Chapter 1

Introduction

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Lake Malawi/Nyasa - An African Great Lake and Great Resource

Lake Malawi/Nyasa is located in the southern end of the great rift valley systems which fracture the ancient plateau of eastern Africa (Westcott et al. 1996). A lake has existed in the rift for over two million years. The geology of the catchment is relatively simple (Fig. 1.1), with most of the basin consisting of ancient metamorphic rocks and granites of the basement complex with scattered coverings of Cretaceous sediments in the south, more recent Cenozoic lake sediments along segments of the western and southern lakeshore and, in the north, volcanics of the Rungwe volcanic field in Tanzania. The process of rifting was accompanied by regional uplift which reinforces the dramatic topography created by graben formation. Consequently, the lake is surrounded by mountains with highest elevations to the north where the mountains rise over 2000 m above the lake's surface, and lower elevations to the south. The lake merits the adjective "great" by almost any measure, e.g. area, depth, age, diversity, but most assuredly it is a great resource for the riparian peoples of Malawi, Mozambique and Tanzania. It is the fourth deepest inland water body in the world with its greatest depths (700 m) extending below sea level. It is the ninth largest by area (Hutchinson 1957) and the fourth largest body of freshwater on the globe. The value of such a huge aquatic resource in semi-arid, drought-prone southern Africa cannot be overstated. For the people on the lakeshore, it provides the basis for life itself through abundant water for drinking and domestic uses, production of fish which provides the cheapest animal protein in human diets, easy transport for lake commerce and possible use for irrigation of crops. In addition, for the country of Malawi currently, the lake's catchment provides water for hydroelectric generation and exceptional opportunities for tourism. But the lake is also renowned for its fabulous biodiversity, especially among the numerous cichlid fishes, the haplochromine subfamily being particularly species-rich and nearly completely endemic. Malawi/Nyasa has more species of fish than any other lake in the world with the actual number of species still to be determined. Many of these fishes are colorful and highly sought after by the aquarium trade. The inshore distribution of these fishes and their inquisitive behaviour make them attractive to view and adds immeasurably to the tourism potential of the lake. The existence of this biodiversity has attracted international interest and together with the other resource uses of this international lake has led to the implementation of the SADC/GEF Lake Malawi/Nyasa Biodiversity Conservation Project. At a more fundamental ecological level, these fishes are a scientific wonder as they have made many adaptations to the habitats available in the lake, especially in regard to how they extract food resources from the lake; and challenge science with basic questions such as what limits the number of species in an ecosystem and why are some ecosystems so species-rich while others are poor.

