Spence (1977) found that wave action, phytoplankton competition, and grazing by waterfowl had more effect on macrophyte biomass than other factors.

Zooplankton, including protozoa, rotifers and crustacea, form the next link in the lake food chain. These primary macroconsumers provide the link between the primary producers (phytoplankton) and such secondary consumers (carnivores) as predacious insects and game fish. As such, zooplankton provide a primary constraint on phytoplankton growth. The basic mechanism by which zooplankters feed is by filtering the surrounding water and clearing it of whatever phytoplankton and detritus is present. This filtering rate varies as a function of the temperature, the concentration of phytoplankton, the size of the phytoplankton cell being ingested, and the amount of particulate matter present.

7.2 Nitrogen and Phosphorus as Nutrients

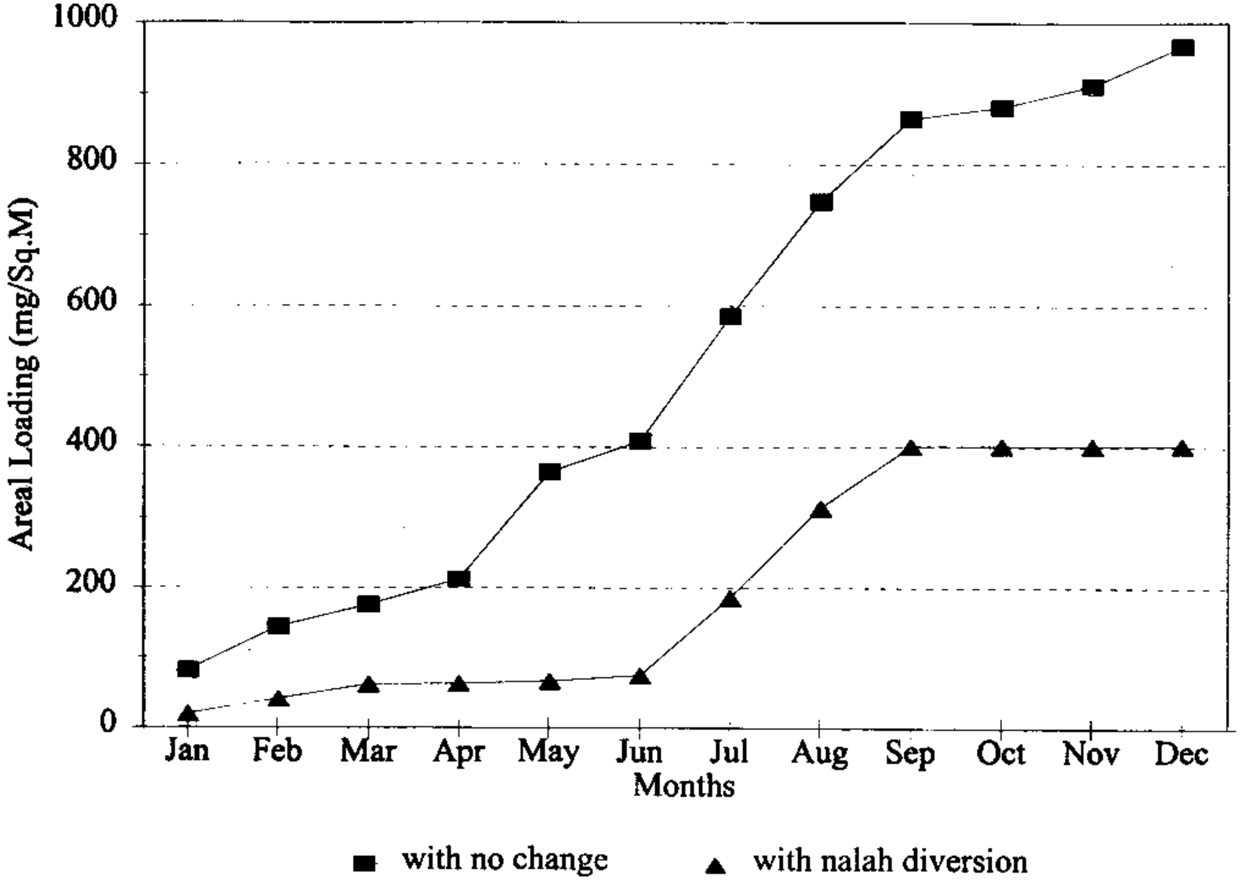
As noted earlier nitrogen and phosphorus are essential nutrients for plant growth. Aquatic vegetation of the free-floating types, such as algae, depends on dissolved nitrogen and phosphorus compounds for its nutrient supply. Growth of these species may also be influenced by the availability of other required elements. Dense, rapidly multiplying algal growths or blooms sometimes occur in water bodies that periodically receive increased concentrations of nitrogen or phosphorus. These dense growths are generally undesirable to water users and may interfere with other forms of aquatic life, especially if the water body becomes overloaded with oxidizable debris as a result of the sudden dieback of an algal bloom. The enrichment of a water body with nutrients is accompanied by a high rate of production of plant material in the water. Troublesome production rates of vegetation presumably occur when optimum supplies of all nutrients are present and available. Phosphorus availability is generally believed to be a critical factor in eutrophication of water bodies, as the nutrient in shortest supply will tend to be the control on production rates.

