Lake Toba

The First Sound Science Initiative to Abate Change in the Lake Environment

Research and Monitoring for Basin Management Decisions

By

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Cover: View from Samosir to the east by Pasi Lehmusluoto
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1. Introduction: The History of Research and Monitoring at Lake Toba.

Lake Toba and its surrounding area are the homestead to the exuberant *Batak* tribe who came to inhabit these highlands many millennia ago (**Figure 1**). This spectacular North Sumatra lake resource is renowned throughout the world for its remarkable clarity and enormous volume (240 km^3) of deep, blue waters. The ninth deepest lake in the world (529 meters), Toba has a surface area of 1,130 square kilometers. The drainage basin is composed mainly of basaltic rocks and partly of sedimentary rocks. The sedimentary rocks of Samosir, the size of Singapore, are generally sand and gravel deposits. The drainage land area of 294 stream basins is small (2,568 km^2) in comparison to the lake itself. Indonesia is more fortunate than most Southeast Asian countries in possessing an abundant supply of clean lake water. Lake Toba is half of the supply.

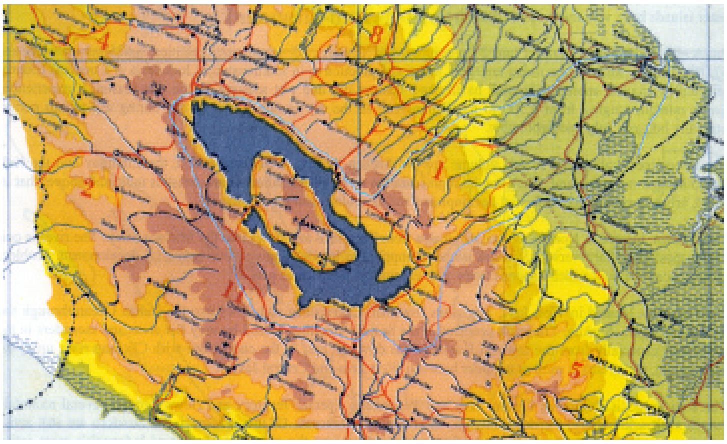

Figure 1. Location of Lake Toba in North Sumatra.

The rock type, altitude and very limited drainage area are largely responsible for the clear waters, lake's sparse algal population and low fish production. Few nutrients are naturally available to fertilize the lake. **The drainage area development with large townships, numerous tourist facilities and intensive agriculture, and aquaculture in the lake, however, may create the future problems if proper solid waste and waste water control is not arranged.**

The small but sustained reduction in rainfall has caused a declining trend in the net inflow of water and unbalanced water discharge at the regulating dam has caused lake level decline and lengthening of the water renewal time to well over 300 years. This makes the lake very sensitive and vulnerable for nutrient and other chemical additions. All that enters the lake stays there with continued, synergistic and cumulative consequences.

The first disturbance of the basin has occurred when the forests were lumbered in historical times and cleared for agriculture. There is evidence that deforestation has started already thousands of years ago in the area. Quite extensive deforestation took place some 100 years ago to provide timbers and conversion of land for agriculture. Sedimentation records of that period in similar great lakes elsewhere, discussed later in this initiative, indicate that, in the absence of extensive road-building and other development, the watersheds have healed quickly from this disturbance and the water quality of the lakes is very little affected.

Lake Toba has not yet responded to nutrient loading from the streams, atmosphere, and groundwater and from the watershed development activities with steadily increasing algal growth and a progressive loss of transparency. The northern and southern parts of Lake Toba and the Pangururan and Porsea basins show natural differences in plankton productivity and transparency, and deepwater oxygen. They may be considered as separate ecological entities, although closely interconnected.

The following initiative presents the evidence for the decline in water quality in a similarly large crater lake elsewhere (Lake Tahoe, California/Nevada, USA), discusses the possibility for similar development in Lake Toba and establishes the need of the Lake Toba Interagency Environment Monitoring Programme (LTIEMP) in providing water quality data for the basin management. LTIEMP shall make possible the extension of what has previously been uncoordinated sporadic basic research and facilitate both continuous research and monitoring. LTIEMP shall be designed to serve the needs of both planning and regulatory agencies by supplying data they need for solving development problems in the Toba basin (**Figure 2**).

Research and monitoring at Lake Tahoe has lead to the basin management decisions to divert all waste waters, including treated waste waters, from the lake.

Figure 2. For effective monitoring of the Lake Toba basin ecosystem, LTIEMP shall study the hundreds of samples from the 294 streams, from various areas and depths of the lake, and from precipitation and perform thousands of physical, chemical and biological analyses every year.

