WATER POLLUTION ASSESSMENT OF PHEWA LAKE POKHARA, NEPAL

by

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Phewa Lake Surroundings

ABSTRACT

This study was undertaken to assess the Phewa Lake water quality so as to provide baseline data for future use and to suggest remedial measures for pollution control. The study period was relatively short and bimonthly samples from September to December were analysed in Kathmandu (200 km. from the site).

From this study it can be said that nutrient concentrations (P_{av} = 0.122 mg/l & N_{av} > 0.71 mg/l) remained very high resulting in a high primary productivity; and the Lake falls in the eutrophic category. Thermal stratification and anoxic condition of sediments remained till October; in December the water temperatures started falling and complete mixing occured till the temperatures remained constant at 17.5 °C and the dissolved oxygen remained at 7 mg/l throughout the depth.

BOD and COD concentrations increased (upto 9 & 184 mg/l respectively) towards the downstream of Baraha Temple suggesting inflow of organic matter from shore developments and/or blooming of dead algae, whereas the coliform concentrations decreased towards the Lake center and downstream (3000 MPN/100 ml) compared to the inflow (17000 MPN/100 ml) of the Lake.

It seemed that the Lake sediments, rich in nutrients, released the accumulated P and N to the overlaying waters. Nutrients and silt might come mainly from non-point sources (agricultural and deforested lands).

Tentative magnitude of pollution loads (P = 14 t/a) was estimated using WHO waste factors and the Lake retains 38 % of the total P (130 kg/d) and 78 % of the ortho-P (28 kg/d) transported to it by the tributaries (during the study period).

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LIST OF ABBREVIATIONS

Abbreviation	Name
a	Annum (Year)
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
C	Capita
Ca	Calcium
Chl_a	Algal Chlorophyll
$[Chl\_a]_{av}$	Average Chl_a
$[Chl\_a]_{s}$	Average Chl_a in Summer
COD	Chemical Oxygen Demand
d	Day
DADO	District Agricultural Development Office
DISVI	International Cooperation (Italian NGO)
DO	Dissolved Oxygen
DTN	Dissolved Total Nitrogen
DTP	Dissolved Total Phosphorus
FC	Fecal Coliform
Fe	Iron
Fig.	Figure
FINNIDA	Finland International Development Agency
g	Gram
GTZ	Gesellschaf fuer Technische Zusmmenarbeit
ha	Hectare
HOD	Hypolimnetic Oxygen Depletion
ICIMOD	International Cooperation for Integrated Mountain Development
kg	Kilogram
m	Meter
Mg	Magnesium
Mn	Manganese
µg	Microgram
mg	Milligram
MPN	Most Probable Number
MT	Metric Ton
N	Nitrogen
NGO	Non-Government Organization
NH_3-N	Ammonia Nitrogen
NO_3-N	Nitrate Nitrogen
NO_2-N	Nitrite Nitrogen
OECD	Organization for Economical Cooperation and Development
P	Phosphorus
$[P]_{av}$	Average Phosphorus
$[P]_{i}$	Average Phosphorus Inflow
$[P]_{sp}$	Average Phosphorus in Spring

contd...

POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
PVC	Polyvinyl Chloride
Q	Flow
RBC	Rotating Biological Contractor
SDT	Secchi Disc Transparency
SS	Suspended Solids
Sta.	Station
t	Ton
TC	Total Coliform
TN	Total Nitrogen
TP	Total Phosphorus
TDS	Total Dissolved Solids
WHO	World Health Oeganization
WT	Water Temperature

I INTRODUCTION

1.1 General

As the human population grows, interactions with water resources on which we are completely dependent become more and more critical. As industrialization rapidly soars, there is an increasing concurrent prevalence of environmental issues and problems. This is especially true in developing countries where there is an economic need to maximize the use of resources.

One of the most obvious, pervasive, and worldwide water quality problems is eutrophication of lakes and reservoirs. These water bodies have deteriorated rapidly, through excessive additions of plant nutrients, organic matter and silt, which combine to produce increased populations of algae and rooted plants thereby decreasing lake or reservoir volumes. Lakes and reservoirs in this condition lose much of their beauty, attractiveness for recreation, and usefulness as industrial and domestic water supplies. Therefore, at the present time, there is an urgent need for effective management of water resources and environmental quality. In order to protect, manage, and restore the quality of lakes and reservoirs, basic and applied research necessary to understand them must be expanded. The establishment of facilities for environmental monitoring, environmental education and fields of studies in environmental systems engineering and environmental impact assessments are positive signs towards these goals.

With the advent of tourism and industrial development (though in a small scale) in Nepal, Pokhara which is a major city in the western central part of the country (Figure 4.1) has kept its industrialization pace, related to tourism, due to its abundant sources of water and natural beauty. The population of Pokhara, the most important tourist center of Nepal,is increasing day by day.

The Phewa Lake in the south-west of Pokhara Valley is a recreational center, especially for tourists. The Lake is also used for irrigation, hydropower generation, and for fisheries. Thus the Phewa Lake is a multipurpose reservoir. Morphometric and hydrological data of Phewa Lake are shown in Table 1.1

Table 1.1 Morphometric Details of Phewa Lake (1989)

Description	at High Water Level	at Normal Operating Level	at Low Water Level
Normal pool elevation (m)	794.7	793.7	792.3
Reservoir area (km^2)	6.7	5.8	-
Gross storage capacity (m^3)	$53x10^6$	$47x10^6$	$40x10^6$
Effective storage capacity (m^3)	$13x10^6$	$7x10^6$	0
Dead storage capacity (m^3)	$40x10^6$	$40x10^6$	$40x10^6$
Maximum depth (m)	20	19	17.6
Hydraulic retention time (monthly average)	18 - 450 days		
Drainage basin area	120 km^2		

1.2 Objectives of the Study

Before any environmental management/monitoring program and lake restoration method can be implemented, the uses of the lake, the problems of the lake, and the causes of the problems must be evaluated. For the visualization of the concepts mentioned above, the objectives of this study are to:

- assess the existing water quality of the Phewa Lake;
- estimate the magnitude of water pollution loads;
- provide baseline data for future use and water quality management of the lake; and
- suggest remedial measures to decrease the pollution load.

1.3 Scope and Limitations of the Study

So far as it is known, an in depth study of the Phewa Lake water quality has not been yet conducted. Due to the unavailablity of data on the lake water quality and lack of equipment on site to determine all the water quality parameters, the scope of this study was as follows:

- Analyses of water samples from the lake and two rivers flowing into the lake.

- Determination of some of the main water quality parameters in the field (wherever possible) and in the laboratory in Kathmandu, 200 km. away. The parameters to be measured are as follows:

    - Biochemical Oxygen Demand
    - Chemical Oxygen Demand
    - Dissolved Oxygen
    - Total-P
    - Ortho-P
    - Ammonia-N
    - Nitrite-N
    - Nitrate-N
    - pH
    - Turbidity
    - Conductivity
    - Temperature
    - Total coliforms
    - Fecal coliforms
    - Chlorides
    - Total Hardness
    - Detergents
    - Sediment Volatile Solids

- Evaluation of the lake based on the above parameters.

- Tentative estimation of the magnitude of pollution loads using "emission (waste) factor". (Being a non-sewered area, the main point source of pollution is domestic waste from lodges and hotels).

- To have a general view of the extent and profile of water pollution.

- To summarize the total assessment results and pollution source inventory of those waste generating activities in the area (which could serve as guidelines for further assessment and provide basis for formulating policy guidelines in controlling pollution of the lake).

II LITERATURE REVIEW

2.1 The Environmental Context

Water conditions are closely linked to environmental factors, some of which are "natural" (such as climate, soils, natural plant coverage etc.) and some of which depend on human activities (such as industries, agricultural land use, settlement, etc.). These factors form a complex network of inter-relationships. For example, the current water conditions determine which water uses are possible, but water uses, in turn, alter water conditions and thus influence the possibility of further water use.

Whether water conditions will be qualified as good or bad can be considered from two different points of views:

a) as the determinants of water quality standards, or
b) as possible sources.

It is evident, that these two perspectives have to be carefully balanced to guarantee an undisturbed functioning of the whole complex system.

If a deterioration in water conditions is directly due to the current water uses, the linkage is easy to define. It may, however, be difficult to discover, when a long chain of ecological interactions connects the original problem sources with the effects on water conditions. Every component of the environment influences water conditions to a certain extent and consequently, may become a problem source either directly or indirectly in connection with other factors.

2.2 Lake Water Quality

Lake water contains dissolved gases (such as oxygen), organic, suspended and dissolved matters. The color of a lake is caused by dissolved or suspended matters; eutrophic lakes and reservoirs also have colored water (green/brown) and low levels of dissolved oxygen in the deepest areas (Cooke et al. 1986).

The degree of lake water deterioration depends on the extent of pollution. People living around the catchment area of lakes and reservoirs are an uncontrollable source of pollution. Lake water may contain pathogenic bacteria and viruses. According to Pescod (1973), industrial wastewater and agricultural run-off contain synthetic chemicals and toxic materials which have long term effects on the ecosystem of the water environment.

Various activities can affect the water quality of a lake, such as clearing of forest land, mining, use of chemicals to control unwanted growth, use of fertilizer and pesticides, etc. Swamp drainage carries high concentrations of color, organic and inorganic materials, and usually has a low pH and dissolved oxygen content (Velj, 1984). Water quality can also deteriorate when there is heavy rain following a long dry period.

Fleming (1983) who conducted a study (1976 - 1978) on the Phewa Lake catchment area from the forestry and soil conservation point of view found (based on the soil loss information) that 129,400 MT per year of sediment and 13,800 Kg per year of phosphorus are washed into the lake from the catchment. It has been observed that the total phosphorus and nitrogen concentrations in the surface waters of the lake (March - May, 1978) were 0.16 mg/l and >0.5 mg/l respectively.

Nakanishi et al. (1984) had conducted studies on some limnological variables in subtropical lakes of the Pokhara Valley in December 1982 and September 1984 (Appendix IX). From the published data on physical and chemical variables like water temperature, Secchi disk transparancy, pH and dissolved oxygen, it has become clear that the lakes of the Pokhara Valley are monomictic (complete mixing occurs once a year) or incompletely monomictic and mostly anoxic in hypolimnion during the thermal stratification period. However, there was no information on diagnosis for trophic status of the lake and phytoplankton growth.

All the chemical and biological samples were flown to Japan for the analysis (Nakanishi, 1986). They investigated the trophic status of the lake on the basis of the data on TN, TP, Chl_a and phytoplankton productivity. According to them Phewa Lake seems to be eutrophic, or rather meso-eutrophic. C:N:P ratios of particulate matter in the surface water through the seasons was 98:15:1 - 287:33:1 (Appendix IX). The C:N:P ratios obtained here indicate that N is sufficient for phytoplankton growth but P may not be sufficient for their further growth.

Based on nutrient and chlorophyll-a concentrations, Phewa Lake is mesotrophic as stated by Lohman et al. (1988) who had assessed pre- and postmonsoon limnological characteristics (Appendix Xa & Xb) of the Phewa Lake in 1985. This assessment agrees with that of Nakanishi (1986). Ratios of TN:TP in premonsoon samples were < 10 which suggests nitrogen might limit algae growth, where as a postmonsoon ratio of 17:1 could reflect either nitrogen or phosphorus limitation (Smith 1979).

2.2.1 Water Transparency and Turbidity

The Secchi disk transparency serves as an index and a means of comparision of the water body at different times. As light penetrates the waters of a lake, it is rapidly absorbed and the light intensity decreases exponentially. This loss of light is designated by the extinction coefficient and is simply a value of the fraction of light held back per meter of depth by absorption and diffusion of particulates and dissolved materials. The higher the value of Ec , the lower will be the transmission of light through the water.

Since one of the more frequently used optical relations in water studies is the euphotic depth, some limnologists find it convenient to estimate euphotic depth by using only the simple Secchi disk. The 1 % light peneration depth is generally defined as the lower limit of the euphotic zone. The observed Secchi disk visibility is multiplied by a factor(obtained by dividing true euphotic depth by average secchi disk visibility) to estimate euphotic depth when a submarine photometer is unavailable. According to Lind 1979, this factor should fall between 2 and 5 for most natural waters without unusual turbid layers.

2.2.2 Water Temperature

Water temperature is often a good indicator of contamination. Any sudden change in temperature of ground water suggests that the water is contaminated, possibly from industrial discharges. Temperature has a marked effect on bacterial and chemical reaction rates in water and can control the initiation of algal blooms, the degree of dissolved oxygen saturation and carbon dioxide concentration.

As the air temperatures rise , the upper layers of water warm up and mix with the lower layers by wind action. With cooler air temperatures during the winter and fall seasons, the temperature of the epilimnion decreases. This decrease in temperature continues until the epilimnion has the same temperature as the hypolimnion. The lake then enters "fall turnover" . Following closely to the temperature variations in water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. These two interrelated forces are capable of creating widely differing characteristics within the lake strata of water.

2.2.3 Dissolved Oxygen

The concentration of Dissolved Oxygen (DO) in waters varies greatly and is dependent on several physical, chemical and microbiological processes. Water in contact with air will contain a quantity of oxygen depending on:

a) atmospheric pressure
b) temperature of water
c) salinity or ion concentration
d) content of organic matter
e) microbiological oxygen production or/and consumption
f) light intensity

While, for fresh waters the main variables are temperature and atmospheric pressure, for polluted and eutrophic water bodies the main variables are salinity, planktonic and bacteriological action. Increased temperature generally lowers the amount of DO in water and increased atmospheric pressure raises the amount of DO. These physical phenomenon are important for fresh waters, but chemical and microbiological actions play the main roles in polluted waters.

The suitability of water for fish and other organisms and the progress of self-purification can be measured or estimated from the DO content. The DO content varies with the water depth, sludge deposits, temperature, clarity, time and flow regime. Oxygen production by algae may supersaturate the surface layers of the lake during the day time.

2.2.4 Conductivity and Salinity

A rapid method of estimating dissolved salts in a water sample is by measurement of its electrical conductivity. The conductivity is related to the total concentration of ions in solution, their valency (change) and mobility, and to the temperature of measurement. Conductivity is more related to inorganic components of a water sample than less dissociated organic components. Changes in conductivity of a sample may signal changes in mineral composition of raw water, seasonal variations in reservoir, and pollution from industrial wastes.

2.3 Water Pollution

Pollution of lake water comes from many sources, natural as well as anthropogenic origin. Criteria for determining characteristics of the watercourses are Dissolved Oxygen (DO) content, Biochemical Oxygen Demand (BOD), Total Solids (TS), pH, temperature, turbidity, nutrient content, etc.

Domestic Sewage Discharge: In many countries of Asia, people are living conveniently along river banks, lakes and canals, and on boats; various wastes from their activities, such as sewage, are directly discharged to the water bodies. According to Pescod (1973), the BOD loading of these people is estimated to be 50 g/d per person and he referred that Phantumvanit et al. (1974) estimated that people use 150 l/d of river water per person and discharge sewage containing a BOD content of 200 mg/l or 30 g/d per person.

In the Phewa Lake periphery, many people are living in make-shift houses and hotel business is rapidly increasing as Pokhara is the tourist center of Nepal. Consequently, various wastes from their activities are discharged to the lake, notably sewage. Even sewage disposal systems including septic tanks and leach fields are the primary source of biological contamination of waters draining through these areas.

Run-off: Run-off is an important contribution of urban discharge into a receiving water body. It is generated during rainy periods and consists of storm drainage, sewer overflow, etc. Agricultural run-off is one of the main non-point source of nutrients. Land-use analysis indicates that nearly half of the land in the catchment area of Phewa Lake is in terrace which is used as cropland. The average run-off from the catchment, measured at the outlet of Phewa Lake, has been calculated as 9.21 m^3/s (Fleming, 1983).

2.4 Nitrogen and Phosphorus

Phosphorus in waters is present in several soluble and particulate forms, including organically bound phosphorus, inorganic orthophosphates and inorganic polyphosphates. All inorganic phosphate (reactive phosphorus) is usually considered as PO_4. Only inorganic compounds of phosphorus are significant in engineering practice. Organically bound phosphorus is usually a minor consideration.

Although needed in small amounts, P is one of the most common phytoplankton growth-limiting elements because of the geochemical shortage of P in many drainage basins together with the lack of a P equivalent to nitrogen fixation. Phytoplankton are only able to use P in the phosphate form for growth. According to Goldman & Horne 1983, the P cycle in lakes involves only two states - phosphates and organic phosphorus. Because P is a biologically active element, its concentration in any one state depends on the degree of metabolic synthesis or decomposition occurring in that system; for example, lower concentrations are expected at times of high synthetic activity.

Nitrogen is present in aquatic ecosystems in several forms. Nitrogen which exists in the combined forms of ammonia (NH_4^-), nitrate (NO_3^-), nitrite (NO_2^-), urea ($CO[NH_2]$), and dissolved organic compounds are of more interest for the environmental engineer. Nitrate is normally the most common form of combined inorganic nitrogen in non-polluted lakes. The concentration and rate of supply of NO_3^- is intimately connected with the landuse practices of the surrounding watershed. Nitrate ions move easily through soils and are quite rapidly lost from the land even in natural drainage systems. This contrasts with phosphates or ammonium ions which are retained by charged soil-particles. When present in sufficient quantities, NH_4^+ is the preferred form for plant growth since the utilization of NO_3^- requires additional energy. NH_4^+ as a metabolic waste product of animals provides a source of recycled N to plants. NO_2^- is an intermediate product of the decay of nitrogenous material. It is formed by the bacterial oxidation of NH_4^+ and then rapidly oxidised by bacterial action to an end-product (NO_3^-).

2.5 Sediments

Lake sediments are better understood than the water with regard to P cycle because the sediment has only one active layer, the sediment-water interface (Goldman & Horne, 1983). Although sediments are mixed with larger benthic organisms, they are physically more stable than turbulent lake waters. The most important reactions in the sediments are those which change P from a solid phase into soluble phosphate in the interstitial waters, which may then in turn be released to overlying waters.

2.6 Eutrophication

Eutrophication is the process of excessive addition of inorganic nutrients(P, N, Si etc.), organic matter,and/or silt to lakes and reservoirs, leading to increased biological population and a decrease of lake volume. The excessive fertilization of natural water is one of the most significant causes of water quality deterioration in many countries. A lake has its assimilative capacity to some extent, but when the incoming rates of sediments, organic matter and nutrients are faster than what the lake can assimilate or discharge them, then eutrophication occurs.

That phosphorus plays a key role in eutrophication has been accepted by most scientists (Vollenweider, 1968); the presence and rate of increase of phosphorus concentrations in lake waters are considered by them as an important indication of the trophic state of lakes. The nitrogen-phosphorus ratio is one way to assess whether phosphorus is the limiting nutrient. According to Smith (1979), N:P ratio greater than 21 strongly suggests that phosphorus is the limiting element, whereas when the ratio is less than 13 nitrogen may be the limiting factor. Lakes with intermediate ratios could be limited from time to time by either element.

The major water quality consideration for the management of Phewa Lake is eutrophication, that is, increase in nutrient content and biological growth and the consequent decrease of oxygen supplies (Fleming, 1983).

Several physical, chemical and biological parameters can be used to assess the trophic status of lakes. The main trophic parameters (indicators) are chlorophyll-a, secchi disk transparency, and areal hypolimnetic oxygen depletion (HOD) rate, g $O_2/(m^2.d)$. The chlorophyll_a data can also be used to compute a trophic state index, and as part of a predictive model of lake recovery (Cooke et al., 1986).

2.7 Models for Assessing Eutrophication

The water quality of a lake will deteriorate when nutrients and pollution load to the lake keeps increasing, such as from population increase, economic development, etc. Mathematical modeling is desired to assess the existing situation and to predict the future conditions of a water body.

There are two major types of mathematical models being used for assessing and managing eutrophic water bodies, i.e.phosphorus loading models and ecological models. The phosphorus loading models are based on steady-state analytical solution of phosphorus mass balance equation for closed water bodies and key parameters were derived from statistical analysis of trophic state indicators observed in many different states of lake and reservoirs. Phosphorus loading models are empirical (inductive) models (Okada, 1982).

The basic idea for phosphorus loading models has been proposed by Vollenweider (1969) defining a correlation between phosphorus concentration and trophic indicators; OECD (Organization for Economical Cooperation and Development) adopted this idea and confirmed the phosphorus loading models.

Correlation between chlorophyll-a concentration and phosphorus concentration in a lake: Chlorophyll_a (chl_a) is a photosynthetic pigment which is present in all species of phytoplankton. Thus chl-a concentration is the most common indicator of phytoplankton biomass. Concentration of phytoplankton is dependent on the concentration of phosphorus in a lake if the growth of phytoplankton is limited by phosphorus. According to Okada (1982), a relationship between average chlorophyll_a concentration in summer, $[Chl]^{s}$ (mg/m^3) and total phosphorus concentration during spring circulation, $[P]^{sp}$ (mg/m^3) is expressed as follows (regression coefficient, r = o.975):

$$\log [Chl]^{s} = 1.583 \log [P]^{sp} - 1.134 \qquad (2.1)$$

Based on the same idea, annual average chlorophyll_a concentration, $[Chl]_{av}$ (mg/m^3) is related to annual average phosphorus concentration, $[P]_{av}$ (mg/m^3) as follows:

$$\log [Chl]_{av} = 0.96 \log [P]_{av} - 0.533 \qquad (2.2)$$

Correlation between phosphorus concentration and phosphorus loading in a lake: From the phosphorus budget in a whole lake, total phosphorus concentration in a lake [P] ($mg\ P / m^3$) can be expressed (from mass balance) as:

$$\frac{d\,[P]}{dt} = \frac{[P]_i}{t_w} - \frac{[P]}{t_p} \qquad (2.3)$$

where,

$[P]_i$: average inflow phosphorus concentration, $mg\ P/m^3$
t_w : average hydraulic residence time, a
t_p : average residence time of phosphorus, a

The steady state solution to this model is

$$[P] = \frac{t_p}{t_w} [P]_i \qquad (2.4)$$

But it is very difficult to calculate t_p which is related to sedimentation rate of phosphorus (v). Vollenweider (1975) gave the following empirical equation.

$$\frac{t_p}{t_w} = \frac{1}{1 + t_w^{1/2}} \qquad (2.5)$$

Then,

$$[P] = \frac{[P]_i}{1 + t_w^{1/2}} \qquad (2.6)$$

<u>Correlation between trophic indicators and phosphorus loading</u>: Phosphorus concentration in a lake can be estimated by using equation (2.6). A correlation between chlorophyll_a concentration and the phosphorus loading is given by Vollenweider (1975, r = 0.868),

$$\log [Chl] = 0.91 \log [P] - 0.435 \qquad (2.7)$$

or,

$$[Chl] = [P]^{0.91} - 10^{0.435} \qquad (2.7a)$$

where,

$$[P] = \frac{[P]_i}{1 + t_w^{1/2}} = \frac{L(p)}{q_s\ (1 + t_w^{1/2})}$$

L(p) : areal loading of phosphorus, mg P / (m^2.a)
q_s : areal hydraulic loading (Q/A), m^3 / (m^2.a)

OECD program reported correlations not only for chlorophyll_a but also for other trophic parameters such as secchi disk transparency [SDT] and areal hypolimnetic oxygen depletion [HOD], g O_2 / (m^2.d).

$$\log [SDT] = - 0.39 \log [P] + 1.17 \qquad (2.8)$$

$$\log [HOD] = 0.467 \log [P] - 1.07 \qquad (2.9)$$

Phosphorus loading models can be applied to regular lakes or reservoirs only in relation to phosphorus loading.

2.8 Trophic status

An eutrophic lake changes through the stages from oligotrophic, mesotrophic to eutrophic. Each of these terms defines a certain state of lakes during the succession of the trophic scale. The boundaries between trophic states, however, are not exactly fixed or are not precise lines for differentiation as several factors complicate the attempt to quantify the relationship between trophic status and measured nutrient concentrations of lakes . A certain fraction of the nutrients (e.g. P) becomes refractory while passing through successive biological cycles. Also, morphometric (mean depth, basin shape, detention time, and other physical attributes) and chemical factors affect the availability of nutrients in làkes. However, comprehensive knowledge or judgement has been acquired to assesss the trophic states of a lake under consideration.

Nutrient concentration and primary productivity (phytoplankton biomass) have been used as indexes of eutrophication. Transparency and DO concentrations are also indexes of primary productivity. Chl_a (photosynthetic pigment) concentration is the most common indicator of phytoplankton biomass. It must be noted, however, that chl_a content in algal cells varies depending on phytoplankton species and environmental conditions.

2.9 Emission Factor

A relatively simple procedure for the identification and assessment of environmental problems which may exist in a given area, region or even country has been developed and tested by the World Health Organization (WHO) for over the past years. The process which is a rapid environmental assessment methodology for conducting base line studies, and for forecasting and evaluating impacts is accomplished with the usage of emission factors (amount of pollutants emitted with production capacity).

Results of rapid environmental assessment studies using emission factors serve as guidelines for the government in the determination of the appropriate balance and stability between economic development, health and environmental pollution control, planning and monitoring.

The idea of using "emission factor" for environmental assessment has been practiced in many countries especially the developed ones, since the last few years. Sittig (1975) defined "emission factor" (some times known as "discharge factor") as an average estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity. Typical examples of emission factors are: kilogram of Biochemical Oxygen Demand (BOD) per ton of product, kilogram of carbon monoxide (CO) released per ton of coal burned, and others.

The latest concept of applying emission factor for rapid pollution inventory studies as stated in the publication, WHO Offset Bulletin No. 62, 1982, is the "streamlining of the inventory procedure", enabling the user to identify and assess environmental problems which may prevail in any given area or region and to produce reasonably reliable results in a very short period of time.

The usage of emission factors as a rapid technique for preliminary assessment of pollution sources, has been conceived by WHO with the concern of helping many developing countries in safeguarding public health as well as the environment from the hazardous effects of excessive environmental pollution.

According to De Koning (1981), determination of pollution load with the usage of emission factor for rapid assessment studies provides direct contribution or offers assistance in:

a) Defining high priority control actions;
b) Organizing more effective detailed source survey programs;
c) Organizing more appropriate environmental monitoring programs;
d) Assessing the impact of proposed pollution control strategies, thus helping to establish proper control measures.

New terminologies are introduced to broaden and understand the concept of determining pollution loads. Foremost among these terminologies are pollution factor and waste factor. Pollution factor is the amount of a pollutant or a combination of pollutants released into the environment by an industry per unit of merchandise produced or per unit of raw material consumed. Whereas, waste factor in the case of domestic and municipal wastes, refers to the total amount of waste (solid or liquid) released into the environment by one person per year (WHO, 1982).

Sittig (1975) mentioned that emission factors may not be precise indicators for single source emission and that they may be more valid when applied to a large number of processes. Emission factors as he stated, are extremely useful when intelligently applied in conducting source inventories, as part of community or nationwide area pollution studies.

III MATERIALS AND METHODS

3.1 Sampling

The sampling techniques used in a lake water survey must assure that representative samples are obtained, because the data from the analyses of the samples will ultimately serve as a basis for defining high priority control actions. There are no universal procedures for sampling; thus suitable sampling locations must be selected, and the frequency must be determined.

3.1.1 Sampling Location

Since the mass of water being investigated is usually great relative to the sample, the sample is representative of the mass only to the extent that the mass is homogeneous. Such homogeneous conditions do not usually exist in the dimensions of either surface area or depth. Thus care must be exercised in the selection of the location and number of sampling sites. Selection of suitable sampling locations depends on area, shape and size, depth of the lake, and location of pollution discharges to the lake. 6 sampling locations as shown in Figure 3.1 (2 river inlets, 1 in the middle, 1 downstream of Baraha Temple, 1 downstream of Fish Tail Lodge and 1 outlet) were selected for Phewa Lake (6.7 km^2 in area). Water sampling locations for Phewa Lake and its tributaries are summarized in Table 3.1.

