Improving the Water Quality of Lake Toba, Indonesia

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Abbreviations

ASC	Aquaculture Stewardship Council
ATR/BPN	Ministry of Agrarian Affairs and Spatial Planning/National Land Agency *(Kementerian Agraria dan Tata Ruang/Badan Pertanahan Nasional)*
BAPPENAS	National Development Planning Agency *(Badan Perencanaan Pembangunan Nasional)*
BIG	Geospatial Information Agency *(Badan Informasi Geofisika)*
BKPEKDT	Coordinating Agency for Lake Toba Ecosystem Management *(Badan Koordinasi Pengelolaan Ekosistem Kawasan Danau Toba)*
BMKG	Meteorology, Climatology, and Geophysical Agency *(Badan Meteorologi, Klimatologi, dan Geofisika)*
BNPB	Indonesian National Board for Disaster Management *(Badan Nasional Penanggulangan Bencana)*
BOD	Biochemical oxygen demand
BOPDT	Lake Toba Tourism Area Management Authority *(Badan Otorita Pariwisata Danau Toba)*
BPPT	Agency for the Assessment and Application of Technology *(Badan Pengkajian dan Penerapan Teknologi)*
BPS	Statistics Indonesia *(Badan Pusat Statistik)*
BPSan	District Sanitation Strategy *(Buku Putih Sanitasi)*
BWRMP	Basin Water Resources Management Plan 2001–2004 *(Perencanaan Pengelolaan Sumber Daya Air Wilayah Sungai)*
BWS-Sumatera II	River Basin Management Organization—Sumatra II *(Balai Wilayah Sungai Sumatera II)*
CAPEX	Capital expenditure
CL	Control Location, a location of PT *Aquafarm Nusantara*
CMMA	Coordinating Ministry for Maritime Affairs *(Kementerian Koordinator Bidang Kemaritiman)*
COD	Chemical oxygen demand
CSO	Civil society organization *(Lembaga Swadaya Masyarakat)*
DAERMA	Local Fishermen's Association
DG	Directorate General
DG Perikanan Budidaya	Directorate General of Marine and Fisheries Resources *(Direktorat Jenderal Pengawasan Sumber Daya Kelautan dan Perikanan)*
DLH-SU	Provincial Environmental Agency of North Sumatra *(Dinas Lingkungan Hidup-Sumatera Utara)*
DO	Dissolved oxygen
DPSIR	Driver, Pressure, State, Impact, Response concept

DPKH	Department of Animal Husbandry and Animal Health *(Dinas Peternakan dan Kesehatan Hewan)*
FCR	Food conversion ratio
FEWS	Flood Early Warning System *(Proses Data Hidrologi berdasarkan Sistem Peringatan Dini Untuk Banjir)*
Germadan	Lake Rescue Initiative *(Gerakan Penyelamatan Danau)*
GIS	Geographic Information System
HYMOS	Hydrological Modelling System *(Sistem Pemodelan Hidrologi)*
(PT) INALUM	*PT Indonesia Asahan Alumunium*; a state-owned company in the aluminium industry (owner of hydroelectric power plant along Asahan river)
ISO	International Organization for Standardization
Kabupaten	District
Kota	City
Kecamatan	Subdistrict
Kelompok Keagamaan	Religious group
KLHK	Ministry of Environment and Forestry *(Kementerian Lingkungan Hidup dan Kehutanan)*
KPTS	decree/decision *(Keputusan)*
KSM	Local community support group *(Kelompok Swadaya Masyarakat)*
KSPPM	Study Group and Community Initiative Development *(Kelompok Studi dan Pengembangan Prakarsa Masyarakat)*
LAPAN	Indonesian National Institute of Aeronautics and Space *(Lembaga Penerbangan dan Antariksa Nasional)*
LIPI	Indonesian Institute of Sciences *(Lembaga Ilmu Pengetahuan Indonesia)*
MoPWH	Ministry of Public Works and Housing *(Kementerian Pekerjaan Umum dan Perumahan Rakyat)*
MPS	Sanitation Sector Program Memorandum *(Memorandum Program Sanitasi)*
N	Nitrogen
NGB	Pangambatan, a location of PT *Aquafarm Nusantara*
NGO	Non-governmental organization *(Lembaga Swadaya Masyarakat)*
O&M	Operation and Maintenance *(Operasi dan Pemeliharaan)*
OPEX	Operational expenses
P	Phosphorous
Palawija	Staple crops other than rice (coarse grains, pulses, roots and tubers)
PDAM	Regional Water Utility Company *(Perusahaan Daerah Air Minum)*
Permen	Ministerial Regulation *(Peraturan Menteri)*
Perpres	Presidential Regulation *(Peraturan Presiden)*
Peternak	Livestock farmers
PHT	Panahatan, a location of PT *Aquafarm Nusantara*
PJT1	Jasa Tirta 1 Public Corporation *(Perusahaan Umum Jasa Tirta 1)* (state-owned enterprise of water resource management for Brantas, Bengawan Solo and Toba Asahan and other river basins)

PJT2	Jasa Tirta 2 Public Corporation *(Perusahaan Umum Jasa Tirta 2)* (state-owned enterprise of water resource management for Citarum River Basin)
Pola	strategic framework plan (and in this report: Strategic Water Resources Management Framework Plan)
PP	Government Regulation *(Peraturan Pemerintah)*
PPSP	National Accelerated Sanitation Development for Human Settlements Program *(Program Nasional Percepatan Pembangunan Sanitasi Permukiman)*
PTAN	PT Aquafarm Nusantara
PusAir	Agency for Research and Development in Water Resources *(Pusat Penelitian dan Pengembangan Sumber Daya Air Kemen)* under Ministry of Public Works and Housing
Rencana	Master plan (and in this report: Master Plan for River Basin Management) (follow up of Pola)
RIDA	Regional Infrastructure Development Agency (*Badan Pengembangan Infrastruktur Wilayah*, BPIW) under Ministry of Public Works and Housing
RPJMN	National Medium-Term Development Plan *(Rencana Pembangunan Jangka Menengah Nasional)*
Sawah	Rice field
Sumatera Utara	North Sumatra
SSK	City Sanitation Strategy *(Strategi Sanitasi Kota)*
SSM	Sumatra Spatial Model
SWOT	Strengths, Weaknesses, Opportunities & Threats *(Kekuatan Kelemahan Kesempatan dan Ancaman)*
Tala-lata ripe-ripe	Onshore fish ponds containing fish that are periodically released to Lake Toba after reaching a certain age and size
TKPSDA	Basin Water Resources Management Council *(Tim Koordinasi Pengelolaan Sumber Daya Air)*
TMK	Tomok, a location of PT *Aquafarm Nusantara*
TN	Total nitrogen
TP	Total phosphorous
USDP	Urban Sanitation Development Program (Program Pengembangan Sanitasi Perkotaan)
WALHI	Friends of the Earth Indonesia *(Wahana Lingkungan Hidup Indonesia)*
WEF	World Economic Forum
WUA/P3A	Water User Association *(Perkumpulan Petani Pemakai Air)*
WWT	Wastewater treatment

Exchange rate (November 3, 2017):[1]

1 United States Dollar (USD) = 13,500 Indonesian Rupiah (IDR)

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[1] IMF Representative Exchange Rates.

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Most data were sourced from the Provincial Environmental Agency of North Sumatra (DLH-SU), the Indonesian Institute of Sciences (LIPI) and PT Aquafarm Nusantara (PTAN). For the full list of stakeholders that provided data, see Appendix A.

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Executive Summary

The long-term economic and environmental value of Lake Toba's water is central to achieving multi-sector objectives as well as sustaining the livelihoods and well-being of communities in the catchment. Addressing the deterioration of Lake Toba's water quality requires consensus and enforcement of the carrying capacity for fish production and catchment management measures, including the control of emissions from livestock manure and wastewater. Enabling adaptive management of the lake is dependent on timely and accurate data on lake dynamics and creating a cooperative, interagency platform for water quality monitoring. This is especially important as Lake Toba is not a homogenous water body but consists of discrete compartments that are not uniformly affected by pollution. The success of any interventions relies on the establishment of functioning and financially viable institutional arrangements that can facilitate cross-sectoral collaboration and bridge national-regional-district divides. Furthermore, the recommendations and the roadmap for improving water quality are relevant and transferable to the management of lakes and reservoirs across Indonesia.

Lake Toba

The Government of Indonesia has prioritized development of Lake Toba as a tourism destination. The aesthetic appeal of Lake Toba, that could draw 3.3 million visitors by 2041 (including 265,000 foreign visitors), stems from its clear warm water (25–28°C), compelling scenery, and many recreational opportunities. Realizing the tourism potential of Lake Toba is contingent on improving the water quality of the lake. By 2041, in a best-case scenario that includes improved water quality, tourism to Lake Toba could generate almost 5,000 additional jobs[2] and an increase in annual tourism spending of IDR 2,200 billion (USD 162 million).[3] Indonesia is implementing a sequenced development of priority destinations, with Lake Toba being one of the first three supported under the Tourism Development Project.[4] Recognizing the importance of sustainable tourism, the government is preparing an Integrated Tourism Master Plan for each of these destinations. Among key objectives, the project aims to enhance the country's institutional capacity to facilitate integrated and sustainable tourism development. The project seeks to improve natural and cultural asset management as a sustainable foundation for growth in tourism.

Lake Toba is Indonesia's largest lake and one of its most important freshwater resources. Situated in the North Sumatra Province, Lake Toba is a volcanic lake with depths reaching 505 meters and steep cliffs created by the collapsed volcano rising 1,200 meters from the lake surface level. At the center of the lake lies Samosir Island. The bathymetry of the lake coupled with its hydrodynamics create different compartments such that it should not be considered a homogeneous body of water for management purposes. Lake Toba's water sustains numerous social, environmental, and economic functions for the catchment's seven districts.[5] These functions include the 180 MW run-of-river hydropower plant on the

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[2] Horwath HTL, 2017.

[3] Tourism spending in the Lake Toba area was IDR 931 billion (USD 69 million) in 2015.

[4] World Bank, 2018 and MoPWH, 2018. The other two destinations are Lombok in West Nusa Tenggara Province and Borobudur-Yogyakarta-Prambanan in Central Java Province and the Special Region of Yogyakarta.

[5] The seven districts had an average regional GDP of IDR 8.3 trillion/USD 568 million in 2016 and average growth rate of 4.8 percent in 2015.

Asahan River (Asahan I) that flows from the lake, aquaculture production in excess of 80,000 tons of fish (2015), and a source of water supply and livelihoods for 0.5 million people living around Lake Toba.

The natural state of Lake Toba is oligotrophic, meaning it is low in nutrient concentrations, has a high transparency, and is suitable for drinking water (Box 1). The government has categorized Lake Toba as *Class I Raw Water for Drinking Water* (the first of four classifications as per Government Regulation 82/2001, "water usable for standard water of drinking water and/or other designation requiring the same quality of water as the usage"). The government has also decreed that its trophic status should be maintained as oligotrophic (Governor Regulation 1/2009). Building on the National Medium-Term Development Plan 2015–2019 (*Rencana Pembangunan Jangka Menengah Nasional*, RPJMN), the 2015 Lake Rescue Initiative *(Geraken Penyelamatan Danau, Germadan)* outlines a series of measures to protect Lake Toba. The *Germadan Toba* outlines a set of recommendations and timelines for management actions.[6]

Observed water quality values in Lake Toba show phosphorous concentrations and dissolved oxygen profiles above the threshold for mesotrophic conditions. While nitrogen concentrations, chlorophyll a, and levels of transparency are associated with oligotrophic conditions, these occasionally rise to the level of mesotrophic conditions (i.e., indicating a biochemical and biological imbalance). The process of eutrophication is driven by changes in the concentration of phosphorous and nitrogen (i.e., nutrients), which are indicated by the levels of dissolved oxygen, chlorophyll a, and transparency. The deterioration of Lake Toba's water quality manifests in events such as algae blooms and large fish kills. Drinking water standards allow for concentrations of phosphorous and nitrogen in excess of those needed to achieve an oligotrophic condition (i.e., 200 µg/l of phosphate and 10,000 µg/l of nitrate), and so managing the emission of nutrients into Lake Toba is central to addressing eutrophication and its negative environmental impacts.

BOX 1. The trophic status of Lake Toba—Why is it important?

Lakes and freshwater bodies can be categorized by their trophic status. The trophic status indicates the level of biological productivity in the lake as sustained by the level of nutrients and other chemical compounds of the lake's water (e.g., nitrogen and phosphorous). Lake Toba has been classified as Oligotrophic—meaning the water in the lake has naturally low levels of nutrients, high levels of dissolved oxygen, and high transparency.

The process of eutrophication refers to the buildup of nutrients in the lake that spurs biological productivity. This buildup can occur naturally, albeit slowly, or be accelerated by human activity (e.g., aquaculture, leaching from fertilized soils, wastewater discharge, etc.). As the levels of nutrients increase, the trophic status of the lake or parts of the lake can cross trophic thresholds, shifting from oligotrophic to mesotrophic and then eutrophic. Oligotrophic conditions exist when the concentration of phosphorous is below the threshold of 10 µg/l and the concentration of nitrogen is below 350 µg/l. Mesotrophic conditions exist when the concentration of phosphorous is between 10 µg/l and the upper threshold of 30 µg/l, and the concentration of nitrogen is between 350 µg/l and the upper threshold of 650 µg/l. Above this is considered to be eutrophic to hypereutrophic. More details on the trophic classification system are provided in Table 19 and Table 20.

The combination of Lake Toba's low levels of dissolved oxygen, its low nutrient concentrations, and high transparency supports fish and other aquatic life, as well as makes the lake a suitable source for drinking water (free from nuisance algal and other plant growth). Controlling and reducing the inflow of nutrients into Lake Toba is therefore important for its classification as suitable for drinking water ('Class 1. Raw Water for Drinking Water') as well as to retain water quality levels consistent with oligotrophic conditions.

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[6] Government of Indonesia, 2014.

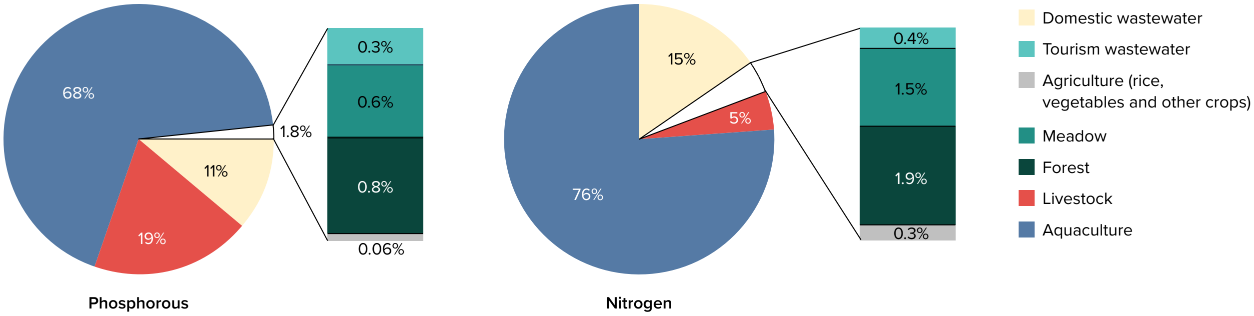
Rapid deterioration of water quality

The water quality of Lake Toba has deteriorated rapidly since the mid-1990s primarily because of nutrient emissions from aquaculture. An analysis of nutrient concentrations shows that in 2015, 76 percent of total nitrogen loads and 68 percent of total phosphorous loads came from aquaculture-related emissions (fish feed, manure, and carcasses) (Figure 1). The annual phosphorous emissions from aquaculture doubled between 2012 and 2016 to an estimated 2,124 tons. This is equivalent to the wastewater emissions from 2.3 million people. After aquaculture, 19 percent of the total phosphorous load is estimated to have come from livestock manure and 11 percent from wastewater.

Management of water quality in Lake Toba is informed by a long residence time (80 years) and non-homogenous mixing that results in compartmentalization of the lake. The residence time represents the theoretical time required for refreshing the lake's water and correlates to the large volume and relatively small outflow. However, the theoretical residence time assumes homogenous mixing of the lake. Spatial variations in topography, bathymetry, circulation flow directions and velocities, and hydrometeorological conditions mean Lake Toba is not a homogenous water body. Mixing of water in Lake Toba is also influenced by thermoclines which reflect the transition layer between the warmer water at the surface and the cooler deep water below, and are identified by a sudden change in temperature. The density difference between the warm surface waters (epilimnion) and the cooler bottom waters (hypolimnion), separated by thermoclines, restricts lake water mixing during much of the year and determines the volume over which the incoming nutrients are diluted, in turn influencing nutrient concentrations. Deeper thermoclines mean that concentrations may be lower as dilution occurs in a larger volume of water. In other words, the entire lake water body is not fully mixed. Therefore, the actual residence time of Lake Toba could be longer, and the impact of nutrient inputs does not affect the lake equally across space and time.

Localized and heterogeneous impacts of eutrophication call for a conservative approach with targeted interventions to manage nutrient emissions. The quality of water in Lake Toba has deteriorated from an oligotrophic condition when it comes to nutrient concentrations and transparency, with levels of phosphorous and dissolved oxygen reflecting mesotrophic conditions. Other water quality parameters (i.e., nitrogen, chlorophyll a, and transparency) show variation between oligotrophic and mesotrophic states. For example, 2016 saw an increase in chlorophyll a concentrations (Figure 2), rising surface and water temperatures, and reduced transparency, along with localized algae blooms (Figure 3). Compared to long-term historical data from 1930,[7] the quality of both the lake's surface and deep waters have deteriorated.

FIGURE 1. **Relative contributions of total phosphorus (left) and total nitrogen (right) loads into Lake Toba (2015)**



Source: Results from Deltares water quality model for calculating nutrient loads.