The chemistry of the element favours its precipitation, and dissolved phosphorus added through disposal of waste or leaching of fertilized fields may not remain available for long periods. Thus, a decrease in phosphate inflows may decrease productivity more quickly than would be possible by altering the influx of readily available nitrogen.

7.3 External Phosphorous Loads to the Lake

There are two main type of surface inflows to the lake. They are a) through the nalahs which is sustained by the groundwater and domestic effluents and b) the rainfall related surface runoff. The Soluble Reactive phosphorous content of the latter is around 0.2 mg/L during non-monsoon season and 0.15 mg/L during monsoon season. The drain water PO4-P varies from 0.2 mg/L to 1.75 mg/L. Using this information along with the inflow to the lake (see Water balance report) the total load of SRP to the lake has been computed. It is clearly seen from Fig. 5 that the annual areal loading to the lake in the present scenario is around 2000 mg/m^2. If the nalah waters are excluded then the annual areal loading reduces to 1500 mg/m^2. That is if the nalah waters are diverted away from the lake then the loading is reduced by a significant 25%. This figure will further improve if the rainfall induced runoff during non-monsoon season is also considered as part of diverted water. The nalah diversion measure will not seriously affect the water availability in the lake, as the combined rainfall induced runoff and channel flow during non-monsoon season is just 2.2 meters, while the total surface inflow during monsoon season is 9.6 meters.

Fig. 5.Cumulative External SRP Loading



7.4 Chlorophyll, Phosphorus & Secchi Depth Relationships

Strong relationships between chlorophyll-a and total phosphorus have been shown by Sakamoto (1966), Dillon and Rigler (1974), Jones and Bachmann (1976), Carlson (1977), Rast and Lee (1978), Bartsch and Gakstatter (1978), Smith and Shapiro (1981), Smith (1982), Lambou et.al. (1982) and Ryding (1983).

Several investigators have also proposed the use of empirical relationships between secchi depth and chlorophyll - a to predict changes in transparency to be expected from changed chlorophyll-a levels. The following are the relationships found for the lakes of Kumaun region (Shewa, 1998).

$$\log \text{Chlor} = -0.259 + 0.844 \log \text{TP} \quad [r = 0.93] \tag{1}$$

$$\log \text{SD} = 0.822 - 0.444 \log \text{Chlor} \quad [r = 0.83] \tag{2}$$

$$\log \text{SD} = 1.072 - 0.450 \log \text{TP} \; [r = -0.95] \tag{3}$$

The correlation coefficient obtained in the present investigation indicate a strong relationship between chlor and TP. Hence, it can be argued that the factors which may affect the chlor-TP relationship are uniform in the lakes of Kumaun region. The factors include availability of light, biological availability of phosphorus, limitation of phytoplankton growth by nutrients other than phosphorus, domination of aquatic flora by vascular plants, temperature, lake hydraulic retention time, lake morphometry, grazing of phytoplankton and the presence of toxic substances.

Using the equations developed for the lakes (Eq. 1 & 2), a nomogram combining chlor, TP and SD has been constructed (Shewa,1998) and presented in Fig.6. This nomogram can be used as a predictive tool for the Kumaun lakes particularity for winter conditions.

As far as the chlor-SD relationship is concerned, Lorenzen (1980) contended that a constant chlor-SD relationship can result in misleading projections. Lorenzen stated that, when chlor concentrations are high, the SD and light extinction coefficient are largely controlled by