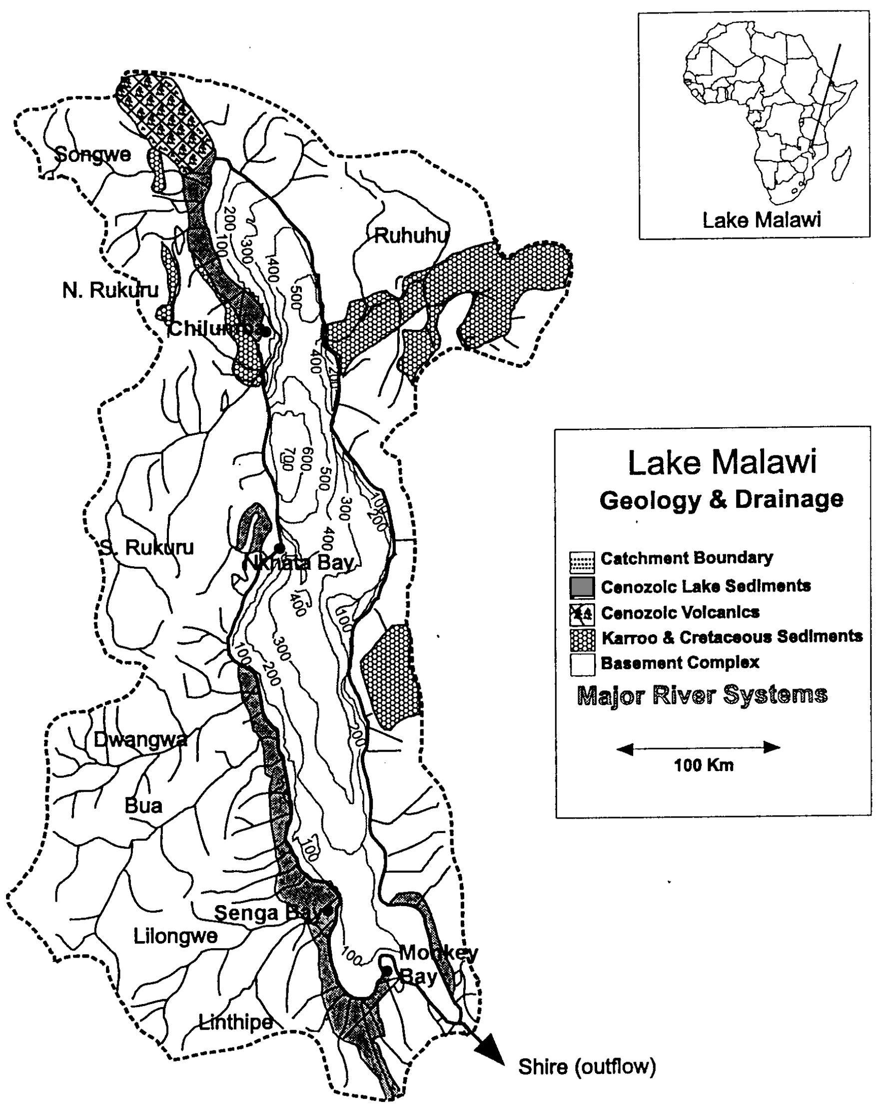

Figure 1.1. General geology and river systems in the Lake Malawi/Nyasa catchment (after Kalindekafe et al. [1996], with bathymetry from François et al. [1996]).

Why Water Quality Studies?

All the many positive aspects of Malawi/Nyasa share one common requirement to maintain their beneficial uses. They all depend on the maintenance of good water quality. It could easily be said that the lake has had “great” water quality. Water clarity is perhaps the most universally accepted indicator of good water quality, and Malawi/Nyasa excels in all seasons and over most of the lake in having exceptional quality with water clarity often exceeding 20 m. This great water quality has allowed the development of manifold uses and the sustenance of large lakeshore populations. However, experiences in the last few decades in other great lakes of the world have demonstrated that good water quality can be easily degraded by human activities and the many beneficial uses of the lake impaired to the point of elimination. The lesson from lakes around the world is that the quality of water in inland water bodies is directly in the hands of those who use the water and use the catchment and atmosphere which supply the water. It will be not different in Malawi/Nyasa. Appreciation of this fact and the knowledge of the essential processes which determine water quality in Malawi/Nyasa must be institutionalized in effective management action soon if the lake is going to avoid the worst of the degradation that other great lakes have endured. Therefore, as part of its contribution to the SADC/GEF project, the Canadian International Development Agency has funded studies of water quality of Lake Malawi/Nyasa with special reference to the condition of water inputs to the lake, and with special reference to internal lake processes which maintain and express the water quality that sustains the lake’s biodiversity.

The overall goal of the SADC/GEF Lake Malawi Biodiversity Conservation Project, as stated in the Project Implementation Plan, is to develop an integrated management plan for the purpose of protecting fisheries and biodiversity in Lake Malawi/Nyasa. The lake currently has more species of fish than any other lake in the world with over 500 species and over 90% endemic i.e. found only in Lake Malawi/Nyasa. Given that only three lakes (in Africa) or four lakes (Baikal) in the world have species richness on this scale, our understanding of the factors and conditions which allow such diversity to develop and be maintained is limited as are examples of demonstrably effective management. Experience in the Laurentian Great Lakes of North America (Ragotzkie 1988; Sweeney 1993) and within Africa (Lake Victoria; 1993) has shown that fisheries and biodiversity in these lakes can be affected seriously by changes in water quality resulting from human activities within the lakes’ watersheds. Therefore, there is little doubt or need to relearn the lesson in Malawi/Nyasa that good water quality is essential to maintenance of healthy, diverse aquatic ecosystems.