Mark Twain has described Lake Tahoe's beauty and remarkable transparency in his book *Roughing It.* The same description applies to Lake Toba. The renowned developers of limnology Franz Ruttner, Einar Naumann and Heinrich J. Feuerborn made the first scientific observations at Lake Toba in 1928-29 and reported their findings in numerous publications. The latest is from 1952. Lehmusluoto and his colleagues report lake observations of the 1990s in 1995, 1997 and 1999, and Acreman and coworkers in 1993, Schmitz 1994, Thomas 1995 and Ratulanggi in 1995.

Limnology, the science of inland waters, is similar to its sister science, oceanography. Both disciplines focus on the interaction of physical, chemical, and biological processes occurring in water bodies. Modern limnology considers the watershed to be an integral part of the ecosystem because the extent of vegetative cover and the degree of erosion from the parent soils profoundly influence the quality and biological activity of the receiving waters.

The first intensive long-term limnological study of Lake Toba is still a dream and an evaluation of solid waste management and sewage disposal alternatives in the basin need yet to be accomplished. The measurement of the algal growth rate in Lake Toba and the corresponding measures of water transparency and eventually oxygen shall evidence the absolute necessity of long-term data sets for detecting trends in dynamic ecosystems. Because of the year-to-year variation in weather conditions in North Sumatra, the first data must be collected over a five-year period to detect statistically significant baseline for trends.

National and provincial planning and law enforcement agencies must base their decisions on data that will withstand the most careful scrutiny. Long-term, effective monitoring of the lake and its tributary streams, to be accomplished by the LTIEMP programme, is required as part of the adoption of the recommendation of the Biodiversity Action Plan for Indonesia (BAP) addressing Lake Toba as a key site for conservation of ecological diversity. Because regulatory agencies must make informed final decisions regarding protection of the resource, they require unequivocal results for example what ecological diversity to conserve. LTIEMP has to provide a comprehensive data set useful in determining the long-term causes of the possible deterioration of the lake, while at the same time providing a means to evaluate the adequacy of remedial measures being developed to meet the requirements of the Toba basin development.

The Lake Toba Interagency Monitoring Programme (LTIEMP) shall be a result from a series of meetings between the local communities, civil society, universities, private sector and regional and national agencies. It is apparent that ***much basic research has not been done*** in the past. A strong environmental monitoring programme is necessary to accommodate the needs of the agencies concerned with land-use planning and regulation. The basic research programmes of the local universities could provide additional extensive data collection and publication but there shall be sufficient funding for such activities (**Figure 3**).

No monitoring of stream borne nutrients has been made during the years. Thus, at a time of particular need for high quality environmental monitoring data, the lapse has resulted in a loss of important information. The urgent requirement for routine data collection and publication is so apparent that representatives of regional and national agencies must be brought together. In the meetings, it is necessary to set the goals and objectives and secure funding for the LTIEMP programmes for at least for the first 5-year period. The LTIEMP programme will be fully developed after review of the first 5-year period of research and monitoring efforts at Toba. A comprehensive report from that period will be central to this LTIEMP planning process because it will summarize the results. It shall include information on stream monitoring and studies of the local universities, as well as the lake and watershed studies.

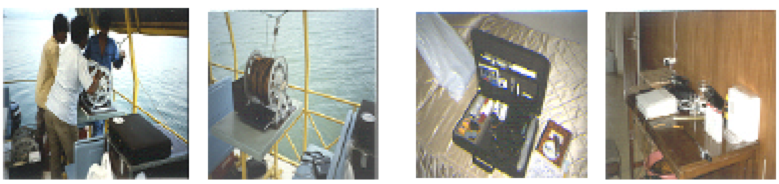

Figure 3. A variety of physical, chemical, and biological measurements shall be taken spatially from Lake Toba at certain intervals year-round, as part of the LTIEMP programme.

The main objective of this initiative is to provide the basis for the establishment of a cooperative interagency monitoring programme by providing recommendations on the types of data to be collected. The programme, the product of interagency discussions, shall acquire and annually disseminate essential water quality information to support regulatory, planning and research activities in the Toba basin. The advisory committee of contributing agencies shall be established. After incorporating all data, the results shall be analyzed and the annual report prepared and distributed.

2. Land-use History: The Cause for Concern?

Lake Toba's large size, the recreational opportunities of its clear deep waters and surrounding mountains, and its ease of access have proven to be a magnet for development. ***Historical Batak-induced changes have been evident for thousands of years***. A marked increase in population and construction in the basin has taken place during the last decades (**Figure 4**). Visitors make often a great proportion of the number of basin residents during peak recreational periods.

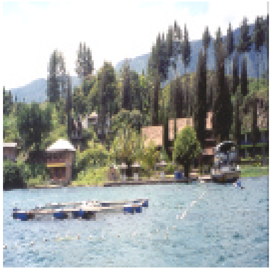

Figure 4. Population and construction of houses and tourist facilities have increased during the last decades, as also fish farming.