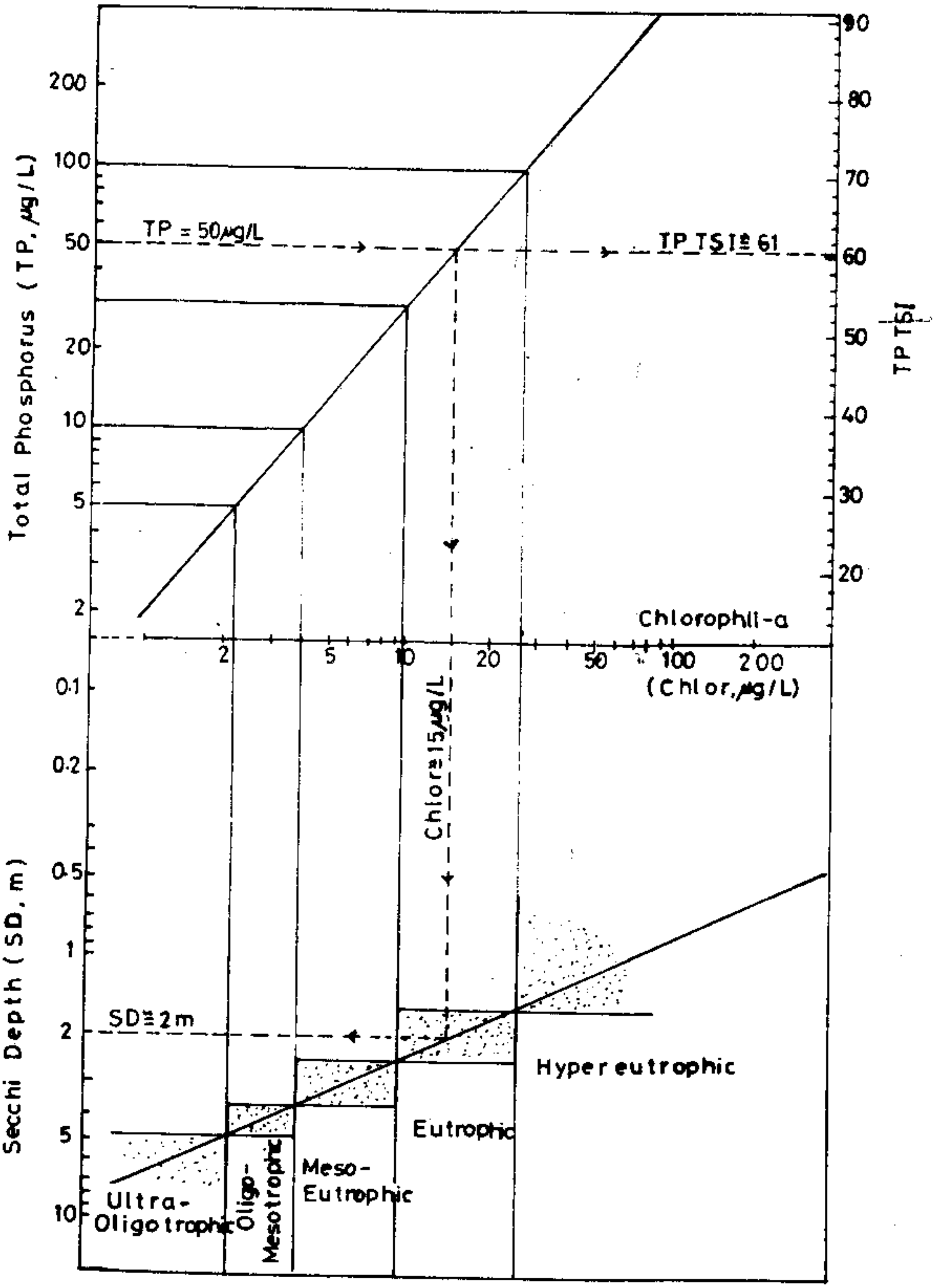


Fig. 6 Nomogram for determining the trophic status of Kumaun lakes combining Chlorophyll - a, Total Phosphorous and Secchi Depth

chlor concentration and when chlor concentration are low, the SD and light extinction coefficient are largely controlled by light absorbing particles other than chlor. In the data presented for lake Naukuchiatal in which chlor values are very low, the SD observed is not reasonable and the comment given by Lorenzen can be attributed to the observation of SD values in lake Naukuchiatal. The SD values of Naukuchiatal were therefore not utilized while developing the relationships.

7.5 Trophic Status of the Lakes

As mentioned earlier, eutrophication refers to nutrient enrichment that promotes the growth of aquatic plants. At least 19 elements (all of which can be found dissolved in water) are essential for life in a water body although some of them are needed in minute traces (Hino, 1994). Five of them are required in large amounts: carbon, hydrogen, oxygen, nitrogen and phosphorus in proportions of approximately 106:181:45:16:1. The first three (C, H & O) are readily available either in water (H_2O) or dissolved carbondioxide (CO_2) and thus never become a long - term limiting factor in aquatic plant growth. However, the concentration of nitrogen and phosphorus, dissolved in natural waters are much lower and they are usually the limiting factors for the growth of aquatic plants.

From the observations made while visiting the surroundings of the lakes, the sources of the nutrients (P&N) in the lakes can be summarized as below:

1. Direct addition of solid waste and sewage to rain water fed channels which ultimately reach to the lakes
2. Storm runoff from agricultural land, township and forest
3. Debris from surrounding hills
4. Litter from the vegetation in the catchment
5. Defecation of excreta of some local and floating population in the catchments.
6. Randomly deposited faecal matter of animal origin
7. Rooted aquatic plants which can release nutrients when they die and decompose
8. Even though it is insignificant, nutrients can be expected from the atmosphere (dust, debris carried by wind) and precipitation falling on the lake.