Table 3.1 Sampling Locations

Station No.	Description
1	Aneri Khola source
2	Sedi Khola source
3	Center of the lake
4	Downstream of the Baraha Temple
5	Downstream of the Fish Tail Lodge
6	Upstream of the outlet (Dam)
7	Canal Discharge from Seti River
8	Firke Khola (Flow in Rainy Season)

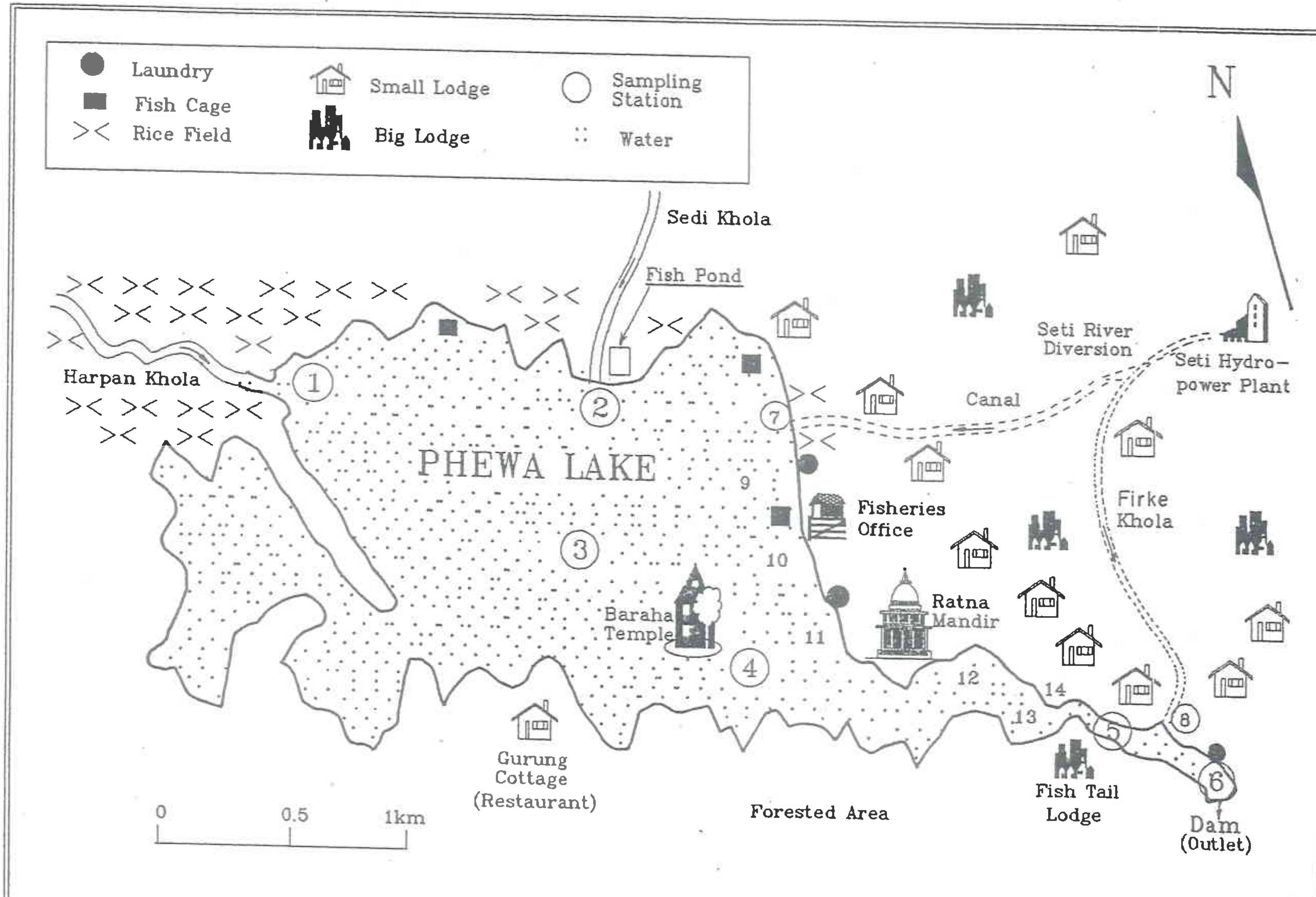

Figure 3.1 Phewa Lake Surroundings with Sampling Locations

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3.1.2 Sampling Frequency

Frequency of sampling varies with the intent of the investigation. For general information-gathering surveys, bimonthly series may suffice (Hutton, 1979). Although, many investigations are based on fewer samples, 24 can hardly be considered representative of the environmental conditions in a year (Lind, 1979). Conducting a study on a lake is a long-term process and can even take some years. As time was very short (4 months or one season - Autumn), most of the water quality parameters may not fluctuate to that extent in a short period, especially in one season. Samples for the analyses were taken monthly during the study period. Some parameters (DO and temperature) were measured hourly (whenever possible) at the site.

3.1.3 Sample Collection

Several types of samplers have been designed, including the Kemmerer, the Nansen and the Van-Dorn. They differ principally in closing mechanisms. The Van-Dorn water sampler, made of polyvinyl chloride (PVC), was used for sampling from various depths (5 m intervals up to 0.5 m above lake bottom) for each station. The water samples were transferred to the laboratory in 1 liter polyethylene sampling bottles for physical and chemical analysis. Before filling, the sample bottles were rinsed two or three times with the water being collected.

Samples were taken separately for bacteriological examination and BOD determination. Samples for bacterial examinations and BOD determination were collected in 250 ml sterile glass bottles and 200 ml BOD bottles respectively and placed in ice immediately.

3.1.4 Sample Preservation and Transportation

Physical, chemical and biological integrity of the samples should be maintained during interim periods between sample collection and sample analysis. But complete and unequivocal preservation of samples is practically impossible and complete stability for every constituent can never be achieved (APHA, 1981). At best, preservation techniques only retard chemical and biological changes that inevitably continue after sample collection. Storage at low temperature (4°C) was perhaps the best way to preserve most samples until the next day. Therefore, all the samples collected were stored in polyethylene and glass bottles in ice box for refrigeration.

In general, the shorter the time between collection of a sample and its analysis, the more reliable will be the analytical results. For certain constituents and physical values, immediate analysis of all the variables is ideal.

But in this study, there was no laboratory facility nor field kit in Pokhara. The samples were collected, refrigerated (until chemical analysis were performed) and transported 200 km. to Kathmandu on the same day at night by bus for analysis.

3.2 Analytical Procedures

Physical, chemical and bacteriological examination of water samples were performed in accordance with " Standard Methods for the Examination of Water and Wastewater " (APHA, 1986). Temperature (°C), Dissolved oxygen (DO) and pH were measured in the field. Temperature and DO were measured weekly and even hourly for 24 hours to know the diurnal changes and vertical profiles with depth at 1 m intervals, using a Portable Digital DO/O_2 / TEMP Meter, Model UC-12.

To calculate hydraulic retention times from September to December 1989, reservoir volumes were divided by discharge rates using biweekly data provided by the Department of Irrigation, WRD, Pokhara. Data on discharge rates to the reservoir from tributaries were calculated from the flow velocities and croos sectional area of the tributaries. Data on morphometic details were also provided by the Department of Irrigation, WRD, Pokhara.

All the samples were preserved in a refrigerator in Pokhara and transported to the Laboratory of Health Education and Services Project financed by International Cooperation (DISVI), Kathmandu. The variables given in Table 3.2 were the parameters that could be analysed. Analyses were performed as soon as possible after collection, usually within 24 hours.

However, it could be noted that the lower ranges of the spectophotometer calibration for the analysis of NH_3-N, NO_2-N, NO_3-N, ortho-P and total-P were 0.05, 0.01, 0.10, 0.10 and 0.10 respectively. Values less than these lower limits may not be accurate. But these values give general information for evaluating the N & P budgets in the Lake for the study period.

Table 3.2 Methods Used for the Analyses of the Chemical Parameters

Parameters	Method Used for Analyses*
Turbidity	Nephelometric
pH	Potentiometric
Conductivity	Potentiometric
Total Hardness	EDTA Titrimetric
Chloride	Titrimetric method
Detergent	Spectrophotometric
Ammonia-N	Phenol Hypochlorine IRSA
Nitrite-N	NED dihydrochloride
Nitrate-N	Sodium Salicylate
Orthophosphate	Ascorbic acid
Total Phosphate	Ascorbic acid
Biochemical Oxygen Demand	Titrimetric
Chemical Oxygen Demand	Open reflux
Total Coliform	Membrane filter technique
Fecal Coliform	Membrane filter technique

* Standard Methods (1981).

3.3 Data Collection

Most of the parameters for water quality assessment were assessed in the laboratory or in the field. But for the pollution load assessment, a preliminary field survey and interviews were conducted. The foregoing procedures, based on WHO publication (1982), were considered as outlined by Nakamura et al. (1982):

a) Get an overall picture of the study area, waste generating activities, their magnitude and location, geographical boundaries, and others (tourism, history of the lake etc.).

b) Identify proper sources of information.

c) Visit actual sources of information.

d) Cross-check data collected from various sources.

e) Establish a pollution parameter profile, and the major sources showing their contribution.

In addition to the results and findings using these methods, guidelines for reporting a rapid assessment study, as recommended by WHO (1982), were followed:

a) Interpret environmental impacts based on the calculated pollution loads in relation to the general background of the study area and environmental quality.

b) Assess impacts of major emissions/discharges in correlation to the population and valuable natural resources.

c) Summarize possible areas for effective environmental control measures.

d) Assess the effectiveness of the existing pollution control programs and recommend appropriate improvements.

3.3.1 Interview

To have the latest knowledge of all the pollution sources and waste generating activities in Phewa Lake and catchment, as well as to update the available data interviews were undertaken. From personal interviews the following information was collected:

- Number of tourists and their average stay in Pokhara.
- Land use categories.
- Fertilizer and pesticide use.
- Pollution control devices.
- Other activities.

Interviewing was one of the most reliable procedures in defining the latest and correct information for the rapid assessment of environmental pollution loads where data is unavailable, especially for developing countries like Nepal.

Annual data on fish production in the Lake and bimonthly data on DO, temperature and pH of the surface water were provided by the Fisheries Development Center, Pokhara (Appendix XI). The land-use categories, area, yield and production of major crops in the Lake watershed were provided by the District Agricultural Development Office (DADO), Pokhara (Table 5.5). Interviews were conducted with the concerned persons of DADO and the farmers to get the information on chemical fertilizer and pesticide use. Information were provided by the Tourism Office, Pokhara.

3.3.2 Survey

Preliminary surveys were carried out in the Lake by boat; and around the lake shore on foot to determine sampling locations, wastewater discharge, land use, etc. Collection of samples and data, measurement of physical parameters of the Lake water and analyses of several biological and chemical water quality parameters were then performed.

Detailed surveys were carried out around the lake shore, particularly in the business area, to get the latest information on the number of hotels and lodges, shops and tea-shops, number of employees, average stay of tourists, sanitary condition, and overall thinking of the general public.

Visual inspection of the waste generating sources, municipal solid waste dumping sites, piggery, fishery and poultry farms around the Phewa Lake were conducted, so as to see and have an idea of the extent of water pollution in the Lake. During the course of the survey, photographs were also taken so as to capture the existing pollution problems within the Lake and the catchment area.

IV GENERAL DESCRIPTION OF THE STUDY AREA

4.1 Nepal

Nepal is a small Himalayan country with the highest mountain in the world. It is located in the central part of Asia (84° Longitude and 28° N. Latitude) between China and India. The total land area of Nepal is 142,000 km² with a population of 17.5 million. Mountains comprise 83 % of Nepal with only 17 % of plain area.

4.2 Pokhara/Catchment Area

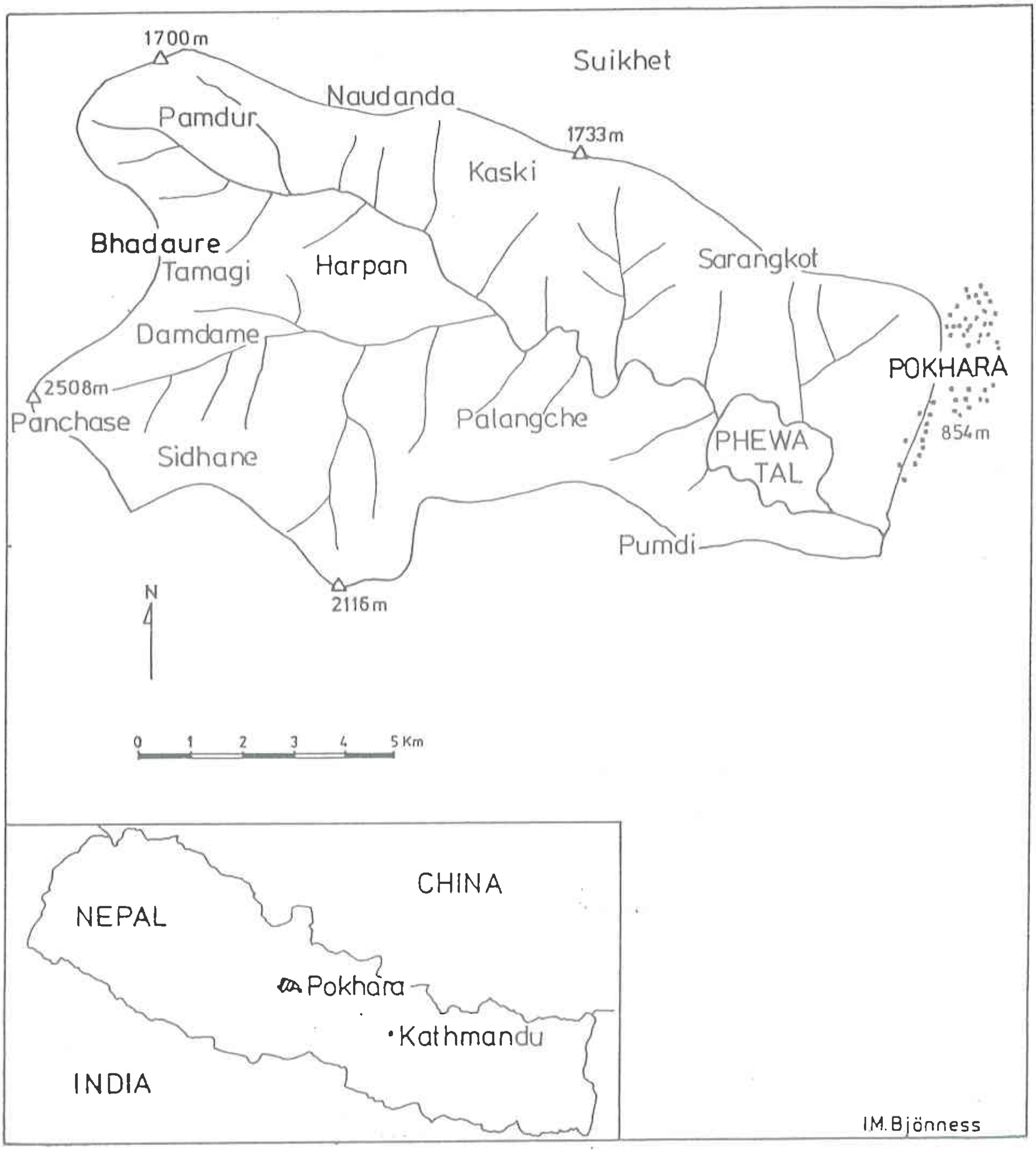
As the degree of water pollution of a lake depends on many factors (natural as well as due to human activities), it is desirable to know the topography, geology, climate, hydrology, land use, and socio-economic activities of the lake catchment area.

4.2.1 Geography, Topography and Geology

Geographical Situation: Pokhara, in Kaski District, is the headquarter for the Western Development Region and is about 200 km west of Kathmandu, the capital of Nepal. The Phewa Lake catchment is adjacent to the western side of the town of Pokhara (Figure 4.1). The catchment has an area of 120 km² and drains into one of Nepal's most prominent lakes, the Phewa Lake. The elevations range from 850 m at the lake to 2,500 m at Panchase Peak, and the topography is steep slope except for the Lake valley. Thus we can say that it is a mountain lake.

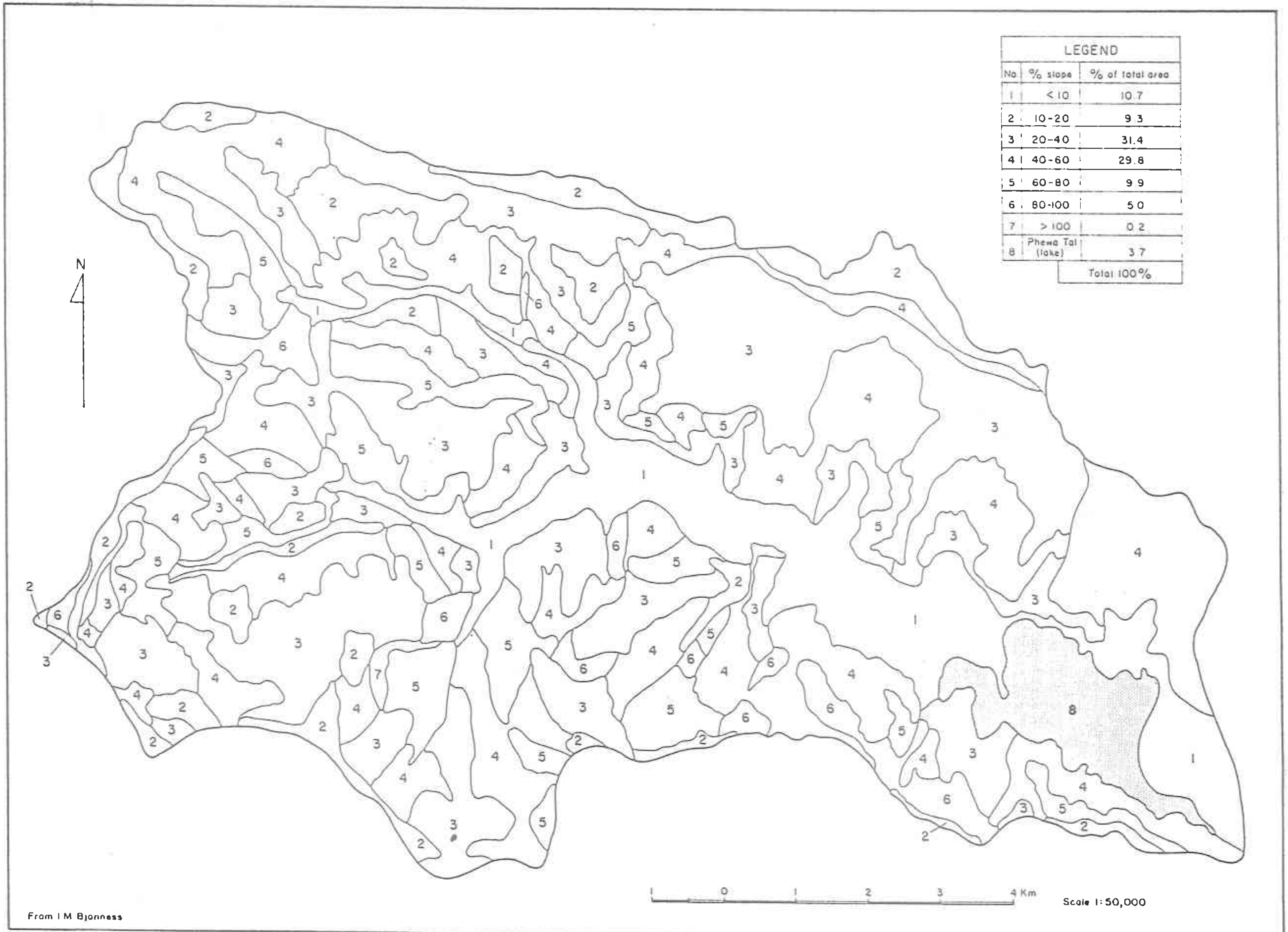
Topography: It has been observed that 70 % of the catchment area has slopes of between 20 and 60 % , with an average slope of 40 % (Figure 4.2). About 11 % of the catchment area has a slope of 0 - 10 % , and 15 % is very steep (70 - 100 % slopes). Some portions have slopes greater than 100 % (Fleming, 1983).

Most of the very steep slopes occur in the southern part of the lake/catchment and are mainly forested.



Source: Fleming, 1983.

Figure 4.1 Location and Orientation Map of the Phewa Lake Catchment, Pokhara, Nepal.



Source: Fleming, 1983.

Geology: Two metamorphic rock types, primarily *"schists"* and *"phyllites"*, predominate in the catchment (Fleming, 1983). The northern part of the catchment area is phyllite consisting mainly of micas and chlorites (Figure 4.3). Because of the phyllites'weak structure (low-grade metamorphic rocks) and deep slope situation that encourage downward movement of soil and rock, this part of the catchment is geologically the most susceptible to erosion.

The southern part of the catchment consists of quartzose of a higher metamorphic grade than that of the north. Bedding structures are moderately strong. Because of more resistant rock types and structure, the southern part of the catchment does not have erosion problems common to the northern part.

4.2.2 Climate and hydrology

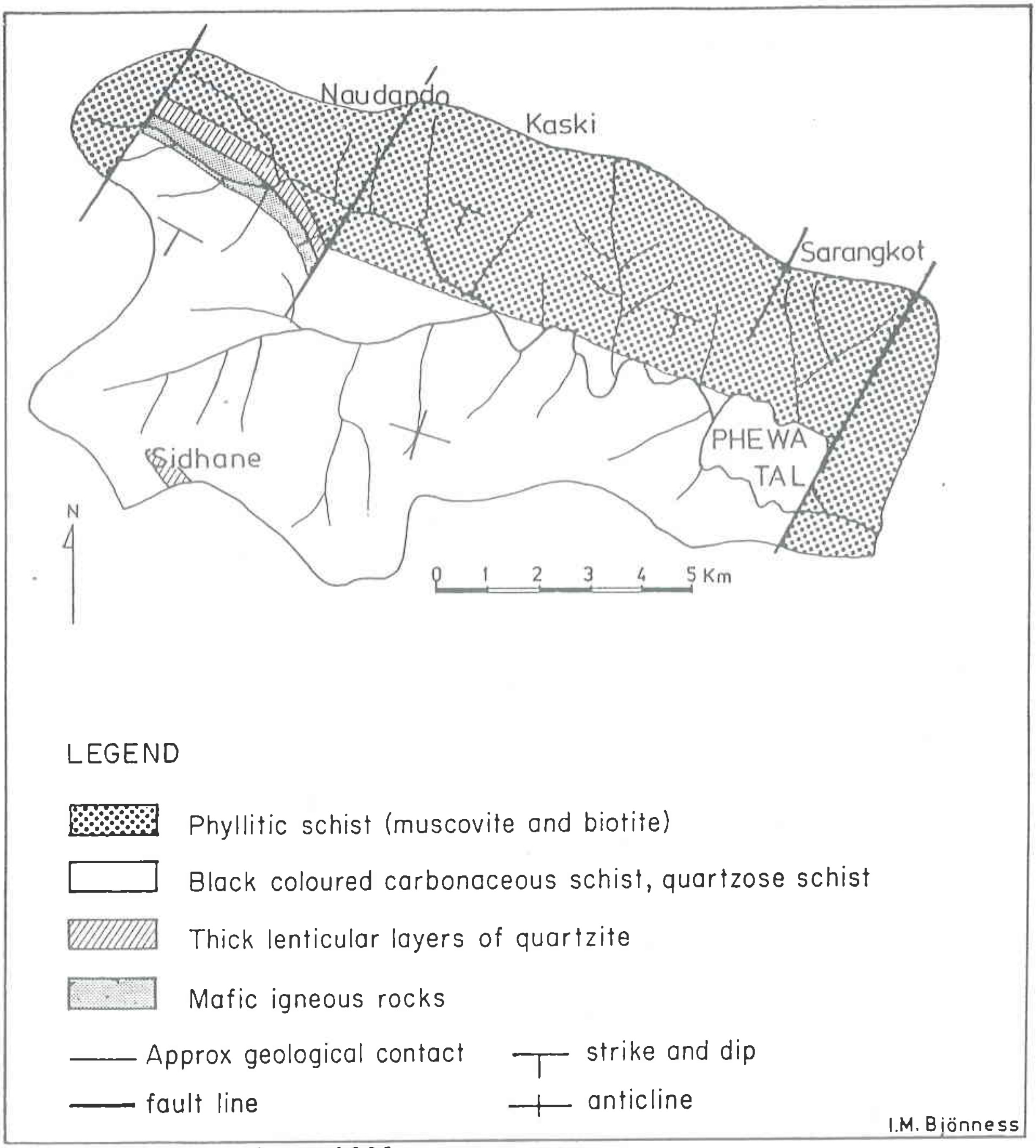
Climate: Pokhara's climate is humid subtropical to humid temperate. Mean temperatures vary between 12° C in the winter to 30° C in the summer. The rainfall pattern is monsoonal, with 80 percent of the total annual rainfall falling during the period of May - September (Appendix VI).

Hydrology: Rainfall in Pokhara is the highest yet recorded in Nepal. The average annual precipitation in Pokhara (854 m elevation) is 3,885 mm and 5,407 mm in Lumle (1,675 m elevation and just outside the catchment boundary), which is the highest in Nepal. Average precipitation for the catchment is estimated at 4,500 mm, which is equivalent to 540×10^6 m^3/a (Fleming, 1983). The annual precipitation in 1989 was observed as 4086 mm (Appendix VI).

The average runoff from the Lake has been calculated as 9.20 m^3/s (290×10^6 m^3/a); the 100-year flood has been observed as 630 m^3/s (Fleming, 1983).

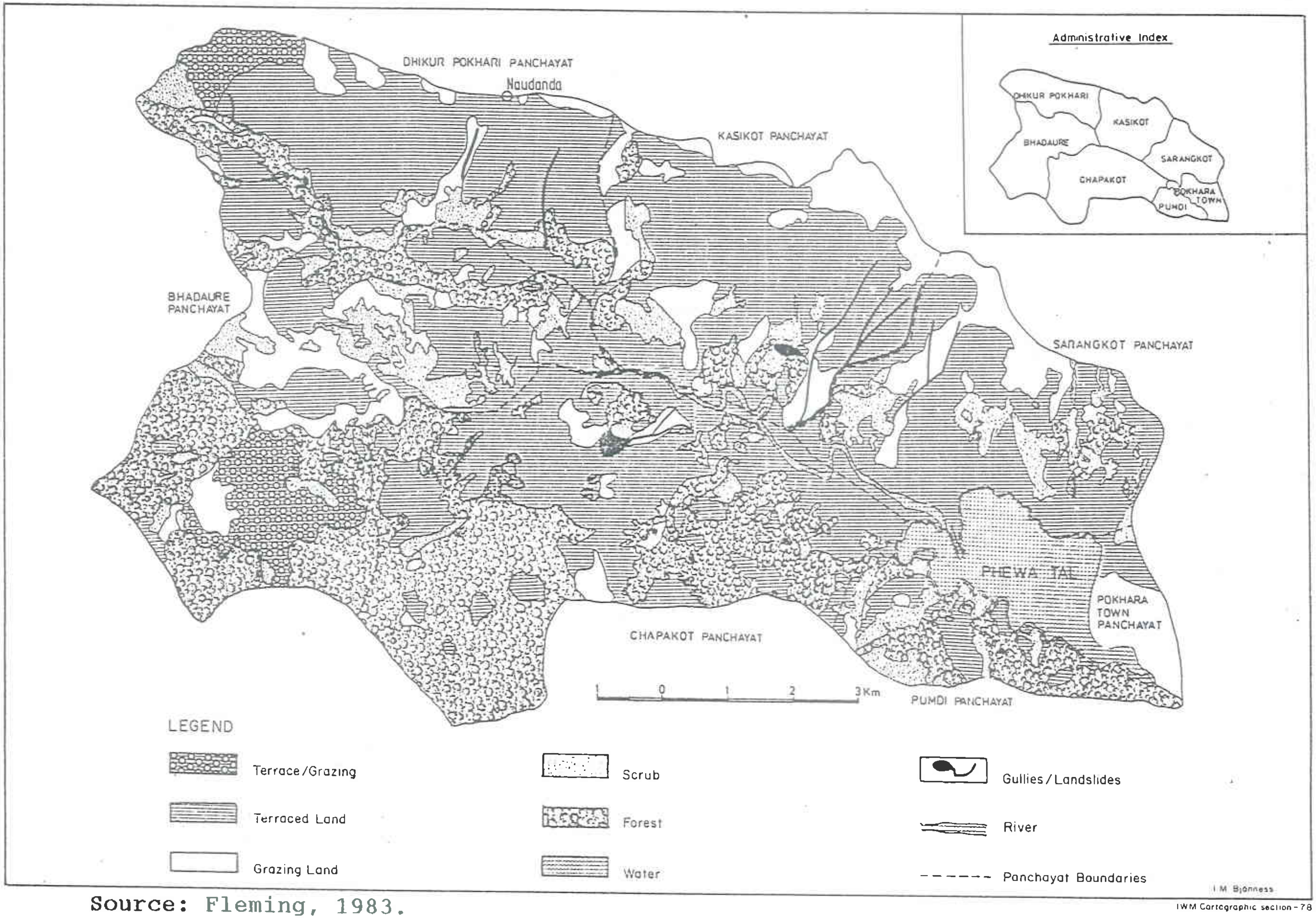
4.2.3 Land-Use

Land-use information is based on aerial photographs, which provides the database for interpreting a land-use map (Figure 4.4). It has been calculated that nearly half (48 %) of the land is terraced, about a quarter (26 %) forested, and a tenth (10 %) open grazing land (Appendix XVII). The terraced land is used for cultivation.



Source: Fleming, 1983.

Figure 4.3 Geological Map of the Phewa Lake Catchment, Pokhara, Nepal.



Source: Fleming, 1983.

Figure 4.4 Land-Use in the Phewa Lake Catchment, Pokhara, Nepal.