In recent years, there has been extensive publicity and concern about the consequences of development of the Toba basin. One important question, raised in numerous public forums, involves the effects of the erosion from basin-wide logging activities during the 1900s and especially in the 1990s, including the decline of water level. It has been suggested that the loss of water quality may also have occurred in the early 1900s when Toba basin logging provided timbers. Fortunately, it has been possible to reconstruct the effects that these activities had on similar lakes elsewhere.

In a LTIEMP-supported applied research project, sediment cores from the deep, central part of Lake Toba can be examined to identify the fine layers of materials deposited over the last few hundred years. These materials yield a wealth of information about the physical and chemical environment and the organisms that once lived in Toba. Measuring the abundance of a radioactive isotope of lead can accurately date the layers in which the microfossils and chemicals are found. Dating of sediment layers can reveal the development that has occurred in the Toba ecosystem, in the similar manner studies have been made in the lake's watershed. One of the major groups of planktonic algae in Lake Toba is ***diatoms***. One of the diatom species found today in Toba is found in the ancient Toba deposits around the lake even at 700 meters above the present lake level. These organisms, whose ***composition and abundance have not changed in Lake Toba at least during the last 70-year period***, are most responsible for influencing water clarity but became dominant in Lake Tahoe in the mid-1950s (**Figure 5**).

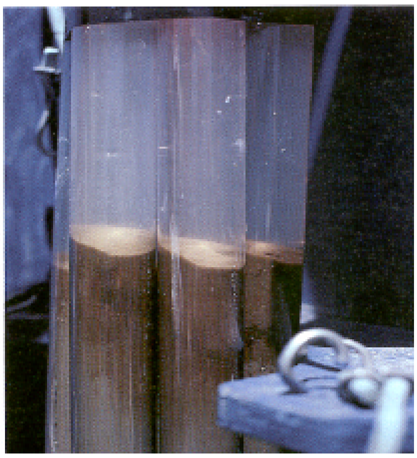

Figure 5. Sediment cores from 430-meter deep in Lake Tahoe show the light brown sediment of recent years overlying older gray sediments.

Evidences of such sudden changes will not be found in Lake Toba for any time period during the last few hundred years. In particular, there has been no demonstrable change in the algal community that correlates with the period of early 1900s logging in similar great lakes of the world. The sudden increase in the abundance of algae would correspond with a shift towards greater algal growth rate in the lake. Such an increase in productivity of the algal community results in a greening of the waters and a decrease in water clarity. **The minor changes in the lake documented in recent years close to the townships and tourist facilities are presumably much greater and longer-lasting than those, if any, resulting from the early 1900s and 1990s logging of the basin.** Available maps show that the Lake Toba area was already in 1932 deforested.

In fact, the lumbering activities of the early 1900s can be considered undetectable and appear to have had an unobservable impact on water quality. The possible changes in the most recent sediments can be expected to clearly correlate with the advent of population growth and basin construction activities during the last decades. This is thoroughly confirmed by research and monitoring of the similar lakes over most of that same period, and is further demonstrated below.

Since untreated sewage is now imported to the basin, nutrients resulting from human impact originate primarily from point sources. **Soil and vegetation disturbance** (**Figure 6**), enhanced runoff over impervious surfaces, air pollution, fertilizer applications, fish farming, and disturbance of wetlands are also noticeable non-point sources of nutrients. Additionally, solid waste management, littering, agro-chemicals and oil spills need special attention. The LTIEMP programme for measuring these inputs is discussed in the appropriate sections below.

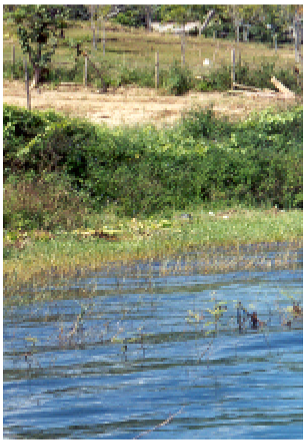

Figure 6. Disturbed soils are a continuing source of soil erosion especially in Samosir.

Wetlands, including rice paddy fields, form important buffer ecotones between the land and receiving water that not only actively remove nutrients but also slow the flow of water permitting all but the finest sediment to settle out. Perhaps most important is the ability of wetland bacteria to convert nitrogen compounds, so stimulating to lake algae, to unusable nitrogen gas by the process known as denitrification. Sediment and nutrient removal are two important ecological services performed naturally by wetlands. LTIEMP should consider saving the remaining wetlands that have considerable denitrifying ability, because the green belts along Lake Toba are very limited. This is only possible through the strict control of water discharge at the regulating dam at Siruar to keep the Lake Toba water level close to its pre-dam natural level of 905 meters.