9. In addition to the above listed external sources, the release of nutrients from the sediments can not be ruled out. The source of all the sediments is soil erosion from croplands, overgrazed lands, construction sites, deforested areas, bare patches around schools, homes, shopping centres, roads etc.

To denote the nutrient status of or else to describe the effects of the nutrients on the general water quality of the lakes, three descriptive terms which are broadly classified as oligotrophic, mesotrophic and eutrophic were used.

Oligotrophic (Greek for "little food") lakes are usually characterized by low nutrient concentrations in the water, a diverse plant and animal community, a low level of primary productivity and biomass, and good over all water quality for most uses. By contrast, eutrophic (Greek for "well fed") lakes have a high level of productivity and biomass, frequent occurrence of algal blooms, anoxic bottom water, enhanced growth of littoral zone aquatic plants, and poor water quality for many uses. Mesotrophic is the transition state between oligotrophic and eutrophic.

Specific boundary values of total phosphorus, chlorophyll-a, and secchi depth for these tropic conditions have been provided by various authors. There are limitations, however, to 'fixed' values to delineate lake trophic conditions; some over lap is inevitable i.e., some waters are classified in one trophic condition based on one parameters and in other trophic condition based on a second parameter (Ryding 1989).

In the present study the tropic status of the 5 lakes has been determined based on the boundary values of total phosphorus given by Wetzel (1975), which were modified from Vollenweider (1968). The general relationships of lake productivity to average concentrations of eplimnetic total phosphorus is given in the following Table:

General level of productivity	Total phosphorus ($\mu g/l$)
Ultra - oligotrophic	< 5
Oligo - mesotrophic	5 - 10
Meso - eutrophic	10 - 30
Eutrophic	30 - 100
Hypereutrophic	> 100

The lakes in Kumaun region can, therefore, be classified in the tropic states as given below (Shewa, 1998):

Lake	Average total phosphorus ($\mu g/l$)	Tropic state
Nainital	127.25	Hypereutrophic
Bhimtal	26.43	Meso-eutrophic
Khurpatal	16.17	Meso-eutrophic
Sattal	6.67	Oligo-mesotrophic
Naukuchiatal	3.00	Ultra-oligotrophic

Several investigators have also developed a numerical tropic state index in an attempt to remove the subjectivity inherent in the terms oligotrophic, mesotrophic and eutrophic. Total phosphorus, chlorophyll - a and Sechhi depth relationships were used by Carlson (1977) to develop a numerical Tropic State Index (TSI) which is probably the most commonly used (Cooke et.al. 1993).

Carlson used transformations to log 2 to interrelate these indices with in a scale of 0 to 100 (applicable to any lake). For comparison representative values for TP, chlor and SD calculated from these equations are given in the following Table. The range from 40 to 50 is most often associated with mesotrophy.

TSI	Sechhi depth (m)	Surface phosphorus (μg/l)	Surface chlorophyll (μg/l)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.12
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

The Carlson TPTSI is used for determining tropic state index of the lakes and the values are given below:

Lake	Average total phosphorus (μg/l)	Tropic state Index (TSI)
Nainital	127.25	74
Bhimtal	26.43	51
Khurpatal	16.17	44
Sattal	6.67	32
Naukuchiatal	3.00	20

8.0 MEASURES FOR AMELIORATION OF LAKE WATER QUALITY

There are several methods in vogue for the arresting the progressive eutrophication of surface water bodies. A few of the major and widely reported methods are given below.

However, the applicability of any one or more methods for ameliorating water quality of Lake Nainital had to be adopted on the basis of cost effectiveness.

8.1 Phosphorous inactivation

Internal release of phosphorous (P) may be a significant source that could delay recovery of lake quality. Sediment P release can be controlled by adding aluminium salts to the water having problem, resulting in an aluminium hydroxide floc that settles to the sediment surface forming a barrier to further release, even if anoxia persists. This is a powerful, effective and popular technique. Sediment oxidation through enhanced denitrification and resulting improved complexation with iron is included with P inactivation.

8.2 Dilution and Hypolimnetic Withdrawal (siphoning)

Dilution involves the addition of low nutrient water to reduce lake nutrient concentrations and can be effective where external or internal sources are not controlled. Flushing simply removes algal biomass and may be accomplished with large volume of water even if nutrient concentration is high. Nutrient enriched hypolimnetic waters may be preferentially removed through siphoning, pumping or selective discharge through sluices / gates instead of low nutrient surface water. This has been shown to be effective at accelerating P exports, reducing surface P concentrations, and improving hypolimnetic oxygen content in many cases.

Presently, the lake water is being drained during the rainy season from the upper portion of the lake by opening the lake sluice gates to control only the water level in the lake but not to control the eutrophication level. The lake water in the upper portion is comparatively less polluted and unknowingly, we are draining the less polluted water from the lake. This is a great loss to the natural purification capability of the lake. Therefore, the water from the lake bottom should be drained in rainy season by constructing a siphon system at Tallital Dat region replacing the present practice. The details of this system can be discussed if Authorities are interested.