It has been estimated that about 1717 ha of terraced land in the catchment area of Phewa Lake is upland and about 3016 ha of that is lowland. The major crops which are cultivated in a total area of 4733 ha are rice, maize, millet and wheat. The total production is about 11004 t/a and the average cropping intensity is equal to 1.6.

4.2.4 Socio-Economic Activities

Population Growth and Distribution: The population growth rate was estimated at 1.95 %/a. The present population of the catchment area is about 29,000 excluding tourists. Pokhara is the most popular and attractive tourist center of Nepal with significant views of the Himalayas. More than 58,000 tourists besides Indian visit Pokhara every year (Appendix XIV).

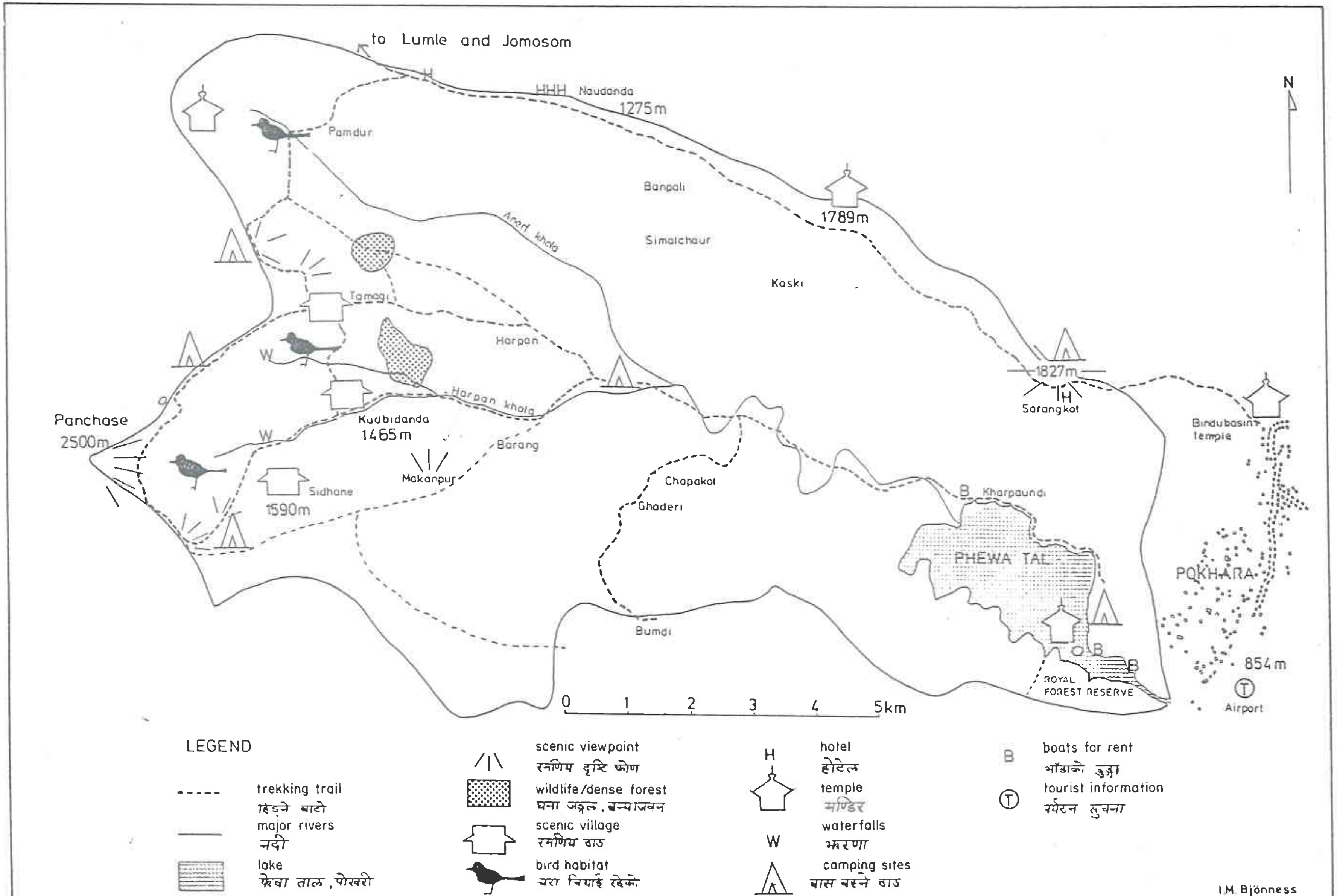
Economy: Agriculture is the resource base of the Phewa Lake catchment; rice, corn, millet, wheat, and vegetables are cultivated. Most families keep 4 to 5 large animals for the production of manure and milk. Forests supply fuelwood and timber for building.

The next source of income is tourism. The hotel business is booming due to the increase in tourists. Expeditions to the Himalayan peaks start from Pokhara and through the northern part of the catchment. Although most tourists who hike through the catchment area are en route from Pokhara to Jomsom, substantial recreational opportunities exist within the catchment itself (Figure 4.5). Many attractions for hikers and naturalists exist in the Panchase Peak area, and more facilities such as hotels and restaurants could be encouraged.

4.2.5 Infrastructures and Services

Transport: Pokhara has an airport which will be soon converted into an international airport. Vehicular facilities are available, and Pokhara is connected to other cities by 2 highways and the third highway, which passes through the northern side of the catchment, is under construction.

Power and Electrification: There are two hydro-electric plants which generate a total rated capacity of 2,500 kW.



Source: Fleming, 1983.

The water required for one of the plants is fed by the Phewa Lake.

4.3 Phewa Lake

4.3.1 Physical Features

Phewa Lake lies in the south-west of the valley of Pokhara and is bounded on three sides by mountains. The lake has an area of 6.7 km^2 with a maximum depth of 20 m, and a water volume of 53×10^6 m^3 (Fleming, 1983).

An estimate of the sedimentation rate in the Phewa Lake has been made based on the soil loss information. The total soil loss from the catchment has been estimated to be 129,400 MT per year (Fleming, 1983). But the total loss per annum is expected to be reduced due to the development of the watershed project. This project mainly looks after the control of landslides and mass erosion by planting and construction of gabion works. This has been found to be useful measures in protecting the Phewa Lake from siltation.

To provide accommodation for the increasing tourists, the hotel business is increasing every year in an alarming rate. Most of the hotels are almost attached to the lake shore and the waste generated is directly discharged into the lake. No measures for domestic waste disposal has been taken , and this has accelerated the pollution of the lake water.

There is a temple on an island in the lake and many people visit the temple every day, especially during the holidays and festival periods. In addition to this many people use it as a picnic spot. Wastes generated by these people also contribute to the lake pollution.

4.3.2 Beneficial Uses

<u>Hydropower Generation</u>

Electricity produced by hydrogeneration is the cheapest source of energy available in Nepal. There is a small hydroelectric plant which is fed by Phewa Lake water, stored by constructing a dam. After the construction of the dam, the storage capacity of the lake was increased from 30×10^6 m^3 to 53×10^6 m^3. The hydroelectric plant generates 1,000 kW of electricity throughout the year.

Irrigation

The water from the Phewa Lake is used, not only for hydroelectricity generation, but also for irrigation. The irrigated area is about 320 ha, which is served by the Phewa Lake water due to the increased level of water after the construction of the dam. Generally, two crops are grown in a year in this area.

Fishery

The Fisheries Development Center (FDC), Pokhara has developed a fishery in the lake. Additionally, private sectors are also allowed to develop cage fishery in the Lake. Except this there are more than 100 fishermen living around the lake who fish in the open areas for commercial and personal uses. These fishermen are totally dependent on fish production in the lake. Fishing procedures involve netting and hook-and-line fishing. Sometimes, FDC releases many thousands of fish into the Lake for the public.

Recreation

Pokhara is the most popular tourist center of Nepal with lakes and magnificant views of the Himalayas. Most of the tourists live around the Phewa Lake and use the Lake for their entertainment like swimming and boating.There are more than 200 boatmen, either fishermen or plying for the tourist trade.

The lake site is also a convenient picnic spot. Many people come (generally during the holidays) to the lake site and spend the whole day picnicing, swimming and boating.

4.3.3 Water Quality Management

Pokhara Town Panchayat looks after the Phewa Lake and there is no particular organization for the Lake water quality management. Building multistoried buildings in the Town Panchayat around the lake is not permitted so as to protect the magnificent views of the Lake. The Phewa Watershed Project is supposed to be a monitoring organization for the catchment area and to control landslides and mass erosion; this Project could be helpful for the water quality management of the Lake.

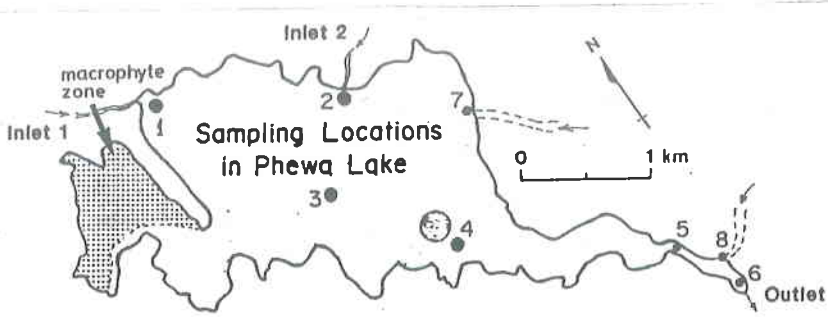
V RESULTS AND DISCUSSION

5.1 Water Storage

Harpan Khola (Sta. 1) is the major source of water for the Phewa Lake. It is a typical rapid-flowing, rainfed Himalayan stream with a drainage area of about 120 Km^2. Sedi Khola (Sta. 2), canal discharge (Sta. 7) and Phusre Khola (Sta. 8) are small and temporary (seasonal) tributaries of Phewa lake. Both the canal and the Phusre Khola (rich in Ca) are discharges from the Seti Hydropower Plant (Fig. 3.1) and is used for irrigation. While the monthly mean run-offs (Appendix VIII) were estimated as 1.03 m^3/s in April to 34.00 m^3/s in August, the run-offs in 1989 had been calculated as 1.30 m^3/s in February to 49.06 m^3/s in August. The average monthly rainfall (Appendix VI) and run-offs (Appendix VIII) are shown in Figures 5.1 and 5.2.

Figures 5.3 and 5.4 show the probability of equal to or higher rainfall and flow occurring respectively. It seemed that probability of 30 m^3/s or higher flow occurring was 60 % in September and might be noted that flushing action due to the high flow occurred till September. Gross water storage of Phewa Lake varies from 40×10^6 m^3 in the dry season to 53×10^6 m^3 in the monsoon season.

Retention times for the Lake averaged about 250 to 450 days from December to May; decreased to 50 to 30 days from June to July and to 18 days in mid-August. Subsequently, they gradually increased to 28 days by September and were maintained between 62 to 150 days until November.The rainfall and run-off in 1989 were greater than average. The retention times decreased to 12 days (for a few days) in July-August 1989. A decrease in the hydraulic retention time induces better mixing and aeration due to turbulence, thereby decreasing the deposition of nutrients to the bottom; decreasing primary productivity and growth of rooted plants. Thus the Lake is less polluted due to the flushing action of the water in the Lake. Flushing involves the addition of large volumes of water to wash out algal cells and complete mixing (turnover) might occur during the heavy rainfall period (July - September).



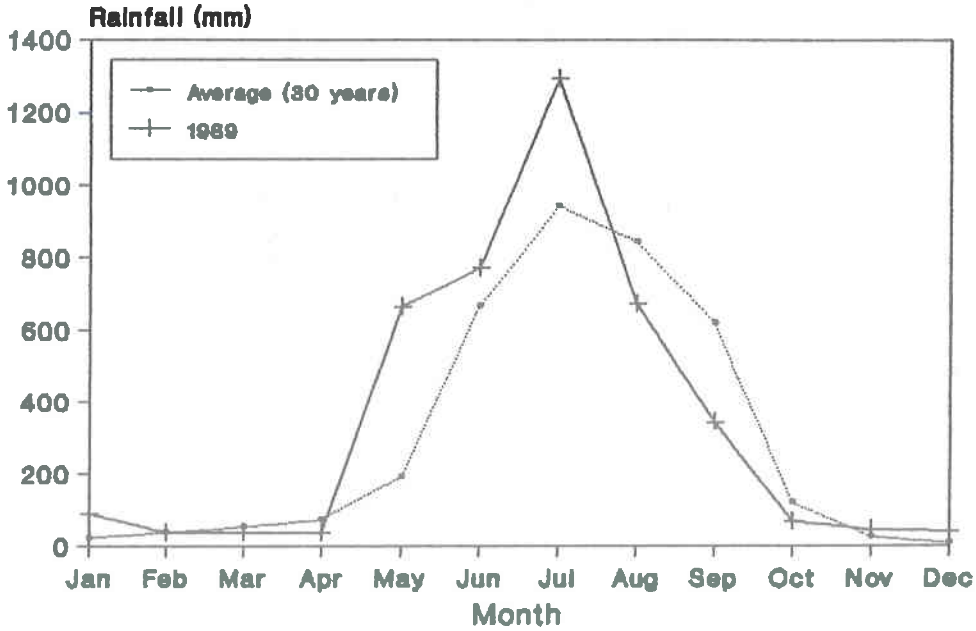


Fig. 5.1 Monthly Rainfall in the Phewa Lake Catchment

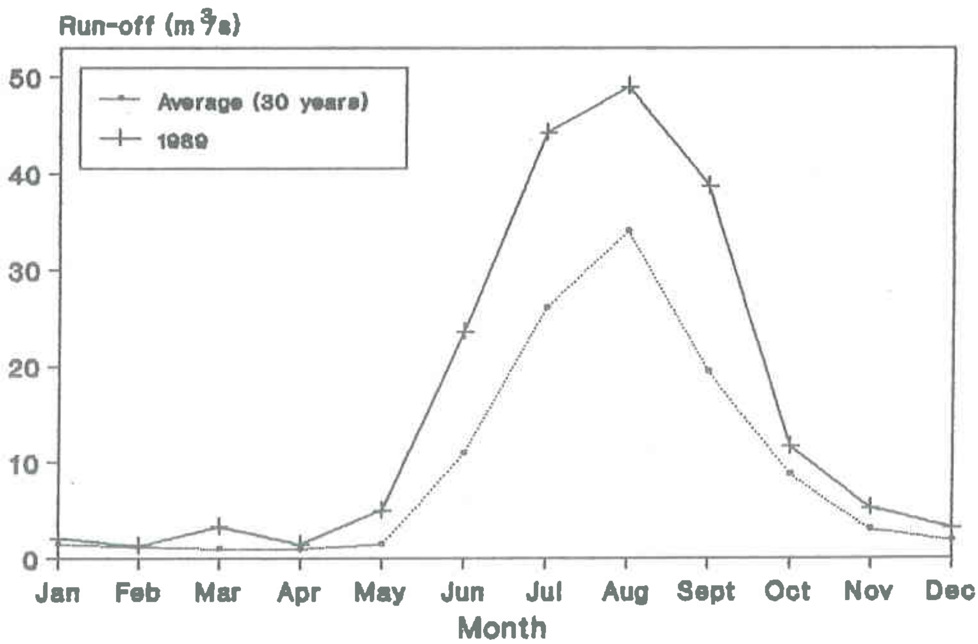


Fig. 5.2 Monthly Average Run-off from the Phewa Lake

5.2 Water Transparency and Turbidity

Mean Secchi disc values ranged over 2.2 - 3.0 m in deep waters to 1.8 - 2.4 for the shallower portions. These values were found near the Baraha Temple and downstream. These values indicate that they are somewhat related to lake depth, suggesting that boating activities and wind actions, which could stir up the bottom sediments in shallow areas, significantly affect the depth of light penetration.

The mean value of transparency for Phewa Lake and the factor for euphotic depth (Chapter 2.2.1) may be considered as 2.6 m and 3.5 respectively. Multiplication of these two values gives 9.1 m representing the average euphotic zone or 1 % light penetration depth of Phewa Lake. The vertical profiles of DO concentrations also indicate that there was no mixing or wind action below the 10 m depth in September - October. Extinction coeffecients for the euphotic zone ranged from 0.63 to 1.02 m^{-1} (Appendix IXc).

Turbidity, the function of transparency or light penetration, is caused by the presence of components such as clay, mud, organic material, bacteria , algae , lime or rust held in colloidal suspension . Turbidities of the euphotic zone waters (up to a depth of 9 m) in Phewa Lake remained low throughout the study, ranging from 2 to 7 NTU in October, and 5.2 to 30 NTU in November 1989. It was higher (up to 110 NTU) in the near-bottom samples (Appendix III). Concentration of turbidity at Sta. 4 and 3 are given in Figs. 5.3 and 5.4 respectively. Figure 5.4 shows that turbidity was significantly high below the depth of 10 m in comaresion to the surface waters. No significant differences existed among the sampling locations for mean values on turbidities estimated for the euphotic zone depth. The total suspended solid estimated by Lohman et al. (1988) was 3.4 mg/l in April - May and 1.8 mg/l in September - October 1985. The higher value of turbidity in the near-bottom samples and the long hydraulic retention time (up to 450 days) indicate that there might be a thick deposit of solids at the bottom of Phewa Lake.

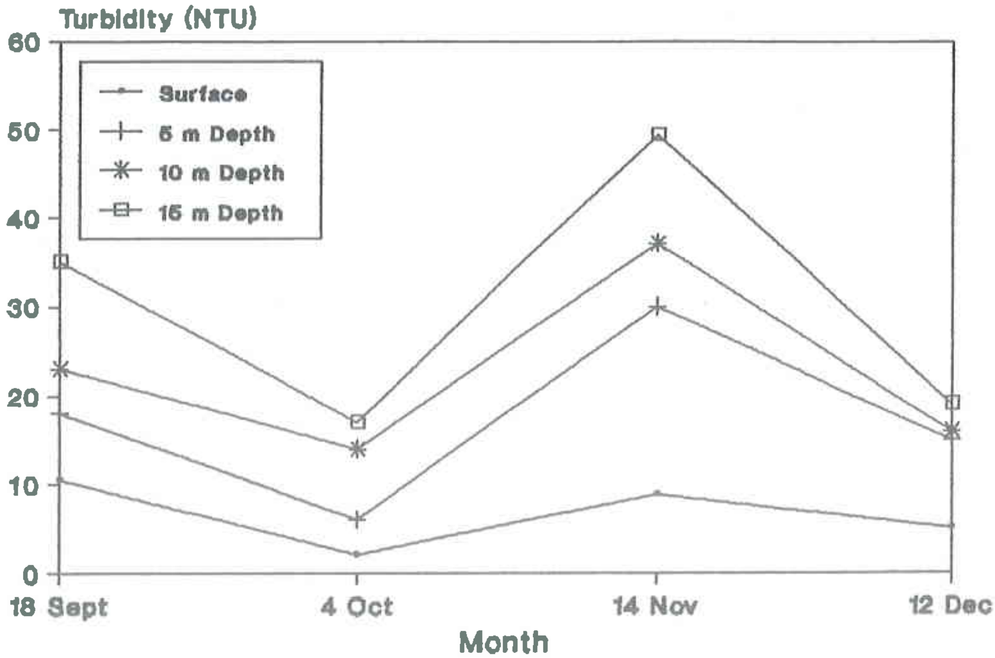


Fig. 5.3 Seasonal Changes of Turbidity at Sta.4

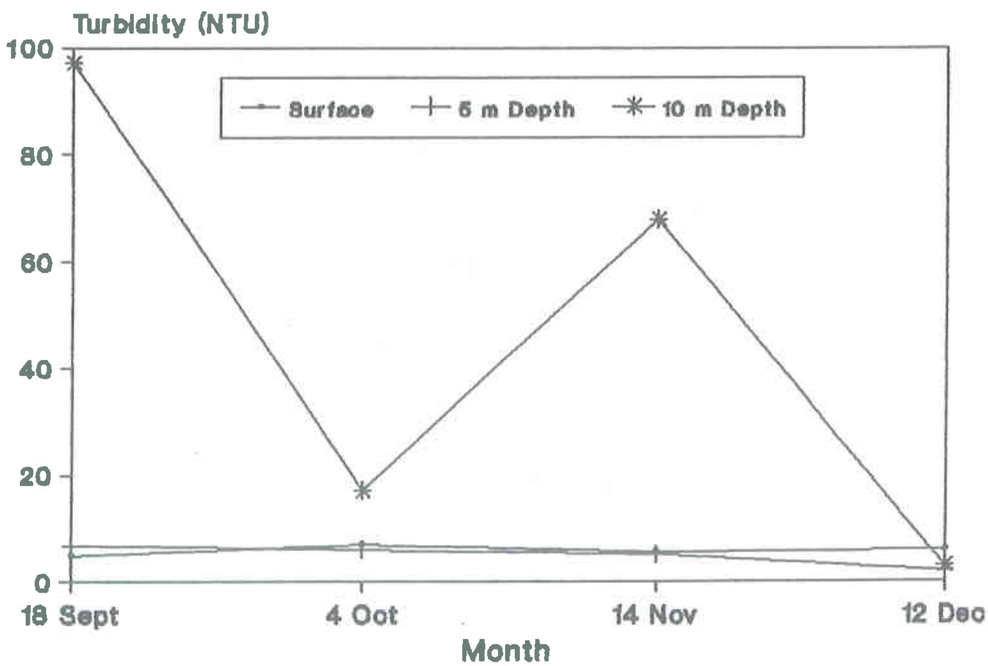


Fig. 5.4 Seasonal Changes of Turbidity at Sta.3

5.3 Water Temperature

The horizontal distribution of surface water temperatures ranged from 24.6 to 28.9 °C in the late-monsoon (September) and 17.5 to 19 °C in the winter (December), similar to the results of Nakanishi et al. (1984). Taking diurnal changes in surface water temperature into consideration, it may be noted that the local variation in water temperature was not so significant except for a slight rise at 4 P.M. at the surface (Fig. 5.5).

Isothermal plots for the sampling Station 4 are shown in Fig. 5.6. While the maximum temperature (28.9 °C) for surface waters was observed in mid-September, the maximum temperature (21.5 °C) for deep-waters was found in October. Water temperatures in the column varied with depth until late-October, but were nearly uniform for November and December. It might be concluded that there was a thermal stratification in Phewa Lake till mid-October.

Temperature data of the Lake for about 2 years were available from unpublished reports of Fisheries Development Centre Pokhara (Appendix XI) and for certain periods from published reports (Nakanishi, 1986 and Lohman et al., 1988). As referred by Nakanishi et al. (1984), Ferro (1981/82) found that the surface water temperatures change seasonally ranging 15.2 - 28.2 °C. Thus the water temperatures during the investigated period were similar to that mentioned by Nakanishi et al. (1985). Surface mean water temperatures did not differ significantly among the six sites during this study (Appendix I).

The vertical distribution of water temperature decreased gradually with depth in the late monsoon season (September - October), and remained a constant value of 17.5 °C throughout the depth in the winter (December). The variation of water temperature with depth and time for the study period is presented in Figs. 5.6 (isothermal plots), 5.7 and 5.8 (vertical profiles) illustrating startification types which occur in this impoundment. Mean water temperatures in the euphotic zones did not differ significantly among the six sites. But the mean temperatures at the deep waters were equal and significantly cooler than the surface waters by about 8 °C in the late-monsoon and 0.4 °C in December (Appendix II).

The epilimnion (surface water) temperature remained warm until late October (Fig. 5.6). During the summer the hypolimnion (bottom waters) warmed slightly as the epilimnion increased to 28 °C. Temporary thermocline (region of rapid temperature change) remained at all over the depth. After November , the temporary thermocline dropped as the surface water cooled. The temperature gradually decreased to 18 °C by early December. Even in the winter, the temperature variatioin between the surface and the

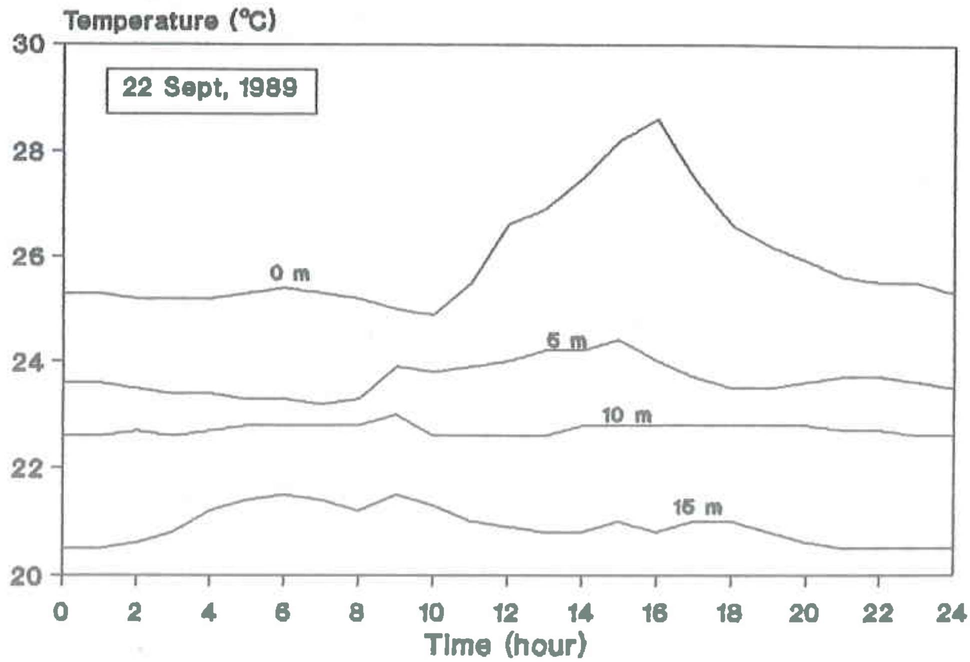


Fig. 5.5 Diurnal Changes of WT at Different Depths (Sta.4)

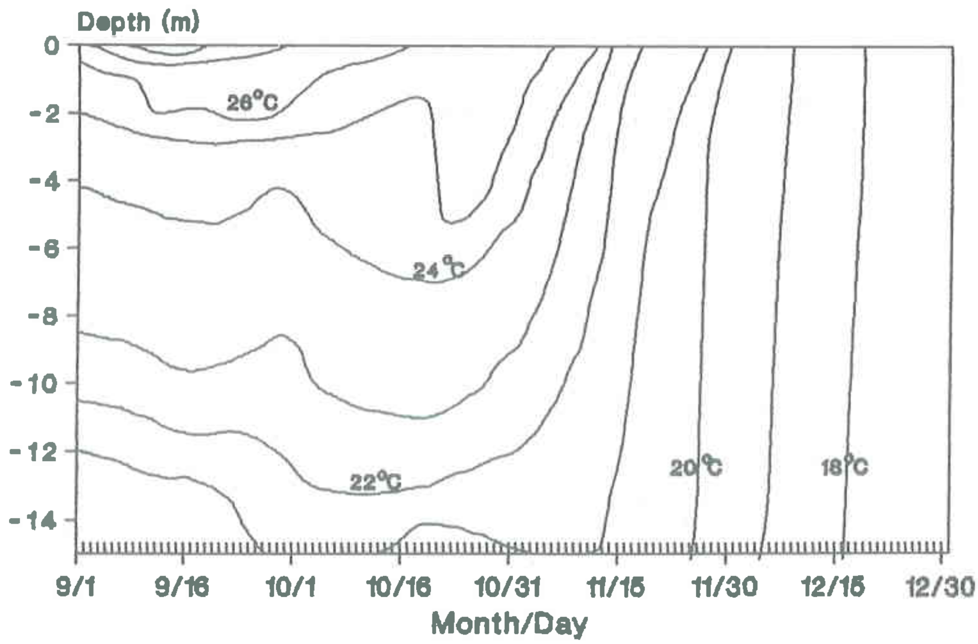


Fig. 5.6 Isotherms of WT (Sta.4)

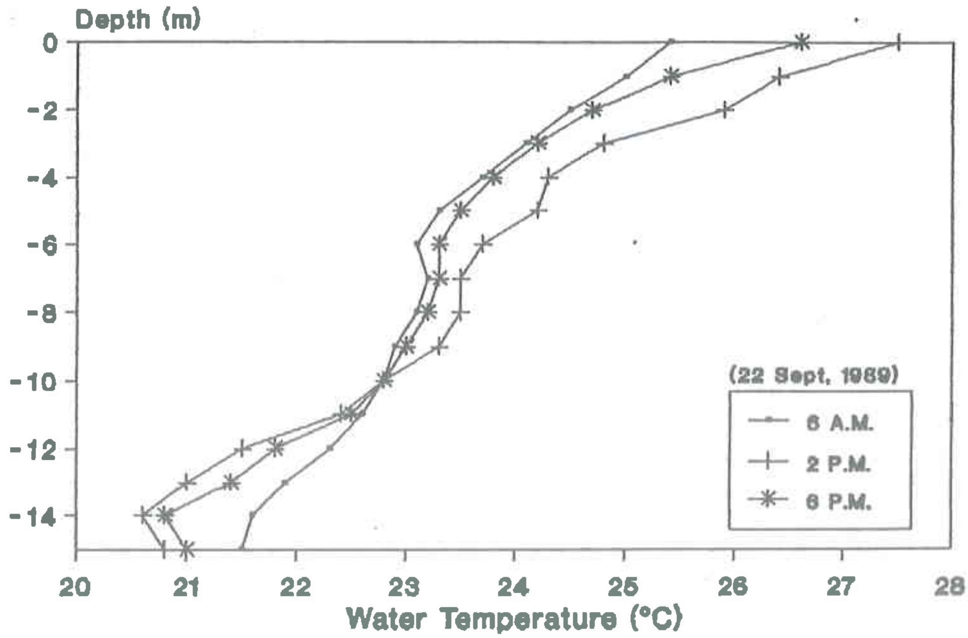


Fig. 5.7 Diurnal Vertical Profiles of WT (Sta.4)

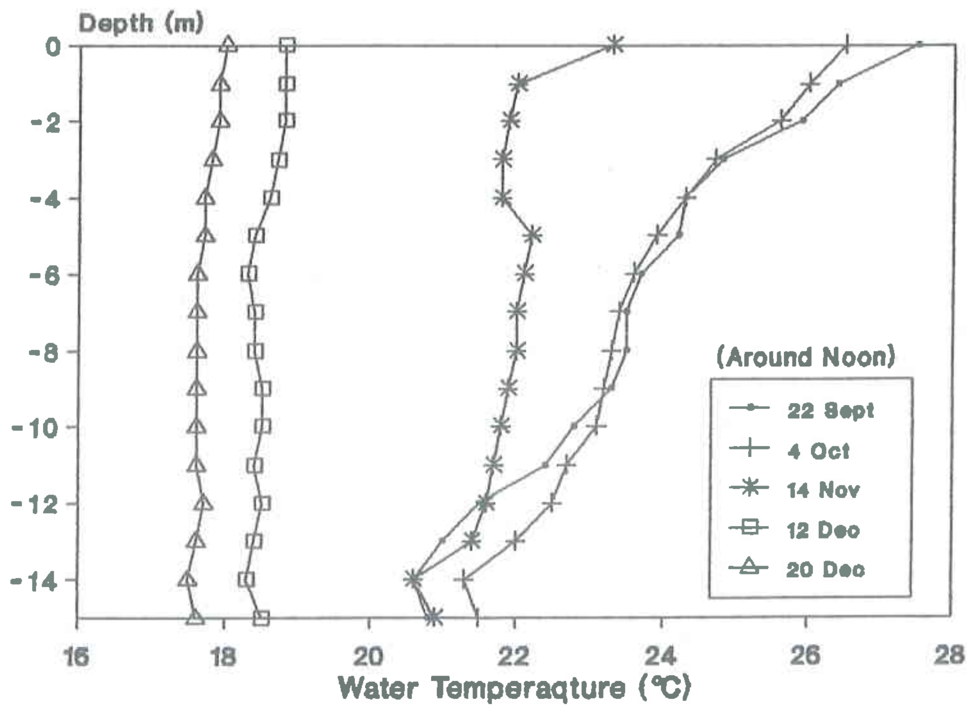


Fig. 5.8 Seasonal Vertical Profiles of WT (Sta.4)

bottom was slight (0.4 °C). Then, with the result of cooler (dense) water in the surface a turnover (complete mixing) occurred remaining 17.5 °C throughout the depth at the end of December. The vertical changes in water temperatures with time, monitored hourly for 24 hours, is presented in Appendix IV.

