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Assessment of Water Quality, Sediment Environment, and Nutrients Budget of Lake Tega
手賀沼における水質，底質環境および栄養塩収支の解析

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Acronyms and Abbreviations

µm	Micrometer
^{0} C	Degree Celsius
^{137} Cs	Radioactive Isotope Cesium
^{210} Pb	Radioactive Isotope Lead
^{226}Ra	Radioactive Isotope Radium
C/N	Carbon /Nitrogen
Chl *a*	Chlorophyll *a*
COD	Chemical Oxygen Demand
D_L	Shoreline Development Index
DO	Dissolved Oxygen
Hrs	Hours
ln	Natural Logarithm
LSR	Linear Sedimentation Rate
MAR	Mass Accumulation Rate
mS	Milli Siemens
NTU	Nephelometric Turbidity Units
pH	$-\log_{10}[H^+]$ (Potential of Hydrogen)
R^2	Linear Correlation Coefficient
ROI	Region of Interest
SD	Secchi Depth/Disk
SS	Suspended Solids
$T^{\frac{1}{2}}$	Half Life
TG1	Sampling Station 1 (St. 1), Teganuma
TG2	Sampling Station 2 (St. 1), Teganuma
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index

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CHAPTER 1: INTRODUCTION

Background

Lakes are the natural water bodies which support various species of plants and animals and are the hot spots for recreation and tourism activities. The biodiversity in the lake and its other functions depend upon its water quality. It has been observed that the change in water quality has significantly altered the availability of species diversity of plants and animals as well as its eco-tourism value. Moreover, whole ecosystem function is changed due to the alteration in the water quality. The effects can be observed in all trophic levels of the food chain such as micro organisms to the larger species.

Keeping the lake water environment clean has been a big challenge in the situation where the industrialization and urbanization is on the rise. The land use change in the watershed brings changes in lake and river water quality. The agricultural practices and use of fertilizers in the agricultural lands, changes in the forest cover, sewage discharge and waste water treatment facilities, construction activities in the basin may have positive as well as negative impacts in the water quality of rivers and the lakes.

In-lake restoration techniques and integrated watershed management programs are carried out for the lake purification and conservation.

The physical, chemical as well as biological parameters are used as water quality indicators to check the status of the lake environment. The sediment cores are also studied by the researchers to read history of the water quality as well as land use activities and past events in the watershed.

Introduction

Description of the Study Area

Lake Tega is situated in the northern part of Chiba Prefecture in central Japan. The lake, before becoming a fresh water lake, was a part of a large stream which was connected with the Pacific Ocean until 16th Century. The reclamation and other activities in the past has resulted the small, shallow and closed lake at the present.

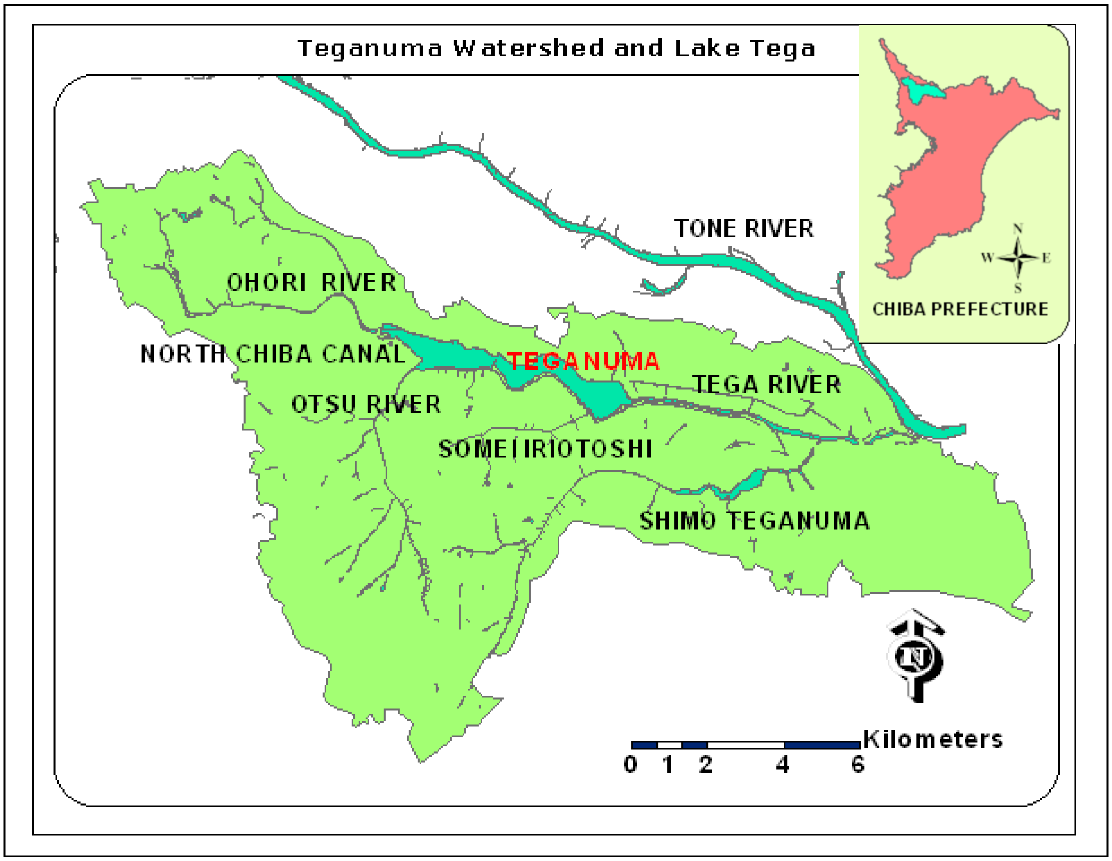


Figure 1.1: Teganuma Watershed and Lake Tega

Lake Tega is a polymictic shallow lake (average depth of 0.86 m) with a surface area (*A*) of 4.28 km^2. (only enclosed lake area). The lake Tega is a long lake with the length of about 7 km. The lake has the shoreline (*L*) of 17 kilometers with shoreline development index (D_L) of 2.37. The shoreline development index is a measure of roundness of a lake, and calculated as $D_{L=} L/2\sqrt{\pi A}$. The lake receives the water from about 162.88 km^{2}catchment area, through mainly two rivers and two canals. Since April 2000, aiming at Water Quality improvement of Lake Tega, clean water (discharge: 6 m3/s-10 m3/s) is brought from Tone River through 22 km underground pipeline and discharged at the North Chiba No. 2 Pumping Station, southern edge of Lake Tega. The out flowing river, Teganuma river is in the eastern part (Shimonuma) of the lake which discharges the lake water to the Tone River.

According to the Tokyo Metropolitan Government, April 2005, the population density in the Teganuma watershed is 3339.1 person per unit area. Matsudo, Kashiwa, Nagareyama, Abiko, Kamagaya, Inzai, Shiroi - and one village, Motono are the major areas in the watershed.

Along with the time, the Lake Tega has experienced many ups and downs in terms of the water quality. It is categorized as B category by the Ministry of Environment, Japan (on the Basis of COD - 5mg/L). For reference, the largest lake of Japan, Lake Biwa is categorized as AA (Used for Drinking Water Purpose as well) and none of the lakes in Japan are categorized as C. Prior to 1955, the water quality of Lake was good enough which could be used for drinking purposes. The *Potamogeton dentatus was found in lake Tega in the past. The plant is* listed as a critically Endangered (CR) species in the Red List of Threatened Plants of Japan by the Biodiversity Centre of Japan, Red Data Book Categories (Environment Agency 1997). After the population growth and urbanization, the influx of pollutants from the surrounding areas increased in such a way that the self purification capacity of natural lake crossed the threshold and became one of the polluted lakes in Japan.

Various activities have been carried out to improve the water quality of the lakes including introduction of Tone River Water, extension and improvement of wastewater treatment facilities, formulation implementation of dedicated rules and regulations in the local as well as national level etc. Some improvements can be realized, however, the lake is still ranked as one of the polluted lakes.

Statement of the Study

The lake Tega is an icon of Kashiwa and Abiko , uniquely located in the both cities. The water quality of the lake was very good before 1955 AD. But the present scenario is very different than the past history. The lake has been in the hypertrophic trophic state for many decades. Research interest in the fresh water lake, accessibility, ideal site (in terms of geo-physical and morphometric characteristics) and availability of various research aspects etc are the inspirations to choose lake Tega as the research site.

Objectives

To assess the water quality, nutrient budget and sediment environment are the major objectives of the research. To achieve this goal, the following aspects will be studied.

- the spatial and temporal variation of water quality of Lake Tega
- the land use change over last 30 years of period (1974 to 1994)
- the relation of land use change with water and sediment environment
- the nutrient budget of the lake Tega
- the physical and chemical characteristics of sediment
- the sedimentation rate and establish a geo- chronology of sediment cores by performing ^{210}Pb and ^{137}Cs Dating

CHAPTER 2: LITERATURE REVIEW

This chapter is divided into two sections- General and Lake Tega Related Literature

2.1 General

2.1.1 Eutrophication

Eutrophication is the response in water due to over enrichment by nutrients, primarily phosphorus and nitrogen, and can occur under natural or manmade (anthropogenic) conditions. Algal blooms, heavy growth of rooted aquatic plants (macrophytes), algal mats, de-oxygenation and, in some cases, unpleasant odour, which often affects most of the vital uses of the water such as water supply, recreation, fisheries (both commercial and recreational), or aesthetics are the characterstic features of eutrophication. In addition, lakes become unattractive for bathing, boating and other water oriented recreations.

Eutrophication is a process whereby water bodies receive excess nutrients especially nitrogen and phosphorus, causing an accelerated growth of algae (Carlson 1977, OECD 1982).

Two sources of nutrients can lead to eutrophication in lakes and reservoirs. External loading occurs when run off from the watershed brings in nutrients from the anthropogenic sources, such as agriculutural run off, industrial effluents, sewage plants and from natural sources. External loading , because of its large scale , is the main determining factor in a lake's trophic status (Horne 1998) . In addition, nutrients can enter the water column from the sediment in a process known as internal loading (Bostrom et al 1988). Two most important nutrients that can be introduced by internal loading are phosphorus and nitrogen.

2.1.2 Trophic State Index of Lakes

The Trophic State Index of Carlson (1977) is recommended as the simplest method of calculating and explaining trophic state concepts and chlorophyll a is used as the primary index of trophic state classification, however, the deviations of the Secchi depth and total phosphorus indices from the chlorophyll index are used to infer additional information about the functioning of the lake (Carlson R.E and J. Simpson, 1996).

The principal advantage of Carlson 's trophic state index used in water quality assessments is that it presents the trophic condition on a 1 to 100 scale easily understood by both the public and the scientific community (Osgood R A. 1982).

Chlorophyll*a* is considered the principal variable to use as a trophic state indicator. There is generally a good agreement between planktonic primary production and algal biomass, and algal biomass is an excellent trophic state indicator. Chlorophyll*a* is relatively easy to measure compared to algal biomass (OECD 1982).

The scale is numerical rather than nomenclatural, allowing a large number of individual lake classes rather than three to five distinct ones and it allows sensitivity in describing trophic changes. The data used can be minimal or extensive, depending on the level of accuracy desired and the resources available. (Carlson 1977).

Secchi disk values alone can give a trophic state classification, information that can be collected by non scientists in public participation programs at little expenses (Shapiro et al. 1975). According to Carlson (1977), the index number gives both the public and the limnologists a reasonably accurate impression of a lake’s water quality. The TSI can be a valuable predictive tool in the lake management programs, but it is also a valid scientific tool for investigations where objective standard of trophic state is necessary.

2.1.3 Residence Time and Dilution of Lake Water

Nancy E. Monsen *et al*., 2002 suggested that the residence time was the complement to age and according to the authors the age is the time required for a parcel to travel from a boundary to a specified location within a water body; residence time is how long a parcel, starting from a specified location within a water body, will remain in the water body before exiting out of it.

Dilution involves the addition of low nutrient waters to a lake or reservoir. To be effective, the low nutrient water additions should reduce in-lake nutrient concentrations, there by reducing algal quantities. Flushing is a physical process related directly to an increase in the flushing rate of the lake or reservoir. If the increase in flushing rate is sufficient, an increase in algal cell wash out can be expected, there by decreasing algal biomass within the system. Both systems work together to reduce algal densities (Wedepohl, R. E., *et al.* 1990).

2.1.4 Land Use and Water Quality of the Lake

The watershed area consists of the point sources as well as non point sources to influence the qualities of the water bodies. Point sources of pollution are easier to regulate than nonpoint sources. Land use activities have direct impacts on water resources and in the same time land use are also determined by environmental factors such as soil characteristics, climate, socio-economical aspects of the area, topography, and vegetation. In another side, the water quality and water quantity also influence the influence the siting of land use activities.

Nonpoint source pollutants enters a stream, lakes and cannot be identified because it comes from entire landscape areas: anywhere that rain falls and carries pollutants. Nonpoint source pollution is directly related to land use.

Agricultural areas occupy major areas in the water shed area and are important sources of pollution when rainfall carries sediment, nutrients, or chemicals to streams and lakes. Common nonpoint source pollutants in urban areas are sediment, pathogens, nutrients, oxygen-demanding substances, heavy metals, oil and other petroleum products, and road salt.

Point source pollutants refer to contaminants that enter the water bodies directly and often through a pipe or canal. Examples of point source pollution are sewage treatment plants (which treat wastewater but still release a regulated amount of pollution in their discharge) and industrial sources. Unregulated sewage canals could also be the point sources for domestic and other types of pollutants.

2.1.5 Nutrients Release from Sediment

As quoted by M. Sakamoto *et al*. 1989, a large amount of evidence suggests that several factors affect the release of nutrient from bottom sediments in freshwater lakes, and are largely responsible for its seasonal variation (cf. Mortimer, 1941, 1942). Similarly, Hosomi and Sudo (1984) examined the effect of temperature on NH_4 - N release rate from the sediment, and found that an increase in temperature from 10 ^{0}C to 20 ^{0}C had little effect, whereas one from 20 ^{0}C to 30 ^{0}C resulted in a 2 - 4.4-fold increase in NH4 release from the upper sediment. Sediments have been noted to take up phosphorus at low temperature and release it at high temperatures (Fisher *et al*., 1982).

There are several nutrient transport mechanisms from sediments to overlying water, i.e diffusion, wind induced water turbulence, bioturbation, gas equilibration, attached algae and aquatic plants (Wetzel, R. G., 2001).

Existing concentration gradient between sediment pore water and overlying water cause the release of nutrients from the sediment to the overlying water and nutrient concentrations in the sediment pore water were considerably higher than those in overlying water (Qin Boqiang *et al*. 2006).

For PO_4- $^{3-}$ -P release from the sediment to overlying water, P bound to particles or aggregates in the sediment must be mobilized by being transferred to the pool of dissolved P (primarily phosphate) in the pore water and the processes such as desorption, dissolution, ligand exchange mechanisms, and enzymatic hydrolysis which transport the dissolved phosphorus to the lake water must function. These processes are affected by a number of environmental factors, of which redox potential, pH and temperature are the most important (L. Hakanson *et al*. 2002).

When $PO_4{}^{3-}$ -P in the water exceeds the equilibrium concentration, $PO_4{}^{3-}$ -P moves into the sediments and when $PO_4{}^{3-}$ -P in the water column is below the equilibrium concentration, $PO_4{}^{3-}$ -P moves out of the sediment (Carl 1989). During the summer, release of nitrogen and phosphorus from the bottom sediments plays an important role in maintaining active plankton production in a lake ecosystem (M. Sakamoto *et al*. 1989).

When the sediment becomes reduced, both metal (Fe, Al, Mn etc) and sorbed phosphate is returned to solution and then dissolved phosphate is then transported to overlying water. A pronounced concentration gradient will favor diffusion of phosphorus from sediment to lake water.

Especially in the eutrophic non-stratified shallow lakes the efflux of nutrients from sediment to their rather small water volume may be crucial during productive season.
Temperature can have a major effect on the release rate of P from sediment to water. The changes in temperature affect on the microbially and chemically mediated redox reactions in sediments (Jouni Lehtoranta, Webpage).

2.1.6 Nutrients in Sediment Pore Water

Sources of nutrients in pore water include regeneration from decomposition of aquatic plants and primary producers in the water column and substrates, mixing processes between the sediments and the overlying waters, terrestrial sources such as domestic sewage, fertilizer leached soils or precipitation of particulate matter (Wetzel, 1983).

The chemical particles of the water column as well as those which are adsorbed in the suspended solids are also trapped in the bottom sediment during the process of sedimentation. The processes such as precipitation, adsorption, reduction, remobilization, biological degradation and biological uptake, the concentrations of nutrients in the pore water are higher then the overlying water (Bufflap and Allen, 1994).

When the organic matter in the sediment decomposes and ammonia is released by the process of re-mineralization. Ammonia diffuses into water and/or oxidized to nitrate. A large percentage of the nitrate produced in the sediments is denitrified. In many fresh water sediments much of the organic nitrogen mineralized in the sediments is lost through nitrification and de-nitrification (Wetzel, 2001).

The high ammonia content suggests high rates of sedimentary re-mineralization, suggesting that sediments are an important source of nitrogen to the overlying waters.
The nutrient concentrations in porewater increase with sediment depth in shallow lakes
(Qin B. Q *et al*. 2004).

2.1.7 Particle Size Analysis

Laser Diffraction analysis is based on the Fraunhofer Theory, which states that the intensity of light scattered by a particle is directly proportional to the particle size (Mc Cave et al., 1986). Large particles scatter light at high intensities through high angles (Walker and Reynolds, 1991).

Below 0.007 mm, particles don't diffract light in the manner required for the application of the Fraunhofer theory because their diameter approaches that of the wave length of the light (de Boer et al., 1987; Mc Cave *et al.*, 1986). For the particle in this size range, the mode of scattering is termed as Mie Scattering and depends upon particle size and differences in the refractive indices (Haley and Joyce, 1984). Combining these scattering modes permits a particle size range from clay sized through sand sized (Claude E Boyd, 1995).

Particle size is the most basic physical parameter of sediment analysis. Various scale for the classification of sediment particle size exists and used different system by different individuals and research institutes based on their interest.

- Wentworth worth grade scale 1922
- American Geophysical Union (AGU) Sediment Classification System
- Folk's Classification Scheme 1954, 1974
- Shepard's Classification Scheme, modified by Schlee 1973
- Modified version after Friedman and Sanders, 1978

Grain size (texture) of sediments is a basic physical parameter required for environmental, mineral resource, sediment transport, and other assessments. Blatt and others (1972), Folk (1974), and Syvitski (1991) further elaborate on some of the uses for this parameter as mentioned by (Lawrence J. Poppe *et al.*, 1998).

Grain size is the most fundamental property and descriptive measure of sediment and grain size distributions are characteristic of sediments deposited in certain environments. Grain size can often be related to other properties such as permeability, cohesiveness, or stability, and variations in these properties may be predicted from variations in grain size.

Contaminants are often associated with fine-grained sediments because of adsorption onto the charged surfaces of clay minerals and the large grain surface area available for adsorption.

Particle cohesiveness has important chemical and physical implications for sediment quality and sand will settle to the bottom almost immediately when a river enters a reservoir and velocity is reduced. By contrast, silt and clay will stay in suspension much longer and move further within the reservoir. Furthermore, it is the ≤ 62 µm fraction of suspended sediment that is mainly responsible for the transport of chemicals adsorbed on particles.

Fine grained sediment (silt + clay) is responsible for a significant proportion of the annual transport of metals, phosphorus, chlorinated pesticides and many industrial compounds such as polynuclear aromatic hydrocarbons, polychlorinated biphenyls, dioxins and furans.

Of the 128 priority pollutants listed by the United States Environmental Protection Agency, 65 per cent are found mainly, or exclusively, in association with sediment and biota. Unfortunately, water quality agencies throughout the world still tend to pay little or no attention to suspended sediment quality (E. Ongley 1996*)*.

As mentioned in the Chapter 4, Sediment Characterstic (Website: Sandiego Gov), the analysis of various sediment parameters (e.g., particle size, sorting coefficient, percentages of sand, silt, and clay) can provide useful information relevant to the amount of wave action, current velocity, and sediment stability in an area. The organic content of sediments is greatly affected by primary productivity in nearshore waters, as well as terrestrial plant debris originating from bays, estuaries, and rivers (Mann 1982, Parsons *et al*. 1990). Concentrations of various constituents within sediments are often affected by sediment particle size. For example, the levels of organic materials and trace metals within ocean sediments generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Vanketesan 1993).

2.1.8 Carbon Nitrogen Ratio in Sediment

Increases in C:N ratio within sediment profiles have been interpreted to identify periods in a lake's history when sediments received a high proportion of terrestrial organic matter (Guilizzoni *et al*., 1996) . Conversely, decreases in C:N ratios have been used to identify periods when lake sediments have received a high proportion of algal organic matter (Kanassanen & Jaakkola, 1985). C:N ratios in lake sediments can be used reliably to identify historical sources of sedimentary organic matter, and indicate human disturbance of watersheds (Sujay Kaushal *et al.* 1999).

2.1.9 ^{210} Pb and ^{137} Cs - Dating

^{210} Pb based sediment dating, first proposed by Goldberg (1963), has, over the last few years, been applied with increasing frequency to lakes within which sedimentation has been affected by catchment disturbance (P G Appleby *et al*. 1986).

It has been applied successfully to sediments from lakes, lagoons, estuaries and coastal environments with sedimentation rates ranging from millimeters to centimeters per year Lake, lagoon and estuarine sediments are favorable for the use of the ^{210} Pb dating method as ^{210} Pb is concentrated in a stratified manner and then decays at a known rate [Brush *et al*., 1982].

In the book entitled ' Principle of Lake Sedimentology' , L Hakanson *et al.* mentioned that the ^{210} Pb may reach these sediments in two forms:

- a 'supported' component derived directly from eroded soil /soil substrate of the lake's catchment - 'Supported' ^{210} Pb has not been in the atmosphere and emanates from its parent isotope ^{226}Ra, which is present in the eroded sediment [Hakanson *et al*., 1983].
- An unsupported component derived from the atmosphere - An 'unsupported' (or excess) component from the atmosphere deposited either directly onto the estuarine surface or deposited within the estuary's catchment and reaching the estuary via the drainage network [Oldfield *et al*., 1984].

The unsupported ^{210} Pb concentration in each sediment layer declines with its age in accordance with the usual radioactive decay law. This law can be used to calculate the age of the sediment provided that the initial unsupported ^{210} Pb concentration when laid down on the bed of the lake can be estimated in some way. (P. G. Appleby et al.1983).

In this case the unsupported ^{210} Pb concentration will decline exponentially with the cumulative dry mass of sediment. When the unsupported ^{210} Pb concentration is plotted on a logarithmic scale, the resulting ^{210} Pb profile will be linear. The sediment accumulation rate can be determined graphically from the mean slope of the profile, or analytically by using a least squares fit procedure. In this model, sometimes referred to as the constant flux-constant sedimentation rate (cf:cs) model, the exact mechanism by which the sediment accumulated ^{210} Pb is immaterial (P. G. Appleby' & F. Oldfield, 1983).

^{210} Pb dating method ^{210} Pb (T $^{1/2}$ = 22.3 yrs) is a natural radionuclide in the ^{238} U decay chain. Disequilibrium between ^{210} Pb and its parent nuclide ^{226} Ra (T $^{1/2}$ = 1622 yrs) arises through diffusion of the gaseous intermediate radionuclide ^{222} Rn from land into the atmosphere. Within the sediment column, ^{210} Pb in excess (^{210} Pb $_{\text{excess}}$) of radioactive secular equilibrium with ^{226} Ra decays, achieving an equilibrium level with ^{226} Ra. Data of ^{210} Pb excess are used to estimate rates of accumulation with assumptions of a constant sediment accumulation rate and a constant input flux of ^{210} Pb $_{\text{excess}}$ (S. Ueda, 2004).

The artificial radionuclide ^{137}Cs (T $^{1/2}$ = 30.1 y) was released into the global atmosphere from the testing of nuclear weapons. Most atmospherically-injected radio-activities peaked around 1963, after which there was a discontinuation of atmospheric testing of large yield devices as a result of the International Test Ban Treaty (S. Ueda, 2004).

Low-background gamma counting to measure naturally occurring levels of ^{210} Pb, ^{226} Ra, and ^{137}Cs in sediment samples is simple and non-destructive, ^{226} Ra activity provides a direct measure of supported ^{210} Pb activity for each sample analyzed, and ^{137}Cs activity may provide an independent age marker for the 1962-1963 peak in atmospheric fallout of this radionuclide (Claire L. S, 1994).

^{137}Cs, with a half-life of 30.3 years, is a thermonuclear by product. Its presence in natural systems is directly related to atmospheric thermonuclear activity. The curve below shows that ^{137}Cs fallout production (and deposition) began about 1952; deposition peaked during

1963 and 1964. Under ideal conditions, the sediment profile should mimic the ^{137}Cs production. However, the inability to accurately sample small intervals and the mixing of the sediment by organisms, often cause deviations from the ideal profile (Charles W. Holmes, 1998).

According to National Resources Defense Council, USA, since 1945 to 1998, there have been 2,056 nuclear tests conducted worldwide, highest by the USA. Importantly, in the years 1960s to 1969, the maximum number of nuclear tests was conducted.

The sediments of a lake contain the information on its history. Dating of sediments combined with other measurements allow to study the impact of nature and man on a lake and its environment. Goldberg [1] was the first to use ^{210} Pb to date the sedimentary record of the last 100 years. Extensive testing of nuclear weapons in the atmosphere between 1954-1963 caused a significant enhancement of the radioactive fall-out. The maximum fall-out in 1963 is usually well preserved in sediments of lakes and other depositional basins and can thus be used as a time marker. Among other nuclear fission products ^{137}Cs can easily be detected in the sediments by Gamma-ray spectroscopy (H. N. Erten, 1985).

^{210} Pb**,** with a half-life of 22.3 years, is ideal for most ecosystem studies. Dates of sediment deposition are calculated by determining the decrease in ^{210} Pb activity at each selected sediment interval; this decrease is a function of time. Ideally, a plot of ^{210} Pb activity and depth will be an exponentially decreasing curve asymptotically approaching the supported value (Charles W. Holmes, 1998).

2. 2 Teganuma Related Literature

At least 30 years ago the lake had been covered widely by hydrophytes which declined with eutrophication. The parameters of eutrophication exceed the range of 'eutrophic' and belong to that of 'hypertrophic' according to the definition by OECD (1982). The inflowing rivers collect the sewage water from the urban area. A peak concentration of chlorophyll a was found in spring through out the lake. Gross primary production of phytoplankton was highest in August and September, when blue-green algae bloomed and lowest production was in April, late June and December 1983, and in January, February and March 1984.

Similarly, the photosynthetic rate was highest in September and lowest in March (Kenzi Takamura, 1989).

The Ministry of Land, Infrastructure and Transport took a noble initiation for taking water from the Tone River and pumping it through underground pipes to Lake Teganuma through Kita Chiba Conveyancesince 2000 and in 2002, Lake Teganuma finally rose above the worst place in the water quality rankings (JSDA News 18, 2003).

In December 1985, Lake Teganuma was designated as a targeted lake under on the Law Concerning Special Measures for Conservation of Lake Water Quality, and both the national and prefectural governments set out to implement comprehensive lake purification measures, including improvements to the local sewage system. One of the measures that greatly contributed to restoring water quality was the North Chiba channel project, conducted by the Ministry of Land, Infrastructure and Transport (Ichie Tsunoda, Japan for Sustainability).

The measures that were taken for the lake water improvements includes collection and diversion of heavily polluted fresh rainwater to sewerage treatment plants, promotion of environmentally-friendly agriculture, placing priority on dredging sludge from the lakebed in stagnant areas in the western part, and promotion of natural purification through the planting of vegetation in surrounding areas, and these initiatives are expected to gradually have greater effects (JSDA News 18, 2003).

Professor Ryuichi Sudo (Saitama University) mentioned about lake Tega in an interview which was published in JSDA News 18, 2003. He mentioned that everyday and industrial wastewater had only a certain amount of impact on lakes and further added that It was "plane sources" that had the greatest impact. According to him, the biggest issue was the "non-point sources." Rain falls on urban areas, and flows into rivers and lakes together with all kinds of pollution. Rain falls on fields and rice paddies and washes off about half of the fertilizer.

Not only the drain from the factory and the business place but also household wastewater, the pollutant load from non-pointed sources such as farmlands and urban areas, etc., are the cause of the water pollution of lakes and reservoirs (Hidetoshi Kimura, 2006).

On the basis of various data on land usage in areas surrounding the lake, population etc. household waste water (this category includes general household wastewater from kitchens, baths, laundry, toilets and so on) accounts for more than 60% of COD load in lake Tega while the natural wastewater from urban and agricultural areas accounts for 32%, and wastewater from factories accounts for 6% (JSDA News 18, 2003).

As there are no large-scale factories or other industrial facilities in this catchment area, the household wastewater is the major source and contributes for 60% of the water pollution (Ichie Tsunoda, Japan for Sustainability).

Regarding heavy metal pollution, except for Fe, the vertical distributions of heavy metals showed the highest concentrations in the surface 10 cm and decreased gradually with the sediment depth. The high concentrations in the upper layer were caused by an increase in the non-residual fractions. The large influx of heavy metal to Lake Tega seems to be due to the domestic effluents via the two rivers in last decades (Kazutoshi SAEKI *et al.* 1993).

These heavy metal concentrations were influenced by both particle-size distributions and Total Carbon content of sediments. Kazutoshi SAEKI *et al*. 1993).

Large amount of domestic waste water migrates into Lake Teganuma from the surrounding population (Kobayashi, 1982), and also domestic waste water contains large amount of heavy metals (Mori *et al.,* 1983). Thus the source of heavy metals discharged into Teganuma Lake is supposed to be the domestic waste water from the surrounding population even if no specific heavy metal source (such as mines or smelters) is located around it and it suggests a fingerprint for identifying the origin of the recent heavy metal accumulation to be a man-made heavy metal influx from Lake Teganuma's surrounding environment ((Kazutoshi SAEKI et al. 1993).

After providing subsidies the households shifted to better septic tanks which can treat the entire house hold waste water, including discharges from the kitchen, laundry and bath as well as the toilet and this was a the revision of the Purification Tank Law on April 1, 2001, newly installing the former type sewage-only septic tanks is completely forbidden, and installing the latter comprehensive type of tank is obligatory (Ichie Tsunoda, Japan for Sustainability).

The Law Concerning Special Measures for the Preservation of Lake Water Quality was enacted in 1984 to introduce pollution quantity control. Since then, 10 lakes and reservoirs (including Teganuma) have been designated under this Law, and many activities to preserve water quality are being carried out in accordance with the Water Quality Preservation Plan for each lake and reservoir (Hidetoshi Kimura, 2006).

In the spring of 1999, a "Teganuma Biotope" by growing aquatic plants for purifying lake water was completed on its north shore in the participation of local citizens (Ichie Tsunoda, Japan for Sustainability).

According to the Fiscal 2003 Measurement of Water Quality in Public Waters, the achievement of the Environmental Quality Standards for water pollution (BOD or COD) is 87.4%, 76.2% and 55.2% in the river, in the sea area, and in the lakes and reservoirs respectively (Hidetoshi Kimura, 2006).

Chronology of Lake Conservation Efforts including Lake Tega
(Laws and Activities)

Table 2.1: Chronology of Lake Conservation Efforts including Lake Tega

Years	Measures/Laws/Activities
1958	Enactment of Water Quality Conservation Law and Factory Effluent Control Law
1963	Chiba Prefecture Pollution Prevention Ordinance, Incidence of water bloom, decrease in submerged macrophytes and increase in Carp
1965	First Waste Water Treatment Facilities began in Kashiwa City
1967	Basic Law for Environmental Pollution Control /Completion of Land Reclamation in Lake Tega
1969	Periodical Water Quality Inspection in Lake Tega Started
1970	Enactment of Water Pollution Control Law, Establishment of Environmental Quality Standards on Water and Lake and Lake Tega was classified as “ Category B” lake
1972	Teganuma Waste Water Treatment Project was initiated
1973	Waste Water Treatment Facilities started operation in Kashiwa City
1975	Association for Teganuma Water Quality Improvement inaugurated
1976	Dredging of Sediments at Ohori River mouth started
1981	Teganuma Waste Water Project began its operation and experimental planting of Water Hyacinth started
1982	Chiba Prefecture Guidelines for Domestic Effluent Treatment
1982	Establishment of nitrogen and phosphorous control standards for lakes and reservoirs (Environment Agency)
1983	Septic Tank Law
1984	Teganuma classified as “ Category V” lake in the environmental standards for nitrogen and phosphorous for lakes and reservoirs
1984	Special Laws on Water Conservation in Lakes and Reservoirs
1985	Teganuma was designated under the act for improvement and water quality preservation plan (WPPL) by Chiba Prefecture (Kita Chiba Water Conveyance Channel is included in this plan)
1986-87	Institution of First Phase Water Quality Conservation Program (WQCP) for lakes under the Clean Lakes Law (Chiba Prefecture)

1988	Ohori River Water Purification facilities started
1990	Partial Revision of Water Pollution Prevention Law (Domestic effluents and effluents standard for Nitrogen and Phosphorus)
1992-93	Institution of 2nd Phase WQCP for lakes under the Clean Lakes Law (Chiba Pref)
1993	Revision of Prefectural Ordinance based on WPPL (Nitrogen and Phosphorus)
1995	Otsu River Water Purification facilities began, and abnormal growth of algal bloom
1996	Chiba Prefecture Plan for Environmental Standard , and Teganuma Fountain started its operation
1997-98	Institution of 3rd Phase WQCP for lakes under the Clean Lakes Law (Chiba Pref.)
1998	Revision of Prefectural Ordinance based on WPPL
1999	Field Survey on Domestic effluents
2000	Kita Chiba Water Conveyance Channel started full operations
2002-03	Institution of 4th WQCP for lakes under the Clean Lakes Law (Chiba Pref.)
2005	Amendment of Law concerning Special Measures for Preservation of Lake Water Quality
2007-08	Institution of 5th Phase WQCP for lakes under the Clean Lakes Law (Chiba Pref.)

CHAPTER 3: RESEARCH APPROACH

3 .1 Water Quality

3.1.1 Sampling Sites Selection

Spatial and vertical variation of water quality was observed by selecting various sampling points. The sampling points represented the inflowing rivers, out-flowing rivers, shorelines; transect points, the deeper part, the shallow part and narrow and wide region of the lake. The spatial variation of water quality was studied in representative sampling stations as shown by bold dots in the figure (*Figure 3.1*).

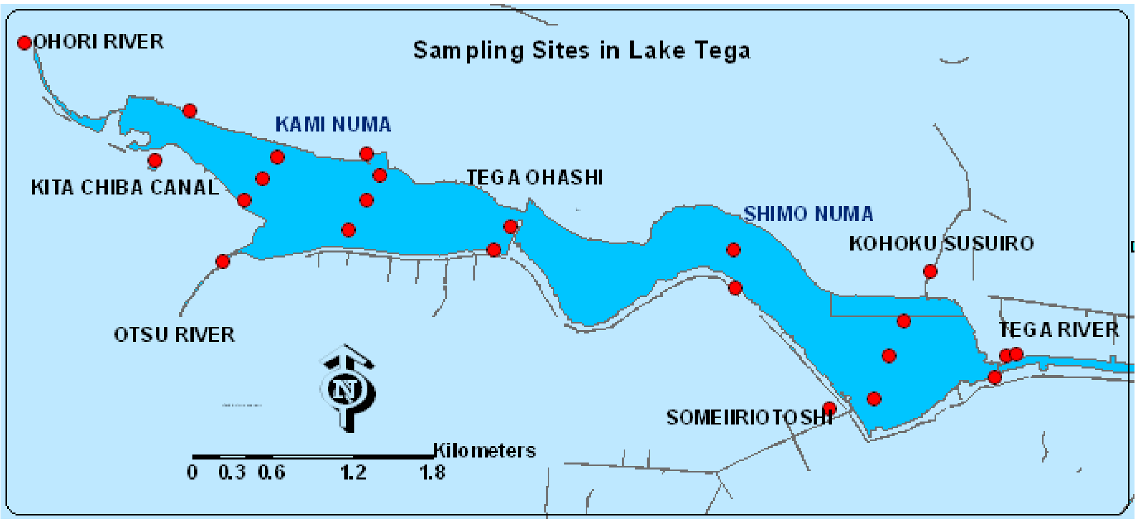


Figure 3.1: In-Situ Measurement Sampling Stations

To select the final sampling stations, consecutive field observations were carried out.. In-Situ- Measurements and Laboratory analysis were performed to analyze the water samples. The spatial variation of some parameters such as Nutrients, Chlorophyll a, Dissolved Oxygen, Temperature, Conductivity, pH and Turbidity were studied. Some selected parameters of the selected sites are discussed.