3. Basin Development: The Close Link to Enhanced Algal Growth?

Many of the world's lakes have been subject to progressive **eutrophication**; "stinking green" as the North American Indians called the excess algae already in the 1700th century. This extensive enrichment of waters usually results from nutrients reaching a stream or lake from septic tanks, sewage treatment plants, agricultural runoff, or the disturbance of land during lumbering or rural and urban development.

Lake Erie in the United States is the first well-known example of an aquatic ecosystem that underwent a catastrophic water quality decline due to a combination of low water and domestic and agricultural runoff. High nutrient loading of a water body causes dense growth of algae and weeds like water hyacinth (*Eichhornia crassipes*).

The suspended algae cloud the lake water and when the algal cells die and decay, they often additionally reduce the dissolved oxygen levels to the point where aquatic organisms cannot longer survive in the deeper waters. In the high temperatures in Indonesian lakes, however, chemical processes primarily reduce dissolved oxygen levels. Fortunately, Lake Toba is still in the early stages of this eutrophication process and continues to maintain sufficient oxygen - all the way to the bottom in the northern basin and down to 200 meters in the southern basin. Still, **the growth of attached algae around the margins of the lake, the increasing density of planktonic algae, and steadily declining transparency can be a genuine cause of concern to Toba residents, region, nation, and conservation groups alike.**

Because of Lake Toba's low fertility, it is necessary to use a sensitive radioisotope-tracer method to measure algal growth rate. Primary productivity, as it is called, is a measure of the rate of inorganic carbon uptake by plants during photosynthesis. The isotope ^{14}carbon is added to bottles of lake water to allow an actual measurement of carbon uptake. The high sensitivity of this method makes possible the detection of increased algal growth in the lake long before the change in watercolor becomes visible. The method was first introduced to Indonesia by the author of this initiative in 1977. As noted earlier, it takes a number of years to accumulate sufficient data to show a significant trend (**Figure 7**).

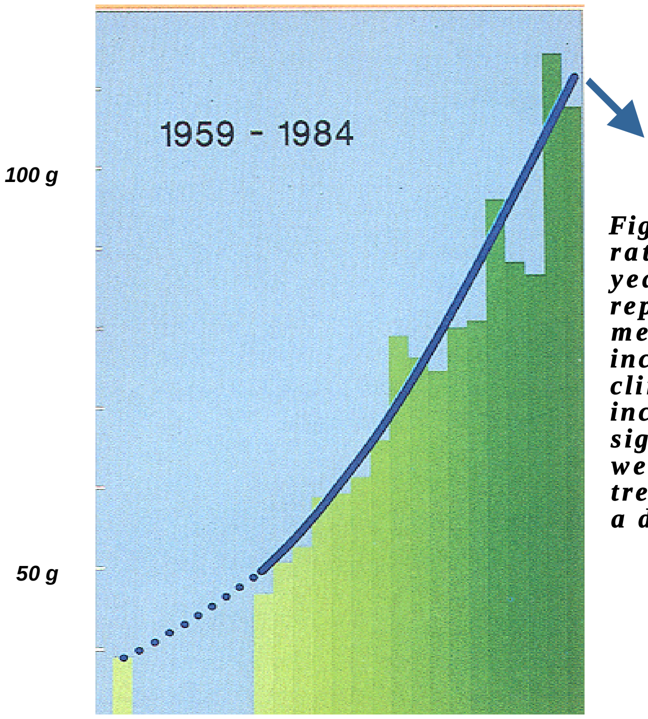

Figure 7. The annual change in algal growth rate as grams of carbon per square meter per year in Lake Tahoe since 1959. Each year represents approximately 1000 individual measurements. The line indicates the trend of increasing productivity. Despite the influence of climatic variation, the upward trend of increasing algal growth rate is highly significant statistically. After all waste waters were diverted from Lake Tahoe, including treated waste waters, the productivity has had a downward trend.

The highest productivity typically occurs during years of high precipitation when nutrient-laden runoff, augmented by nutrients brought up from the depths of the lake by storms, stimulates algal growth. The El Niño event of 1983 modified world weather patterns as well as wind mixing of stored nutrients. ***In Lake Toba*** the results may show the same climatically forced year-to-year variation, but ***no recent upward trend in productivity as is so evident in several other great lakes***. Thus, the changes taking place in lakes cannot be attributed to any general increase in the fertility in lakes; we must look within the Toba basin development for the primary causes of eutrophication, and especially for the wastes and waste waters from the townships, tourist facilities and release from agriculture.