8.3 Artificial Circulation / Hypolimnetic Aeration

Although a potential exists for control of internal loading from anoxic hypolimnia (especially with iron addition), that potential has not been adequately demonstrated as yet to place this technique under algae control. This technique is used to prevent or eliminate thermal stratification through the mixing action of the rising column of air bubbles. However, it is highly effective at increasing dissolved oxygen in the hypolimnion without destratifying the lake. But most importantly it can cause light to limit algal growth in situations where nutrients are uncontrollable and can neutralise the factors favouring dominance while blue-green algae. This is usually accomplished with an air lift device, which brings cold hypolimnetic water to the surface, where gases are exchanged, followed by its return to deep water. This procedure can improve lake or reservoir discharge quality, allow a cold water fishery to reestablish, provide a daytime refuge for zooplankton (from a warm water fishery), and eliminate problems with iron and manganese in potable water supplies. This technique can be applied in case of Nainital. In fact one proposal has already been received by NIH, Roorkee from the University of Lund , Sweeden to apply this technique on Nainital. But, presently it is only at its initial stage.

8.4 Adding Copper Sulphate

This has been a commonly used treatment for lakes and water supply reservoirs suffering from algal biomass and taste and odour problems, for at least a century. It is included because it is commonly practised, rather than because it is advocated. This method can be used to control algal biomass in case of Nainital.

8.5 Trapping and Retention of Sediment at the entry points

In order to restrict the entry of sediments into the lake in future, a wall of atleast 1.5 ft. height should be constructed at the entry point into the lake of such drains through which maximum sedimentation is occurred or a sediment trap structure should be set-up in the drains along the side of Mall road including Naina Devi Drain. These structures should be cleaned periodically without fail, otherwise the situation as prevails with Naina Devi drain and Riksha Stand drain will be occurred where the similar exercise has been tried but due to non-cleaning of sediments deposited due to obstruction of wall, the levels of drains have been up lifted and there is no any benefit of construction of such walls. However, the drains which run through out the year with little discharge can have the provision of a small size net (strong enough) at the lower side of the wall to allow water to enter into the lake during non-monsoon periods.

8.6 Sediment Removal

This technique can be multipurpose, resulting in control of both algae and macrophytes. It is an effective procedure and is frequently recommended for deepening shallow lakes for macrophytes control, curtailing internal nutrient loading by eliminating the enriched sediment layer or eliminating sediments contaminated with toxic substances. It has a significant advantage over nutrient inactivation in that the source is removed rather than simply covered over.

It has been observed that most of the sediment deposition takes place near the debauching points of drains which later on slide to the deeper section. Although, the slide rate of the sediment is very less, the sediments will be deposited at a faster rates at the shallower parts of the lake, as being taking place in the present, the capacity of surface area and ultimately the lake will reduce tremendously. Therefore, the deposited sediments should be removed from these areas every year during the period of summer when the lake level reduced and these areas become dry. This can bring the lake area to its original with in few years, if the removal of sediments is continued at least for a period of 10 years. Therefore, there is a need to evolve a programme to remove the sediments deposited at the banks and nearby areas in the past few decades.

The first major step for the revival of the lake would be to divert the nalahs, especially the perennial ones viz. the Naina devi mandir drain and the rickshaw stand drain. These drains, as shown and discussed above are carriers of large quantity of nutrients and other pollutants. The diversion of the drains have to effected in such a way that the surface inflow during monsoon season can be let into the lake and during other seasons be stopped from reaching the lake. This may be achieved by constructing boundary drains bordering the lake, operated by appropriate gates. This arrangement will also be useful in checking the sediment inflow to the lake.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The dissolved oxygen in the top 3 meter zone varies from 18.4 mg/1 (maximum) in rainy season, (observed in the month of August 1995) to 1.3 mg/1 (minimum) in winter (observed in the month of Dec.1994). The D.O. value below 9m is negligible.

The mean annual of total dissolved solids in epilimnion (top 3 meter zone) is 484 MT, in mesolimnion (3-9 meter zone) 1059 MT, and hypolimnion, below 9m depth is 2022 MT. Anoxic condition exists in the hypolimnion region for most part of the year. During annual turnover, the D.O. is around 2-3 mg/l in the hypolimnion region. Epilimnion however is sufficiently rich in D.O. except during winter. Therefore, it is contemplated that the bottom water is more mineralised (and hardened) and chemically polluted than the water in the top zone.

Only Nitrate nitrogen and orthophosphate have been found as the major pollutants for Nainital. Phosphate concentration increases during water turnover. This is probably released from the sediments. NO_3-N is observed in higher concentration in winter. From the available data, it appears that PO_4-P is the limiting factor. If the phosphate content of the inflow could be controlled by suitable measures, the trophic state of the lake could be ameliorated.