The analysis of the water parameters revealed a difference in the eastern and western parts of the lake. Finally, two stations namely; TG1 and TG2 were finalized for water and sediment environment study and these stations represent the western and eastern part of

Lake Tega respectively (*Figure 3.2*). The station TG1 is very close to the three inflowing water sources such as Ohori River, the North Chiba Water Conveyance Channel and the Otsu River. The station TG2 is near the outlet of the lake Tega , which has comparatively wide area and lies in front of Someiiriotoshi River and a canal, Kohoku Susuiro. A considerably long lake with shoreline development index (DL) of 2.37 caused exposure of lake to the long shorelines covering of a long area. The surface area of the Shimonuma (TG2) was higher having the area of 2.45 km^2 than the Kaminuma (TG1) with the area of 1.85 km ^{2} but the Kaminuma (TG1) was deeper than average depth of the lake.

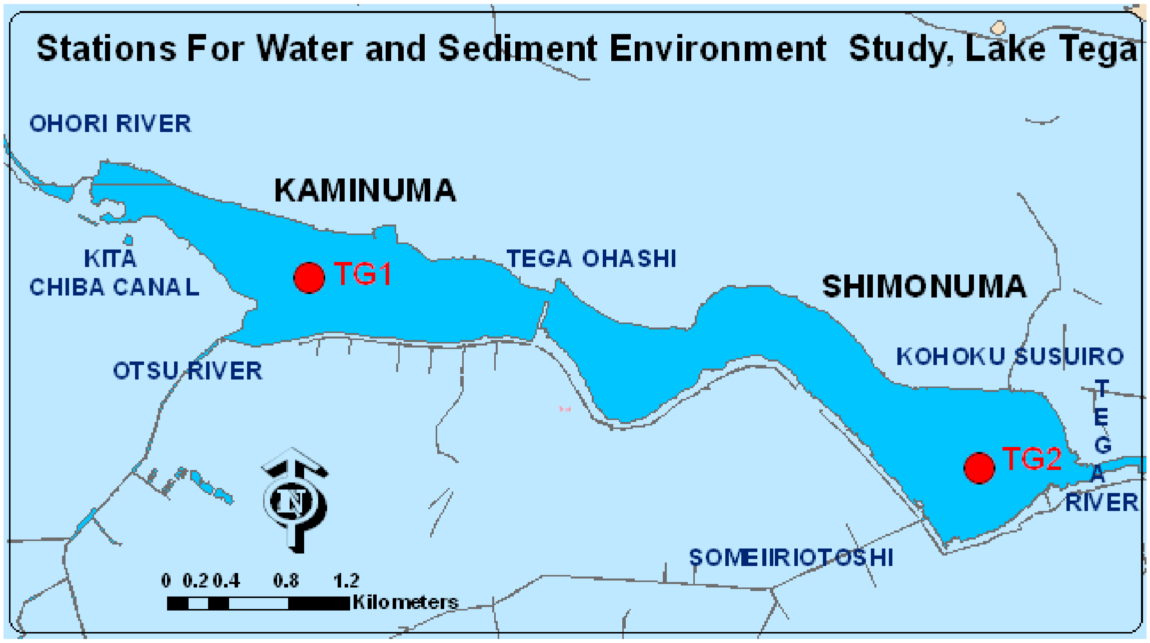


Figure 3.2: Stations for Water and Sediment Environment Study, Lake Tega

3.1.2 Water Quality Analysis

Water quality analysis includes field observations, In situ measurements, water sampling and laboratory analysis of nutrients.

In situ measurement

Water Depth (m), Water Temperature (^{0}C) , Conductivity (mS/cm), Dissolved Oxygen (% and mg/L), pH, Chlorophyll *a* (mg/L) and Turbidity (NTU) were measured as an in-situ measurements in the defined stations using AAQ 1183 S/N. 21 (Alec Electronics Co. LTD, Japan) and the data were retrieved using AAQ 1183 Data Transfer Tool Ver 1.04 (Japanese).

Water Sampling

For nutrients analysis, water samples were collected from the surface, middle and the bottom of the water column of the lake. During each sampling, two types of water samples were collected; a) sample without filtration and b) sample filtered using micro filter (0.45 µm, Dismic-25, ADVANTEC). Thus collected samples were carried to the laboratory in the insulating box containing ice packs and preserved in the refrigerator at the temperature of 4 ^{0}C before the analysis. The nutrients were analyzed in the laboratory adopting prescribed methods of water quality analysis using the standard instruments.

Laboratory Analysis of Nutrients

For certain anion analysis, DIONEX ION CHROMATOGRAPH (Model CRB-1, Dionex CORP. USA) and DIONEX AUTO SAMPLER - AS 3500 (Dionex CORP. USA) were used which allows for the analysis of either cations or anions at the parts per billion level using conductivity detectors on the basis of retention time of the specific ions in the column. An eluent (mobile phase) was prepared using required proportion and concentration of Na_2CO_3 and Na HCO_3 and the eluent was degassed .After preparing the standard solutions of required concentration for calibration curve, the analysis of samples were carried out. The measurement process and methods were adopted as per the manual of Dionex Ion Chromatograph.

For total nitrogen (TN), total phosphorus (TP), NH_4^+-N, PO_4^{3-}-P, the Auto Analyzer 3- AACS- III (BRAN + LUEBBE) and Auto Sampler (BRAN + LUEBBE) were used and for digestion of the unfiltered sample to analyze the TN and TP, Autoclave SP 200F (YAMATO Scientific Co. LTD) was used. The analysis was carried after preparing the reagents and standard solutions as prescribed by the standard manual of the instrument (AACS III Analysis Method, 1999, BRAN+LUEBBE) and Standard Methods for the Examination of Water and Wastewater, APHA. The absorbance was measured at standard wave lengths such as NH_4^+-N at 630 nm, PO_4^{3-}P at 880 nm, NO_3 –N and NO_2–N at 550 nm for specific nutrients to be analyzed. The correlation between the absorbance and concentration of the standard solutions gives the basis of measurement for the samples.

Window based BRATTEC Version 5.1 was used as software for the analysis and measurement processes.

3.1.3 Water Quality Trend and Seasonal Variation

Eutrophication

Secchi disk transparency, chlorophyll *a*, and total phosphorus are often used to define the degree of eutrophication, or trophic status of a lake. The concept of trophic status is based on the fact that changes in nutrient levels (measured by total phosphorus) causes changes in algal biomass (measured by chlorophyll *a*) which in turn causes changes in lake clarity (measured by Secchi disk transparency). The computational forms of the equations are:

$$TSI\ (Chl\ a) = 10\left(6 - \frac{2.04 - 0.68\ln(Chl\ a)}{\ln 2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$TSI\ (SD) = 10\left(6 - \frac{\ln(SD)}{\ln 2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \ldots (2)$$

$$TSI\ (TP) = 10\left(6 - ln\ \frac{48/TP}{\ln 2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,
SD = Secchi Disk Transparency in meters,
Chl a = Chlorophyll a in milligrams per cubic meter and
TP = Total Phosphorus in milligrams per cubic meter
Thus calculated index numbers were checked with the Carlson’s Trophic State Index chart (Figure 3.3).

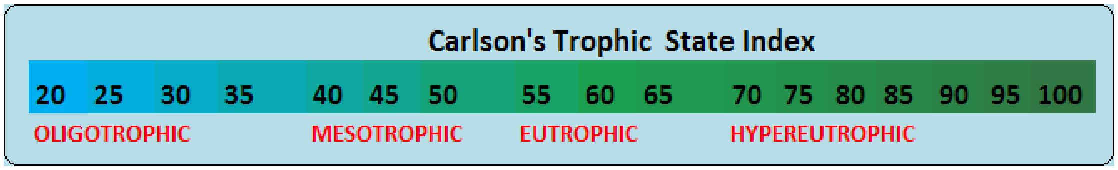


Figure 3.3: Carlson’s Trophic State Index Chart

Total Nitrogen, Total Phosphorus and COD Level

To study the long term trend of Nutrients, COD Level and River Discharges, the Chiba Prefecture’s Water Quality Data of Teganuma were used.

3.2 Nutrients and Water Budget Analysis

Nutrient budget is defined as the amount of nutrients loading into the lake from inflowing sources like rivers, canals and nutrients going out from the lake through out flowing sources such as irrigation canal, out-flowing river. Similarly, the water budget describes the amount of inflowing and out flowing water through various sources. Water budget is an important aspect that creates basics to study the assessment of nutrient budget. Nutrient budget keeps track of how much nutrient is coming in and going out.

Nutrient load is the product of the volume of water that the nutrient is using as its transport medium and the concentration of the nutrient in the water. The nutrient load is calculated a

$$\begin{aligned}&Nutrient\ Flux\ (\mathrm{MT/day})\\ &\qquad = River\ Discharge\ (m^3 sec^{-1})\\ &\qquad \times Nutrient\ Concentration\ in\ River\ Water\ (mg\ l^{-1})\end{aligned}$$

The units are first converted in to SI units and finally calculated in metric tons per year. The product of nutrient concentration (mg/L) and river discharge (m^3 sec $^{-1}$) is multiplied by the conversion factor 0.0864 to get the nutrient flux in metric tons per day.

3.2.1 Inflowing Sources

In case of Lake Tega, there are following major inflowing rivers/canals which discharge the nutrients into the lake and the water and the nutrient budget of theses sources was assessed to calculate the total influx into the lake Tega.

a) Ohori River
b) Otsu River
c) Somei-iriotoshi River
d) Kita Chiba No. 2 Pumping Station
e) Ground Water Infiltration
f) Non point sources and small adjoining canals
g) Precipitation

The daily discharge data of inflowing rivers for the year 2001 to 2005 were provided by the Water Quality Division, Chiba Prefecture Government, however for the year 1999 and 2000; the data from Ministry of Environment were assessed. The nutrients data for the past years are available in the Chiba Prefecture's websites. However, influx from non point sources, some small canals and ground water are calculated by referring the literature review. For nutrient budget calculation, the precipitation and evaporation contribution were neglected. However, incase of water budget calculation, these figures were used. The annual precipitation data were taken form Abiko Metereological Station, the nearest station from the research site.

To calculate the nutrient load contribution of Kita Chiba Pumping station, the TN and TP concentration at Fukawa in Tone River was considered.

The ground water contribution is considered as 24% of the total amount of inflowing sources and the non point sources along with small channels contribute about 9% of the total inflowing amount in lake Tega as quoted in a report on Lake Tega (Ministry of Environment, Management Bureau, Water Environment Management Division, JAPAN 2001). The nutrient load for non point sources is calculated taking a mean concentration value of all the inflowing rivers. Similarly, in case of ground water nutrient input calculation, NH_4^+ -N and PO_4^{3-} -P concentrations in the sediment pore water of the sediment depth of 0-10 cm were used. The nutrients in the sediment pore water were analyzed in the laboratory. Similarly, to calculate the internal loading from the sediment, a laboratory experiment for nutrient release was carried out.

Nutrient Release Experiment was performed in the laboratory under static conditions. Different temperature baths were used. The incubation was done on three different temperature scenarios such as 7 ^{0}C, 16 ^{0}C and 26 ^{0}C. The temperature scenarios were fixed on the basis of long term lake water temperature conditions in the respective sampling stations, representing four seasons – Fall/Winter, autumn and Spring respectively. The details of nutrient release experiment are described in later part of this report.

3.2.2 Out-flowing Sources

Regarding Out flux sources at Lake Tega, Tega River is the only river which drains out the lake water. However, there are some irrigation pumping stations which pump out the Tega Lake Water to the adjoining paddy fields.

Only major canals were considered in the budget calculation. The major out-flowing sources include:

a) Tega River
b) Izumi Irrigation Pumping Station
c) Takano Yama Irrigation Pumping Station
d) Evaporation

Each year, during the irrigation period (from April to August), the two major irrigation pumping stations pump out the Tega Lake water to the adjoining paddy fields . Both the major pumping stations are located in the Shimunuma (TG2). Depending upon the needed amount of water to be supplied to the paddy fields, the amount of pumping water also vary between month to month. However, the Government has fixed a limit of water that can be drawn in each month. Though the contribution of evaporation is very small, the evaporation in the lake was calculated based on bulk transfer formulations described by KONDO JUNSEI (1994).

The evaporation rate is calculated as:

$$Evaporation\ (E) = \rho C\,E\,U\ (qs - q)$$

Where,

ρ= Air Density (kg/m^3)

U= Wind Speed (m/s)

CE= Bulk Transfer Coefficient,

CE = (1.1 to 1.3) x 10^{-3} if Wind Speed is 1 m/s < U10 < 30 m/s,) and

CE= (1.2 to 1.3) X 10^{-3} if Wind Speed is 5 m/s < U10 < 30 m/s)

qs = Saturated Specific Humidity (h Pa)

q = Specific Humidity (h Pa)

The meteorological data were taken from the Tateyama Meteorological Station (TY) which measures various parameters and was found comparatively closer to the research site with the measurement facilities required for the calculation.

3.2.3 Average Water Residence Time

An average length of time water spends in a lake or a reservoir before being discharged through the outlet is termed as the average water residence time and may be called as hydraulic retention time. It is calculated as

$$\boldsymbol{Average\ Water\ Residence\ Time} = \frac{\boldsymbol{Volume\ of\ Lake\ Water\ (m^3)}}{\boldsymbol{Outflow\ (\frac{m^3}{Day})}}$$

Where the volume of the lake water is calculated as

$$Volume\ of\ Lake\ Water = Lake\ Surface\ Area * Average\ Depth$$

3.3 Nutrient Release Experiment

The recovered cores were carefully placed in the water bath machine and incubated under specified constant temperature conditions in the dark place in almost anoxic condition. Temperature logger was used to check the temperature. Then sampling was done at 0 hrs, 3 hrs, 6 hrs and 12 hrs of experiment period. Sampling was done near the water sediment interface without disturbing the calm condition. After taking the sample, the volume of the overlying water was maintained at the same level by adding the lake water of the same station very carefully. The samples were filtered (0.45 µm, Dismic-25, ADVANTEC) and preserved at 4 ^{0} C before carrying out the nutrient analysis. The nutrients $NH_4{}^+$-N and $PO_4{}^{3-}$ P were analyzed using Auto analyzer- AACS- III (BRAN + LUEBBE) and Auto Sampler (BRAN + LUEBBE) , as explained in the above section. After analysis, the nutrient releasing rates were calculated as described by the following governing relation (QIN Boqiang *et al.*, 2006):

$$R = \frac{\left[\boldsymbol{V(C_n - C_o) + \sum_{j=1}^{n} V_{(j-1)}\left(C_{(j-1)} - C_a\right)}\right]}{\boldsymbol{S.t}}$$

Where;

- R is Nutrient Release Rate (mg m^{-2} d^{-1});
- V is volume of overlying water in the columns (l) ;
- C_n, C_o and C_{j-1} is nutrient concentration in the overlying water at time of n, o (origin) and j−1 (mg L^{-1}), respectively;
- Ca is nutrient concentration in the water added to the overlying water (mg L^{-1});
- V_{j-1} is the sample volume at time of j−1 (l);
- S is the surface area of sediment cores (m^2);
- t is release time (d).

Calculation Steps for Release

For e.g. Case 1:
Water Height in the Corer (h): 15 cm
Internal Radius of the Corer (r): 2.7 cm
Volume of the Overlying Water $V = \pi r^2 h = 0.3437$ L
Surface area of the sediment (S) $= \pi r^2 = 0.002291$ m^2
Volume of the sample taken $V_{j-1} = 0.04$ L
Release time (t) in Days: 12 hrs = 0.5 day

The calculations were made for different cases in the similar way. The volume of overlying water in the sediment cores may vary depending upon the core size. However, the sediment depth was tried to maintain around 20 cm as only the overlying water at the upper water sediment interface contribute in nutrient release as the internal loading.

The calculation resulted the nutrient release rates (mg m^{-2} day^{-1}) for different temperature scenarios in consideration. The linear regression lines were plotted against temperature and the release rate (mg m^{-2} day^{-1}) in both the stations and for both the nutrients PO4 $^{3-}$-P and NH_4^+-N and on the basis of those regression equations, the daily nutrient release rates were calculated with the daily water temperatures of the TG1 and TG2 (The details are followed below) .

Water temperature was considered as one of the contributing factors for nutrient release, so daily water temperature of the stations of the lake was computed with the help of daily atmospheric temperature of the nearest meteorological station, Abiko Meteorological Station of the year 1999 to 2006.

For this, the correlation equations were obtained by plotting the graphs against water and atmospheric temperatures of TG1 and TG2 of lake Tega for last 28 years, since 1978 to 2006 (*Figures 3.4&3.5)*. A very good correlations were found with the highest confidence level ($R^2 = 0.96$, p=<0.0001). Based on the correlation equations, the daily water temperature of TG 1 and TG2 of Lake Tega were computed.

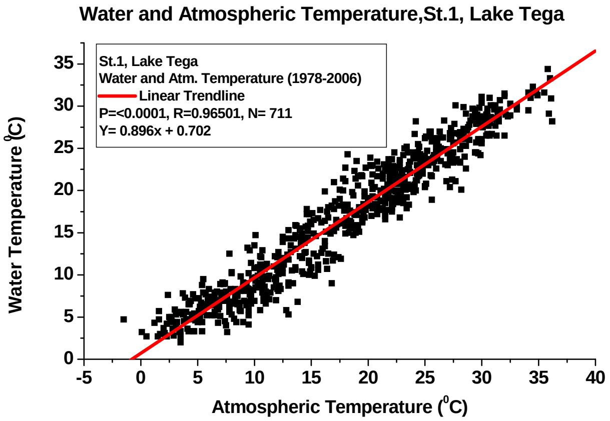


Figure 3.4: Water and Atm. Temp at TG1

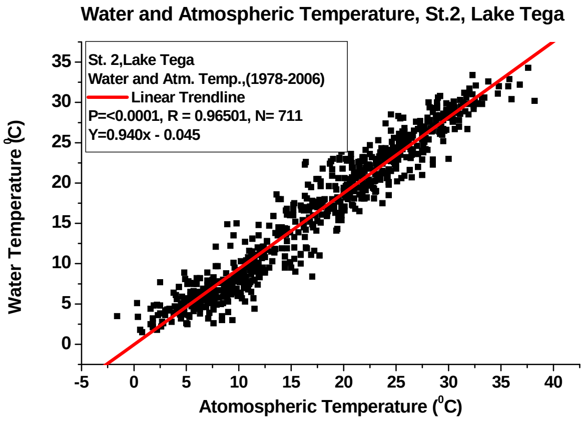


Figure 3.5: Water and Atm. Temp at TG2

Thus computed water temperature of TG1 and TG2 were used to calculate the daily nutrient release rates based on the correlation equation obtained from the various temperatures scenarios and the nutrient release rates during the nutrient release experiment. The nutrient loads from the year 1999 to 2006 were calculated.

3.4 Land Use Pattern/Ratio Analysis

3.4.1 Teganuma Watershed Delineation and Land Use Ratio Analysis

To calculate the land use ratio in the watershed, the Teganuma watershed was delineated by Geo-referencing the source map and watershed boundary map using Arc GIS 9. The numeric maps were converted into shape files using Numerical Map Data Converting Tool. Similarly, using the 10 m grid map, the raster maps were prepared. The following maps were used to delineate the watershed and to calculate the land use ratio.

a) Watershed Boundary Map
   Scale: 1:50,000 Date: 2005
   CHIBA Prefecture Government
b) Numeric Maps of the cities in the watershed area
   Scale: 1: 25, 000 Date: 2005
   Kashiwa, Abiko, Shonan and Shirai
   Geographical Survey Institute, Japan

c) Digital Topographical Map ,CHIBA and TOKYO
Scale: 1: 25,000 Date: 2000
d) 10 m Grid Land Use Map
Detailed Digital Information Metropolitan Area
Years 1974, 1979, 1984, 1989 and 1994
Geographical Survey Institute, Japan

The area for each land use type and the land use ratio for the year 1974, 1979, 1984,1989 and 1994 was calculated by counting the pixels.

3.5 Sediment Environment Analysis and ^{210} Pb and ^{137} Cs Dating

The Sediment Quality Analysis began with the sediment core recovery, sub sampling of the cores of the desired intervals and analysis of sediments for specific parameters adopting specific measurement procedures. Physical and chemical aspects of sediment such as water content (%), porosity (%), bulk density (gm cm $^{-3}$), particle size diameter (μm), C/N ratio, pore water nutrients - $NH_4{}^{+}$-N and $PO_4{}^{3-}$-P concentration (mg/L), ^{210} Pb and ^{137} Cs radioactivity (counts gm^{-1} sec^{-1}) , linear sedimentation rate (cm year^{-1}) , sediment mass accumulation rates (gm cm^{-2} year^{-1}) and the geo chronology (years in AD) of the sediment cores were analyzed and studied. The nutrient release experiment was also carried out to study the net nutrient release rate from the sediment water interface to the overlying water to estimate the contribution of internal loading in the nutrient budget analysis.

3.5.1 Core Sampling/Recovery

The station TG1 was selected in an un-dredged area in western lake near the mouth of Otsu River and station TG2 is selected in the eastern part of the lake. Sediment cores were recovered using hand corer from the anchored boat (Koike Boat Centre). The cores were recovered with the help of thin, light-weight, strong, and smooth walled PVC tubes with an internal diameter of 5.4 cm. The length of the corers was decided based on the objectives of the core recovery (Table 3.1). The longest cores from station TG1 and TG2 were sub sampled in 5 cm intervals using stainless steel knife immediately after the recovery and transferred to the polythene sample containers.

Table 3.1: Sediment Core Length

S.N.	Core Length (cm)	Purpose	Remark
1.	59	Sediment Charactertics Study and Pb and Cs Dating	St. TG1
2.	89	Sediment Charactertics Study and Pb and Cs Dating	St. TG2
3.	20	Nutrient Release Experiment (26 ^{0}C)	St. TG1
4.	21	Nutrient Release Experiment (7 ^{0}C)	St. TG2
5.	22	Nutrient Release Experiment (16 ^{0}C)	St. TG2
6.	25	Nutrient Release Experiment (26 ^{0}C)	St. TG2
7.	22	Nutrient Release Experiment (7 ^{0}C)	St. TG1
8.	20	Nutrient Release Experiment (16 ^{0}C)	St. TG1
9.	55	Reserve Core Samples (2)	Both

The sediment core sub samples were collected and transported to the laboratory by keeping in the insulated containers containing ice packs. The sub samples were collected to study the physical and chemical characteristics of sediment as mentioned above.

The recovered cores were brought to the laboratory in the upright/vertical position without shaking. The Nutrient Release Experiment was immediately started after 3 hours of recovery of the cores, soon after arrival in the laboratory. Sediment sub samples were transferred to the refrigerator before analysis (EPA, Technical Manual- 2001). The analysis and measurements were carried out based on the prescribed procedures, methods of analysis and each method is described in the following section.

3.5.2 Analysis of Physical Characterstics of Sediment

Water Content

The weight and volume of wet sediment sample were noted and kept at refrigerator at 0 ^{0}C for 24 hours. After freezing, the pre frozen samples were freeze dried using the EYELA FDU-1200 for the required time (24 hours to 72 hours). Freeze drying involves the removal of water from the frozen sediment by the sublimation process (frozen liquid is converted to gaseous state without passing through the liquid phase). Temperature and pressure are very carefully controlled for this process. After freeze drying, the weights of the samples were measured again to calculate the water content using the following relation.

$$Water\ Content\ (\%) = \frac{Weight\ of\ Wet\ Sample\ (gm) -\ Weight\ of\ Dry\ Sample\ (\ gm)}{Weight\ of\ Wet\ Sample\ (gm)} * 100$$

The numbers for this calculation were determined by taking the weights of each sample before and after freeze-drying.

Bulk Density

The bulk density is the ratio of the dry mass of the sediment sample to the bulk volume of the sample. It is the dry weight per unit volume of the sediment, and the volume includes the pore space among the soil particles. It is calculated using the following relation, weight divided by volume.

$$Bulk\ Density\ (\ gm\ cm^{-3}) = \frac{Weight\ of\ the\ Dry\ Sediment\ (gm)}{Bulk\ Volume\ of\ the\ Sediment\ Sample\ (cm^{-3})}$$

Porosity

The amount of void space in the sediment particles is described by the term porosity which is given by

$$Porosity\ (\%) = \left(1 - \frac{Bulk\ Density\ (\ gm\ cm^{-3})}{Particle\ Density\ (\ gm\ cm^{-3})}\right) * 100$$

Particle Density of the Sediment may be considered in between the value of 2.60 gm cc^{-1} to 2.75 gm cc $^{-1}$ (Claude E Boyd, 1995) and in this study, the sediment particle density is considered as 2.65 gm cc^{-1}.

Dry Bulk Density (DBD)

The dry bulk density can be calculated using porosity and particle density as:

$$Dry\ Bulk\ Density\ (gm\ cm^{-3}) = \left(1 - \frac{Porosity}{100}\right) * Particle\ Density\ (\ gm\ cm^{-3})$$

Dry Sediment Mass

The mass of dry solids per unit area ($gm\ cm^{-2}$) of each sample is computed as

$$
\begin{aligned}
&Dry\ Mass\ (\ gm\ cm^{-2})\\
&\qquad = (1 - Porosity\ ) * Particle\ Density(gm\ cm^{-3})\\
&\qquad * Sample\ Thickness(cm)
\end{aligned}
$$

(USGS-2004-5184, National Water Quality Assessment Program)

Where DS, Solid Density, i.e sediment particle density =2.65 gm cc^{-1}

Th= Thickness of sample interval (cm). In this case the sample thickness is 5 cm.

Particle Size Analysis

A Laser Diffraction Particle Size Analyzer (SHIMADZU SALD-3000 S) with the compatible software (Wing SALD -3000S) were used to analyze particle size distribution of each sample. Laser diffraction and laser scattering were principles of the measurement**.** The particles cause diffraction of a laser beam directed through the carrier fluid (water). The angle of scattering is inversely proportional to the particle size, while the intensity of scattering is proportional to the number of particles.

A very small quantity of sediment sample was taken and stirred manually and/or mechanically. The cohesive samples such as clays and silts of the deeper part of the sediment column were manually but carefully stirred before placing inside the sample bath. In the sample bath, the sample was stirred mechanically with the stirrer. A cleaned, disaggregated sample was dispersed in a carrier fluid (clean water) and passed through the inlet flow. The measurement result of the particle size distribution was displayed which was retrieved for further data analysis and interpretation.

Sediment particles are classified based on their size (measured in diameter). However, the classification system is arbitrary and many classification systems are found in various literatures related to engineering and geological sciences. Among the various scales of classification, the standard size classes of sediment were classified on the basis of Wentworth Grade Scale 1922 (*Table 3.2*).

Table 3.2: Wentworth Particle Size Grade Scale

Particle Description	**Particle Size (mm)**	**Cohesive Properties**
Very Coarse Sand	2-1	Non Cohesive
Coarse Sand	1-0.5	
Medium Sand	0.5-0.25	
Fine Sand	0.125-0.063	
Silt	0.62-0.004	Cohesive
Clay	0.004-0.00024	

The American Geophysical Union (AGU) Sediment Classification System is on the same line with that of Wentworth Grade Scale with more sub division in the classification (*Table 3. 3).*

Table 3.3: American Geophysical Union Sediment Classification System

Particle Description	**Particle Size (µm)**
Very Coarse Sand	2000-1000
Coarse Sand	1000-500
Medium Sand	500-250
Find Sand	250-125
Very Fine Sand	62-125
Coarse Silt	62-31
Medium Silt	31-16
Fine Silt	16-8
Very Fine Silt	8-4
Coarse Clay	4-2
Medium Clay	2 -1
Fine Clay	1.0-0.5
Very Fine Clay	0.5 - 0.24

Mode: The most frequently-occurring particle diameter is the mode and it's a peak of the frequency curve. The mode is quite valuable in sediment genesis transport studies, especially when two or more sources are contributing.

Median: Half of the particles by weight are coarser than the median, and half are finer. It is the diameter corresponding to the 50% mark on the cumulative frequency curve

$Median = \emptyset\ 50$ (Folk and Ward, 1957)

Mean: Mean is calculated based on the following relation as described in the Shimadu's Instruction manual.

$$Mean = 10^{\mu}$$

Where,

$$\mu = \frac{1}{100}\sum_{j=1}^{n} q_j \left(\frac{log_{10}x_j + log_{10}x_{j+1}}{2}\right)$$

3.5.3 Chemical Analysis of Sediment Characterstics

Carbon Nitrogen Ratio

The Carbon Nitrogen (C/N) ratio of sediment core sub samples of Lake Tega was measured in the laboratory using YANACO, CN CORDER MT-700 and AUTO SAMPLER MTA 600, Japan. The sediment sub sample of stations 1 and 2 were analyzed to study the Carbon and Nitrogen content in the sediment depth profile.

The samples to be analyzed were freeze dried and grinded well using mortar and pestle. After taking the weight (about 100 mg), the samples were kept in the Nickel sample boat and then placed in the auto sample sampler (Auto Sample MTA 600). The sample was heated to 850 ^{0} C in the flash heater to decompose the sample. The sample was completely burnt and oxidized and combustion gas was sucked through oxidation furnace, reduction furnace, the water absorption tubes etc. The sequence of a sample analysis was completed in 10 minutes comprising following processes such as sweeping, combustion, mixing and recording and the two thermal conductivity detectors measure the carbon and nitrogen separately.

The calibration of the instrument for measurement was done using Hippuric Acid (C_6H_5 $CONHCH_2COOH$, mol. wt 179.18) of weights 25 mg, 35mg, 45mg and 55 mg and blank sample boat. The calibration method is set as Y= AX +B.

For Nitrogen,	For Carbon,
Theoretical % N = 7.82	Theoretical % C= 60.33
A= 0.0003, B = - 0.1047	A=0.0056, B=-1.2302

The instrument setup during the measurement is shown in below:

Helium Gas Set Pressure: 200 k Pa,
Combustion Flow Rate: 125 ml/min,
Flash Heater: 63 Volt,
Reduction Furnace: 555 ^{0}C,
Detector Oven: 100 ^{0}C,
Sweeping Flow Rate: 700 ml/min
Reference Flow Rate: 100 ml/min
Oxidation Furnace: 850 ^{0}C
Pump Oven: 55 ^{0}C
Bridge Current (C): 33 mA, (N): 121 mA

Pore Water Nutrient

To extract the sediment pore water of sediment samples of various depth, the centrifugation process, an ex-situ method of extracting sediment pore water was applied using H - 3R (KOKUKOSAN RF -110), at 3500 rpm for 10 minutes at the temperature of 5 ^{0}C of about 15 gm of wet sample. The extracted samples were filtered (ADVANEC, Dismic-25 Mixed Cellulose Easter, 0.45 µm) and collected in a polythene sample container. After extraction and filtration, the pore water samples were analyzed for NH_4-N and PO_4-P using Auto Analyzer- AACS- III (BRAN + LUEBBE) and Auto Sampler (BRAN + LUEBBE).

Heavy Metal Analysis- Hexa-chromium

The DR 2800 Spectrophotometer (HACH Company, U.S.A) is a visible spectrum spectrophotometer with a wave length range of 340 to 900 nm for laboratory and field analysis. A method consists of calibration, digestion, analysis and calculation steps. It is calibrated by determining the absorbance values of several standard solutions of known concentration. Hexavalent chromium is determined by the 1,5-Diphenylcarbohydrazide method using a single dry powder formulation called ChromaVer 3 Chromium Reagent. This reagent contains an acidic buffer combined with 1,5-Diphenylcarbohydrazide, which reacts to give a purple color when hexavalent chromium is present. Test results are measured at 540 nm (340–900 nm). This method has been approved by USEPA and adapted from Standard Methods for the Examination of Water and Wastewater. The light absorbed by the sample is measured in absorbance units and a concentration factor can be entered to enable the measured absorbance values to be converted into concentration values in desired units.

3.5.4 Radio-nuclides Activity Analysis and Sedimentation Rate

Gamma-ray spectrometry measures the gamma-rays emitted from natural or man-made radioactive elements that are present in solid and liquid samples. The natural decay of Uranium (U) and Thorium (Th) produce a series of radio-nuclides with different half-lives that can be used to determine the sediment ages and accumulation rates of sediments.

The U-series and Th-series elements that emit gamma-rays include ^{234}Th, ^{226}Ra, ^{212}Rn, ^{218}Po, ^{214}Pb and ^{210}Pb. Emission rates from these radio-nuclides can be quantitatively measured utilizing high-resolution semiconductor detectors. In addition, gamma-ray spectrometry can identify the presence of man-made radio-nuclides including ^{137}Cs from radioactive fallout during the nuclear testing worldwide before 1963 and Chernobyl accident in 1986 in Ukraine, the former USSR. In the year 1957, the International Atomic Energy Agency (IAEA), an intergovernmental forum for scientific and technical co-operation in the peaceful use of nuclear technology worldwide was established. Followed by this, the Governments of the USA, UK and the former USSR signed and decided to impose a Limited Nuclear Test Ban Treaty in August 5, 1963. Following 4.5 decades global contamination with ^{137}Cs has slowly decreased. So, the highest activity peak of ^{137}Cs was considered for the year 1962-1963. Basically, the ^{137}Cs is used to verify the ^{210}Pb dating and commonly known as independent time specific marker for certain events.

Preparation and Placement of Sample

The freeze dried samples were grinded with mortar and pestle. The weight and volume of the sample were noted. The samples were then placed very gently above the vertical cryostat and the door was closed.

^{210}Pb and ^{137}Cs Dating

^{210}Pb is a naturally occurring radioactive element which is a part of ^{238}U (Uranium) radioactive decay series and ^{137}Cs is a man-made radio-nuclide.

EG & G ORTEC GAMMA-X® HPGe (High-Purity Germanium) Coaxial Photon Detector along with Seiko EG & G Spectrum Navigator as a software tool were used to measure the activities of ^{210} Pb, ^{226} Ra and ^{137} Cs. Liquid Nitrogen was weekly filled to keep the cool environment during the measurements. The activities of total ^{210} Pb and ^{226} Ra were obtained from 46.2 keV and 185.99 keV of photopeaks respectively and the 662.7 keV photopeak was used to measure ^{137} Cs activity. The instrument was calibrated with ^{57} Co and ^{60} Co. Before measuring the ^{210} Pb and ^{137} Cs activities, the background radioactivity measurement was taken using an empty sample container for the same period of live time as the sample measurement. The ^{226}Ra photopeak at 185.99 keV with interfered with that of ^{235}U at a near energy (i.e. 185.72 keV). So, the activity of ^{226}Ra was slightly adjusted based of ^{137} Cs activity peak. The regions of Interest (ROI) were defined as the appropriate number of channels (three to six) above and below the each photo peak (Table 3.4)

Table 3.4: Sediment Dating for Activity Measurement

Radio-Nuclide	Half Life	Central Channel (ch)	ROI	Photopeak keV	Gross Counts (Activity)	Net counts (Activity)
^{137} Cs	30 Yrs	1325.45	1322-1329	662.7	***	**
^{210} Pb	22.3 Yrs	92.4	86-96	46.2	****	***
^{226} Ra	1622 Yrs	371.9	368-380	185.99	***	**

On the basis of the activities of these radio-nuclides, the linear sedimentation rate, mass accumulation rate and geo-chronology were computed.

Linear Sedimentation Rates and Mass Accumulation Rates and Geo-Chronology

To determine the sediment ages by ^{210} Pb, the unsupported or excess ^{210} Pb activity has to be calculated as:

$$^{210}\text{Pb}_{\text{(Excess or Unsupported)}} = {}^{210}\text{Pb}_{\text{(Total)}} - {}^{210}\text{Pb}_{\text{(Supported)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

An ‘unsupported’ (or excess) ^{210} Pb reach to the lake sediment from dry and /or wet atmospheric wash out where as the supported ^{210} Pb is the component derived directly from eroded soil /soil substrate of the lake’s catchment area. The supported ^{210} Pb, not having been in atmospheric contact, emanates from ^{226} Ra in the U series. So, the activity measurement of ^{226} Ra (185.9 keV) was carried out to figure out the supported ^{210} Pb. The supported ^{210} Pb is in the secular equilibrium with ^{226} Ra (1622 years). It means beyond certain point, the decay product decays at the same rate it is produced or the radioisotopes have the equal and constant activity levels. The methodology and the instrument that is used for this study generated the activity of ^{235} U and ^{226} Ra in the same channel and energy which interfered the counts. Hence, the activity of ^{226} Ra is adjusted to certain value so that it matched the sediment depth and the years with distinct ^{137} Cs activity peak. As the half life period of ^{226} Ra is comparatively long (1622 years), it was assumed that the activity in mightn't vary significantly in short span of time.