While routine productivity measurements shall be made at Toba, transparency shall be also carefully recorded. ***Lake Toba's remarkable transparency remains one of its unique characteristics***. Thus, water clarity monitoring will always be an essential part of a Toba monitoring programme. Transparency measurements are routinely made with a 2O-cm diameter flat white disk, called a Secchi disk, which is lowered into the water until it just disappears. This transparency measure is traditional in limnology and oceanography and has stood the test of time because of its surprising accuracy. Since the surface light must reach the disk and return to the eye of the observer, it is not unlike using an optical instrument of considerable sensitivity.

An analysis of Secchi depths measured in ***Lake Toba has not shown a decline in water clarity*** (**Figure 8**). Toba has not lost of transparency over the last 70 years. **If increasing**

numbers of algae cloud the waters, the lake is slowly but steadily losing its famous transparency.

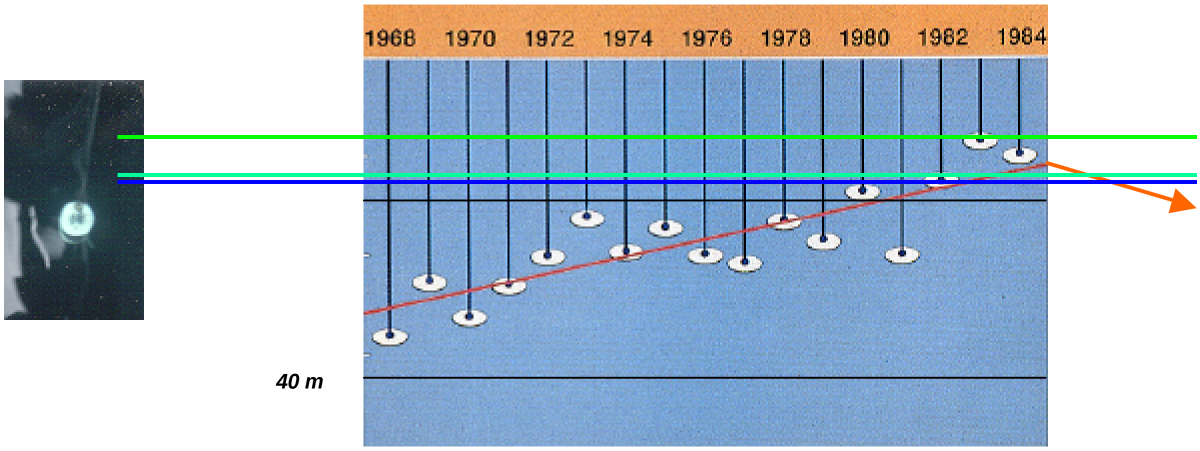

Figure 8. The water clarity in Lake Toba's the northern basin (dark blue), in the southern basin (greenish blue) and in the Pangururan basin (green) since 1929 and in Lake Tahoe (red) in 1968-1984. After all waste waters were diverted from Lake Tahoe, including treated waste waters, the water clarity has had an increasing trend.

In studies of both free-floating algae and the algae attached to rocks of the shore zone, it will be apparent that the growth and abundance of these organisms in Lake Toba will be strongly associated with the areas of greatest development. **Extensive research on the spatial distribution of free-floating algae can indicate a marked correspondence of the highest algal growth rates with the most extensive shoreline development.** Lake wide studies will show that the lowest density of algae characterizes the central portion of the lake, while those areas nearest to the Parapat tourist area and south shore developments may exhibit enhanced planktonic algal production. Similar studies of the attached algae will also demonstrate this pattern (**Figures 9 and 10**).

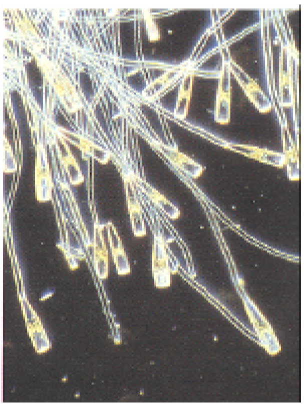

Figure 9. The dominant attached algae at Tahoe, seen under the microscope.

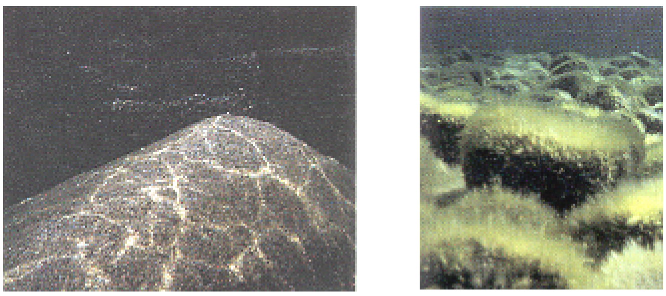

Figure 10. A boulder from an undeveloped area (left) at Lake Tahoe compared to one from a developed area (right) at the same depth on the same day.