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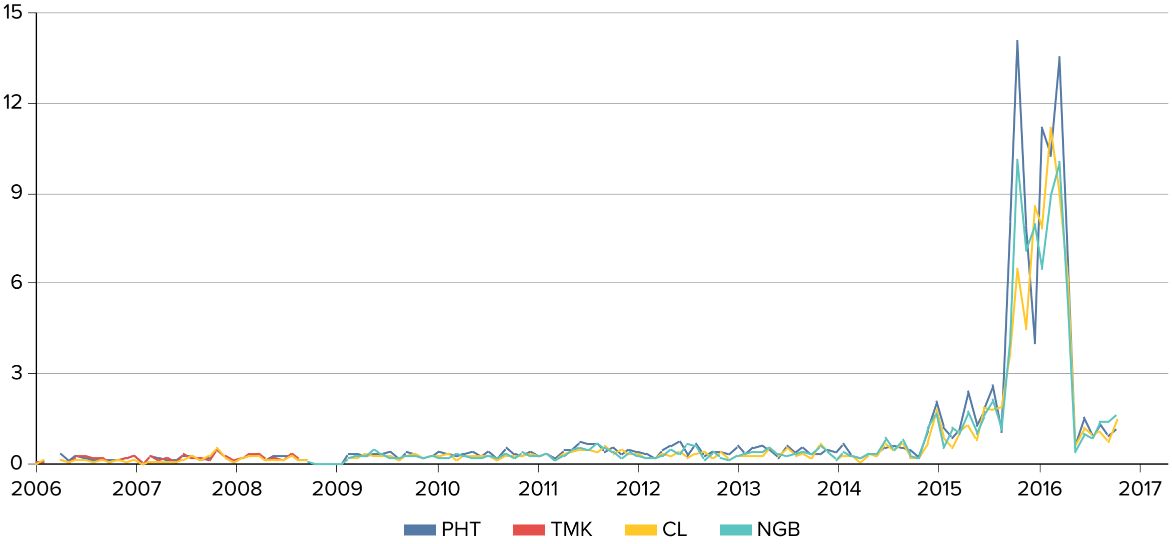
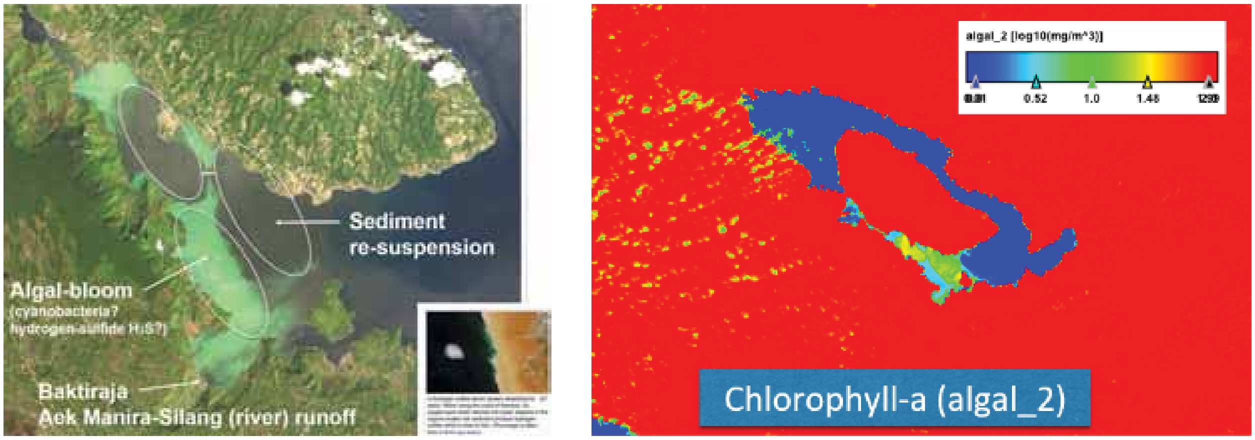
[7] Ruttner, 1931.

FIGURE 2. Chlorophyll a concentration measured at the four PT Aquafarm Nusantara locations (mg/l)



Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pagambatan, and CL = Control Location.

FIGURE 3. Hypoxia and harmful algae bloom event January 9, 2017

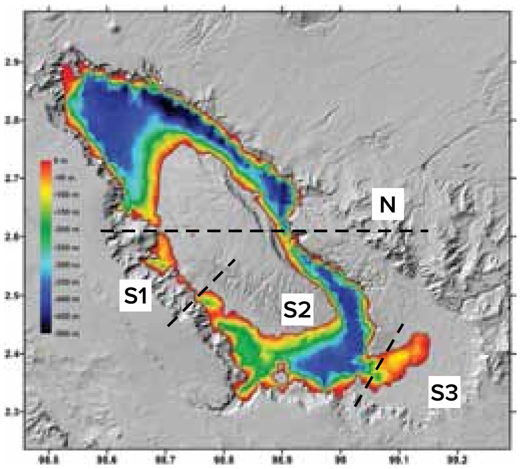


Source: Landsat-8 and Sentinel-3A.

Objectives, Methodology, and Stakeholders

The objectives of this analysis are to understand the drivers of deteriorating water quality and inform recommendations for improving management. This is part of the government's goal of maintaining the lake in an oligotrophic status and fit for drinking water. The analysis and recommendations include identification, design, and costing of specific investment scenarios to reduce nutrient inflows. Realizing the tourism potential of Lake Toba is contingent on improving the water quality of the lake and specific investments in infrastructure, improved information management, and enhanced institutional arrangements to facilitate a coordinated response across a broad range of stakeholders. These recommendations are intended to inform the Integrated Tourism Master Plan for Lake Toba and help capitalize on the development potential of the natural goods and services afforded through the lake. They also aim to guide improvements in water quality monitoring and adaptive management for the lake.

FIGURE 4. Map of Lake Toba showing the north, south 1, south 2, and south 3 compartments



The analysis followed an iterative process of stakeholder consultations and inputs from a Reference Group set up by the government. This consultative process was coupled with an analysis of the lake dynamics, with specific differentiation of the whole lake and four compartments delineated for illustrative purposes (Figure 4). Key outputs included an in-depth review of the institutional context, identification, and network mapping of more than 170 stakeholders, and a comprehensive set of costed scenarios with specific interventions aimed at improving Lake Toba's water quality through institutional, management, and monitoring interventions.

There are several institutions involved in water quality monitoring in Lake Toba collecting data on different variables, with different frequency and spatial coverage. The primary source of water quality data for the report was provided by the Provincial Environmental Agency for North Sumatra (DLH-SU), the Indonesian Institute of Sciences (LIPI) and PT Aquafarm Nusantara (PTAN). The PTAN data covered a high-frequency and consistent time-series, allowing for better quantitative insights. The stations, however, are limited to the area of PTAN's aquaculture operations. In contrast, the DLH-SU and LIPI data have a larger spatial coverage but lower or incidental frequency. This data is helpful to verify the spatially confined observations of PTAN. The DLH-SU data set was the most comprehensive with respect to parameters. A consistent, higher frequency and spatially distributed monitoring regime is needed to properly understand lake functions.

Key Drivers—Findings from Investment Scenarios

A scenario analysis was performed to identify the types of interventions and quantify the level of investment required to reduce nutrient loading and improve the water quality of Lake Toba. A total of five scenarios were created (A–E) based on different levels of interventions across aquaculture, livestock manure, and wastewater alongside investments to improve water quality monitoring (see Table 1). The contribution of each scenario on nitrogen and phosphorous was quantified for the whole lake and the four compartments to illustrate relative impacts of combined interventions (Figure 5). Previous water quality assessments have been made on whole lake estimates assuming complete vertical and horizontal mixing. Therefore, the compartmentalized approach to modelling provided new insights into lake functions and drivers of water quality. The delineation of these compartments needs to be validated through continued monitoring and modelling, with the possibility of increasing resolution through additional compartments.

TABLE 1. Summarized targets and costs for all scenarios and interventions (2018–2022)

	Scenario A	Scenario B		Scenario C		Scenario D		Scenario E	
	Million IDR								
	n/a	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
Water quality management									
Targets									
Fish production (tons)	84,800	106,000		50,000		10,000		10,000	
Conversion of manure into biogas (%)				20		30		30	
Peak tourist numbers	343,114	343,114		368,623		368,623		368,623	
Access to:									
On-site and community-based systems (%)	0	66		85		69		85	
Centralized systems (%)		1		2		31		2	
Investments									
Aquaculture					9,700		34,150		34,150
Livestock				5,340	7,576	7,440	11,333	7,440	11,333
Wastewater[8]		528		659,528	35,081	3,632,528	234,393	659,528	35,081
Subtotal		**528**		**664,868**	**52,357**	**3,639,968**	**279,876**	**666,968**	**80,564**
Total (CAPEX + OPEX in million IDR) for 5 years		529		717,225		3,919,845		747,533	
Water quality monitoring									
Function	*n/a*	*Signaling*		*Exploratory*		*Statistical*		*Statistical*	
Total (million IDR) for 5 years		**78,966**		**227,978**		**433,775**		**433,775**	
Total water quality management and monitoring for 5 years (milion IDR)	**n/a**	**79,495**		**945,203**		**4,353,620**		**1,181,308**	
	Scenario A	**Scenario B**		**Scenario C**		**Scenario D**		**Scenario E**	
	USD equivalent								
	n/a	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
Water quality management									
Fish production (tons)	84,800	106,000		50,000		10,000		10,000	
Conversion of manure into biogas (%)				20		30		30	
Peak tourist numbers	343,114	343,114		368,623		368,623		368,623	
Access to:									
On-site and community-based systems (%)		66		85		69		85	
Centralized systems (%)		1		2		31		2	
Investments									
Aquaculture					719,000		2,531,000		2,531,000
Livestock				396,000	561,000	551,000	840,000	551,000	840,000
Wastewater		39,000	0	48,872,000	2,600,000	269,176,000	17,369,000	48,872,000	2,600,000
Subtotal		**39,000**	**0**	**49,268,000**	**3,714,000**	**269,727,000**	**20,739,000**	**49,423,000**	**5,970,000**
Total (CAPEX + OPEX in USD) for 5 years		39,000		52,982,000		290,466,000		55,393,000	
Water quality monitoring									
Function	*n/a*	*Signaling*		*Exploratory*		*Statistical*		*Statistical*	
Total (USD) for 5 years		**5,849,359**		**16,887,237**		**32,131,511**		**32,131,511**	
Total water quality management and monitoring for 5 years (USD)	**n/a**	**5,888,359**		**69,869,237**		**322,597,511**		**87,524,511**	

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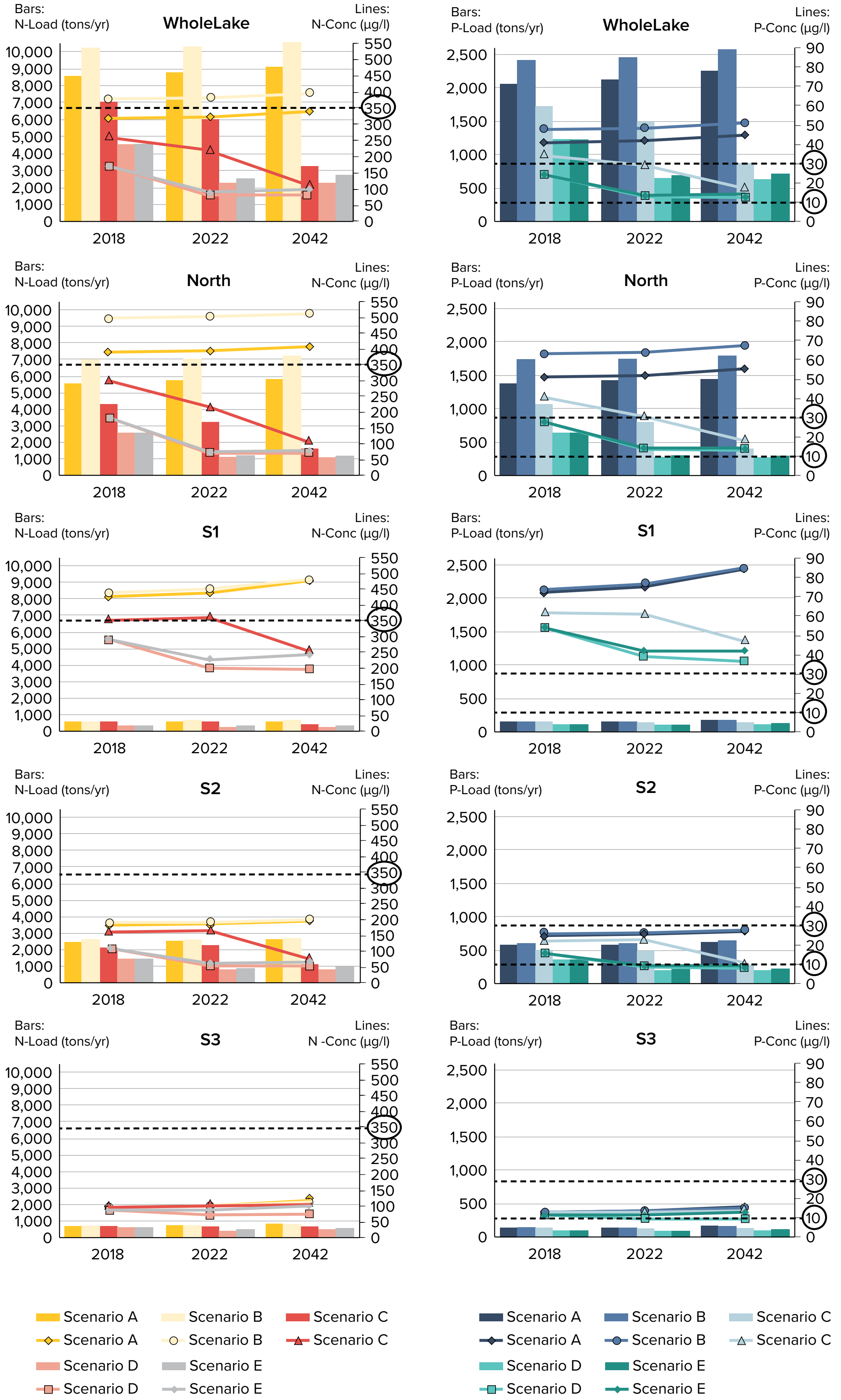
[8] For wastewater management, net required investments (minus reserved funds) are listed.

FIGURE 5. **Projected impact of all scenarios on long-term nitrogen and phosphorous concentrations by the whole lake and by lake compartment—against oligotrophic and mesotrophic concentration thresholds**



Note: The threshold for oligotrophic (10 µg/l phosphorous and 350 µg/l nitrogen) and mesotrophic threshold conditions (30 µg/l phosphorous) are marked by circles and dotted lines.[9]

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[9] Nürnberg, 1996.

The scenario analysis concludes that:

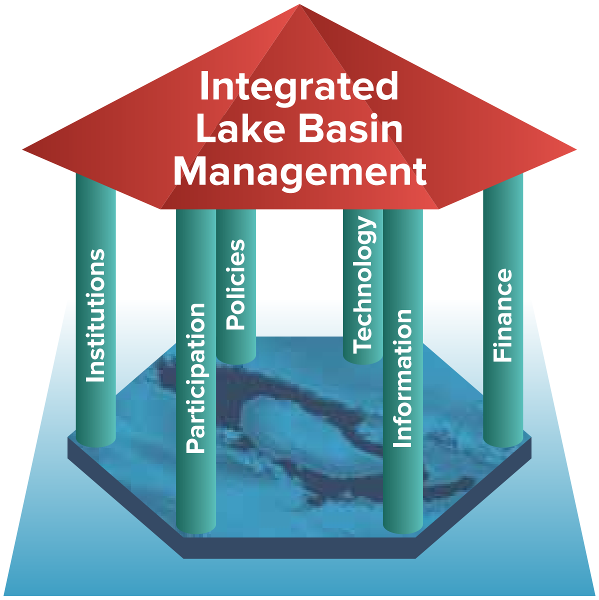
- Reducing nutrient emissions from aquaculture is essential to improving the water quality and trophic state of Lake Toba (i.e., Scenarios C, D, and E). Measures to reduce nutrient emissions from other sources will have a marginal impact on the lake's trophic state;
- Nutrient concentrations will rise to long-term eutrophic conditions for phosphorous, and mesotrophic for nitrogen, in the north and S1 compartments in the absence of interventions (i.e., Scenarios A and B);
- Sustained oligotrophic conditions in terms of phosphorous are only possible under Scenario D and Scenario E in the S2 compartment (and only Scenario D for the S3 compartment);
- A balanced and financially viable alternative to the ambitious targets for reducing nutrient emissions from the three main sources of nutrient loading (aquaculture, livestock manure, and wastewater discharge) is provided in Scenario E; and
- The S1 compartment will experience high long-term nutrient concentrations even if aquaculture is halted completely because of high population and livestock densities in the immediate catchment.

A comprehensive water quality monitoring plan is required to monitor the outcomes of interventions to reduce emissions, and to inform adaptive management in response to changing circumstances. The most important water quality parameters would need to be covered, and collective sampling across institutions would need to be streamlined. Five-year cost estimates for three different levels of monitoring, conceptualized in three matching scenarios, were estimated to illustrate the benefits of different levels and complexity of water quality monitoring. The first water quality monitoring scenario would provide a *signaling* function based on monthly monitoring for background information and requiring capital investments in two meteorological stations and four sensors for a total estimated cost of IDR 80.0 billion (USD 5.8 million). The second water quality monitoring scenario would provide an *exploratory* function based on the same monitoring as the third statistical scenario but at a lesser monitoring frequency and with capital investments in four meteorological stations and eight sensors for a total estimated cost of IDR 228 billion (USD 16.9 million). The third water quality monitoring scenario would provide a *statistical* function based on weekly monitoring, along with sampling for background monitoring and for aquatic life, fishery, and recreation, as well as capital investments in four meteorological stations and 16 sensors. The total estimated cost for the third statistical function scenario is IDR 433.8 billion (USD 32.1 million). More details on the three water quality monitoring scenarios and functions are provided in Table 38 and encompass the following actions and recommendations:

- One key coordinating agency mandated with quality assurance and control functions (with adequate financing and institutional frameworks);
- Optimizing the design and implementation of monitoring to balance trade-offs between cost, extent, and frequency of monitoring;
- Enhancing coordination and alignment of the 40 DLH-SU, LIPI, and PJT1 stations referenced;
- Developing real-time monitoring capabilities at priority sites to facilitate transmission of data and coordinated decision making;
- Installation of four on-lake meteorological stations to provide continuous data on temperature, rainfall, and wind strength and direction;
- Development of passive sampling modules to provide cost-effective mechanisms for monitoring the presence of toxic substances;
- Integrating Internet and mobile phone technologies to provide cost-effective solutions;
- Building remote sensing capabilities to improve understanding of key parameters and the dynamics of Lake Toba, such as suspended particles and algae blooms; and
- Promoting open data access to facilitate collaboration with research institutions and universities.

