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Distribution and Transformation of Nutrients in Large-scale Lakes and Reservoirs

The Three Gorges Reservoir

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Preface

The objectives of this book are to provide a clear description of early eutrophication in large-scale lakes and reservoirs and to present readers with an overview of large-scale lake and reservoir management problems and the tools that can be applied to solve these problems. This book recognizes the need for a description of both the opportunities and limitations inherent in the distribution and transformation law of nutrients in large-scale lakes and reservoirs. The Three Gorges Reservoir, one of the largest dam projects in the world as an example, will draw great concern from the public and government. This book presents some research results of early eutrophication in the Three Gorges Reservoir. Lake management tools are presented in detail, including environmental technological methods, ecotechnological methods and the application of models to assess the best management strategy.

The intent of this book is to present an integrated coverage of hydrodynamics, sediment processes, fate of nutrients and transport, and water quality and eutrophication in large-scale lakes and reservoirs. We hope we have provided a timely book that will be a resource for graduate students, environmental engineers, environmental scientists and ecological chemistry researchers with an interest in the environmental processes, mathematical modeling and fate of nutrients in large-scale lakes and reservoirs.

We would like to take this opportunity to thank all the authors who have offered their contributions and also the financial support of the National Basic Research Program of China (973 Program, Nos. 2003CB415204 and 2010CB429003) that enabled this book to come to fruition.

The authors
Beijing, China
September, 2012

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Distribution and Transformation of Nutrients in Large-Scale Lakes and Reservoirs

We present readers with an overview of lake management problems and the tools that can be applied to solve problems. Lake management tools are presented in detail, including environmental technological methods, ecotechnological methods and the application of models to assess the best management strategy.

1.1 Introduction

Nutrients are elements that are the basic atomic building blocks of living tissues. There are 16 elements generally considered as necessary nourishment. C, H, O, N, P, K, S, Ca, Mg are the macro-nutrients and the micro nutrients are like Fe, Mn, B, Zn, Cu, Mo and Cl. However, the atmosphere is the major reservoir of nitrogen on earth. Nitrogen is present in the atmosphere in its elemental form (diatomic N_2) and it also has a very strong triple bond which is very hard to break. Even in the aquatic environment, the dominant elements are hydrogen and oxygen. However, a variety of salts are dominated by the cations Na^+, K^+, Mg^{2+}, and Ca^{2+} and the anions Cl^-, SO_4^{2-} and NO_3^- which are essential for aquatic organisms as nourishment. The aquatic environments such as lakes and reservoirs are often referred to as standing waters. Man-made reservoirs, or dams, are purpose built principally to supply water to homes, industry and agriculture or, in some cases, for electrical power generation. Basically, lakes are divided into three trophic categories: oligotrophic, mesotrophic and eutrophic. An oligotrophic lake is a large deep lake with crystal clear waters and a rocky or sandy shoreline. Both planktonic and rooted plant growth are sparse, and the lake can sustain a cold water fishery. A eutrophic lake is typically shallow with a soft and muddy bottom. Rooted plant growth is profuse along the shore and out into the lake.

Water can enter lakes as well as reservoirs from a variety of sources including groundwater, runoff from the watershed, surface waters (like streams and rivers) flowing into the lake, evaporation and direct precipitation into the lake. Flowing water typically undergoes significant changes as the water enters the lake or reservoir, primarily because its velocity reduces: sediments, nutrients and other material carried in the faster-flowing water settle out in the basin, undergoing sedimentation (Ford, 1990). As result, water accumulating huge amounts of nutrients from natural environments is often called eutrophic. Compared to natural lakes, reservoirs tend to be more influenced by nutrients and other substances transported from the surrounding land. Lakes and reservoirs also differ in the amount of phytoplankton and aquatic plants (primary production) that can be supported. Elevated levels of nitrogen and phosphorous from agricultural runoff, and also from fertilizers, liberate the phosphorous and nitrogen limitations that phytoplankton experience and lead to an algal bloom or eutrophication. These blooms might stimulate bacterial growth and reduce dissolved oxygen levels in lakes, which makes aquatic life miserable. Accordingly, the two most noticeable markers of heavy nutrient loading in lakes are an excessive plant growth (eutrophication) and a decreased concentration of dissolved oxygen. However, it is a very slow and natural process; it could be significantly accelerated by human activities that increase the flow of nutrient input in a water body.