The best guide initially as to what water quality is required to maintain the diversity of Malawi/Nyasa is to define the current state of Lake Malawi/Nyasa and then try to determine how sensitive these current conditions may be to change or whether these conditions may already be changing. Degraded water quality reduces the value of the aquatic resource and limits its beneficial uses, of which biodiversity is one product. The riparian peoples around the lake also depend on the lake for drinking water, livestock management, food production from fish, and transportation. All these uses can be impaired or lost through poor water quality. Excessive sewage loading can breed pathogens in local situations and excess algal growth due to nutrient enrichment can increase the cost of water treatment or eliminate lake water as a source for drinking if toxic algae blooms occur (Davies and Day 1998). The phycotoxins from such algae usually affect livestock first because of the quantities of water intake. They can also cause fish kills. In the North American Great Lakes, contaminants, such as organic pesticides and metals such as mercury, have closed entire fisheries to harvest or required consumption advisories limiting fish consumed in the diet. In Lake Victoria the water hyacinth thrives because of the very high level of nutrients in that ecosystem, and the hyacinth clogs major harbours and brings fishing beaches to a standstill. Loss of any of these beneficial uses of the Malawi/Nyasa by the riparian people will have dire consequences because they have no or only limited alternatives to the services which the lake currently supplies without cost. North American Great Lakes management has shown that degraded great lakes can be restored in many aspects (Sweeney 1993), but only at great cost. It is far preferable to avoid the onset of these problems. Prevention of degradation is the best and most cost-effective strategy when dealing with water resource issues.

Learning from Lake Victoria

The possibility of substantial degradation of these great African lakes has now been established. Lake Victoria on the equator in eastern Africa has suffered major losses in its biodiversity and substantial changes in its water quality. The introduction of Nile perch to the lake and the upsurge in Perch populations in the late 1970's to early 1980's have contributed to the reduction of native fishes (Witte et al. 1992). However, nutrient enrichment, also known as eutrophication (Hecky 1993), has occurred in Victoria at an accelerating rate since the turn of the century (Lipiatou et al. 1996) with a doubling of nutrient concentrations and algal productivity since 1960 and a 10 fold increase in algal biomass (Mugidde 1993). The resulting excessive growth of algae (Kling et al 1998) includes some species which may be toxic to humans and animals, has deoxygenated the lake's deep water (Hecky et al 1994), decreased habitat for bottom dwelling, endemic cichlids and reduced their ability to discriminate mates and prevent hybridization (Seehausen et al 1998), and has created nutrient conditions in which the exotic water hyacinth has thrived, increasing the incidence of water borne diseases and disrupting transport, hydroelectric generation and lakeshore use around the lake. The physical and nutrient changes which accompany eutrophication alter food web structure and feeding relationships among fishes which in Lake Malawi/Nyasa are finely adjusted to specific food resources (Bootsma et al 1996). Cultural eutrophication arises from the activities of dense human populations in the catchment of the lake. Human land use can also lead to excessive erosion and sedimentation which affects fish habitats directly by burying food resources, reducing light penetration required for benthic photosynthesis, clogging fish gills and smothering eggs of invertebrates and fishes. Excessive sedimentation results from high sediment yields from catchments and threatens the diversity of nearshore fishes in Lake Tanganyika (Cohen et al 1996). Sediment yields are affected by human activities, especially agriculture, with highest global yields occurring in areas of intensive agriculture (Stone and Saunderson 1996), especially in mountainous terrain (Milliman and Syvitski 1992).

Lake Victoria is an important case with obvious relevance to Lake Malawi/Nyasa. It was similarly rich in endemic species of haplochromines. Whether or not it was as diverse as Malawi/Nyasa prior to the recent changes in the Victoria ecosystem will likely never be known because comprehensive faunistic studies such as those undertaken by the SADC/GEF project in Malawi/Nyasa were never completed. The fact is that many once common species in Victoria are no longer found and may be extinct (Witte et al. 1992), which demonstrates that these diverse systems are vulnerable. Victoria is the largest lake by area in Africa (second largest in the world) but with only one-third the volume of Lake Malawi (Table 1.1). Victoria is much shallower than Malawi/Nyasa, which has a permanently stratified and naturally anoxic deep hypolimnion (below 200 m). The Nile outflow from Victoria is nearly twice the Shire flow (nearly proportional to the difference in catchment area of the two lakes, which means that the flushing rate of Victoria is much more rapid (Table 1.1). The consequence of these hydrologic characteristics of the two lakes is that pollutant concentrations can rise much more quickly In Lake Victoria, but Victoria will recover much more rapidly if the pollutant inputs are stopped (Figure 1.2). Lake Erie in North America is the best known case of substantial recovery from pollution on the great lake scale (Sweeney et al. 1993). Lake Erie is a large, shallow lake like Victoria, but its flushing rate is on the order of five years, allowing it to flush out excess nutrients and contaminants relatively rapidly. It could take centuries to millenia for Lake Malawi/Nyasa to recover if it ever experienced pollutant concentrations such as those that occurred in Lake Erie. Again, prevention is the only realistic and affordable policy for maintaining Malawi/Nyasa in a healthy condition and insuring its continued beneficial uses by the people.