Lake receives the radio nuclides from land such as rivers, ground water, geological weathering or from the atmosphere as wet precipitation and dry fall out. However, it was assumed that ^{210} Pb doesn't migrate in the sediment column and the flux of sediment was constant.

Then, the activity A (x) of the radio nuclide in the sediments at depth X is given by:

$A(x) = A_0 * e^{-\lambda.t}$……………………………… (2)

Where,

A_0 = the activity (in counts per gram of sediment per second) of the freshly deposited sediment at the surface at time t = 0

t = sediment age in years

λ = the radio active decay constant

$\lambda = \frac{\ln 2}{half\ life\ periods})$…………………………..… (3)

The decay constant for ^{210} Pb is calculated as

$$\lambda_{210\ Pb} = \frac{0.693}{22.3} = 0.031$$

From the above Eq. 2,

$\ln A = \ln A_0 - \lambda\, t$……………………………… (4)

$Sediment\ Age\ (t) = \frac{1}{\lambda} * ln \frac{A_0}{A(x)}$ ……………… (5)

Thus, the sediment age of the certain layer was calculated. This procedure for calculating ^{210}Pb dates was first outlined by Goldberg (1963), and was set out in detail in Appleby & Oldfield (1978), and Robbins (1978).

a) Linear Sedimentation Rate (LSR)

In the mean time, this calculation also provided the sedimentation rate and chronology of sediment column. Similarly, the linear sedimentation rate (LSR) was calculated with the help of ^{137} Cs tracer as well as ^{210}Pb activity. The LSR, derived from ^{137} Cs was calculated on the basis of highest activity counts of the ^{137} Cs at the corresponding sediment depth. In case of ^{210}Pb, the activity counts of ^{210} Pb $_{(Excess)}$ was plotted on which an exponential curve was fitted. On the basis of a half life period (22.3 years), the corresponding years of accumulation and sedimentation rate was calculated for each sediment depth interval. However, LSR doesn't take into account of sediment compaction in the sediment core. Hence, mass accumulation rates are preferable because they automatically adjust the compaction of the sediment in the core column.

b) Mass Accumulation Rate (MAR)

Mass Accumulation Rates given by:

Method 1:

$$\begin{aligned} Mass\ Accumulation\ Rate\ (gm\ cm^{-2} year^{-1}) \\ = Linear\ Sedimentation\ Rate\ (cm\ year^{-1}) \\ * \ Dry\ Bulk\ Density\ (gm\ cm^{-3}) \end{aligned}$$

Adoption Source: Johnson, T.C., *et al*., 2003

Method 2:

After calculation of the age of the specific sediment layer using the Eq. 5, the sedimentation rate was calculated. Then, the mass accumulation rate is calculated as the product of sedimentation rate and the bulk density.

c) Geo-chronology:

$$\boldsymbol{Date\ i = Sample\ date - \frac{Cumulative\ Dry\ Mass\ (gm.cm^{-2})}{Mass\ Accumulation\ Rate, MAR\ i(\ gm\ cm^{-2}\ yr^{-1})}}$$

Adoption Source: (USGS-2004-5184, National Water Quality Assessment Program)

Where,

Date $_I$ = deposition date of sample (decimal years)

Sample Date =date of core collection (decimal years)

cum $_I$ = cumulative mass (gm cm^{-2}) from the top of the core to the mid point of the sample i

Alternately, the geo chronology can be established by using Eq. 5 for specific layers of sediment.

CHAPTER 4: RESULTS

4.1 Water Quality

4.1.1 Spatial Variation of Water Quality in Lake Tega

The chlorophyll *a* (Chl *a*) concentration was higher in TG2, eastern part, of the lake than the TG 1, western part (*Figure 4.1*). The Chl *a* concentration at the transect points of the lake showed an increment towards the outlets.

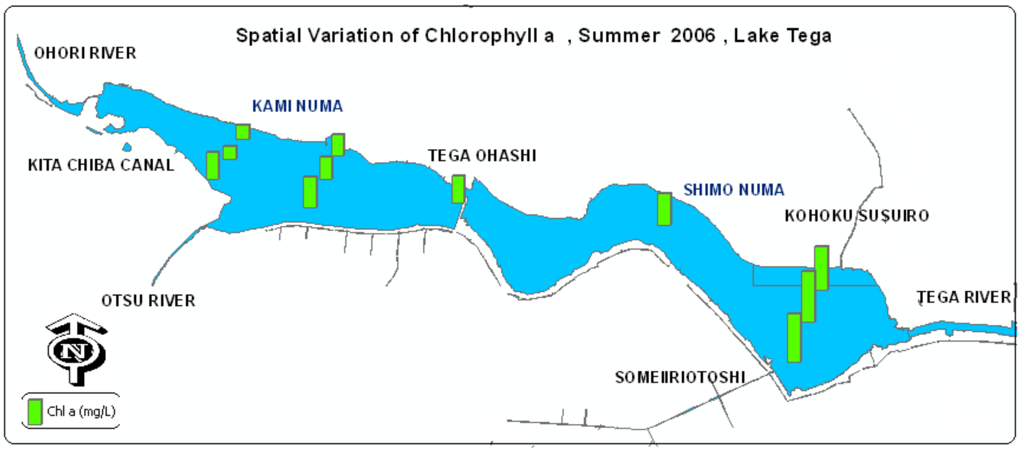


Figure 4.1: Spatial Variation of Chl a

Dissolved oxygen (DO) and pH were found to be higher in the eastern lake. A slightly positive correlation (R^2 =0.528) between Chl *a* and DO was found in the entire lake.

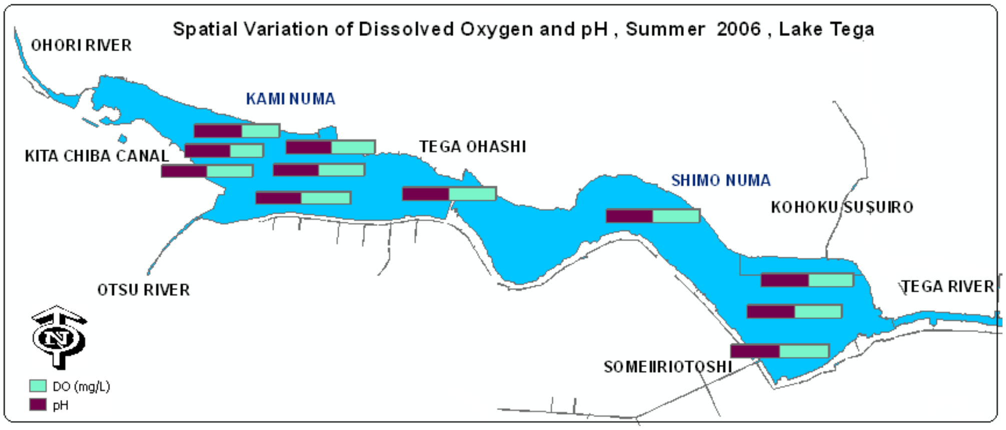


Figure 4.2: Spatial Variation of DO and pH

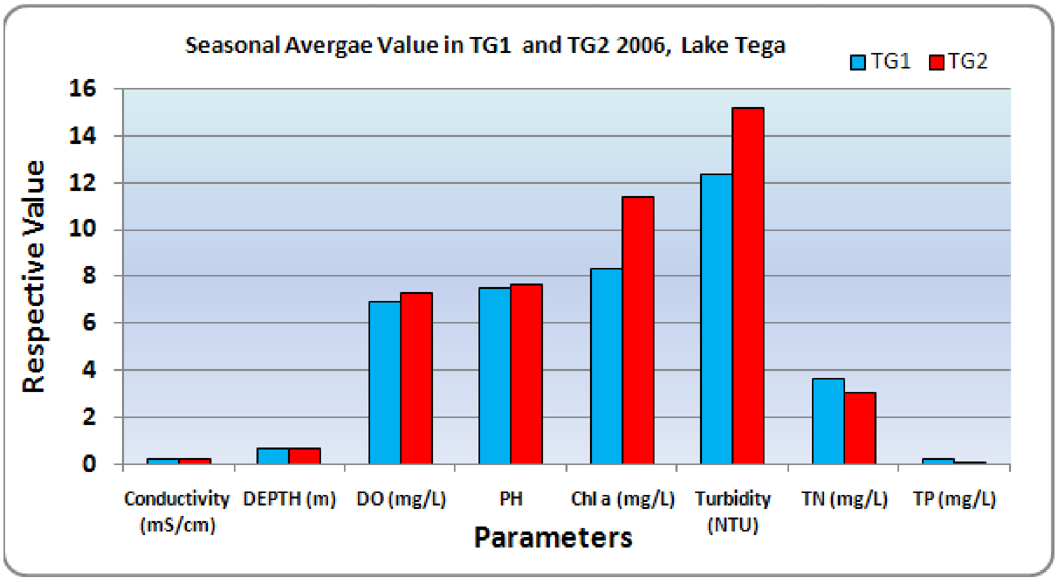
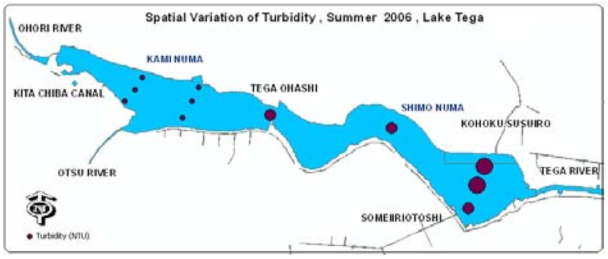


Figure 4.3: Seasonal Average Values of W Q parameters in TG1 and TG2

The turbidity was also found higher in eastern lake than in western lake (*Figure 4.3 & 4.4*). Temperature and conductivity were found almost similar in both the regions. The Figure 4.3 showed that the Total Phosphorus (TN) and Total Phosphorus (TP) concentrations had been higher in TGI than in TG2. The TG2 was found shallower than TG1 and TG1 was deeper than the average depth of Lake Tega (0.86 m).



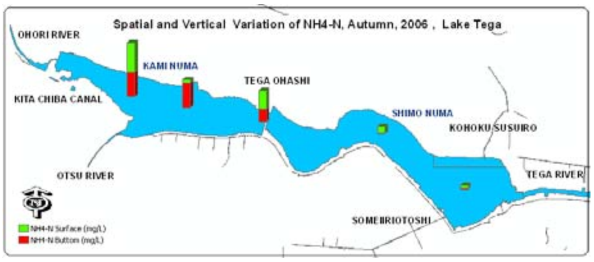


Figure 4.4: Spatial Variation of Turbidity *Figure 4.5: Spatial and Vertical Variation of* NH_4*-N*

NH_4^+-N was found higher in the TG1 than in TG2. Compared to bottom layer, NH_4^+-N was higher in the surface layer (*Figure: 4. 5*) in the transect points except in the middle of Kaminuma.

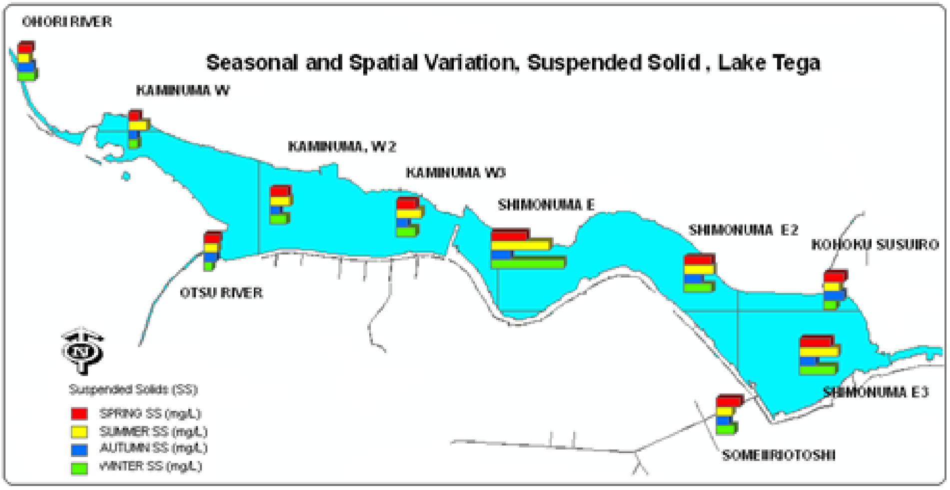


Figure 4.6: Seasonal and Spatial Variation of SS

The highest concentration of suspended Solids (SS) was observed in Shimonuma E, the central part of the lake in all seasons (*Figure 4.6*) and the average of all season was 31 mg/L. The lowest value was observed in Kaminuma W with the value of 7.8 mg/L. It could be inferred that the SS had been higher in the TG2 region than in TG1 region with a distinct variation among the seasons.

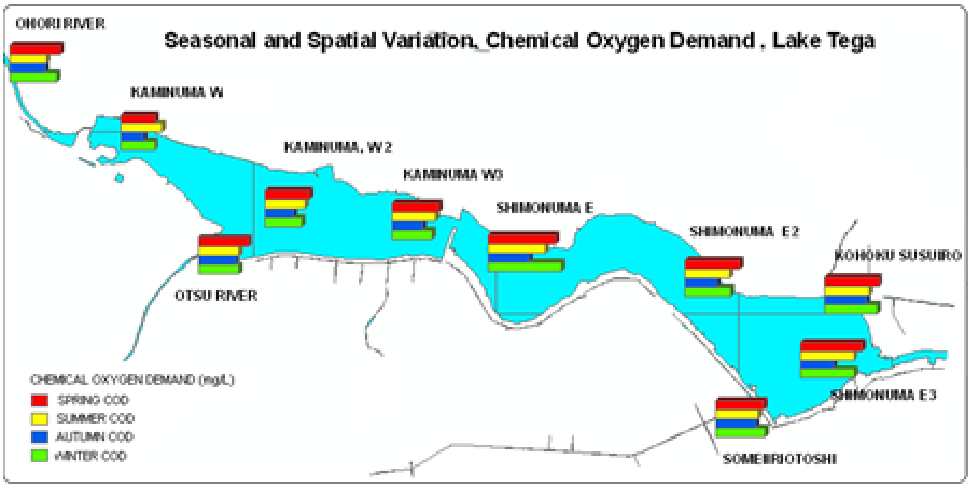


Figure 4.7: Seasonal and Spatial Variation of COD

Kaminuma W had the lowest value of COD with 4.4 mg/l and Shimonuma E had the highest value with 8 mg/L. The COD level was found higher in the TG2 of the lake with higher values than the TG1 (*Figure 4.7*).

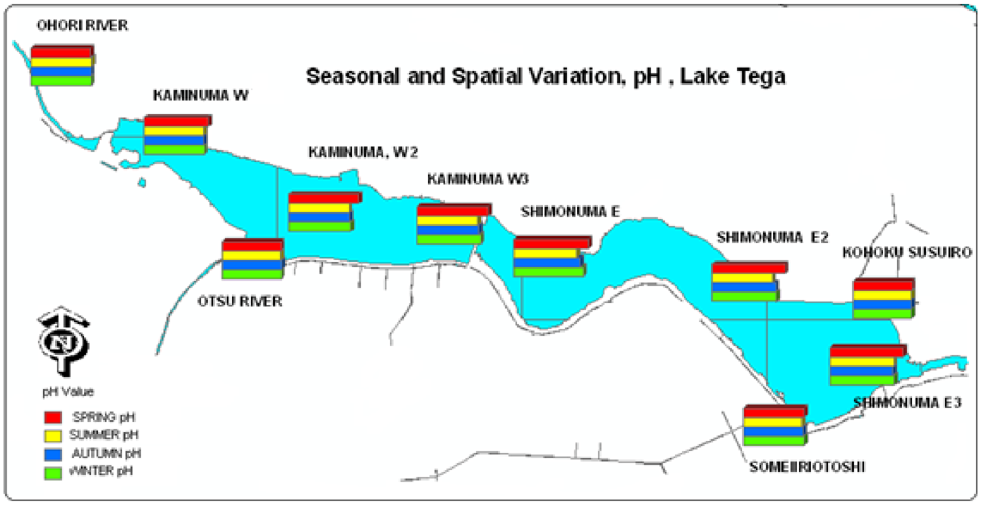


Figure 4.8: Seasonal and Spatial Variation of pH

The pH value was not significantly different in space and seasons. However, the value was slightly higher in the TG2 area with the average value of 8.4 while 7. 8 was the value in the TG1 (*Figure: 4.3&4.8*).

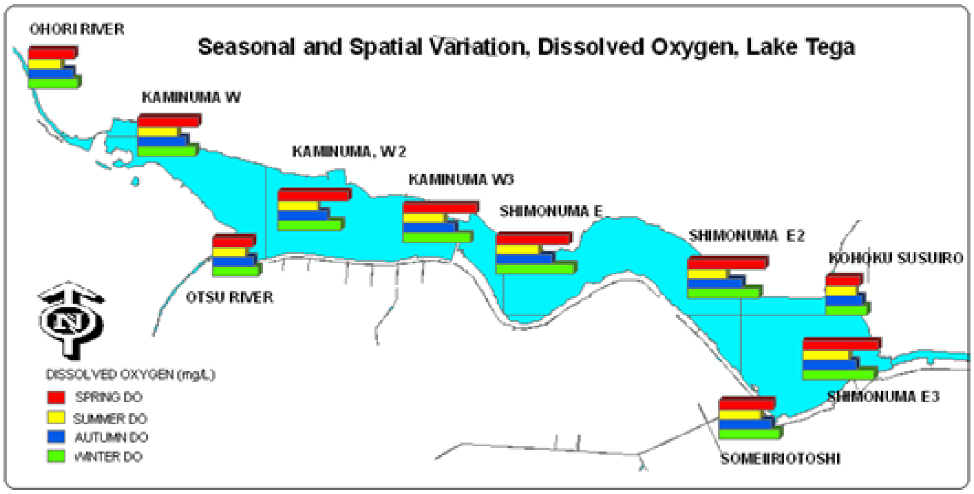


Figure 4.9: Seasonal and Spatial Variation of DO

An average DO level in the TG2 was 11 mg/L while it was 10 mg/L in the TG1. The value was higher in spring and it was followed by winter in both parts of the lake. Summer season was the lowest DO in all stations (Figure*: 4.2*, *4.3* and *4.9*).

4.1.2 Vertical Variation of Water Quality Parameters

In case of TG1 and TG2, the vertical variation of water quality parameters such as pH, temperature wasn’t significant (*Figure 4.10 and 4.11*). However, turbidity, chlorophyll *a* (Chl *a)* and dissolved oxygen (DO) showed a slight vertical variation. Turbidity, Chl *a* and DO were decreasing along the depth of water column (*Figure 4.10 and 4.11).*

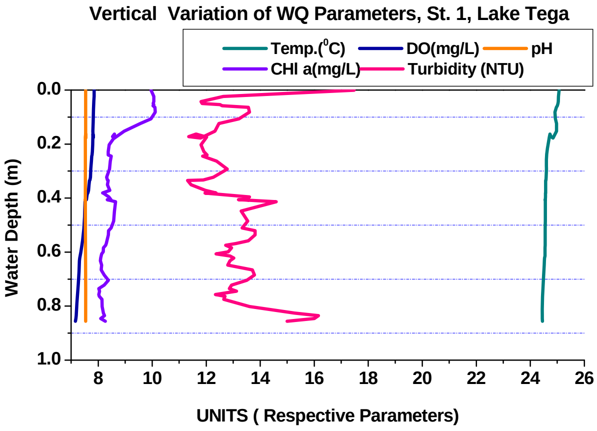


Figure 4.10: Vertical Variation of WQ

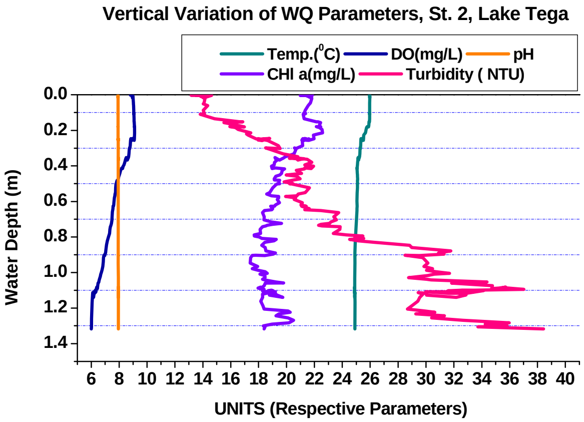


Figure 4.11: Vertical Variation of WQ

4.1.3 Lake Water Quality Trend and Variation

Yearly and Seasonal Variation of Chemical Oxygen Demand (COD) Level

In the year 1968, the annual average of COD level dropped to the lowest value as 3 mg/L at the center of the lake and since then the COD level kept on increasing. The lake Tega experienced the highest COD level in the year 1979 and the value reached to 28 mg/L (annual average) since 1967 (*Figure 4.12*).

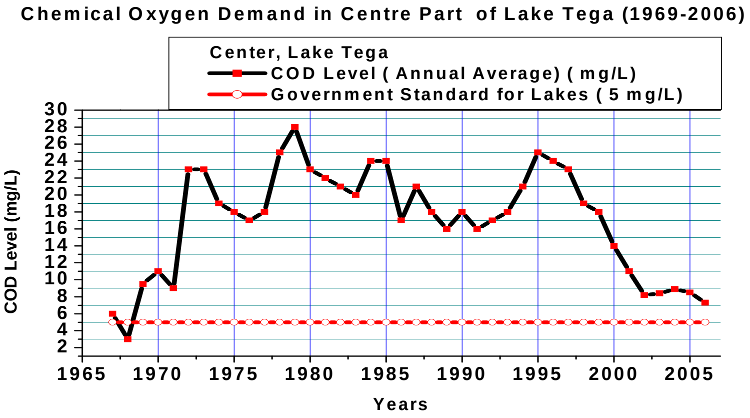


Figure 4.12: Yearly Variation of COD (1967-2006)

The years 1978 and 1995 also had one of the highest values and the annual average value of COD level reached to 25 mg/L. Some distinct peaks were observed since 1978 to 1985 having the COD values of 23.3 mg/L (average values of the years 1978 to 1985). Similarly, one of the higher value regions was observed in between the years 1993 and 1999 with an average value of COD as 21.1 mg/L (*Figure 4.12).*

The monthly average data of TG1 showed that the maximum value had been observed in the year 1979 and the COD concentrations in the spring and summer reached to 44 mg/L and 43 mg/L respectively. The COD level was decreased sharply since 2000 in all seasons. However, spring had the highest concentration of COD while autumn had the lowest value. After the year 2000, the seasonal variation pattern was not that distinct as it used to be (*Figure: 4.13*). Based on the highest value and the lowest value in four seasons between the years 1980 to 2005, the COD level was found to be decreased by about 90 %. Lower values were observed after the year 2001.

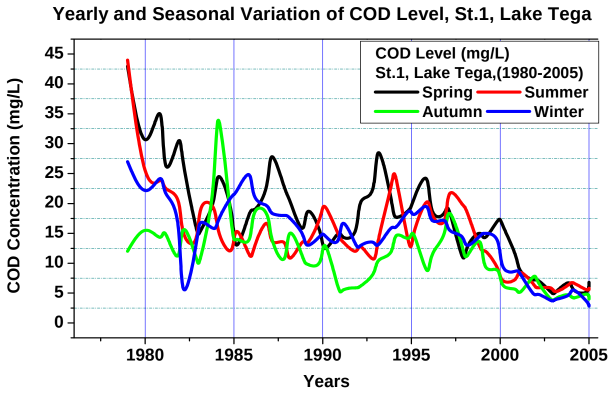


Figure 4.13: Variation of COD at TG1

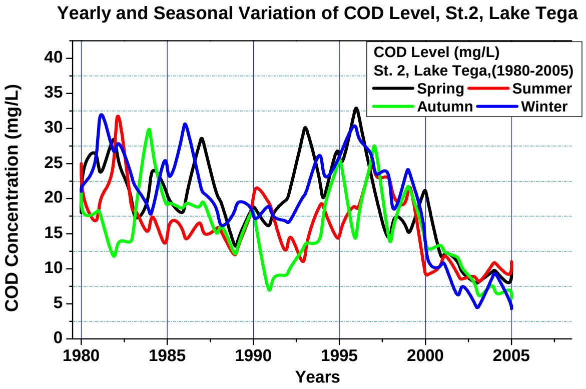


Figure 4.14: Variation of COD at TG2

Similarly, the COD level decreased significantly in TG2 as well. The highest concentration of COD was observed in the summer 1982 with the value of 38 mg/L and this was followed by 36 mg/L in the year 1981 in the winter season. Like TG1, the COD level was found lower than other seasons. Since 2000, the COD concentration was decreased, but the value was still higher than that of government standard value (5 mg/L). Similar to the TG1, based on the highest value and the lowest value in four seasons between the years 1980 to 2005, the COD level decreased by about 82.7% in TG2. The lowest values were observed after the year 2001 (*Figure 4.14*).

Yearly and Seasonal Variation of Total Nitrogen and Total Phosphorus

The highest value of TN was recorded in winter 1985 with 12 mg/L and 1.7 mg/L was the lowest value measured in the summer 2004.

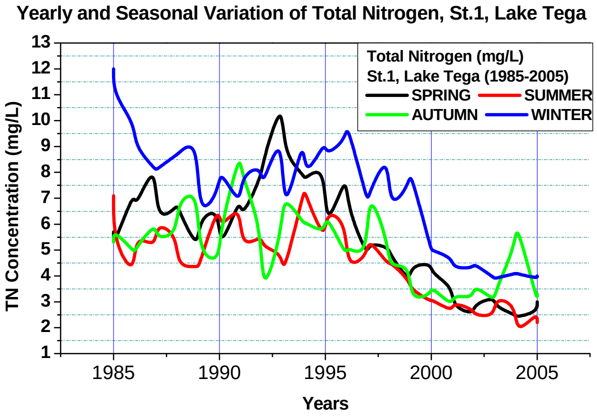


Figure 4.15: Variation of TN at TG1

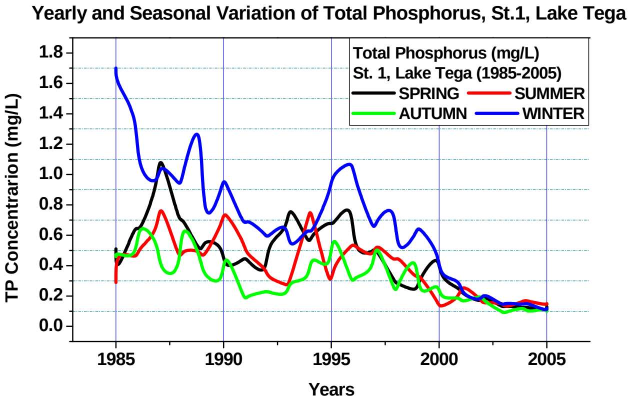


Figure 4.16: Variation of TP at TG1

Similarly, the TP concentration reached to 1.7 mg/L in the winter season of the year 1985 as the highest value during the period of 1985 to 2005 and the lowest value was 0.1 mg/L in the spring and winter of the year 2005. The five year average data of TN and TP since 1985 to 1989 and five years average of 2001 to 2005 for four seasons were compared and it was found that the TN concentration was decreased by 50% in TG1 and TP was also found decreased by 78% in the same periods and seasons (*Figure: 4.15 and 4.16*).

For the year 1985 to 1989, the five years average values of TN and TP were 6.6 mg/L and 0.7 mg/L respectively and for the period of 2001 and 2005, the average TN value was 3.32 mg/L and TP value was measured as 0.52 mg/L. In the period of 1985 to 2005, TG2 experienced the highest TN value in the summer of 1994 with the concentration of 8 mg/L and highest TP value in the winter of 1986 and the value was 0.18 mg/L.

Similarly, the lowest value of TN was observed in the summer of year of 2004 with the value of 1.3 mg/L and 0.11mg/L was the lowest value of TP observed in the year 2004 winter and one of the lowest values in 2005 spring as 0.12 mg/L (*Figure: 4.17 and 4.18*).

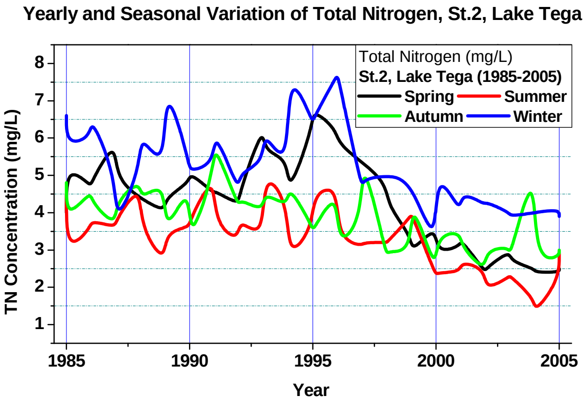


Figure 4.17: Variation of TN at TG2

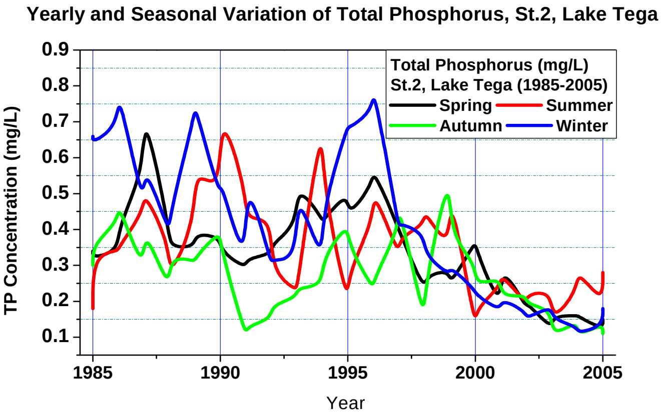


Figure 4.18: Variation of TP at TG2

In TG 2, the average TN and TP concentrations of the year 1985 to 1989 were 4.6 mg/L and 0.4 mg/L respectively and the recent five years (2001 to 2005) average TN and TP was observed as 3 mg/L and 0.18 mg/L respectively. Looking at these data, it was observed the TN and TP concentrations were decreased by 34% and 55% respectively comparing first and last five years average concentration. The decrement of TN and TP concentration since 2001 was observed significant in the TG1 and TG 2.

Yearly and Seasonal Variation of Chlorophyll *a* Concentration (Chl *a*)

The concentration of Chl *a* was considered as the indicator of the growth of phytoplanktons including algae and other aquatic species which utilize nutrients for their growth.

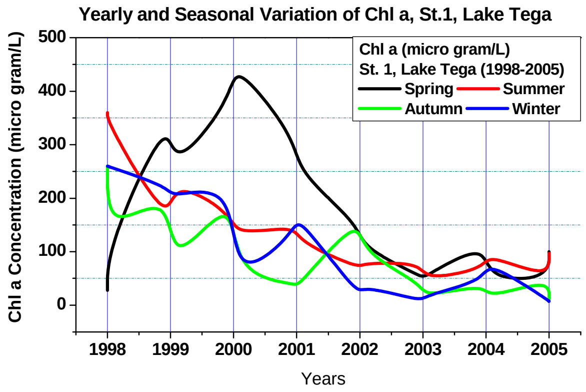


Figure 4.19: Variation of Chl a at TG1

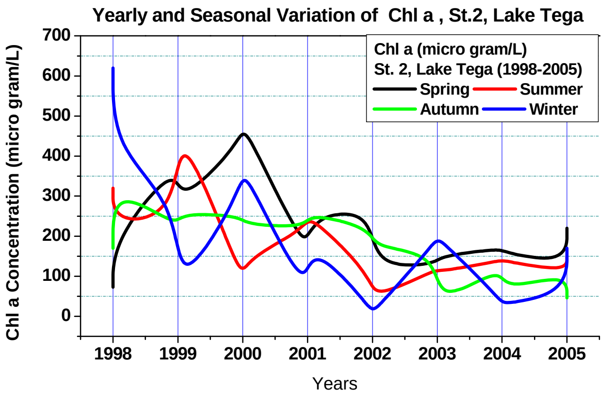


Figure 4.20: Variation of Chl a at TG2

The Chl *a* concentration was found higher in spring season in TG1 and autumn and winter had the lower values. The highest value of Chl *a* was observed in the spring of the year 2000 with 460 µg/L and after 2001, the lowest value was observed in winter of the year 2003 with the value of 6 µg/L (*Figure 4.19*). Chl *a* concentration was decreased by 75 % compared to the average data of the period 1998-2000 and 2004-2005 (*Table 4.1*).

Table 4.1: Chlorophyll *a* Concentration in TG1 and TG2

Chlorophyll *a* Concentration TG1, Lake Tega (1998-2005)

	Chl *a* (µ g/l)	Chl *a* (µ g/l)	Chl *a* (µ g/l)	Chl *a* (µ g/l)
Year	SPRING	SUMMER	AUTUMN	WINTER
1998-2000	**266.3**	**230.0**	**157.3**	**200.7**
2001-2003	**153.8**	**90.5**	**66.0**	**64.5**
2004-2005	**78.8**	**77.8**	**28.5**	**36.5**

Chlorophyll *a* Concentration TG2, Lake Tega (1998-2005)

	Chl *a* (µ g/l)	Chl *a* (µ g/l)	Chl *a* (µ g/l)	Chl *a* (µ g/l)
Year	SPRING	SUMMER	AUTUMN	WINTER
1998-2000	**308.8**	**254.8**	**243.3**	**344.3**
2001-2003	**176.7**	**141.7**	**175.3**	**107.7**
2004-2005	**170.0**	**135.0**	**87.0**	**74.0**

Chl *a* concentration was observed highest in winter 1998 with the value of 620 µg/L but the higher values are observed in any seasons regard less any pattern or trend in case of TG2. The lowest value was observed in the year 2002 in winter season with the value 7 µg/L.

However, compared to the average data of the period 1998-2000 and 2004-2005, Chl *a* concentration was decreased by 59 % (*Table 4.1*). The Chl *a* concentration was found higher in TG2 than in TG1 and decrease in concentration was observed more sharply since 2001 (*Figures: 4.19 and 4.20*).

Yearly and Seasonal Variation of Eutrophication

The Trophic State Index (TSI) value of Chlorophyll *a*, TSI (Chl a), TSI value of Secchi Disk, TSI (SD) and TSI value of Total Phosphorus, TSI (TP) of summer and winter seasons of the year 1984 to 2005 are discussed for the yearly, seasonal and spatial variations of eutrophication in terms of Trophic State Index (Carlson 1977).

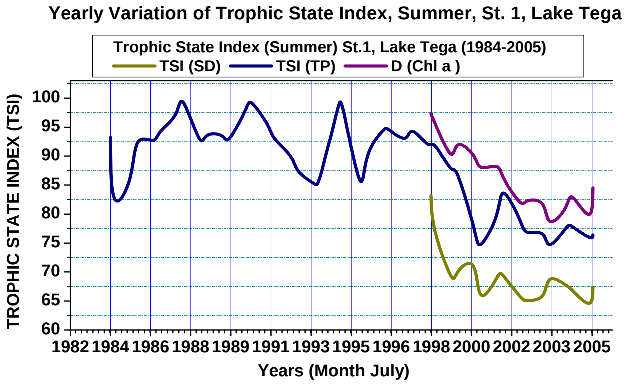


Figure 4.21: Variation of TSI at TG1

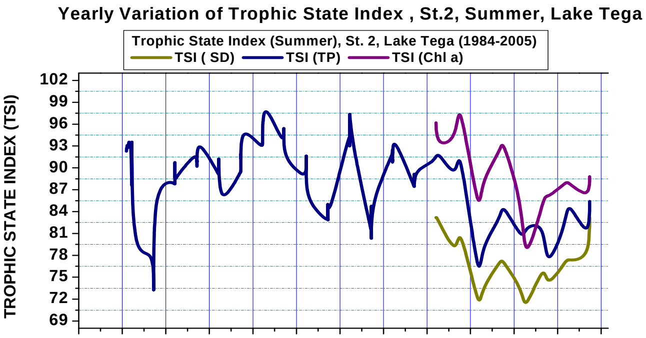


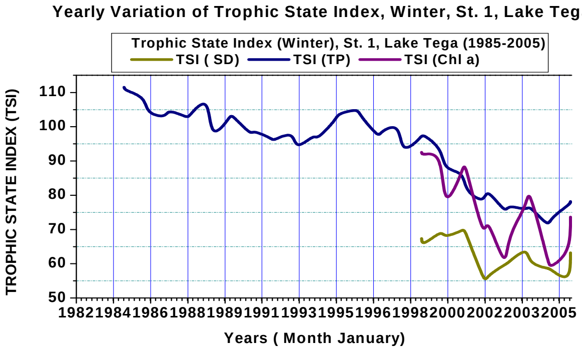
Figure 4.22: Variation of TSI at TG2

The TSI values for all the parameters in consideration were found higher than 55 in all seasons in both the stations.