The optimal solution represents a combination of specific interventions and cost considerations. Scenario E represents the optimized solution, enabling significant interventions in aquaculture and livestock with intermediate interventions in wastewater, coupled with a comprehensive water quality monitoring program (Figure 6). The total five-year costs of

FIGURE 6. Conceptual model for integrated lake management and monitoring



Source: International Lake Environment Committee Foundation, 2018.

Scenario E would be IDR 747.5 billion (USD 55.4 million), which is not significantly higher than Scenario C (IDR 717.2 billion/ USD 53.0 million) but achieves larger reductions in nutrient emissions. Combined with the water quality monitoring scenario that would provide the best statistical function, the total costs for Scenario E are estimated to be IDR 1,181 billion (USD 87.5 million) over five years.

The oligotrophic conditions in the S2 compartment can only be achieved through the integrated interventions of Scenario D or Scenario E that include the most ambitious reduction in the carrying capacity of aquaculture (and in the smaller compartment S3 in Scenario E). However, the total net investment costs for the most ambitious interventions of Scenario D are significantly higher (IDR 3,920 billion/USD 290.5 million) because the scenario includes substantial investments in wastewater infrastructure. The impacts of the combined interventions on long-term nutrient concentrations will be different for each of the compartments. In the S2 and S3 compartments, the long-term phosphorous concentrations would start moving toward the oligotrophic threshold from 2022 onward (Figure 5). In the northern compartment, concentrations would be just above the oligotrophic threshold of 10 µg/l. The intermediate Scenario C (IDR 717.2 billion/ USD 53 million) would start moving toward such results by 2042.

Reducing nutrient emissions from aquaculture is the most effective way to improve water quality in Lake Toba. Government regulations stipulate this to be equivalent to 10,000 tons of fish per year or less. Achieving this requires increased enforcement of existing policies, improved monitoring and compliance, and addressing license mechanisms, coupled with training and support for alternative livelihoods. The estimated five-year cost to gradually bring down production from 64,000 tons of fish in 2018 to 50,000 tons by 2022 and 10,000 tons by 2042 would be IDR 9.7 billion (USD 719,000) under Scenario C. The five-year cost to reach 10,000 tons of fish per year already by 2022 would be IDR 34.2 billion (USD 2.5 million) in Scenario D and Scenario E but would subsequently reduce nutrient loading by 72 percent for phosphorous and 67 percent for nitrogen.[10] Political commitment, credible livelihood alternatives, and enforcement will be instrumental in achieving reductions in production. Such a strategy will have different impacts for different districts around Lake Toba, with the districts benefiting from increased tourism growth and the districts being affected by reduced aquaculture not always being the same. Similarly, tourism job gains and aquaculture job losses will not be distributed evenly. The government's agenda thus requires recognition and quantification of trade-offs, which can be eased by measures such as revenue-sharing arrangements between districts, alternative livelihoods (possibly through intensified training opportunities), and a phased implementation.

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[10] This analysis was not able to confirm the license status of all aquafarmers. The need for possible license revocation could increase these costs.

Interventions in livestock manure and wastewater management can complement nutrient reductions from aquaculture but not substitute them. These interventions are particularly important in the northern compartment and in the S1 compartment. The long-term concentrations of phosphorous would still reach levels above the oligotrophic limit in the north and mesotrophic in S1. Converting 20 percent of livestock manure into biogas by 2022 (Scenario C) would require IDR 12.9 billion (USD 957,000), and a conversion of 30 percent by 2022 (Scenarios D and E) would require IDR 18.8 billion (USD 1.4 million). For wastewater management, Scenario C and Scenario E propose construction of individual and community-based on-site systems, based on septic tanks, for 85 percent of the population by 2022 at the cost of IDR 694.6 billion (USD 51.5 million). Scenario D proposes larger investments in centralized sewerage systems for 31 percent of the population by 2022 for IDR 3,866.9 billion (USD 286.5 million).

Key Recommendations

The long-term sustainable development and management of Lake Toba requires development and implementation of an Integrated Lake Basin Management Platform. This requires adequate resources and enhanced coordination across the responsible agencies. Lakes and their catchments are a single interacting and interdependent management unit that need to be managed through an integrated framework. This creates a variety of challenges, particularly because the boundaries of lake basins rarely coincide with established political and administrative systems. Addressing the challenges of lake basin management requires due consideration of the information requirements to inform timely decisions, the appropriate institutional and policy requirements, stakeholder participation, and targeted investments to ensure effective management responses (Figure 6).

Improvements in water quality can only be achieved through enforcement of policy measures relating to the carrying capacity of Lake Toba. Significant research has been conducted to determine the carrying capacity for aquaculture production. This has been established through government regulation at 10,000 tons of fish per year. Despite several assessments and regulations, the 2015 production is in excess of 80,000 tons of fish per year. The enforcement of policy measures will require supporting measures to facilitate the transition in the structure of the local economy and livelihood restoration of those affected. Other investment options and catchment management measures, including the control of emissions from livestock manure and wastewater, can provide incremental gains but are not sufficient in isolation to facilitate the transition back into the (original) oligotrophic state.

A comprehensive and integrated water quality monitoring plan with a shared information management platform is required to assess the outcomes of any intervention and adapt to changing circumstances. Such a plan and platform should be capable of integrating data from several different sources to provide timely and accurate data on lake dynamics and inform adaptive management of Lake Toba. New and innovative techniques, such as using various remote sensing techniques, can be integrated to supplement traditional in situ measurements.

Cooperative institutional mechanisms are needed to provide an interagency platform and the enabling environment for the integrated management of Lake Toba. The success of any interventions to address the challenge of sustainable development in Lake Toba rely on the contributions of several different agencies across various sectors and levels of government. The scope of this analysis primarily covers the drivers of deteriorating water quality of Lake Toba and a range of interventions that will be necessary to address nutrient emissions in the lake. However, these scenarios highlight the importance of improving coordination and cooperation among relevant government agencies and other stakeholders. Realizing improvements in the water quality of Lake Toba ultimately requires fully functioning, financially viable, and cooperative institutional arrangements.

Introduction and Objectives

Lake Toba—A Priority Tourism Destination

The tourism industry in Indonesia offers inclusive and sustainable growth opportunities. Indonesia is home to one of the world's most biodiverse habitats. It has a rich array of natural and cultural endowments that are the principal reasons for tourism. By increasing the size of protected areas and expanding online marketing of nature-based activities, the Government of Indonesia is actively promoting its natural resources as part of its tourism agenda. However, environmental degradation is a key threat to growth in the tourism industry.[11]

The Government of Indonesia has clear objectives and programs for developing Lake Toba as a priority tourism destination. Situated in North Sumatra Province (Figure 7), Lake Toba is one of three destinations to be supported under the Indonesia Tourism Development Project.[12] Recognizing the importance of sustainable tourism, the government is preparing an Integrated Tourism Master Plan (ITMP) for each of these three priority destinations. Among the key objectives, the project will seek to enhance the country's institutional capacity to facilitate integrated and sustainable tourism development, and improve natural and cultural asset management as an important foundation for sustainable tourism.

Sustainable tourism has the potential to bring significant economic benefits to Lake Toba. In a best-case scenario that includes improved water quality, tourism to Lake Toba could generate almost 5,000 additional jobs and increase annual tourism spending by IDR 2,200 billion (USD 162 million) by 2041.[13] Lake Toba is largely a destination for local tourism with several challenges having led to its declining appeal. With improvements in environmental sustainability, accessibility, and activities, Lake Toba has the potential to become an attractive destination for a wider variety of domestic visitors and specific segments of the international market, particularly short-haul weekend tourists from Singapore and Malaysia.

Water Quality Concerns

Water quality in Lake Toba has deteriorated since the mid-1990s. In 1996, the lake's water was considered to be of 'good' quality according to government monitoring and reporting. However, by 2012, the water quality had deteriorated, with high levels of suspended solids and high concentrations of chlorophyll a, phosphorous, and nitrogen.[14] This biochemical and biological imbalance manifests itself in events such as algae blooms, with wide-ranging impacts on the aquatic environment and human activity.

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[11] World Economic Forum, 2017.

[12] World Bank, 2018. The other two destinations are Lombok in West Nusa Tenggara Province and Borobudur-Yogyakarta-Prambanan in Central Java Province and the Special Region of Yogyakarta.

[13] World Bank, 2018 and Horwath HTL, 2017.

[14] DLH-SU, 2017.

FIGURE 7. Map of Lake Toba in the North Sumatra Province of Indonesia

The main source of nutrient loading into Lake Toba is aquaculture. The loading (i.e., the amount of nutrients entering an ecosystem) of phosphorous and nitrogen from aquaculture comes from fish feed, fish manure, and fish carcasses. Small-scale aquaculture started in the northeastern areas of Haranggaol Bay in 1996. Large-scale operations were started by PT Aquafarm Nusantara in 1998 and by PT Suri Tani Pemuka[15] in 2012. Between 2012 and 2016, phosphorous loading into Lake Toba from aquaculture is estimated to have doubled, reaching 2,124 tons.[16] This amount equates to the direct input of 2.3 million people (the current catchment population is 0.5 million). The use of fish cages in Lake Toba has been controversial following several large-scale fish kills and concerns over the environmental and health impacts. These are often due to a range of different causes. For example, a two-year ban followed a mass fish death caused by the Koi Herpes virus in Haranggaol Bay in 2004, while fish kills in 2016 in Haranggaol Bay[17] and Silalahi village were linked to overstocked cages.[18]

The Government of Indonesia has sought to establish a maximum carrying capacity of 10,000 tons of fish produced per year in Lake Toba in order to maintain the Lake's status as oligotrophic. However, the 2015 production level was estimated to be in the excess of 80,000 tons of fish, and the current state of the lake is mesotrophic with respect to phosphorous and dissolved oxygen. The government has issued several instructions in response to the deteriorating water quality of Lake Toba. In a letter dated April 3, 2017,[19] the Minister of Environment and Forestry asked the Governor of North Sumatra to establish the maximum fish production in floating cages at 10,000 tons per year and to set the status of Lake Toba as *Class 1, oligotrophic lake*. Oligotrophic lakes often have clear water with high drinking quality due to low nutrient concentrations and low algae productivity. This letter was followed by two provincial government decrees issued by the Governor of North Sumatra on the lake status[20] and reaffirming the carrying capacity of 10,000 tons per year.[21]

Livestock and domestic wastewater also contribute to the nutrient loading of Lake Toba. Nutrients and pollution from both livestock manure and domestic wastewater reach Lake Toba through surface runoff, drainage channels, and percolation through the soil near shorelines and tributaries. Few of the residents in the Lake Toba catchment are connected to sewer networks, with most people relying on on-site sanitation facilities, such as pit latrines. This increases the risk of contamination, particularly when facilities are not properly maintained. During high rainfall and floods, latrines are known to overflow and speed up the waste-to-lake transfer of pollution and nutrients. The phosphorous input generated by the waste of half a million people living in the catchment area amounted to 197 tons in 2016. Given that some of this waste stays on land, this is equivalent to the direct input of approximately 0.2 million people, roughly 8 percent of the input generated by aquaculture. The phosphorous input from livestock, agricultural, and other sources has smaller contributions.

Deforestation and land conversion can accelerate the release and inflow of major nutrients, impacting water resources and reducing the base flow of rivers. Over a fifth of the catchment is identified as critical land[22] according to the Minister of Environment and Forestry.[23] The conversion of forests into agricultural land, deforestation for timber, and illegal logging have increased in the catchment.[24] Combined with steep slopes and sensitive soils,[25] erosion has accelerated sediment input into rivers and the lake. By November 2017, two forest areas remained in the catchment—the upstream

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[15] A subsidiary of PT Japfa Comfeed Indonesia.

[16] From 1,082 tons in 2012 to 2,124 tons in 2016; DLH-SU, 2017.

[17] Danaparamita, 2016.

[18] NGOs subsequently launched court cases against the licenses of commercial aquaculture companies operating on Lake Toba.

[19] menlhk/ppkl/pkl.2/4/2017

[20] no. 188.44/209/KPTS/2017

[21] no. 188.44/213/KPTS/2017

[22] Degraded land in Indonesia can be defined as "critical land" based on the standard as described in the Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land by The Ministry of Forestry (The Ministry of Environment and Forestry since 2014). Based on the regulation, critical land is the land which has been damaged, hence losing or reducing the function up to the defined or intended level. Also, critical land is defined as "a land which experienced the function decline (degradation) up to the given and supposed level due to the land damage. The function intended in that definition is production and water system function." In Prasetyo S. et al. (2013).

[23] Times Indonesia, 2016.

[24] Hadinaryanto et al., 2014; Gunawan, 2016; Sitanggang, 2017.

[25] KLHK, 2017.

Sibuatan/Silalahi forest[26] in the northwest and patches of forest in the southeast (e.g., the Taman Eden forest). Neither area has conservation status and both experience pressure from land conversion.[27] According to the Global Forest Watch, the biodiversity of both areas is rich.[28]

Objectives and Analytical Process

The objectives of this analysis are to understand the drivers of deteriorating water quality and to identify, design and cost investment scenarios to reduce nutrient inflows as part of a roadmap for improving water quality in Lake Toba. Realizing the tourism potential of Lake Toba is contingent on improving the water quality of the lake. These investment scenarios seek to inform the Integrated Tourism Master Plan for Lake Toba, and budgeting processes, providing a framework for effective and sustainable tourism development of Lake Toba.

A Reference Group was established by the Coordinating Ministry of Maritime Affairs and the Ministry of Public Works and Housing to provide feedback and guidance in developing the roadmap. The Reference Group included key experts and organizations mandated with monitoring and management of Lake Toba. The group was central to the development of the scenarios, identifying historical and present water quality management arrangements and ensuring a comprehensive approach to the analysis based on available data. Details on the stakeholder consultations and the Reference Group are provided in Appendix A.

Development of the roadmap was based on an iterative process of stakeholder consultations coupled with modelling and analyses. The outputs from the initial modelling and analyses were discussed with stakeholders, who also provided a deeper understanding of the legislative and institutional context. Pre-identified stakeholders and the Reference Group met to produce detailed stakeholder network maps that explore the relationships, incentives, and influence of actors at multiple levels involved in the management of Lake Toba. Subsequently, stakeholders themselves clarified roles and responsibilities for managing and monitoring the water quality of Lake Toba. Consultations, field visits, and semi-structured interviews provided further information and data for modelling and analyses.

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[26] The Sibuatan/Silalahi forest covers the upstream watershed of the run-of-river hydroelectric powerplant on the Renum River that drains into Lake Toba.

[27] BWS Sumatera II, see also: www.globalforestwatch.org/map

[28] Globalforestwatch.org accessed in September 2018, where both areas are given high values in terms of significance and intactness.

CHAPTER 1

Characteristics of Lake Toba

Lake Toba

Batak culture[29]

Lake Toba is an integral, sacred, and unifying part of the local Batak history and culture. The Batak communities of North Sumatra maintain a rich cultural heritage based on local knowledge, respect for trust, and care-based relationships. The Toba Batak are one of six subgroups of the Batak ethnic group, and they reside in the Lake Toba area. This cultural heritage is captured in myths, legends, and historical inheritance. One myth explains the origins of Lake Toba: a woman's secret, that she was once a fish, was revealed to her daughter by her husband. In sadness, the woman told their daughter to run uphill because a huge disaster was imminent. When her daughter left, she prayed. A big earthquake struck soon thereafter followed by nonstop pouring rain. The area got flooded and became Lake Toba. The woman turned into a fish again and the man became the Samosir Island.

The cultural heritage of the Batak includes strong beliefs and norms regarding natural resource management. These include no-fishing zones, capture quotas (e.g., specified amount of fish and fish of certain size), and management rules relating to *tala-lata ripe-ripe,* onshore fish ponds from which fish were periodically released having reached a certain age and size. Forests could not be cut down carelessly and according to cultural norms, people had to exit the lake to urinate, and violations, such as throwing garbage into the lake, could result in sanctions from local chieftains. Most of this local knowledge and norms were shared verbally through word of mouth and not documented in written rules or customary guidelines. With demographic changes much of this local wisdom and traditional norms is being eroded.

Economy

Lake Toba and its catchment provide important economic benefits to local people and commercial enterprises. The average gross regional domestic product of the seven districts around Lake Toba was IDR 8.3 trillion in 2016 (USD 568 million, at constant prices of 2010) with an average growth rate of 4.8 percent in 2015. Agriculture, forestry, and fishing make the largest contributions to district gross domestic product (Table 2). The main commercial commodities include food crops, horticulture, plantations, aquaculture, and livestock farming (Table 3).

Aquaculture is an important economic driver of regional growth and source of employment. The aquaculture sector started in Haranggaol Bay around 1996 and is estimated to employ over 9,000 people with a production capacity of 96,000 tons of fish. However, fish production is not systematically monitored, and estimates vary between sources and years (Table 4). Production is almost exclusively *Red Tilapia*[30] and derived from two private companies as well as numerous small-scale operations using floating ponds that are distributed across the lake (Figure 8). The two commercial firms,

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[29] The primary source for the section is Sianipar, 2011.

[30] Ditjen Perikanan Budidaya, October 2015.