The major inorganic ion, calcium seems to be brought into the lake in dissolved form. This is possible as the ground water component is significant in the lake water balance. The

Ca is brought in by the over saturated (with respect to Ca) groundwater tends to precipitate as Calcite between May and August or co-precipitate with Mg to form dolomite. But this aspect has not been investigated in detail, as this is outside the purview of the present objectives.

Sulphate is also present in significant concentration in the lake. The quality of springs indicate that the source for sulphate could be dissolution of minerals like gypsum. The presence of gypsum in the rock formations has been reported by various geologists. Sodium and potassium vary within very narrow range. Chloride is also not significant. Max. concentration observed in the lake is of the order of 40 mg/l, that too only once in the entire study period.

Poisonous elements like As (Arsenic) and Pb (Lead) have been detected in the sediments in considerable amounts. The over all dissolved oxygen level also reduced tremendously during winter in the lake water. The mixing of bottom and top layers water is more dominant during the period from mid December to mid January. It further intensifies during more colder years. Therefore, due to reduced D. O. level and mixing of poisonous elements in the water, the fish mortality is observed in Nainital lake almost every year but, more in colder years.

The average water quality of the lake derived using volume weights of point data is shown alongwith IS:10500 standard for domestic water supply in Table 27. The limits for both class A (without treatment) and class C (with treatment) are indicated. The pH is well within the prescribed range. The DO is very low during winter and just near the required limit in February. During other months the observed lake value fall much below the prescribed level. The TDS has been calculated as a function of electrical conductivity. The accepted calibration factor for waters not too high in sulfate is 0.59. During March, April and May, the TDS values are very close to the set standard.

The lake water is classified as hard water. The total hardness frequently exceeds the prescribed limit of the IS:10500. Except during July in all other months the Hardness of the lake water exceeds 300 mg/L. This hardness, as described above, is due to natural factors. Nitrate-Nitrogen, Chloride and Sulfate values are well within the maximum limit set for the

Table 27: Water qualitity of Lake Nainital compared to IS:10500 standard

				0.69*ec	Total						
Paramete		pH	DO	TDS	Hardness	Mn	Cl	SO4	NO-3	Pb	Zn
			mg/L	mg/L	mg/L						
Class-A		6.5-8.5	6	500	300	0.5	250	400	20	0.1	15
Class-C		6.5-8.5	4	1500			600	400	50	0.1	15
Lake	# Samples	[Volume Weighted Means]									
Jan	20		***1.0***	330	***394***	0.30	21	99	0.7	***0.12***	0
Feb	18	6.7	5.0	350	**325**		11	91	0.5		
Mar	37	8.4	2.7	**500**	**340**		16	97	0.9		
Apr		8.0	3.6	470	**334**	0.55	14	95		***0.16***	0
May	18	7.6	4.5	430	**329**		12	94			
Jun	6	8.0	3.4	460	**326**		10	104			
Jul		8.2	2.8	400	**309**	0.65	13	100		***0.16***	0
Aug	20	8.4	2.2	330	292		16	96	0.9		
Sep	20	7.2	3.2	350	**338**		23	85	1.2		
Oct	28	7.5	3.1	440	**309**		14	60	1.9		
Nov	18	7.6	4.4	420	***396***	0.49	15	90	1.3	***0.14***	0
Dec	19	8.1	***0.9***	330	***367***	0.42	13	84	1.8	***0.15***	0

domestic water supply. However, the trace elements Mn exceeds the limit of 0.5 mg/L during April and July. The Pb value exceeds 0.1 mg/L during all the five observation months. This may not be directly linked to anthropogenic activities. Because the Pb values in upstream springs such as Alma cottage, Chuna dhara are also above 0.1 mg/L. Therefore, the sources of Pb in lake waters may be the geological formations in the catchment area. The trace elements Zn, Co, Cu, and Fe are well within the limits, with some of these elements being non-traceable or below detection limits in the entire lake during the study period.

The public awareness programme including the tourists' should be organised at all levels in order to avoid the pollution problem and each tourist or a group of tourists should be provided written instructions regarding `what to do and what to not do' in order to avoid unwanted pollutants and waste materials reaching into the lake. It should be clearly indicated that the suitable penalty will be imposed, if the instructions are not followed strictly. The nominal charges of the instruction booklet etc. can be charged to the tourists themselves while delivering it to the tourist at the time of entry into the city. The same instructions should be applicable to the residents of the town of Nainital strictly.

Lot of unauthorised residences have come up all along Naina Devi Drain/ Pardha dhara spring including Bhutiya Market whose sewerage is not connected with the main sewerage system of the city. The pollutants are also reaching to the lake through Rickshaw Stand drain. Therefore house/kitchen waste are reaching the lake continuously through Naina Devi and Rickshaw stand drains causing a major pollution threat to lake water. As an immediate measure, the flow from these drains should be diverted during non-monsoon seasons when the flow is comparatively less but highly polluted. However, it will be better for the good health of Nainital that the sewerage and kitchen waste disposal from the unauthorised construction and leakage from the sewerage lines be tackled on top priority.