The difference in algal growth on the rocks at various shoreline locations is closely linked to nearby development and may be immediately visible and that the undeveloped shore yields very little algal growth (**Figure 11**).

Figure 11. Samples of plankton in lake water receiving increasing nutrient inflow of various sources (from left to right) show the response of algae to nutrient inputs.

When rocks or artificial surfaces are supplied for these algae to grow on, the growth rate near south shore townships of Lake Toba may be expected to represent of the highest values for the lake. It is not surprising that both free-floating and attached algae respond to nutrient pollution associated with basin development.

4. Nutrient Inputs to the Lake: The Problem?

Various cooperative projects and a 5-year LTIEMP programme for water flow and suspended sediment, nitrogen, phosphorus, and iron discharge must monitor stream borne nutrients of the major streams. The discharge of important algal nutrients from the **tributary streams** is closely correlated with stream and groundwater inflow to the basin as a whole. Not surprisingly, high rain years may result in higher amounts of nutrients being released from the watersheds. The year-to-year variation in lake algal growth is directly related to nutrient inputs from streams and from **wastes and waste waters** (**see Figure11**).

One of the most important findings of the LTIEMP stream programme may show the conclusive evidence that Toba stream water is stimulatory to the growth of Toba algae but that the major contributors to the stimulation of algal growth are community wastes and waste waters. The stimulation of algal growth may be proportionally greater than that expected to occur in view of the measured amounts of major nutrients in the water, such as phosphorus and nitrogen. This response indicates that the unique combination of major and minor nutrients, trace elements, and natural organic compounds released by the erosion of Toba watersheds, are necessary to stimulate the algal growth. For this reason the Toba's watersheds cannot be excluded, despite the introduction of wastes and waste waters to the lake, as one source of nutrients responsible for enhanced algal growth.

The ratio of phosphorus to other nutrients may be higher in Toba basin stream water than in precipitation falling on the watershed. In recent years, Toba algae may have become increasingly sensitive to additions of phosphorus and trace metals instead of nitrate, alone, as a growth-stimulating substance. These nutrient elements are associated with the particulate sediments transported by stream flow, in marked contrast to nutrients entering the lake directly as precipitation (see next section) and in the from of wastes and waste waters.

Chemical analyses have shown that several other trace nutrients and organic compounds are added and some are taken up from the incoming rain as it passes through the ground, over the soil and artificial surfaces, and along the stream channels. This whole process of selective removal and release of nutrients by the watershed is crucial in determining the extent of stimulation of algal growth where streams and groundwater enter the lake. An important consideration in the nutrient balance at Toba is this increasing sensitivity of algae to phosphorus and trace metals. Surface runoff becomes enriched in these nutrients as watersheds erode, thus underscoring the importance of erosion control.

A second major finding of the program may be that **the nutrient yield from the various Toba watersheds is generally related to the extent of disturbance of soils in those watersheds. Disturbance of soils is especially pronounced in Samosir.** The more disturbed the greater the nutrient release (**Figure 12**). The monitoring programme may find that streams located in less developed regions of the basin, always rank lowest in nutrient concentrations and nutrient discharge in comparison to streams found in the more developed watersheds, not forgetting waste water "streams".

The "sensitive lands" are those classified as having the most "fragile" soils within stream environment zones and other "high hazard" areas. LTIEMP-sponsored research shall be carried out to characterize more thoroughly the sediment storage and release from various Toba watersheds and their relation to the extent of development.

Figure 12. Soil disturbance in Samosir.

The measurement of rain and dry fallout (dust and gases), collectively as "atmospheric deposition" will be an important part of the LTIEMP programme. In attempting to understand the way in which nutrients are supplied to the algae of Lake Toba, it is important to remember the basic process of the water cycle and how nutrients are carried into the lake. The **three main natural sources** of new nutrients are streams, groundwater, and direct atmospheric deposition onto the lake surface. In addition to these sources, we shall not forget to underscore nutrients from the man-induced activities.

Atmospheric deposition that falls onto the watersheds is modified largely during its travel over and through the land before some portion of it reaches the lake (blue water). Further, it is quite different in chemical composition than the stream waters of the basin or the lake itself. A substantial supply of important nutrient chemicals in the form of ammonia and nitrate settle from the air into the basin. **Those nutrient chemicals that fall on the watersheds rather than on the lake surface are, in the undisturbed ecosystem, available for use by the wide variety of terrestrial and wetland plant communities.** It is the disruption of the uptake of nutrients by those natural plant and soil communities that allows the accelerated release of nutrients that were either already part of the watershed soil or were supplied from precipitation. When combined with direct runoff from impervious surfaces such as roads, and with soil erosion from construction activities it is not surprising that atmospheric deposition on the land surface results in widely varying nutrient inputs to the lake depending on the extent of watershed disturbance.