In summer at TG1, the maximum values for TSI (SD), TSI (TP) and TSI (Chl *a*) were 83, 101 and 97 respectively and the minimum TSI values of SD, TP and Chl *a* were found to be 63, 73, 77 respectively in the same season (*Figure 4.21*).

The maximum values for TSI (SD), TSI (TP) and TSI (Chl *a*) in winter were 70, 110 and 92 respectively (*Figure 4.23*). Similarly, the minimum values of the TSI (SD), TSI (TP) and TSI (Chl *a*) values were 55, 70 and 57 respectively in the winter in TG1 (*Figure 4.23*).

The highest values of TSI (SD), TSI (TP) and TSI (Chl *a*) were observed as 83, 100, 101 in TG2 in the summer season. Similarly, the minimum values were 70, 73, 76 for TSI (SD), TSI (TP) and TSI (Chl a) respectively in the same periods (*Figure 4.22).*



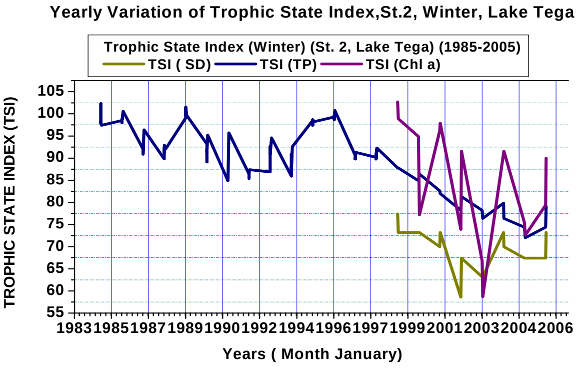


Figure 4.23: Variation of TSI at TG1

Figure 4.24: Variation of TSI at TG2

In winter, the TG2 showed the highest values of TSI (SD), TSI (TP) and TSI (Chl a) as 77, 102 and 104 and lowest values as 59, 72 and 59 (*Figure 4.24)*. It was observed that the TSI values were found to be higher than 55 in all seasons and all years.

The minimum annual average of TSI values for TSI (SD), TSI (TP) and TSI (Chl *a*) were 61, 72 and 73 respectively and the maximum values were 73, 100 and 95 for TSI (SD), TSI (TP) and TSI (Chl *a*) (*Figure 4.25)*. Most of the values were corresponding with hypertrophic state of lake.

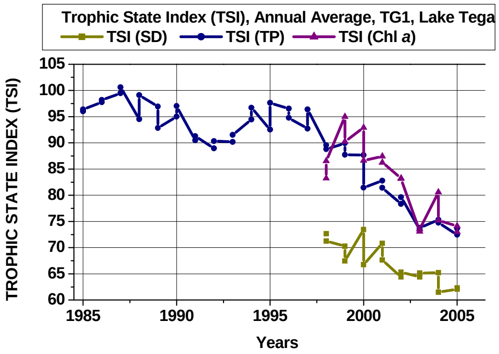


Figure 4.25: Variation of Annual Average of TSI at TG1

4.2 Water and Nutrients Budget Analysis of Lake Tega

4.2.1 Water Budget

Water In-Flux

Following are the major inflowing sources which discharge water in the lake Tega.

a) Ohori River
b) Otsu River
c) Somei-iriotoshi River
Kita Chiba No. 2
d) Pumping Station
e) Internal Loading
f) Ground Water Infiltration
g) Non point sources
h) Precipitation

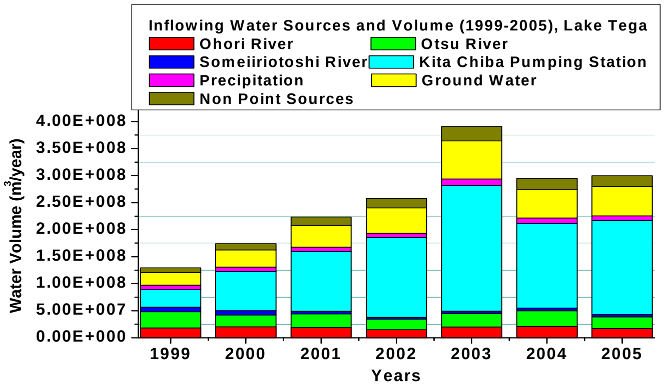


Figure 4.26: Inflowing sources and water volume

The water, being introduced to lake Tega through Kita Chiba pumping station, found to contribute the highest volume after the year 2000 in the water budget scenario.

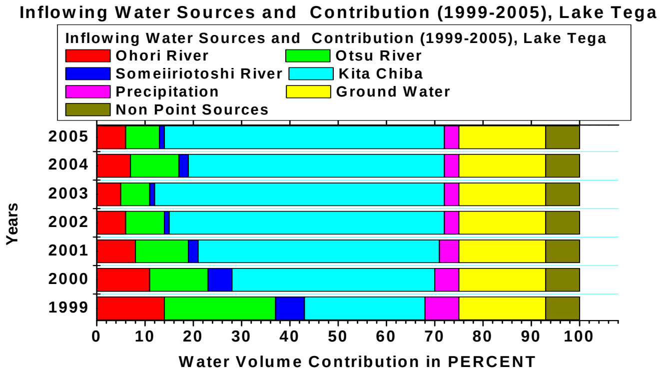


Figure 4.27: Inflowing sources and water volume Contribution

For the purpose of cleaning Lake Tega, Kita Chiba No.2 pumping station is constructed and the water from Tone River is discharged in to the Lake Tega from this conveyance channel. Fresh Tone River water is discharged In Lake Tega depending upon seasons and water uses pattern for irrigation. However, there exists some days without any discharge or very small amount of discharge.

Among the natural sources, Otsu is the largest source of inflowing water to lake Tega.Ground water, the major source of inflowing water and contributed about 18% of the total inflowing volume (*Figure 4.26 & 4.27*).

Water Out-Flux

Following are the out-flowing sources which drain out the lake water, one way or other.

a) Tega River
b) Izumi Irrigation Pumping Station
c) Takano Yama Irrigation Pumping Station
d) Evaporation

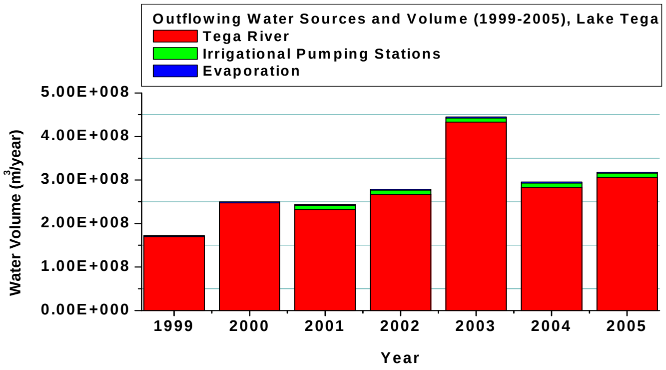


Figure 4.28: Inflowing sources and water volume

Tega River is the major out flowing source and accounted for about 96% of total out flowing volume. The Izumi Pumping Station and Takanoyama Pumping Station pump out the Tega Lake water during the irrigation period (April to August) but out-flux volume accounted only 4% along with evaporation from the lake surface area (*Figure 4.28*).

The yearly water budget (*Figure 4.29*) showed almost balanced figures except the year 1999, 2000 and 2003. However, the volume is in the same order of numbers. The difference in the volume might have been resulted due to the assumptions that were made for non point sources and ground water.

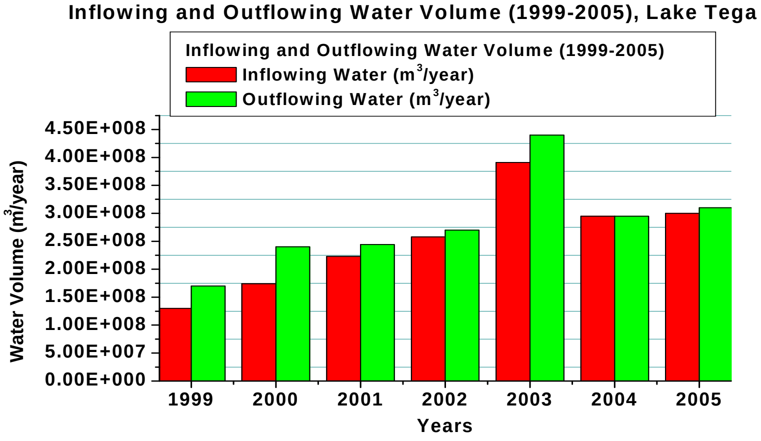


Figure 4.29: Lake Water Budget 1999-2005

However, the average inflowing and out flowing volumes showed reasonably balanced figure accounting 2.53 E+08 m^3 and 2.81 E+08 $m^{3.}$ The average contribution of the inflowing and out flowing sources are shown in the following figures (*Figures 4.30 &4.31*).

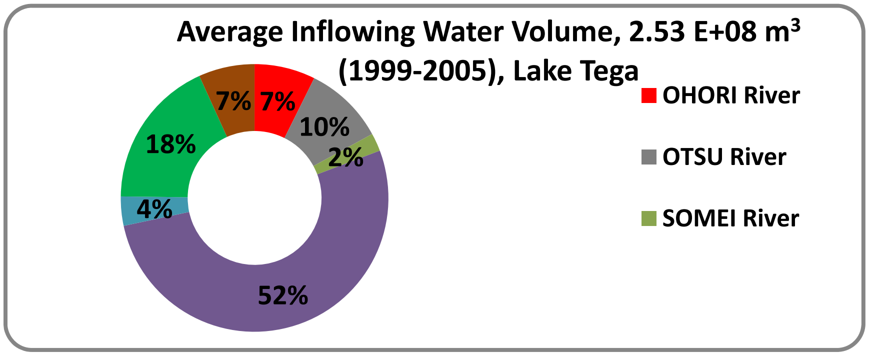


Figure 4.30: Average Inflowing Water Volume 1999-2005

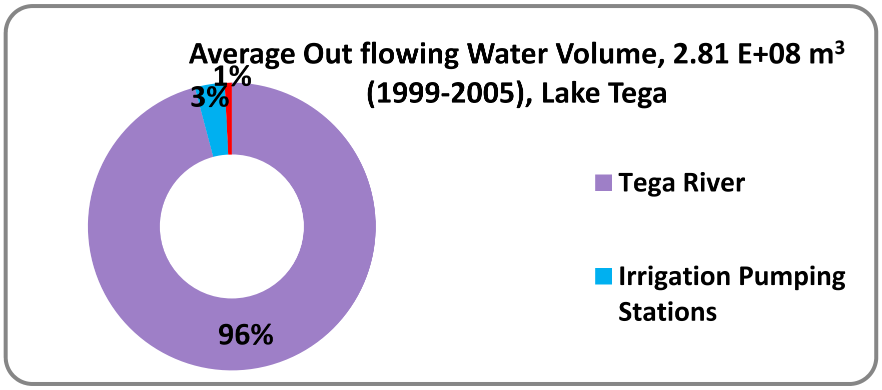


Figure 4.31: Average Out-flowing Water Volume 1999-2005

The existence of lakes depends upon a sound balance between the inflowing amount of water and the losses that they experience. The contribution of the inflowing rivers was found decreasing since 1999. After the extension of Tega Waste Water Treatment facilities coverage , the sewage canal that used to be discharge in the inflowing rivers were diverted to the treatment facilities which might have decreased the discharge of the rivers. Ground water was one of the major inflowing sources and significantly contributes to the water balance of a lake. During ground water infiltration, the lake is recharged through the soil under gravitational influence. Precipitation was another source reaching a lake's surface directly but the amount wasn't significant as the surface area of the lake was comparatively small. However, the precipitation influences the non-point sources.

4.2.2 Nutrient Loads and Budget Analysis

Nutrient budget has a significant implication for Lake conservation/purification. Being familiar with the nutrient budget, lake's management plan can be designed to abate the problem. Total Nitrogen (TN) and Total Phosphorus (TP) budget of Lake Tega was assessed.

Inflowing Rivers and Nutrient In-Flux

The sampling points for nutrients concentration and river discharges to calculate the nutrients are shown in the figure- 4.32 (Chiba Prefecture Water Quality Division's Sampling stations).

Following are the major inflowing sources which contribute in the loading of the nutrients.

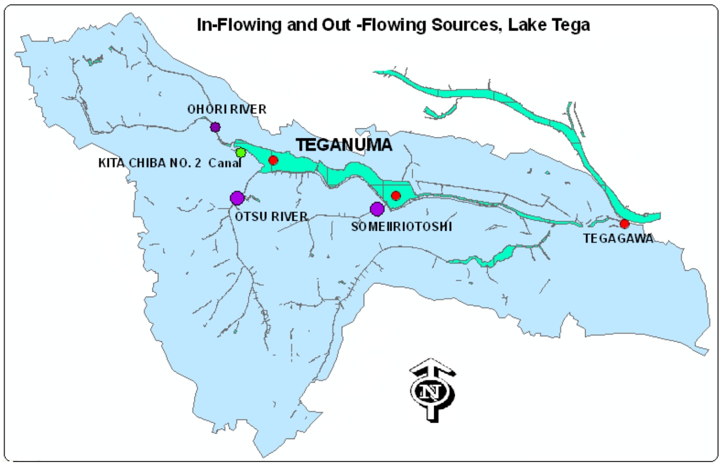


Figure 4.32: Sampling points for nutrients budget calculation

a) Ohori River
b) Otsu River
c) Somei-iriotoshi River
d) Kita Chiba No. 2 Pumping Station
e) Internal Loading
f) Ground Water Infiltration
g) Non point sources and small adjoining canals

a) Ohori River

The TN and TP influx of Ohori River decreased by 12% and 14% respectively since 1999 to 2005. The seven years (1999-2005) average TN influx of Ohori River is 84 Tons/Year and that of TP was 8 Tons/Year (*Figures 4.33 and 4.34*). TN and TP influxes accounted for 10% and 15% of total influx in the Lake Tega respectively (*Figures 4.35 and 4.36*).

b) Otsu River

Otsu River contributed the highest loading of nutrients among the natural inflowing sources and accounts for 18% and 19 % of total influx of TN and TP respectively based on the average influx of the years 1999 to 2005 (*Figures 4.35 and 4.36*). The nutrients load was decreased since 1999 to 2005 and the decreasing trend can be observed. The average TN and TP influxes of Ohori River I are 154 Tons/year and 10 Tons/year respectively (*Figures 4.33 and 4.34).*

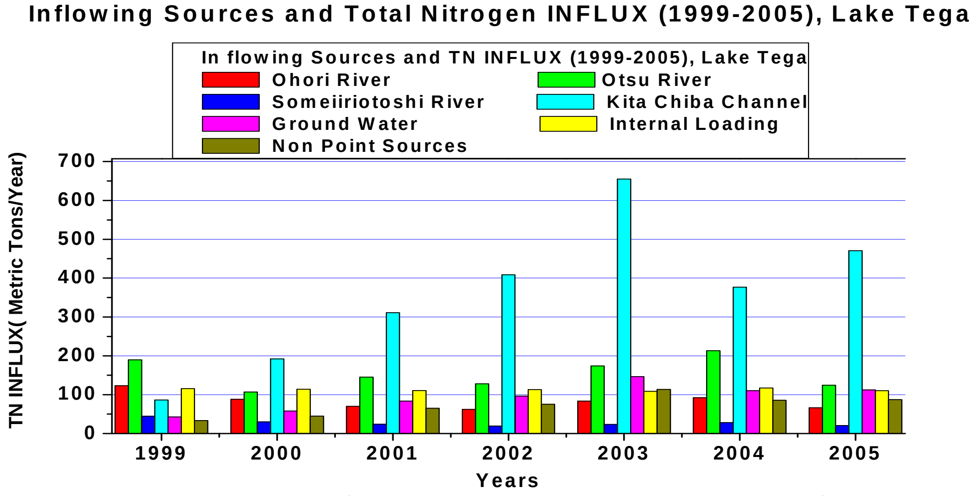


Figure 4.33: Inflowing sources and TN In-flux

c) Somei-iriotoshi River

Among the rivers, the Someiiriotoshi had the lowest contribution in the nutrient loading accounting 27 Tons/year and 1Ton/year of TN and TP influx respectively on the basis of nutrient influx date since 1999 to 2005(*Figures 4.33 and 4.34).* In the total influx, it contributed 3% of total TN influx and 2% of TP influx respectively. The influx of the Someiiriotoshi had the consistent loading in the consecutive years (*Figures 4.35 and 4.36*).

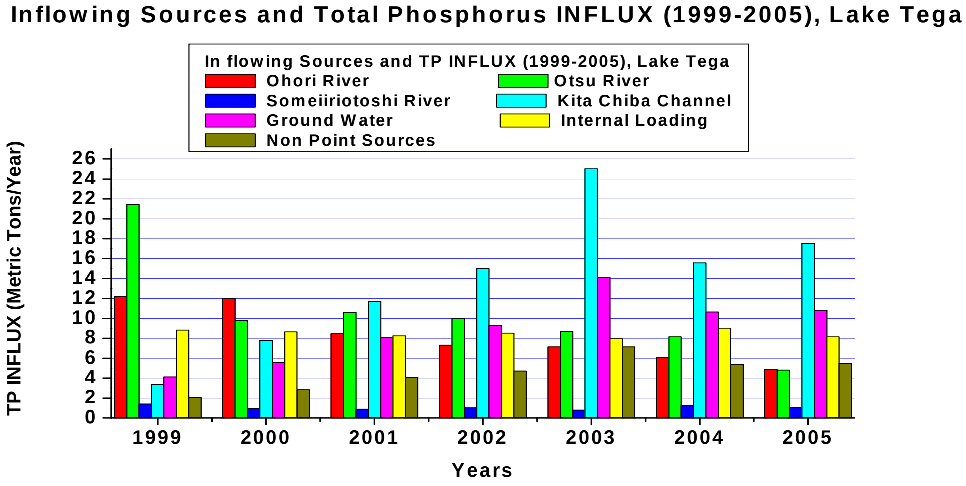


Figure 4.34: Inflowing sources and TP In-flux

d) North Chiba Water Conveyance Channel (Kita Chiba No. 2 Pumping Station)

It is to be noted that Kita Chiba No. 2 Pumping Station contributes significantly in the nutrient loading as the water volume to be discharged is the highest among other inflowing sources. It was observed that the Kita Chiba contributed 37% of TN and 24% of TP influx in the total budget (*Figures 4.35 and 4.36*). An average of 358 Tons and 14 Tons of TN and TP respectively were loaded by the Kita Chiba Pumping Station annually (*Figures 4.33 and 4.34).*

Since 2001, the nutrient load was fairly constant with slight ups and downs. It can be said that the nutrient load from the Kita Chiba No.2 Pumping station has a significant portion of the total load. However, the TN and TP concentration is lower in the water of Kita Chiba No.2 Channel (Fukawa, Tone River, with annual average TN and TP concentrations 2.7 mg/L and 0.1 mg/L respectively), the load is the highest because of the highest discharge.

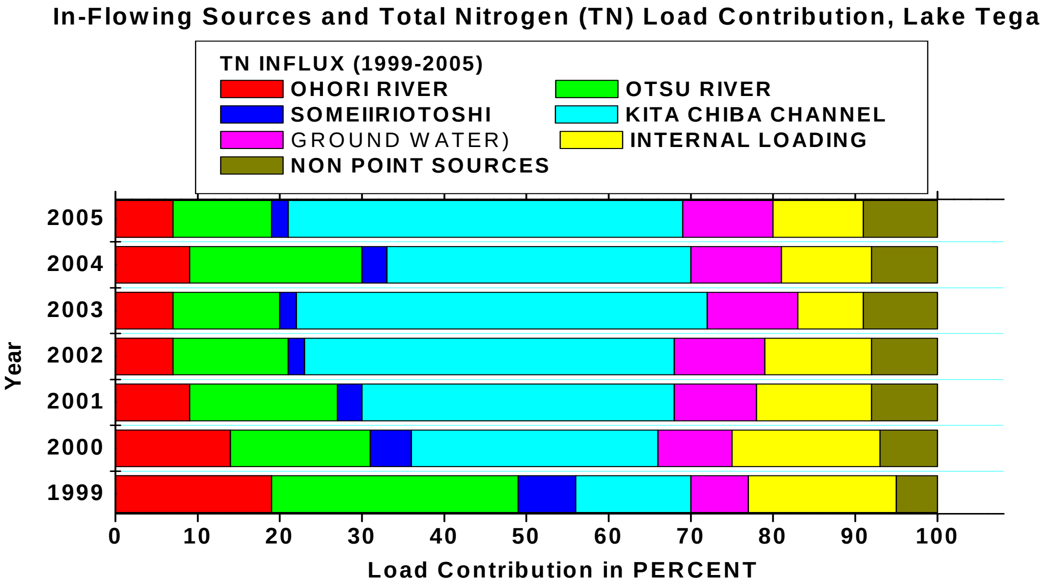


Figure 4.35: Inflowing sources and TN In-flux Contribution

e) Internal Loading

The share of nutrient release from the water sediment interface in the total nutrient influx was 113 Tons/year of TN and 9 Tons/year of TP based on the average data of seven years (1999-2005) (*Figures 4.33 and 4.34)*. Importantly, the nutrient release from the sediment was contributing to the lake water as equal as from the inflowing rivers which accounted

13% and 15 % of Total Nitrogen and Total Phosphorus respectively (*Figures 4.35 and 4.36*). (Details in the later part of the Chapter 4)

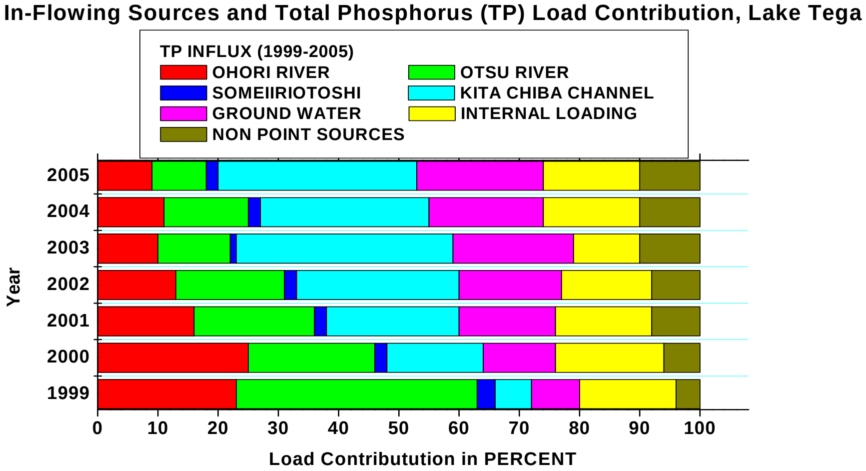


Figure 4.36: Inflowing sources and TP In-flux Contribution

Similarly, the non point sources contributed 8% of total influx of TN and TP accounting 72 Tons/year and Tons/year respectively (*Figures 4.33 and 4.34).* The nutrients influx contribution by non point source was highest in the year 2003 and this value was correlated with the annual precipitation of the year 2003 (*Figure 4.37*). This may be because of the heavy rainfall followed by run-off.

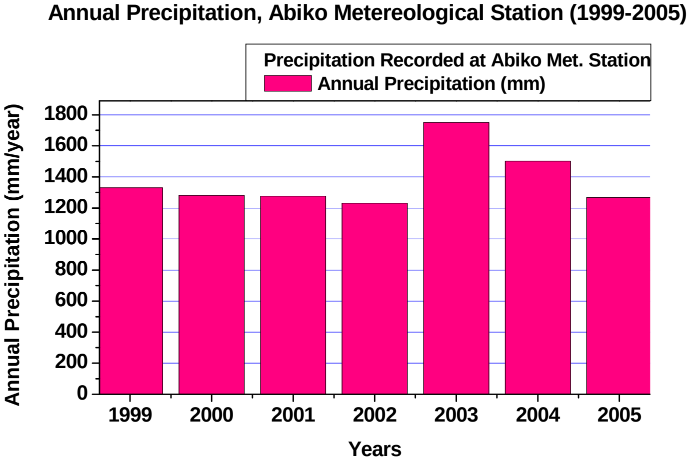


Figure 4.37: Annual Precipitation Recorded in Abiko Meteorological Station

f) Ground Water Infiltration and Non Point Source

Ground water contributed 10% of the total TN influx where as the TP load contribution accounted for 16 % based on the average value of seven years (1999 to 2005) (*Figures 4.35 and 4.36*). It was observed that 93 Tons/year of TN and 9 Tons/year of TP was loaded to lake Tega by ground water infiltration (*Figures 4.33 and 4.34).*

Out-flowing rivers and Nutrient Out-Flux

The major out-flowing sources include:

a) Tega River

b) Irrigation Pumping Stations

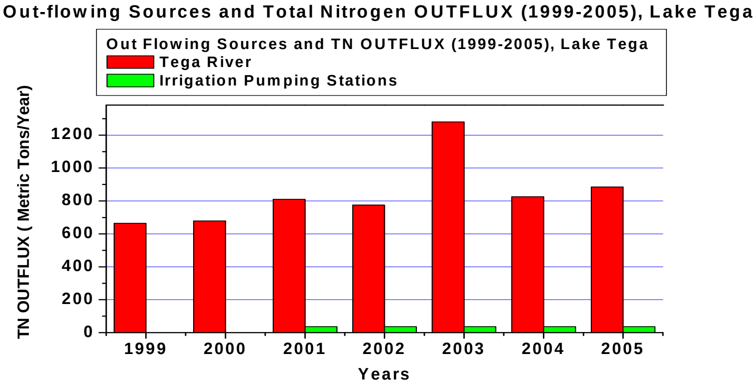


Figure 4.38:Out-Flowing sources and TN Out-flux

a) Tega River:

Tega River is the only major out flowing river which drains out 96 % of the total nutrients from the lake Tega based on the 1999 to 2005 out flux data. An average value of TN out-flux was calculated as 872 Tons/year and the TP out-flux was 59 Tons/year (*Figure 4.38 and 4.39*). Similar to the nutrient influx, the out-flux in the year 2003 was the highest among the other studied years.

b) Irrigation Pumping Stations:

The rest 4% of the total out-fluxes was shared by the seasonal irrigation pumping stations such as Izumi Pumping Station and Takanoyama Pumping Station (*Figures 4.38 and 4.39).* These stations were found to be operated during the months of April to August, the mid spring to summer seasons for paddy fields irrigation.

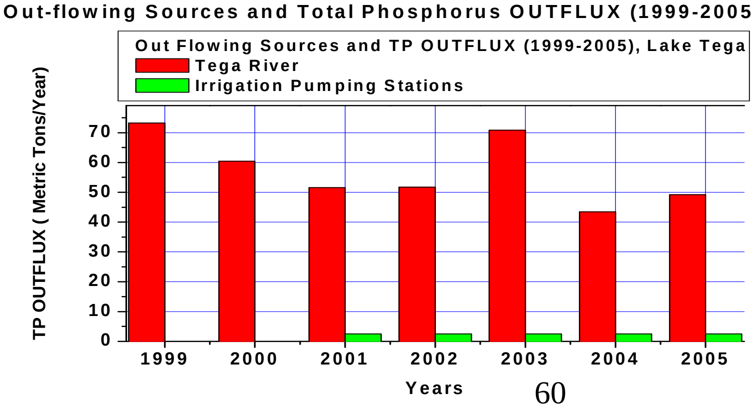


Figure 4.39: Out-flowing sources and TP Out-flux

The Nutrient Budget: INFLUX and OUTFLUX of Nutrients

In an average of seven years (1999 to 2005), 900 Tons of Total Nitrogen and 56 Tons of Total Phosphorus were loaded in Lake Tega where as 872 Tons of Total Nitrogen and 59 Tons of Total Phosphorus was out-fluxed from the lake Tega annually (*Figure 4.40 and 4.41*). In the years 1999, 2000 and 2001, the out-flux was observed to be higher than influx but since 2002, the influx of the nutrients was found to be higher than influx. However, the average difference is not very significant (about 3%).

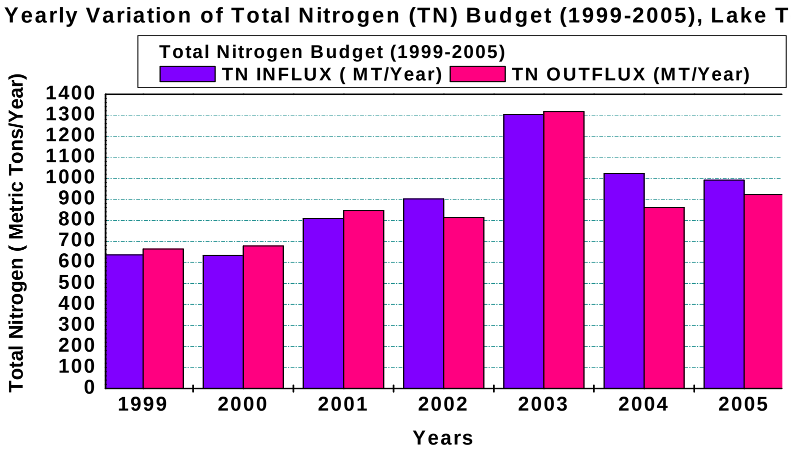


Figure 4.40: Yearly Variation of TN Budget, 1999-2005

The introduction of Tone River water increased the input of nutrients. However, the water retention time has decreased significantly after the Tone River water introduction through the North Chiba Water Conveyance Channel.

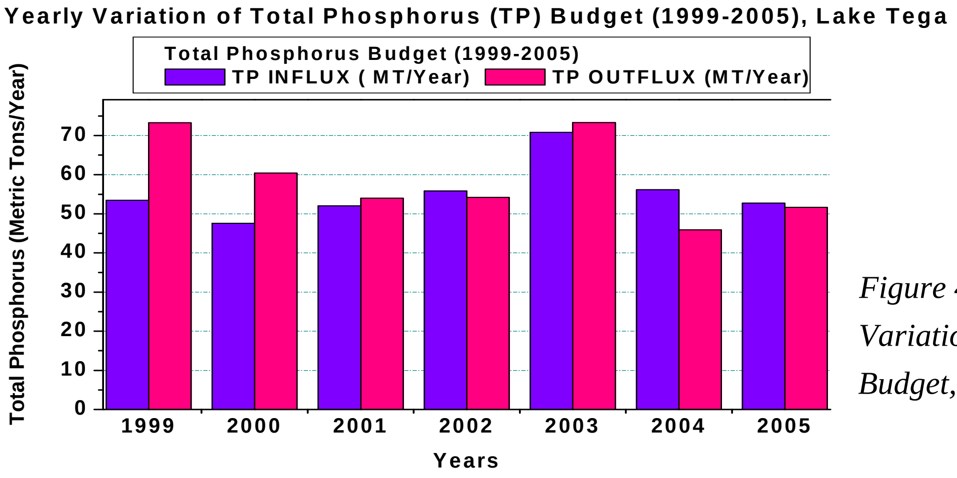


Figure 4.41: Yearly Variation of TP Budget, 1999-2005

4.2.3 Average Water Residence Time and Water Quality

The area of the lake is considered as 6.5 km^2 with an average depth of 0.86 meter. It means that the volume of lake water is 5.59 million m^3. With an annual average out-flux from the Tega Lake of the year 1999 to 2005, the residence time was calculated. The out-flux from Tega River, Irrigation Pumping Stations and Evaporation was considered (Detail in Water Budget Calculation).

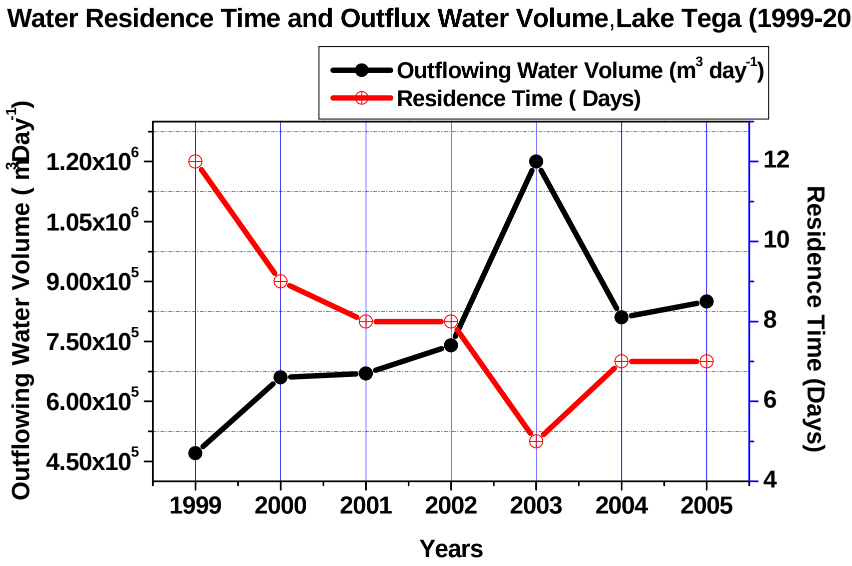


Figure 4.42: Water Residence Time and Out-flowing Water Volume

In the year 1999, the water residence time was 12 days and decreased to 9 days in 2000 and further decreased to 8 days in the year 2001 (*Figure 4.42)*. In the late 2000, Tone River water was introduced in a trial basis and after 2001; the introduction of Tone River Water through Kita Chiba was made regular. The minimum water residence time was 5 days and achieved in the year 2003 (*Figure 4.42)*.The precipitation in the year 2003 was highest in the period between 1999 to 2005 (*Figure 4.37*).

The relationship between Water Residence Time (WRT) and water quality of lake was studied. Since the period of 1999 to 2005, the correlation between water residence time and the TN, TP, COD and TSI (Chl *a*) were observed separately. It was found that there was a strong correlation between each water quality parameters and water residence time (*Figures: 4.43 to 4.50*) at both TG1 and TG2.

The regression lines were plotted (not shown here: but the R value and p value are mentioned in each graph (*Figures 4.43 to 4.50*).

In TG1, The COD level and water residence time showed a strong correlation (R=0.84, p=<0.02) and indicated that the COD level was dropped significantly along with the reduction of water residence time (*Figure 4.44*). Similarly, TN, TP and Chl *a* also showed significant reduction in their concentration level. For TSI (Chl *a*), the correlation coefficient and confidence level was R=0.86, p=<0.02 respectively (*Figure 4.43*).