Presently, eutrophication is one of the main factors causing rapid growth of micro-organisms and turbid waters in Donghu Lake, China (He et al., 2002). Excessive growth of Eicchornia crassipes and Alternanthera pheloxirodes has been noted in the shallow, eutrophic Donghu Lake. The blooming in terms of biomass and height of the species was noted in the month of November in 1996 and 1998. Alternanthera pheloxirodes showed the beginning of a bloom in September and E. crassipes in October (Liu et al., 2004). Taihu Lake (China), is under threat from eutrophication due to the excessive amount of nutrients it receives from local industries and agricultural activities. However, Meiliang Bay is the major eutrophic area of this lake. The chemical oxygen demand was 4.63 mg/L in 1993. Total nitrogen and total phosphorus contents were 3.93 mg/L and 0.107 mg/L, respectively, in 1995. The Microcystis spp. among five major component phytoplankton species occupied 85% of the algal biomass and led to an algal bloom in summer that, in turn, affected the supply of water to the city of Wuxi (Weimin et al., 1997).

Compared to natural lakes, reservoirs tend to be more influenced by nutrients and other substances transported from the surrounding land. Lakes and reservoirs also differ in the amount of phytoplankton and aquatic plants (primary production) that can also be supported. In Developing Eutrophication Standards (DES) for Lakes and Reservoirs, the North American Lake Management Society (1992) states, "For the purposes of this document, perhaps the most important distinction between rivers, reservoirs and lakes is that of algal abundance per unit of phosphorus" (p. 9). Canfield and Bachman (1981) observed data from more than 700 natural lakes and reservoirs and compared their nutrient and response parameters. They found that reservoirs usually have substantially lower chlorophyll levels than natural lakes in the same phosphorus concentrations (Søballe and Kimmel, 1987). Cooke and Carlson (1989) reported mean chlorophyll-a values of 14.0 μg/L in natural lakes (n=309) and 10.0 μg/L in reservoirs (n=306). Based on these overall chlorophyll-a values, primary productivity appears to be lower in reservoirs than in natural lakes. Similarly, Søballe et al. (1992) found mean and median chlorophyll values for reservoirs in the southeastern U.S. to be significantly lower than those found in studies of natural lakes by Walker (1981) and Jones and Bachmann (1976). Lower productivity in reservoirs could occur because reservoirs tend to have higher concentrations of suspended solids and shorter hydraulic residence times compared to natural lakes (Søballe et al., 1992; Walker, 1984; 1985).

Many scientific experts have noticed that co-limitation of primary productivity by nitrogen and phosphorus is a common process in lakes and other water systems. As reported by Dodds et al. (1989), "statements that phosphorous is the major nutrient controlling primary productivity in freshwater systems should not be taken to mean that phosphorous is the only nutrient limiting productivity in all systems". The most commonly discussed of all nutrients, the three essential nutrients in fertilizer required for crop growth are nitrogen, phosphorus and potassium. These nutrients, when discharged into water bodies, promote phytoplankton (microscopic plants or algae) growth. Phytoplankton is primary producer, signifying the base of the food chain in all aquatic environments. The zooplankton feed upon phytoplankton, and small fish feed upon zooplankton. The smaller fish are consumed by large carnivorous fish. The growth of phytoplankton, or the primary productivity, is the first step in the food chain of a lake. The extent of algal production indicates to a certain degree the productive capacity of a lake. However, there are limits beyond which algal growth becomes detrimental to other aquatic life (Reutter, 1989).

Nutrients are necessary for all living cells; however, phosphorus is an important component of adenosine triphosphate, adenosine diphosphate, nicotinamide adenosine dinucleotide phosphate, nucleic acids, and phospholipids in cell membranes. Phosphorus may be stored in intracellular volutin granules as polyphosphates in both prokaryotes and eukaryotes. It is a limiting nutrient for algal growth in lakes and reservoirs. Phosphorus enters all water bodies continuously in runoff water and inlet streams. Phosphorus is also regularly lost from the water bodies through outlet streams and by assimilation into the sediments/mud. When a lake has anoxic bottom water in summer and stratifies, the top few millimeters of mud are chemically reduced to a condition that allows the phosphorus to be released back into the water. The bottom water thus becomes phosphorus rich. Water circulating around the lake due to winter storms brings the phosphorus-rich water to the surface, completing an annual cycle and fertilizing the lake for a spring plant bloom.