5.4 Dissolved Oxygen

The horizontal distribution of surface DO content ranged from 9.1 to 12.3 mg/l from September to October and 4.6 to 6.6 mg/l in December (Appendix I). Diurnal changes of DO at different depths at Station 4 (Appendix V) is shown in Fig. 5.9. Taking the diurnal change of DO into consideration, it may be noted that the local variation in DO was significant in the epilimnion. Photosynthesis occurred from early in the morning and the DO rose to 12 mg/l at 2 P.M. DO concentrations in the surface water decreased suddenly from 2 to 4 P.M. suggesting slow mixing by the wind action. After 4 P.M. the DO increased gradually and peaked to 11.9 mg/l at 6 P.M. The diurnal variations of DO below 10 m depth were not significant.

The isopleths of DO for Sta. 4 in Phewa Lake are shown in Fig. 5.10. While the maximum surface water DO (12.3 mg/l) was found in mid-September, the minimum DO (0.3 mg/l) at deep-waters was found in mid-October. The bottom portion of the Lake in the summer was found to be anoxic. The oxygen demands exerted by the Lake bottom sediments on the overlying waters appear to be more than the oxygen replenishment from the atmosphere and algae activity. This phenomenon is pronounced for the observations made in the summer when the observed DO concentrations at the bottom were less than the DO concentrations in the upper layers. However, oxygen levels near the bottom in shallow portions of the Lake did not decrease below 6 mg/l in most cases.

The vertical distribution of DO is shown in Figs. 5.11 and 5.12. At first in September - October DO decreased with depth from 12 mg/l (at surface) to 1 mg/l at 10 m depth and remained constant below that depth. But in November-December, although the surface DO decreased (8 mg/l) as compared to September-October, the DO in deep-waters notably increased (up to 7 mg/l) and remained nearly constant throughout the depth (Fig. 5.10).

During the summer, oxygen depleted (Fig. 5.12) at the hypolimnetic (deep water) zone. The lower values with depth may be due to the oxidation of organic materials thereby depleting the oxygen as the water percolates downwards or may be related to oxidation of iron and manganese. According to Nakanishi, 1986 (Appendix IXb) Fe and Mn concentrations of surface waters of the Phewa Lake were 0.09 and 0.009 mg/l respectively and 8.7 and 1.25 mg/l respectively in the near-bottom samples. While, Fe and Mn concentrations in the surface water samples were less than the international drinking water standards (WHO), their concentrations increased noticeably with depth. The oxygen demand of bacteria decomposing both the BOD and COD of the sediments as well as the dead algae sinking from the epilimnion and the oxidation of Fe and Mn probably caused the O_2 depletion at increasing depths. There was a strong H_2S odor at depths of 15 m and below during sampling suggesting that anaerobic conditions existed at the bottom sediment layers.

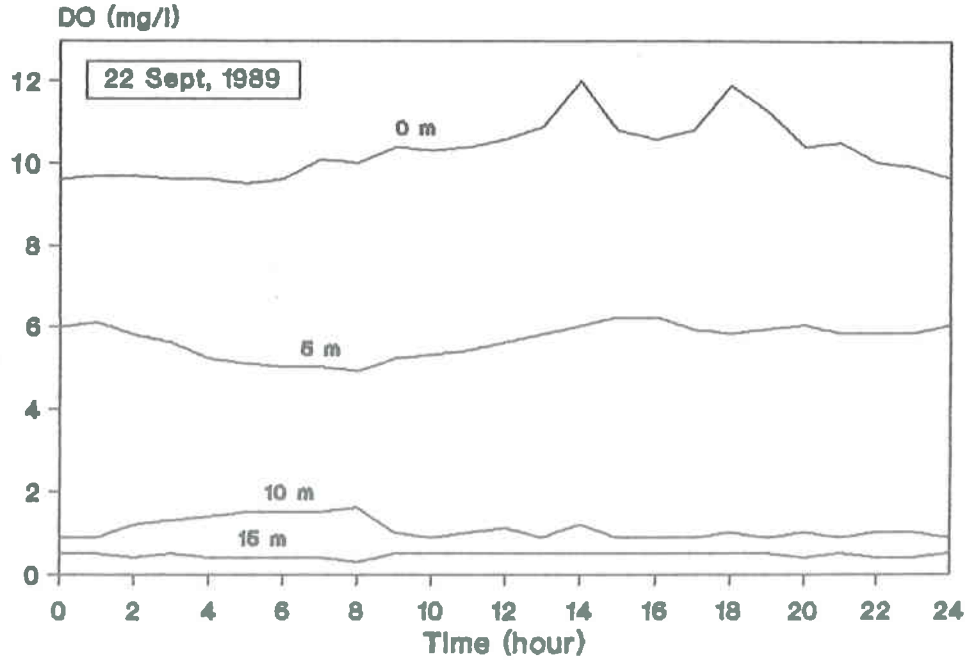


Fig. 5.9 Diurnal Changes of DO at Different Depths (Sta.4)

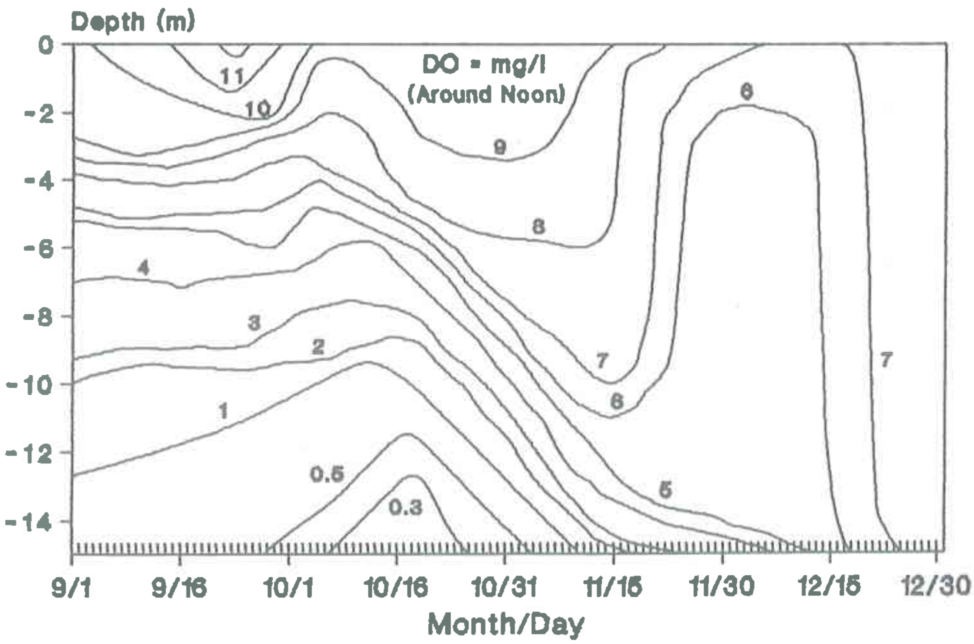


Fig. 5.10 Isopleths of DO (Sta.4)

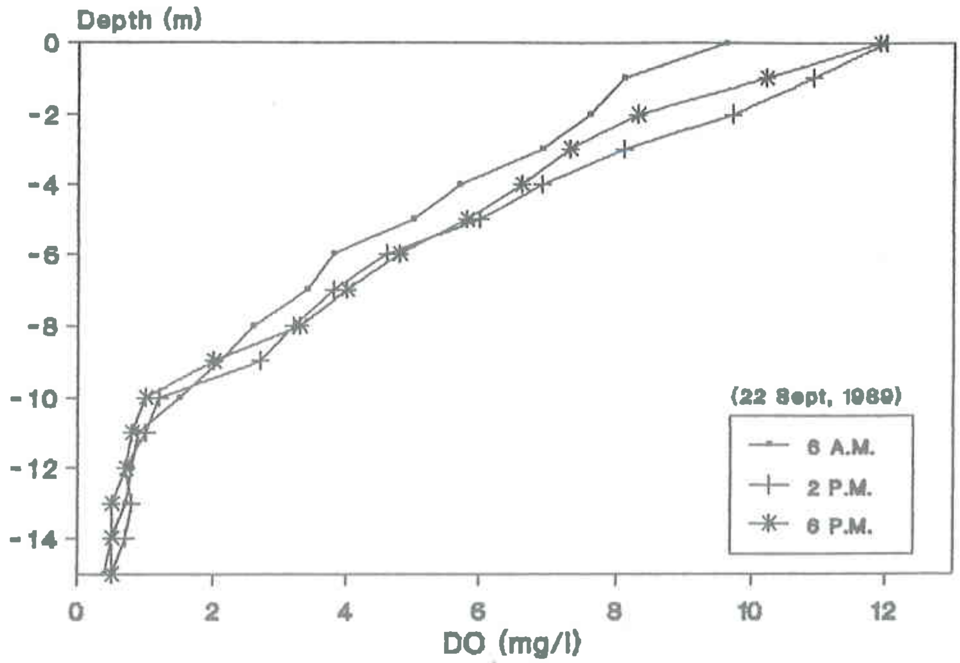


Fig. 5.11 Diurnal Vertical Profiles of DO (Sta.4)

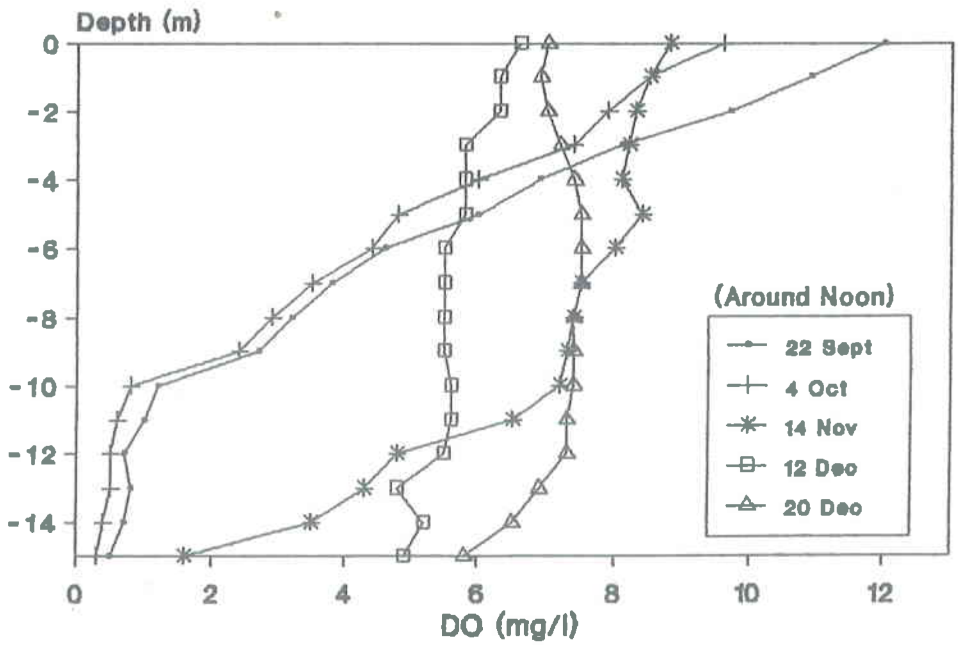


Fig. 5.12 Seasonal Vertical Profiles of DO (Sta.4)

During the summer months as water temperatures increase, bacterial decomposition of the bottom organic matter exerts a high rate of oxygen demand on the over-lying waters. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanisms. When the rate of oxygen demand at the bottom exceeds the oxygen replenishment, and remains so for a long period, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom.

As the epilimnetic temperature dropped through November and successive cooling through the thermocline to the hypolimnion resulted in a nearly uniform temperature through the water column, various depths of the Lake were reaerated due to the fall turnover. However, oxygen depletion at the bottom still existed in November. In the winter oxygen was present (nearly constant values) throughout the depths, although the water above the sediments was still not saturated. High BOD and COD values with depth might be the main cause of oxygen depletion at the bottom.

5.5 pH

pH indicates the acidity or alkalinity of the water. Most natural waters usually have pH values between 4-9. pH measurements for Phewa Lake ranged from 6.6 to 8.6 (Figures 5.13 & 5.14). Mean pH for the near-bottom samples from the deep water sites were more acidic than found in the euphotic zone at the respective sites (Appendix II & III). Such differences are due to different factors. In the bottom waters CO_2 is added during the bacterial decomposition of organic materials and dead algae thereby increasing bicarbonate/carbonic acid. Solubilization of the acid at the deep waters lowers the pH. Values of pH above 8.0 in natural waters are generally considered to be due to photosynthesis that demands more carbon dioxide than that furnished by respiration, decomposition and diffusion from the atmosphere.

Photosynthesis by aquatic plants utilizes CO_2, removing it from bicarbonate and producing carbonate when no free CO_2 exists in the water column. This photosynthetic uptake of CO_2 increases the pH reducing concentrations of carbonic acid in the euphotic zone. Ca and Mg carbonate which are weakly soluble, tend to precipitate out, thereby increasing the calcium and magnesium carbonate content of the deep waters. Various chemicals in the sediments also dissolve into the hypolimnetic waters because of the change in chemical potential induced by the oxygen depletion in the summer. Hence, decomposition of organic matter tends to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonates.

Mean pH of most of the surface water samples in the Phewa Lake ranged between 7 and 8. pH values in the Harpan Khola and Sedi Khola were 6.9 and 9.0 respectively. There was a fish pond fed by the water of Sedi Khola before entering into the lake. The peak value of pH in the Sedi Khola may be due to the pollution from fishery industry.

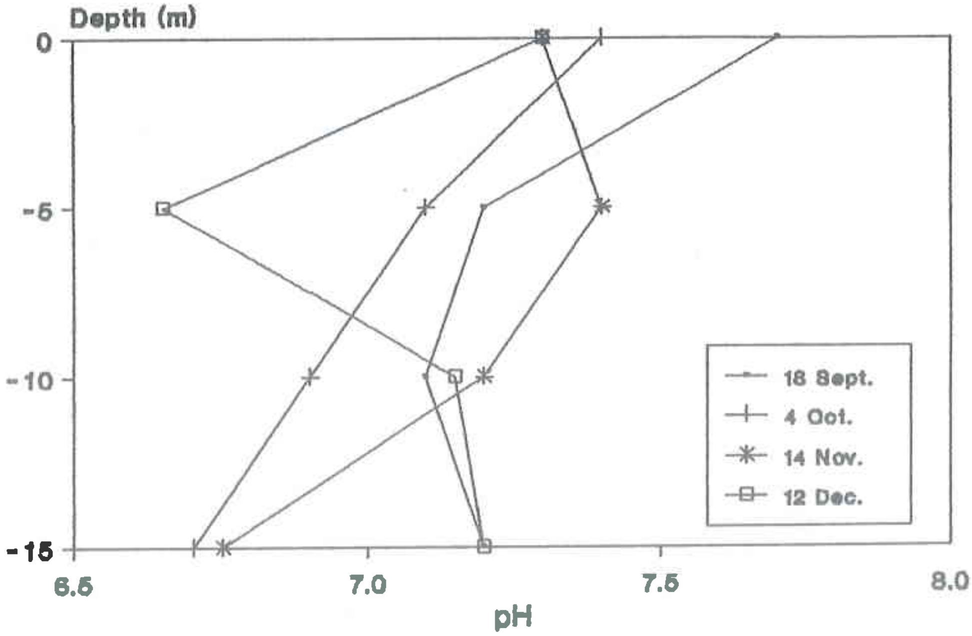


Fig. 5.13 Vertical Profiles of pH (Sta.4)

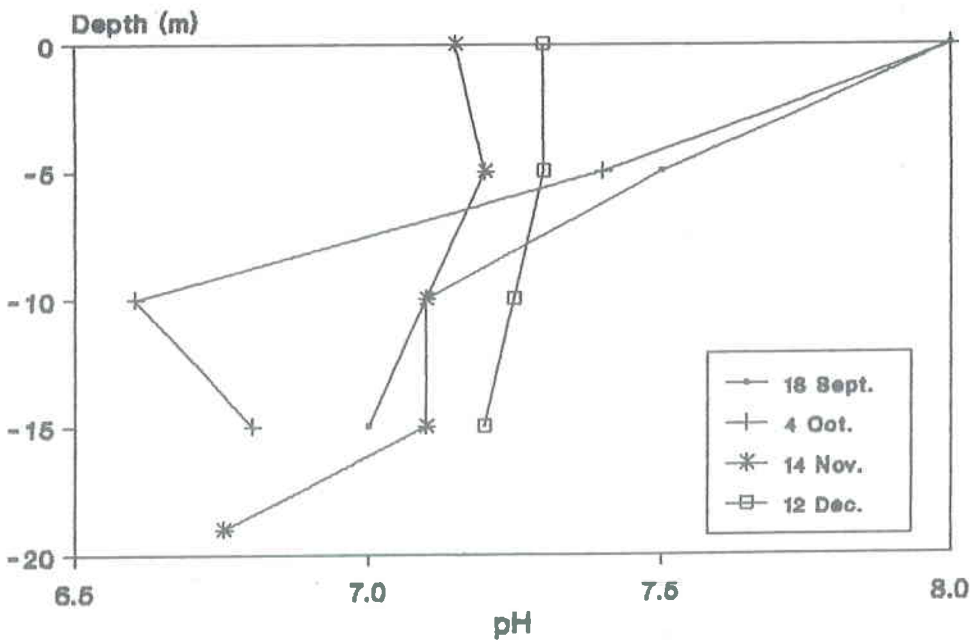


Fig. 5.14 Vertical Profiles of pH (Sta.3)

5.6 Conductivity and Salinity

The conductivity of surface waters in Phewa Lake remained low ranging from 24 to 73 µS/cm (Appendix I) during the study period. During the sampling period, conductivities in tributary inflows were relatively low and waters with the higher conductivities were being discharged from the Lake (Appendix I). Average conductivities increased slightly up to 91 µS/cm with increase in depth (Appendix II). The seasonal changes in conductivities at different depths of Stations 3 and 4 are shown in Figs. 5.15 and 5.16.

There was no significant difference in the average total hardness between the surface water and the deep-water samples. However, hardness increased slightly with depth (Appendix II) and the downstream of the Lake (Appendix I), thereby discharging more hard water.

Hardness is attributable principally to Ca and Mg as other polyvalent cations are seldom present in appreciable concentrations in natural waters. Ca was the dominant cation in the Phewa Lake (Appendix IXb & Xa). Hard waters have no demonstrable harmful effects upon the health of consumers, except excessive soap consumption and scale formation.

The alkalinity for surface water samples of Phewa Lake ranged from 22.7 (April-May) to 12.6 (September-October) mg $CaCO_3$/l in 1985 (Appendix Xa). The major cations in the Lake were in the ratio 2.71:0.57:1.32:0.45 (Ca:Mg:Na:K), and major anions were present in the ratio 16.37:0.44 (HCO_3:Cl) in September 1985. The values of these variables in April 1985 were nearly twice the values of September 1985. The values of Ca, Mg and K found by Nakanishi et.al. in September 1984 were slightly lower than that of Lohman et.al. in September 1985. However, the ion concentrations in the lake waters were relatively very low.

Ca accounted for more than 53% of the cation concentration in the Phewa Lake, and anions were predominately bicarbonate. Low salinity in these lakes is attributable to the metamorphic geology of the Pokhara valley, which is dominated by *phyllite* and *schist* with some *calcareous* and *arenaceous* sediments (Sharma 1977). High Ca (compared to other cations) concentrations in Phewa Lake are due to the product to two factors: calcareous deposits in the watershed and inflow of Ca rich water from a diversion of the Seti River which drains an area of the Himalayas.

A decrease of nearly 46 % in the total salinity and a change in relative cationic proportions in the post-monsoon as compared to the pre-monsoon period indicates the dilution of the Lake water. Ionic dilution is likely a result of hydrologic flushing by heavy surface run-offs during the monsoon. Hydraulic retention

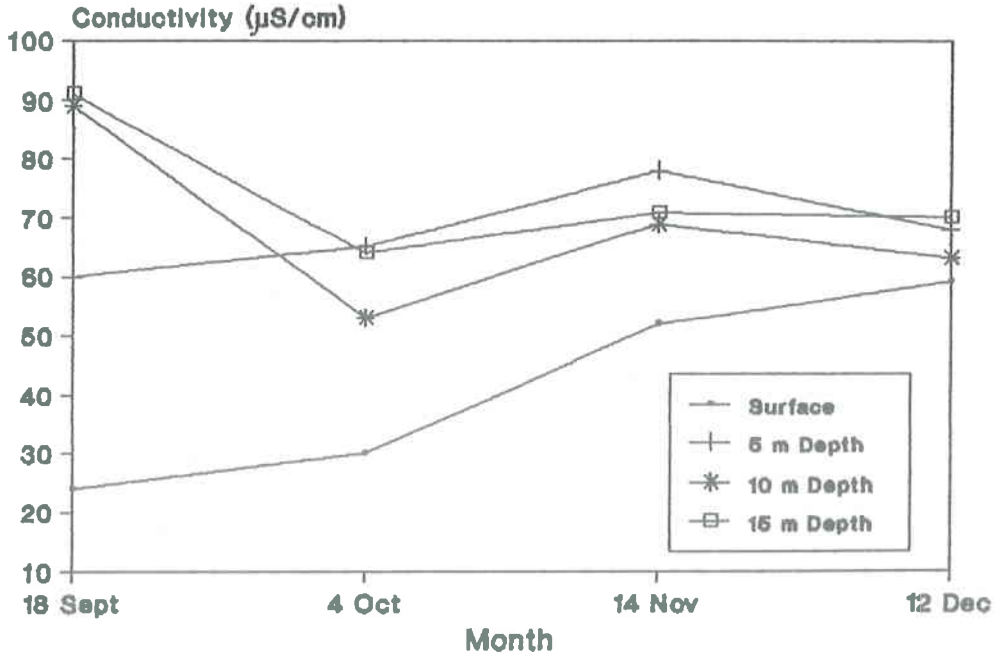


Fig. 5.15 Seasonal Changes of Conductivity (Sta.4)

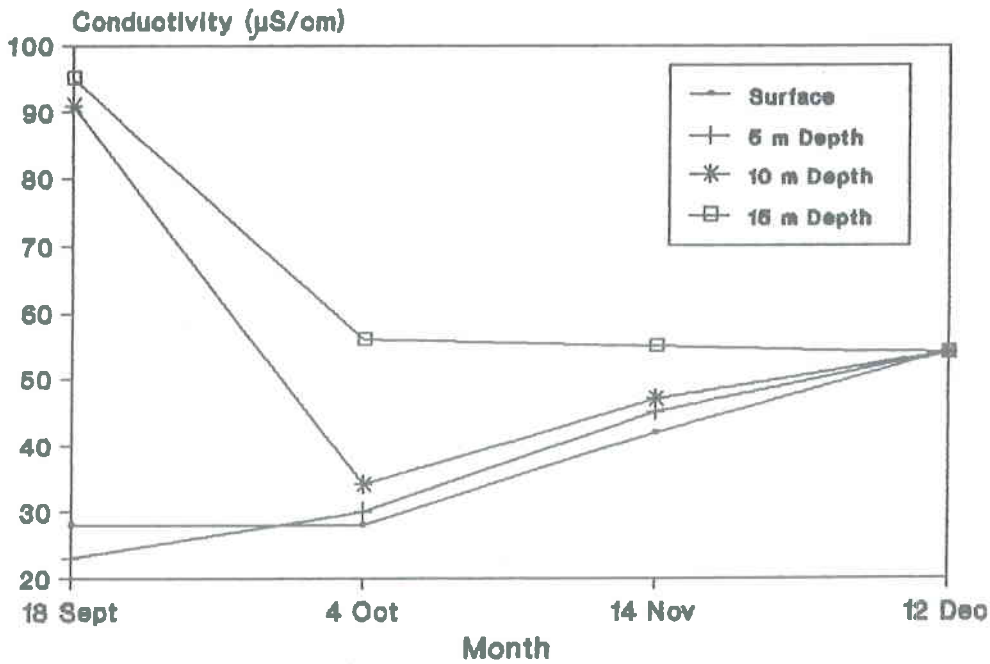


Fig. 5.16 Seasonal Changes of Conductivity (Sta.3)

time being short, the Lake volumes were replaced by rainwater within 10 days and Lake levels were observed to be higher in the fall to that in the spring, which may also contribute to the observed dilution. A warmer hypolimnion and cation dilution throughout the water column in Phewa Lake (Appendix Xa & Xb) suggest that water movement is extremely dynamic and that considerable advective mixing occurs during the monsoons.

5.7 Nitrogen and Phosphorus

Average ammoni-N concentrations in the top layers fluctuated between 0.01 (Sept) and 0.23 (Dec) mg/l; whereas, it ranged from 0.70 (Sept) to 1.07 (Nov) mg/l in the bottom waters (Table 5.1). The maximum value (1.34 mg/l) was found in the bottom water of Station 4 in November, 1989 (Fig. 5.17). Although these values in the top layers increased in the dry season, the values were found to be always higher in the bottom waters.

Average concentrations of nitrate-N were between 0.05 (Sept) and 0.29 (Dec) mg/l at the top water layers and between 0.12 (Oct) and 0.46 (Dec) mg/l in the bottom waters (Table 5.1). These values always remained lower in the surface waters with higher values in the deep-waters and increased in the dry season except for values at the surface at Station 4 (Fig. 5.18). Nitrite-N concentrations were less than 0.005 mg/l. These values decreased in the dry season. No significant differences by sites or depths were found for the concentrations of nitrite-N.