TABLE 2. Regional GDP of Toba regencies

Industry	Regional GDP of Toba Regencies at constant price of 2010 by industry (million IDR, %)													
	Karo	%	Pakpak Barat	%	Dairi	%	Samosir	%	Humbang Hasu	%	Tapanuli Utara	%	Toba Samosir	%	Simalungun	%
Agriculture, forestry and fishing	7,123,559.75	57	425,784.11	59	2,617,659.46	46	1,385,461.90	53	1,654,889.35	46	2,431,668.98	48	1,620,067.80	34	13,203,969.70	56
Mining & quarrying	30,634.33	0	288.75	0	3,727.68	0	16,417.50	1	21,046.74	1	3,762.95	0	14,008.70	0	53,954.10	0
Manufacturing	387,997.37	3	1,336.18	0	18,954.53	0	14,277.80	1	56,471.72	2	101,727.74	2	524,576.50	11	2,529,290.10	11
Electricity & gas	11,302.38	0	1,755.86	0	5,186.49	0	1,941.90	0	3,437.86	0	5,583.12	0	4,132.40	0	19,760.80	0
Water supply, sewerage, waste management & remediation activities	10,217.54	0	469.50	0	5,079.92	0	1,302.60	0	2,434.12	0	5,364.68	0	2,462.40	0	18,668.60	0
Construction	813,954.62	7	65,821.24	9	735,019.30	13	267,911.90	10	482,624.12	13	635,966.05	13	613,835.80	13	2,037,563.00	9
Wholesale & retail trade, cars & motorcycle repair	1,243,155.78	10	75,475.15	11	920,838.25	16	293,781.40	11	524,852.23	15	624,827.69	12	762,992.10	16	3,194,169.30	14
Transportation & storage	560,896.99	5	14,499.05	2	209,413.35	4	79,487.50	3	87,213.74	2	237,197.57	5	141,297.70	3	358,667.70	2
Accommodation & food services	305,208.80	2	16,144.65	2	173,332.88	3	127,683.10	5	114,912.67	3	112,940.47	2	139,284.70	3	205,646.50	1
Information & communication	115,780.93	1	5,785.70	1	64,814.89	1	26,617.80	1	41,097.12	1	47,653.29	1	62,422.00	1	165,234.50	1
Financial & insurance activities	159,881.14	1	6,170.97	1	115,168.38	2	24,182.90	1	41,312.07	1	79,909.16	2	81,873.40	2	229,737.60	1
Real estate activities	391,078.37	3	10,675.70	1	148,766.37	3	54,336.30	2	95,420.12	3	109,492.78	2	134,491.40	3	203,716.00	1
Business activities	23,210.94	0	135.23	0	3,495.11	0	3,054.50	0	4,602.02	0	14,254.06	0	39,592.70	1	19,094.30	0
Public administration & defense; compulsory social security	695,684.32	6	81,059.91	11	521,808.68	9	299,786.40	11	382,968.00	11	522,284.68	10	450,008.00	9	924,458.50	4
Education	314,507.22	3	9,406.44	1	108,117.93	2	23,948.70	1	36,991.10	1	90,934.77	2	132,378.60	3	237,003.70	1
Human health & social work activities	150,793.34	1	2,917.53	0	35,973.86	1	13,750.20	1	22,370.10	1	39,919.53	1	39,119.80	1	83,729.00	0
Other services	157,003.60	1	165.20	0	1,098.84	0	1,825.20	0	5,105.97	0	6,707.34	0	7,261.30	0	23,306.30	0
Regional GDP	**12,494,867.42**		**717,891.17**		**5,688,455.92**		**2,635,767.60**		**3,577,749.05**		**5,070,194.86**		**4,769,805.30**		**23,507,969.70**	

Source: Central Bureau of Statistics, North Sumatra.

TABLE 3. Commercial commodities produced in the catchment area

Sector	Commodities	Location
Food crops and horticulture	Rice, corn, sweet potato, potato, citrus pepper *(andaliman)*, orange	Dairi, Simalungun (Haranggao Horison), Samosir (Panguruan, Palipi), Toba Samosir (Porsea, Sigumpar, and others), Humbang Hasundutan (Dolok Sanggul)
Plantation	Coffee, incense, sweet skin, clove, candlenut	Samosir, Pakpak Bharat, Humbang Hasundutan, Tapanuli Utara, Karo
	Rubber, cocoa, palm oil, tea	Humbang Hasundutan, Simalungun
Aquaculture	Fish *(nila, emas, mujair)*	
Farming	Pig, chicken, cow, buffalo	Simalungun (Dolok Pardamean)

Source: Ministry of Public Works and Housing, 2016.

TABLE 4. Estimated fish production through aquaculture (tons/year)

Producer	Estimated production			
	2014	2015	2016	*Potential*
PT Aquafarm Nusantara		34,000	30,000	30,000–40,000
PT Suri Tani Pemuka		20,800	4,000	55,000
Haranggaol Bay small-scale operators		30,000	40,000	30,000–50,000
Other small-scale operators				30,000–50,000
Total	**96,000**	**84,800**[31]	**74,400**	**64,000–96,000**
Source	Directorate General of Aquaculture and Fisheries	DLH-SU, 2017	Discussions with stakeholders, 2017	Estimation 2008–2016

PT Aquafarm Nusantara and PT Suri Tani Pemuka, employ over 4,000 people. PT Aquafarm Nusantara was established in 1998 as part of an investment agreement between the Swiss government and the Republic of Indonesia. This initiative was one of Indonesia's first bilateral development projects in the fisheries and aquaculture sector.[32] PT Suri Tani Pemuka started production in 2012 following a request by the local government to stimulate employment and the economy.[33] Most produce is exported for the European, United States, and ASEAN markets.[34] The small-scale enterprises produce for local markets and are normally owner-operated. They provide employment for approximately 5,000 people. In 2014, it was estimated that there were some 23,000 floating fish cages in the lake.[35] This number of cages would suggest direct employment for 11,500 people (for an average income of approximately IDR 60 million/USD 4,450 per person per year)[36] and could produce approximately 96,000 tons of fish per year.

Aquaculture production has decreased in both commercial and locally owned fish farms since 2015. While estimates of fish production vary between sources and years, the estimated total production peaked in 2015 at 84,800 tons of fish. In 2016, it dropped to 74,400 tons, mainly due to reduced production at PT Suri Tani Pemuka (Table 4). At the same time, PT Aquafarm Nusantara moved some cages from Samosir Island in the north to the lake's southern areas. Furthermore, many locally owned cages were abandoned after 2016 when district authorities acted to reduce aquaculture, resulting in as much as a 50 percent reduction of small-scale production.

Tourism has the potential to provide significant economic benefits and employment opportunities in Lake Toba. Tourism to Lake Toba could generate almost 5,000 additional jobs[37] and increase annual tourism spending by

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[31] At the request of the Reference Group, the 2015 production level of 84,800 tons of fish has been used in the assessment of nutrient loads for 2015 and in baseline Scenario A. There was no agreement about the production level in 2016, but various stakeholders suggested that the local small-scale aquaculture production might be underestimated.

[32] PT Aquafarm Nusantara, 2017; Letter from I Wayan Mudana, Director of PT Aquafarm Nusantara to Deltares dated July 28, 2017.

[33] Communication with PT Suri Tani Pemuka.

[34] Financial data on the commercial and small-scale aquaculture operations were inaccessible during the technical analysis. However, the export value of tilapia produced by PT Suri Tani Pemuka was reported to be USD 9 million in 2015 (Kompas.com article published July 20, 2016).

[35] According to the Directorate General of Aquaculture and Fisheries, Ditjen Perikanan Budidaya, October 2015.

[36] Communication with Harian Analisa (North Sumatra-based newspaper). June 5, 2017.

[37] Horwath HTL, 2017.

FIGURE 8. Floating fish farms on Lake Toba

Source: Photo by Marcus Wishart, 2018.

IDR 2,200 billion (USD 162 million) by 2041 in a best-case scenario that includes improvements in water quality.[38] Total money spent by tourists could rise from IDR 931 billion (USD 69 million) in 2015 to IDR 3,414 billion (USD 253 million) by 2041 (compared to IDR 1,215 billion/USD 90 million in a business-as-usual scenario).[39] Most of this spending stays in the local economy, and has significant multiplier impacts.[40] Sixty percent of the projected increase in spending will primarily come from lower spending domestic visitors. The incremental financial impact from the estimated five-fold increase of foreign visitors would be more limited (reflecting a lower starting level of 60,000 visitors in 2015). Investor interest has increased according to the Lake Toba Tourism Area Management Authority *(Badan Otorita Pariwisata Danau Toba, BOPTD)* and is reflected in reported increased interest in hotel construction.[41] Completion of road infrastructure by 2020 is expected to facilitate additional investments. With support from the Indonesia Tourism Development Project, the government aims to realize IDR 111 billion (USD 8.2 million) in private investment in and around Lake Toba by 2023.[42] The expectation is that Lake Toba can become an attractive destination for a wider variety of both domestic and foreign visitors, particularly short haul weekenders from Singapore and Malaysia.[43]

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[38] Tourism spending in the Lake Toba area was USD 69 million in 2015.

[39] Horwath HTL, 2017 and World Bank staff estimates.

[40] Every 1 rupiah of foreign tourist expenditure translates into an estimated 0.74 rupiah of GDP in Lake Toba, based on input output (I-O) tables drawn from the tourism satellite account produced by Indonesia Statistics (*Badan Pusat Statistik,* BPS) and the Ministry of Tourism. For Lake Toba, the I-O tables for South Sumatra—the closest province for which there is available I-O data—are used. Once the direct GDP impact is calculated, it is adjusted using tourism spending 'multipliers' to account for additional indirect and induced impacts—i.e., the additional output, income, and employment generated by tourist expenditures as they propagate throughout the economy. Recent World Travel and Tourism Council studies of Indonesia's tourism sector suggest spending multiplier values ranging from 1.7 to 3.

[41] Ratman, 2016; Gumelar, 2017; and Kumparan, 2017.

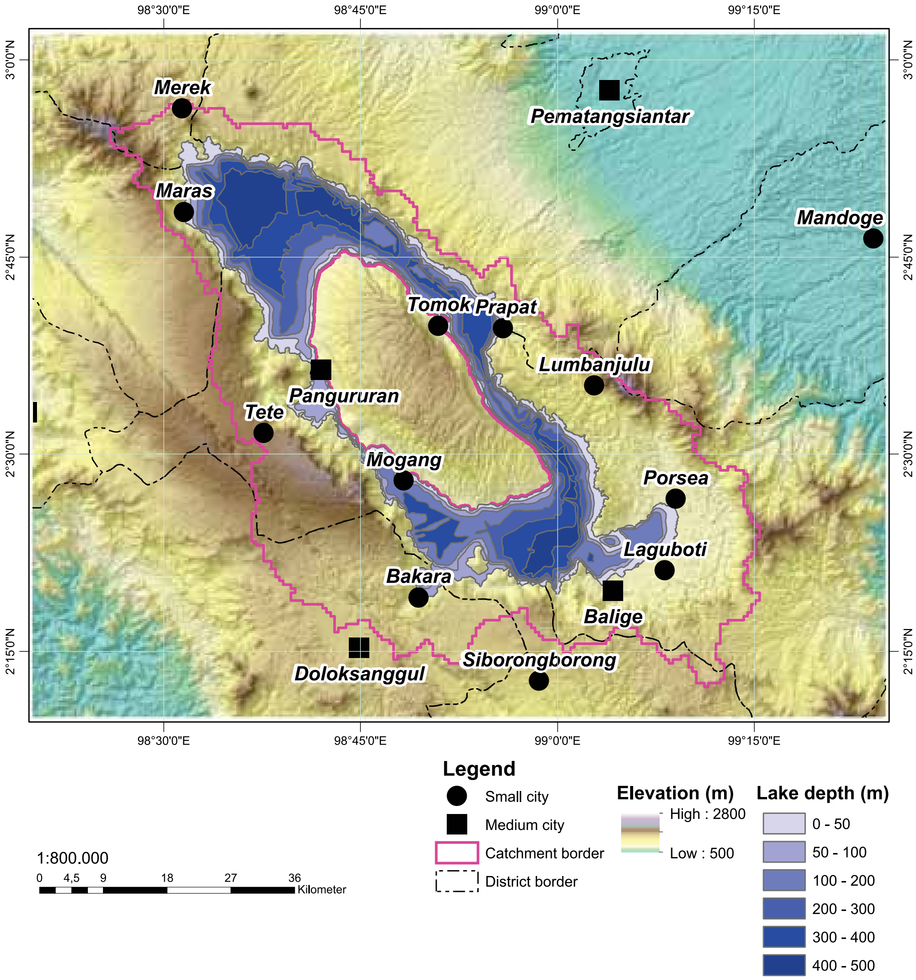
[42] World Bank staff estimates.

[43] Horwath HTL, 2017. As part of the Tourism Development Project preparation, upon the Government of Indonesia's request, the World Bank conducted demand assessments, prepared by Horwath HTL, covering for each of the destinations: (i) baseline supply and demand of tourism services; (ii) investment analysis; (iii) future market demand analysis (future visitors and investors); and (iv) investment needs (destination infrastructure, tourism infrastructure, skills, firm capabilities, and legal and regulatory environment).

Bathymetry, topography, land use, and climate

Lake Toba is the largest lake in Indonesia with a 1,130 km^2 surface area, depths reaching 505 meters, and a volume of 240 km^3. The lake lies at 900 meters above sea level (masl), is 100 km long, 30 km wide, and has an average depth of 227 meters. Lake Toba is part of the Toba Volcanic Complex on the island of Sumatra and occupies the caldera formed after a massive volcanic eruption 74,000 years ago (Figure 9). Steep cliffs of the caldera reach 2,100 masl, rising to 400–1,200 meters above the lake surface level. In the center of the lake lies the island of Samosir, a resurgent volcanic dome uplifted by pressure from un-erupted magma in the chamber beneath the volcano with a maximum elevation of 700 meters above the lake surface level. The Indian Ocean lies to the west, and the lowlands of North Sumatra stretch out to the Malacca Strait east of the lake (Figure 7). Several volcanoes dominate the landscape to the northwest of the lake. In the south, a larger flatter valley extends with cultivated land. The main outflow from the lake is through its eastern narrow valley where the lake discharges into the Asahan River which flows to the Malacca Strait. Lake levels and hydropower generation on the Asahan River are regulated by the Siruar Dam (Asahan I, run-of-river plant with 180 MW capacity). Soil in the region is typical for weathered volcanic areas and varies between light clay and loamy sand, with different sensitivities to erosion.[44]

FIGURE 9. Bathymetry and topography of Lake Toba and the catchment area



Source: Lake Toba atlas, BWRMP-TOBA; and WS Perment MoPWH 4/2015, DEM STRM 3" (90 m). Technical analysis by Deltares, World Resources Institute and Royal Haskoning DHV, 2017.

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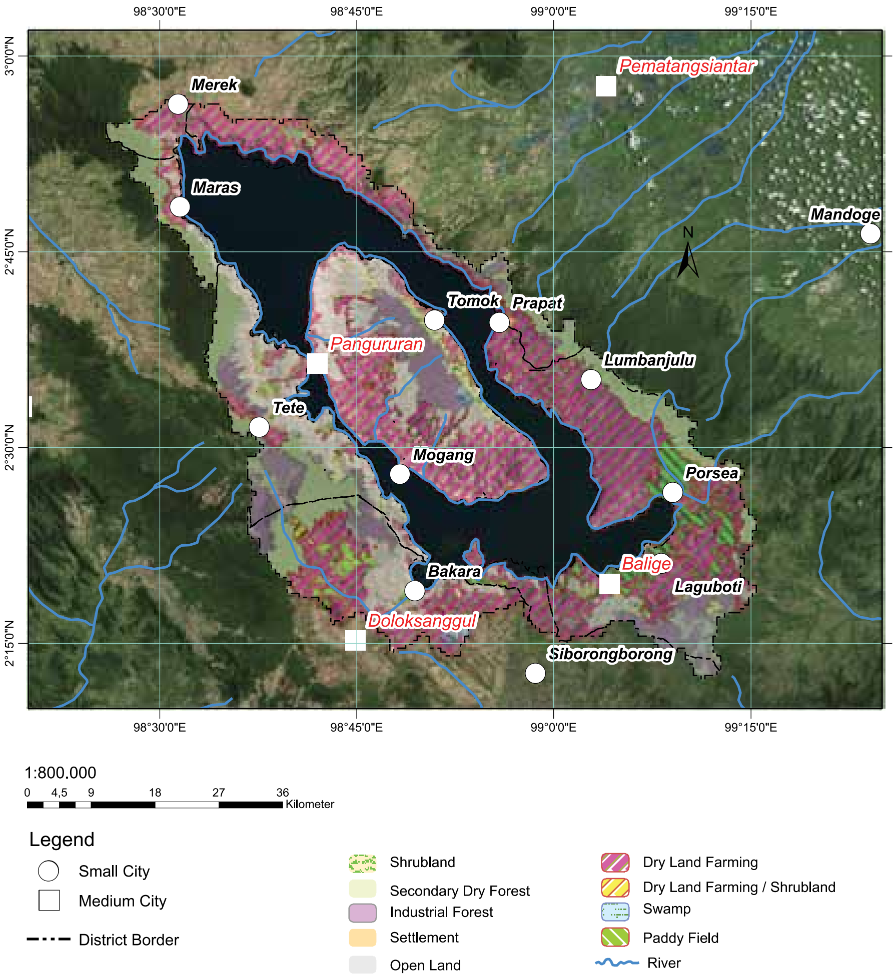
[44] Damage Control Directorate of Aquatic Ecosystems, 2017.

The Lake Toba catchment area supports productive crop cultivation, livestock, aquaculture, and tourism. Approximately 10 percent of the catchment is used for wet rice fields *(sawah),* 11 percent for plantations, and 27 percent for agricultural dryland crops. Forests cover 20 percent of the catchment while shrubs, grassland, and other natural vegetation cover another 20 percent. Plantations extend along eastern and southeastern cliffs of the caldera and crop cultivations toward the north. Samosir Island is largely cultivated with upland plantations, various crops toward its western shores, and grasslands for cattle in the north (Figure 10). The Lake Toba region is also renowned for coffee plantations. Animal husbandry includes cattle raising in the west and large pig farming. Rice and other crops are grown in the relatively flat southern valley to the south. Aquaculture using floating fish ponds, are used across the lake. Most tourist accommodations are located along eastern shores and on the peninsula of Tuktuk of Samosir Island.

FIGURE 10. **Land use in the Lake Toba catchment**



Source: The 2013 dataset from BIG *(Badan Informasi Geospasial).* Source of satellite imagery for this and other maps: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGA, AeroGRID, IGN, and the GIS User Community.

Catchment Hydrology

Catchment dimensions and lake level

The water balance for Lake Toba provides the foundations for the management of water quality. The lake's surface area accounts for about a third of the total catchment area (Table 5) with the water balance determined by the inflow from rivers in the catchment and precipitation over the lake, and the outflow through the Asahan River and losses due to evaporation from the lake surface (summarized in Table 6). Lake Toba experiences a typical rainfall regime for the humid tropics, with a major wet season between August and November, and a minor wet season between March and May.

Precipitation averaged 2,850 mm per year between 2003 and 2016, with significant interannual variation. Temperatures averaged 21.5°C between 2006 and 2016 (at Parapat) and annual reference evaporation is 1,556 mm.[45] The 19 rivers that drain into Lake Toba provide an average inflow of 56 m^3 per second (1.8 billion m^3 per year). These inflowing rivers drain an estimated 153 smaller sub-catchments with steep slopes and typically shallow soils (Figure 11). An interbasin transfer from the Renun River constructed in 1993 diverts approximately 8–9 m^3 per second on average (20–21 m^3 per second during peak power supply) to augment water supplies for the Renun Hydropower Plant.[46] Similarly, the outflow from Lake Toba into the Asahan River is regulated by the Siruar Dam to maintain lake levels between 905.25 and 902.50 meters above sea level. This is used to provide 90–140 m^3 per second downstream flow for various water uses (e.g., hydropower). An average outflow of 110 m^3 per second was selected for the water quality analysis.