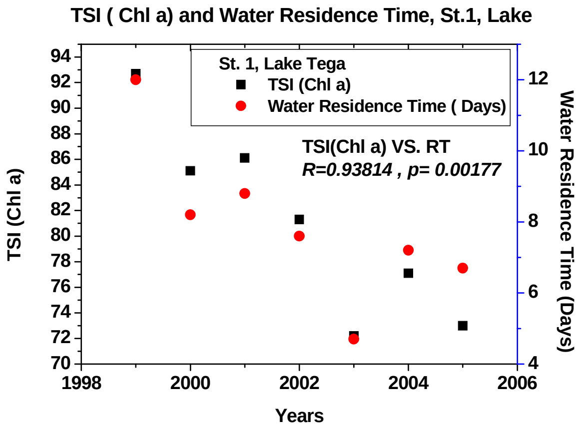


Figure 4.43: WRT Vs Chl a at TG1

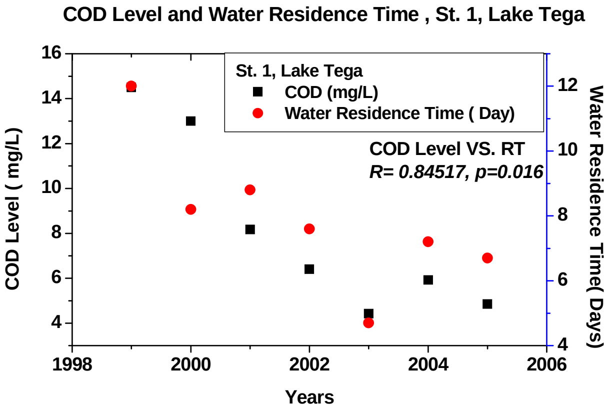
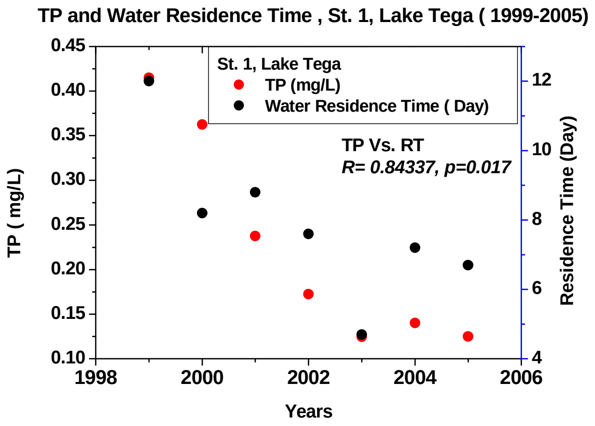


Figure 4.44: WRT Vs COD at TG1

The regression lines were plotted against TN and residence time and it was found a good correlation (R=0.86, p=<0.02) however, the TN concentration was not dropped below the concentration of 3 mg/L even though the residence time was lower than 6 days (*Figure 4.46).*



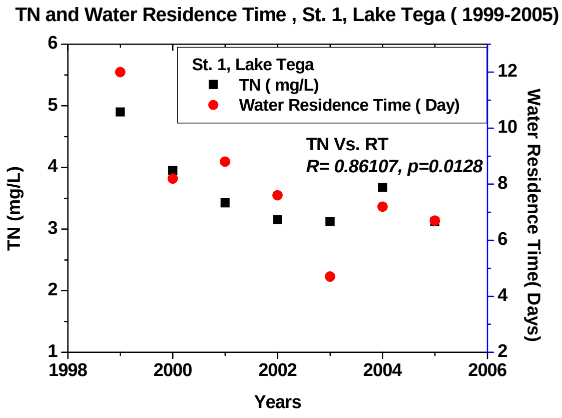


Figure 4.45: WRT Vs TP at TG1

Figure 4.46: WRT Vs TN at TG1

Similarly, the TP concentration was found to be dropped at its minimum level when the water residence time was the minimum and TP concentration and residence time was in good correlation (R=0.84, p=<0.02) (*Figure 4.45*).

In case of TG2, reduction in water residence time significantly reduced the concentration of TN, TP, COD and Chl *a*.

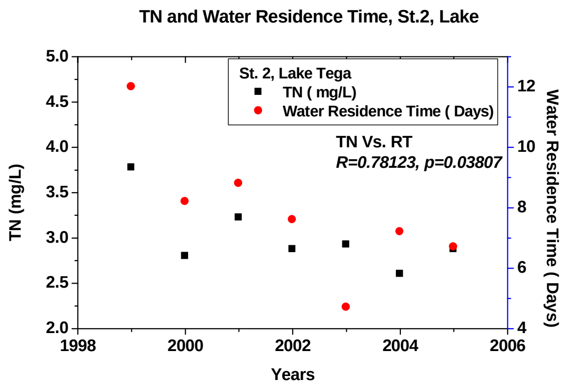


Figure 4.47: WRT Vs TN at TG2

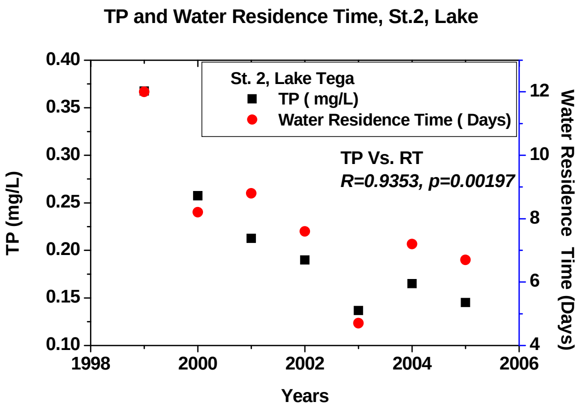


Figure 4.48: WRT Vs TP at TG2

The TN and TP concentrations were found to be dropped along with the reduction of residence time. The correlation between TN and water residence time was in good agreement (R=0.78, p=<0.04) as that of TG1. The TP and water residence time showed a very good correlation (R=0.93, p=<0.002) indication the dropping of TP concentration along with reduction of water residence time.

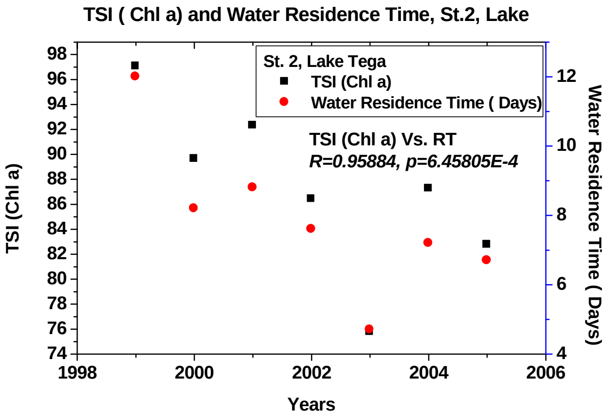


Figure 4.49: WRT Vs Chl a at TG2

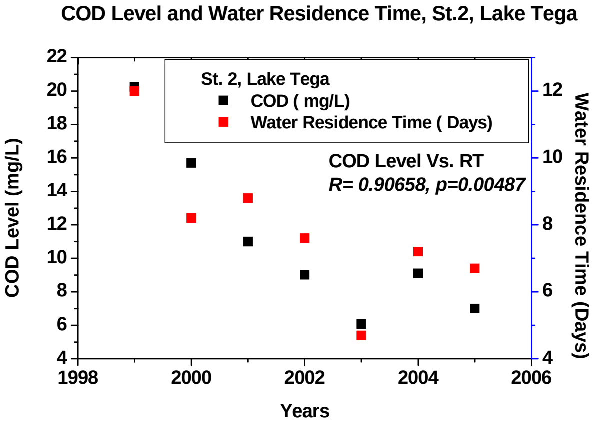


Figure 4.50: WRT Vs COD at TG2

Similarly, COD level and water residence time and Chl *a* and water residence time also showed similar results. It was found that the COD level decreased well when the water residence time dropped down (R= 0.90, p= 0.005). A very strong correlation between Chl a concentration and water residence time was observed (R=0.95, p=<0.02) in TG 2 and shown in the figures 4.47 to 4.50.

4.3 Sediment Nutrients Release (Internal Loading of Nutrients)

The nutrient release experiment showed the concentration variation of $PO_4{}^{3-}$-P and $NH_4{}^{+}$-N at 7 ^{0}C, 16 ^{0}C and 26 ^{0}C and the samples were drawn in the interval of 0 hrs, 3 hrs, 6 hrs and 12 hrs and analyzed.

Table 4.2: Temperature, Time Interval and Nutrient Release

Nutrient Release Experiment , Lake Tega					
Temperature	Conc. at Lake	Conc_ 0 Hrs	Conc_ 3 hrs	Conc_ 6 Hrs	Conc_ 12 Hrs
^{0}C	mg/L	mg/L	mg/L	mg/L	mg/L
TG 1: Phosphate- P					
7 ^{0}C	**0.0988**	**0.1031**	**0.1134**	**0.0978**	**0.11572**
16 ^{0}C	**0.0988**	**0.0932**	**0.149**	**0.188**	**0.2521**
26 ^{0}C	**0.0988**	**0.114**	**0.1373**	**0.14798**	**0.1621**
TG2: Phosphate- P					
7 ^{0}C	**0.057**	**0.06842**	**0.0513**	**0.05261**	**0.063**
16 ^{0}C	**0.057**	**0.06272**	**0.0728**	**0.07598**	**0.0796**
26 ^{0}C	**0.057**	**0.0602**	**0.0736**	**0.0789**	**0.0871**
TG 1 : Ammonium-N					
7 ^{0}C	**0.79**	**1.2539**	**1.6716**	**1.5883**	**1.1876**
16 ^{0}C	**0.79**	**1.06**	**1.615**	**1.7402**	**1.9241**
26 ^{0}C	**0.79**	**1.9048**	**1.629**	**1.8902**	**2.1695**
TG 2 : Ammonium-N					
7 ^{0}C	**0.62**	**0.7117**	**0.7584**	**0.7282**	**0.7613**
16 ^{0}C	**0.62**	**0.6452**	**0.6313**	**0.7121**	**0.943**
26 ^{0}C	**0.62**	**0.6916**	**1.179**	**0.8334**	**0.8986**

In TG1, the concentration of $PO_4{}^{3}$-P increased significantly at 16 ^{0} C reaching to 0.25 mg/L from 0.098 mg/L of lake water concentration (R^2= 0.91) after 12 hours of the beginning of the experiment. The concentrations measured at 0 hrs, 3 hrs, 6 hrs and 12 hrs showed an increment along with the increment of the time hours of incubation (*Figure 4.51* and *Table 4.2*). However, at 7 ^{0} C, the concentration variation wasn't that significant. At 26 ^{0} C, the increment of concentration along with the time period consistently increased reaching to 0.16 mg/L (R^2= 0.98).

Similarly, at TG2, $PO_4{}^{3}$-P concentration increased along with the time period of incubation at 16 ^{0}C (R^2= 0.95) and 26 ^{0}C (R^2= 0.97) reaching to 0.079 mg/L and 0.087 mg/L after 12 hrs of incubation. However, at the temperature of 7 ^{0} C, the concentration of $PO_4{}^{3}$-P was found to be lower than the concentration at the beginning of the incubation. In this case the nutrient was loaded into the sediment and sediment worked as a sink rather than a source of internal loading (*Figure 4.53* and *Table 4.2*).

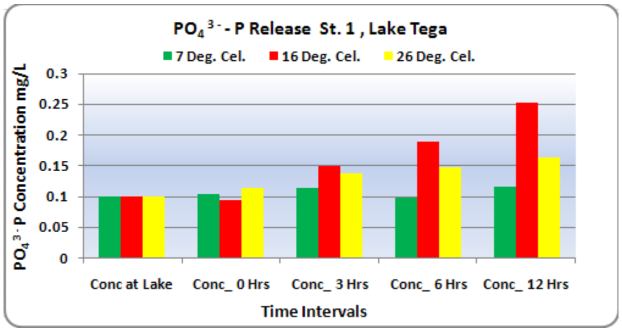


Figure 4.51: $PO_4{}^{3-}$-P Release at TG1

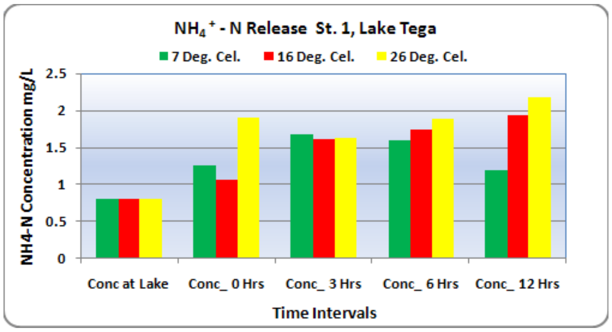


Figure 4.52: $NH_4{}^{+}$-N Release at TG1

In case of TG2, the concentration was observed the highest at the sample which was drawn after three hours of incubation at 26 ^{0}C (R^2= 0.25). The other samples that were incubated at 16 ^{0}C and 7 ^{0}C also showed the higher concentration value than that of at 0 (at 16 ^{0}C, R^2= 0.70 and at 7 ^{0}C, R2= 0.67).

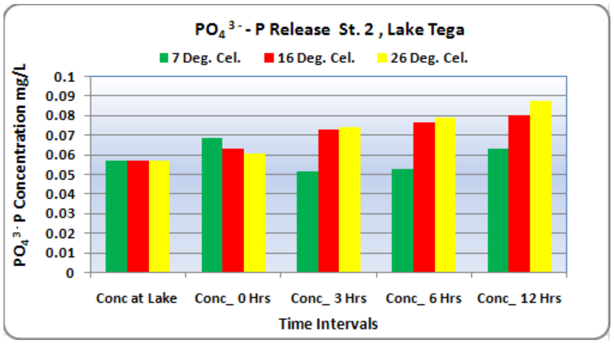


Figure 4.53: $PO_4{}^{3-}$-P Release at TG2

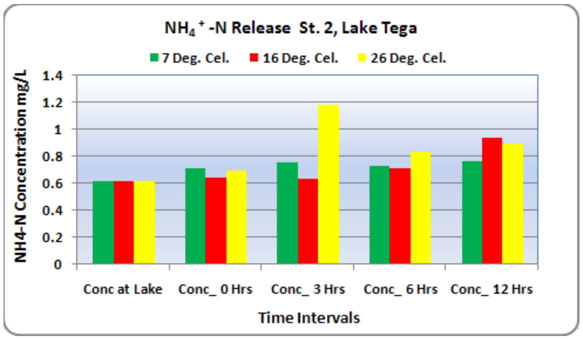


Figure 4.54: $NH_4{}^{+}$-N Release at TG2

The nutrient release experiment also showed a significant influence of temperature on $NH_4{}^{+}$-N release from the sediment water interface along with the time period at different temperature scenarios during the incubation (*Figure4.56 and Table 4.2).*

In TG1, the NH_4^+-N concentration increased significantly at 16 ^{0}C along the time period and the concentration increased from 1.06 mg/L at 0 hrs to 1.92 mg/L at12 hrs. At 16 ^{0}C t the concentration increment was very consistent (R^2= 0.94) unlike at 26 ^{0}C (R^2= 0.66). At 3 hrs and 6 hrs of incubation, the NH_4^+-N concentration was found to be lower than that of concentration at 0 hrs at 26 ^{0}C. At 7 ^{0}C, the concentration was observed to be the highest after 3 hrs of incubation and then slowly decreased (R^2= 0.25) (*Figure 4.52 and Table 4.2).*

Based on this nutrient release experiment at different temperature and time period conditions, the daily nutrient release per square meter area of the lake was calculated (QIN Boqiang *et al*., 2006) .

Table 4.3: Nutrient Release Rates at Various Temperature Conditions

Nutrient Release Rate (mg m^{-2} day^{-1}) Lake Tega				
Temperature	TG 1: NH_4^+-N	TG2: NH_4^+-N	TG1: PO_4 $^{3-}$.-P	TG2: PO_4 $^{3-}$-P
^{0}C	mg m^{-2} day^{-1}	mg m^{-2} day^{-1}	mg m^{-2} day^{-1}	mg m^{-2} day^{-1}
7	**54.97**	**26.20**	**4.41**	**-1.53**
16	**101.06**	**70.00**	**10.12**	**5.13**
26	**164.88**	**95.61**	**14.17**	**10.05**

Particularly, the TG1 showed the higher release rates of nutrients at all temperature conditions while at TG2 at lower temperature condition, the sediment acted like a sink rather than a source for PO_4 ^{3}-P. The release of NH_4^+-N was highest at TG1 at the temperature of 26 ^{0} C and reached to 164 mg m^{-2} day^{-1} which was lower in TG2 at the same temperature. Similarly, the release rates of NH_4^+-N at 7 ^{0}C and 16 ^{0}C were higher in TG1 than in Station 1 (Table *4.3 and Figure 4.55*). However, in the both the stations, the NH_4^+-N release rates were positively correlated with the temperatures (*Figure 4.55*).

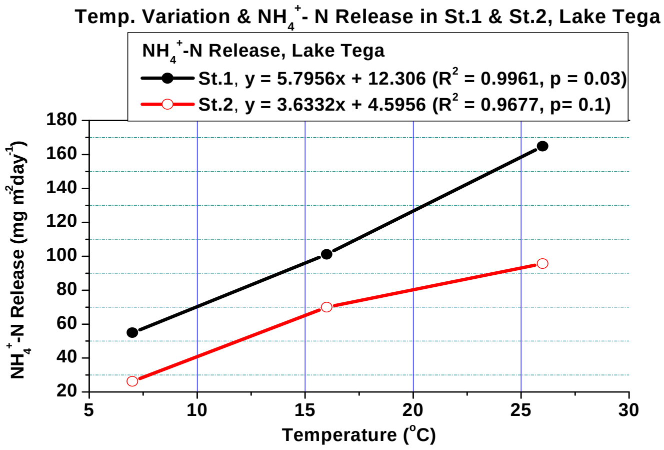


Figure 4.55: NH_4^+-N Release at TG1

Similarly, the $PO_4{}^{3}$-P release rates were also found higher at the higher temperature in both the stations. However, at TG2, $PO_4{}^{3}$-P was absorbed by the sediment at the lower temperature *(Figure 4.56)*. The highest value of $NH_4{}^{+}$-N release rate was observed at 26 ^{0}C in TG1and it reached to 14 mg m^{-2} day$^{-1.}$. Similar to $NH_4{}^{+}$-N, the $PO_4{}^{3}$-P also showed the positive correlation as shown in the figure 4.56.

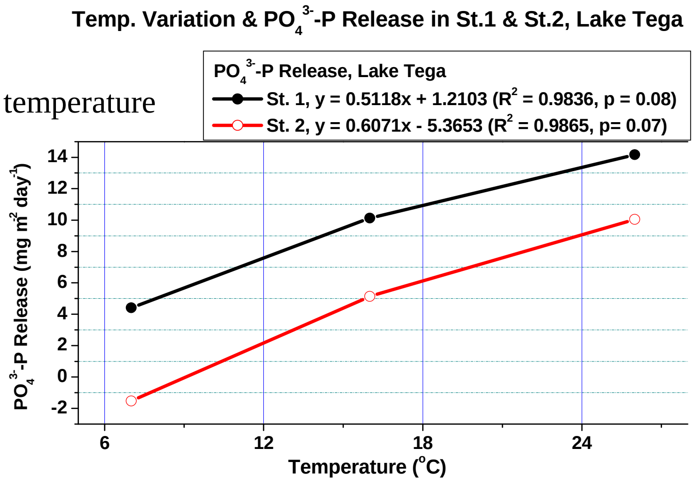
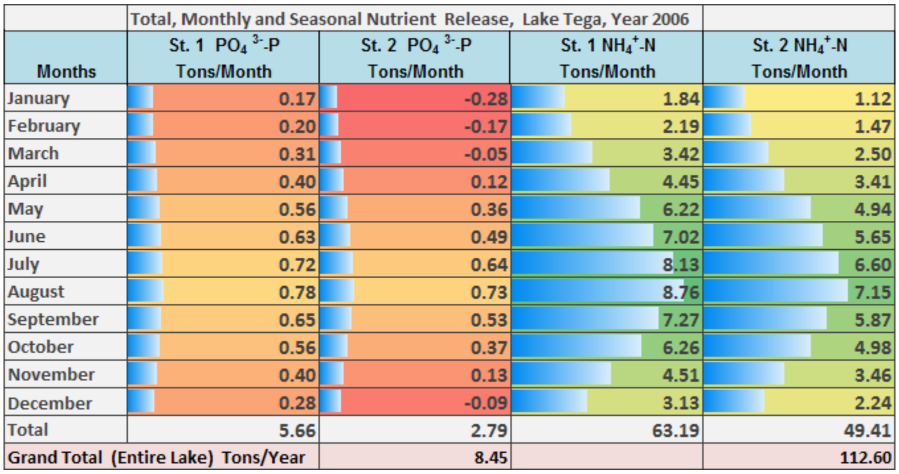


Figure 4.56: $PO_4{}^{3-}$P Release at TG1

The linear regression lines were plotted against temperature and the release rate (mg m^{-2} day^{-1}) in both the stations and for both the dissolved nutrients $PO_4{}^{3-}$-P and $NH_4{}^{+}$-N. On the basis of those regression equations, the daily nutrient release rates were calculated with the daily lake water temperatures of both the stations.

The highest nutrient release rates were observed in August and July of the year 2006. About 9 tons and 8 tons of $NH_4{}^{+}$-N were released at TG1 in the months of August and July. Similarly, the $PO_4{}^{3-}$-P also released highest in the months of June, July and August. The internal loading of $PO_4{}^{3-}$-P was lower in TG2 than in TG1with the values of 5.6 Tons/year and 2.8 Tons/year respectively, totaling of 8.4 Tons/Year for the year 2006 (*Figure 4.57*).



	Total, Monthly and Seasonal Nutrient Release, Lake Tega, Year 2006			
Months	St. 1 $PO_4{}^{3-}$-P Tons/Month	St. 2 $PO_4{}^{3-}$-P Tons/Month	St. 1 $NH_4{}^{+}$-N Tons/Month	St. 2 $NH_4{}^{+}$-N Tons/Month
January	0.17	-0.28	1.84	1.12
February	0.20	-0.17	2.19	1.47
March	0.31	-0.05	3.42	2.50
April	0.40	0.12	4.45	3.41
May	0.56	0.36	6.22	4.94
June	0.63	0.49	7.02	5.65
July	0.72	0.64	8.13	6.60
August	0.78	0.73	8.76	7.15
September	0.65	0.53	7.27	5.87
October	0.56	0.37	6.26	4.98
November	0.40	0.13	4.51	3.46
December	0.28	-0.09	3.13	2.24
Total	5.66	2.79	63.19	49.41
Grand Total (Entire Lake) Tons/Year		8.45		112.60

Figure 4.57: Monthly Variation of Nutrient Release

NH_4^+-N with its highest release at TG1 in the summer, accounted for 63 Tons/Year, where as at TG2, the load reached to 49 Tons/year and the total release of NH_4^+-N in the entire lakes was accounted to 112.6 Tons/Year (*Figure 4.59*). Similarly, the PO_4^{3-}P release was higher in summer and lowest in the winter (*Figure 4.58*).

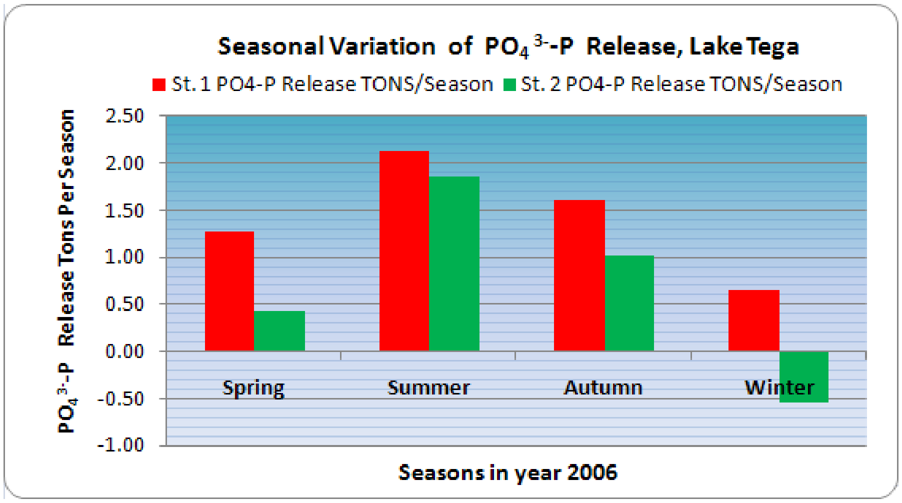


Figure 4.58: Seasonal PO_4^{3-}-P Release at TG1

Based on the monthly release, the seasonal variation was calculated and it was found that the summer had the highest release of nutrients from the sediment interface to the overlying water. Winter season showed the minimum release load to the overlying water. The nutrient release rates at spring and autumn were moderate, in between two extremes, the summer and the winter (*Figures 4.57, 4.58, 4.59*).

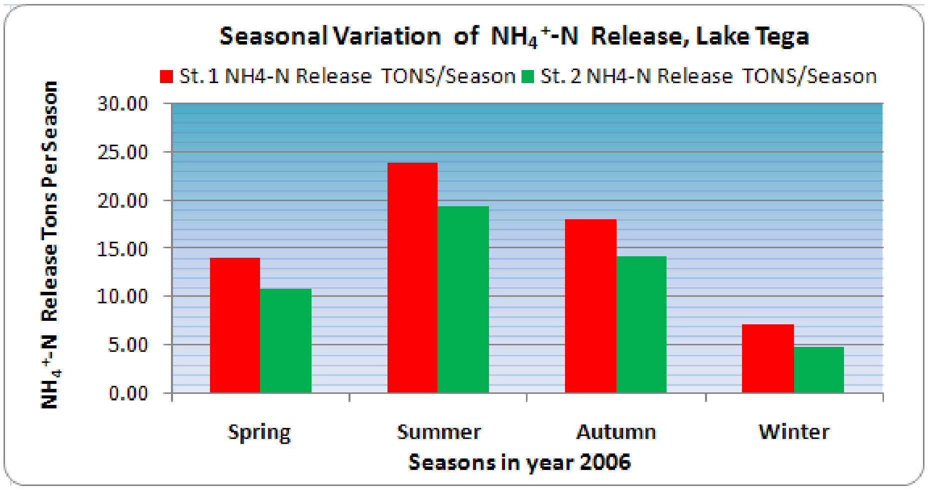


Figure 4.59: Seasonal NH_4^+-N Release at TG1

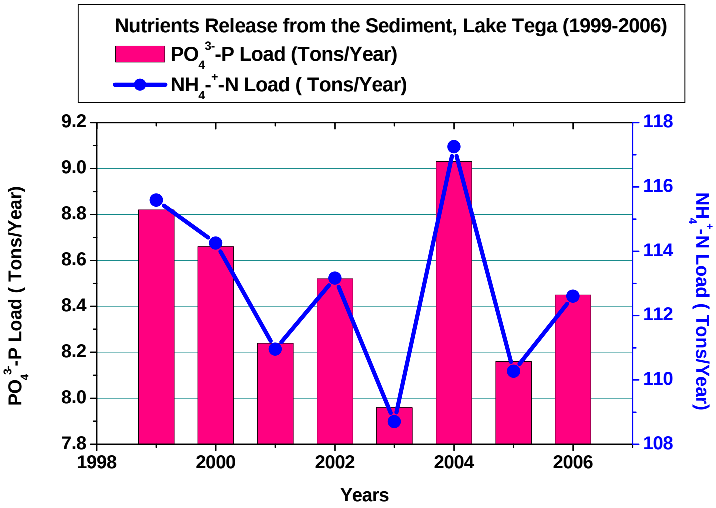


Figure 4.60: Nutrient Release from Sediment, 1999-2005

In the similar way, the internal loading of nutrients in the lake for the year 1999 to 2006 was also calculated (*Figure: 4.60*). Importantly, the nutrient release from the sediment was contributing to the nutrient load to the lake water as equal as from the inflowing rivers which accounted 11% and 15% of Total Nitrogen and Total Phosphorus respectively in the year 2005. Similarly, the internal loading contribution in the nutrient budget calculation was found significant in the years 1999-2005 (*Figure 4.61*).

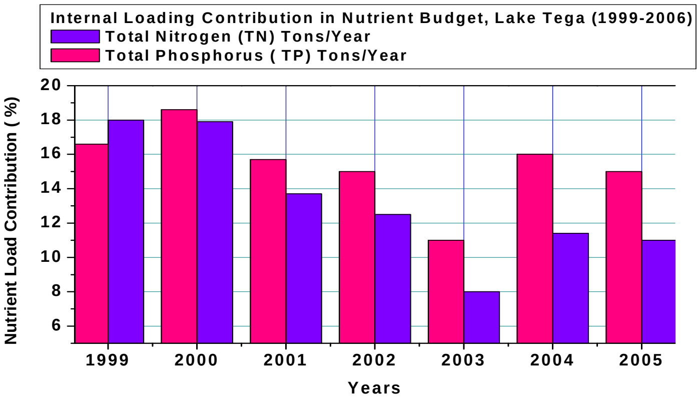


Figure 4.61: Internal Loading Contribution, 1999-2005

However, the calculation of internal loading for the previous years was estimated based on the nutrient release experiment that was done in the year 2006. To attain the accuracy, the daily lake water temperature was computed on the basis of daily atmospheric temperature.

4.4 Land Use Pattern/Ratio Analysis, Lake Tega Watershed, 1974 to 1994

The land use map of the year 1974 shows that the land use pattern in the watershed was dominated by the forest and barren land, covering 27% of the total area and it was followed by paddy fields which cover 19% of the area (*Figure 4.62 (b*). However, an empty area was observed in the in the eastern region (*Figure 4.62 (b*)) due to unavailability of the land use data.

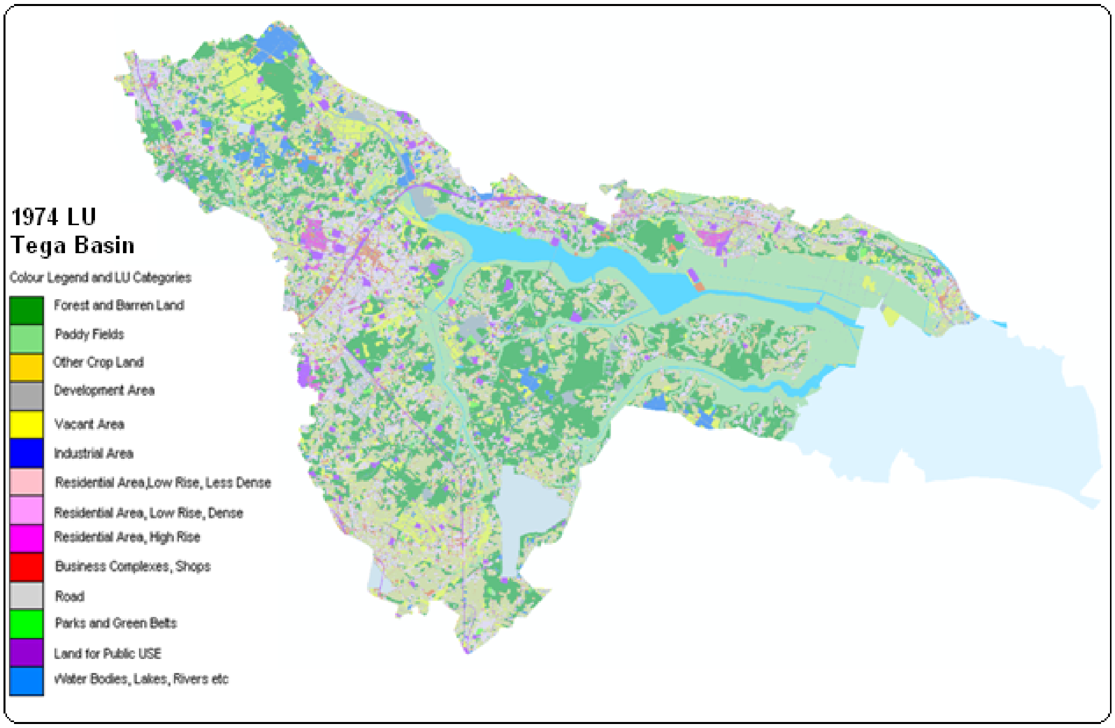


Figure 4.62 (a): Land Use 1974)

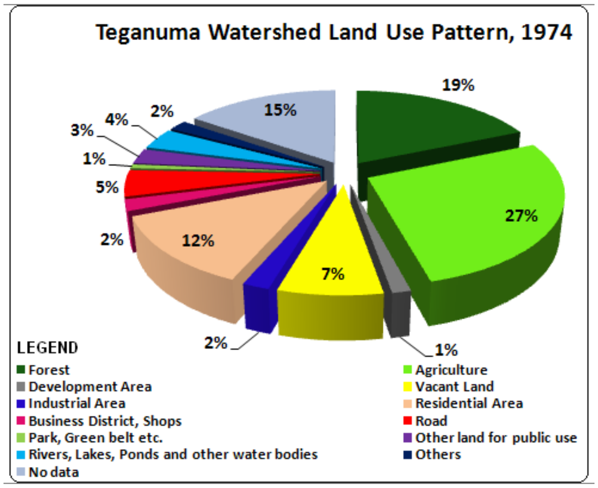


Figure 4.62 (b): Land Use 1974

In the year 1979, the major land area in the watershed was covered by the agricultural lands which account for 35% and is followed by the forest and barren land, comprising 22% of total land area (*Figure 4.63 (a)*. About 17% of the of the total agricultural land area (35%) was covered by paddy fields and rest 18 % was shared by other crops such as vegetables and other food varieties.

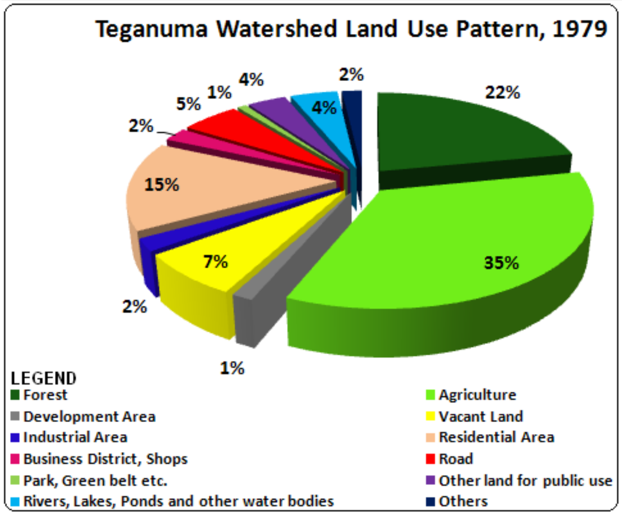


Figure 4.63 (a): Land Use 1979

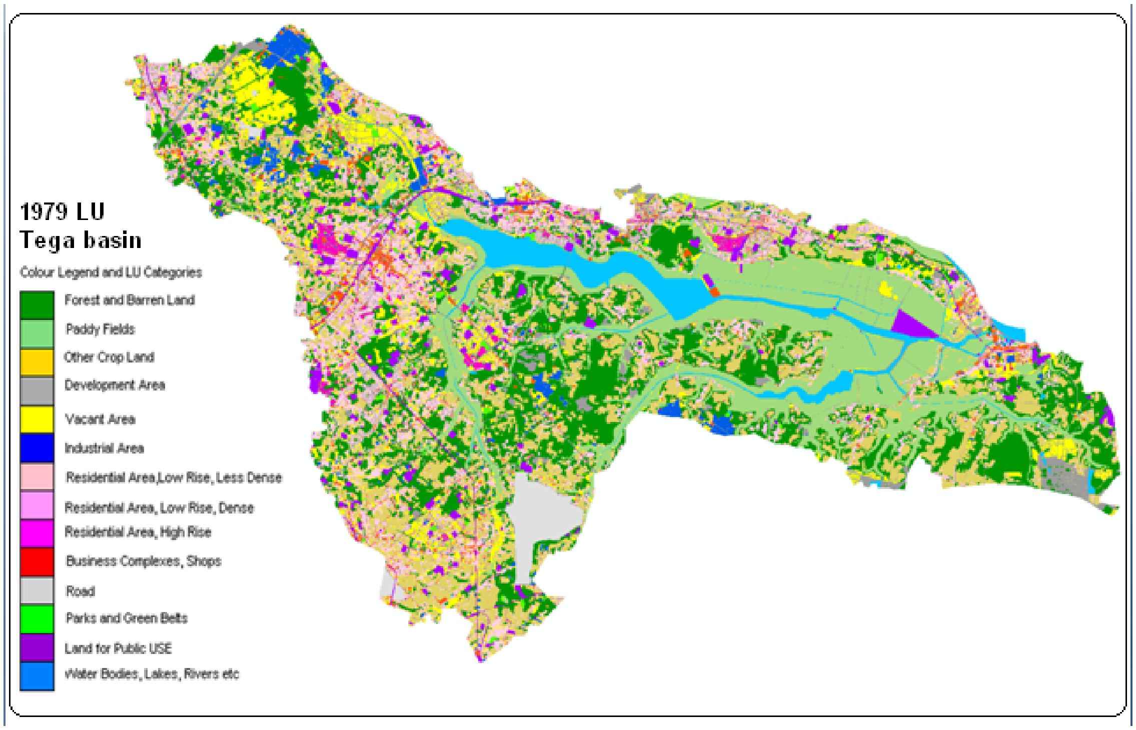


Figure 4.63 (b): Land Use 1979

Low rise house with less densely inhabited, Low rise house with densely inhabited, and high rise house and apartment account for 13%, 1% and 1 % respectively, totaling of 15% (*Figure 4.63 (a)*). It was observed that the both banks of Otsu River, Tega River, Shimo Teganuma and the southern part of the Teganuma areawere covered by paddy fields. The major sources of irrigational water for the paddy fields are the near by lakes and rivers.