Phosphorus can be cycled some times through lakes and reservoirs, and transferred from one organism to another by food chains. Alternatively, it can sink to the bottom sediment as a part of fecal waste, a dead organism, or attached to a sinking particle. Once at the bottom of the lake or reservoir, phosphorus may become buried and unavailable to the system. Alternatively, rooted plants can transport phosphorus from the sediment into their tissues where, upon death, the phosphorus can be released back into the water (Horne and Goldman, 1994). Phosphorus in sediment may be released back into the system through chemical reactions; e.g., at pH values above 8, phosphate may disassociate from its particle and become soluble in water. Bottom-feeding fish and organisms that inhabit the bottom sediments such as worms and other aquatic organisms can also disturb the sediment, releasing phosphorus back into the water column. Phosphorus is released from lakes and reservoirs through the outflow to downstream waters (Hutchinson, 1957; Brönmark and Hansson, 2005).

Like phosphorus, Nitrogen (N) is also an essential nutrient for living organisms. It may come from natural sources, such as the decomposition of plants and animals, waste products from aquatic life within the water, urine and feces of wildlife in the catchments, or (in generally small amounts) mineral dissolution of rocks. Nitrogen also can enter lakes and reservoirs and is often of direct human origin (such as discharges from sewage treatment plants or leachate from septic systems) or is related to human activities (such as waste from poultry and livestock facilities, runoff of fertilizers, or nitrous oxides from fuel combustion). Nitrogen can be transported to lakes and reservoirs through atmospheric deposition (precipitation on the lake surface), runoff, or groundwater (Hutchinson, 1957; Wetzel, 2001).

Various chemical constituents of wild waters are thought to be an important factor in regulating the abundance, composition and geographical distribution of phytoplankton. Although phosphorus is mainly considered as the limiting nutrient for phytoplankton growth in every water system, the consequence of atmospheric nitrogen and its major role in the acidification of water can also be detrimental. Among nitrogen, phosphorus and silicon, nitrogen is usually considered as the primary limiting nutrient for the accumulation of phytoplankton diversity (Rabalais et al., 2002). Nitrogen is also an important component of chlorophyll, the green pigment that makes photosynthesis possible. It may limit phytoplankton production in temperate eutrophic waters, especially when phosphate concentrations are high (when nitrogen/phosphorus ratios are low). It is ever present in the water body in various forms. Phytoplanktons and other primary producers are able to utilize inorganic forms of nitrogen: nitrates (NO_3^-), nitrites (NO_2^-), ammonia (NH_3), and ammonium ions (NH_4^+) (Smith 1986). Some species of cyanobacteria (bluegreen algae) are also able to use nitrogen (N_2) directly from the atmosphere. Various forms of organic nitrogen (nitrogen that is bound to carbon-based molecules) may also become available in phytoplankton, like urea ($[NH_2]_2CO$), a soluble organic compound containing nitrogen that is excreted by urine and which can also be applied to the land as fertilizer, easily degrading into inorganic forms of nitrogen. Similarly, organic nitrogen found in plant and animal tissues can become available for use by primary producers if converted by bacteria into inorganic forms of nitrogen (Wetzel, 2001). Primarily, nitrogen can reduce from lakes and reservoirs through the outflow, in an exchange with groundwater, in the sediments and by denitrifying bacteria (e.g. converting NO_3^- to N_2) with subsequent loss of nitrogen gas (N_2) to the atmosphere (Hutchinson, 1957; Wetzel, 2001).

Including nutrients, other environmental factors also inhabited by plankton are heterogeneous, like temperature, irradiance and nutrient availability which are among the more obvious variables (Reynolds, 1984). The algal bloom caused by phosphorus input also modifies several abiotic factors in the water body. These factors directly rule the growth, diversity and density of the biotic components. The impact of algal bloom on any one or some of these factors indirectly influences the structure and characteristics of the water bodies. Ambient energy that can influence eutrophication dynamics may be fully investigated when long-term data with respect to time series are available (Lau and Lane, 2002).