The water quality in Lake Toba is determined in part by the long residence time. The residence time of Lake Toba is estimated to be 80 years, correlating to its large water body and relatively small outflow, and represents the theoretical time required for refreshing the water in the lake. However, the theoretical residence time assumes homogenous mixing of the lake, which is influenced by spatial variations in topography, bathymetry, circulation flow directions and velocities, the thermocline, and hydrometeorological conditions. Therefore, the actual residence time of Lake Toba could be longer due to stratification and discrete hydrological compartments within the lake (see Appendix B). These restrictions on mixing in the lake determines the volume over which the incoming nutrients are diluted, in turn influencing nutrient concentrations. This means that the impact of nutrient inputs does not affect the lake equally across space and time, and soluble pollution and nutrient loads will take more than 80 years to be replaced by theoretically non-polluted water.

TABLE 5. Lake Toba sub-catchment surface area

Sub-catchment	Size (km^2)
Lake Toba	1,130
Samosir Island	653
Sub-catchment areas outside lake and Samosir	2,030
Total	**3,813**

Source: MoPWH 4/2016.

TABLE 6. Summarized water balance for Lake Toba

Variables	Rate	Inflow (mm^3/year)	Outflow (mm^3/year)
Precipitation	2,850 mm/year	3,203.4	
Evaporation	1,556 mm/year		1,748.9
Inflow	56 m^3/s	1,762.2	
Interbasin transfer Renun	8 m^3/s	252.3	
Outflow	110 m^3/s		3,469.0
Total		**5,217.9**	**5,217.9**

Stratification, horizontal lake circulation, and zonation

Water quality is influenced by vertical stratification. Lake Toba can be classified as a *warm monomictic* lake as it never freezes and is thermally stratified throughout most of the year.[47] This means that the lake contains temperature gradients called thermoclines that delineate the water by different levels of mixing, different temperatures, and different oxygen concentrations. The density difference between the warm surface waters (epilimnion) and the cooler bottom waters

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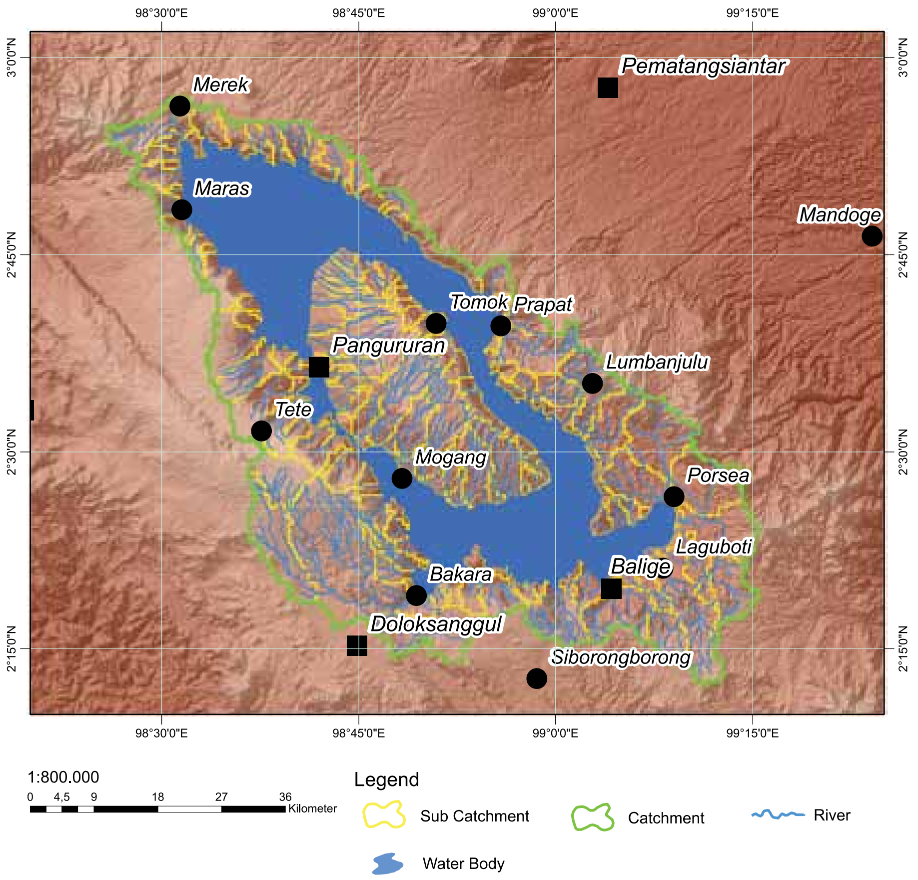
[45] Hargreaves and Allen, 2003; Zomer et al., 2008.

[46] Peak power operations are during 04:00–08:00 hrs and 16:00–23:00 hrs.

[47] Definition by Lewis, 2000.

FIGURE 11. Lake Toba catchment and sub-catchment



Source: 2013 dataset from BIG *(Badan Informasi Geospasial)*. Source of satellite imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGA, AeroGRID, IGN, and GIS User Community.

(hypolimnion), separated by thermoclines, restricts mixing of the lake's waters during much of the year and determines the volume over which the incoming nutrients are diluted, in turn influencing nutrient concentrations (see Appendix B for more detail). Deeper thermoclines mean that concentrations may be lower as dilution occurs in a larger volume of water. Stratification is observed in the temperature and oxygen profiles recorded at various locations across the lake (Figure 12). The profiles fall within the generalized temperature and oxygen ranges recorded for major Indonesian lakes deeper than 100 meters.[48] The period of stratification in tropical lakes is typically long. The stability of the middle layer is, however, relatively low and is influenced by wind and rain events that cause partial mixing.[49]

Horizontal mixing of water in Lake Toba creates spatial variations that affect water quality. Modelling by the Indonesian Institute of Sciences (*Lembaga Ilmu Pengetahuan Indonesia*, LIPI) indicates normal flow velocities, cells of circulating water with no clear direction of flow, and no intensive mixing in the north and south (Figure 13). These spatial variations are driven by complex interactions between hydrometeorological conditions, the lake's bathymetry, and the biochemical characteristics of the water body that influence circulation flow directions and velocities. The resultant flow velocities are normal for lakes (below 0.2 m^3 per second). The horizontal circulation patterns are shown in Figure 14.

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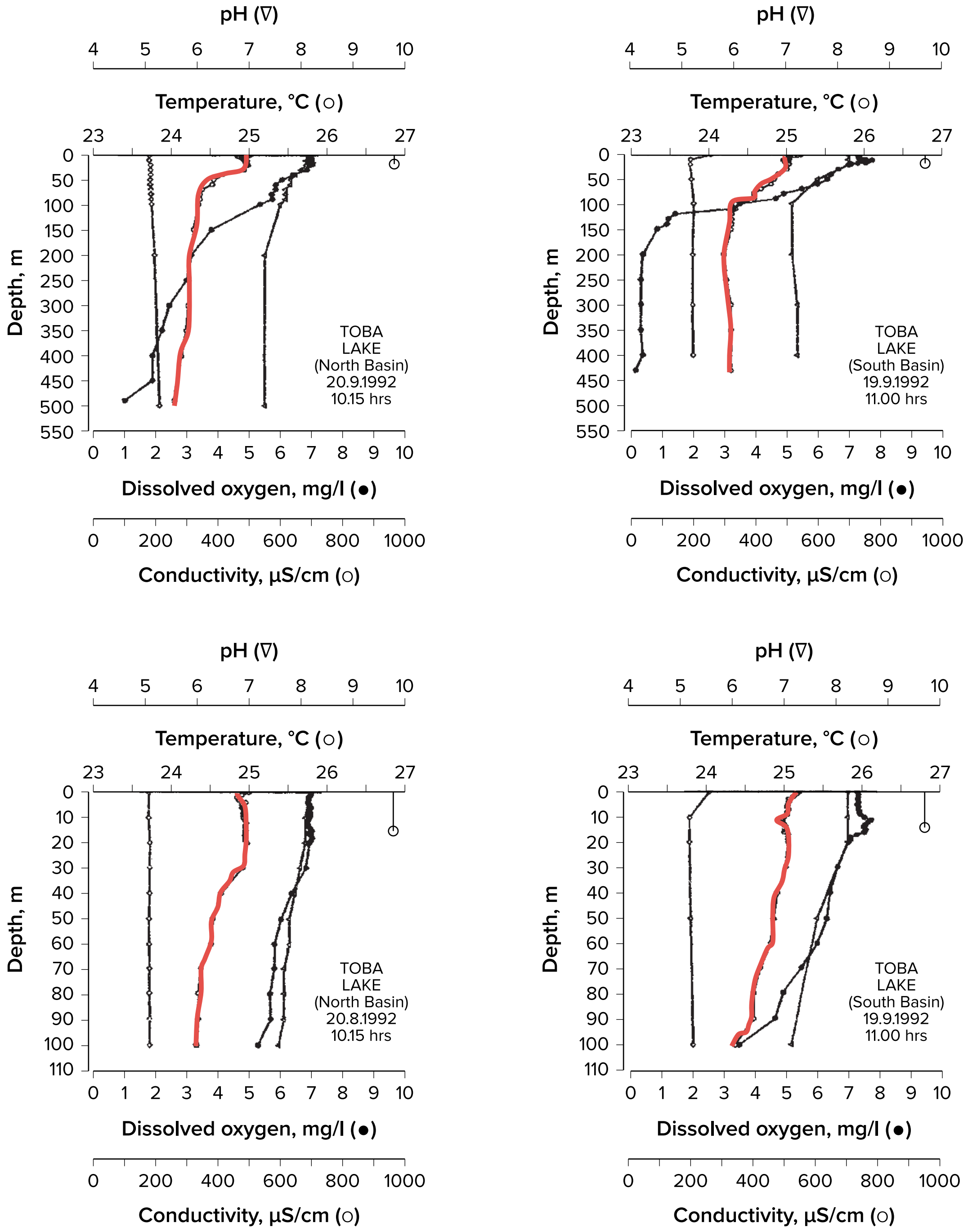
[48] Lehmusluoto and Machbub, 1997.

[49] Lewis, 2000.

FIGURE 12. Thermal profiles of north and south Lake Toba (shown in red)



Source: Lehmusluoto and Machbub, 1997.

While current water quality estimates are based on complete vertical mixing and complete horizontal mixing, Lake Toba is not a homogenous water body. Limited vertical and horizontal mixing mean nutrient inputs do not affect the lake equally across space and time. Further, nutrient concentrations may vary depending on specific emissions from the upstream parts of the basin and the predominant circulation patterns. Applying a compartmentalized approach[50] to modelling the water quality of Lake Toba provides new insights into the functioning and drivers of water quality, and a better understanding of the impact of local pollution on the lake. The compartments represent a delineation of the

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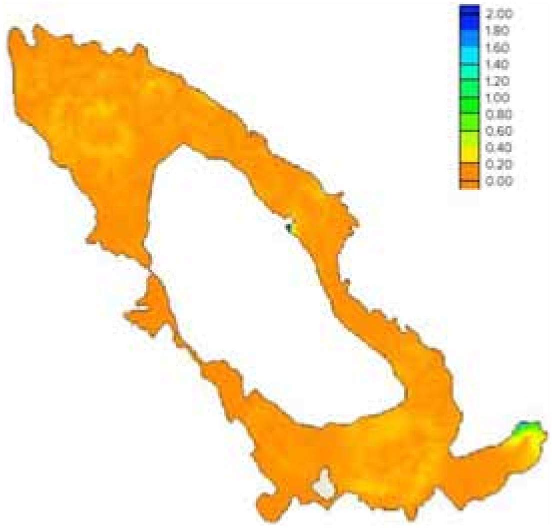
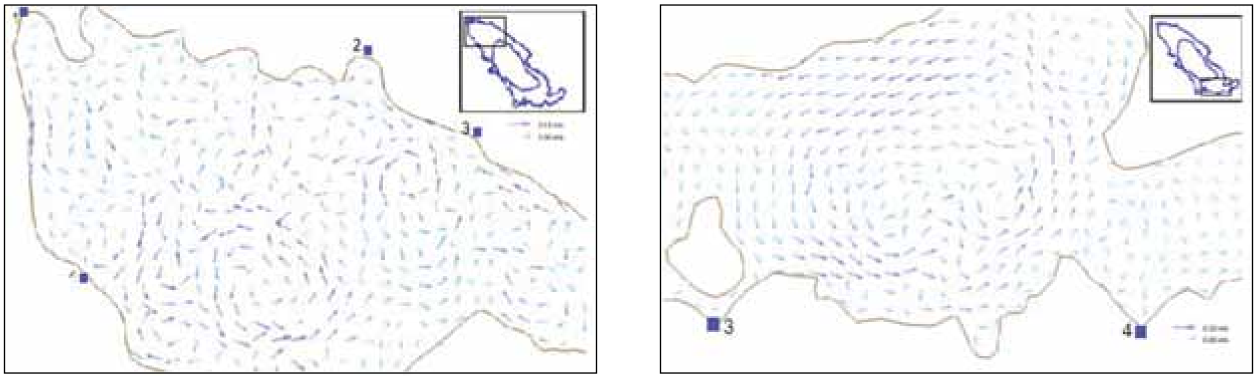
[50] Zonation enables better understanding of the impacts of local pollution on a lake system.

FIGURE 13. **Flow velocities as calculated by modelling Lake Toba**



Note: Orange indicates 0–0.20 m/s, yellow 0.20–0.40m/s, light green 0.40–0.60 m/s and dark green 0.60–1.00 m/s. Clearly the outflow of the lake in the southeastern part is seen, where flow velocities are locally higher.
Source: Rustini et al., 2014.

FIGURE 14. **The circulation pattern in the northern (left) and southern (right) part of Lake Toba**



Source: LIPI modelling; Rustini et al., 2014.
Note: The image shows cells of circulating water. The length of the arrows indicates flow velocity.

lake based on spatial variation in topography, bathymetry, circulation flow directions, and velocities, as well as sampling sites.[51] Better data is required to verify and validate the delineation of the compartments. Three sets of compartments were defined for exploring localized implications on water quality dynamics (Figure 15):

- 1 compartment: the lake as 1 zone,
- 2 compartments: the lake as consisting of 1 northern zone and 1 southern zone (divided by Samosir Island)
- 4 compartments:
  - The lake as consisting of 1 northern zone and 3 southern zones
  - South 1 (S1) representing the narrow shallow channel-like waters west of Samosir Island;
  - South 2 (S2) representing the deeper and larger waters south of Samosir Island; and
  - South 3 (S3) representing the smallest, shallow waters to the east near the outlet to Asahan River.

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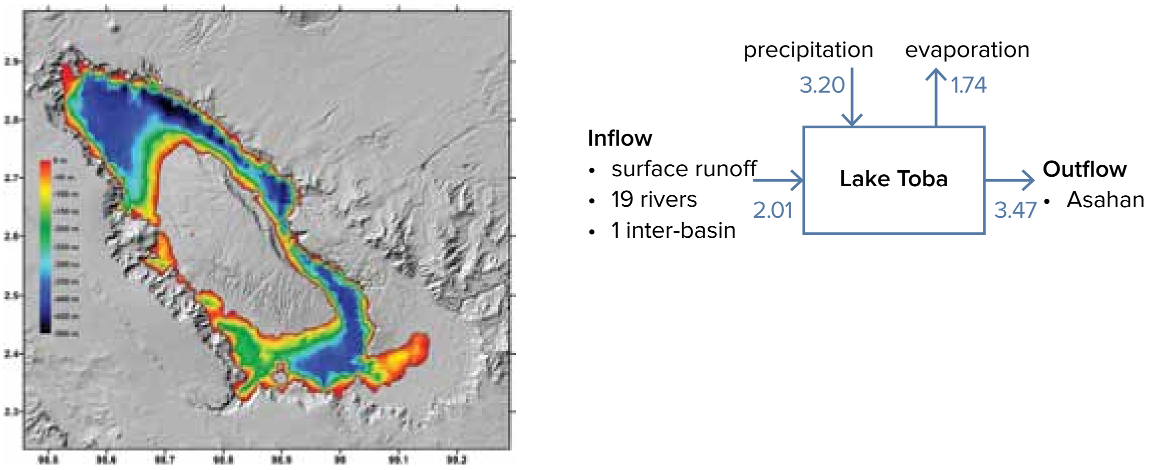
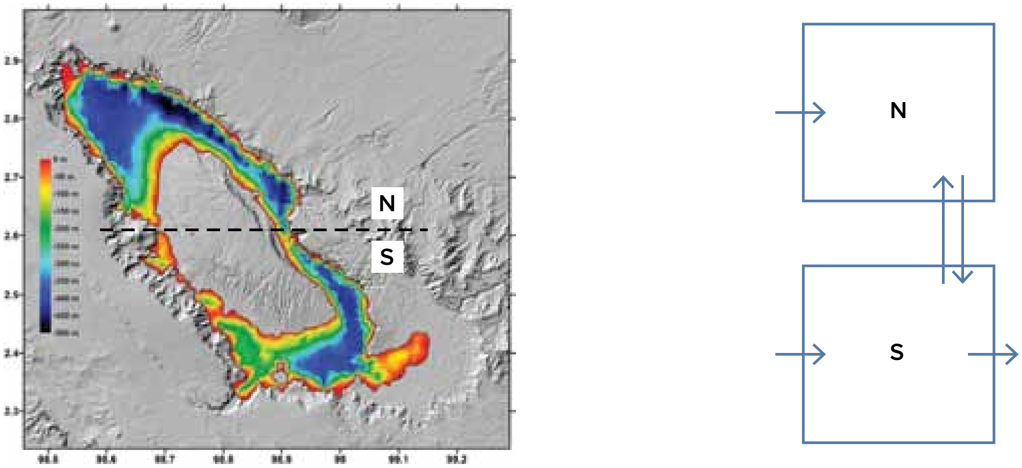
[51] Following recommendations in Oakley, 2015.