Some amount of poisonous elements like arsenic, mercury, chromium and lead are reaching into the lake only due to the anthropological activities. The possible sources may be the laboratories where such chemicals are being used for some testing/educational purposes and later on these are being disposed off into the drains meeting to the lake or at places from were these elements reach to the lake during the rainy season. The main sources of lead may be the paint which is used on large scale for the painting of boats and other belongings/buildings. Therefore, efforts are required to spread the message to take care in this respect by the concerned people for disposing such chemicals carefully at the places/drains which do not have direct and indirect access to the lake.

As already stated that the Phosphorous is a limiting factor in case of Nainital, therefore, it is essential to control the external as well as internal recycling of phosphorous to control the increasing order of eutrophication in the lake. In addition, the sediment entry reduce the lake capacity alongwith the increase of different types of pollutants.

ACKNOWLEDGMENTS

Suggestions and comments by Dr. A. V.Shedkar, Sceintist and Head, Solid Waste Management Division, National Environmental Engineering Research Institute, Nagpur to improve the manuscript is greatfully acknowledged.

REFERENCES

Bartsch, A.F. and J.H. Gakstatter. (1978) "Standard methods - for the examination of water and waste waters, 19th edition.

Carlson, R.E. (1977). "A tropic state index for lakes", Limnol. Oceanogr., 22:361-369.

Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. (1993). "Restoration and management of lakes and reservoirs", Lewis Publishers, Boca Raton, Florida.

Dillon, P.J. and F.H. Rigler. (1974). "The phosphorus-chlorophyll relationships in lakes", Limnol. Oceanogr. 19(4):767-773.

Gupta, P.K. and Pant, M.C., 1983. Chemical Composition of Surface Sediments in a Eutrophic Lake: Nainital (UP India), Environmental Pollution (Series B), 6, pp. 95-107.

Gupta, P.K. and Pant, M.C. 1986. Analysis of the Inshore Macrozoobenhic Community in Lake Nainital U.P., India, Int. Revue ges . Hydrobiol., 761, No.1, pp. 115-125.

Gupta, P.K. and Pant, M.C. 1989. Sediment Chemistry of Lake Bhimtal U.P. India, int. Revue ges. Hydrobiol., 74, No.6, pp. 679-687.

Gupta, P.K. and Pant, M.C. 1990. Distribution and seasonal abundance of benthic macroinvertebrates in lake Nainital, U.P., India, Int. Revue ges. Hydrobiol., 75, No.4, pp. 493-506.

Hino, M. (1994). "Water quality and its control", A.A. Balkema Publishers, Rotterdam, Netherlands.

Hutchinson, G.E., 1975. A treatise on limnology, Vol.1, No.2, Chemistry of Lakes, New York, John Wiley.

Jauhari, p. and Hashmi, N.,1994. On the surficial sediments of the fresh water Naini Lake, Kumaun Himalaya, India, Proc. Indian Natn. Sci. Acad., 60, No.5, pp. 675-682.

Jones, P.J. and R.W. Bachmann. (1976). "Prediction of phosphorus and chlorophyll levels in lakes", J. Water Pollut. Control Fed., 48(9): 2176-2182.

Kemp, A.L.W., Gray, C.B.J. and Mudrochova, A., 1972.Changes C, N, P and S in the last 140 years in three cores from lakes Omrio, Erie and Huron, In: Allen H.E. and Karmer J.R. (Eds), Nutrients in natural waters, New York, Wiley, pp. 251-279.

Khulbe, R.D., and Durgapal, A., 1994. Sweage mycoflora in relation to Pollutants in Nainital, Kumaun Himalaya, Poll. Res., 13, No. 1, pp. 53-58.

Lambou, V.W., S.C. Hern, W.D. Taylor and L.R. Williams. (1982). "Chlorophyll, phosphorus, secchi disk and trophic state", Water Resources Bulletin, American Water Resources Assoc., 18(5): 807-813.

Lorenzen, M.W. (1980). "Use of chlorophyll secchi disk relationships", Limnol. Oceanogr., 25:371-372.

Mortimer, C.H., 1941. The exchange of dissolved substances between mud and water in,lakes, II. J. Ecol. 29, 280-329.

Mortimer, C.H., 1942. The exchange of dissolved substances between mud and water in lakes, II. J. Ecol., 30, 147-201.

Pant, M.C., Gutpa, P.K. Pande, J. Sharma P.C. and Sharma A.P., 1981, Aspects of Water Pollution in lake Nainital, U.P., India, Environmental Conservation, Vol.8, No.2, pp. 113-117.