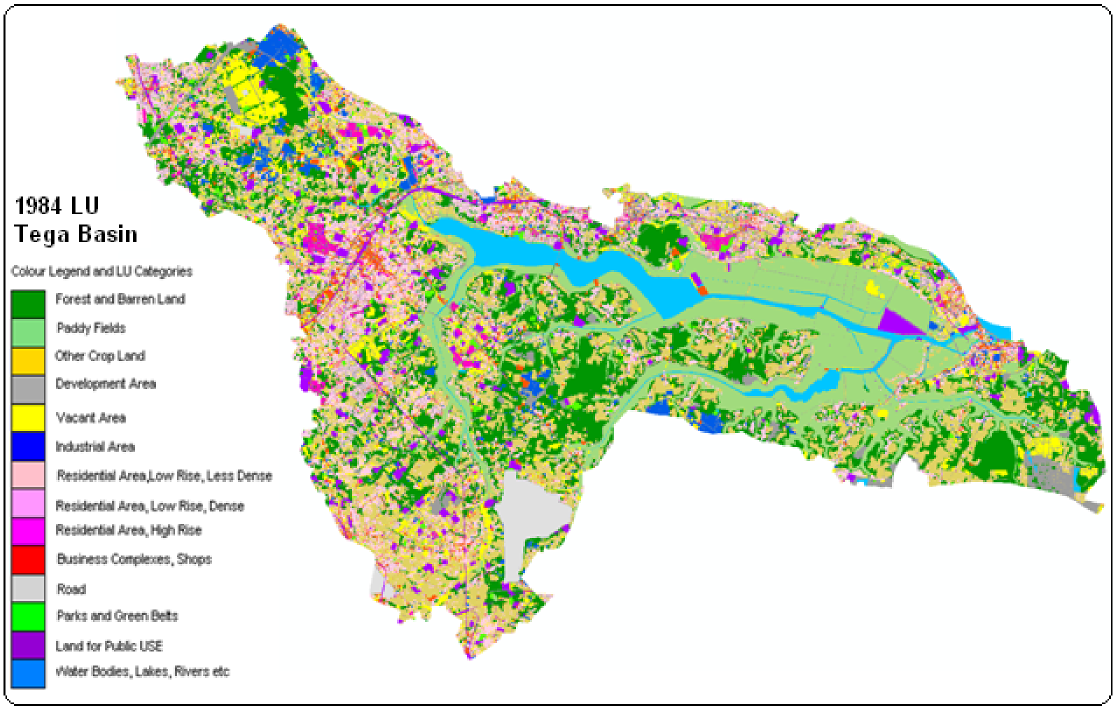


Figure 4.64 (a): Land Use 1984

Similarly, the LU pattern for the year 1984 (*Figure 4.64*) suggests that the agricultural land has the equal almost equal share with paddy fields and other crops lands comprising 16% and 17% of the total agricultural land respectively. The forest area and barren land category has decreased by 3% compared to the 1979 LU, accounting 19% of the total watershed area (*Figure 4.64 (b)).* The residential area comprised 16% of the total basin area and it was 1% increment than five years ago. High rise apartment houses and densely inhabited low rise houses showed no increment since 1979. However, the business complexes, shops increased by 1% since 1979.

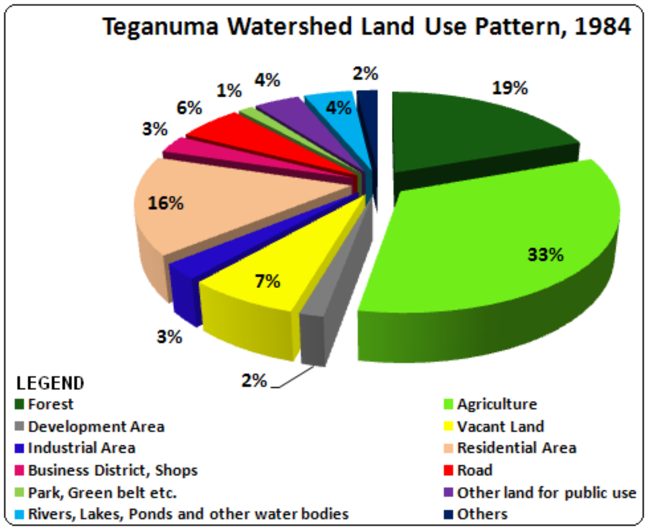


Figure 4.64 (b): Land Use 1984

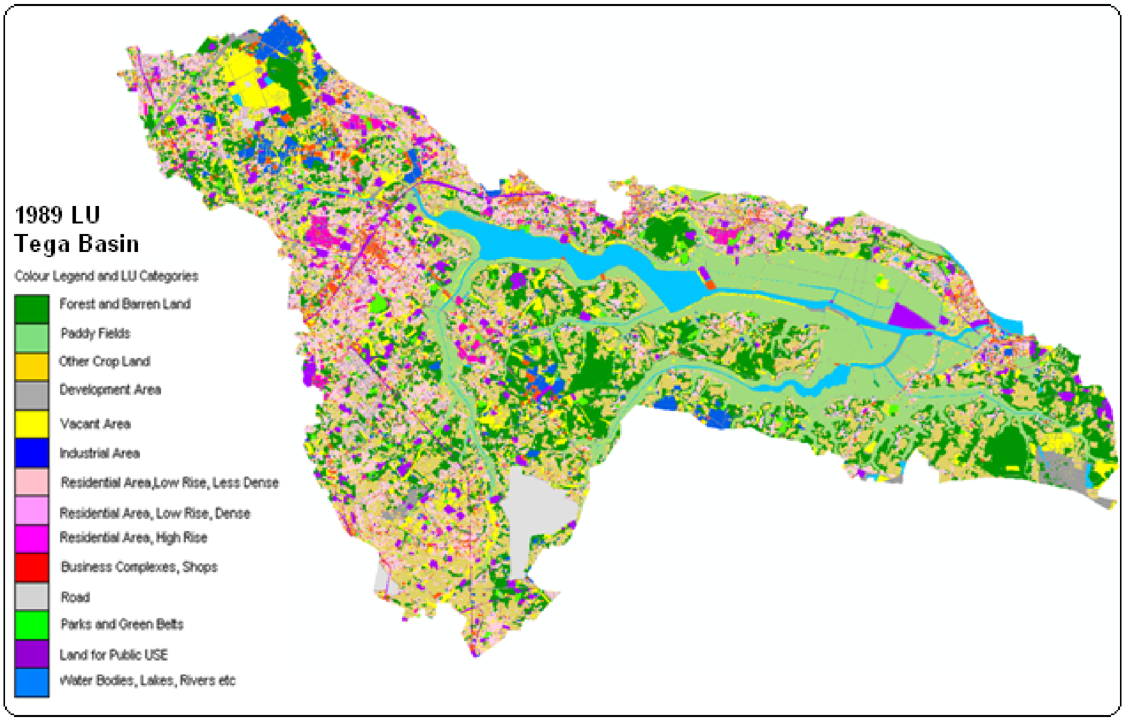


Figure 4.65 (a): Land Use 1989

In 1989 (*Figure 4.65*), the paddy field was decreased by 1% while the crop and other agricultural land remain constant. The residential area comprises 17% of the total area which includes high rise apartment type and low rise buildings. The forest and barren land type was decreased by 2%, and the vacant area was increased by 2% compared to the land use practice of the year 1984 (*Figure 4.64 (b)).* But the industrial area, development area, road area were remained constant in five years of period in the watershed.

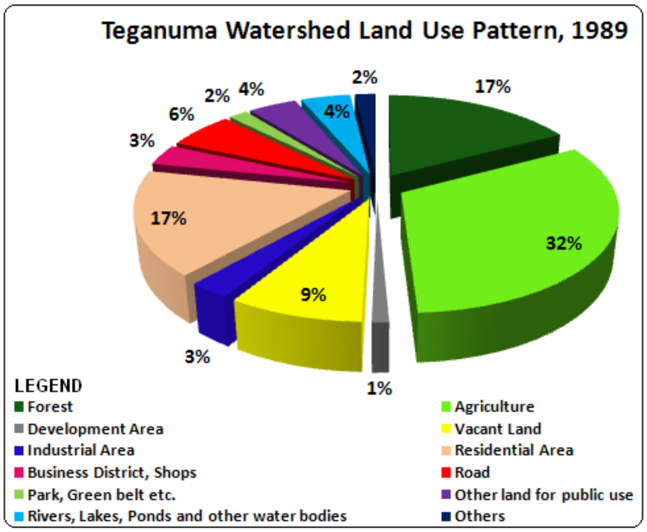


Figure: 4.65 (b): Land Use 1989

The land use ratio of the year 1994 showed that the forest and barren land, agricultural area and vacant land have been decreased by 1% but the business complexes and land for public uses increased by 1% each (*Figure 4.66 (a)).*

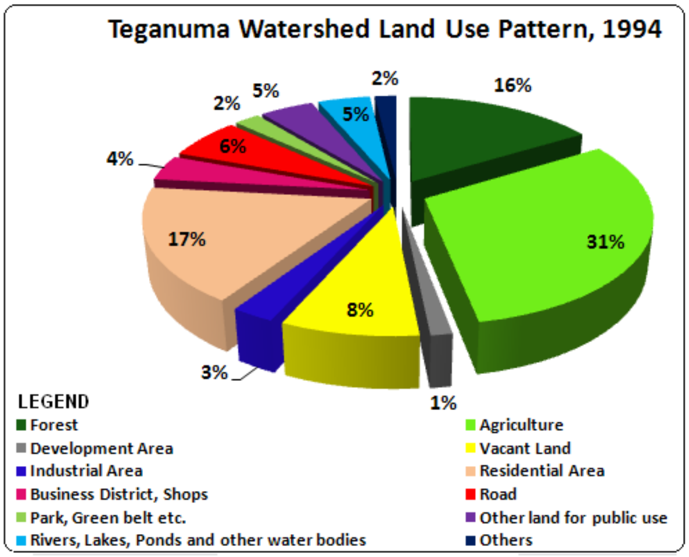


Figure 4.66 (a): Land Use 1994

So, within the five years period the land use pattern wasn’t significantly changed in the Tega watershed. However, if the land use pattern for 20 years is observed, some changes could be noticed. The western part of the lake Tega has more urbanized characteristics with more residential areas, business complexes, shops etc while the eastern and southern part of the lake have more agricultural areas, including paddy fields (*Figures 4.62 and 4.66).*

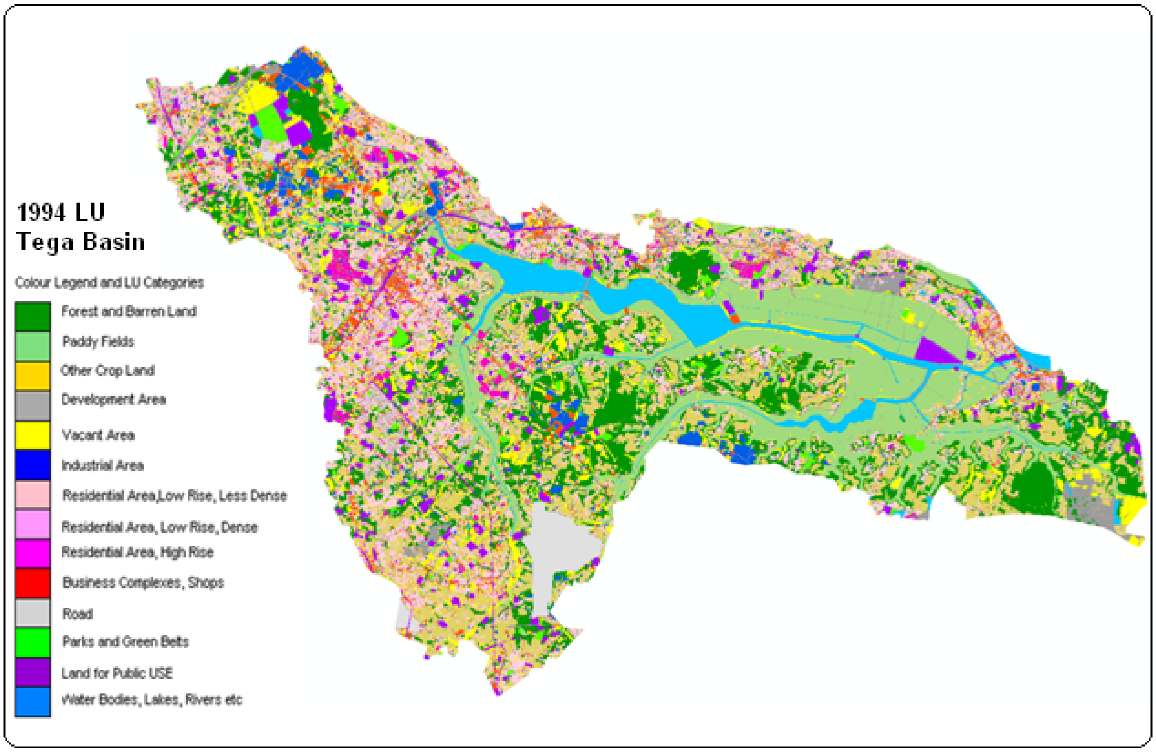


Figure 4.66 (b): Land Use 1994

4.5 Sediment Environment Analysis

4.5.1 Analysis of Physical Characteristics of Lake Tega Sediment

Water Content

The water content of the sediment cores were decreased down along with the sediment depth. In TG1, the highest water content was found to be 72% at the depth of 25-30 cm. Average water content in the station was 68%. The water content decreased along with the depth significantly from the depth of 25 cm ($R^2 = 0.66$). The bottom layers had the lowest water content as 65% (*Figure 4.67*).

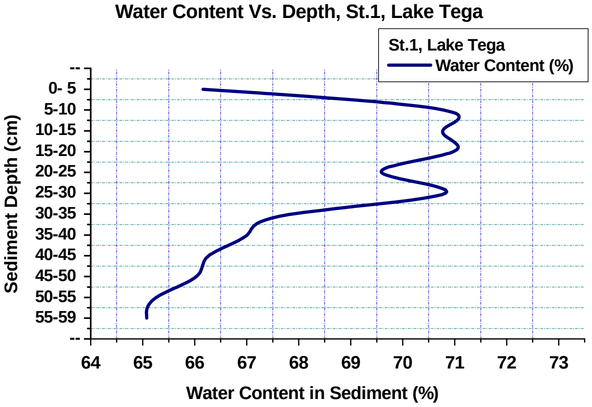


Figure 4.67: Water Content Vs. Depth TG1

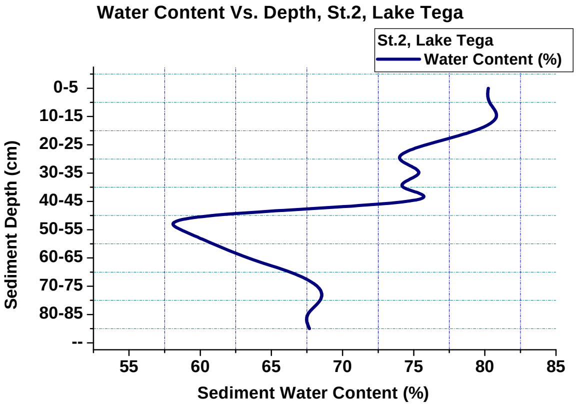


Figure 4.68: Water Content Vs. Depth TG2

The water content at TG2 had the highest value as 81% in the upper layer (10-15 cm) and average water content in the overall core was found to be 71%. The water content reached minimum as 57% at the sediment depth of 45-50 cm (*Figure 4.68)*. Like in TG1, the water content was decreased along with the depth ($R^2 = 0.47$). Comparing to the stations, it was found that the water content in the sediment of TG2 was higher than that of TG1.

Porosity and Bulk Density

Porosity was decreasing along with the sediment depth and found highest in the top layers of both the stations (*Figures 4.69 and 4.70*). The highest porosity value was recorded as 94% in the TG1 at the sediment depth of 5-10 cm and it showed the minimum value as 91% at the depth of 35-40 cm (Figure *4.69).*

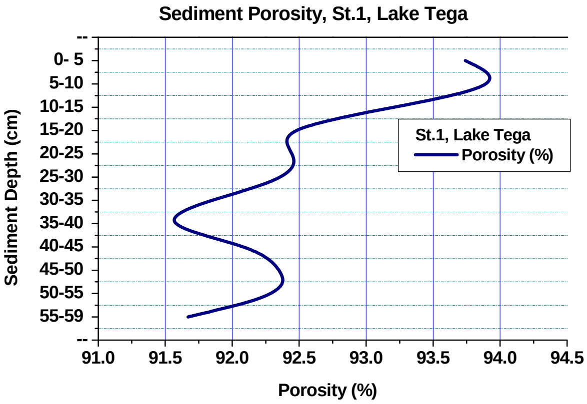


Figure 4.69: Porosity Vs. Depth TG1

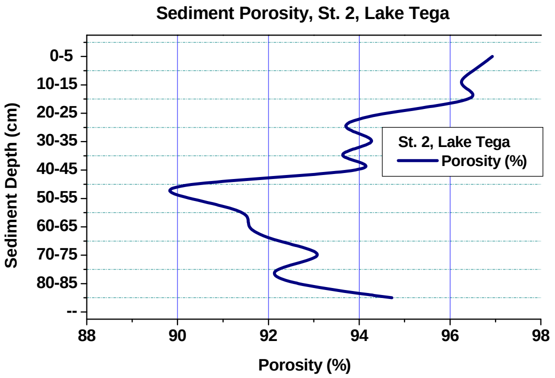


Figure 4.70: Porosity Vs. DepthTG2

Similarly, the sediment of the TG2 was found to be more porous at the depth of 15-20 cm with the value of 97%. However, the upper layers from 0-20 cm, the porosity was higher with the value of 96% (*Figure 4.70).*

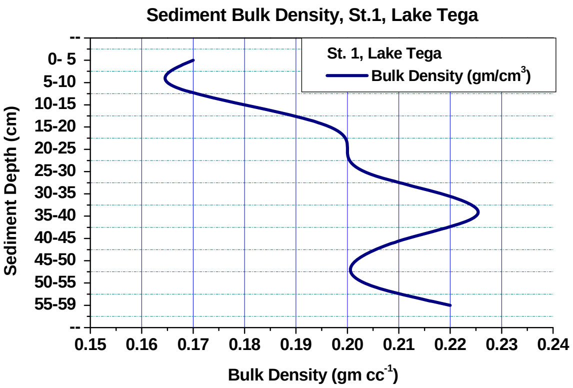


Figure 4.71: Bulk Density at TG1

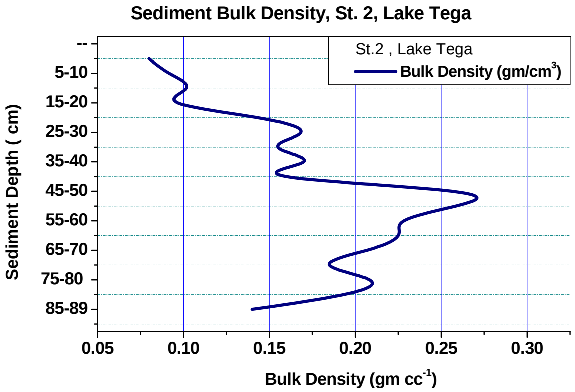


Figure 4.72: Bulk Density at TG2

At both the stations, the highest values of the bulk densities were observed in the middle of the sediment cores. However, the values were higher down to the bottom layers. In TG1, the highest bulk density was observed to be 0.23 gm cc^{-1} at the sediment depth of 35-40 cm and the mean bulk density after the depth of 15-20 cm was 0.21 gm cc^{-1} while the minimum bulk density was 0.16 gm cc^{-1} at 5-10 cm depth (*Figure: 4.71*).

In case of TG 2, the bulk density was reached to 0.29 gm cc^{-1} at the depth of 45-50 cm. The minimum value was observed at the depth top layers and reached to 0.08 gm cc^{-1} at 0-5 cm (*Figure: 4.72*).

Particle Size Analysis

In TG1, the occurrence of sand in the layers of sediment cores was found decreasing along with the down profile ($R^2 = 0.70$, p = 0007). The minimum value reached to around 7% at the sediment depth of 50-55 cm. The highest percent of sand was found in the sediment depth of 5-10 cm with the value of 59%. The sediment layer of 30-35 cm had the highest silt amount accounting 76%. The occurrence of silt slowly Increased down the sediment profile ($R^2 = 0.53$, p = 0.007). The silt was lowest at the depth of 5-10 cm. Similarly, the clay part of the sediment accounted highest at the sediment depth of 50-55 cm with the value of 22%. The clay particles increased along with the sediment depth profile ($R^2 = 0.72$, p = 0.0005). One of the lowest occurrences of the clay particles was observed at the sediment depth of 25-30 cm (*Figure 4.73*).

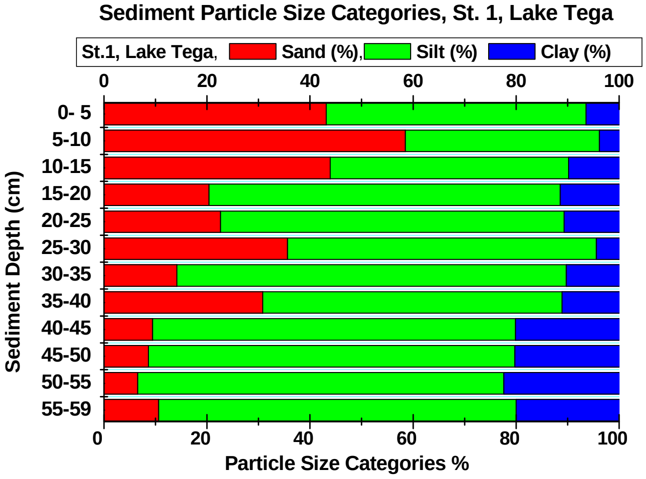


Figure 4.73: Sediment Particle Categories, TG1

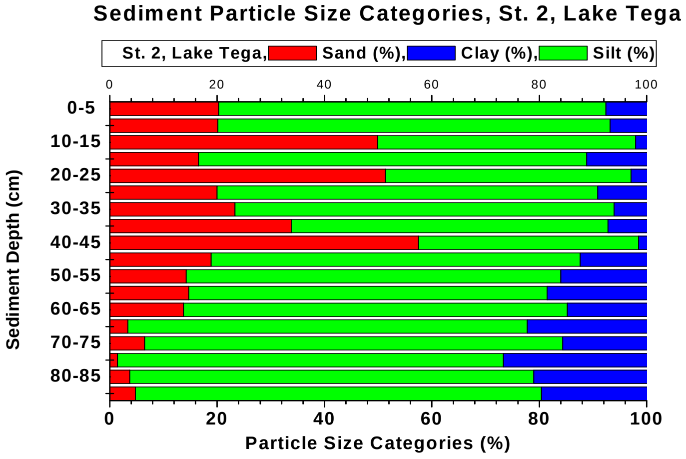


Figure 4.74: Sediment Particle Categories, TG2

In case of TG2 (*Figure 4.74*), the sand particles are dominant in the sediment depth of 40-45 cm, 20-25 cm and 10-15 cm with 58 %, 51% and 50% occurrence respectively. Unlike TG1, the decreasing pattern of sand particles was not consistent ($R^2 = 0.28$ p = 0.007). The silt particles were found almost in the same percent through out the sediment profile ($R^2 = 0.08$, p = 0.1).

The highest occurrence was 78%, which was observed at the sediment depth of 70-75 cm and an average occurrence was in the entire column was 67%. However, silt fraction of the particles was increasing along with the sediment depth (R^2 = 0.62, p = <0.0001) and it reached to 27% at the sediment depth of 75-80 cm as the highest value. Comparatively, the sediment depth of 15-20 cm had the value in the higher range among the other upper layers (*Figure 4.74).*

4.5.2 Chemical Analysis of Sediment Characterstics

Carbon Nitrogen Ratio (C/N Ratio)

The total carbon was found higher at the upper sediment depth layers in both the stations. In TG1, the value reached to 5.5%   at 5-10 cm as the highest value and at the 15-20 cm sediment layer, the value was 4.5 % as the second highest value. The carbon value was decreased along with the sediment depth (R^2 = 0.72) and reached the lowest value at the sediment depth of 50-55 cm (*Figure: 4.75*). Similarly, the Nitrogen value slightly decreased along with the sediment depth (R^2 = 0.52). The higher values of the Nitrogen were 0.48 % and 0.43% at 15-20 cm and 25-30 cm respectively. Similar to that of total Carbon, the Nitrogen had the lower values in the bottom layers (*Figure: 4.75*).

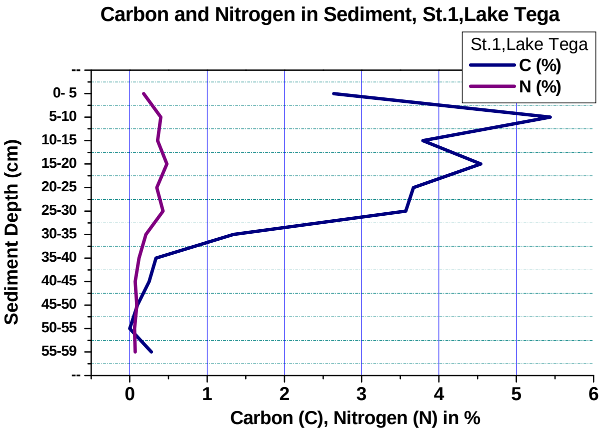


Figure 4.75: C% and N% in Sediment, TG1

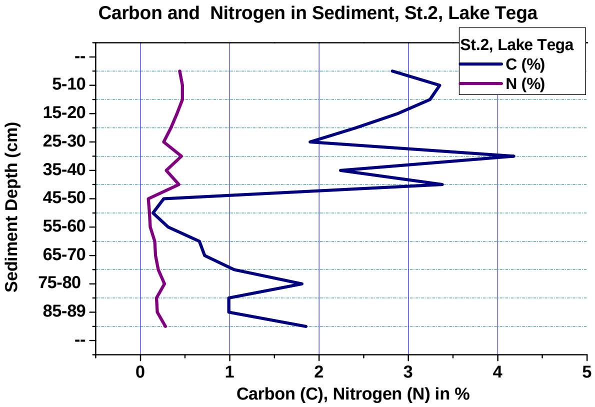
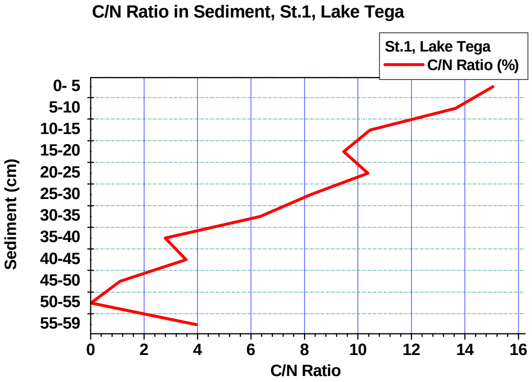


Figure 4.76: C% and N% in Sediment, TG2

The total carbon was highest at the sediment depth of 30-35 cm and the value reached to 4%. The minimum value was observed at the depth of 50-55 cm and was 0.14 %. The upper layers of sediment of the TG2 also showed the higher Nitrogen value (*Figure 4.76*). The upper depth from 5-15 cm had the highest value as 0.47% and the value decreased along with the bottom. The minimum value, 0.09 %, was observed at the sediment depth of 45-50 cm (*Figure 4.76*). Total carbon values were observed higher in TG1than in TG2 in most of the layers and more specifically in the upper layers up to 25-30 cm.

C/N ratio was found to be decreased along with the sediment depth in both the stations. The western part (TG1) had the highest C/N ratio of 15 at 0-5 cm and in eastern side (TG2) at the depth of 30-35 cm, the C/N ratio reached to 9.1.



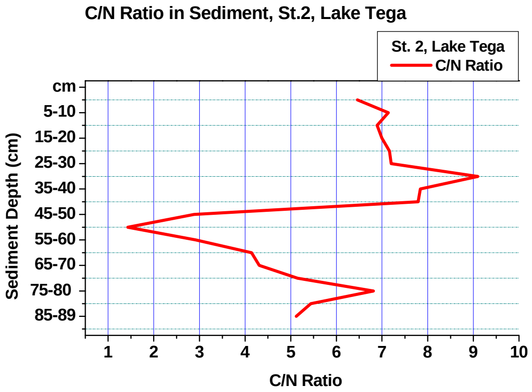


Figure 4.77: C/N Ratio in Sediment, TG1

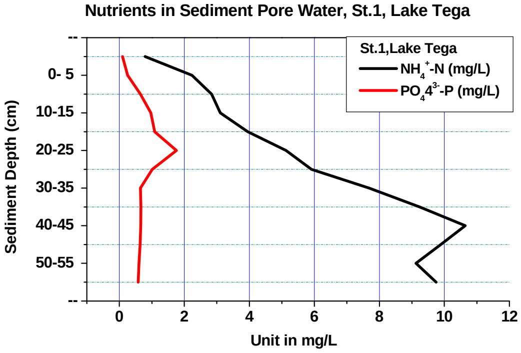
Figure 4.78: C/N Ratio in Sediment, TG2

In TG 1, the C/N ratio was significantly decreasing along with the depth ($R^2 = 0.88$, $p = <0.0001$). The highest C/N ratio of 15 was observed at 0-5 cm and then it decreased to its lowest value as 0.01 at the bottom layer in between 50 cm and 55 cm (*Figure 4.77*).

Similarly, the C/N ratio at the TG2 reached to 9.1 at the depth of 30-35 cm as a highest value in the entire column (*Figure 4.78*). After the depth of 35 cm, the C/N ratio was found to be decreased. But after the depth of 55 cm, it slightly increased to the depth of 75-80 cm and the value reached to 6.8 then started decreasing again.

Pore Water Nutrient

The concentration of $NH_4^{\,+}$-N and $PO_4^{\,3-}$-P were found to be higher in the sediment pore water than that of overlying water. In TG1, the $NH_4^{\,+}$-N concentration increased along with the sediment depth to 40-45 cm and reached the value of 10.64 mg/L and after that it slightly decreased. The $PO_4^{\,3-}$-P concentration was found to be increased till the depth of 20-25 cm and the maximum value was recorded as 1.76 mg/L and then decreased before it attained an almost constant concentration (4.79).



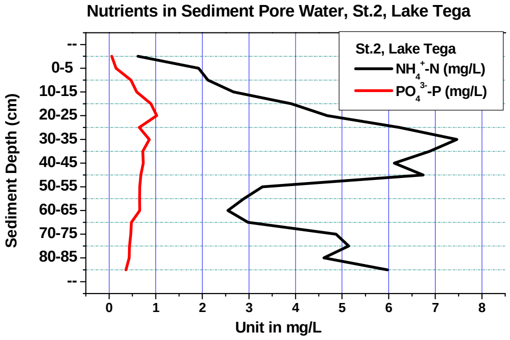


Figure 4.79: Pore Water Nutrients, TG1

Figure 4.80: Pore Water Nutrients, TG2

The NH_4^+-N concentration values in the TG1 sediment pore water were 2.8 to 13.4 times higher than in overlying water. The concentrations of NH_4^+-N and PO_4^{3-}-P at the overlying water of TG1 were 0.79 mg/L and 0.10 mg/L respectively (4.79).

In case of TG2, the concentrations of NH_4^+-N and PO_4^{3-}-P at the overlying water were 0.62mg/L and 0.057 mg/L respectively. The NH_4^+-N concentration was found to be 7.46 mg/L at the depth of 30-35 cm as the highest value in the core column (*Figure 4.80*). The pore water concentrations were 3 to 12 times higher than the overlying water. The NH_4^+-N was increased to the depth of 30-35 cm and then started decreasing till 60-65 cm. The PO_4^{3-}-P concentration at the sediment depth of 20-25 cm was the highest with the value of 1.03 mg/L and the pore water PO_4^{3-}-P concentration values were 2.6 to 17 times higher than the overlying water (*Figure 4.80).*

Heavy Metal Analysis- Hexachromium , Cr (VI)

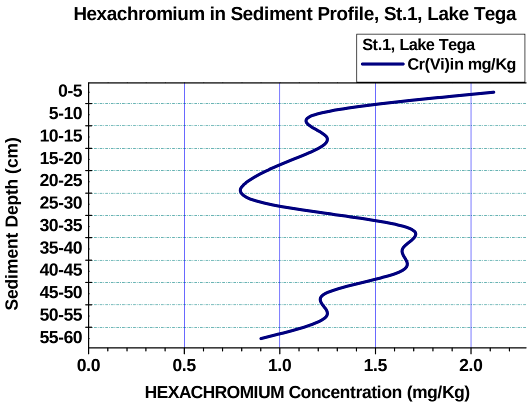


Figure 4.81: Cr (VI) in Sediment, TG1

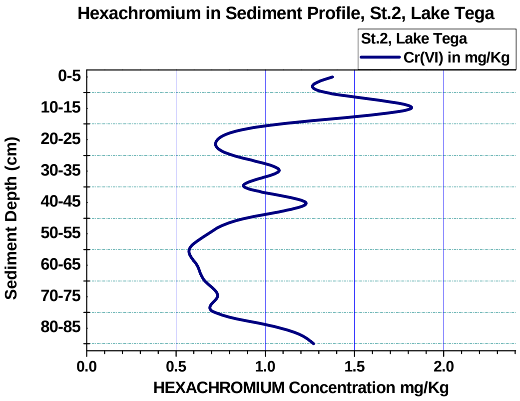


Figure 4.82: Cr (VI) in Sediment, TG1

The concentration of Hexachromium in the TG1was found higher at 0-5 cm, the upper sediment layer and slowly decreased down the profile till the depth of 25-30 cm. After this depth the concentration was increased up to the sediment depth of 45-50 cm. One of the highest values was found at the sediment depth of 30-35 cm and has the value of 1.91 mg/kg (*Figure 4.81).* Chromium (VI) is found highest in the upper layer at the sediment depth of 10-15 cm in TG2 and the value reached to 2 .2 mg/kg. The value was also found higher in at the sediment depth of 40-45 cm. Below the sediment depth of 40-45 cm, the Hexa-chromium concentration was found to be lower (*Figure 4.82).*

4.5.3 Radio-nuclides Activity Analysis and Sedimentation Rate

^{210} Lead and ^{137} Cesium Activity in Tega Sediment

The activity of ^{210} Pb $_{(excess)}$ was found highest in the surface sediment at the depth of 0-5 cm. in both the stations. However, at the depth of 10 -15 cm and 20-25, the activity of ^{210} Pb $_{(excess)}$ was one of the highest in TG1 and TG2 respectively (*Figures 4.83 and 4.84*). The activity was decayed exponentially reaching to the bottom layers of sediment exhibiting the lowest activity.