FIGURE 15. Compartment and zonation options for Lake Toba with indicative flows for the lake (billion m^3/year)

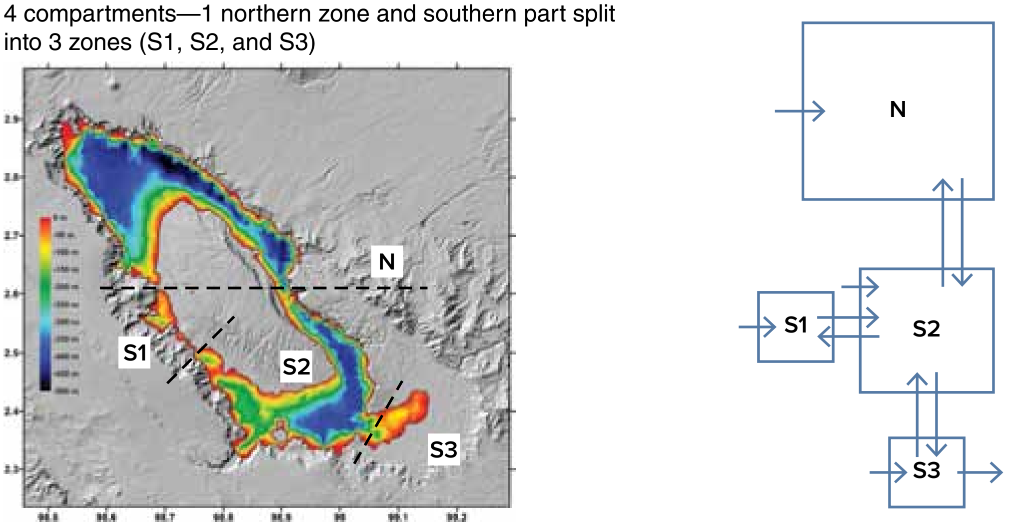
1 compartment—the lake as a 1 zone



2 compartments—1 northern and 1 southern zone



4 compartments—1 northern zone and southern part split into 3 zones (S1, S2, and S3)



Source: Base maps adapted from Chesner, 2012.

Assessing the drivers of water quality

To assess the key drivers of water quality changes in Lake Toba, the ‘drivers, pressure, state, impact and response’ concept (DPSIR)[52] was applied. The drivers, land-use changes (i.e., pressures and state), and impacts relevant to the Lake Toba catchment informed the autonomous growth and intervention scenarios of the model developed. A conceptual overview of drivers and pressures linked to state and impacts is illustrated in Figure 16, where the emission routes into the lake are shown as links. The DPSIR concept identified the point and non-point sources of nutrients. The drivers, pressures, state, impacts, and response specific for Lake Toba are detailed in Table 7. These were used to inform estimates of the trophic status.

TABLE 7. Drivers, pressures, state, impact, and responses specific for Lake Toba

Driver	Pressure	State	Impact	Response
Agriculture	Livestock: manure management	Nutrient loading of P and N runoff	Algae bloom, turbid water, oxygen depletion, gas eruptions (possibility unknown) leading to possible effects, such as: • Decreased quality of swimming water • Lower aquatic biodiversity with shift in kinds of species • Loss of native fish and fish production capacity • Lower aesthetic value	Measures to reduce livestock runoff (unknown)
	Paddy: fertilizer use			Fertilizer management program; WWT (irrigation)
	Plantation: fertilizer use			Fertilizer management program; WWT (irrigation)
	Other agriculture: fertilizer use			Fertilizer management program
Aquaculture	Commercial large-scale aquaculture: feed, fish feces, dead fish	Nutrient loading by direct input of P and N through feed		Limit tonnage produce, improve food conversion ratio
	Small-scale aquaculture: feed, fish feces, dead fish			Limit tonnage produce, improve food conversion ratio
Domestic	Urban population: organic waste, feces, wastewater	Nutrient loading by river discharges of P and N per person day		Centralized WWT (domestic)
	Rural population: organic waste, feces, wastewater			Septic tanks
Forestry	Plantation: fertilizer use, erosion	Nutrient loading by runoff and subsequent discharge from rivers of (natural) emission of P and N		WWT (irrigation)
Land cover (other)	Grass/other			none
	Shrub			none
	Forest			none
Tourism	Tourists in large hotels	Nutrient loading by emission of P and N per tourist day		WWT (hotel)
	Tourists in small hotels and homes			Centralized WWT (domestic)

Note: P = phosphorous, N = nitrogen, WWT = wastewater treatment (centralized system = off-site sewerage system of pipelines and treatment plant facilities), food conversion ratio = the ratio of input feed transformed into output biomass.

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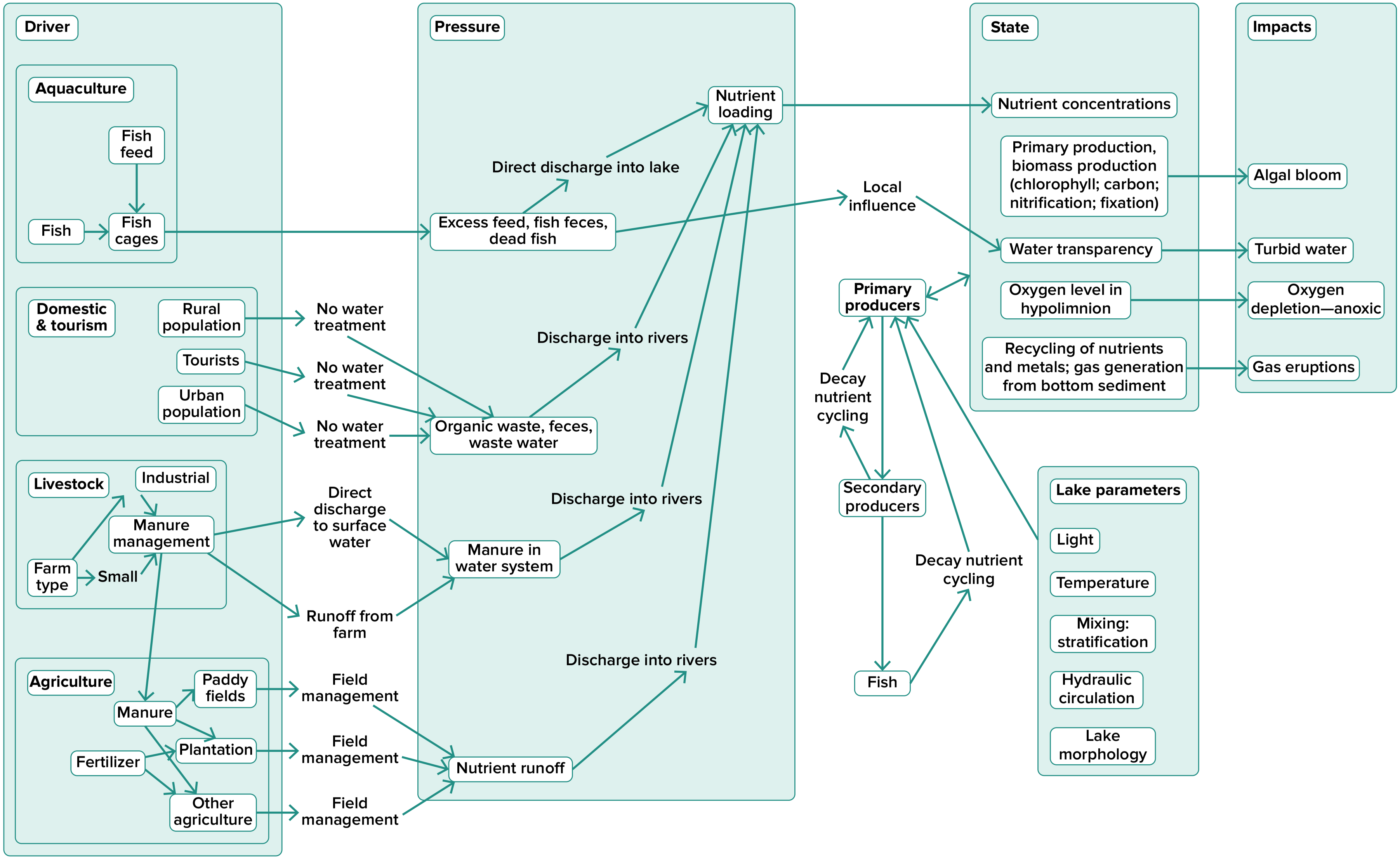
[52] Borja et al., 2006. See Appendix C.

FIGURE 16. Conceptual overview of drivers, pressures, state, and impacts of nutrient loading



Source: Chapman, 1996.

CHAPTER 2

Legal and Institutional Context

The Legal Framework

The legal and institutional arrangements for water quality management often overlap, creating a complex legal and institutional framework. Indonesia is a unitary republic divided into five layers of government: central, provinces, districts (*kabupaten*) and municipalities (*kota*), subdistricts (*kecamatan*), and villages (*kelurahan/desa*). The wide-ranging decentralization programs and reforms adopted in 2000 replaced the previous system of centralized government and development planning, giving greater authority, political power, and financial resources directly to subnational spheres of government. The powers transferred include those of executing a wide range of responsibilities in the areas of public works, along with health, primary and middle-level education, environment, communication, transport, agriculture, and manufacturing along with other economic sectors. Before this reform program, subnational governments had mainly functioned as implementing agencies of national policies and programs. Today, the national level arrangements provide monitoring, evaluation, and guidance on national priorities. Policy implementation is largely through the provinces and districts. District-level mandates and minimum targets for basic services, including drinking and wastewater, are stipulated in the national 2014 Local Government Law.[53] The development of laws and regulations have overlapped at times (Figure 17).

There is a long history of initiatives aimed at addressing the water quality issues of Lake Toba. A Regional Plan prioritizing the protection and management of Lake Toba was issued in 1990 by the governor of North Sumatra. In 2003, a provincial spatial plan[54] was developed which informed the development of the 2004 Lake Toba Ecosystem Management Plan.[55] The Lake Toba area was then designated a National Strategic Region in 2008[56] with direct implication on the sustainable management and protection of its water resources. The 2004 Lake Toba Ecosystem Management Plan was a key input to the first National Conference of Lakes in Indonesia in 2009. The conference issued the 2009 Bali Lake Agreement with the objective to maintain, preserve, and restore lake functions based on balanced ecosystem principles and environmental carrying capacity. The agreement covers 15 priority lakes including Lake Toba. The objective of the agreement was to be achieved, among others, through development of lake monitoring, evaluation, and information systems. The agreement was supported by eight ministries[57] and one agency.[58] In turn, these provided the basis for the

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[53] Law No. 23/2014.

[54] Provincial Regulation No. 7/2003.

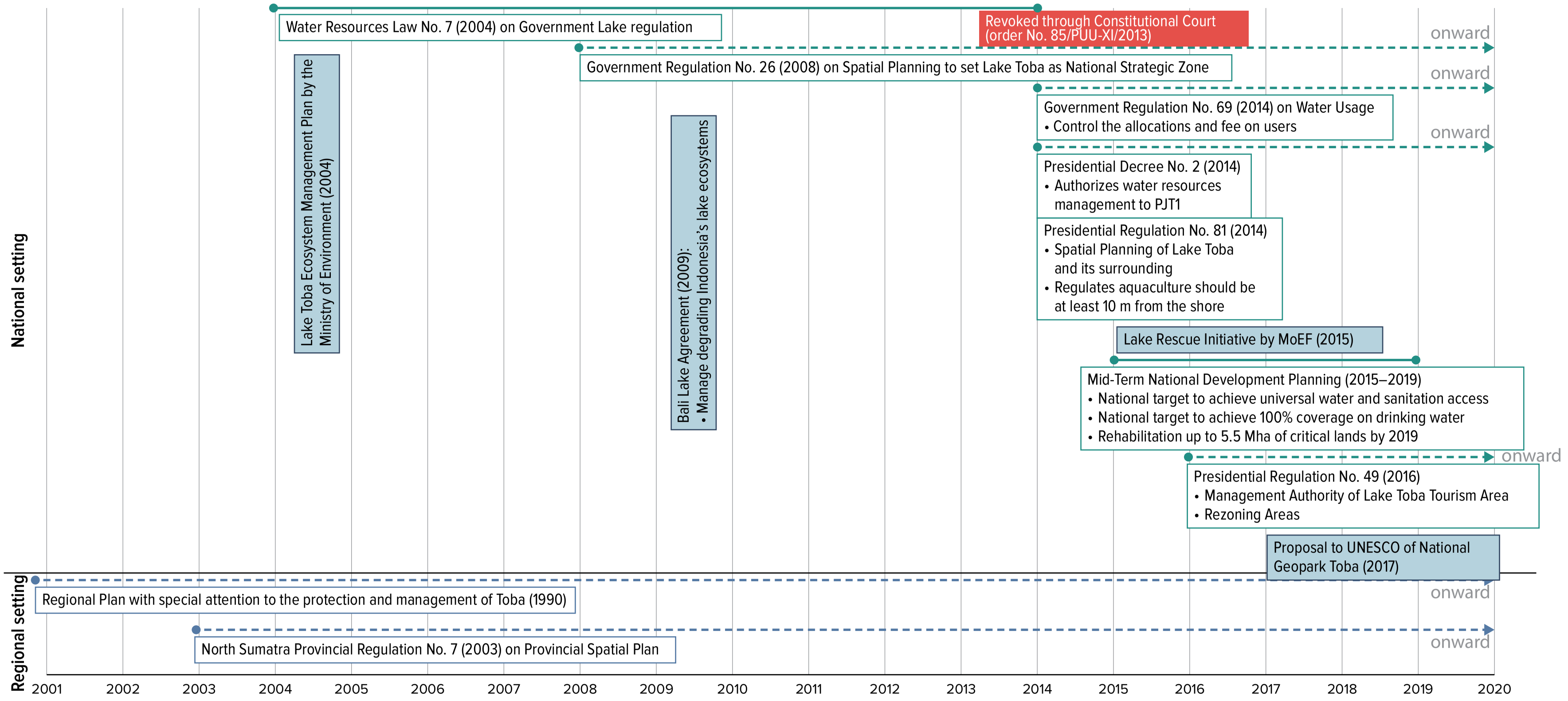
[55] The Asahan Authority and the North Sumatra Provincial Government.

[56] Through the Government Spatial Planning Regulation No. 26/2008.

[57] The Ministries of Environment, Home Affairs, Public Works, Agriculture, Energy and Mineral Resources, Marine and Fisheries, Culture and Tourism, and Forestry.

[58] The Agency for the Assessment and Application of Technology.

FIGURE 17. Overview of legislation and formal institutional arrangements 2001–2020



Source: Technical analysis by Deltares, 2017.

2015 Lake Rescue Initiative (*Germadan*)[59] developed by the Ministry of Environment and Forestry.[60] At the 2016 World Lake Conference in Bali, a priority program for lakes was initiated whereby the Ministry of Public Works and Housing made IDR 330 billion (USD 25 million) available for the restoration and safeguarding of seven priority lakes including Lake Toba. The Ministry of Environment and Forestry also issued the *Germadan* as part of the Government's National Medium-Term Development Plan (RPJMN) 2015–2019. This encompassed 15 priority lakes including Lake Toba.

Despite the commitments and consensus to improving water quality, implementation remains a challenge. All of the institutional and legal arrangements were near completion in 2014 to allow for full-scale implementation. The Ministry of Public Works and Housing had prepared the draft Government Lake Regulation. However, in February 2015 the Water Resources Law 7/2004 was cancelled by the Constitutional Court.[61] Lacking a legal basis, the process came to a standstill and the Bali Lake Agreement has not been implemented. Consequently, the Lake Toba Ecosystem Management Plan was not adopted by the Ministry of Home Affairs nor implemented as it did not provide any legally binding implications at district and local levels. Implementation of the Lake Toba Rescue Initiative *(Germadan Toba)* has commenced, with a review of the regulatory framework and a set of timebound recommendations for different management aspects. A reforestation program has been implemented by the Ministry of Environment and Forestry with the Provincial Forest Service in which members of the community were invited to manage ten hectares of forest for which they get permission to plant one hectare with trees of their choice. However, stakeholders have expressed concern that momentum has been lost and fear that the *Germadan Toba* is at risk of becoming yet another review or planning document with little impact or implementation due to the lack of legally binding arrangements.

The Toba Caldera was designated a National Geopark of the Republic of Indonesia by the president of Indonesia in 2014. The Toba Caldera is the largest Quaternary Tectonic-Volcano in the world and has distinct features of a super volcano caldera. The Government of Indonesia has submitted an application for Toba Caldera Geopark to become recognized as UNESCO Global Geopark. If approved, the government will be required to maintain the ecological, archaeological, historical, and cultural values with respect to local economic development through conservation, education, and tourism.

Water Quality Standards

Regulatory standards

Government regulations establish Lake Toba as an oligotrophic lake that should be managed to meet the standards of a Class I Raw Water for Drinking Water. The legal frameworks highlighting the relevant water quality standards for Lake Toba are presented in Figure 18. The standards for drinking water in Indonesia are stipulated in Government Regulation 82/2001. Within this context, the governor of North Sumatra has classified Lake Toba as Class I through Regulation 1/2009, establishing the desired trophic status for the lake as oligotrophic. It should be noted that the water quality thresholds for oligotrophic status in terms of phosphorous and nitrogen are not the same as the water quality standards for the Class I Raw Water for Drinking Water classification. According to the same regulation,[62] aquaculture must be done at least 10 meters from the shore and fish cages located in waters that are at least 100 meters deep.