Because NH_4^+ dominated the total inorganic N during the study, total inorganic N concentrations might be followed by NH_4^+ concentrations. The various N forms tended to increase with increase in depth, but ammonia-N concentrations in the bottom waters at Station 4 were found to be significantly greater ($P < 0.05$) than in the surface water samples. Inorganic-N concentration increased highly towards the deeper layers (Appendices II & III). For the bottom samples at Station 4, ammonia concentrations increased and peaked (1.34 mg/l) in November 14. The noticeable increase in inorganic-N in the deeper layers seemed to be closely related to an ammonia-N accumulation. Consequently, it was expected that ammonia-N and dissolved phosphate-P would be released from the sediments and accumulate in the deeper layers. On the other hand there was no observable increase in the dissolved phosphate-P (in comparison to inorganic-N) concentration in these layers, perhaps due to the originally poor storage of P in this Lake.

Table 5.1 Average Concentrations of N and P in Phewa Lake (September - December, 1989)

	NH_3-N	NO_3-N	Ortho-P	Total-P
	(mg/l)			
Surface	0.01-0.23	0.05-0.29	0.005-0.04	0.08-0.15
Near-bottom	0.7-1.07	0.12-0.46	0.013-0.04	0.06-0.21

Average of 4 sites (n = 4)

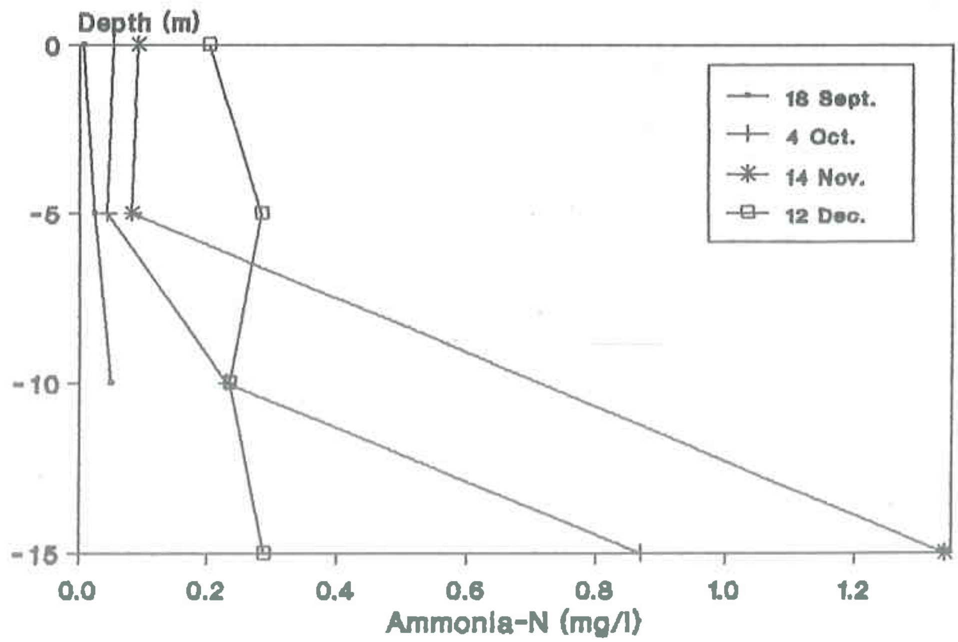


Fig. 5.17 Vertical Profiles of Ammonia-N (Sta.4)

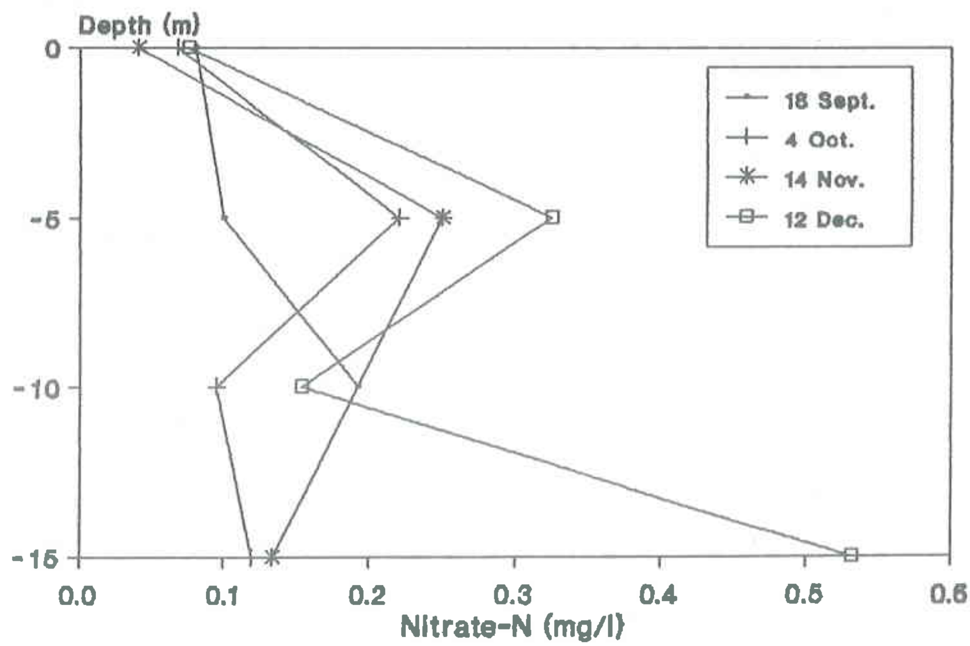


Fig. 5.18 Vertical Profiles of Nitrate-N (Sta.4)

Average concentrations of orthophosphate-P in the surface water during the study period ranged from 0.005 (Sept) to 0.04 (Dec) mg/l and from 0.013 (Sept) to 0.04 (Dec) mg/l near the bottom (Table 5.1). These values of ortho-P increased in the dry season and remained lower in the surface waters with higher values near the bottom of the Lake (Fig. 5.19).

Average concentrations of total phosphorus in the surface waters fluctuated between 0.15 (Sept) and 0.08 (Dec) mg/l, whereas concentrations in the deep waters ranged from 0.21 (Sept) to 0.06 (Dec) mg/l (Table 5.1). No significant differences by sites (Appendix I) or depth (Fig. 5.20) were found for average concentrations of total P. On the other hand, with the exception of ortho-P, total P decreased during the dry season and remained nearly constant throughout the depth of the Lake (Fig. 5.20). Seasonal changes of N and P at Sta. 3 are shown in Fig. 5.21.

Ratios of dissolved inorganic-N to reactive phosphate-P in individual samples ranged from 9 to 92 (Fig. 5.22). The N:P ratio for the Lake bottom samples at Station 4 was significantly greater than found for the euphotic zone samples. The environmental N:P optimal for algae growth is 10 (Smith 1980); higher ratios suggest P limitations and lower ratios suggest N limitations. Based on the measured N:P, it might be noted that, Phewa Lake was limited by low phosphorus concentrations during the study period. Lohman et al. (1988) report N:P values between 6 and 16, mentioning that this could reflect either N or P limitation.

A relationship between nutrients and flow is shown in Fig. 5.23. It seemed that a decrease in total phosphorus in the dry season was due to the decrease in surface run-off (with P) into the Lake. On the otherhand, an increase in orthophosphate-P in the dry/winter season (Figs. 5.23 & 5.24) observed to be higher in the bottom of the Lake indicating the release of dissolved phosphates from the Lake sediments.

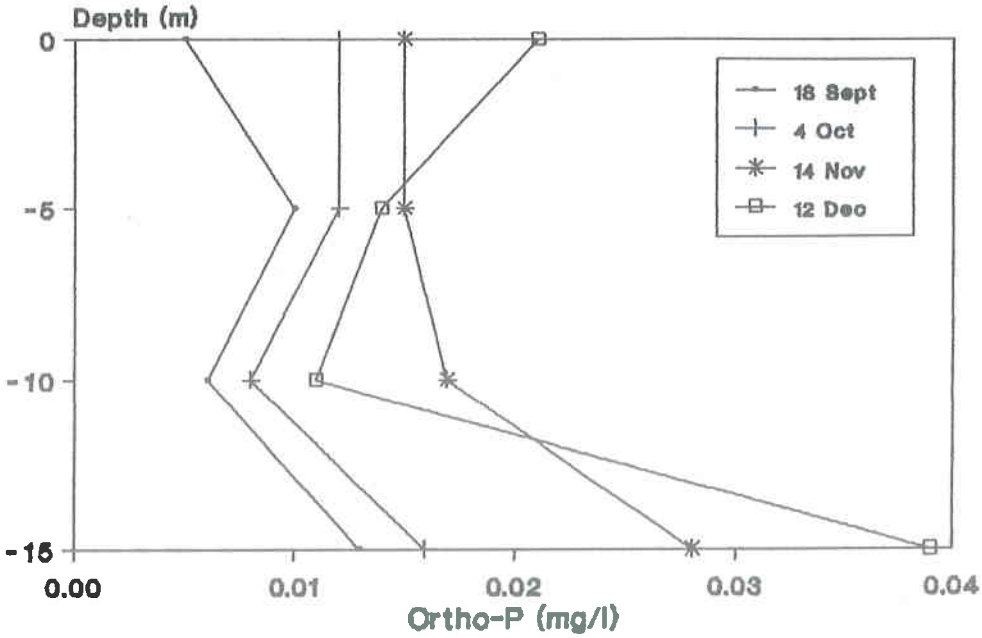


Fig. 5.19 Vertical Profiles of Ortho-P (Sta.4)

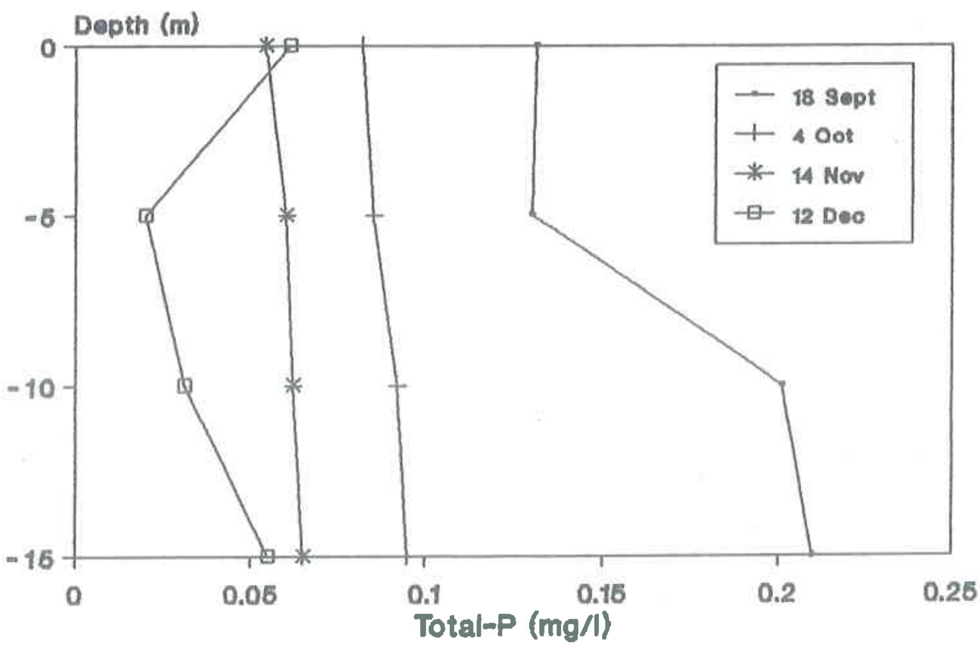


Fig. 5.20 Vertical Profiles of Total-P (Sta.4)

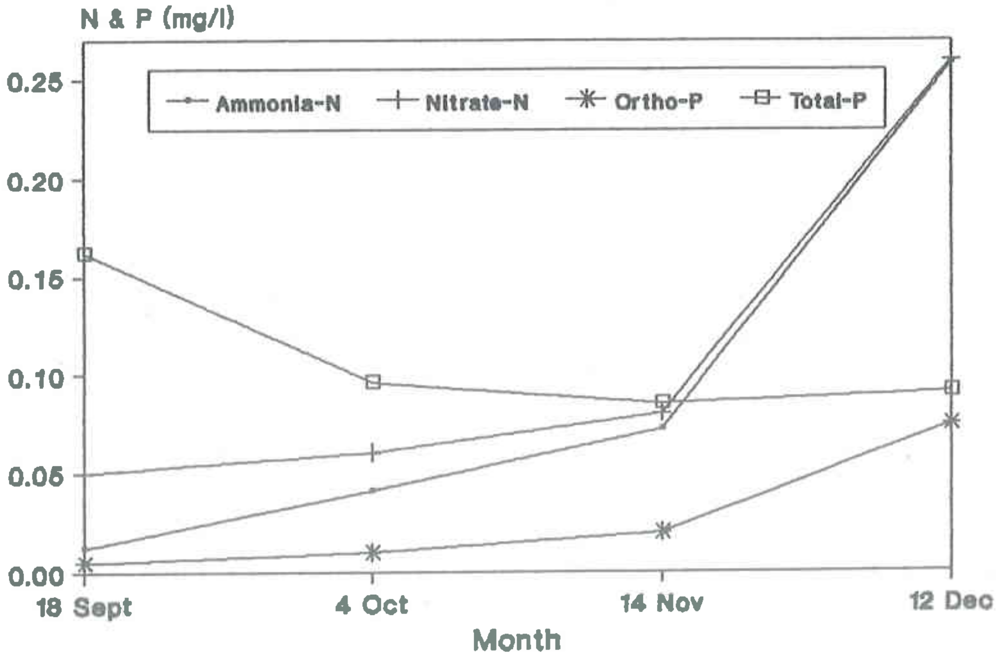


Fig. 5. 21 Seasonal Changes of N and P (Sta.3)

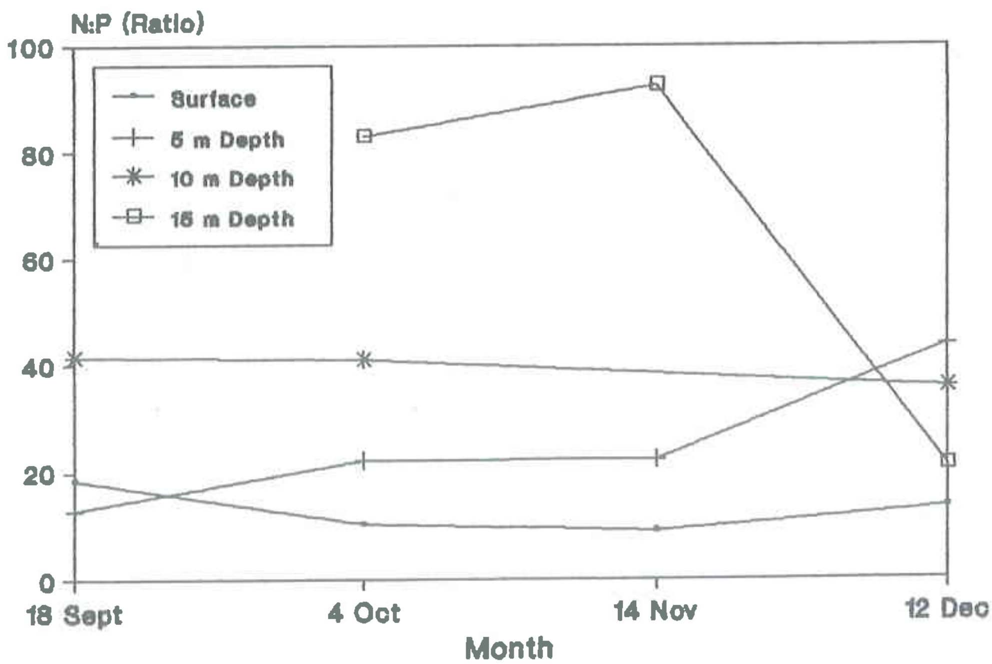


Fig. 5.22 Seasonal Changes of N:P Ratio (Sta.4)

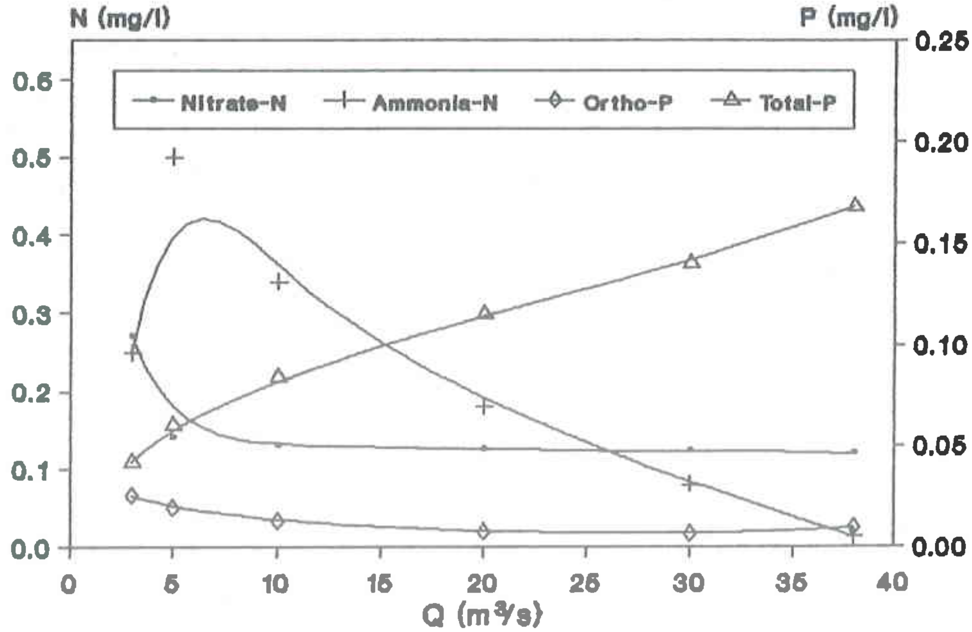


Fig. 5.23 Relationship Between Flow and Nutrient Concentrs.

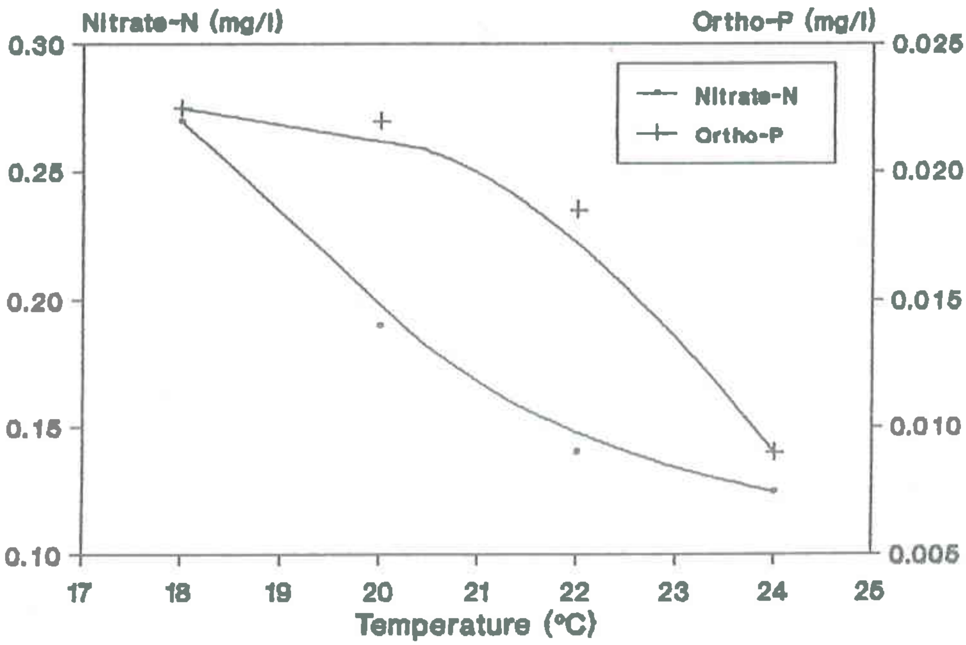


Fig. 5.24 Relationship Between WT and Nutrient Concentrs.

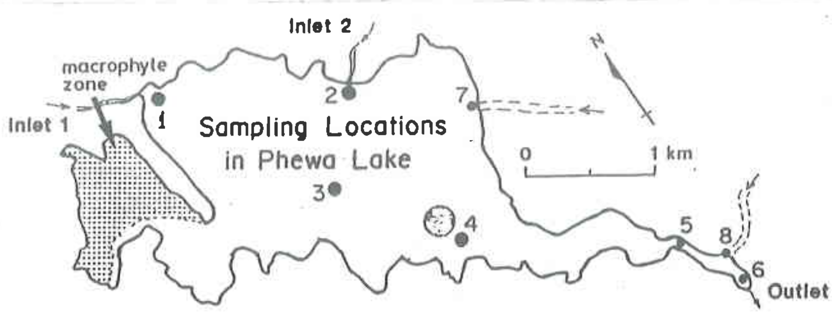
5.8 BOD, COD and Coliforms

Biochemical Oxygen Demand (BOD) is defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. BOD is widely used to determine the pollutional strength in terms of oxygen required and to evaluate the purification capacity of receiving water-bodies.

The maximum BOD value for surface water during the study period was found to be 3.85 mg/l. The variation of BOD values among the 6 sites were not significant. Though, there was no trend of BOD and COD increase with depth, maximum values of 9 and 184 mg/l respectively were found at the bottom waters of station 4 (Figs. 5.25 & 5.26). This fact might be due to the oxygen depletion (< 0.3 mg/l) in the bottom waters during thermal stratification and the solubilisation of organic matter (wastage from the Temple).

Varied concentrations of total and fecal coliform bacteria have been found in the Phewa Lake during the 4 months of study. Measured concentrations of total coliforms ranged from 160 to 17000 MPN/100 ml, whereas fecal coliforms ranged from 0 to 900 MPN/100 ml. The maximum concentrations of total coliforms were found in tributary (Harpan Khola) inflows with the minimum values at Station 3 in the center of the Lake. Consequently, waters with higher values of total coliformws were entered and with lower values of total coliforms were discharged (Fig. 5.27).

Although some of the high coliform counts might be explained as an index of pollution, Fruh and Davis (1969) pointed out that such high counts were sporadically found in all of the upstream highland lakes during 1968. Acording to them, factors such as run-off, eroded soils and particulate organic matter can greatly affect the coliform growth and die-off. Presence of fecal coliform indicates water contamination. Fecal coliform concentration in the Phewa Lake was zero at the center (Sta. 3) and slightly increasing from the center to the discharge point/Sta.6 (300 MPN/100 ml). Consequently, it might be concluded that the downstream portion of Phewa Lake was more contaminated due to shore development activities than the upstream portion.



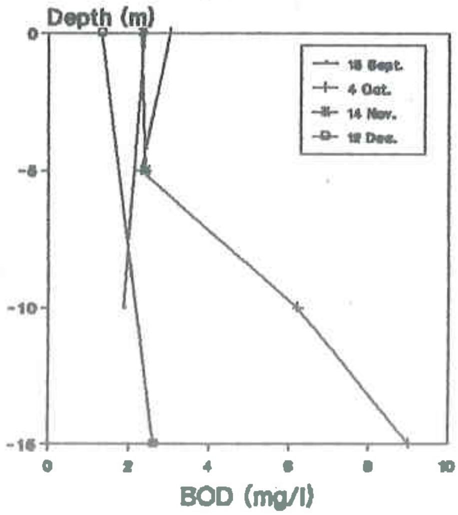


Fig. 5.25 Vertical Profiles of BOD

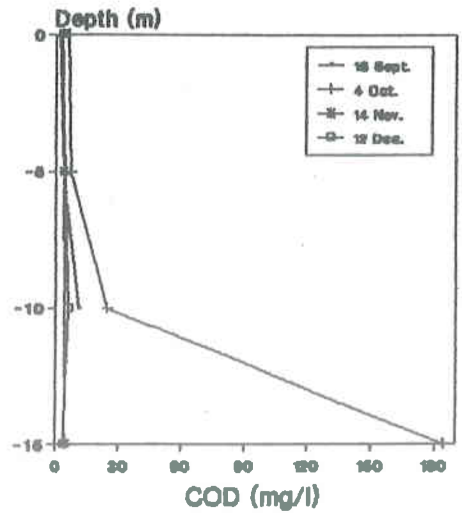


Fig. 5.26 Vertical Profiles of COD

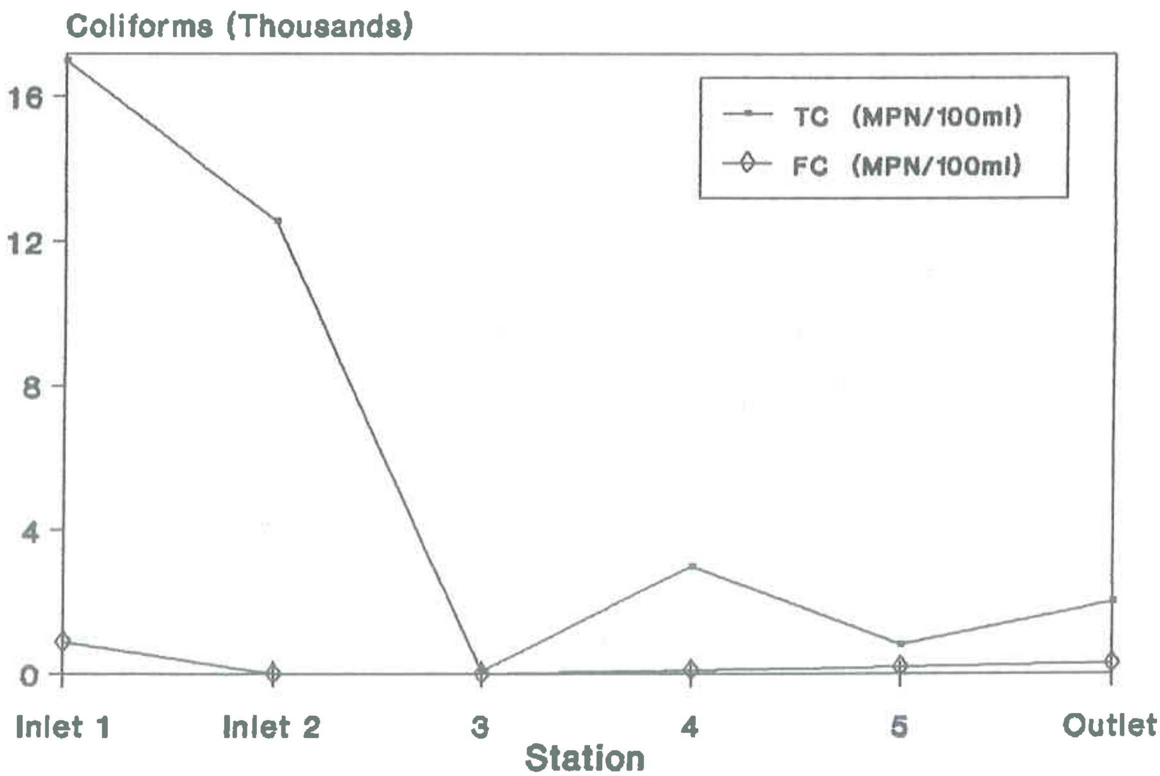


Fig. 5.27 Mean Concentration of Total & Fecal Coliforms

5.9 Sediments

Thirteen sediment samples were collected from 13 stations (Fig. 3.1) in Phewa Lake. Unfortunately, it was not possible to analyse these samples in Nepal due to the unavailability of well equiped laboratory facilities at the time. These samples (air-tight) were flown to AIT, Bangkok and tentative moisture, organic matter and total carbonate contents were analysed (Table 5.2).

The maximum values of 8.6 and 10.1 % for organic matter and carbonate respectively were found at Station 5 (near Fish Tail Lodge). The high concentration of carbonate may be related to drinking water treatment in that Lodge. The concentration of carbonate was significant at Station 7 (entering point of canal discharge from Seti River diversion).

Sediment samples reflect the relative fertility of the lake and may contain from 0.06 to 10 mg/l of soluble interstitial phosphate (Goldman & Horne, 1983). These levels are many times greater than those of the overlying waters. Subsequently, sediments play a big role in eutrophication in closed water-bodies such as lakes because of internal loading of P from sediments or macrophytes following the control of external loading. The sediments thus provide a major reservoir of P. The DO depletion or anoxic conditions in the bottom of Phewa Lake during the summer thermal stratification plays an important role in increasing the rate of P release from the sediment. Anoxic sediments release P at rates as much as 1000 times faster than the release from oxygenated sediments (Goldman & Horne, 1983). Furumai & Oghaki (1989) found that anaerobic conditions in a lake sediment cause a large increase in exchangable P especially at a pH less than 8. The amount of exchangable P plays a major role in P release to overlying waters in the Lake . A view of sediment is shown in Appendix XX.