Table 1.1 Morphometric and hydrological data for Africa's three largest lakes (after Bootsma and Hecky 1993).

	Malawi	Tanganyika	Victoria
Catchment Area (km^2)	100,500	220,000	195,000
Lake Area (km^2)	28,000	32,600	68,800
Maximum Depth (m)	785[a]	1470[a]	79[b]
Mean Depth (m)	292[a]	580[a]	40
Volume (km^3)	8400[a]	18,900[a]	2760[b]
Outflow (*O*) ($km^3\ y^{-1}$)	11[c]	2.7[d]	20[b]
Inflow (*I*) ($km^3\ y^{-1}$)	29[c]	14[d]	20[b]
Precipitation (P) ($km^3\ y^{-1}$)	39[c]	29[d]	100[b]
Evaporation ($km^3\ y^{-1}$)	55[e]	44[d]	100[b]
Flushing time (*V/O*) (years)	750	7000	140
Residence time (V/(P+*I*) (years)	140	440	23

[a] Gonfiantini et al. (1979)
[b] Rzoska (1976)
[c] Owen et al. (1990)
[d] Coullter and Spigel (1991)
[e] Eccles (1974)

Natural or Man-Made Changes - The Management Challenge

Hence, a specific goal of the project as stated in the Implementation Plan is to "develop a comprehensive understanding of the limnology and water quality of the lake and the manner in which it is affected by anthropogenic and natural activities in the catchments". Anthropogenic activities arethose conducted by the people of the lakeshore and catchment in pursuing their livelihoods and meeting their daily needs. It is safe to say that no one in the catchment is deliberately degrading the lake, although they may unknowingly have negative effects. It is also the case that a few people may unknowingly indulge in some practices which degrade the lake, but that their effects might be undetectable in the lake because the lake is large and the population small. Certainly the density of people occupying a catchment will determine how much effect the population can have on the lake. For example, the Lake Victoria catchment is much more densely populated than the other African Great Lakes (Fig. 1.3) and that fact together with the smaller volume for dilution of Lake Victoria (Table 1.1) has caused that lake to have substantial changes in its water quality while Malawi/Nyasa and Tanganyika have yet to exhibit such obvious changes.

Natural phenomena can also affect the water quality and the biota of the lake. Most important are meteorological and climatological events. The deep waters of Lake Malawi/Nyasa (which are naturally rich in nutrients and anoxic) exchange water very slowly with the surface waters and there-