The comparison between atmospheric deposition and watershed release by a stream is best illustrated by data (**Table 1**). Annual average nutrient loading values will describe these two sources of nutrients.

Table 1. A Comparison of Nutrient Loading from Atmospheric Deposition and Stream.

Source	Nitrogen*	Phosphorus*	N/P Ratio
Atmospheric Deposition	1.122	0.052	21.6
Stream	0.174	0.108	1.6

* Nitrogen measured as nitrate, and ammonium and phosphate measured as soluble reactive phosphorus. Units are kg N or P per hectare per year.

Note that nitrogen levels may be higher in atmospheric deposition than in stream inputs, but

that phosphorus levels are higher in stream flow. Thus, there is a large difference between the nitrogen/phosphorus ratios of the two nutrient sources. **Within the Toba watershed there is a net uptake of nitrogen from precipitation and a net release of phosphorus from soil erosion.**

Because phosphorus in stream water is particularly associated with soil erosion, land disturbance greatly increases the input of this nutrient. Watersheds change the chemistry of incoming rain to a degree that is particularly important when one realizes that much more precipitation falls at the higher mountain elevations of Toba basin watersheds than on the lake surface itself. However, the soils in the Toba watershed are very low in phosphorus and well covered by vegetation.

To measure direct atmospheric deposition onto the lake's surface, a large, mid-lake, spar buoy will serve as a year-round precipitation station. The 7-meter long buoy, topped with an equipment platform, will provide a surprisingly stable surface in even the roughest "seas" (**Figure 13**).

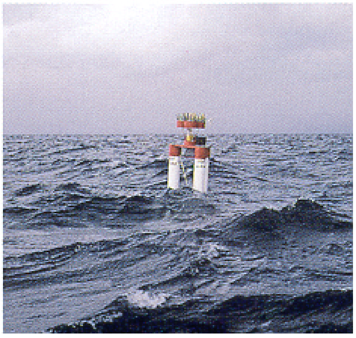

Figure 13. The buoy in 1 to 2-meter waves below.

The results may show a definite tendency towards greater deposition of nutrient chemicals onto the portions of the lake nearest population centers. Previous meteorological research may show that the strong atmospheric inversion layer that commonly forms at Toba traps basin-generated pollutants while excluding pollutants, particularly nitrogen-rich fine particles and gases, that blow over the basin from distant sources. Thus, **it is not surprising that the highest nutrient deposition onto the lake's surface may be found near the areas of greatest basin development.**

The LTIEMP shall begin a series of special studies to characterize the extent of the problem in more. The continued monitoring of atmospheric deposition will be an important part of the LTIEMP programme in attempting to understand the total nutrient balance of the lake. It is important to realize that, whatever the source of airborne nutrients and whatever their total magnitude, the vegetation and soils of the watershed reduce the impact on the lake to a great degree. Toba will certainly benefit from any nationwide improvement in air quality, but **strict watershed management and in-basin pollution controls will undoubtedly have the greatest and most immediate effect on the control of nutrients and trace elements derived from soils and from human activities.** Solid wastes generated in the basin shall be transported and dumped in dumpsites elsewhere and all waste waters, even treated by secondary and tertiary treatment systems: by activated sludge, ammonia stripping and charcoal adsorption shall be diverted from Lake Toba to the Asahan River.

The Lake Tahoe example shows that diversion of all waste waters from the lake, including treated waste waters, has made it possible to improve the lake's water quality.

5. The Environmental Monitoring at Lake Toba: The Necessity for Basin Management Decisions?

It has become obvious that a combination of long-term monitoring and specific targeted applied studies will be necessary to solve the complicated planning and regulatory problems of the Toba basin. Those monitoring and research needs shall be set forth as the goals and objectives of the LTIEMP programme. An uninterrupted monitoring record is crucial. **The long-term monitoring of Lake Toba water quality shall become an essential part of the Lake Toba planning and managing the basin.** It will provide the baseline information on the lake, its tributary streams and development activities needed by the variety of regional and national agencies comprising the LTIEMP.

High quality monitoring information will also be required to uphold the threshold standards to be set for the basin. In addition, it will provide necessary information on the effects of various

development plans and mitigation measures in progress or under consideration for the basin. Erosion control measures shall be also underway at Toba. Only the LTIEMP programme can provide a measure of their overall effectiveness.

Long-term data will also provide the necessary groundwork for future applied studies. For example, knowledge of the effects of climate on algal growth, over many years of record may make it feasible to separate short-term effects from long-term effects in various basin mitigation measures. The eventual modeling of both nutrient inputs and algal growth at Toba, although awaiting several key studies, will depend in large part on the proper interpretation of the continuous record of algal growth.