Some microorganisms are also found to be proficient scavengers of phosphates from sewage sludge. A few strains of bacterium (Acinetobacter calcoaceticus) were found to remove substantial amounts of phosphates from an acetate medium-based pilot plant (Lawson and Tonhazy, 1980). Florentz and Hartemann (1984) also reported some varieties of A. calcoaceticus (var. lwoffi and var. anitratus), which is an efficient phosphate-removing bacteria in acetate-enriched pilot plants.

Eminent scientific groups have classified trophic status according to phosphorus absorption. Lakes with phosphorus concentrations below 0.01 mg/L are indicative of mesotrophic lakes, and phosphorus concentrations exceeding 0.02 mg/L are eutrophic lakes (Muller and Helsel, 1999). No rationale or state criteria have been established for concentrations of phosphorus compounds in water. However, to control eutrophication, the U.S. Environmental Protection Agency makes the following recommendations: Total phosphate (as phosphorus) should not exceed 0.05 mg/L in a stream at the point at which it enters a lake or reservoir and should not exceed 0.1 mg/L in streams that do not discharge directly into lakes or reservoirs (Muller and Helsel, 1999). Phosphate levels greater than 1.0 mg/L may interfere with coagulation in water treatment plants. As a result, organic particles that harbor microorganisms may not be completely removed before distribution. Eutrophic growth of aquatic plants seems to continue. Removal of detergent phosphates, by itself, will not usually accomplish such a large reduction because other inputs, such as runoff from agricultural lands, are much greater sources of phosphates. Those countries whose economies are based on agriculture have to take adequate measures in controlling the use of fertilizers, specifically phosphorus. Research and proper advice to farmers on the optimum requirement of the nutrients needs to be emphasized. Urban waste and sewage must be treated to reduce phosphorus before it is discharged into a water body.

Muller and Helsel (1999) suggested that, in order to reduce nutrient loads on lakes to within the limits permitted by the Organization for Economic Cooperation and Development, not only will all sewage inputs need to be prevented, and non-phosphate detergents used, but losses from agricultural land must be reduced.

The Three Gorges Project, the largest dam project in the world, is located in the mid-downstream area of the Yangtze River in Hubei and Sichuan Provinces, China. Despite the benefits of the dam in terms of power generation and flood control, the project has attracted attention for its potential impact on ecosystems and socio-economic stability. Especially in recent years, water bloom has occurred frequently in the backwater areas of the TGR in summer and autumn. Proper bio-indicators are expected to be provided to anticipate the trophic condition of the TGR, and to prevent the occurrence of water bloom based on previously effective measurements. The lack of functional bacteria data from the TGR is particularly worrying because environmental degradation in the TGR will probably be the most severe problem in the future.

Eutrophication of water components leads to harm for fisheries, recreation, industry, or for drinking, due to the adverse growth of algae and aquatic weeds and low oxygen level caused by decomposition. Also, many drinking water supplies throughout the world experience periodic huge surface blooms of cyanobacteria (Kotak et al., 1993). These blooms contribute to a wide range of water-related problems including summer fish kills, unpalatability of drinking water, and formation of trihalomethane during water chlorination (Kotak et al., 1994). Consumption of cyanobacterial blooms, or water-soluble neuro- and hepatotoxins (released when the blooms die), can kill life and may pose a serious health hazard to humans (Lawton and Codd, 1991). Mainly nitrogen (N) and carbon (C) are associated with accelerated eutrophication; special awareness has been paid to phosphorus (P), due to the difficulty in controlling the exchange of N and C between the atmosphere and a water body, and fixation of atmospheric N by some blue-green algae. Consequently, P is often the limiting element and its control is of the most importance in reducing the accelerated eutrophication of surface waters.