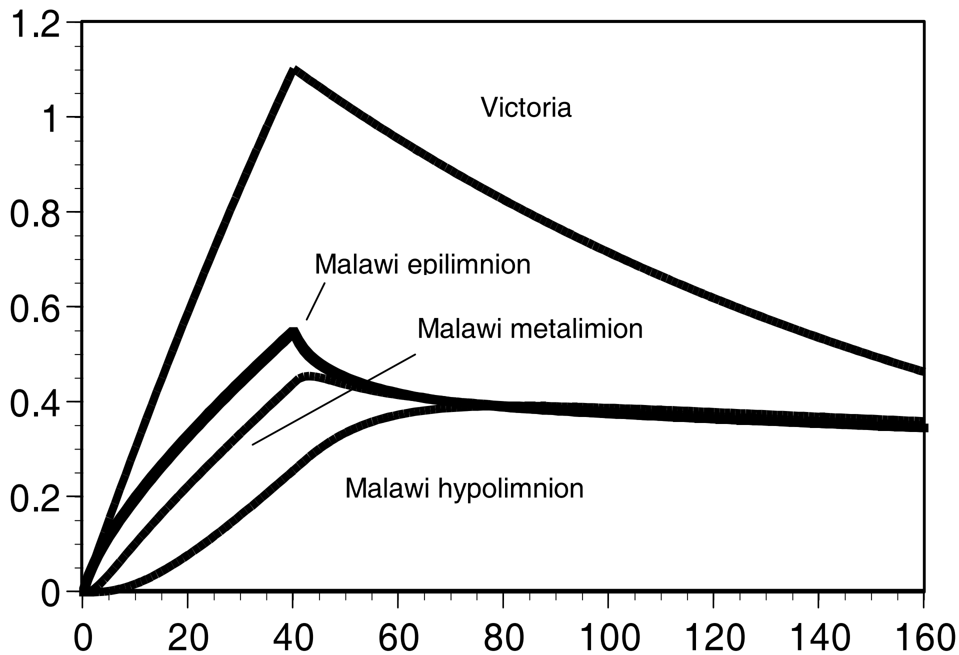

Figure 1.2 Pollution scenario for Lakes Victoria and Malawi/Nyasa in which all inflowing rivers contain 5 mg L-1 pollutant for 40 years, followed by complete cessation of pollution input. The model assumes that the only pollutant loss mechanism is outflow, and that all inflow enters the epilimnion. Modified from Bootsma and Hecky (1993), using the vertical exchange rates reported by Vollmer and Weiss (chapter 4 of this report).