In addition to a pressing need for high quality monitoring data, there is an immediate need for specific studies that will help elucidate the factors governing algal growth at Toba. An important goal of the LTIEMP programme will be to develop an overall nutrient budget for the lake, based on the knowledge of proportionate loadings from various sources. Several fundamental in-lake studies not yet undertaken will need to be accomplished before this goal can be attained. Lake sediments must be examined to determine the existing balance between permanent storage and continuous release of nutrients. The large quantity of nutrients stored in the water column in dissolved or particulate form will have to be categorized more-precisely and the transformations between the two forms quantified. These are complicated studies, which involve additional basic research but they contribute importantly to a better understanding of the factors regulating algal growth in Toba.

A better understanding is needed of the various ways that nutrient pollutants reach the lake. **Further information is required to assess how quickly and to what extent fertilizers applied to the basin's agricultural area travel to the lake** (**Figure 14**)**. Examination of shore-zone attached algal growth may indicate that fertilizers are transported by groundwater and surface runoff to the lake's edge.** The problem of nutrient loading caused by fertilizer application could easily be corrected through use of slow-release compounds and by intercepting runoff. Applied research can provide a sound basis for urgently needed regulation of fertilizer use.

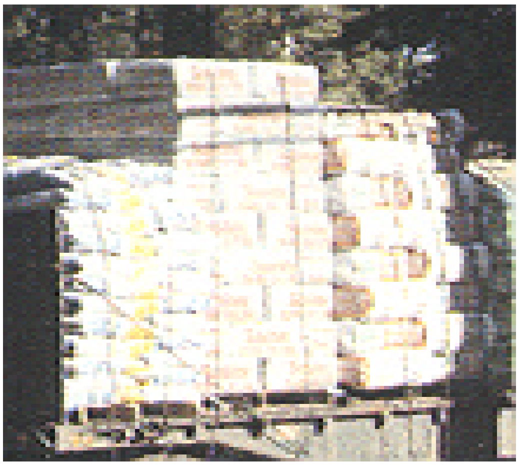

Figure 14. Fertilizers could be important contributors to basin nutrient loading.

Although sewage spills of considerable magnitude occur as the result of direct discharge of sewage to the lake a small-scale but essential research project could identify the actual magnitude of the sewage input of nutrient chemicals. The extent and significance of shoreline erosion caused by unbalanced water discharge at the regulating dam requires further investigation. Once the problems have been described, corrective action shall be taken.

There is a need to characterize the relative amount of nutrient inputs from direct atmospheric loading. As discussed above, research can be made using lake buoys and air monitoring equipment, but much more remains to be done. Research on the nutrient content of stream borne sediments is also important. However, additional stream and watershed work is needed to reveal the differences in nutrient release from various watersheds. In such studies, the levels and types of cultural development, land-use practices, and erosion control and revegetation measures can be evaluated for their effect. Differences in the quality of groundwater from Toba watersheds may also be studied through a project. The results will aid in understanding the magnitude of this important nutrient source. Research may indicate that, at least for nitrate, nutrient input from groundwater could be comparable to that from streams.

For the future, the Lake Toba Interagency Monitoring Program (LTIEMP) may plan to include several applied studies that will be needed to thoroughly understand the complex Toba basin

ecosystem. **The combined approach of long-term environmental monitoring and research offers exceptional opportunity for providing the essential data necessary for making the best future planning and regulatory decisions** (**Figure 15**).

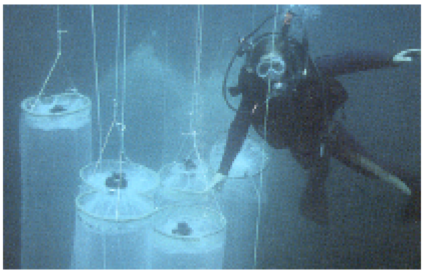

Figure 15. Proposed lake and watershed research and study of algal growth will provide an important and sound basis for basin management decisions.

The national and regional governments shall be committed to protecting water quality with the adoption of the recommendation of the Biodiversity Action Plan for Indonesia in which Lake Toba is one of the key sites for conservation of biological diversity. Lake Toba Heritage Foundation has proposed the Lake Toba watershed to be decreed as a special zone for arts, culture and ecotourism.

The Lake Toba Interagency Environment Monitoring Programme (LTIEMP) shall be planned and dedicated to providing the information necessary for future planning and regulation in the Toba basin to abate change in the lake environment and water quality. This may create the need to establish the Lake Toba Research and Education Center at the lake. The Lake Tahoe case shall lead the way.

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