In practice, aquatic ecosystems are large sinks of nutrients such as phosphorus, nitrogen and carbon that are stored in the sediments of the water body, which is very important to water quality management. However, sinks of nutrients in aquatic or wetland systems also play a major role in regulating the transformation of nitrogen and carbon (Moore et al., 2003) as well as other biologically regulated elements such as sulphur. With the liberation of nutrients from the lake, reservoir or wetland systems, the subsequent inundation is controlled by leaching from the sediments and the decomposition of organic matter such as vegetation and detritus. Water temperature, inundation frequency, timing, duration and areal extent (St. Louis et al., 2003) have also been acknowledged to impact the above systems and affect the release, mineralization and transport of nutrients from aquatic sediments to surface waters as well as the potential transfer to hydrologically based aquatic ecosystems.

Aquatic ecosystems are sensitive to amplification of the external burden of phosphorus (organic and inorganic) from both anthropogenic and natural sources. Organic phosphorus is always associated with lake sediments and vegetation (Hogan et al., 2004). However, inorganic phosphorus is adsorbed in particles of soil or bound with lake sediments, held in complexes with iron (Fe^{3+}), aluminum (Al^{3+}) and calcium (Ca^{2+}) (Song et al., 2007). Changes in hydrological features may affect the water system. The adsorption ability of sediments decreases due to alteration from inundation. However, the hydrolysis of Fe and Al phosphate complexes gradually increases leading to the release of phosphorus into the overlying water column through leaching. As water levels recede, the subsequent decomposition of organic matter is accelerated as oxygen is initiated and phosphatase enzyme activity gradually increases, which regulates the mineralization of organic phosphorus (Song et al., 2007). On the other hand, naturally extracted inorganic phosphorus from inundated water sediments is liberally transported to adjacent water bodies by surface runoff during precipitation events (Young and Ross, 2001; Kieckbusch and Shrautzer, 2007).

Reducing P inputs into lakes may not always attain the preferred or even predictable water quality improvement, due to the sustained input of P from other sources. The direct input of P in rainfall into lakes may be sufficient to enhance the algal growth in certain states. Elder (1975) projected that rainfall P may account for up to 50% of P entering Lake Superior, and the enrichment of lakes in Ontario (Schindler and Nighswander, 1970) and Wisconsin (Lee, 1973) has been attributed to rainfall P. In addition, the release of P from sediment can sustain the growth of aquatic biota for several years after its deposition (Ahlgren, 1977; Jacoby et al., 1982). Therefore, the same form of in-lake management to reduce aquatic bioproductivity may be necessary and cost-effective. Obviously, lake use has an impact on desirable water quality goals, which will require contradictory management. Watershed management often becomes more complex with multiple-use lakes and streams, which tend to dominate U.S. waters. For example, a reservoir may have been built for water supply, hydropower, and/or flood control and, although not a primary purpose, recreation is often considered a benefit, with aesthetic enhancement (including property value) as an additional fringe benefit. Nutrients might be lost dissolved in water and involved with eroded soil/sediment in surface runoff and dissolved in leaching water. Losses of the major nutrients nitrogen (N) and phosphorus (P) from terrestrial to water resources cause water quality concerns with regard to the health of humans and aquatic systems as well as damaging the utility of water resources.

In aquatic ecosystems, the primary producer is an imperative component enhancing microbial activity, where nitrate (NO_3) and nitrite (NO_2) act as electron acceptors under anaerobic conditions during the decomposition of organic matter (D'Angelo and Reddy 1999). Generally, nitrogen is continually cycled and transformed by microbial activity (Mitsch and Gosselink 1993). Nitrogen can exist as ammonium (NH_4^+), NO_3, NO_2 or be bound in organic forms; under anoxic conditions, the partial or complete denitrification of inorganic nitrogen by microbial activity may be released as nitrous oxide (N_2O) or nitrogen gas (N_2) (Anderson, 2004). While organic matter decomposes, organic nitrogen is readily mineralized into NH_4^+ and it may dispersed into the water column as aquatic soils are inundated. If mineralization rates of organic nitrogen exceed denitrification rates in water sediments or macrophyte nitrogen-limitation becomes saturated, the transport of inorganic nitrogen to hydrologically connected aquatic systems may occur (Hemond, 1983).