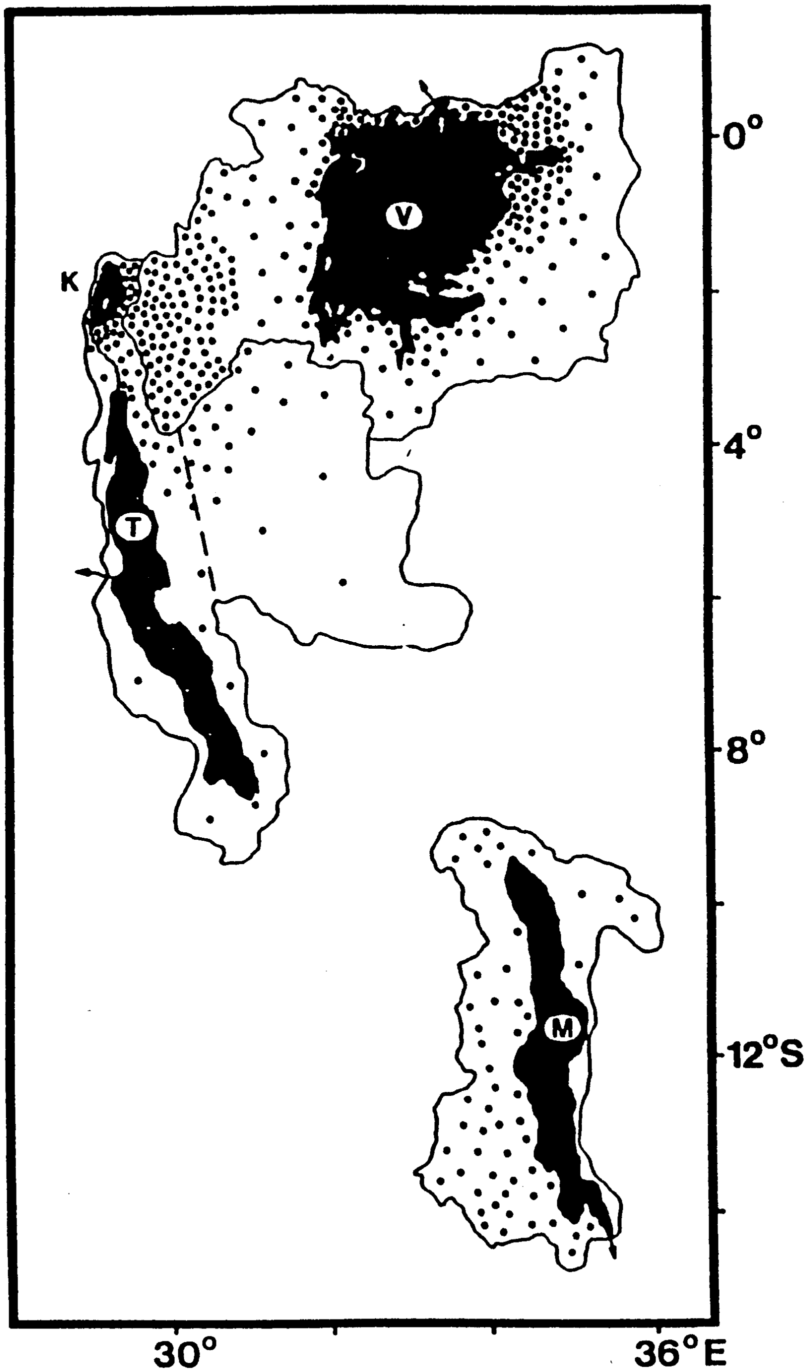

Figure 1.3. Human population densities in the drainage basins of Africa's largest three lakes. One dot = 100,000 persons. Estimates are for 1992 (Bootsma and Hecky 1993), based on official government figures and an assumed population growth rate of 2.8% per annum. V=Victoria; K=Kivu; T=Tanganyika; M=Malawi/Nyasa.

fore the surface waters remain low in algal abundance with high clarity. Processes that affect this rate of exchange can also change the quality of surface waters. When storms or persistent strong winds introduce deep, nutrient-rich but anoxic water quickly to the surface then fish kills and algal blooms can result. This is an example of how natural processes can change water quality. The challenge for the management of lakes is to appreciate the causation of perceived changes. Some changes can be prevented or ameliorated while others resulting from natural processes are beyond our abilities to control. Scientific knowledge is necessary to discriminate natural and anthropogenic changes and to recommend corrective action, if possible, to reverse or modify man-made effects. The studies in this report therefore have had to address the natural water circulation of the lake which is controlled by winds and radiant energy exchange as well as how the inputs to the lake from rivers and atmosphere may or may not be changing due to human activities. The interchange with the deep water in Malawi/Nyasa is also important to quantify because previous studies have suggested that the nutrient inputs to the surface waters are in fact dominated by deep water inputs (Bootsma and Hecky 1993). If this were the case, then the lake would be insensitive to short term changes in catchment or atmospheric inputs. In order to determine the lake's sensitivity to changing inputs (whether natural or anthropogenic) requires knowledge about the timing as well as the rate of total nutrient inputs to the surface of the lake from all sources. It also requires knowledge about which nutrients are most likely to change algal growth conditions, and such studies are also included in this report.

In the case of contaminants the issue of anthropogenic vs. natural is much easier to resolve. Industry and agriculture use (or have used) a wide variety of artificial compounds which have not existed on earth before. The occurrence of these compounds in water and biota is clearly related to human activities. Many of these compounds are toxic to aquatic life and humans. Some are persistent in the environment and bioaccumulate and biomagnify in food chains, often posing risks to top predators including humans. The waters of all the Great Lake of North America have been affected by such toxic compounds. Fish consumption advisories are posted on all the great lakes there and the Lake Erie walleye fishery was closed to commercial fishing in the early 1970's because of methyl mercury contamination. Although the Lake Erie mercury situation has improved and commercial fishing resumed, fisherman did suffer lost income. A contamination event such as this in Africa would have dire health and economic consequence because of the dependence of the populations on fish as a source of cheap protein. In the case of other contaminants, e.g. cadmium, aquatic biota are actually more at risk than humans from low level contamination. The consequences of long term exposure to many of organic contaminants are still being scientifically debated in the developed world which has had the highest exposure to these contaminants. But, because of the persistence of many of these toxins (e.g. DDT and its degradation products) in the environment and their demonstrable affects on top predators, this water quality report establishes the current level of many of these contaminants of concern in Lake Malawi and its biota, and assesses the possible risk they pose.