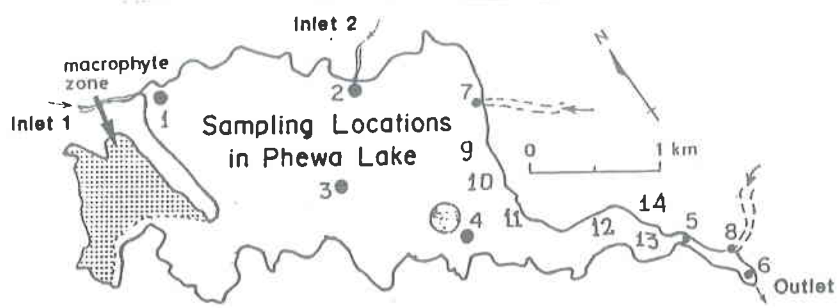
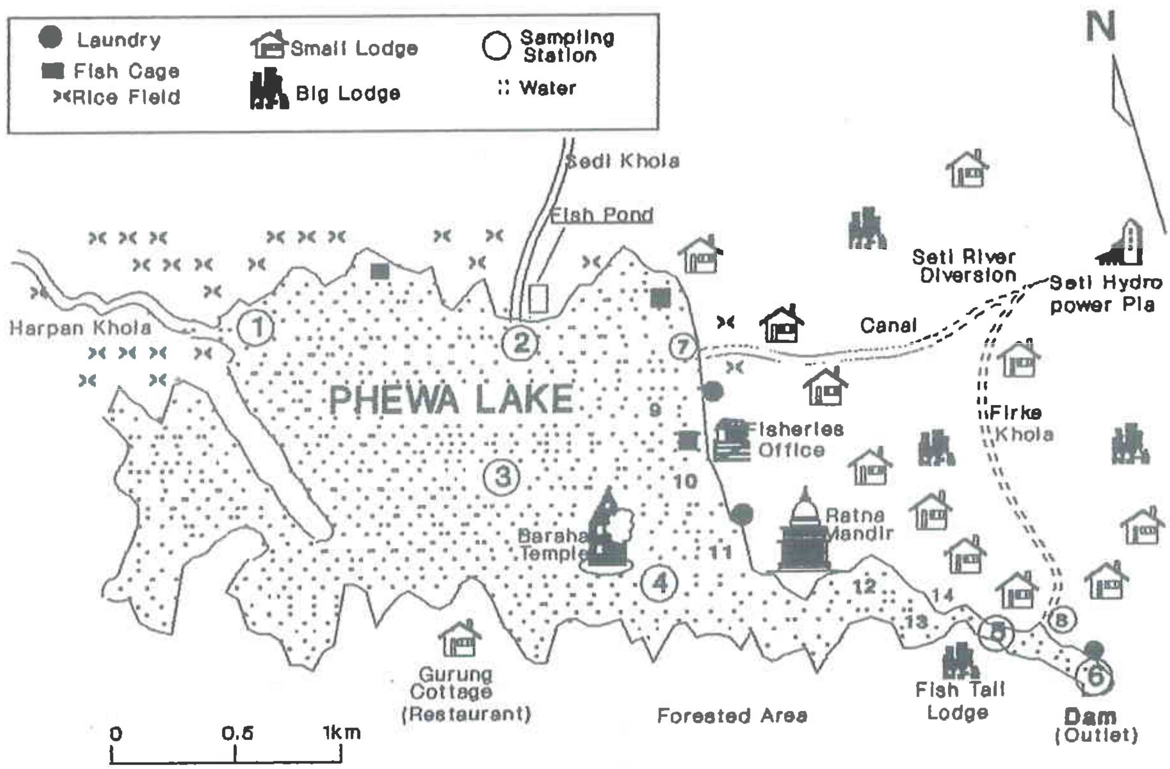


Table 5.2 Values of Moisture Content, Organic Matter and Carbonate Contents in the Sediment at Fixed Stations* in Phewa Lake (20 - 22 Dec, 1989)

Station	Moisture Content (% of wet wt.)	Organic Matter/ Volatile Solids (% of dry wt.)	Carbonate Content (% of dry wt.)
1	27	2.0	1.5
2	49	3.2	1.5
3	62	6.6	2.9
4	67	6.7	3.2
5	40	8.6	10.1
6	28	6.5	4.3
7	19	2.3	6.0
9	27	3.3	0.8
10	13	3.0	1.0
11	28	6.5	2.0
12	29	5.1	3.6
13	36	5.0	6.7
14	30	4.9	9.9

* Stations are shown below.



5.10 Mixing Pattern in the Lake

Water has a unique property of reaching its maximum density at 4°C; then it becomes lighter as it cools or warms. This property leads to vertical circulation in impoundments which is termed fall and spring turnover. As the atmospheric temperature becomes higher, both inflowing water and the surface water of the Lake get warmer. It then becomes more resistant to mixing, and a layering effect (thermal stratification) develops. Thermal stratification in deep portions of the Phewa Lake might be developed from the spring.

As we have seen in Figs. 5.6 and 5.10, temperature and DO variation along the depth were significant and there was no mixing. Nutrient enrichment in the Lake might cause algal blooms, and one of the causes of DO depletion in deepwaters may be the decay of dead algae. As the temperature of epilimnion begins to approach that of the hypolimnion in November, the marked stratification of summer begins to disappear. By the fall in December, the temperature of the Lake became uniform with depth and occurred complete mixing of the waters.

Except WT and DO, another good indicator of complete mixing in December was the conductivity (Fig. 5.16) which was the same value of 54 µS/cm throughout the depth. pH, total hardness, chloride, BOD, COD and NH_3-N are the other parameters that indicate a complete mixing of water in the Lake in December (Appendix III). There may not occur winter stratification because the WT will not go down below 4°C which could float on top of the 4°C water. The mixing in the Lake will continue throughout the winter.

Mixing in the Phewa Lake may occur temporarily during the heavy rainfall in August. Hence, it may be said that there is only one long term effect of mixing in the Lake, that is in winter.

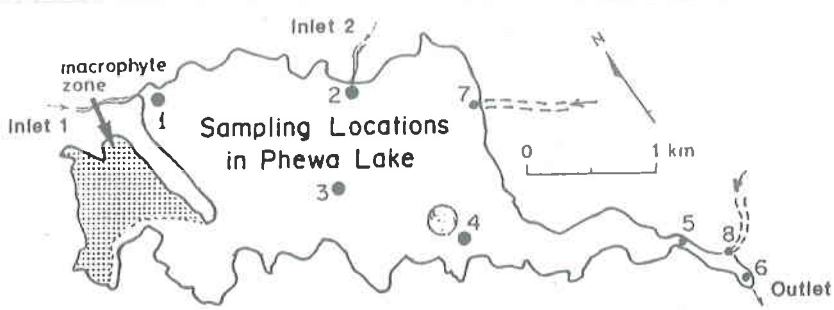
5.11 Nutrient Budgets

Nitrogen and phosphorus are generally considered to be the two main nutrients involved in the lake eutrophication process, even though these two are not the only nutrients required for algal growth. In spite of the controversy over the role of carbon as a limiting nutrient, a vast majority of researchers regard P as the most frequently limiting nutrient in lakes (Vollenweider, 1968).

Partial input – output budgets (based on individual measures and interval flows) for N and P compounds in Phewa Lake are shown in Table 5.3. Subsequently, Fig. 5.28 shows the mean nutrient concentrations at different Stations, while Fig. 5.29 shows the mean concentrations of other variables. Figs. 5.30 & 5.31 show the seasonal changes of WT at inflow, center of the Lake & outflow and the Lake level.

Table 5.3 Average Nutrient Budgets (September–December, 1989) for H_3-N, NO_3-N, Ortho-P, & Total P in Phewa Lake

Description	NH_3-N	NO_3-N	Ortho–P	Total–P
	(kg/d)			
Total Input	70	50	28	130
Total Output	50	120	6	80
Net Change	–20	+70	–22	–50
Percent Change	–28 %	+140 %	–78 %	–38 %



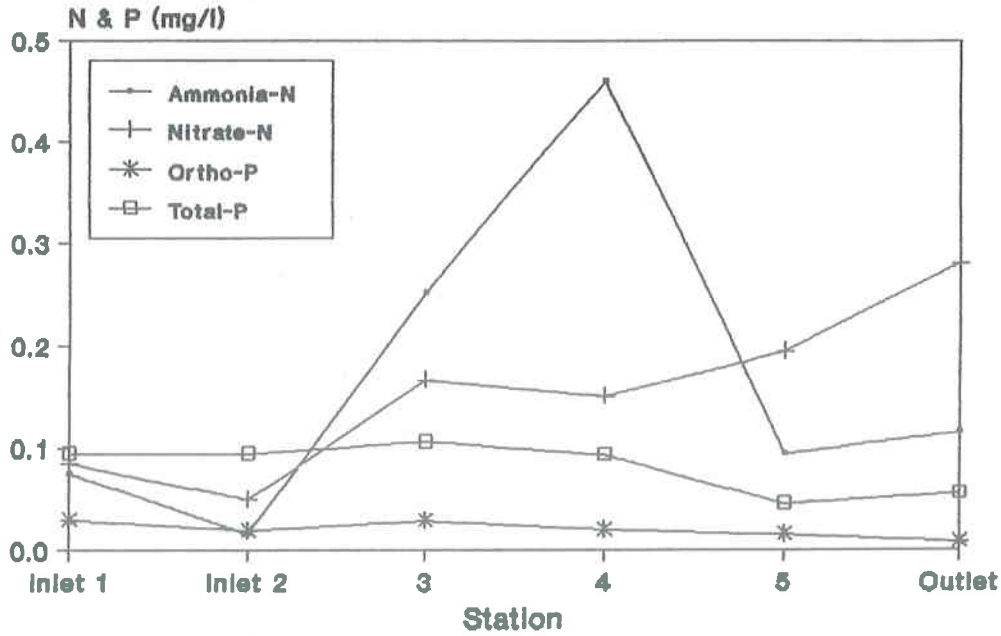


Fig. 5.28 Mean Nutrient Concentration Along the Sites

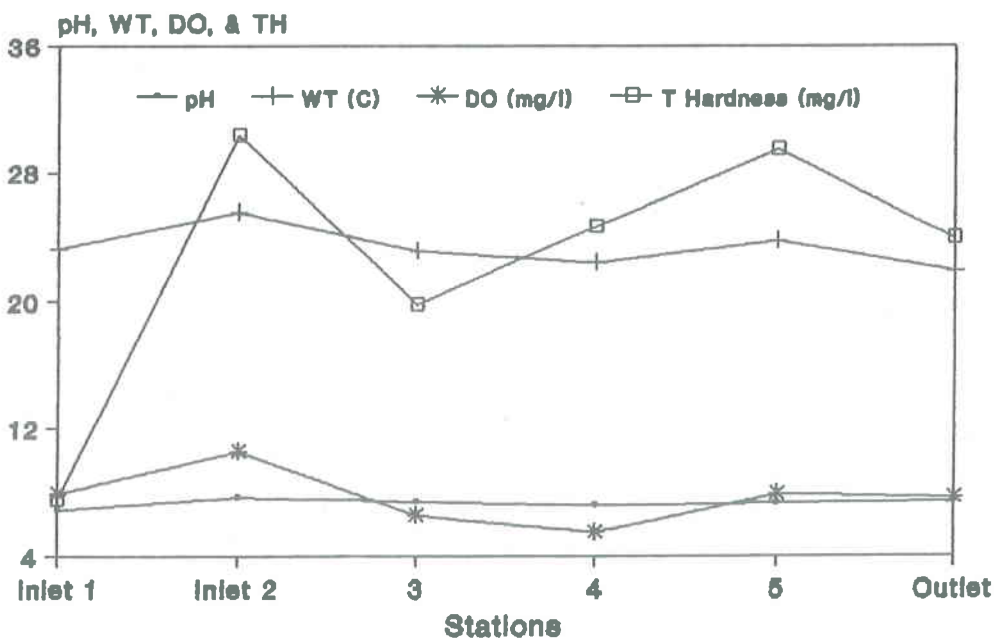


Fig. 5 29 Concentration of Some Variables Along the Sites

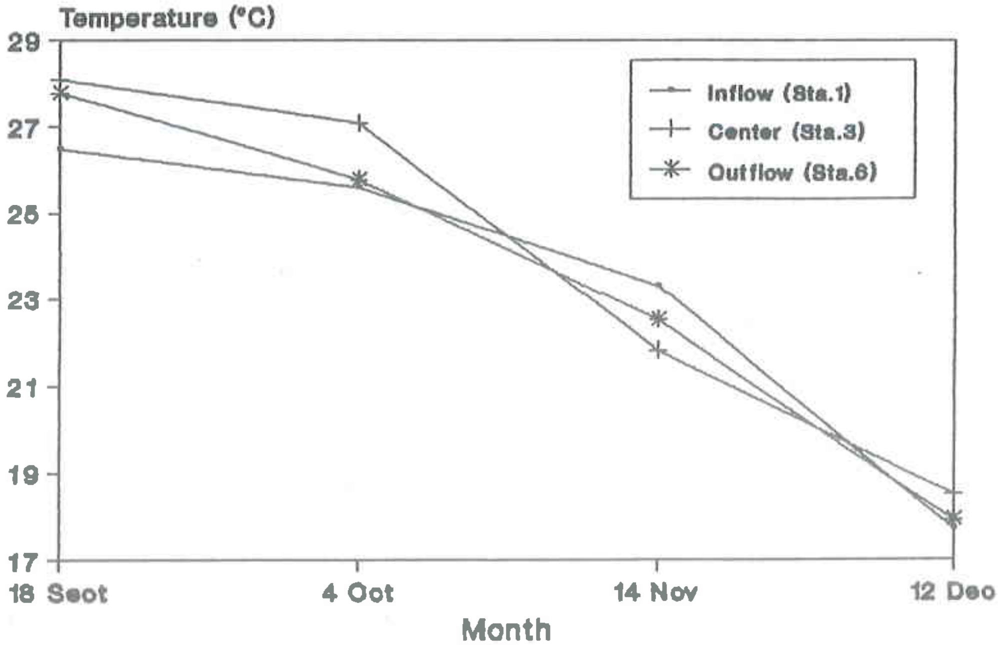


Fig. 5.30 Seasonal Changes of WT at Stas. 1, 3 & 6

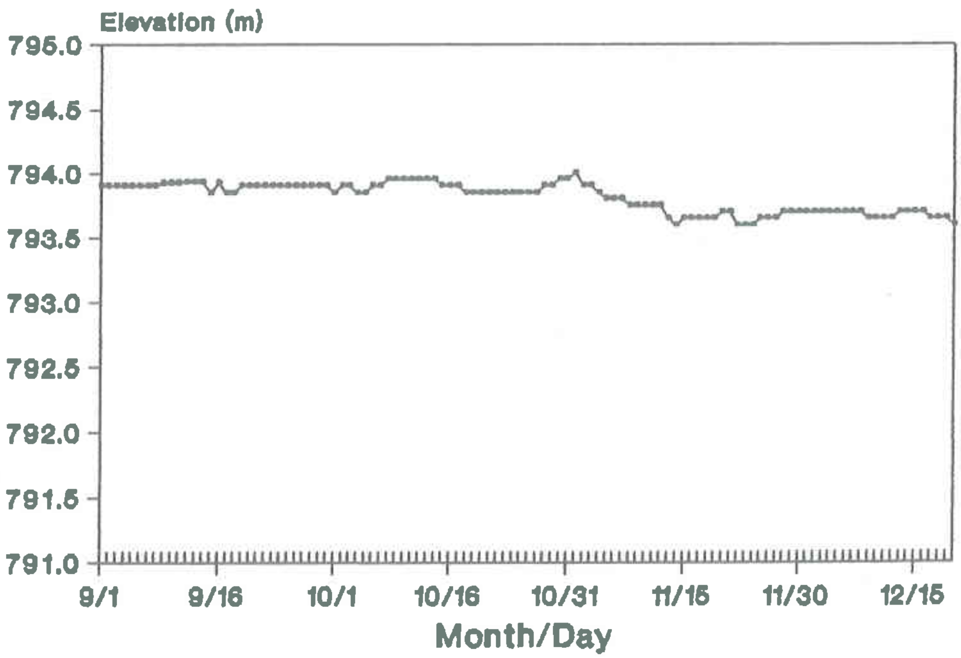


Fig. 5.31 Seasonal Changes of Lake Level

These budgets indicate that between September and December about 140 % more nitrate–N was discharged from Phewa Lake than can be accounted for by inflows. Significantly greater concentrations of nitrate–N were found in the bottom of the Lake at the site nearest the dam. Certainly, some of the differences in the partial inflow–outflow budgets may be accounted by the facts that the budget covers only four months, and the contributions from the early spring run–off have not been included.

Two basic mechanisms have been proposed to explain the increase in nutrients in the reservoir outflows. First, N fixation by blue–green algae is seen frequently as the most direct cause of at least a portion of the increased N concentratons in reservoir discharges (Rada and Wright, 1979). Secondly, while lakes and reservoirs with surface outlets allow nutrients to settle from the surface to deeper waters and to the sediments, removing nutrients from surface outflows, reservoirs with deep–water outlets continually discharge settling nutrients, thereby increasing outflow over inflow concentrations (Martin and Arneson, 1978). Marcus (1989) also emphasized that enrichment of N concentrations in outflow over inflow waters is hypothesized to occur through nitrogen fixation by *aphanizomenon flos–aquae*.

A combination of mechanisms may account for N enrichment in Phewa Lake. Some unknown concentrations of these nutrients could have entered through groundwater. Also, some enrichment could have resulted from nutrients released from sediments. Perhaps, N fixation was the principal cause of nitrogen enrichment in outflows.

Out of the 0.07, 0.028 and 0.13 kg/d of NH_3–N, ortho–P and total P entering the Lake, 28 %, 78 % and 38 % respectively were retained in the Lake. With a total surface area of 6.7 km^2 of the Lake, the loading rates for total P and total inorganic N ammount to 7.08 and 6.54 mg/(m^2.d) respectively. Considering only the dissolved P the loading rate ammounts to 1.5 mg/(m^2.d). The average mass of total P in the water column of Phewa Lake was estimated as to 7720 kg.

5.12 Primary Productivity and Phytoplankton Dominance

Daily primary production of phytoplankton (Nov – Dec, 1982 and Sept, 1984) was measured by Nakanishi, 1986 (Appendix IXc). These values ranged between 657 and 764 mg C/(m^2.d). No significant differences were found between September 1984 and November – December 1982, though it was expected to be higher in September than winter (December) because of the higher water temperature and light intensity in the late–monsoon season (Nakanishi, 1986). Daily primary production depends not only on water temperature and light intensity but also on phytoplankton biomass and total inorganic carbon (TIC) concentration.

The species composition of phytoplankton was surveyed qualitatively and quantitatively at Station 11 (Appendix IXa) in Phewa Lake (Nakanishi, 1986). 34 algal species were found in the late-monsoon season and 41 in the dry season in Phewa Lake. Of the qualitative composition, green algae were most abundant in the species number throughout both seasons. The measured chlorophyll_a concentration ranged between 4 and 62 mg/m^3 (Appendix IXa).

Lohman et al. (1988) conducted a study on pre- and post-monsoon limnological characteristics of Phewa Lake (Appendix X) and found the Chl_a concentrations in surface water as 11.2 and 4.8 µg/l for pre– and post-monsoon seasons respectively. The predominant phytoplanktons were *melosira granulata* during the pre-monsoon, and *melosira granulata, diatoma elongatum* and *ulothrix subtilissima* during the post-monsoon seasons. The values of Chl_a increased at a depth of 5 – 8 m and peaked (97.6 µg/l) at a depth of 7 m. Chl_a is directly related to P budgets in a lake.

Swar (1981) noted that as far as the composition and abundance of zooplankton are concerned, the *cladocera* were dominant during most of the year.

5.13 Trophic status

As discussed in Chapter 5.7, Phewa Lake might limitted by low P concentrations. By using Equation 2.2 based on P loading models (Chapter 2.7) (Vollenweider, 1975 and confirmed by OECD – Okada, 1982), the Chl_a concentration in the Phewa Lake may be calculated as follows (r = 0.975):

Average total-P = 122 mg/m³

Average Chl-a = 30 mg/m³

(This value is reliable when compared to Nakanishi & Lohman – Appendices IXa & Xb)

Maximum total-P = 210 mg/m³

Maximum Chl-a = 50 mg/m³

The report from OECD as referred by Okada (1982), gives the approximately fixed boundary system for trophic status categorization as shown in Appendix XVI. The measured and calculated values were compared to the boundary values (fixed by OECD, Paris) for trophic category as shown in Table 5.4.

Table 5.4 Comparision of Measured and Calculated Values to the Values Fixed for Eutrophic State

Description	Measured or Calculated Values	Boundary Values for Eutrophic State*	Trophic Status of Phewa Lake**
$[P]_{av}$ (mg/m³)	122	35 – 100	Hypertrophic
$[Chl\_a]_{av}$ (mg/m³)	30	8 – 25	Hypertrophic
$[Chl\_a]_{max}$ (mg/m³)	50	25 – 75	Eutrophic
$[SDT]_{av}$ (m)	2.6	3 – 1.5	Eutrophic
$[SDT]_{min}$ (m)	2.0	1.5 – 0.7	Mesotrophic

* Adapted by OECD, Paris
** With Respect to Different Indicators
SDT: Secchi Disc Transparency

Another way of defining the trophic category was proposed by Yoshimura (1937) who proposed the boundary values of total P and N concentrations to classify the trophic status of lakes and defined lakes with the concentrations above 0.02 mg P/l and 0.2 mg N/l as eutrophic and below them as oligotrophic. Measured values of total P (P_{av} = 0.122 mg/l) and N (N_{av} > 0.71 mg/l) in Phewa Lake were much higher than that of Yoshimura's standard. Even the average values of ortho-P (0.026 mg/l) and inorganic N (0.71 mg/l) were higher than that of Yoshimura's.

Fish production may be another indicator of the trophic status of a lake. Eutrophication in its early stages is almost certain to increase fish production, especially in flowing waters , while at the same time altering the fish species composition to what may be less desirable (Goldman & Horne, 1983). One of the most serious effects of eutrophication in lakes is its effect on depleting oxygen in the hypolimnion. Fish kills may also result from excessive eutrophication where bacterial and plant respiration deplete DO during a dark or windless period in summer. The fish production of Phewa Lake seems to be increasing (Appendix XI) but the quality of the fish species is decreasing according to the fishermen.

From a summary of the data (P, N, Chl_a, SDT and Fish Production) discussed above for diagnosis of the trophic status, Phewa Lake seems to be eutrophic.

5.14 Land–Use and Major Crop Production

Information on locations and types of land–use must be the basis to calculate nutrient flow together with surface run–off and for a rational management program (Fleming, 1983). Land–use information is based on aerial photographs taken in 1978, which provides the database for interpreting a land–use map (Fig. 4.4). The amount of each land–use type in each Panchayat is presented in Appendix XVII.

The land–use analysis indicates that nearly half (48 %) of the land is terraced, about a quarter (26 %) forested, and a tenth (10 %) open–grazing land. The terraced land is divided into upland and lowland excluding the valley floor, which is used for cultivation. Categories of terraced land, their areas, % occupied by crops, and multiple crops index in each Panchayat are shown in Table 5.5. Subsequently, the major crops, their yield, cropping intensity, and area covered by them are shown in Table 5.6.

Table 5.5 Terraced Land Categories (Excluding Valley Floor), their Utilization Pattern, and Population in Different Panchayats

Panchayat	Upland			Lowland			Population
	Area (ha)	MCI* (t/a)	LUI** (%)	Area (ha)	MCI* (t/a)	LUI** (%)	
Sarangkot	273	2.65	83.4	468	1.23	52.8	5817
Kaskikot	371	2.66	80.0	744	1.09	50.8	6532
Dhikur Pokhari	435	2.83	94.9	925	1.13	48.5	7774
Bhadaure	363	2.66	85.8	314	1.18	51.2	5665
Chapakot	275	2.15	78.3	565	1.16	49.1	3367
Total	1717			3016			29155

Source: Agriculture Department

* Multiple Crops Index (Crop Production time/year)
** Land Utilization Index (%)

Table 5.6 Major Crops and Area Covered by them, Yield and Production, and Cropping Intensity in the Watershed Area

Crops	Area (ha.)*	Yield (t/ha.)**	Production (t)
Paddy	3016	1.55	4674
Maize	1717	1.68	2885
Millet	1717	1.30	2235
Wheat	1187	1.02	1210
Total	7637		11004
Cropping Intensity = (7637/4733) x 100 = 161 %			

Source: Agriculture Department, Nepal

* Base Line Survey 1980
** Farm Management Survey 1979

The population of Phewa Lake watershed in 1989 was 29155 (Table 5.4). The demand for agricultural land for cereal production is very high, and thus farming on marginal slopes is common. Traditional farming practices exist all over the watershed. Land is being lost continuously due to sedimentation and flooding in the valley floor, and reduced productivity due to erosion on the uplands is actually reducing the farm output, hence decrease in the level of food supply. It is believed that terraces have the potential to increase the production by 40 % through proper farm management and improved agricultural practices. Programs suggested in this component are being applied in practice. Consequently, use of chemical fertilizers and pesticides is increasing, thereby threatening the Lake during the surface run—off.

The amount of fertilizer used in special pocket areas (improved agricultural practices) during the monsoon season is as follows:

Complexal (20 % N and 20 % P) = 7.0 kg/Ropani = 137 kg/ha
Urea (46 % N) = 3.5 kg/Ropani = 69 kg/ha
(19.65 Ropani = 1 ha)

Net application of N & P for each Ropani of special pocket areas (about 300 ha) was 2 kg N & 1.4 kg P respectively.

5.15 Estimation of Water Pollution Loads

The pollution load, that the Phewa Lake is receiving, was mostly from non-point sources. The Lake surrounding is a non-sewered area and there were no direct waste discharges to the lake except from some hotels and buildings . Non-point source pollution load assessment is very difficult . Hence, the magnitude of pollution loads (calculated in this Chapter) of Phewa Lake would be preliminary and tentative in nature. The main purpose of pollution load estimation was to get an overview of the pollution loads originating from major non-point sources and their overall potential impacts on the water of Phewa lake.

The main pollution load of Phewa Lake was due to nutrient inflow, particularly P (being limited), N, BOD, COD, and SS. Emphasis was given to the amount of P generated from domestic, urban land, agricultural land, forest land, and rainfall sources. Rough estimates can only be made for the assessment of the magnitude of water pollution potential from non-point sources by using factors given below in Tables 5.7 and 5.8.

Table 5.7 Pollution and Waste Factors for Domestic Effluents

Description	Waste	BOD	COD	SS	TDS	N	P
	[$m^3/(C.a)$]	[kg/(C.a)]					
People Connected to Sewer	73.0	19.7	44	20	36.5	3.3	0.4
People Not-connected to Sewer	7.3	6.9	16	16	-	-	-

Source: WHO Offset Publication No. 62 (1982)

Table 5.8 Watershed Phosphorus Export Coefficients

Source	Phosphorus Export Coefficient [g P/(m^2.a)]
Urban Land	0.10
Rural/Agricultural Land	0.05
Forest Land	0.01
Rainfall	0.02
Dry Fallout	0.08

Source: Cooke et al., 1986 (from Rast & Lee, 1978)

5.15.1 Magnitude of P load

Potential sources of P and N for Phewa Lake are from the watershed drainage areas which include agricultural run-off, urban run-off, forest and grazing land run-off, domestic and industrial (in a small scale) waste discharges, septic tank discharges from lakeshore developments precipitation, dry fallouts (leaves, dust, seeds etc), underground influxes (if any), nitrogen fixation, sediment recycling, and aquatic bird and animal wastes. Potential sinks include outlet losses , fish catches, denitrification, ground water recharge, and sediment losses.

Phosphates, in contrast to nitrates, are readily adsorbed to soil particles and do not move easily with groundwater. High inflows of total P are due to erosion of particles from steep slopes with easily erodible soils. Agricultural, domestic and industrial wastes are major sources of soluble phosphates and frequently contribute to lake eutrophication. P is one of the more common limiting elements on land and in freshwater.

The population of the Lake shore development area {including Fish Tail lodge, other hotels and lodges (90 in number), make-shift houses (totalling 330), tourists (average stay = 6 days) and local inhabitants} and 5 Village Panchayats (Table 5.5) in the catchment area is 34,655. The domestic waste factor for the people not-connected to sewer is assumed as 50 % [0.2 kg/(C.a)] of the people connected to sewer.

Table 5.9 P Loading from Different Sources

Source	P Load (kg/a)
Domestic wastes	6931
Urban land	209
Rural/Agricultural land	3804
Forest land	294
Rainfall	2400
Dry fallout (leaves, dust, etc.)	235
Fisheries	?
Laundry (Fig. 3.1)	?
Boating	?
Baraha Temple	?
Police Residence	?
Fish Tail Lodge	?
Other Lodges & Restaurants	?
Total	13873

Calculation of the P concentration in the Lake using Equation 2.6 for the study period (Sept - Dec, 1989):

$$P = \frac{P_i}{1 + t_w^{1/2}} = \frac{112\ (mg/m^3)}{1 + (100/365)^{1/2}} = 74\ mg/m^3$$

where,
- P : phosphorus concentration, mg/m^3
- P_i : phosphorus inflow, mg/m^3
- t_w : hydraulic retention time, a

The calculated value of P concentration (based on P inflow) was less than the measured value (122 mg/m^3). This could be due to the P released from the Lake sediments and decomposition of dead algae.