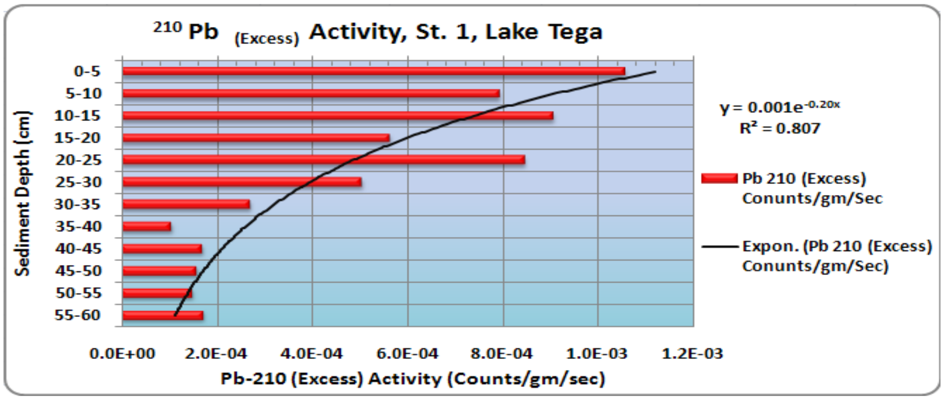


Figure 4.83 (a): ^{210} Pb $_{(excess)}$ Activity, TG1

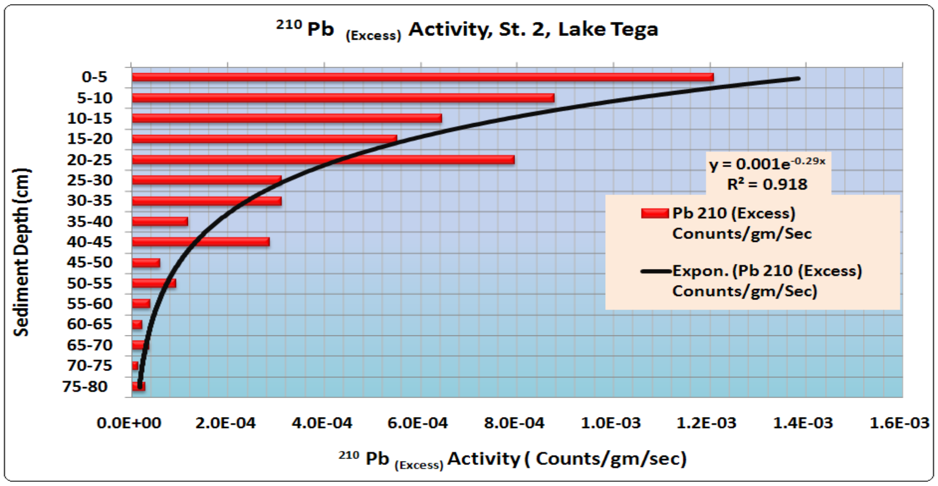


Figure 4.84 (a): ^{210} Pb $_{(excess)}$ Activity, TG2

Linear Sedimentation Rate (LSR)

In case of TG1, the linear sedimetation rate was calculated and considered for three distinct layers (*4.83 (b)*). The linear sedimentation rates up to the depth of 0 to 20 cm, 20 to 30 cm and 30 to 40 cm were calculated as 0.78 cm yr^{-1}, 0.62 cm yr^{-1}, 0.45 cm yr^{-1}

respectively. From this results it can be inferred that the sedimentation rate was the minimum before the year 1960s and the maximum after the 1980s and the sedimentation rate was moderate in the years 1960s to 1980s.

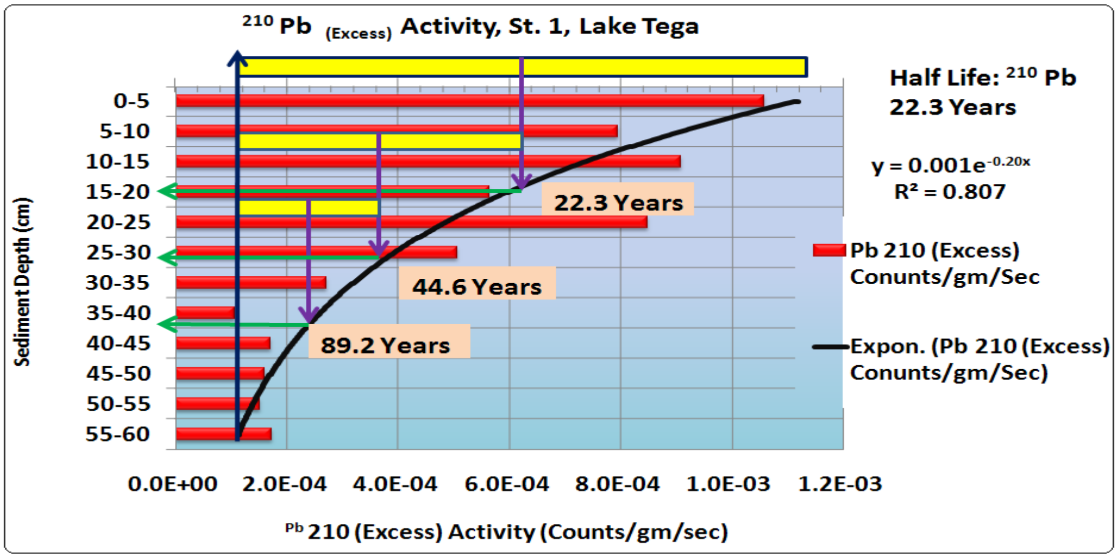


Figure 4.83 (b): ^{210} Pb $_{(excess)}$ Activity, TG1

The ^{210} Pb $_{(excess)}$ activity was the highest in the first 0-5 cm layer of sediment in TG2 indicating the recent deposit of the lead via atmospheric wet deposition or dry fall out as that of TG1 (*Figure 4.84*). .Like in TG1, the one of the highest activity value was corresponding at the 20- 25 cm depth of sediment core. In case of TG2, the sediment was deposited in the sediment depth layer of 20-25 since 1980s to the present.

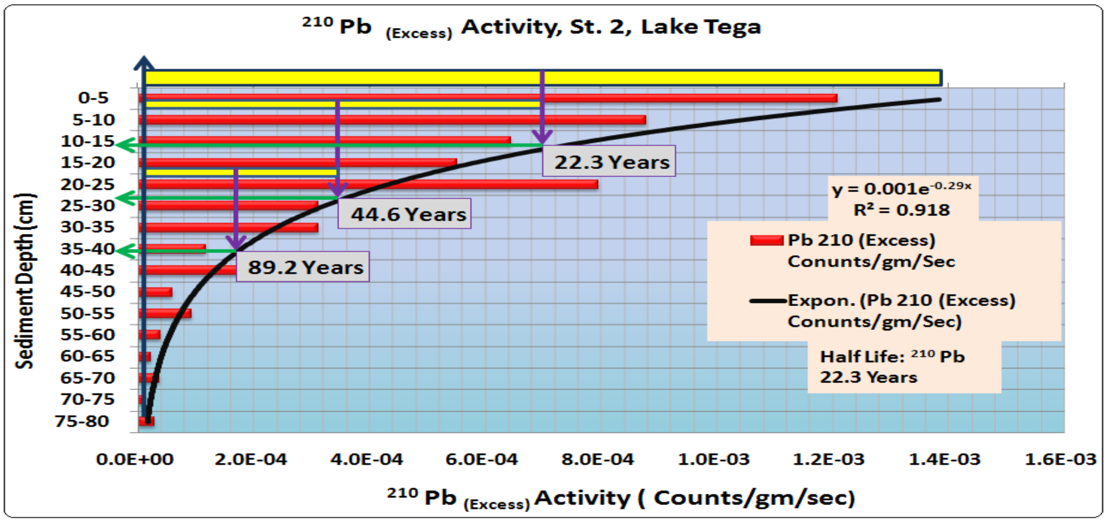


Figure 4.84(b): ^{210} Pb $_{(excess)}$ Activity, TG2

Similarly, the sedimentation rates are 0.56 cm yr^{-1} , 0.62 cm yr^{-1} , 0.42 cm yr^{-1} for the sediment depth 0 to15 cm, 15 to 30 cm, and 30 to 40 cm repectively in TG2.

Similarly, the sedimentation rate was calculated based on the age of sediments using Eq. 5 From these results, it can be interpreted that the sedimentation rates were higher in TG1 than in the TG2. The inflowing rivers such as Ohori River, Otsu River might have carried the suspended particles from the upstream and settled more in the western part of the lake, the TG1. The high percent of sand in the sediment depth of 5-10 cm was also in the same line of result suggesting the high sedimentation rate.

In case of TG2, one of the highest percent of sand was found in the sediment depth of 10-15 cm and the sedimentation rate was also highest around the same sediment depth. So, the high concentration of sand particles and high sedimentation rate were matched in case of TG1and TG2.

The activity of ^{137}Cs, the man made radio-nuclide, was found highest at the sediment depth of 25-30 cm (*Figure 4.85*). The peak was distinct and clear corresponding to the year 1962-1963 when a Limited Nuclear Test Ban Treaty was imposed worldwide. Based on the highest activity counts, the sedimentation rate for TG1was 0.63 cm yr^{-1} which was almost same as the average sedimentation rate calculated by ^{210}Pb $_{(excess)}$ activity. However, if the second highest peak were considered as Chernobyl disaster of 1986, then the sedimentation rate would be 0.81 cm $yr^{-1.}$

If the sedimentation rate were calculated based on the sediment thickness lying between the year 1986 and 1963, then the 10 cm of sediment layer was deposited in 23 years, resulting to the sedimentation rate of 0.43 cm yr^{-1}.

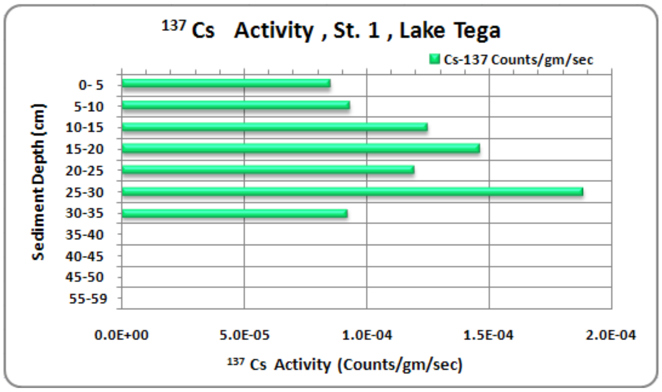


Figure 4.85: ^{137}Cs Activity, TG1

The different values of sedimentation rate were observed in St 2 based on the activity of ^{137}Cs. If the highest peak at the sediment depth of 20-25 cm (*Figure 4.86*) were considered to be of the year 1962-1963, then the linear sedimentation rate would be 1 cm yr$^{-1.}$ This rate of sedimentation was little higher than expected. Similarly, if the second highest peak were considered as that of the year 1986, corresponding to the sediment depth of 15-20 cm, then the sedimentation rate would be 0.83 cm yr$^{-1.}$ Both the rates showed the higher sedimentation rate in TG2 than in TG1.

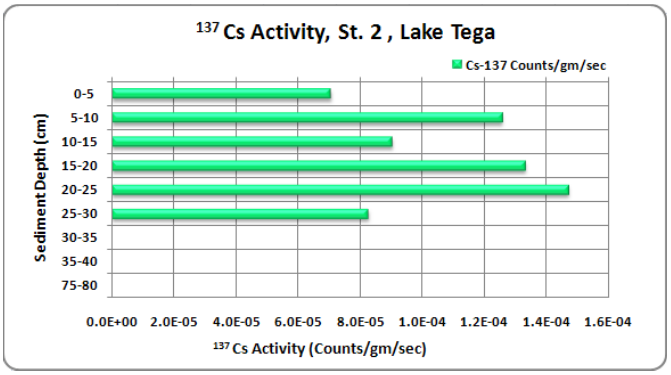


Figure 4.86: ^{137} Cs Activity, TG2

The sedimentation rate would be 0.65 cm yr^{-1} if the sediment thickness of 15 cm (7.5 cm to 22.5 cm) were deposited in 23 years (1986 to 1963). Unlike the sedimentation rate calculated based on ^{210}Pb$_{(excess)}$, the sedimentation rate was higher in TG2 than in TG1.

The sedimentation rate calculated on the basis of sediment age by the ^{210}Pb$_{(Excess)}$ method (Chapter 3) showed that the sedimentation rate was higher in TG1 than in TG2. (*Figures 4.87 and 4.88*). So, both the methods of ^{210}Pb$_{(Excess)}$ were in the good agreement. Hence, the mass accumulation rate was calculated on the basis of ^{210}Pb$_{(Excess)}$ activity using both the methods to have clear picture of sediment accumulation in lake Tega.

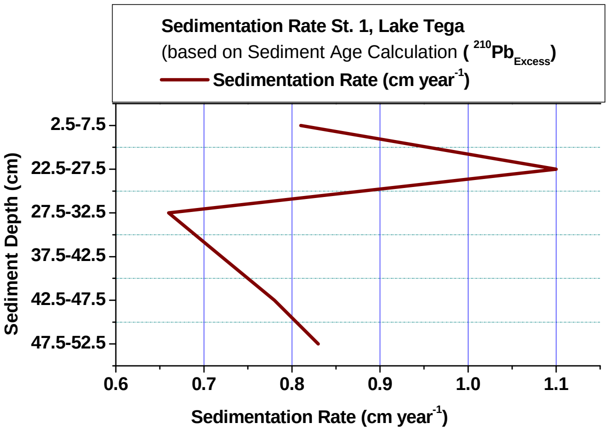


Figure 4.87: Sedimentation Rate, TG1

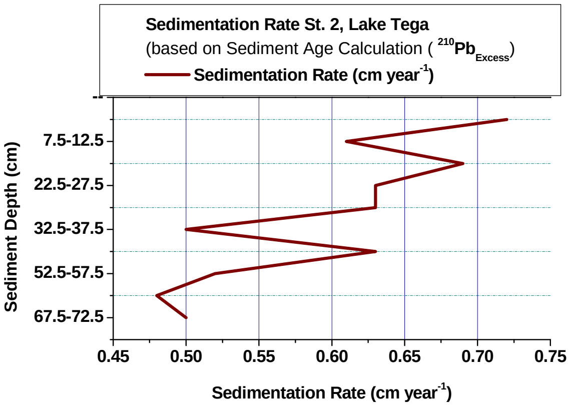


Figure 4.88: Sedimentation Rate, TG2

Mass Accumulation Rates (MAR)

The mass accumulation rates were calculated on the basis of ^{210} Pb $_{(excess)}$ activity in two methods: a) based on age of the sediment and b) based on the exponential curve fitted on the radio active decay of the activity.

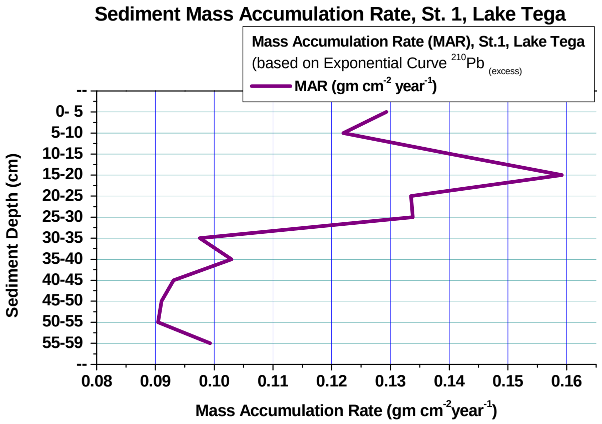


Figure 4.89(a): MARs, TG1

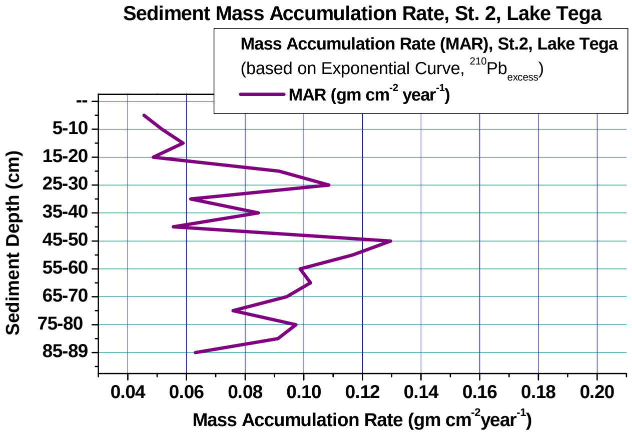


Figure 4. 90(a): MARs, TG2

In TG1, the MAR was found to be highest at the sediment depth of 15-20 cm and reached to 0.16 gm cm $^{-2}$ year $^{-1}$ (*Figure 4.89*).This depth corresponded with the Upper core region that represents the year 1980 to the recent years. The rates were observed higher from 0 to 30 cm of sediment depth and decreased afterwards. The decrement began along with the depth from of 30-35 cm.

In TG2, the MAR was 0.13 gm cm $^{-2}$ year $^{-1}$, the highest, in the sediment depth of 40-45 cm and the rate was followed by 0.11 gm cm $^{-2}$ year $^{-1}$ at the depth of 25-30 cm (*Figure 4.90*). The MAR was found to be decreased along with the depth after 45-50 cm of the sediment core.

The MARs calculated on the basis of sediment deposition years also showed the similar results (*Figures 4.89(b) and 4.90(b))* but the MARs were found slightly higher (0.22 gm cm $^{-2}$ year $^{-1}$ in TG1at the depth of 25-30 cm and 0.17 gm cm $^{-2}$ year $^{-1}$ in TG2 at the depth of 50-55 cm) than the previous methods. However, the differences were not significant.

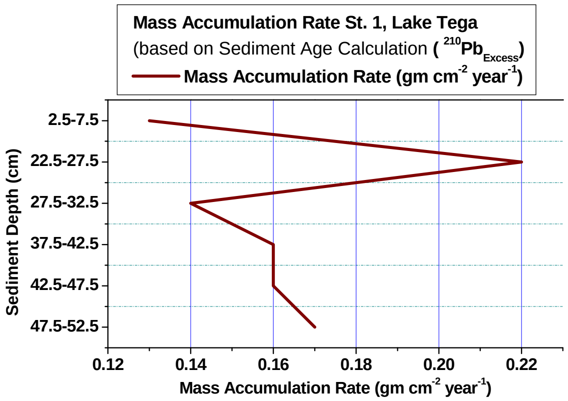


Figure 4.89(b): MAR, TG1

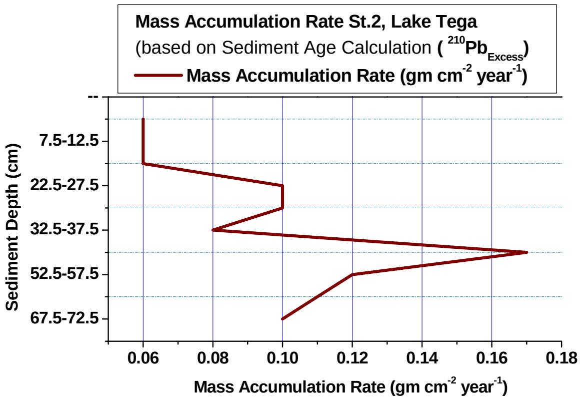


Figure 4.90(b): MAR, TG2

Geo Chronology

Based on the activities of ^{210} Pb $_{\text{(Excess)}}$ and ^{137} Cs, the sediment depth interval is assigned to particular years in the chronological order. However, the geo- chronology resulted from ^{137} Cs activity is not exactly the same as that of ^{210} Pb $_{\text{(Excess)}}$ activity based geo chronology. Based on the two methods of age calculation using ^{210} Pb $_{\text{(Excess)}}$, and ^{137} Cs activity , the geo- chronology of the sediment core is established and divided into three layers in each station (*Table 4.4*).

Table 4.4 Geo- Chronology of Lake Tega Sediment

Station	Sediment Core Region	Sediment Depth (cm)	Year (AD)
Station 1			
	Upper	**0 to 20**	**1980 to Present**
	Middle	**21 to 35**	**1960 to 1979**
	Bottom	**36 to 60**	**Before 1960**
Station 2			
	Upper	**0 to 25**	**1980 to Present**
	Middle	**26 to 45**	**1960 to 1979**
	Bottom	**46 to 80**	**Before 1960**

CHAPTER 5: DISCUSSIONS

5.1 Water Quality and Nutrients in Lake Tega

5.1.1 Spatiotemporal and Vertical Variation of Water Quality

The spatial and temporal variation of water quality in the western part (TG1) and eastern part (TG2) is discussed and the Tega Ohashi (bridge) was considered as the middle part of the lake. The morphometric characterstics such as surface area, depth, location of inflowing sources weren't found similar in the western and eastern part of the lake. These all above mentioned characterstics cause the spatial variation of the water quality.

The western lake (TG1) is in the river mouths of the major inflowing river sources which carry the pollutant loads such as suspended solids, organic wastes, nutrients to the lake.

Higher level of Chlorophyll *a* suggests that the TG2 has the higher biomass of photosynthetic algae which produce oxygen during daylight hours but use up oxygen during the night. After the death of algae, they decompose and the decomposition of the phytoplankton also releases nutrients which may allow more algae to grow. The processes of photosynthesis and respiration caused higher pH in TG2 and similarly the presence of the phytoplanktons and solid particulate matters which reside for a longer period in the water column increased concentration of chlorophyll *a* and turbidity in the TG2.

Longitudinal increase of chlorophyll *a* and decrease of Inorganic nitrogen and inorganic phosphorus suggest the high primary production along the length of the lake. High dissolved oxygen (DO) in TG2 is a result of high photosynthesis rate carried out by enormous phytoplanktons along with atmospheric input of oxygen.

Depending on the parameter, there wasn't a considerable variation from the water surface to the bottom. However, the vertical distribution of the DO showed that the superficial water layer being exposed to the open air, the DO was higher in the surface layer and the O_2 concentration was decreasing gradually down to the bottom. It was noted that the Chl *a* had been higher in the upper layer and varied with a slight gradient from the lake surface to the lake bottom. The high cell densities and phytoplankton biomass might have been restricted to the upper layer of the water column. It also indicated that the photosynthetically active phytoplanktons were limited to the upper layers of the lake. Being a shallow lake the thermal stratification wasn't observed.

5.1.2 Nutrients Status in Lake Tega

The Kita Chiba Water Conveyance Channel contributed the highest nutrient loads in the nutrients budget of lake Tega, however, the nutrients level in the discharged water was found lower. The highest contribution of Kita Chiba Pumping Station was due to the higher discharge rate rather than higher concentration of nutrients. An annual average concentration of TN and TP at the Kita Chiba Channel (measured at FUKAWA, Tone River) was 2.7 mg/L and 0.1 mg/L respectively. Similarly, the share of nutrient release from the water sediment interface in the total nutrient influx was 113 Tons/year of TN and 9 Tons/year of TP based on the average data of seven years (1999-2005). Importantly, the nutrient release from the sediment was contributing to the lake water as equal as from the inflowing rivers which accounted 13% and 15 % of Total Nitrogen and Total Phosphorus respectively.

Nutrients are supplied to the sediments and when the loading is excessive then the sediment becomes saturated. Beyond the point of saturation of nutrients in the sediment, the concentration gradient of nutrients in the overlying water and pore water occurs.

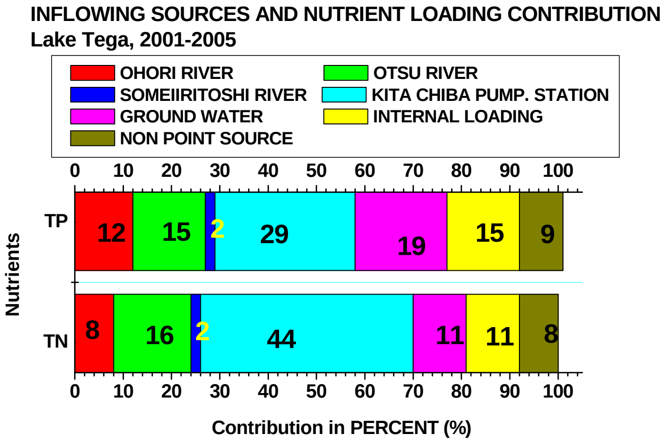


Figure 5.1: Average Nutrient Release Contribution, 2001 - 2005

The inflowing rivers such as Otsu, Ohori and Someiiriotoshi contribution is shown in the figure 5.1. Regarding Out flux from the Lake Tega, Tegagawa was found the only river which drained out the lake water. However, some irrigation pumping stations were observed which pump the Tega Lake Water to the adjoining paddy fields. Tegagawa River was the major sources of nutrient out-flux and 96% nutrients (both TN and TP) were discharged through this river. Irrigation pumping station was seasonal and operated from April to August each year and the TN load out fluxed by irrigation system is only 4% of total out flux.

In an average of seven years (1999 to 2005), 900 Tons of TN and 56 Tons of TP were loaded in Lake Tega where as 872 Tons of TN and 59 Tons of TP was out-fluxed from the lake Tega annually. In the years 1999, 2000 and 2001, the out-flux was observed to be higher than influx but since 2002, the influx of the nutrients was found higher than influx.

During the summer and autumn, the uptake of dissolved inorganic nitrogen by the primary producers resulted in the low concentration of the TN in TG1 and TG2. TN and TP concentration in TG1 and TG2 were higher in winter season compared to other seasons. Chlorophyll *a* increased along the longitudinal direction where as Inorganic nitrogen and inorganic phosphorus decreased in the similar pattern. This suggested that there was high primary production along the length of the lake. The uptake of nutrients by phytoplanktons and macrophytes as well as settlement of nutrients along with particulate matters might be another reason for decrement of TN and TP in the TG2.

The ammonification of organic nitrogen by bacterial and fungal decomposers produces NH_4-N. The high concentrations of NH_4^+ -N recorded near the bottom of the lake are probably the result of anaerobic metabolism of organic waste containing organic nitrogen. As the phytoplanktons directly can absorb the NH_4-N, the concentration of TN was found lower in the TG2. Along with absorption of dissolved inorganic ions by planktons, nitrification of the ammonia with the help of *Nitrosomanas* Bacteria (NH_4^+ to NO_2^{2-}) and *Nitrobacter* Bacteria (NO_2^{2-} to NO_3^{2-}) might have caused the lower concentration of TN in the TG2. Similarly, de-nitrification (conversion of NO_3^{2-} to NO_2^{2-} and then NO_2^{2-} to N_2 with the help of de-nitrifying bacteria) could be another important phenomenon in the Tega aquatic environment by which a large portion of nitrogen is lost in the sediment water interface (Hosomi, M *et al*. 1992).

The high concentrations of NH_4^+ -N recorded near the bottom of the lake are probably the result of anaerobic metabolism and the absorption of NH_4^+ -N by the planktons and nitrification of the ammonia caused the lower concentration in the TG2. The decreasing TN concentration along the transect point of the lake towards the outlets is governed by nitrification and de-nitrification of the nitrogenous compounds as well as absorption by the macrophytes and planktons.

The introduction of Tone River water has the flushing and dilution effects in lake Tega which significantly reduced the TN and TP concentration by 34% and 55% respectively (comparing the average values between 1985-1990 and 2001-2005) in TG2 and 50% and 78 % in TG1 in the same period and seasons. The TN and TP concentration of lake Tega has to be decreased more to achieve the Government Environmental Standards which is set as 1 mg/L for TN and 0.1 mg/L for TP. Though a significant improvement has been achieved, the further dilution in TN concentration mayn't be achieved even if the volume of Tone River Water has been increased. When the residence time was below 6 days, the TN concentration was found unchanged and remained around 3 mg/L. However, the TP concentration found to be more correlated with reduction of water residence time in TG2.

The influx of nutrients from the inflowing rivers such as Ohori and Otsu has been decreased in the recent years compared to the past. One of the main reasons for decreasing the nutrients load from the inflowing rivers could be considered as the extension and improvement of the Tega waste water treatment facilities. In 1985, the population coverage by Tega waste water treatment plant was only 42% which is increased to 84% in the year 2005 (*Figure WWTP 5.2*).

Improvement in household septic tanks, which treat all household wastewater, including discharges from the kitchen, laundry and bath as well as the toilet, were carried out by providing the subsidies by the local governments.

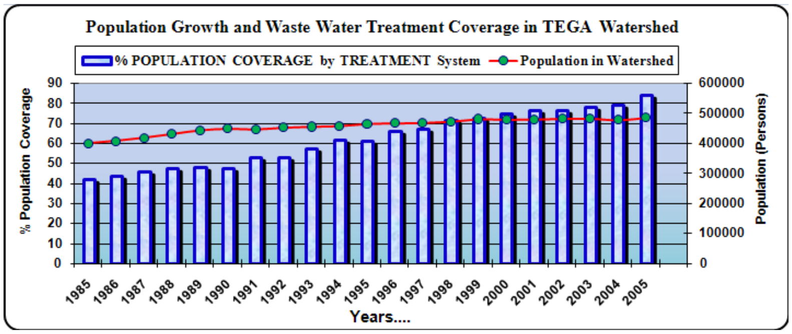


Figure: 5.2 WWTP

In the mean time the revision of the Purification Tank Law on April 1, 2001 also came into the force which forbids the former type sewage-only septic and the improved septic tank have been made obligatory. Various rules, regulation and guidelines as mentioned in Table 2.1 (Chapter 2) were implemented during the period along with other lake conservation activities.

The septic tank related sources had contributed the highest loads of TN, TP and COD in the entire watershed according to the Chiba Prefecture Water Quality Report. However, unlike TN and COD loads, the industrial sources contributed TP loads following the septic tank related sources. This result also showed that the improvement in sewage facilities has played a significant role in reducing the nutrient loads in the lake.

Combined Sewage Outflow (CSO) system has been slowly outdated and Separate Sewage Outflow (SSO) has been practiced in the watershed which also contributes in reducing organic wastes and nutrients loads contributing by the non point sources during run off.

The decreasing loads of TN and TP in the inflowing rivers can be considered as the positive sign for nutrients level improvement in the inner lake. The Kita Chiba Water Conveyance Channel contributed the highest nutrient loads in the nutrients budget of lake Tega, however, the nutrients remain in the lake water for a reasonably short period. The reduction in water residence time allows flushing out the nutrients before they could be utilized by phytoplanktons to cause a nuisance in the water environment.

So, it can be inferred that the decreasing TN concentration along the transect point of the lake towards the outlets is governed by nitrification and de-nitrification of the nitrogenous compounds as well as absorption by the macrophytes and planktons. Similarly, the dissolved inorganic phosphorus, one of the main constituents of TP, was decreased in the TG2, possibly by absorption by plants and adsorption in suspended solid particles.

5.1.3 Chemical Oxygen Demand (COD) Level

The COD level has been considered as an important water quality indicator which significantly reflects the water quality condition of any water bodies.

The COD level in Lake Tega can be described in four major time period: a) early to mid70’s, b) late 70’s to mid 80’s c) mid 90’s and d) Year 2000 onwards. The late 70’s and mid 80’s was a period in which the lake Tega experienced highest level of COD level.

Since 1995, the COD level started going down and reached to 11 mg/L in the year 2001. The COD concentration was sharply decreased from 14 mg/L in 2000 to 11 mg/L in 2001. When we considered the values of the years 1979 and 2006, about 71% of COD level was decreased. It was found that the extension and improvement of waste water treatment facilities significantly reduced the organic loads in the lake. Along with the reduction of the discharges of the inflowing rivers such as Ohori and Otsu, the organic pollutants load also has been decreased. Moreover, the introduction of Tone River Water through Kita Chiba Pumping Station has played an important role to flush out the pollutants there by decreasing water retention time.

However, the present level hasn't yet reached below the government standard value which is given as 5 mg/L. But it can be inferred that due to various water quality purification and conservation practices, the COD level could reach this level.

5.1.4 Eutrophication

Based on Carlson Trophic State Index (TSI), the trophic state has been fluctuating depending upon seasons and has shown some decreasing trend in terms of years. Compared to the past decades, the TSI has shown little improvement. However, in most of the cases, the lake is still under hypertrophic condition with some difference between TG1 and TG2 as well as summer and winter seasons. The summer TSI (SD), TSI (TP) and TSI (Chl a) have decreased since 1998 in TG1 but the index values are still high enough to rank the lake as a hyper-eutrophic lake. Compared to TSI (SD) and TSI (TP), the TSI (Chl a) value is higher in TG1 in summer but the TSI (TP) value is higher in winter in most of the years since 1998.

The Chlorophyll concentration is higher TG2 than in TG1, indicating higher growth of algae and other kinds of planktons utilizing dissolved Phosphorus. The TSI (SD) value is the lowest in summer and winter in TG1 and TG2. Unlike, TG1, the TSI (Chl a) is higher in both summer and winter in the TG2.

The TSI (Chl a) had reached the lowest in the year 2003 but in the higher range in rest of the years since 1999. The TSI for phosphorus and chlorophyll are higher than the TSI for secchi depth which may indicate that inorganic turbidity or color of the water reduces the clarity of the lake. All the indicators are in good agreement from 1998 through 2005. During this period of time many lake purification and restoration activities were carried out in Lake Tega which resulted slight decrement in the TSI values. It was observed that the TSI values were highest in summer, lowest in winter and at the middle in the autumn and spring. By knowing the trophic status of a lake, scientists can predict what problems are likely to occur and what management strategies will be the most effective.

Eutrophication is still a major problem in Lake Tega. Though the TSI (SD), TSI (TP) and TSI (Chl a) have been decreased in the recent years, the status of lake is still in between hypertrophic and eutrophic condition, more towards hypertrophic state.

5.1.5 Water Retention Time and Lake Water Purification

The water residence time of Lake Tega has significantly deceased in the recent years. The water residence time less than ten days is considered to be very good in terms of self purification mechanism of the lake.

On the basis of an average depth of lake 0.86 m and the lake surface area as 6.5 km^2 (considered beyond Akebone Bride in Outlets) , the total volume of lake water that remains in the lake is calculated as 5.59 x 10 ^{06} m^3. So, after each water retention period, a volume of 5.59 x 10 ^{06} m^3 of water is changed with the inflowing sources. Lesser the retention time, the faster is the changing process of lake water which significantly enhances the dilution and wash out of pollutants of the lake water. The reduction in water residence time has significantly reduced the COD level and Chl *a*.

The algal cells that are produced in water column are washed out faster than they can grow and accumulation. Longer water residence times provide plenty of time for algal biomass to accumulate if sufficient nutrients are present.

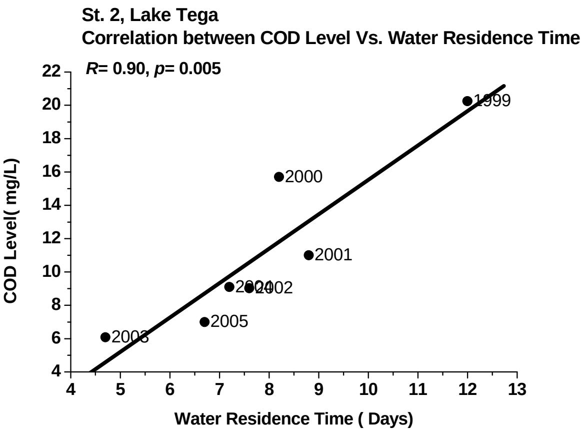


Figure 5.3: Correlation Between WRT & COD, TG2

As residence time increases, interaction between the water column and bottom sediment have more influence on water quality. At very short residence time (less than one to two weeks), algae may not have enough time to respond to the inflowing nutrient supply (*Figures 5.5 and 5.6*).

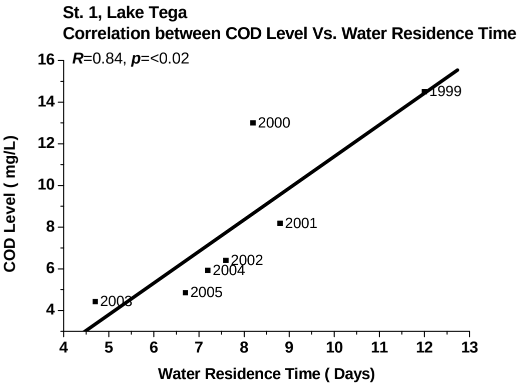
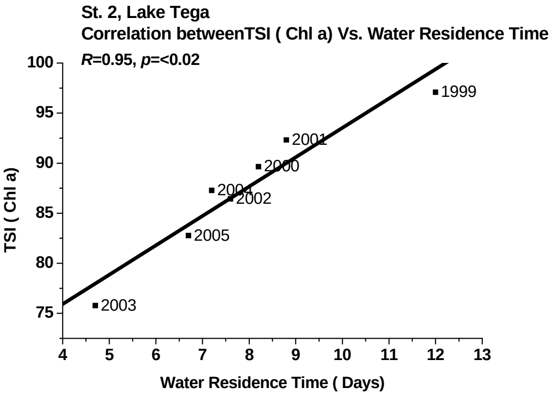


Figure 5.4: Correlation Between WRT & COD, TG1



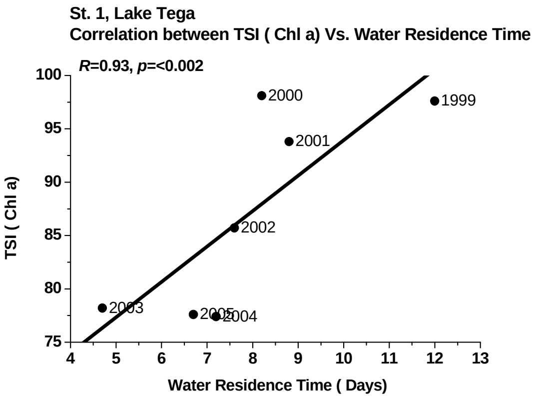
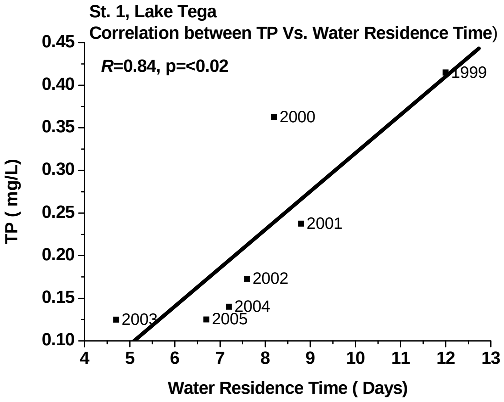


Figure 5.5: Correlation, WRT Vs Chl a, TG2

Figure 5.6: Correlation, WRT Vs Chl a, TG1



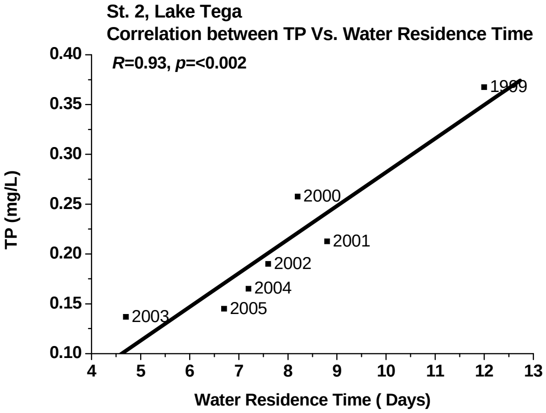


Figure 5.7: Correlation, WRT Vs TP, TG1

Figure 5.8: Correlation, WRT Vs TP, TG2

In case of nutrients, the TP level and water residence time has a very good correlation and as the water residence time has decreased, the TP level has also been decreased (*Figures 5.7 and 5.8*). However, TN has attained a certain concentration and not shown further decrement even the water residence time has been decreased and reached less than 5 days in the year 2003. It can be inferred that even reducing the water residence time less than 6 days, the achievement in reducing TN, mayn't be achieved (*Figures 5.9 and 5.10*).