Ecosystem Monitoring - The Ongoing Requirement

In evaluating the water quality of Lake Malawi-Nyasa, it is relatively easy to establish current conditions given adequate resources, but this is only a first step in insuring the conservation of the lake's many beneficial uses and its biodiversity. Knowing what conditions are today, and whether they are acceptable, is the necessary first step towards management of the lake. It identifies whether current conditions pose any risks or hazards, and it establishes a "baseline" to which future studies can refer to evaluate whether positive or negative changes may be occurring. The baseline of current conditions established in this study, for the most part, has no previous, comparable, reference data against which to evaluate change. In water quality management, trends are as important as current conditions. In this regard the Water Quality Study has established a monitoring programme which is currently being operated on the lake (Figure 1.4) and which may be continued in whole or in part to allow evaluation of trends into the future. This component has a remote monitoring program which measures and records physical data at daily (or higher frequency) intervals and a chemical and

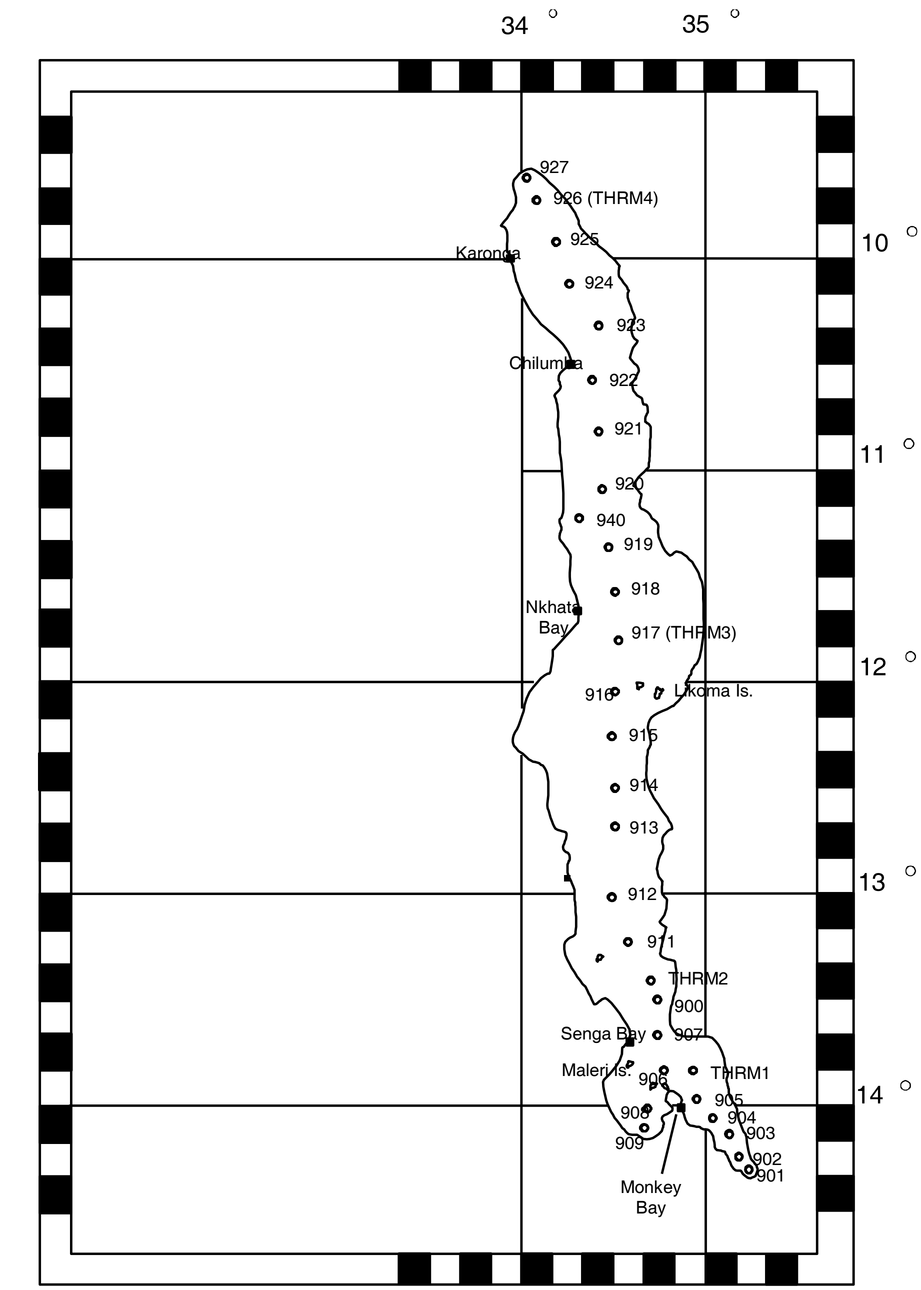

Figure 1.4. Locations of limnology sampling station on Lake Malawi/Nyasa. Thermistor locations are labelled THRM. Sediment traps were place at THRM2 and THRM3. Meteorological stations were installed at Senga Bay, Likoma Island, Chilumba, and on board the R/V *Usipa*. Deep chemical profiles were regularly sampled at Stations 905, 900, 915, 918, 924 and 940.

biological component which acquires data lakewide every three months and at a standard station monthly.

The remote monitoring includes (up to) twice daily acquisition of CCD (computer compatible data) at the Senga Bay receiving station (support from Natural Resources Institute-UK through DFID contribution to the project) from the NOAA AVHRR satellite, the operation of four remote weather stations (as well as acquiring data from four lakeshore weather stations operated by Malawi Meteorological Dept.), the operation of recording thermistor chains from near-surface to near-bottom depth at up to four locations, and continuous trapping of sedimenting materials at two of the thermistor chain stations. The remote monitoring is supported by nearly continuous monitoring of several atmospheric deposition monitoring activities including biweekly collection of aerosol chemistry (including a broad range of pesticides and other volatile organic contaminants such as polynuclear aromatic hydrocarbons) for a period of one year, dry fall depositon (nutrients), and (up to) daily monitoring of the chemistry of wet deposition (nutrients and major ions) at Senga Bay, which is still continuing.