The retention potential of wetland systems is quite significant, as a large portion of nitrogen entering aquatic ecosystems through precipitation and surface runoff is lost to the atmosphere (Gergel et al., 2005) or assimilated by wetland macrophytes (Laiho and Vasander, 2003). Despite this, the eutrophication of aquatic ecosystems by nitrogen loading, specifically inorganic forms such as NO_3, is readily documented (Camargo and Alonso, 2006). While most temperate freshwater systems are phosphorus limited, increases in total nitrogen concentrations may shift the phytoplankton community structure. Increases in cyanobacterial biomass have been correlated with both total nitrogen and total phosphorus concentrations, an important implication for drinking water reservoirs.

Organic carbon is also an important component of the microbial food web, providing an energy source to power many of the biologically-mediated nutrient cycling processes. While sediment of the water systems generally acts as a sink of organic carbon, the inundation of soils can lead to increased leaching of organic carbon (Asada et al., 2005) and the subsequent transport to the overlying water column (Moore et al., 2003; Corstanje and Reddy, 2004; St. Louis et al., 2004). The inundation of sediment also stimulates the mineralization of organic carbon and the subsequent release of carbon dioxide (CO_2) (Kelly et al., 1997; St. Louis et al., 2003). Under very reducing environments, the CO_2 is also subject to methanogenesis, being reduced to methane (CH_4) (Mitsch and Gosselink, 1993; Kelly et al., 1997; St. Louis et al., 2003). In addition to increasing the export of organic carbon to hydrologically connected aquatic ecosystems (Moore et al., 2003; St. Louis et al., 1996), both the methanogenesis and mineralization processes can switch a wetland system from being a carbon sink to a carbon source, significantly increasing the emission of CO_2 and CH_4 after inundation (Kelly et al., 1997).

In wetland systems, dissolved organic carbon is often transported to adjacent and hydrologically connected aquatic ecosystems, carrying with it heavy metals (St. Louis et al., 2004). As wetland soils are inundated and organic carbon is processed, decomposition, mineralization, respiration and hydrologic transport all influence the potential export of carbon to hydrologically-connected aquatic ecosystems.

The management of phosphorus, nitrogen and organic carbon in aquatic ecosystems is an important factor in controlling cultural eutrophication (Schindler, 1977), especially in drinking water reservoirs, where increases in total phosphorus and nitrogen concentration can significantly increase algal biomass, potentially creating blooms of taste and odour causing species or cyanobacteria. Total phosphorus concentration is also a predictor of other odour-producing compounds in drinking water reservoirs. However, increased concentrations of organic carbon react with bromine and chlorine to produce carcinogenic disinfection byproducts and may increase bacterial biomass within distribution systems (LeChevallier et al., 1996).

1.2 Water Quality and Eutrophication

The term eutrophication refers to the natural and artificial addition of nutrients to water bodies and to the effect that these added nutrients have on water quality (Vollenweider and kerekees, 1980). The characteristic of eutrophication is the excessive growth of algae, although many components and elements contribute to the algal growth. The most crucial nutrients are usually required in a ratio of 106 units of carbon to 10 units of nitrogen and 1 unit of phosphorus (Ryther and William, 1971). It has been shown by Liebig's Law of Minimum that the component in shortest supply will control the growth rate (Shu, 1982; Hecky, 1988). Commonly, nitrogen and phosphorous are both considered as the most frequent limiting factors in the aquatic environment, and investigations of the nutrient profile of the water body and also algae have afforded threshold estimates of nitrogen and phosphorus concentration that limit algal growth. When the total nitrogen (TN) to total phosphorus (TP) ratio in water exceeds 12 during the spring period, then phosphorus should be the limiting nutrient (Dillon and Rigler, 1974). The primary symptom of eutrophication is a high concentration of TNand of TP in the water. Sawyer (1947) suggests that TP concentration in excess of 0.01 mg/L and TN concentration above 0.3 mg/L are adequate to cause nuisance algal blooms.Since eutrophication is increased nutrient input, any activity in the watershed of a lake that increases nutrient input causes eutrophication. New Hampshire revealed that phosphorus export from agricultural lands is 5 times more than from forested lands, and from urban areas it may be more than 10 times greater. Storm water runoff from the developed land areas is the major source of nutrients for most lakes and resorvoirs. Other activities that contribute to eutrophication are lawn and garden fertilizers, faulty septic systems, washing with soap in or near the lake, erosion into the lake, dumping or burning leaves in or near a lake, and feeding ducks.