5.15.2 Magnitude of BOD, COD and SS from Domestic Effluent

Using the factors (Table 5.7) for people not connected to sewers annual BOD, COD, and SS loading were calculated (Table 5.10).

Table 5.10 BOD, COD and SS Loading from Domestic Effluents

Parameters	Load (t/a)
BOD	239
COD	554
Suspended Solids	554

The calculated value of BOD (700 mg/l) was much higher than the measured value (9 mg/l). This indicates that not all the BOD, generated by the people, entered into the Lake. From the soil loss information (Fleming, 1983) of the catchment area it had been expected that annual soil loss is equal to 129,400 tons and 86,640 tons/a (2/3) of it is deposited in the Lake .

VI CONCLUSIONS

The most beneficial uses of Phewa Lake are recreation, hydropower generation, irrigation and fisheries. While this study has been aimed at providing baseline data on the water quality of Phewa Lake and was relatively brief (monthly samplings from September to December), it yielded clear evidence that the Lake water quality is being degraded due to a large quantity of nutrients received from point as well as non-point sources.

It has been observed that the main recent problem of the Lake is the nutrient budgets as well as siltation. Increasing and expanding human activities/shore developments have been adding heavy pollution loads on the Lake, thus posing serious waste disposal problems. The pollution loads have adversely affected the Lake environment (such as smell, change in color, growth of algae and rooted plants etc.), thereby causing immediate adverse impacts on human health and the natural ecosystem of the area. Hence, serious environmental problems in the Lake have recently surfaced, but very little study has been done on the lake.

Considerable fluctuations in hydraulic retention times (10 to 450 days) and water temperature (17 to 29 °C) thermal stratification and anoxic conditions (DO = 0.3 mg/l) exist in summer. Flushing and turnover resulting in a DO of 7.5 mg/l occurs during the rainy & winter seasons.

Average P (0.122 mg/l) and N (>0.71 mg/l) concentrations for the study period are notably high and sufficient for primary production. Nutrient budget computations for the study show that Phewa Lake retains 38 % of total P (130 kg/d) and 78 % of ortho-P (28 kg/d) transported to it by the tributary inflows. It has been estimated that the P loading for the Lake is about 14 t/a.

N concentration increased in the outflow compared to the inflows probably due to N fixation and leaching of nutrients from the sediments and exposed shore developments. The overall N:P ratio ranged from 9 to 92 indicating high productivity.

Though the relationship of land-use to water quality was difficult to assess, the effects of non-point sources were greater than those of point sources as experienced during the study,. The identifiable non-point source was the agricultural land.

BOD and COD remained high at the bottom (9 and 184 mg/l) as compared to the surface (3 and 6 mg/l respectively). Total and fecal coliforms remained high (17000 and 900 MPN/100 ml) in the tributaries inflow as compared to the outflow (3000 and 300 MPN/100 ml).

Fe and Mn concentrations (up to 8 and 1 mg/l) exceeded drinking water quality standards (0.1 and 0.05 mg/l). The dominant cation was Ca and accounted for more than 53 % of the cation (Ca, Mg, Na & K) concentrations and anions were predominantly bicarbonate. Low salinity in the Lake is attributable to the metamorphic geology of the catchment (Lohman et al., 1988).

The sediments were in anoxic conditions till October due to the summer thermal stratification. High nutrient concentrations in the bottom waters and increase in ortho-P in the dry season suggest nutrient enrichment in the sediments and release to the overlying waters.

Nutrient balancing was difficult due to the overlapping of water flow changes and thermal stratification.

The data collected in the study suggests that Phewa Lake is eutrophic.

VII RECOMMENDATIONS

In spite of a great deal of research, there is no simple solution to the eutrophication problem; the following remedial measures are recommended:

1. While this study was relatively brief and data may not be sufficient/representative for further assessment and formulating policy guidelines in controlling eutrophication, a detailed study (at least one year monitoring) on the Lake (especially for run-off, nutrient input-output budgets, stratification and destratification, sediments, land-use, etc.) is necessary. For this, laboratory facility should be provided in Pokhara.

2. One of the sources of nutrient leachate as well as siltation is alarming erosion of deforested and terraced land. The newly constructed Pokhara-Baglung road, which passes through the Lake catchment area, may cause notable increase in siltation and nutrient in the Lake. Hence reforestation is urgent.

3. Another source of nutrient leachate as well as siltation is land-use practice. The Government should motivate (with facilities) the people in the catchment area to cultivate crops which need less excavation as well as less chemical fertilizers and pesticides to decrease the erosion and nutrient leachate from agricultural land. Investigations on land-use should be performed to take such measures.

4. The Phewa Watershed Project (PWP) is supposed to be a monitoring organization for the catchment area. But there are no effective measures being taken by the PWP for Lake water quality management. Hence Phewa Lake needs a particular organization (or to make PWP more active) for regular monitoring and to take effective remedial measures to control the pollution loads.

5. Though it seems to be expensive for a resource limited country, construction of a canal around the shore is a good idea for the diversion of nutrient and silt from the catchment. As Karki et al. (1988) suggested, the Lake level can be raised by 1 m by constructing an earthen embankment to protect the well cultivated land from inundation in the upper reaches of the Lake.

6. An intentional discharge of water through a canal from the Seti River diversion is causing a problem of erosion of paddy fields nearby the Lake with inflow of high silt and Ca rich water to the Lake. The silt (come through the canal) filled up (covered) the Lake by more than 4 Ropani within 2

years suggesting recent control or treatment of the canal discharge.

7 It is necessary to set up national environmental standards for the Lake and strictly follow up them.

8 It is necessary to specify the rights and duties of state and other agencies for the development and implementation of drinking as well as waste water programs to stop the domestic waste discharge from the shore developments (especially hotels & lodges). It should be compulsery for all lodges, restaurants and hotels not to discharge any waste into the Lake.

9 Decentralized small treatment plants (e. g. RBC for Fish Tail Lodge) are recommended for individual waste treatment.

10 Island in the Lake (where exists Baraha Temple) should not be used as a picnic spot.

11 Washing of cloths in the Lake water seems to be undesirable as it is not aesthetic and adds detergents to the Lake. Reasonable and adequate facilities should be provided to stop it.

12 There is an urgent need for effective environmental management of the Lake catchment area. Human activities may have to be regulated to prevent further damage. Baseline studies and environmental assessment will have to be made and Environmental Impact Assessment (EIA) statements must be required.

13 Finally, public participation through NGOs seems to be required in developing such programs.

14 Future hydraulic modelling may be partly done by using the parameter conductivity.

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APPENDIX A

Primary Data
(Obtained from the Research)

APPENDIX I

Surface Water Quality at Fixed Stations in Phewa Lake
(September - December, 1989)

Parameters	Sta. 1 (Tributary Inflows)	Sta. 2 (Tributary Inflows)	Sta. 3	Sta. 4	Sta. 5	Sta. 6	Sta. 7 (Canal Inflow)	Sta. 8 (Canal Inflow)
pH								
18 Sept	6.90	7.40	8.00	7.70	7.70	–	–	–
4 Oct	6.90	9.00	8.00	7.40	7.20	7.40	–	–
14 Nov	6.90	6.90	7.15	7.30	7.35	–	–	–
12 Dec	7.00	7.50	7.30	7.30	7.35	7.50	8.45	8.40
Temperature (°C)								
18 Sept	26.50	28.50	28.10	28.50	28.00	27.30	–	–
4 Oct	25.60	28.90	27.10	26.50	25.60	25.30	–	–
14 Nov	23.30	23.60	21.80	23.30	22.90	22.50	–	–
12 Dec	17.70	21.30	18.50	18.80	18.60	17.90	16.00	15.00
Dissolved Oxygen (mg/l)								
18 Sept	9.40	11.40	9.10	11.40	9.90	–	–	–
4 Oct	8.30	12.30	10.30	9.60	9.40	9.40	–	–
14 Nov	6.90	9.40	7.80	8.30	8.10	–	–	–
12 Dec	7.10	8.90	4.60	6.60	5.60	6.10	9.00	9.00
Turbidity (NTU)								
18 Sept	10.00	4.10	4.80	10.50	8.20	–	–	–
4 Oct	7.00	8.00	7.00	2.00	8.00	4.00	–	–
14 Nov	6.00	5.50	5.60	6.00	7.00	–	–	–
12 Dec	5.00	2.00	6.00	5.00	5.00	2.00	1.00	1.00
Conductivity (µS/cm)								
18 Sept	23	90	28	24	34	–	–	–
4 Oct	21	36	28	30	36	43	–	–
14 Nov	25	44	42	52	69	–	–	–
12 Dec	26	103	54	59	72	73	2.2	21.8
Transparency (m)								
18 Sept	–	–	2.5	2.3	2.2	2.2	–	–
12 Dec	–	–	3.0	2.8	2.6	2.5	–	–
Total Hardness (mg/l) as $CaCO_3$								
18 Sept	6.93	41.20	10.60	8.97	14.28	–	–	–
4 Oct	6.12	13.46	10.40	11.22	14.28	18.36	–	–
14 Nov	7.14	19.40	18.20	37.50	61.10	–	–	–
12 Dec	9.90	47.50	22.60	24.60	28.30	29.50	94.60	94.60

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Surface Water Quality at Fixed Stations in Phewa Lake
(September - December, 1989)

Variables	Sta. 1 (Tributary Inflows)	Sta. 2 (Tributary Inflows)	Sta. 3	Sta. 4	Sta. 5	Sta. 6	Sta. 7 (Canal Inflow)	Sta. 8 (Canal Inflow)
Chloride (mg/l)								
18 Sept	3.64	9.00	3.74	3.22	6.76	–	–	–
4 Oct	3.64	3.84	3.84	4.57	5.20	4.57	–	–
14 Nov	6.13	4.47	4.47	4.26	4.99	–	–	–
12 Dec	2.90	29.10	2.20	3.10	2.60	4.50	78.00	88.40
Detergents (mg/l)								
18 Sept	0.05	n.d.	0.08	0.07	0.15	–	–	–
BOD (mg/l)								
18 Sept	2.54	n.d.	1.15	2.39	3.35	–	–	–
4 Oct	1.40	4.00	3.50	3.00	2.10	3.10	–	–
14 Nov	0.0	1.70	1.20	2.30	0.30	–	–	–
12 Dec	0.30	0.70	1.90	1.30	1.30	1.30	1.50	1.90
COD (mg/l)								
18 Sept	n.d.	9.10	5.90	1.30	n.d.	–	–	–
4 Oct	7.10	5.30	4.60	6.00	12.30	8.10	–	–
14 Nov	n.d.	4.84	4.34	3.38	7.74	–	–	–
12 Dec	n.d.	n.d.	4.20	3.00	n.d.	n.d.	n.d.	n.d.
NH_3–N (mg/l)								
18 Sept	0.061	0.021	0.012	0.007	0.002	–	–	–
4 Oct	0.042	0.005	0.041	0.053	0.008	0.008	–	–
14 Nov	0.081	0.003	0.072	0.092	0.011	–	–	–
12 Dec	0.116	0.032	0.258	0.203	0.224	0.176	0.165	0.029
NO_2–N (mg/l)								
18 Sept	0.006	0.002	0.005	0.004	0.005	–	–	–
4 Oct	0.004	0.002	0.003	0.003	0.004	0.003	–	–
14 Nov	0.001	0.001	0.001	0.002	0.002	–	–	–
12 Dec	0.002	0.001	0.002	0.002	0.001	0.001	0.000	0.000
NO_3–N (mg/l)								
18 Sept	0.001	0.001	0.050	0.081	0.011	–	–	–
4 Oct	0.002	0.001	0.060	0.068	0.080	0.090	–	–
14 Nov	0.004	0.002	0.080	0.041	0.160	–	–	–
12 Dec	0.334	0.190	0.260	0.076	0.527	0.470	0.000	0.051

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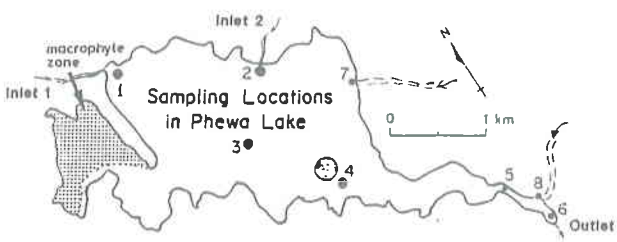
Surface Water Quality at Fixed Stations in Phewa Lake
(September - December, 1989)

Variables	Sta. 1 (Tributary Inflows)	Sta. 2 (Tributary Inflows)	Sta. 3	Sta. 4	Sta. 5	Sta. 6	Sta. 7 (Canal Inflow)	Sta. 8 (Canal Inflow)
Ortho-P (mg/l)								
18 Sept	0.021	0.010	0.005	0.005	0.004	–	–	–
4 Oct	0.019	0.015	0.010	0.012	0.005	0.004	–	–
14 Nov	0.035	0.021	0.020	0.015	0.008	–	–	–
12 Dec	0.041	0.026	0.074	0.021	0.013	0.009	0.017	0.022
Total P (mg/l)								
18 Sept	0.171	0.202	0.162	0.131	0.051	–	–	–
4 Oct	0.081	0.093	0.096	0.082	0.032	0.061	–	–
14 Nov	0.072	0.051	0.085	0.054	0.024	–	–	–
12 Dec	0.055	0.034	0.091	0.061	0.023	0.054	0.030	0.035
Total Coliform (MPN/100 ml)								
4 Oct	17000	–	160	3000	420	2000	–	–
14 Nov	–	12560	10	–	1220	–	–	–
Fecal Coliform (MPN/100 ml)								
4 Oct	900	–	0	100	200	300	–	–
14 Nov	–	10	0	–	57	–	–	–
Inorganic N:P								
18 Sept	–	–	13.40	18.40	4.50	–	–	–
4 Oct	–	–	10.40	10.33	18.80	25.25	–	–
14 Nov	–	–	7.65	9.00	21.87	–	–	–
12 Dec	–	–	7.03	13.38	57.85	71.89	–	–



APPENDIX II

Vertical distribution of some Parameters with time at station 4 in Phewa Lake (1989, Around Noon)

Parameters	Depth (m)			
	0	5	10	15
pH				
18 Sept	7.70	7.20	7.10	7.20
4 Oct	7.40	7.10	6.90	6.70
14 Nov	7.30	7.40	7.20	6.75
12 Dec	7.30	6.65	7.15	7.20
Temperature (°C)				
18 Sept	28.50	24.20	22.70	20.80
4 Oct	26.50	23.80	23.10	21.50
14 Nov	23.30	22.00	21.80	20.90
12 Dec	18.80	18.50	18.40	18.40
Dissolved Oxygen (mg/l)				
18 Sept	11.40	6.00	1.80	0.60
4 Oct	9.60	4.80	0.80	0.30
14 Nov	8.80	8.40	7.20	1.60
12 Dec	6.60	5.80	5.60	4.90
Turbidity (NTU)				
18 Sept	10.50	18.00	23.00	35.00
4 Oct	2.00	6.00	14.00	17.00
14 Nov	8.90	30.00	37.00	49.40
12 Dec	5.00	15.00	16.00	19.00
Conductivity (µS/cm)				
18 Sept	24	60	89	91
4 Oct	30	65	53	64
14 Nov	52	78	69	71
12 Dec	59	68	63	70
Total Hardness (mg/l)				
18 Sept	8.97	26.52	40.80	43.00
4 Oct	11.22	30.60	15.30	21.20
14 Nov	37.50	44.20	31.00	23.70
12 Dec	24.60	22.20	23.40	27.30
Chloride (mg/l)				
18 Sept	3.22	9.36	6.24	–
4 Oct	4.57	6.76	3.53	3.20
14 Nov	4.26	3.64	–	2.91
12 Dec	3.10	4.30	2.80	2.70
Detergent (mg/l)				
18 Sept	0.07	0.11	0.12	–
BOD (mg/l)				
18 Sept	2.39	2.12	1.86	–
4 Oct	3.00	2.30	6.20	9.00
14 Nov	2.30	2.40	–	n.d.
12 Dec	1.30	n.d.	n.d.	2.60

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Vertical distribution of some Parameters with time at station 4 in Phewa Lake (1989, Around Noon)

Parameters	Depth (m)			
	0	5	10	15
COD (mg/l)				
18 Sept	1.80	3.70	11.00	–
4 Oct	6.00	7.10	24.80	184.40
14 Nov	3.38	3.87	–	4.35
12 Dec	3.00	n.d.	6.00	3.60
NH_3–N (mg/l)				
18 Sept	0.007	0.024	0.050	–
4 Oct	0.053	0.043	0.230	0.870
14 Nov	0.092	0.082	–	1.340
12 Dec	0.203	0.284	0.235	0.289
NO_2–N (mg/l)				
18 Sept	0.004	0.004	0.006	–
4 Oct	0.003	0.002	0.002	0.005
14 Nov	0.002	0.001	–	0.002
12 Dec	0.002	0.002	0.001	0.001
NO_3–N (mg/l)				
18 Sept	0.081	0.100	0.192	–
4 Oct	0.068	0.220	0.095	0.120
14 Nov	0.041	0.250	–	0.134
12 Dec	0.076	0.325	0.154	0.532
Ortho-P (mg/l)				
18 Sept	0.005	0.010	0.006	0.013
4 Oct	0.012	0.012	0.008	0.016
14 Nov	0.015	0.015	0.017	0.028
12 Dec	0.021	0.014	0.011	0.039
Total P (mg/l)				
18 Sept	0.131	0.130	0.201	0.210
4 Oct	0.082	0.085	0.092	0.095
14 Nov	0.054	0.060	0.062	0.065
12 Dec	0.061	0.020	0.031	0.055
Total Coliform (MPN/100 ml)				
4 Oct	3000	–	–	–
Fecal Coliform (MPN/100 ml)				
4 Oct	100	–	–	–
Inorganic N:P				
18 Sept	18.40	12.80	41.33	–
4 Oct	10.33	22.08	40.88	82.91
14 Nov	9.00	22.20	–	92.12
12 Dec	13.38	43.64	35.45	21.08

APPENDIX III

Vertical Distribution of Some Parameters With Time at Sation 3 in Phewa Lake (1989, Around Noon)

Parameters	Depth (m)				
	0	5	10	15	19
pH					
18 Sept	8.00	7.50	7.10	7.00	–
4 Oct	8.00	7.40	6.60	6.80	–
14 Nov	7.15	7.20	7.10	7.10	6.75
12 Dec	7.30	7.30	7.25	7.20	–
Temperature (°C)					
18 Sept	28.10	25.60	24.20	21.00	–
4 Oct	27.10	25.00	23.20	22.10	–
14 Nov	21.80	21.40	21.50	21.00	20.00
12 Dec	18.50	18.40	18.40	18.30	–
Dissolved Oxygen (mg/l)					
18 Sept	9.10	6.20	1.50	0.50	–
4 Oct	10.30	6.50	0.70	0.70	–
14 Nov	7.80	7.10	4.70	1.50	1.20
12 Dec	4.60	5.10	4.70	4.70	–
Turbidity (NTU)					
18 Sept	4.80	6.80	97.00	–	–
4 Oct	7.00	6.00	17.00	–	–
14 Nov	5.60	5.20	67.80	60.00	58.60
12 Dec	6.00	2.00	3.00	110.00	–
Conductivity (μs/cm)					
18 Sept	28	23	91	–	–
4 Oct	28	–	34	56	–
14 Nov	42	45	47	55	75
12 Dec	54	54	54	54	–
Total Hardness (mg/l)					
18 Sept	10.60	10.20	43.15	–	–
4 Oct	10.40	–	12.24	19.38	–
14 Nov	18.20	19.40	19.60	–	37.80
12 Dec	22.60	21.40	21.60	21.60	–
Chloride (mg/l)					
18 Sept	3.74	3.53	6.24	–	–
4 Oct	3.84	–	2.91	8.05	–
14 Nov	4.47	4.05	3.64	–	3.84
12 Dec	2.20	2.50	3.30	2.60	–
Detergent (mg/l)					
18 Sept	0.07	0.11	0.12	–	–
BOD (mg/l)					
18 Sept	1.15	–	–	–	–
4 Oct	3.50	n.d.	n.d.	7.00	–
14 Nov	1.20	–	1.10	n.d.	0.80
12 Dec	1.90	n.d.	n.d.	2.00	–

contd...

Vertical Distribution of Some Parameters With Time at Sation 3 in Phewa Lake (1989, Around Noon)

Parameters	Depth (m)				
	0	5	10	15	20
COD (mg/l)					
18 Sept	5.90	5.20	48.20	–	–
4 Oct	4.60	–	5.00	21.30	–
14 Nov	4.84	5.80	16.45	–	15.37
12 Dec	4.20	3.00	4.20	n.d.	–
NH_3–N (mg/l)					
18 Sept	0.012	0.032	0.045	–	–
4 Oct	0.041	–	0.240	0.530	–
14 Nov	0.072	0.093	0.083	–	0.800
12 Dec	0.258	0.278	0.286	0.283	–
NO_2–N (mg/l)					
18 Sept	0.005	0.002	0.003	–	–
4 Oct	0.003	–	0.004	0.006	–
14 Nov	0.001	0.001	0.012	–	0.001
12 Dec	0.002	0.001	0.001	0.007	–
NO_3–N (mg/l)					
18 Sept	0.050	0.080	0.230	–	–
4 Oct	0.060	–	0.060	0.090	–
14 Nov	0.080	0.045	0.080	–	0.080
12 Dec	0.260	0.350	0.176	0.357	–
Ortho-P (mg/l)					
18 Sept	0.005	0.011	0.008	–	–
4 Oct	0.010	–	0.020	0.030	–
14 Nov	0.020	0.014	0.027	–	0.035
12 Dec	0.074	0.015	0.020	0.024	–
Total P (mg/l)					
18 Sept	0.162	0.160	0.130	–	–
4 Oct	0.096	–	0.070	0.090	–
14 Nov	0.085	0.060	0.070	–	0.095
12 Dec	0.091	0.018	0.005	0.086	–
Total Coliform (MPN/100 ml)					
4 Oct	160	–	–	–	–
14 Nov	10	–	–	–	–
Fecal Coliform (MPN/100 ml)					
4 Oct	0	–	–	–	–
14 Nov	0	–	–	–	–
Inorganic N:P					
18 Sept	13.40	10.36	34.75	–	–
4 Oct	10.40	–	15.20	20.87	–
14 Nov	7.65	9.90	6.50	–	25.17
12 Dec	7.03	41.90	23.10	27.00	–

APPENDIX IV

Hourly record of water temperature at station 4 (22 sept,1989)

Time (Hour)	Depth (m)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	25.3	25.3	25.1	24.2	23.8	23.6	23.5	23.4	23.0	22.8	22.6	22.4	21.5	21.0	20.1	20.5
1	25.3	25.3	25.2	24.1	23.7	23.6	23.4	23.3	23.0	22.8	22.6	22.5	21.5	21.1	20.8	20.5
2	25.2	25.3	25.2	24.0	23.6	23.5	23.4	23.3	23.2	22.8	22.7	22.5	21.6	21.2	20.9	20.6
3	25.2	25.3	25.1	24.1	23.7	23.4	23.3	23.2	23.1	22.7	22.6	22.6	21.9	21.5	21.2	20.8
4	25.2	25.2	25.0	24.3	23.8	23.4	23.2	23.1	23.2	22.8	22.7	22.7	22.2	21.8	21.5	21.2
5	25.3	25.2	25.0	24.4	23.7	23.3	23.2	23.1	23.1	22.9	22.8	22.6	22.4	22.0	21.8	21.4
6	25.4	25.0	24.5	24.1	23.7	23.3	23.1	23.2	23.1	22.9	22.8	22.6	22.3	21.9	21.5	21.5
7	25.3	24.7	24.5	24.2	23.7	23.2	23.1	23.1	23.0	22.3	22.8	22.6	22.3	22.1	21.7	21.4
8	25.2	24.6	24.0	23.9	23.8	23.3	23.0	23.0	23.0	22.7	22.8	22.8	22.4	22.2	21.6	21.2
9	25.0	25.2	25.0	24.8	24.5	23.9	23.3	23.6	23.4	23.2	23.0	22.6	22.2	22.0	21.8	21.5
10	24.9	24.3	24.6	24.2	24.0	23.8	23.5	23.3	23.1	22.9	22.6	22.3	22.1	21.9	21.6	21.3
11	25.5	25.4	24.8	24.4	24.3	23.9	23.6	23.4	23.2	23.0	22.6	22.4	22.0	21.7	21.4	21.0
12	26.6	25.8	25.5	25.3	24.7	24.0	23.8	23.5	23.4	23.2	22.6	22.5	22.0	21.5	20.9	20.9
13	26.9	25.3	26.0	25.6	25.0	24.2	24.1	23.6	23.5	23.3	22.6	22.4	22.0	21.2	20.5	20.8
14	27.5	26.4	25.9	24.8	24.3	24.2	23.7	23.5	23.5	23.3	22.3	22.4	21.5	21.0	20.5	20.8
15	28.2	26.4	26.1	25.5	24.9	24.4	23.8	23.5	23.5	23.1	22.8	22.6	21.3	21.5	20.6	21.0
16	28.6	26.4	25.8	24.8	24.4	24.0	23.3	23.6	23.6	23.1	22.8	22.5	21.7	21.5	20.6	20.8
17	27.5	26.4	25.0	24.2	24.0	23.7	23.4	23.3	23.2	22.9	22.8	22.5	21.3	21.6	20.6	21.0
18	26.6	25.4	24.7	24.2	23.8	23.5	23.3	23.3	23.2	23.0	22.8	22.5	21.8	21.4	20.8	21.0
19	26.2	25.6	25.1	24.2	24.0	23.5	23.3	23.3	23.1	22.3	22.8	22.5	21.6	21.5	20.6	20.8
20	25.9	25.4	24.8	24.1	23.8	23.6	23.9	23.2	23.2	22.9	22.8	22.5	21.5	21.4	20.5	20.6
21	25.6	25.5	24.4	24.0	23.8	23.7	23.4	23.2	23.1	22.9	22.7	22.5	21.6	21.4	20.6	20.5
22	25.5	25.4	24.6	23.8	23.6	23.7	23.4	23.2	23.0	22.9	22.7	22.5	21.6	21.4	20.6	20.5
23	25.5	25.5	25.0	23.9	23.6	23.6	23.4	23.3	23.2	22.8	22.6	22.5	21.6	21.3	20.5	20.5
24	25.3	25.2	25.0	24.4	23.9	23.5	23.4	23.3	23.0	22.7	22.6	22.2	21.6	21.1	20.8	20.5

APPENDIX V

Hourly Record of DO at Station 4 (22 Sept, 1989)