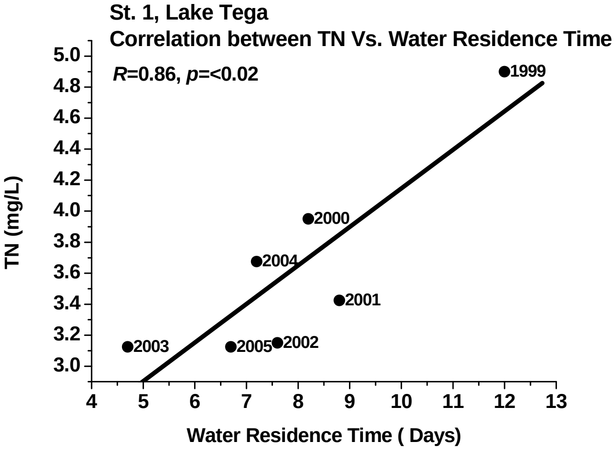


Figure 5.9: Correlation, WRT Vs TN, TG1

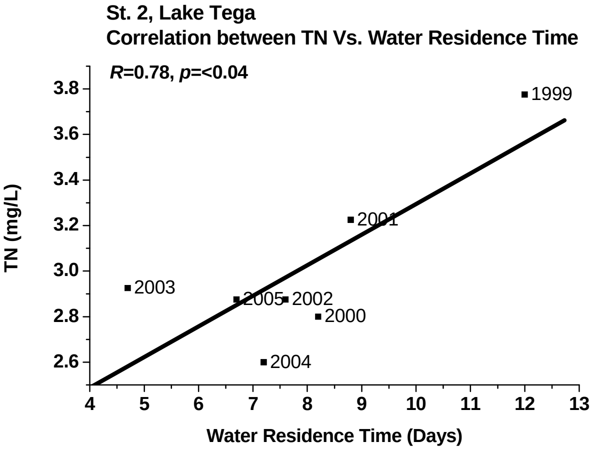


Figure 5.10: Correlation, WRT Vs TN, TG2

While plotting a graph between a set of water residence time (in days) and the lake water volume, it was observed that to attain the six days of water residence time, 5.4 m^3/sec of water have to be supplied from the external sources (*Figure 5.11*).

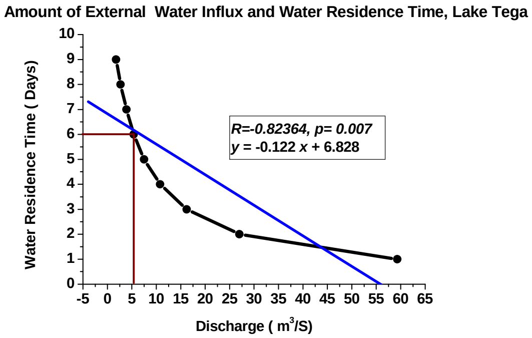


Figure 5.11: WRT & Discharge

Considering 6 days as the residence time, the flushing effects will be effective when about 5.4 m^3/sec of additional water could be discharged from the external sources besides natural influx of water. About 5.5 m^3/sec (in an average) Tone River water is being discharged through the Kita Chiba Water Conveyance Channel to Lake Tega since 2000. However, discharge is controlled depending upon the rainfall and irrigation activities.

5.2 Land Use Change in the Tega Watershed

The land use practices in the catchment determine the water quality of the streams, rivers, lakes and reservoir. Along with the development activities, the land use pattern of the Tega Watershed has been changed. This land use change has certainly led some impacts on the water quality of the water bodies in the catchment. Changes in water quality are primarily a reflection of what happens on land—around the shoreline and within the lake's watershed. In connection with this, the land use changes in Lake Tega watershed since 1979 to 1994 were assessed.

Out of 162.88 Sq. km, the total area of the watershed, the land use ratio shows that forest area and agricultural area has been decreased in each five years interval. Paddy field covers almost 50% of the total agricultural area in the watershed. From the year 1979 to 1994, about 10 km^2 forest land area and 7 km^2 of agricultural area have been decreased in the watershed and in contrast to this, about 4 km^2 residential area has been increased in the same period of time (*Figure 5.12*). Residential area includes low-rise houses (not dense), low-rise houses (densely inhabited) and mid-rise and high-rise apartment. Similarly, industrial area, land area for public use and area for business activities such as shops, restaurants have also been increased since 1974. Altogether, the urbanization components have increased by 6% while the forest covers have been decreased by 6% since 1979 to 1994.

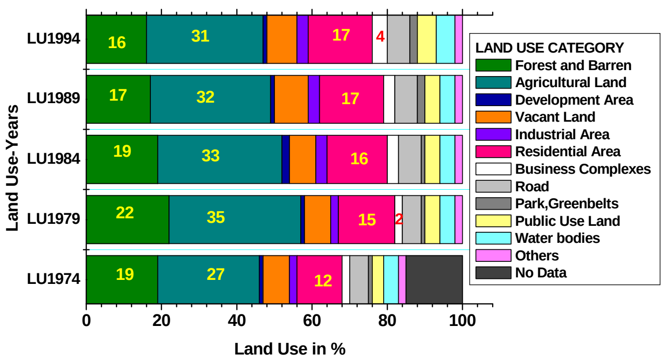


Figure 5.12: Land Use in Teganuma Watershed 1974-1994

The western part of the lake Tega has more urbanized characteristics with more residential areas, business complexes, shops etc while the eastern and southern part of the lake have more agricultural areas, including paddy fields. In the southern part of the watershed, the land use is more utilized for the agricultural practices. In the mid 70's, the water quality of the lake Tega has been deteriorated and the COD level has been reached maximum in the record. The land scape which had been covered with forests area became residential and business complexes and the factors that had played a crucial role to reduce the load began to increase instead which disrupted the natural balance. The land use change in the in the years 1979 and sedimentation rate in the same period revealed a relation between land use change and sedimentation rate. The dominancy of sand particles also supported relationship land use change and sedimentation rate in Tega Watershed. However, the land use change in 20 years in Tega watershed and impacts on water quality couldn’t be linked so apparently except few general hints such as higher mass accumulation rate, total carbon and COD level after mid 70s.

5.3 Sediment Characteristics and Sedimentation Rate in Lake Tega

5. 3.1 Sediment Environment

Bulk density was increasing along with the depth but the water content and porosity was decreasing down to the sediment profile. However, the bulk density showed a relation with water content of the sediment; bulk density can be highly variable as the water content of the sediment is subjected to change due to deposition followed by compaction.

The inflowing rivers carry suspended sediment from the drainage basin and current and wave action along the shorelines also play an important role for additional erosion and sediment deposition and some times some materials may be brought and added to the lake as a result of prevailing wind action. Particles of various shapes and sizes have their own significance in water and sediment quality. Rivers transport the materials of varying sizes and when the river water entered the lake, its speed diminished rapidly and suspended solids of with larger sizes and weight began to settle to the bottom near the river mouth. The finer materials like silts, clay are carried little far away and finally settled.

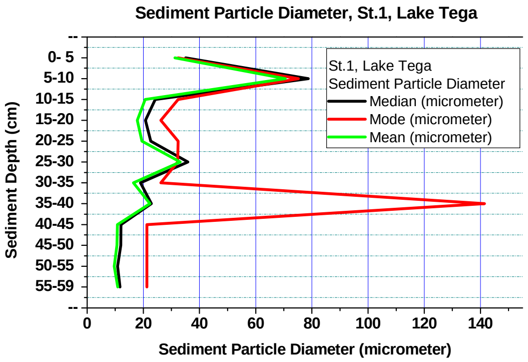


Figure 5.13: Particles Diameter, TG1

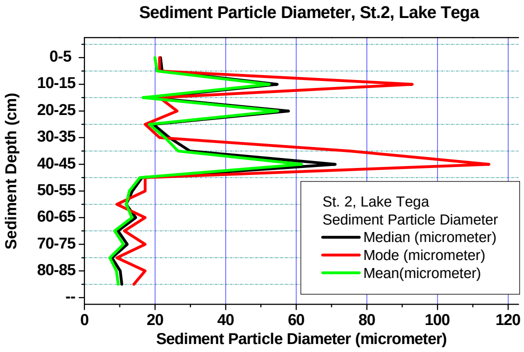


Figure 5.14: Particles Diameter, TG2

The most frequent particle size, described by the mode, was found in the sediment depth of 34-40 cm in TG1 and it was 141 μ m, the Fine Sand according to Wentworth Grade Scale, 1922. Similarly, the mode of the particle size was observed higher at the sediment depth of 5-10 cm with the particle diameter of 75 μ m, the Very Find Sand according to the Went Worth Grade Scale. The mean and median were also found in the same line as mode in the sediment depth of 5-10 cm with the diameter of 71 μ m and 79 μ m respectively. At the depth of 25-30 cm, the mean and median diameters had one of the higher values. The mean particle diameter was 33 μ m and the median was 36 μ m at the sediment depth of 25-30 cm. At the bottom layers the mean, mode and median values were less than 12 μ m, indicating that the fine silts to clay categories were dominant in the bottom layers. In case of TG2, the modal diameter was found to be the highest at the sediment depth of 40-45 cm and the value was 115 μ m (Very Fine Sand). At this depth, the mean and median diameter were also in a good agreement and had the highest values as 61 μ m and 71 μ m respectively. The upper layer, at the sediment depth of 10-15 cm, the mean, mode and median diameter had the higher values with 52 μ m, 93 μ m and 55 μ m respectively.

The sand particles in TG1 were found higher than TG2 as the larger materials are deposited near the river mouth station. The silts and clays are found to be deposited especially away from the river mouths and higher in the TG2. The results of the sedimentation rate and mass accumulation rate are also in good agreement with this finding.

In case of TG2, one of the highest percent of sand was found in the sediment depth of 10-15 cm and the sedimentation rate was also highest around the same sediment depth. So, the high concentration of sand particles and high sedimentation rate were matched in case of TG1and TG2.

Sand settles immediately when the velocity is reduced but silt and clay remains in re-suspension much longer and move further in the water and can absorb/adsorb particulate pollutants which may be suspended in overlying water. Clay and Silts are cohesive in nature and particle cohesiveness has important chemical and physical implications for sediment quality. Silt and clay are responsible for the transport of chemicals such as metals, phosphorus, chlorinated pesticides and many industrial compounds such as PCB, PAH, Dioxins and Furans. But this study didn't cover this aspects and future research could be carried out on this aspect. About 65% of the 128 priority pollutants that are listed by

USEPA, are found mainly or exclusively, in association with sediment and biota (E. Ongley 1996)

The value of C/N ratio revealed that the upper layer of sediment which was deposited after 1906s had high carbon containing contaminants. The highest values in both the stations were observed in the upper layer corresponding to the age of sediments accumulated since 1960 to 1980s. However, the decomposition of Organic matter along with the time period is the reason of decrement of C/N ratio along with the sediment depth. The values of C/N ratios in both the stations suggested high proportion of algal organic matter as algae has C/N ratio between 4 to 10 as described by Meyers, 1994 (Sujay Kaushal *et al.* 1999).

The nutrient release experiment showed a significant release of nutrients from the sediments and this release rates were supported by the results that were obtained by analyzing the nutrient pore water concentrations. A marked concentration gradient was observed between overlying water and sediment water interface. The concentration of NH_4^+-N and PO_4^{3-}-P were found to be higher in the sediment pore water than that of overlying water. The NH_4^+-N concentration values in the TG1 sediment pore water were 2.8 to 13.4 times higher than in overlying water indicating and in case of TG2, the NH_4^+-N concentrations in pore water were 3 to 12 times higher than the overlying water. It indicated that the NH_4^+-N release from the sediment was obvious as there was a significant concentration gradient between overlying water and the sediment water interface. The general increase in NH_4^+-N concentration down profile was an indication of an ammonification reaction, where organic nitrogen (in the form of amino acids) was decomposed by bacteria, and NH_4^+-N released into solution:

$$RCH(NH_2)COOH \rightarrow \text{intermediate amino compounds} \rightarrow NH_4^+ + CO_2 + CH_4$$

As this reaction proceeded, organic carbon and nitrogen constituents of total N and C also decreased. As conditions become more anoxic, the ammonium accumulates, as there is a decreased probability of conversion of NH_4^+ to more oxidized forms due to the lack of oxygen.

Similarly, the PO_4^{3-}-P concentration values were 3 to 18 times higher than the overlying water in both the stations. For PO_4- $^{3-}$-P release from the sediment to overlying water, P bound to particles or aggregates in the sediment must be mobilized by being transferred to the pool of dissolved P (primarily phosphate) in the pore water and the processes such as desorption, dissolution, ligand exchange mechanisms, and enzymatic hydrolysis which transport the dissolved phosphorus to the lake water must function.

5.3.2 Sedimentation Rate in Lake Tega

Various factors seem to influence the sedimentation rates as the sedimentation rates were found non uniform along the sediment depth in the stations TG1 and TG2. The factors that influence the sedimentation rate could be rate of stream flow, watershed size, topographic and soil characteristics, land use practices and precipitation pattern.

In TG1, the linear sedimentation rates in the upper layers (0 to 20 cm) was found the highest with 0.78 cm yr^{-1} and at the depth of 20 to 30 cm, the linear sedimentation rate was 0.62 cm yr^{-1}. The lowest sedimentation rate was observed at 30 to 40 cm and the rate was calculated 0.45 cm yr^{-1} respectively. From this results it can be inferred that the sedimentation rate was the minimum before the year 1960s and the maximum after the 1980s and the sedimentation rate was moderate in the years 1960s to 1980s.

Similarly, the sedimentation rates were 0.56 cm yr^{-1} , 0.62 cm yr^{-1} , 0.42 cm yr^{-1} for the sediment depth 0 to15 cm, 15 to 30 cm, and 30 to 40 cm repectively in TG2. Looking at the geo-chronlogy of the TG2 sediment core , the highest sedimentation rate was observed since 1970s to 1980s and the lowest was observed before 1960. Since 1980s to the present, the sedimentation rate was found moderate among all sedimentation rates.

From these results, it can be interpreted that the sedimentation rates were higher in TG1 than in the TG2. The inflowing rivers such as Ohori River, Otsu River might have carried the suspended particles from the upstream and settled more in the western part of the lake, the TG1. The high percent of sand in the sediment depth of 5-10 cm was also in the same line of result exhibiting the high sedimentation rate. The land use change might have the correlation with this sedimentation rates. The decreasing forest covers, increasing residential areas and urbanization could have the impacts on higher sedimentation rates in the periods.

As the linear sedimentation rates don't consider the compaction phenomenon of sediment, the mass accumulation rates were calculated. In TG1, the MAR was found to be highest at the sediment depth of 15-20 cm and reached to 0.16 gm cm $^{-2}$ year $^{-1}$. This depth corresponded with the Upper core region that represents the year 1980 to the recent years.

The rates were observed higher from 0 to 30 cm of sediment depth and decreased afterwards. The decrement began along with the depth from of 30-35 cm. According to the geochronology, the MAR was found minimum before the year 1960s.

In TG2, the MAR was 0.13 gm cm $^{-2}$ year $^{-1}$, the highest, in the sediment depth of 40-45 cm and the rate was followed by 0.11 gm cm $^{-2}$ year $^{-1}$ at the depth of 25-30 cm. The MAR was found to be decreased along with the depth after 45-50 cm of the sediment core. This depth was corresponding with the years before 1960s.

The MARs calculated on the basis of sediment deposition years also showed the similar results but the MARs were found slightly higher (0.22 gm cm $^{-2}$ year $^{-1}$ in TG1at the depth of 25-30 cm and 0.17 gm cm $^{-2}$ year $^{-1}$ in TG2 at the depth of 50-55 cm) than the previous methods. However, the differences were not significant.

So, it can be concluded that the mass accumulation rates are higher in TG1than in TG2and the highest rates were observed after the years 1960s in both the stations. The MAR found to be decreased along with the sediment depth.

Based on the activities of ^{210}Pb $_{(Excess)}$ and ^{137}Cs, the sediment depth interval is assigned to particular years in the chronological order. Based on the two methods of age calculation using ^{210}Pb $_{(Excess)}$, and ^{137}Cs activity, the geo- chronology of the sediment core is established and divided into three layers in each station. For TG1, the upper sediment layers of the depth 0 to 20 cm corresponded to the periods between 1980 to the present but in case of TG2, the upper layer was 0-25 cm for the same period of time. This result also indicated the fact that the sedimentation rates were higher in the TG1.

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

This study concludes with the following impressions regarding Lake Tega.

The lake Tega exhibited self purification capacity in the past (before the year 1950). Along with development activities, population growth, the water quality deteriorated and reached at its peak in the 1970s to 1990s. Various water qualities related rules, regulations and guidelines were enforced and implemented in national and prefecture level. Moreover, water quality purification activities were carried out intensively. Introduction of Tone River Water through Kita Chiba Water Conveyance Channel (22.2 km underground water channel) was one of the major steps towards lake clean up and conservation. Similarly, the extension and improvement of Teganuma Waste Water Treatment Facilities could be considered as another effective project to improve the lake water quality. Compared to the period of 1970s to 1990s, the water quality has shown some improvements, however, more conservation and clean up measures are to be explored/identified and implemented to achieve a clean lake category by lake Tega.

The lake exhibited spatial and temporal variation of water quality. The nutrients concentration and the sedimentation rate were higher in western part of lake which experienced a direct influence of inflowing sources. This suggests that the conservation and clean up activities should be designed to address the specific problems in the specific parts of the lake. Higher concentration of Chlorophyll *a* and Turbidity in the eastern part revealed the abundance of the photosynthetic phytoplankton in the region.

The late 70’s and mid 80’s was a period in which the lake Tega experienced highest level of COD level. When we considered the values of the years 1979 and 2006, about 71% of COD level was decreased. However, the present level hasn’t yet reached below the government standard value which is given as 5 mg/L. But it can be inferred that due to various water quality purification and conservation practices, the COD level could reach present level.

Eutrophication is still a major problem in Lake Tega. Though the Carlson Trophic State Index (TSI), for TSI (SD), TSI (TP) and TSI (Chl a) have been decreased in the recent years, the status of lake is still in between hypertrophic and eutrophic condition, more towards hypertrophic state.

The Kita Chiba Water Conveyance Channel contributed the highest nutrient loads (44% of TN and 29% of TP) in the nutrients budget of Lake Tega, however, the nutrients level in the discharged water was found lower. Importantly, the nutrient release from the sediment was contributing to the lake water as equal as from the inflowing rivers which accounted 13% and 15 % of Total Nitrogen and Total Phosphorus respectively. The contribution of inflowing rivers such as Otsu, Ohori and Someiiriotoshi was found decreasing since 1999 in the nutrient budget. Otsu River was found to be major contributor in terms of natural inflowing sources. The purification of the inflowing rivers would significantly reduce the nutrients and pollution loads in the lake. Tegagawa is the only river which drains out (96% nutrients, both TN and TP) the lake water along with some seasonal (April to August) irrigation pumping stations (4% of total out flux).

The nutrient release experiment showed a significant release of nutrients from the sediments and this release rates were supported by the results that were obtained by analyzing the nutrient pore water concentrations. A marked concentration gradient was observed between overlying water and sediment water interface. The concentration of NH_4^+-N and PO_4^{3-}-P were found to be higher in the sediment pore water than that of overlying water.

Internal loading could be ranked as one of the significant sources for nutrients loadings in the lake Tega. Seasonal Variation of internal loading was observed, lowest release rates in the winter and the highest in the summer and the correlation between nutrient release rates and temperature was significant. Nutrient release at the western part of the lake was found higher than the eastern part of the lake Tega. The total nutrient release from the water sediment interface to the overlying water was 113 Tons/year of TN and 9 Tons/year of TP based on the average data of seven years (1999-2005).

Introduction of Tone River Water reduced the water retention time in Lake Tega. The reduction of water retention time played a crucial role to reduce the COD Level, TN and TP level. The slight improvement in trophic condition could also be considered as the positive impacts of introducing Tone River Water. Lesser the retention time, the faster is the changing process of lake water which significantly enhances the dilution and wash out/flushing of pollutants of the lake water. However, after reaching to certain concentration threshold, further decrement in water residence time mayn’t reduce the concentration level (TN in this case). The mechanism and function of dilution and flushing effects could describe the impacts of retention time on water quality. This could be suggested for further research.

From the year 1979 to 1994, about 10 km^2 forest land area and 7 km^2 of agricultural area have been decreased in the watershed and in contrast to this, about 4 km^2 residential area has been increased in the same period of time. Similarly, industrial area, land area for public use and area for business activities such as shops, restaurants have also been increased since 1974. Altogether, the urbanization components have increased by 6% while the forest covers have been decreased by 6% since 1979 to 1994.

The impacts of land use changes were observed in terms of higher sedimentation rates and higher C/N ratio since 1970s to 1990s. The land use change might have the correlation with this sedimentation rates. The decreasing forest covers, increasing residential areas and urbanization could have the impacts on higher sedimentation rates in the periods. So, it can be concluded that the mass accumulation rates are higher in western (TG1) than in eastern (TG2) and the highest rates were observed after the years 1960s in both the stations. The mass accumulation rates were found to be decreased along with the sediment depth.

The sand particles in western (TG1) were found higher than eastern (TG2) as the larger materials are deposited near the river mouth station. The silts and clays are found to be deposited especially away from the river mouths and higher in the eastern part of the lake. The results of the sedimentation rate and mass accumulation rate are also in good agreement with this finding.

From these results, it can be interpreted that the sedimentation rates were higher in western part (TG1) than in the eastern part (TG2). The inflowing rivers such as Ohori River, Otsu River might have carried the suspended particles from the upstream and settled more in the western part of the lake, the western (TG1). The high percent of sand in the sediment depth of 5-10 cm was also in the same line of result exhibiting the high sedimentation rate.

6.2 Recommendations

Actions needed in all sectors and the participation of all stakeholders is equally important for sustainable conservation of the lake. The major stakeholders include:

- Individual
- Household
- Community- NGOs and Clubs
- Local and National Government
- Research Institutes and Academia

The JOINT efforts of all the stakeholders are the KEY to achieve the target of getting a CLEAN LAKE.

In-Lake Restoration

- Along with Flushing with Tone River water, some other measures are to be identified and implemented to reduce the nutrients load in the lake
- Time series water quality monitoring is recommended in various representative points in lake

Following measures have shown effective results in some in-lake restoration programs *(*E. Ongley 1996 *and* Wedepohl, R 1990), however, the detail of the techniques isn't described and they are merely based on the literature review, not on the basis of technical experiments; further in-depth research is required to implement the control measures)

- Physical, chemical and biological control measures are to be implemented in an integrated way without harming the ecosystem of the lake

  The physical may be:
- Aeration and Oxygenation,
- Mechanical Removal of algae and associated nutrients in the peak seasons
- Continuation of Dilution and Flushing by Tone River Water
- Light Limiting Dyes and surface covers create light limitation on algal growth

The chemical control measures may be:

- Sediment Oxidation by adding oxidants, binders and pH adjustors which enhance the Phosphorus binding and it is also said that the de-nitrification process would be enhanced thereby reducing TN concentration. However, benthic biota may be affected
- Phosphorus Precipitation/Inactivation with Alum (addition of aluminium salts) is one of the proven lake restoration techniques for controlling algal growth by creating a nutrient- limiting environment

Biological control measures may be:

- Enhanced Grazing, one of a group of procedures called Biomanipulation (Shapiro et al., 1975) as mentioned by E. Ongley 1996. Such as Daphnia graze on algae, bacteria and organic matter.

Watershed Level

Holistic approach for watershed management is needed which considers each component of watershed in an integrated manner.

- Eco- friendly farming practices in the upstream and around the lakes
- The Extension of Tega Waste Water Treatment Facilities
- Channelize the storm run off to reduce non point source pollution
- People‘s involvement in volunteer water monitoring program is suggested which may enhance public attachment with the lake thereby building up the stewardship for lake conservation

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APPENDIX: PHOTO PLATES

Plates 1 and 2: Lake Tega

Plate 3: Kita Chiba Pumping Station

Plate 4: Pollutants entering to Lake Tega

Plates 5 and 6:

Sediment Core Sampling

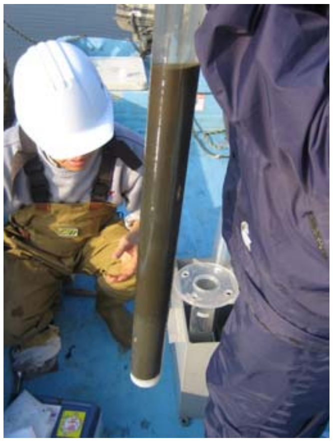


Plate 7: Sediment Core Sampling

Plate 8: Sediment Core Sampling

Plates 9 and 10: CN CORDER MT-700,YANAKO Co. LTD

Plate 11: Nutrients Analysis AACS III (BRAN+LUBBEE)

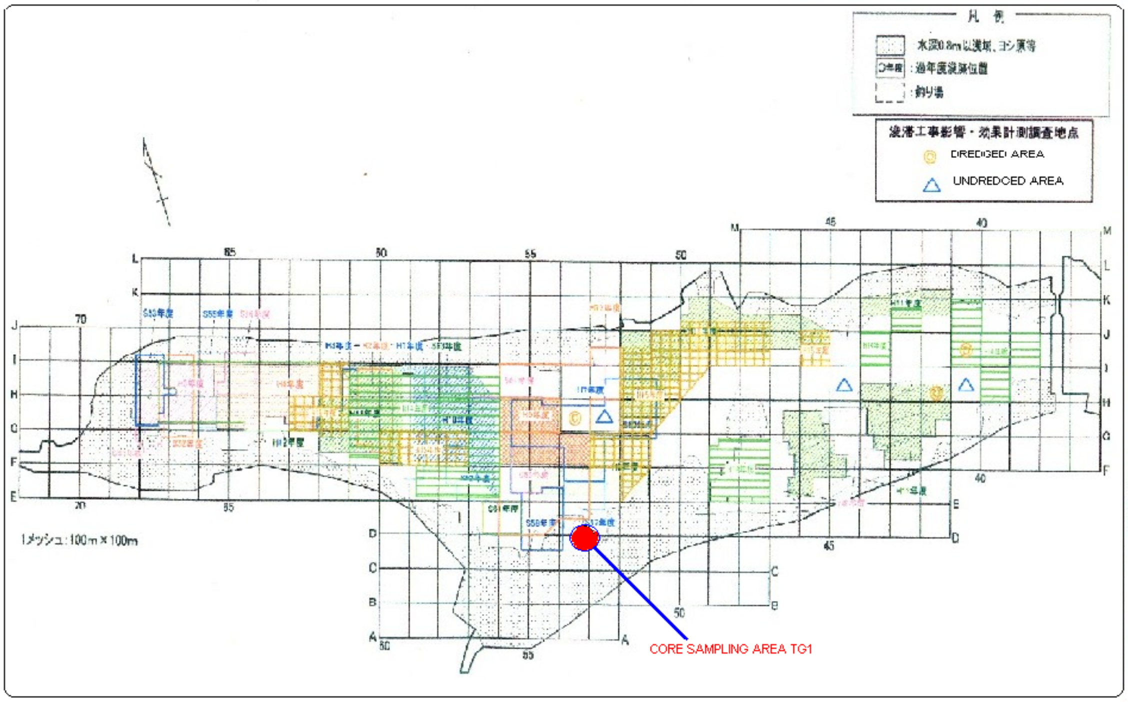


Plate 12: Sampling Recovery Points in an Undredged Area

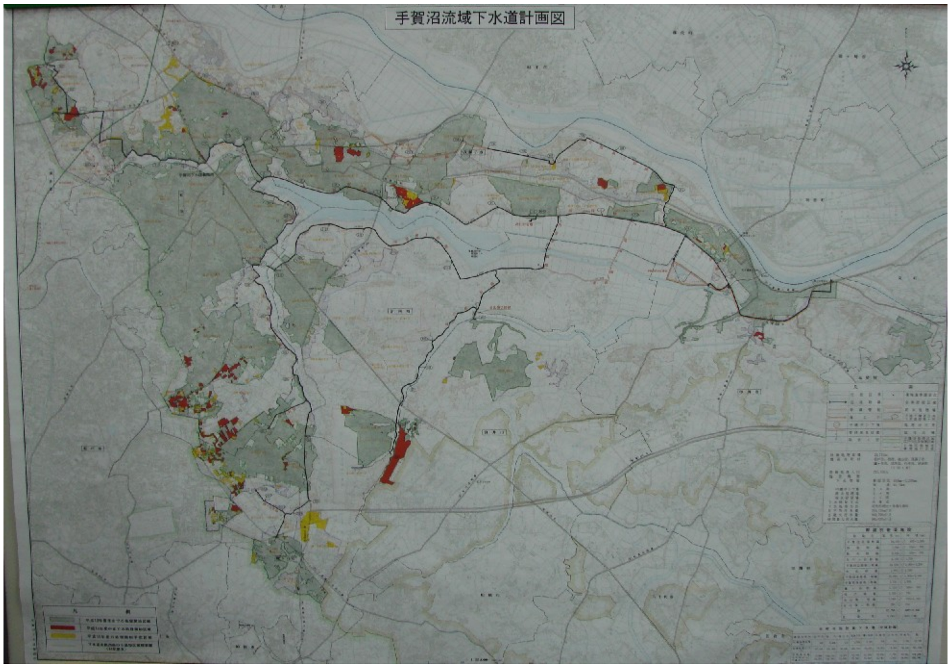


Plate13: Teganuma Waste Water Treatment Facilities Present Coverage and Plan

Plate 14: Laser Diffraction Particle Size Analysis

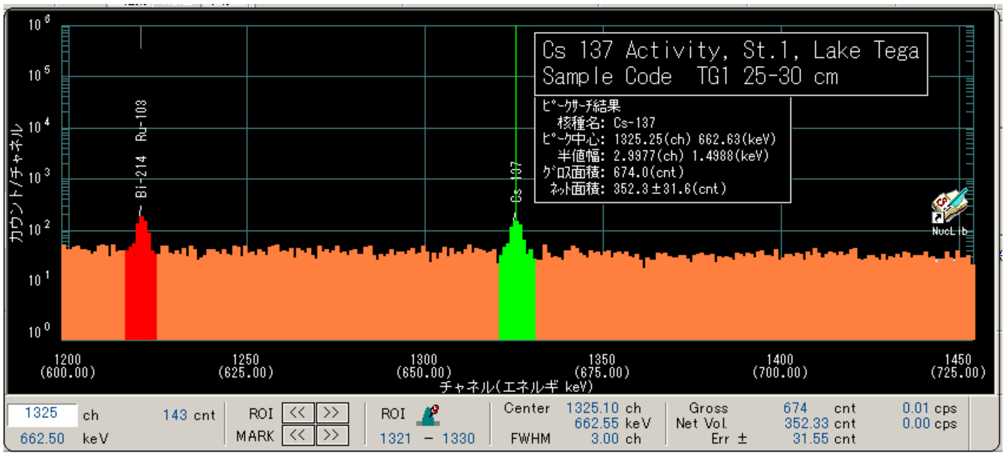
Plate 15: Nutrients Release Experiment

Plate 16: Freeze Drying of Sediment Sample (EYELA FDU-1200)

Plate: 17 ION Analysis, DIONEX ION CHROMATOGRAPH

Plate 18 and 19: EG & G ORTEC GAMMA-X® HPGe, ^{210}Pb and ^{137}Cs Sediment Dating

Plates 20 and 21: ^{210}Pb and ^{137}Cs Spectrograph and Liquid Nitrogen Filling

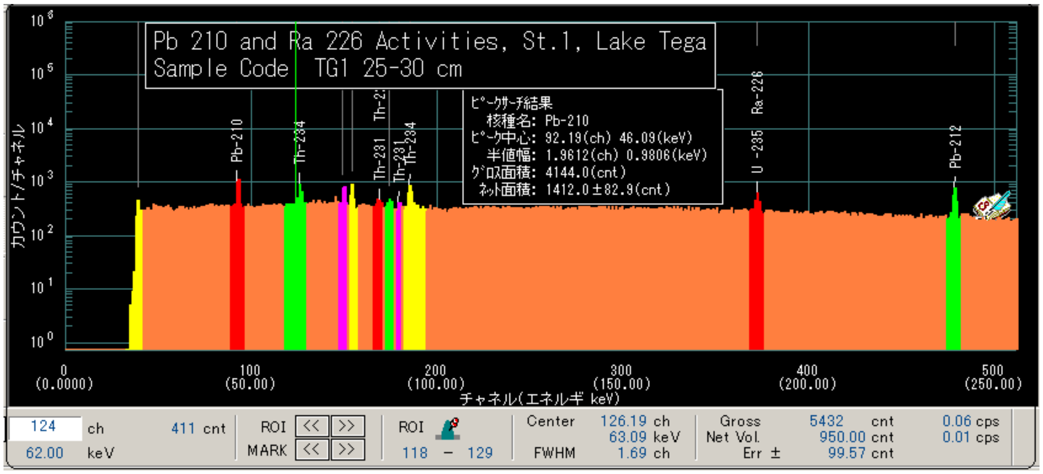


Cs 137 Activity, St.1, Lake Tega
Sample Code TG1 25-30 cm

ﾋﾟｰｸｻｰﾁ結果
核種名: Cs-137
ﾋﾟｰｸ中心: 1325.25(ch) 662.63(keV)
半値幅: 2.9977(ch) 1.4988(keV)
ｸﾞﾛｽ面積: 674.0(cnt)
ﾈｯﾄ面積: 352.3±31.6(cnt)

1325 ch 143 cnt
662.50 keV
ROI 1321 − 1330
Center 1325.10 ch
662.55 keV
FWHM 3.00 ch
Gross 674 cnt 0.01 cps
Net Vol. 352.33 cnt 0.00 cps
Err ± 31.55 cnt

Plate 22: ^{137}Cs Activity Counts, reached the Highest, Indicating 1962-1963 Nuclear Events



Pb 210 and Ra 226 Activities, St.1, Lake Tega
Sample Code TG1 25-30 cm

ﾋﾟｰｸｻｰﾁ結果
核種名: Pb-210
ﾋﾟｰｸ中心: 92.19(ch) 46.09(keV)
半値幅: 1.9612(ch) 0.9806(keV)
ｸﾞﾛｽ面積: 4144.0(cnt)
ﾈｯﾄ面積: 1412.0±82.9(cnt)

124 ch 411 cnt
62.00 keV
ROI 118 – 129
Center 126.19 ch
63.09 keV
FWHM 1.69 ch
Gross 5432 cnt 0.06 cps
Net Vol. 950.00 cnt 0.01 cps
Err ± 99.57 cnt

Plate 23: ^{210} Pb Activity Counts at the Station TG1

2006 4 19

Plate 24: A wonderful SUNSET view in Lake Tega (Ohashi Bridge)

THANK YOU!!!