Quarterly cruises cover Lake Malawi from its southern to northern extremities. During each cruise, 26 stations are sampled. At 21 of those stations, an integrated water sample from 0-50 m is analyzed for chemical parameters while at 5 of these stations, depth profiles of chemical parameters are collected to near maximum station depth. In addition, measurement of light penetration and phytoplankton abundance is measured at all stations. Thermistor chains, sediment traps and remote weather stations are also serviced on these cruises. A standard station northeast of the Senga Bay lab (in 180 m water depth) is sampled monthly. Cruises began in September 1996 and remote data acquisition was in place by January 1997.

River sampling has been conducted over two rainy seasons with analyses completed at the Senga Bay chemistry laboratory and the Freshwater Institute in Winnipeg (for particulate nutrients). This monitoring programme can continue indefinitely, in principle, funds and staff commitments permitting; or a simplified programme could be instituted. The operation of this monitoring network is the responsibility of the project limnologist, Dr. H.A. Bootsma, with technical assistance from the National Water Research Institute, Burlington, Canada (thermistor chains and two weather station deployments), Natural Resources Institute-DFID, U.K. (satellite data receiving), Freshwater Institute, Winnipeg, Canada (chemical, including organic contaminants, and biological analytical services) and ship support through Captain M. Day and crew of the R.V. *Usipa* (DFID).

The information collected by the monitoring programme has already had several applications. First, by comparing the data with that collected by other research projects that have operated over the past several decades in the pelagic of Lake Malawi/Nyasa, change can be evaluated for some parameters sampled in common with similar methods. Second, some of the measurements that are being made have either never been made before in Lake Malawi/Nyasa (e.g. organic contaminants in aerosols and wet deposition) or have been made infrequently, but these parameters are known to be sensitive to changing water quality (e.g. the nutrient composition of particulate material) or are able to change water quality (e.g. atmospheric invasion of volatile organic compounds). These new data will serve as baseline information so that we will be better able in the future to determine if water and air quality conditions are changing, and the rate at which they are changing. Third, ongoing monitoring provides us with a better understanding of the relationship between physical, chemical and biological variables in the lake. This information will be used to construct conceptual and mathematical water quality models for the pelagic (offshore), which can then be used to predict the lake's response to environmental changes. Such predictions are valuable when developing a management plan. An affordable, ongoing monitoring program, to demonstrate the efficacy of the management actions and to allow early detection of departures from expected or acceptable values, should be designed from the studies conducted in the current project.

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