Time (Hrs)	Depth (m)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	9.6	9.6	9.0	8.1	6.3	6.0	5.1	4.5	3.2	2.4	0.9	0.7	0.6	0.5	0.5	0.5
1	9.7	9.6	9.1	7.9	6.5	6.1	5.0	4.5	3.5	2.4	0.9	0.8	0.6	0.5	0.5	0.5
2	9.7	9.2	9.0	7.7	6.3	5.8	4.8	4.2	3.2	2.3	1.2	0.9	0.6	0.5	0.5	0.4
3	9.6	8.8	8.5	7.3	6.0	5.6	4.5	3.9	3.1	2.2	1.3	0.9	0.7	0.6	0.6	0.5
4	9.6	8.6	8.0	6.9	5.8	5.2	4.3	3.5	2.9	2.2	1.4	0.8	0.7	0.6	0.5	0.4
5	9.5	8.4	7.4	6.8	5.6	5.1	4.1	3.8	2.8	2.1	1.5	0.9	0.8	0.7	0.5	0.4
6	9.6	8.1	7.6	6.9	5.7	5.0	3.8	3.4	2.6	2.1	1.5	0.9	0.8	0.7	0.5	0.4
7	10.1	7.8	7.5	7.2	5.8	5.0	4.0	3.5	2.6	2.2	1.5	0.8	0.8	0.6	0.5	0.4
8	10.0	7.8	7.5	7.3	5.9	4.9	4.6	4.1	4.0	2.6	1.6	0.9	0.8	0.7	0.4	0.3
9	10.4	9.8	9.8	9.6	6.6	5.2	4.8	4.7	3.8	2.7	1.0	0.9	0.6	0.6	0.5	0.5
10	10.3	9.9	9.5	9.1	6.7	5.3	4.8	4.5	3.7	2.5	0.9	0.8	0.7	0.6	0.5	0.5
11	10.4	9.8	9.6	9.2	6.6	5.4	4.7	4.3	3.6	2.6	1.0	0.9	0.8	0.7	0.5	0.5
12	10.6	9.7	9.7	9.2	6.7	5.6	4.3	4.4	3.4	2.8	1.1	0.9	0.7	0.6	0.6	0.5
13	10.9	10.0	9.8	9.0	6.6	5.8	4.7	4.5	3.5	3.0	0.9	0.8	0.8	0.8	0.3	0.5
14	12.0	10.9	9.7	8.1	6.9	6.0	4.6	3.8	3.2	2.7	1.2	1.0	0.7	0.8	0.7	0.5
15	10.8	10.0	9.6	8.9	6.9	6.2	4.6	3.7	3.1	2.8	0.9	0.8	0.7	0.7	0.7	0.5
16	10.6	9.8	8.6	7.4	6.6	6.2	4.6	3.7	3.2	2.8	0.9	0.8	0.7	0.6	0.7	0.5
17	10.8	10.2	8.4	7.2	6.4	5.9	4.8	4.0	3.3	2.0	0.9	0.8	0.7	0.5	0.5	0.5
18	11.9	10.2	8.3	7.3	6.6	5.8	4.8	4.0	3.3	2.0	1.0	0.8	0.7	0.5	0.5	0.5
19	11.3	9.8	8.0	7.0	6.6	5.9	4.7	4.1	3.5	2.2	0.9	0.9	0.7	0.5	0.6	0.5
20	10.4	9.6	8.6	7.2	6.7	6.0	4.6	4.2	3.6	2.3	1.0	0.8	0.6	0.6	0.5	0.4
21	10.5	9.6	8.2	7.4	6.8	5.8	4.8	4.4	3.8	2.4	0.9	0.8	0.7	0.6	0.5	0.5
22	10.0	9.5	7.9	7.1	6.7	5.8	4.9	4.5	4.1	2.5	1.0	0.8	0.6	0.6	0.5	0.4
23	9.9	9.7	8.2	7.5	6.8	5.8	5.0	4.6	4.2	2.4	1.0	0.8	0.6	0.5	0.5	0.4
24	9.6	9.6	9.0	8.1	6.3	6.0	5.1	4.5	3.2	2.4	0.9	0.7	0.6	0.5	0.5	0.5

APPENDIX B

Secondary Data

APPENDIX VI

Maximum, Minimum, Average (30 years) and 1989 Monthly Rainfall (mm) in the Phewa Lake Catchment

Month	Max*	Min*	Ave*	1989**
Jan	56.60	0.60	22.00	87.00
Feb	73.60	0.00	37.50	35.40
Mar	168.10	1.60	50.50	35.40
Apr	120.30	24.30	70.90	37.00
May	328.50	62.70	192.10	664.30
Jun	992.60	296.40	666.30	770.90
Jul	1385.20	553.10	938.00	1295.30
Aug	1026.80	429.90	841.30	670.20
Sep	1297.70	363.90	615.50	340.20
Oct	236.50	40.20	118.70	65.10
Nov	107.50	0.00	23.10	45.00
Dec	27.30	0.00	6.70	40.00

* Karki et.al, 1988
** Meteorological Center, Pokhara

APPENDIX VII

Rainfall (1989) at Station Bhadauri 0813 in the Phewa Lake Catchment

Date	Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	46.2	50.5	55.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	50.1	45.1	16.5	12.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	80.8	25.3	0.0	5.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	23.4	100.2	0.0	11.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	29.7	60.0	20.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	5.6	30.9	13.2	21.5	2.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	8.4	62.6	25.0	5.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	18.9	25.4	15.8	25.0	0.0	0.0	0.0
9	0.0	3.0	0.0	0.0	0.0	0.0	10.7	61.6	32.0	0.0	14.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	80.0	41.1	2.9	6.1	0.0	0.0
11	0.0	0.0	0.0	0.0	5.1	0.0	70.1	10.9	0.0	4.5	0.0	0.0
12	0.0	5.0	0.0	0.0	6.3	38.0	40.5	0.0	0.0	0.0	0.0	32.0
13	0.0	0.0	0.0	0.0	0.0	20.1	15.2	10.0	28.1	0.0	16.0	8.0
14	0.0	0.0	0.0	0.0	0.0	40.5	170.6	25.2	17.4	0.0	0.0	0.0
15	40.0	4.0	28.2	0.0	0.0	11.2	112.1	60.5	9.2	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	50.2	25.6	41.5	51.1	12.9	0.0	0.0	0.0
17	0.0	0.0	7.2	0.0	80.6	8.9	26.2	26.9	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	40.6	15.6	16.8	19.6	0.0	0.0	0.0	0.0
19	35.0	0.0	0.0	0.0	100.6	5.7	31.4	30.1	22.2	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	40.4	4.2	10.7	17.2	5.3	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	18.5	2.8	7.0	0.0	31.0	10.0	0.0	0.0
22	0.0	0.0	0.0	0.0	28.5	45.2	2.7	0.0	20.4	17.5	0.0	0.0
23	0.0	0.0	0.0	0.0	20.8	10.8	10.2	0.0	28.8	0.0	15.0	0.0
24	3.0	23.4	0.0	0.0	32.2	40.6	8.6	20.0	11.2	0.0	0.0	0.0
25	0.0	0.0	0.0	35.0	41.1	32.4	0.0	31.5	0.0	25.0	0.0	0.0
26	0.0	0.0	0.0	0.0	50.4	21.9	0.0	50.1	3.5	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	100.0	80.1	15.1	0.0	6.1	0.0	0.0	0.0
28	4.0	0.0	0.0	2.0	36.2	60.0	30.0	17.0	12.0	0.0	0.0	0.0
29	0.0	–	0.0	0.0	10.7	26.5	60.3	25.2	2.8	0.0	0.0	0.0
30	3.0	–	0.0	0.0	2.1	17.7	90.6	10.9	15.7	0.0	0.0	0.0
31	2.0	–	0.0	–	0.0	–	45.0	15.8	–	0.0	–	0.0
Total	87.0	35.4	35.4	37.0	664.3	770.9	1295.3	670.2	340.2	65.1	45.0	40.0

Source: Meteorological Center, Pokhara

APPENDIX VIII

Maximum, Minimum, Average (30 years) and 1989 Monthly Run-off (m^3/s) from the Phewa Lake

Month	Max*	Min*	Ave*	1989**
Jan	1.60	1.14	1.43	2.10
Feb	1.57	0.93	1.23	1.30
Mar	7.25	0.88	1.04	3.30
Apr	1.61	0.80	1.03	1.50
May	3.74	0.47	1.43	5.14
Jun	27.10	4.10	11.00	23.58
Jul	47.20	3.96	26.10	44.30
Aug	70.08	13.80	34.00	49.06
Sept	39.90	12.60	19.40	38.73
Oct	22.70	4.62	8.80	11.68
Nov	4.48	2.26	3.09	5.40
Dec	2.47	1.44	1.88	3.20

* Karki et al, 1988
** Department of Irrigation, WRD, Pokhara

APPENDIX IX

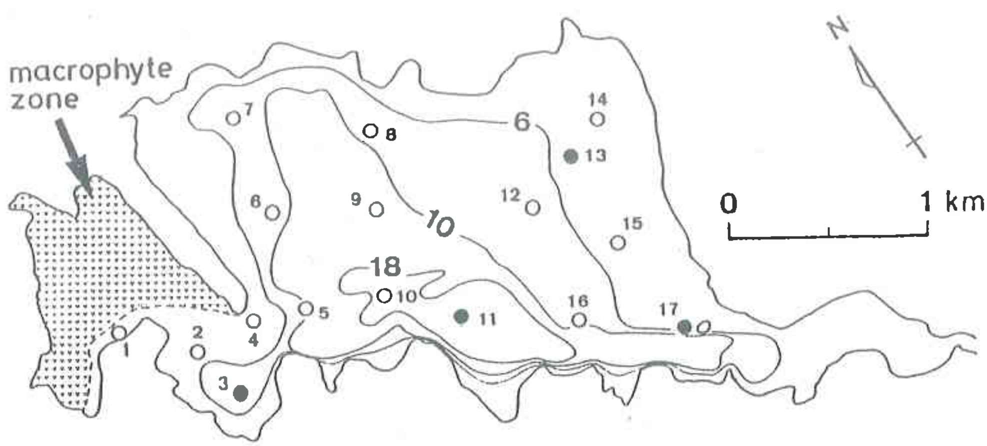
Limnological Characteristics of Phewa Lake (1984)*

IXa. Some Parameters at Fixed Stations** (23 Sept, 1984)

Sta.	W.T. (C)	Trans paren cy(m)	Chl.a	POC	PON	DTN	TP	DTP	TN
			(mg/m³)						
1	24.4	—	4.2	468	74				
2	26.2	2.0	18.6	1261	202				
3	26.1	1.3	61.9	4651	603				
4	26.9	2.2	9.7	817	115	76	13	10	191
5	27.0	2.5	6.0	642	101				
6	27.2	2.0	10.0	983	147				
7	27.0	2.1	18.7	1815	207				
8	27.7	2.5	11.2	1063	135				
9	27.2	2.5	5.2	646	106				
10	27.0	2.9	5.2	594	94				
11	27.2	2.8	5.2	722	101	49	11	6	150
12	27.3	2.6	5.9	726	99	64	13	1	163
13	—	—	—	—	—				
14	27.8	2.6	4.2	598	82				
15	26.2	2.9	4.0	460	61				
16	26.0	3.2	4.0	470	68				
17	26.2	3.4	4.2	462	62	49	12	5	111
18	26.0	2.7	4.3	513	70				
IN						96	18	12	—
OUT						245	14	7	—

* Nakanishi, 1986

** Stations Fixed by Nakanishi



IXb. Vertical Distribution of Some Parameters at Station 11*
(25 Sept, 1984; around noon)

Parameters	0 m	1 m	2.5 m	5 m	10 m	15 m	20 m
pH	8.3	8.3	8.0	6.9	6.4	6.9	6.9
W.T. (°C)	26.7	26.7	26.2	23.7	22.0	19.5	18.9
Chl.a (mg/m^3)	4.8	5.6	6.5	15.3	1.3	1.1	1.1
POC (mg/m^3)	502	579	615	1041	422	519	1082
PON (mg/m^3)	68	80	101	127	74	74	132
DTN (mg/l)	0.049	–	0.096	0.036	0.252	0.936	1.07
TP (mg/l)	0.011	–	0.012	0.011	0.011	0.018	0.026
DTP (mg/l)	0.006	–	0.006	0.004	0.004	0.005	0.005
Na (mg/l)	0.78	–	0.77	0.69	0.74	1.1	1.34
K (mg/l)	0.23	–	0.23	0.27	0.37	0.49	0.55
Ca (mg/l)	1.98	–	1.88	1.61	2.58	5.56	6.12
Mg (mg/l)	0.56	–	0.57	0.6	0.67	0.99	1.07
Sr (mg/m^3)	5.3	–	5.2	5.5	9.3	19.8	22.5
Ba (mg/m^3)	3	–	3	3	10.9	6.7	7.6
Li (mg/m^3)	0.5	–	0.5	0.5	0.5	0.5	0.5
B (mg/m^3)	2	–	2	2	2	6.7	8.2
Si (mg/l)	2.28	–	2.31	2.22	2.34	2.86	3
S (mg/l)	0.22	–	0.22	0.22	0.18	0.18	0.23
Al (mg/m^3)	10	–	13	18	18	73	91
Ti (mg/m^3)	1	–	1	1	1	1	1
Mn (mg/m^3)	9.2	–	13.3	36.7	643	1200	1250
Fe (mg/m^3)	90	–	114	166	660	6990	8700

Nakanishi, 1986

* Station Fixed by Nakanishi

IXc. Daily Primary Production [mg C/(m^2 . d)] and Light Attenution Coefficient (m^{-1}) Between Post Monsoon and Dry Seasion

Station	Date	(m^{-1})	Daily primary production
11	25 Sep, 1984	0.63	764
11	30 Nov, 1982	1.02	657
11	17 Dec, 1982	0.70	765

Nakanishi, 1986

APPENDIX X

Limnological Characteristics of Phewa Lake (1985)*

Xa. Pre-and Postmonsoon Values of Surface Water Parameters

Variables	Units	Premonsoon	Postmonsoon
Water Temperature	°C	26.9	27.3
Secchi Transparency	m	2.5	3.3
Color	Pt	less than 5	less than 5
pH		8.2	7.2
Alkalinity as $CaCO_3$	mg/l	22.7	12.6
Chlorophyll_a	µg/l	11.2	4.8
Total Phosphorus	µg/l	24.0	7
Total Nitrogen	mg/l	0.14	0.12
Silica	mg/l	0.3	4.8
Total SS	mg/l	3.4	1.8
Calcium	mg/l	6.95	2.71
Magnesium	mg/l	1.16	0.57
Sodium	mg/l	1.48	1.32
Potassium	mg/l	0.63	0.45
Bicarbonate	mg/l	27.69	15.37
Chloride	mg/l	0.75	0.44
Predominant Phytoplankton:		Melosira granulata	Melosira granulata Diatoma elongatum Ulothrix subtilissima

* Lohman et. al, 1988.

Xb. Postmonsoon Vertical Distribution of Selected Parameters

Z (m)	Chl_a (µg/l)	Phaeo-phyton (µg/l)	Volatile SS (mg/l)	TN (mg/l)	TP (µg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Bacteria ($x10^6$ cells/ml)
0	3.2	0.7	1.4	0.12	4	2.53	0.58	1.49	0.42	4.09
1	4.3	0.5	1.3	0.18	14	2.56	0.59	1.24	0.40	3.95
2	4.3	0.4	1.4	0.23	14	2.51	0.59	1.25	0.38	3.68
3	4.4	0.6	1.7	0.36	12	2.39	0.59	1.28	0.40	3.32
4	9.0	1.8	1.8	0.20	8	2.34	0.62	1.20	0.39	4.00
5	26.5	2.4	3.5	0.30	12	6.21	0.77	1.22	0.49	4.08
6	41.4	0.2	3.7	0.28	9	3.96	0.67	1.14	0.43	4.16
7	97.6	1.0	2.9	0.32	12	3.63	0.64	1.12	0.48	3.87
8	34.2	2.0	1.0	0.37	8	4.10	0.65	1.20	0.45	2.70
10	5.4	2.3	-	0.43	4	2.96	0.60	1.06	0.46	1.06
15	2.3	1.9	-	-	-	4.67	0.81	1.42	0.57	-

* Lohman et. al, 1988

APPENDIX XI

Values of Some of the Parameters Recorded by Fisheries Development Center, Pokhara

Month	Transparency (m)	pH	Temperature (°C)	DO (mg/l)	Phyto-Plankton (no./ml)	Zoo-Plankton (no./l)	Fish Production (kg)
1987							11878
Jan	2.20	7.40	18.90	4.40	–	–	
Feb	4.00	7.20	18.90	3.10	–	–	
Mar	1.70	9.30	21.30	5.20	–	–	
Apr	1.40	9.30	25.90	5.80	–	–	
May	2.00	8.60	30.80	8.60	–	–	
Jul	2.70	7.90	30.40	7.30	–	–	
Dec	1.80	8.10	21.10	3.90	–	–	
1988							10380
Jul	2.20	7.30	30.00	8.10	154	83	
Oct	2.12	6.50	29.90	8.30	154	83	
Dec	2.10	5.40	24.50	10.10	54	45	
1989							14064
Jan	3.05	5.90	29.40	6.70	64	55	
Apr	2.10	5.80	21.50	5.00	–	–	
May	3.25	6.50	19.10	10.40	–	4	
Jun	1.58	4.70	28.60	4.80	–	11	
Jul	1.70	5.80	29.10	5.20	–	16	
Aug	2.20	7.60	27.10	8.70	–	14	
Sept	2.15	5.00	29.50	–	–	27	

Source: Fisheries Development Center, Pokhara

APPENDIX XII

Tourist Arrivals (by Plane) in Nepal by month (1962 - 1988) (Excluding Indian)

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1962	489	596	787	829	486	237	440	284	328	616	590	497	6179
1966	560	891	1077	976	986	623	1175	943	866	1324	1701	1445	12567
1970	2755	2816	3957	3603	3463	2236	4160	5042	3533	4555	4518	5332	45970
1974	6288	6840	9801	8673	5944	4287	5708	7752	5749	10066	9886	8844	89838
1975	6895	6114	11414	7610	6841	4141	4528	8501	5718	11277	9626	9774	92440
1976	5566	10029	11066	10742	7456	4783	6434	8741	6700	12129	10234	11228	105108
1977	8648	9548	12200	10037	8782	6179	8597	12246	7693	17140	15021	13238	129329
1978	11021	13092	17462	13083	10679	6753	8965	133388	10958	20939	17265	12518	156123
1979	11167	14091	16332	15286	10803	7503	9152	12831	11181	20819	16287	16824	162276
1980	10913	14431	17483	14658	11308	7938	10264	14134	9876	18318	17055	16519	162897
1981	11705	12684	17958	13616	14861	8574	9019	9720	10932	21231	16646	14723	161669
1982	10918	11693	17099	13976	17106	11552	11686	13449	11325	23067	17951	15626	175448
1983	12725	15390	17928	14395	12267	10949	10377	13774	14877	24380	18518	13825	179405
1984	13536	13893	18048	17760	15315	12681	9456	8149	12750	22468	16588	15990	176634
1985	10478	13751	17768	14681	13248	9997	7901	11588	14248	24187	21048	22094	180989
1986	14130	17544	22995	16362	16815	11746	15375	18921	15964	29034	24294	20151	223331
1987	17314	21809	24018	18514	17941	15542	14346	19990	19330	30629	27330	21317	248080
1988													265943
Change over 1987 in %													(7.2 %)

Source: Department of Tourism

APPENDIX XIII

Tourist Arrivals by Purpose of Visit (1962 - 1988) (Excluding Indian)

Year	Pleasure	Trekking & Mountai neering	Business	Official	Others	Total (No.)
1962	–	–	–	–	–	6179
1966	10963	8	327	907	362	12567
1970	41881	556	918	1528	1087	45970
1974	67748	11710	3896	3707	2777	89838
1975	70124	12587	4911	4227	591	92440
1976	82596	11706	4974	4189	1643	105108
1977	106401	13382	4532	4201	813	129329
1978	124465	17304	6642	5660	2052	156123
1979	128811	18270	6381	5495	3319	162276
1980	130600	19302	5491	4654	2850	162897
1981	127709	21668	6379	5674	239	161669
1982	136693	23507	7374	7166	708	175448
1983	132350	24198	9801	8479	4577	179405
1984	140592	15010	8137	9399	3496	176634
1985	128217	28707	10416	9230	4419	180989
1986	163958	33609	10863	8825	6076	223331
1987	184979	36164	11781	8882	6274	248080
1988	–	–	–	–	–	265943
Change over 1987 in %						(7.2 %)

Source: Department of Tourism

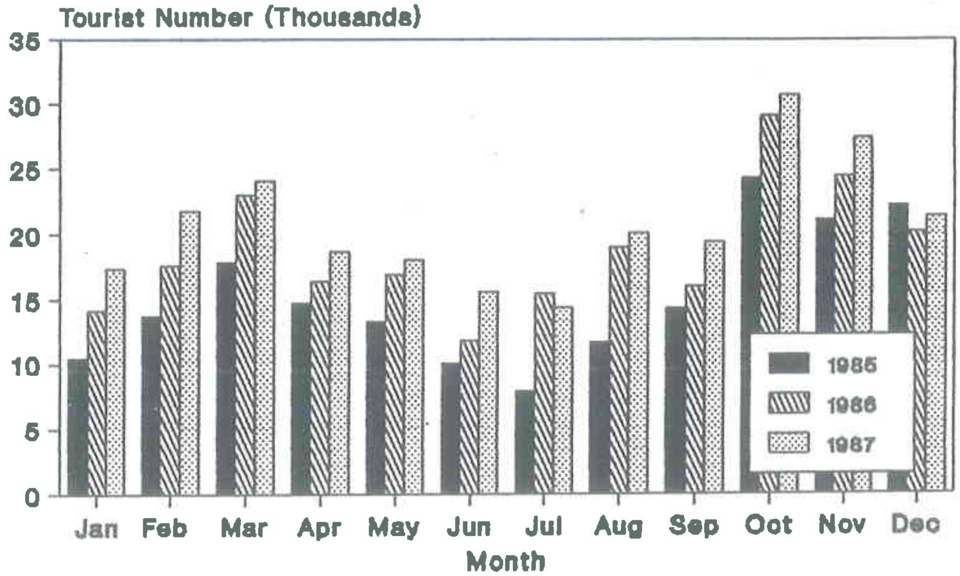
APPENDIX XIV

Tourist Arrivals To Pokhara by Months (1987 - 1988) (Excluding Indian)

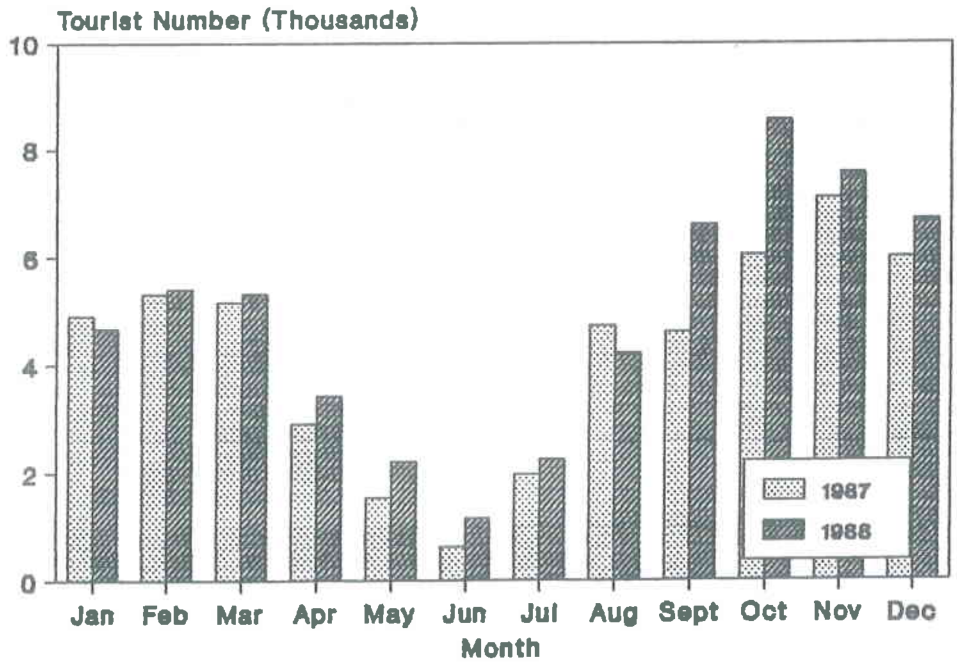
Month	1987	1988
January	4914	4678
February	5311	5400
March	5160	5338
April	2910	3409
May	1547	2206
June	640	1166
July	1967	2257
August	4057	4228
September	4634	6600
October	6039	8560
November	7094	7564
December	6002	6703
Grand Total	50275	58109

Source: Ministry of Tourism

APPENDIX XV
Tourist Arrival by Month (1985 - 1988)
(Excluding Indian)



a. Tourist Arrival to Nepal by Month



b. Tourist Arrival to Pokhara by Month

APPENDIX XVI

Proposed Boundary Values (by OECD) for Trophic Categories (Fixed Boundary System).

Trophic Categories	$[P]_{av}$	$[Chl\_a]_{av}$	$[Chl\_a]_{max}$	$[SDT]_{av}$	$[SDT]_{min}$
	mg/m³			m	
Ultra-Oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

Source: Okada, 1982 (Adapted by OECD, Paris)

Where,
$[P]_{av}$: Annual Average Total Phosphorus.
$[Chl\_a]_{av}$: Annual Average Euphotic Chlorophyll_a.
$[Chl\_a]_{max}$: Annual Maximum Chlorophyll_a.
$[SDT]_{av}$: Annual Average Secchi Disc Transparency.
$[SDT]_{min}$: Annual Minimum Secchi Disc Transparency.

APPENDIX XVII

Land-Use Categories in the Phewa Lake Catchment (ha)

Panchayat	Terrace	Open Grazing	Hay-fields	Scrub	Forest	Water	Gully Slide	Town	Total
Sarangkot	847	235	20	181	103	0	13	0	1399
Kaskikot	1064	338	48	151	111	0	26	0	1738
Dhikur Pokhari	1184	133	3	131	209	0	23	0	1683
Bhadure	953	391	0	378	880	0	3	0	2605
Chapakot	1190	83	0	83	1363	0	8	0	2727
Pokhara Town	43	0	0	10	50	428	0	156	687
Pumdi	129	13	0	136	219	0	0	0	497
Total	5410	1193	71	1070	2935	428	73	156	11336
Percent	47.7	10.5	0.6	9.4	25.9	3.8	0.7	1.4	100

Source: Fleming, 1983

APPENDIX XVIII

Informative Organizations/Institutions

1 Fisheries Development Center, Pokhara

2 District Agricultural Development Office, Pokhara

3 Department of Irrigation, WRD, Pokhara

4 Phewa Watershed Project, Pokhara

5 Kaski District Panchayat, Pokhara

6 Pokhara Town Panchayat, Pokhara

7 Tourist Office, Pokhara

8 Meteorological Center, Pokhara

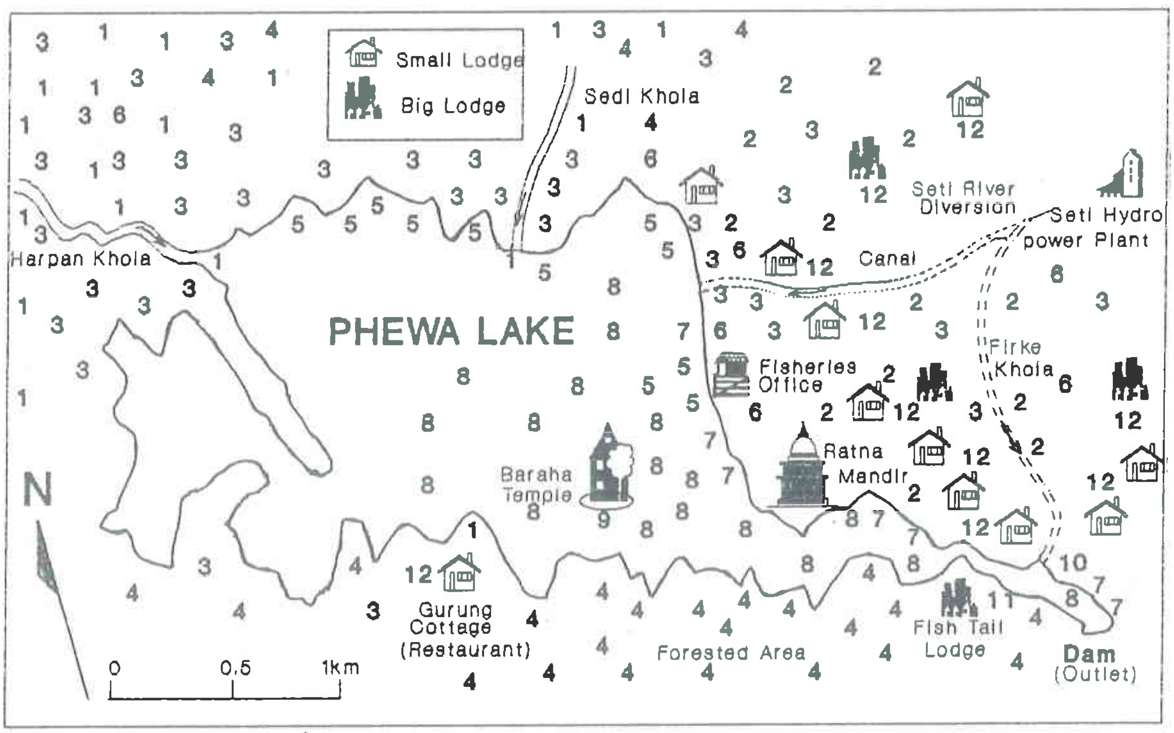
9 International Cooperation (DISVI), Kathmandu

10 ICIMOD, Kathmandu

APPENDIX XIX

Potential Sources of Pollution of Phewa Lake

1 Domestic Wastes from 5 Village Panchayats (about 30000 population) of the catchment, mainly through Harpan and Sedi Khola
2 Domestic Wastes from Baidam (part of Pokhara Town Panchayat) which has about 5000 population)
3 Agricultural Land (about 5000 ha) in the catchment
4 Forest Land (about 300 ha)
5 Fisheries
6 Poultry/Goose
7 Laundry
8 Boating
9 Baraha Temple
10 Police Residence
11 Fish Tail Lodge
12 Other Lodges and Restaurant (about 90)
13 Others



APPENDIX XX. COLOR PLATES

a. View of Phewa Lake with Fish Tail Lodge

b. Field Experiment

c. Erosion & Siltation Problem

d. A View of Sediments

e. Washing Problems Along the Shore of Phewa Lake