Pant, M.C. Sharma, P.C. and Sharma, A.P., 1983. Physio-chemcial Limnology of Lake Nainital, Kumaun Himaloaya (U.P.) India, Acta Hydrochim. Hydrobiool. 13, No.3, pp. 331-340.

Pant, M.C., Sharma, P.C., Sharma A.P. and Gupta, P.K. 1985. Lake Nainital: An Ecological perspective, In: Singh J.S. (eds) Environmental Regeneration in Himalaya Concept and Strategies, Gyonodeya Prakashan, Nainital. pp. 339-347.

Purohit, R., 1988. Relationship between physico-chemical featuresa of water sediment and macrophytic crop of the lake Nainital, Kumaun Himalaya, in. Khulbe R.D. (eds) Perspective in Aquatic Biology, papyrus Publishying House, New Delhi, pp. 177-186.

Purohit, R. and Singh S.P., 1981. Seasonal variation in physio-chemical limnology of shalolow zones of Nainital lake, Western Himalaya (India), Proc. Indian Natn. Sci. Acad., B. 47, No.2, pp. 194-203.

Purohit, R. and Singh, S.P. 1985. Submerged macrophytic Vegetation in relation to eutrophication level in Kumaun Himalaya, Environmental Pollution (Series A), 39, pp. 161-173.

Purhohit, R., Singh, S.P. and Upreti, N. 1986. Effect of non-removal of the macrophytic biomass on the characteristics of water and plant community in lake Nainital, U.P., India, Int. Revue ges. Hydrobiol., 71, No.2, pp. 245-257.

Rast, W. and G.F. Lee. (1978). "Summary analysis of the North American (US portion) OECD eutrophication project: nutrient loading lake response relationships and tropic state indices", USEPA, Corvallis Environmental Research Laboratory, Corvallis, OR 454, pp. EPA-600/3-78-008.

Ryding, S.O. (1983). "Mass-balance studies to, within and from drainage basins: A new approach for water monitoring programmes (in Swedish)", Nordic Co-operative Organization for Applied Research (NORD FORSK), Helsinki, Finland, pp. 149-162.

Ryding, S.O. and W. Rast. (1989). "The control of eutrophication of lakes and reservoirs", The Parthenon Publishing Group, Paris.

Sakamoto, M. (1966). "Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth", Arch. Hydrobiol., 62: 1-28.

Stumm, W. and J.J. Morgan. (1970). "Aquatic chemistry", John Wiley & Sons, Inc., NewYork, pp. 429- 436.

Smith, V.H. (1982). "The nitrogen and phosphorus dependence of algal biomass in lakes: Empirical and theoretical analysis", Limnol. Oceanogr., 27:1101-1112.

Smith, V.H. and J. Shapiro (1981). "Chlorophyll - phosphorus relations in individual lakes, their importance to lake restoration strategies", Environ. Sci. Tech., 15:444-451.

Sawyer, C.N., 1947. Fertilization of lakes by agricultural and urban drainage, J. New England Water Works Asso., 61, pp. 109-127.

Sharma, A.K., 1981 Structural Study of Area East of Nainital with Special reference to the Hillslide Instability, Unp. Ph.D. Thesis, Kumaun University, Nainital, pp.126.

Sharma, A.P., Jaiswal, S., Negi, N. and Pant, M.C., 1982. Phytoplankton Community analysis in lakes of Kumaun Himalaya, Arch. Hydrobiol. 93, pp. 173-193.

Shewa, W. A. (1998) Eutrophication analysis of lakes of Kumaun region. M. E. Dissertation (unpublished), Dept. of Civil Engineering, Univ. of Roorkee, Roorkee.

Vollenweider, R.A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosohorus as factors in eutrophication, organisation for Economic Cooperation and Development, Directorate of Scientific Affairs, Paris Report, pp.220.

Vollenweider, R.A. (1968). "Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to the phosphorus as factor in eutrophication", Organ. Econ. Coop. Dev., Paris, Tech. Report No. DAS/CSI/68.27, pp. 159.

Wetzen, R. (1975). "Limnology", Saunders Publishing Co., Philadelphia, pa.

DIRECTOR Dr. S. M. SETH

CONTRIBUTORS Dr. Bhishm Kumar, SCIENTIST `E'
Mr. Rm. P. Nachiappan, SCIENTIST 'B'

SPECIAL ASSISTANCE BY PROJECT STAFF

Dr. S. P. Rai, Project Officer
Mr. Vinod Kumar, Tech. Asst.
Mr. B. C. Dungarakoti, Jr. Tech. Asst.
Mr. Y. S. Rawat, Tech. Asst.

LABORATORY ASSISTANCE

Mr. Jagmohan, J.R.A.
Mr. Rakesh Goyal, Tech. II
Mr. T. R. Sapra, Tech. III
Staff at USIC, University of Roorkee, Roorkee