The Ministry of Environment and Forestry reaffirmed the desired status of Lake Toba in 2017 and set the carrying capacity for aquaculture at 10,000 tons per year. The target water quality standards and required trophic state of Lake Toba was confirmed after several years of intensive investigation by several institutions, including the Indonesian Institute of Sciences (LIPI), the Provincial Environmental Agency of North Sumatra (DLH-SU), the Agency for Research and

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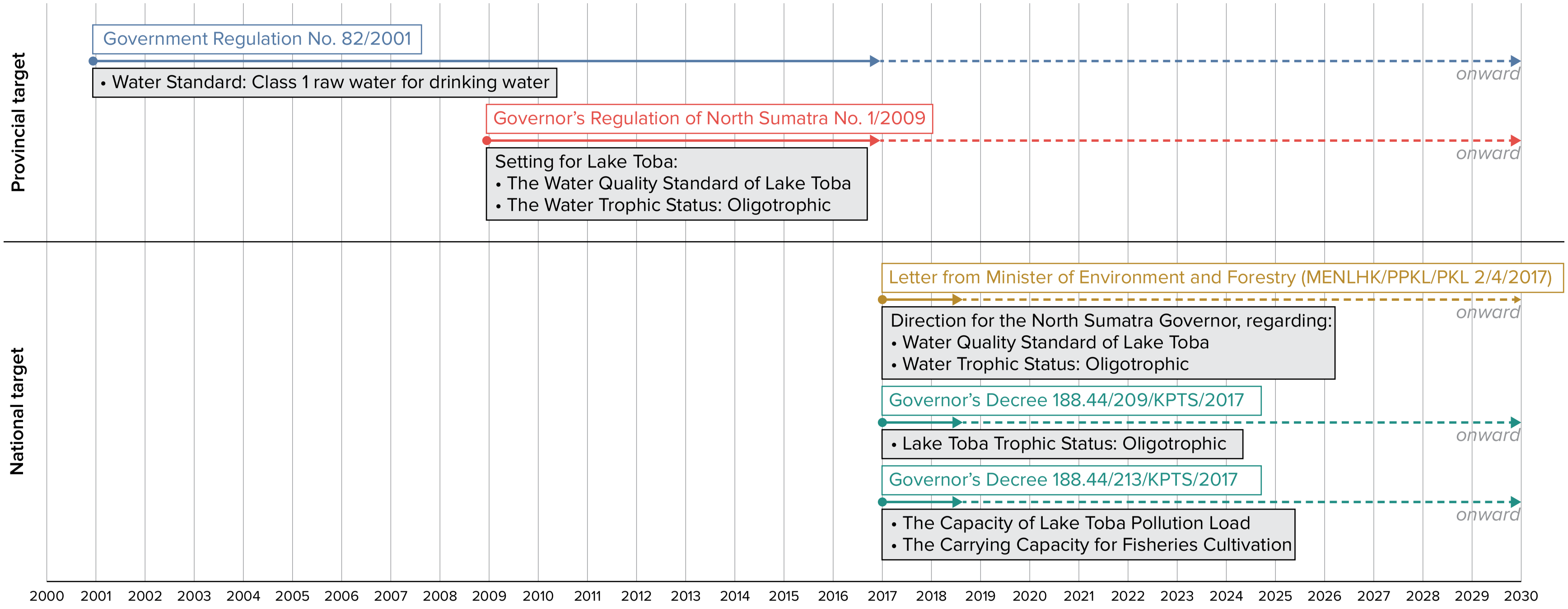
[59] The initiative was partly stimulated by the then upcoming 2016 World Lake Conference in Bali to address a growing concern regarding the rapid degradation of many lakes in Indonesia and in the aftermath of the halted implementation of the 2009 Bali Lake Agreement.

[60] BKPEKDT, 2005; and Soeprobowati, 2015.

[61] Order No. 85/PUU-XI/2013.

[62] Clause 8 (5) a, b, c and d.

FIGURE 18. Legal frameworks for water quality standards for Lake Toba



Source: Technical analysis by Deltares, 2017.

Development in Water Resources (PusAir), and various national and international universities. In a letter to the governor of North Sumatra[63] dated April 3, 2017, the Minister of Environment and Forestry instructed that:

- The water quality of Lake Toba should meet Class I Raw Water for Drinking Water as per Government Regulation 82/2001 and the Governor's Regulation 1/2009;
- The trophic status of Lake Toba should be maintained as oligotrophic in the Governor's Regulation 1/2009; and
- The maximum carrying capacity for fish cultivation in Lake Toba be set at 10,000 tons of fish per year from fish cages.

The governor of North Sumatra subsequently issued two decrees[64] thereafter making near-zero nutrient loading and carrying capacity of Lake Toba legally binding. The decrees served to instruct subnational government officials and district heads on water quality maintenance of Lake Toba. This means that pollution control became one of the key parts of the environmental management of Lake Toba. The DLH-SU issued provincial regulations following the minister's letter. However, the Ministry of Marine Affairs and Fisheries is reviewing the maximum carrying capacity and its impact on alternative incomes, proposing that time should be afforded to investors with a proposed five-year implementation period. The same ministry is in the process of collecting responses from other authorities mentioned in the letter (i.e., the seven districts around Lake Toba). Although the letter from the minister and the governor's decrees allow for immediate action, the letter was not addressed to the Minister of Home Affairs making it difficult to directly involve the relevant districts in implementation.

Licenses and permits

The management of water resources in Lake Toba is informed by numerous other government regulations. A summary of the applicable regulations is presented in Table 8. Targets for providing clean drinking water and sanitation are set in Indonesia's Medium-Term National Development Plan (RPJMN) for 2015–2019 and provide direction to management of Lake Toba. The RPJMN contains targets for universal water and sanitation access by 2019,[65] with priority given to improvement of urban solid waste management. The Sanitation Strategy for the Lake Toba area considers domestic wastewater and not industrial, agricultural, or aquaculture emissions. The Regional Planning Agency and Ministry of Public Works and Housing assembled working groups to prepare a sanitation strategy for districts and cities. The groups have established sanitation roadmaps for provincial and district levels. One of the requirements to submit a request for funding the roadmap investments is the establishment of local community support groups *(Kelompok Swadaya Masyarakat,* KSM*)*. Several KSMs exist in the Lake Toba area.

Licenses to use the water of Lake Toba are authorized based on Government Regulation No. 69/2014 and are valid for a maximum of ten years. Requests for using water are submitted to the Ministry of Public Works and Housing. License applications must include a technical recommendation from the relevant agencies at district or provincial levels. All recommendations must be approved by the water resources manager and include any technical concerns such as: the type and permissibility of water use, location of use, abstraction and utilization methods, infrastructure designs, impact on

TABLE 8. Overview of regulations pertaining to water usage

Water usage	Regulation
Drinking water standards	Ministry of Public Works and Housing Regulation No. 82/2001
Water resources utilization	Ministry of Public Works and Housing Regulation No. 9/2015
Licensing of water use	Ministry of Public Works and Housing Regulation No. 37/2015
Wastewater	Ministry of Environment and Forestry Regulation No. 68/2016
Domestic wastewater management systems	Ministry of Public Works and Housing Regulation No. 4/2017

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[63] MENLHK/PPKL/PKL.2/4/2017. The letter was copied to the Coordinating Ministry of Maritime Affairs, Ministry of Public Works and Housing, Ministry of Marine Affairs and Fisheries, and the seven districts surrounding Lake Toba.

[64] Decrees 188.44/209/KPTS/2017 and 188.44/213/KPTS/2017.

[65] Including 100% coverage for drinking water with 15 liters per capita per day, sanitation, and rehabilitation of up to 5.5 million hectares of critical lands.

the overall water balance, and the current condition of Lake Toba. Based on the technical recommendation, the ministry makes one of three decisions: (i) return for more required documents, (ii) license issuance, or (iii) rejection. Licensing is done at provincial and district levels.

A license agreement for PT Aquafarm Nusantara (PTAN) was issued in 1998 through the Investment Coordinating Board[66] while the license for PT Suri Tani Pemuka expired in 2016. The license of PTAN allows production of 36,000 tons of fish per year. PTAN has voluntarily reduced production to 30,000 tons due to water quality concerns raised by their monitoring and due to external concerns. The production license for PT Suri Tani Pemuka was issued under the guidance of the Ministry of Marine Affairs and Fisheries and is managed at the provincial level. The 2012–2016 license allowed for production of 30,000 tons per year. In 2016, PT Suri Tani Pemuka produced around 4,000 tons per year but is applying for a new license and intends to increase production to the maximum of 30,000 tons as soon as all licenses have been obtained[67] (Table 9). Neither aquaculture firms have obtained technical recommendations from the River Basin Management Organization Sumatra II (*Balai Wilayah Sungai*, BWS Sumatera II) to support their license proposals.

Most small-scale fish farms do not operate with formal licenses. Despite this, the total production potential of these small-scale operations is estimated at 40,000 tons of fish per year. Most of this is in Haranggaol Bay. The production potential dropped from 50,000 tons per year in 2015 due to concerns with water quality and foul odors affecting tourism. As a result, the district governments requested that communities abandon aquaculture between May 2016 and June 2017. Many local fish cages disappeared or are no longer maintained.

TABLE 9. Aquaculture licenses for Lake Toba (tons/year)

Producer	Licensed volumes 2012–2016	Sources	Licensed volumes Nov. 2017	Sources
PT Aquafarm Nusantara	36,000	Letter from Mr. Mudana, 201768	Unknown	
PT Suri Tani Pemuka	30,000	Toba Tilapia, 2016	0	BWS Sumatera II
Haranggaol Bay small-scale operators	0	Stakeholder meetings	0	Stakeholder meetings
Other small-scale operators	0		0	

Approvals are also required for other activities related to the management of potential nutrient emissions into Lake Toba. For example, major buildings are required to include provisions for wastewater facilities as part of the building permit. Sanitary facilities of buildings are the responsibility of the district agencies guided by the Directorate General for Human Settlements of the Ministry of Public Works and Housing. Recommendations need to be issued by the relevant district-level agencies before the building permit is issued by the district head. The district licensing agency and the district environmental agency currently do not systematically monitor the discharge of wastewater. Hydropower development also requires permits from three different ministries: the Ministry of Public Works and Housing provides permits for water usage;[68] the Ministry of Energy and Mineral Resources provides permits for generating electricity; and the Ministry of State Enterprises provides business permits.[69] Similarly, any changes in land use require the approval of customary communities *(masyarakat adat)* given that much of the land surrounding Lake Toba is of cultural significance and under traditional ownership and authority.

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[66] Personal communication with PTAN in letter from I. Wayan Mudana, Director of PT Aquafarm Nusantara to Deltares dated July 28, 2017.

[67] This amount has been used in Scenario B.

[68] In accordance with PP 69/2014.

[69] Permen MoPWH 4/2014.

Aquaculture stewardship council standards

The two commercial aquaculture companies also commit to the voluntarily principles of the Aquaculture Stewardship Council (ASC).[70] The ASC certification promotes better managed fish farming while minimizing negative environmental and social impacts. The ASC principles focus on compliance with national and local regulations, conservation of local habitat and biodiversity, preservation of water quality and water resources, social responsibility, and human welfare. According to the ASC Tilapia Standard V1.1 2017, *diurnal dissolved oxygen fluctuation* has been selected as a practical parameter for assessing the effects of eutrophication. To avoid the excessive loading of nutrient-poor systems, however, a limit on the total phosphorus concentration has been imposed and a limit on the concentration of chlorophyll a has also been established. The ASC standards[71] prescribe that measurements shall be taken at the point where the aquaculture farm effluent has an influence in the receiving waters but is not in the immediate outfall/mixing zone (i.e., downstream in a river or down prevailing current pattern in a lake).

Institutions Monitoring Water Quality

There are several government agencies, institutions, and national and international universities along with stakeholder groups that collect water quality data in Lake Toba. Sixteen different organizations[72] were identified as having different water quality data series. These can be categorized according to three functions: signal, exploratory, and statistically conclusive. For the purposes of developing the water quality model for this roadmap analysis, data from four organizations was used. These organizations are: the Provincial Environment Department of North Sumatra (DLH-SU);[73] the Indonesian Institute of Sciences (LIPI); PT Aquafarm Nusantara (PTAN); and the River Basin Corporation 1 Jasa Tirta 1 Public Corporation (PJT1), a state-owned enterprise of water resource management. The four organizations conduct the most regular and comprehensive monitoring of water quality in Lake Toba and are officially recognized. Their sampling sites that were relevant to the roadmap analysis are shown in Figure 19.

The Provincial Environment Department of North Sumatra, DLH-SU, monitors long-term change at 22 locations. DLH-SU has 22 monitoring sites distributed across the lake. The near-shore sites have been monitored once or twice annually over ten years. The selection of sites is based on monitoring pollutant loads and effect in larger bays, inhabited coastline, and aquaculture locations along the coastline. The frequency aims to capture long-term, decadal changes rather than short-term ones.

LIPI monitors water quality for exploratory and statistical purposes. LIPI has conducted various measurement campaigns across a range of locations and environmental aspects, such as hydro-dynamics, ecology, and water quality issues of Lake Toba. It has data of measurements starting in 2009 for which analysis was carried out at its own laboratory. The spatial distribution of sampling sites for the technical analysis cover deeper central parts of the lake and provide useful depth profiles. The institute focuses on lake system characteristics by selecting mid-lake monitoring sites.

PTAN monitors Lake Toba to assess the impact of its operations and to meet ASC standards.[74] PTAN[75] performs its own water quality monitoring at four sites and has its own on-site laboratory, which is periodically quality-checked by Wageningen University. Three monitoring stations are located at the center of fish farm areas (Panahatan, Tomok, and Pangambatan), and the fourth is in the center of the lake providing a no-aquaculture reference point. Data has been collected monthly over ten years. One of the sites provides temperature and oxygen profiles since the start of PTAN's monitoring.

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[70] The Aquaculture Stewardship Council is an independent international non-profit organization that manages the world's leading certification and labelling program for responsible aquaculture.

[71] See p. 17 of ASC Tilapia Standard Version 1.1, April 2017, for detailed requirements on nutrient releases and water quality parameters.

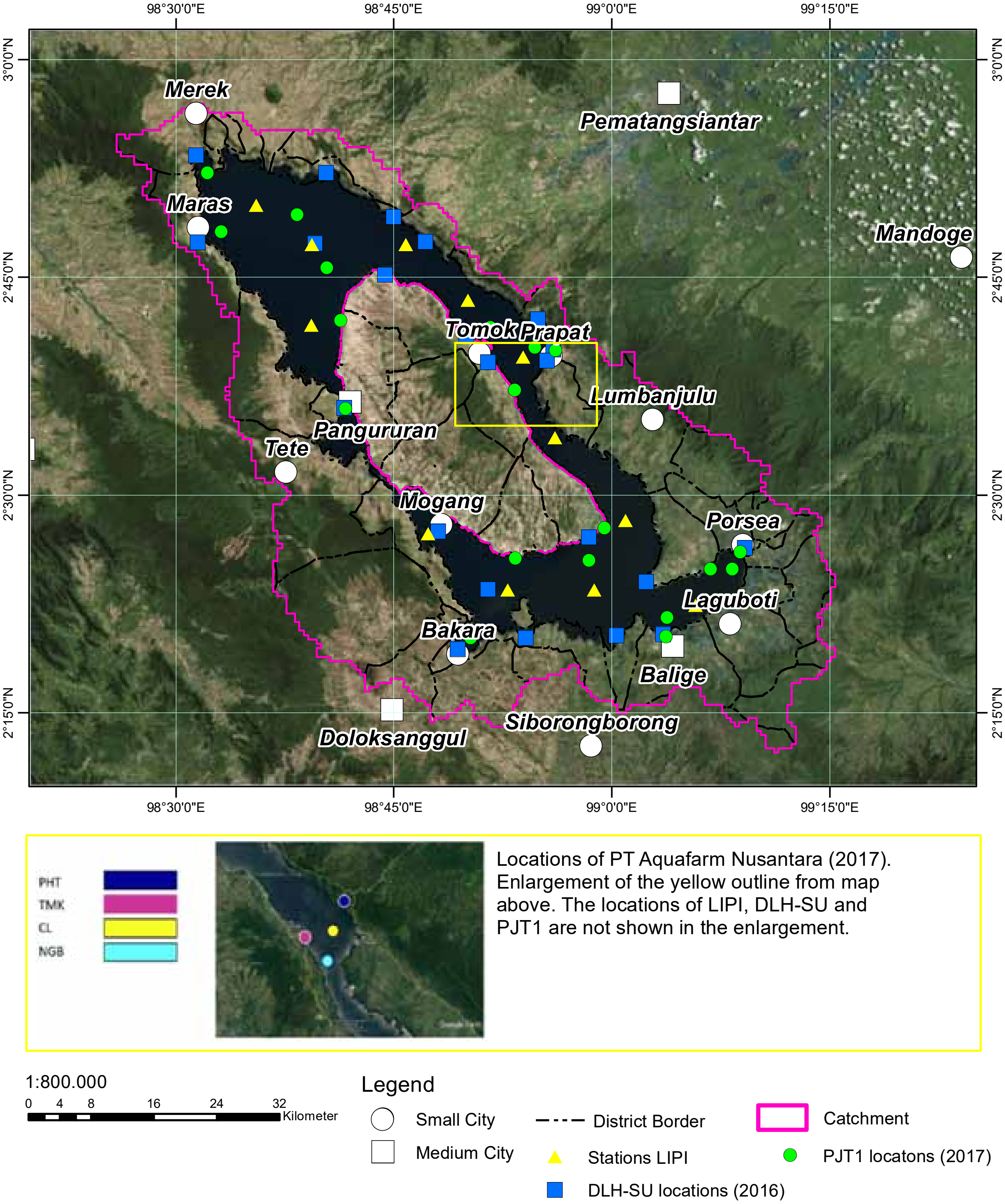
[72] See Appendix A for details.

[73] Before January 2017, DLH-SU was named BLH-SU, *Badan Lingkungan Hidup—Sumatra Utara*.

[74] Aquaculture Stewardship Council.

[75] PT Suri Tani Pemuka outsources water quality monitoring.

FIGURE 19. Water quality monitoring sites of DLH-SU, LIPI, PJT1, and PT Aquafarm Nusantara



Locations of PT Aquafarm Nusantara (2017). Enlargement of the yellow outline from map above. The locations of LIPI, DLH-SU and PJT1 are not shown in the enlargement.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
Note: Aquaculture locations: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

The Jassa Tirta 1 Public Corporation (PJT1) has recently started monitoring water quality in Lake Toba. PJT1 is a national organization responsible for basin management and development (Box 2). PJT1 was given operational jurisdiction for the Toba Asahan River basin[76] through Presidential Decree No. 2/2014 following the designation of Lake Toba as a National Strategic Region.[77] PJT1 collects fees for lake management and monitoring and is planning to build its own water quality monitoring laboratory near Parapat.

BOX 2. The Jasa Tirta I Public Corporation (PJT1)

The Government of Indonesia has established two self-financing state enterprises, or River Basin Corporations, to improve cost recovery and to ensure the fiscal sustainability of river basin management systems. These are the Jasa Tirta I Public Corporation (PJT1, established in the 1990s) and the Jasa Tirta II Public Corporation (PJT2) in the Ministry of State Enterprises.

PJT1 and PJT2 are responsible for the development, operation, rehabilitation, and maintenance of water resources infrastructure; management of catchment areas, including the conservation, development and utilization of water resources; and the rehabilitation of water resource facilities. Revenues are sourced from raw water fees, hydropower, water quality laboratory services, and recreational uses, etc.