A eutrophic lake is typically shallow with a soft and muddy bottom. Rooted plant growth is abundant along the lake and algal blooms are not unusual. Water clarity is not good and the water often has a tea color. A shallow, well-mixed water column usually prevents stratification, so bottom waters are usually oxic in condition, and frequent sediment resuspension inhibits photosynthesis below 0.5–1 m water depth (Dickman et al., 1998). Cyanobacteria populations (Microcystis and Anabaena) have increased and can comprise up to 85% of summer phytoplankton biomass (Chen et al., 2003). Many natural water bodies are described as oligotrophic, for they have clear water ecosystems in which primary and secondary productivity is limited by a shortage of major nutrients (Beeby, 1995). These oligotrophic water bodies, if brought under natural succession, need thousands of years to become eutrophic. The enrichment of aquatic ecosystems through the discharge of human wastes from settlements and excessive fertilizers from agricultural lands brings down the water bodies in an undesirably increased rate of eutrophication.

Among various natural factors, water is an essential, life-supporting factor in every living cell, individual organism, ecosystem and universe. Water quality is deteriorating gradually due to the rapid progress of scientific organizations. Unfavorable fluctuations in the physicochemical characteristics of the water body bring water contaminants, which affect the planktonic flora of the water body. Planktonic flora including micro organisms are inadequately supplied by the available phosphorus or nitrogen. According to Likens et al. (1977), oligotrophic water bodies contain less than 5–10 μg/L of phosphorus and less than 250–600 μg/L of nitrogen. The mean primary productivity in oligotrophic water has been noticed between 50–300 mg carbon/(m^2·day). In moderately eutrophic water bodies, the phosphorus content is 10–30 μg/L and the nitrogen content is 500–1100 μg/L. The primary productivity in eutrophic water is reported to be above 1 g carbon/(m^2·day). If excessive amounts of phosphorus and nitrogen are added to the water, aquatic organisms and plants can grow over a large area and eutrophication occurs. When an organism dies, it is naturally decomposed by bacteria and the decomposers use up the dissolved oxygen in the water body. The dissolved oxygen concentrations often drop too low for aquatic life to breathe, leading to life kills (Murphy, 2002). It is well known that eutrophication is a natural process in lakes as well as reservoirs. Nitrification is usually included in water quality management due to its significance in mediating the contents of dissolved oxygen, ammonia, nitrate-nitrogen and phosphates (Deb and Bowers, 1983).

Nitrification, microbial-mediated oxidation of ammonia to nitrate, is a key process in the N cycling in every water component. It is a two-step process; firstly an ammonia-oxidizing stage that transforms NH_4^+ to NO_2^- by ammonia-oxidizing bacteria (AOB); secondly the nitrite-oxidizing stage that transforms NO_2^- to NO_3^- by nitrite-oxidizing bacteria (NOB), in which the ammonia-oxidizing stage is the critical stage controlling the nitrification (Costa et al., 2006). Hyper-nitrification caused by the heavy loads of N and P, is greatly assisted by the N and P cycling in the natural environment (Jergensen and Richardson, 1996; Paerl, 1997). It is often assumed that nitrification occurs in the water column and that the process follows first-order kinetics with rates calculated as a function of water column ammonia contents (Ambrose et al., 1993; Scott and Abumoghli, 1995). However, nitrification in freshwater is known to take place mainly on suspended particles (SPs) and bed sediments (Bonnet et al., 1997). Consequently, the investigation of the relationship between SPs and the nitrification rate in the aquatic environment is of importance for developing the ecosystem model of nitrogen biogeochemical cycling (Kittiwanich et al., 2007) and water quality management.

Even though the eutrophication process in lakes has not yet led to a significant deterioration in the water quality, the ecological balance within lakes is extremely fragile owing to the high nutrient loadings. Therefore, lake water management must focus on reducing the nutrient input into the lakes from the streams that drain the vast rural areas of Jiangsu and Zhejiang provinces and the Great Shanghai Metropolitan Area.