The operational jurisdiction of PJT1 includes the Toba Asahan River basin in North Sumatera, the Brantas River basin in East Java Province and the Bengawan Solo River basin (an interprovincial river basin lying in Central and East Java Provinces).

PJT1 launched a water quality monitoring program for Lake Toba and the Asahan River in 2015. This program includes four automatic water level and rainfall recorders, and a water quality monitoring system. An additional five automatic water level recorders, 11 automatic rainfall recorders, and two water quality monitoring systems are planned, along with a laboratory scheduled to be completed in 2020.

PJT1 has invested in a range of Integrated Water Resource Management (IWRM) activities, including planting 25,602 trees over three years and removal of 447,675 m^3 of sediment from the Asahan River and its tributaries to improve catchment protection.

PJT1 is required to monitor and evaluate water quality and disseminate the results to communities and stakeholders, as well as provide technical advice and recommendations to natural resource managers and policy makers. With a mandate and the revenue mechanisms to enhance financial sustainability, PJT1 provides a model to implement a coordinated, public platform for water quality monitoring.

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[76] As per Presidential Decree No. 2/2014.

[77] Through the Government Spatial Planning Regulation No. 26/2008.

Implementation

Implementation of national and provincial level regulations is often impaired by challenges around a lack of coordination at district levels resulting in problems in alignment and enforcement of permits. Policy and strategic plans are set by the national government, while implementation is carried out at the district *(kabupaten)* levels. This includes the issuing of permits and recommendations. Bottlenecks in implementation of various programs have occurred due to lack of established official procedures and support and active agreement at the national level with the Ministry of Home Affairs. Implementation of regulations is also impaired by the lack of monitoring and enforcement. For example, hotels or buildings that do not have permits or adequate wastewater facilities do not face penalties, and permits are rarely sought due to above mentioned challenges.

Accelerated investments in tourism need to be carefully considered with respect to protected forests. The planning and execution of erosion control and reforestation is the domain of national and subnational government agencies of the Ministry of Environment and Forestry.[78] Regulations issued to enhance Lake Toba as a tourism destination[79] address re-zoning prerequisites. This means that some areas around Lake Toba classified as protected forest could be converted and used for tourism purposes. Other threats to forests include legal and illegal logging as well as uncontrolled burning.[80]

Regulatory misalignment and resulting failures allow for continued operations even in the absence of formal licenses. Permits are at times issued at the district level but not the central level, or issued at the central level without due consultation at the local level, allowing companies and small-scale operations to operate in the absence of the necessary approvals. Furthermore, the importance of aquaculture for local livelihoods, along with weak capabilities and incentives for enforcement and monitoring of licenses, further undermine regulatory efficiency.

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[78] Local communities, NGOs, and members of the private sector have been involved in restoration and reforestation efforts, though limited in scale, funding, and geographic scope compared to those of the government.

[79] Presidential Regulation No. 49/2016.

[80] See for example Hadinaryanto et al., 2014; Gunawan, 2016; and Sitanggang, 2017.

CHAPTER 3

Stakeholders and Governance

Stakeholder mapping was carried out as part of the broader analysis and effort to improve the management of water quality in Lake Toba.[81] Five categories of stakeholders were defined in accordance with the 2004 Indonesian Water Resources Law, the Strategic Water Resources Management Framework Plan *(Pola),* and Master Plan for River Basin Management *(Rencana).* These include: regulator, coordinator, operator, developer, and user. The fulfilment of these roles is particularly important for water quality management and monitoring of interventions in the Lake Toba area at the level of the 46 lower subdistricts *(Kecamatan).*

A broad range of stakeholders were identified from a range of different sources and grouped into the different categories. These included the 2013–2015 Basin Water Resources Management Council (*Tim Koordinasi Pengelolaan Sumber Daya Air,* TKPSDA); the Lake Toba Rescue Initiative *(Germadan Toba)* of the Ministry of Environment and Forestry; the Coordinating Agency for Lake Toba Ecosystem Management *(Badan Koordinasi Pelestarian Ekosistem Danau Toba);* the Provincial Environmental Agency for North Sumatra (*Dinas Lingkungan Hidup—Sumatera Utara,* DLH-SU); the 2015 Urban Sanitation Development Program (*Program Pengembangan Sanitasi Perkotaan,* USDP); and the updated and verified 2001–2004 Basin Water Resources Management Plan (*Perencanaan Pengelolaan Sumber Daya Air Wilayah Sungai,* BWRMP).

The identified actors were grouped according to the categories to explore the relationships, incentives, and influence of actors at multiple levels involved in the management of water quality in Lake Toba.[82] This included national government agencies, subnational government agencies, non-governmental organizations (NGOs), local communities, academic institutions, and the private sector. Once mapped, interrelations based on authority and flow of information/coordination, as well as in/formality were outlined. Semi-structured interviews and social network mapping was performed as part of two meetings held in Jakarta on May 17, 2017, and in Laguboti, Sumatra, on June 14, 2017. Social network maps were produced to provide a visual representation of the various network linkages, influence of different actors, and goals in the social network.

Stakeholders

Social network mapping

The social network maps identified levels of authority among stakeholders, a high level of interconnections of local non-state actors, and levels of negative influence on water quality. The exercise revealed that state agencies held consistent high levels of authority. Non-state actors, such as NGOs, civil society organizations (CSOs), and traditional leaders,

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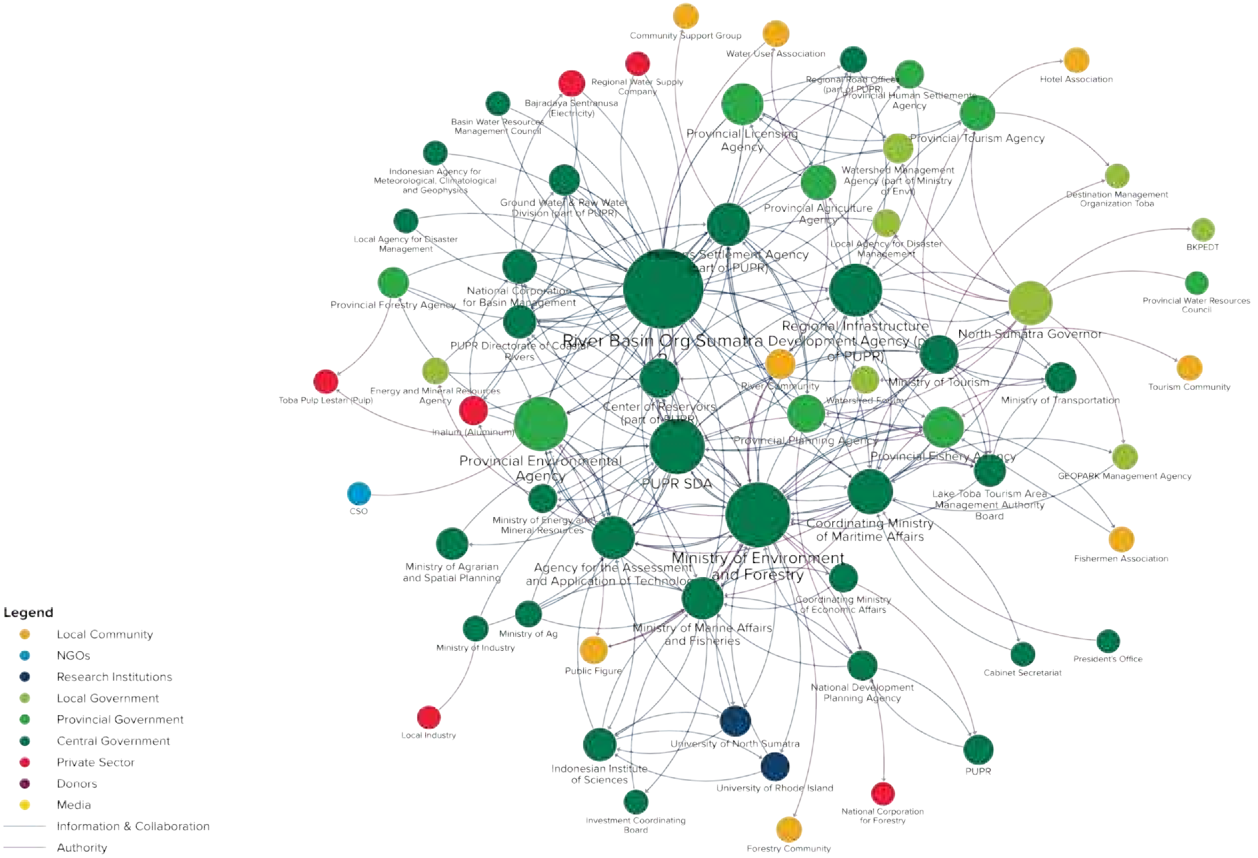
[81] See Appendix D for details on laws and regulations.

[82] See Appendix A.

FIGURE 20. Social network map No. 1: influence on water quality management in Lake Toba



Source: Produced with the Reference Group in Jakarta on May 17, 2017.

were shown to play significant roles in driving the water quality agenda through activities ranging from public education to advocacy. These actors are also highly interconnected at district and provincial levels, but less so with the entire network (i.e., rarely with the private sector or academia).[83] Non-governmental agencies have, however, the potential to drive the agenda further through their active engagement in monitoring and many formal and informal interconnections. The maps also identified actors with perceived negative influences (i.e., polluters).

The network mapping did not reveal a clear leader, despite there being several coordinating bodies managing water quality of Lake Toba. This may be because organizations such as Forum DAS and TKPSDA have been initiated at the national or provincial level, with lesser focus on operations at the district level. However, hubs with intensive interaction and interconnection indicate a potential of some stakeholders to become change agents.

A total of 91 stakeholders were first identified. This was an acknowledged underrepresentation,[84] but was not perceived as altering the network analysis. The social network maps are composed of the following elements:

- Blue arrows indicating authority (one-way interaction)
- Yellow arrows indicating information or coordination (two-way relationship)
- Solid lines representing formal connection

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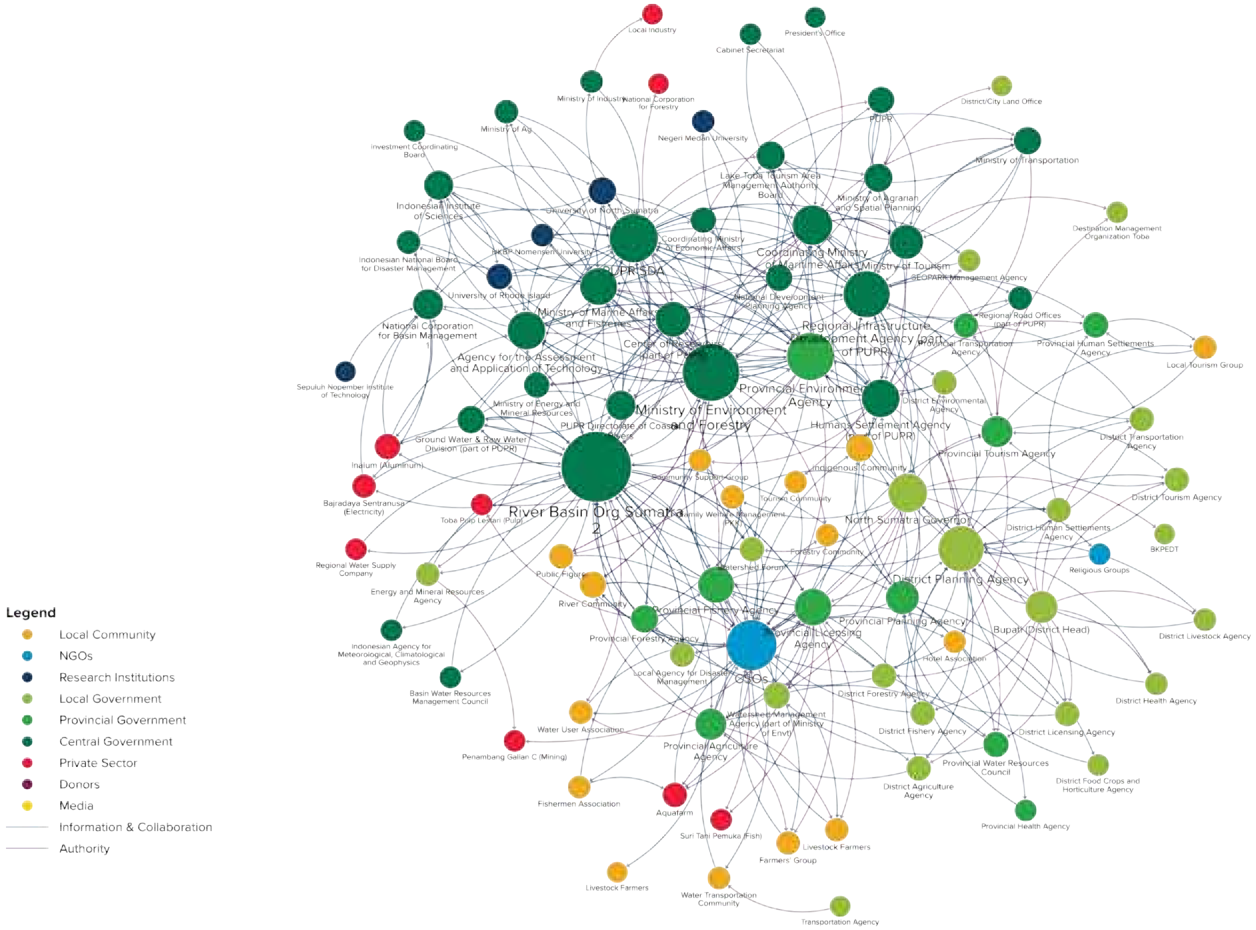
[83] For example, several NGOs and CSOs (such as Yayasan Pencinta Danau Toba, WALHI, Alusi Tao Toba—North Sumatra foundation in education, Study Group and Community Initiative Development (KSPPM), and local communities represented through the Local Fishermen's Association DAERMA) expressed that when their aspirations are not well received by district services, they would go directly to relevant ministries at the national level.

[84] For example, certain district-level agencies were listed only once to represent all seven districts surrounding Lake Toba.

FIGURE 21. Social network map No. 2: influence on water quality management in Lake Toba



Source: Produced by wider participant group at local level in Laguboti, Sumatra, on June 14, 2017, building on first social network map.

- Dotted lines representing informal connections
- Color of circle representing group
- Size of circle illustrating relative influence on management of water quality

The first social network map revealed the presence of highly connected hubs with significant network influence. These are primarily government agencies. The map was produced with the Reference Group in Jakarta[85] (Figure 20) and identified a total of 248 connections (totaling 496 with two-way authority links) and illustrated hubs of significance. These hubs are primarily ministerial and provincial agencies (i.e., the Basin Management Center Sumatra II, the Coordinating Ministry of Maritime Affairs, the governor of North Sumatra, Directorate General Water Resources of the Ministry of Public Works and Housing, and the Ministry of Environment and Forestry).

The second social network map revealed a wider scope of local actors with a greater number of interconnections. This confirmed the hubs of significance identified in the first network map. The second map produced with the larger group of participants in Laguboti[86] (Figure 21) identified a total of 389 connections (totaling 778 with two-way authority links). As more local actors were added to the map, more linkages and hubs were identified. For example, traditional leaders were identified and the District Planning Agency *(Bappeda Kabupaten)* emerged as a hub for district agencies.

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[85] Total 27 participants.

[86] Total 55 participants.

Stakeholder overview

A total of 170 stakeholders were identified with roles ranging from regulators to operators to civil society representatives, working across local districts through to national levels. The full list of stakeholders and an explanation of their roles is provided in Appendix A and a summarized overview in Table 10. Further insights into the role of stakeholders and their ability to affect positive action and diversifying livelihood options for the catchment residents, can be achieved through further deepening consultations across government agencies, the private sector, and civil society.

TABLE 10. Stakeholders and involvement in water quality issues of Lake Toba

Central government level		
Institution	**Activities**	**Involvement**
National Development Planning Agency (Sub-Directorate General of River, Coastal Areas, Reservoir and Lakes)	Coordination and policy formulation on: • development planning and strategy • sectoral, cross-sectoral and trans-regional directive • national and regional macroeconomic frameworks • infrastructure and infrastructure design • regulatory, institutional, and funding frameworks • monitoring, evaluation, and implementation oversight	• National planning across water quality areas, especially for national priority programs such as tourism. • Planning of river, reservoir, and lake uses.
Coordinating Ministry of Maritime Affairs	Coordinates ministries of transportation, marine & fisheries, energy & mineral resources, and tourism	• Chairs the Lake Toba Tourism Area Management Authority.
Coordinating Ministry of Economic Affairs	Coordinates ministries of public works & housing, forestry & environment, finance, industry, trading, labor, agriculture, agrarian & spatial planning, state owned and small enterprises, and cooperatives	• Involved at multiple levels and with cross-cutting issues through ministries.
Ministry of Tourism	Formulates and implements policies on: • tourism destinations and development • foreign tourism marketing • tourism marketing of the archipelago • the tourism institutes	• Tourism is a polluter, employer, and potential ally for improved water quality.
Ministry of Environment and Forestry	Formulates and implements policies on: • sustainable forest and environment conservation • conservation of natural resources and ecosystems • improvement of watershed support capacity and forest protection • sustainable forest management • enhancement of forest industry competitiveness • quality of environmental functions • control of pollution & environmental degradation • climate change adaptation and control of negative impacts • forest & land fire control • social forestry • environmental partnerships	• Lake Toba catchment has classified forest estates under the purview of the Ministry. • Broad involvement due to cross-cutting and numerous environmental issues.
Ministry of Agrarian and Spatial Planning	Formulates and implements policies on: • spatial planning • infrastructure of agriculture • land affairs • land use • soil	• Spatial planning of the Lake Toba catchment as a National Strategic Region (monitored by the Ministry).

Central government level		
Institution	**Activities**	**Involvement**
Ministry of Public Works and Housing	Formulates and implements policies on: • water resources under Directorate General (DG) Water Resources • wastewater management and sanitation • waste management under the Directorate General Human Settlements • management of lakes in the center (lakes and reservoirs) • management of roads under the Directorate General of Highways	• Management of water resources, wastewater, and sanitation, and integrated tourism master plans.
Regional Infrastructure Development Agency (RIDA)	Preparation of technical policy and integrated strategy of regional development (under Ministry of Public Works and Housing)	• Preparation of integrated tourism master plans for tourism destinations.
Basin Management Center Sumatra II	Manages water resources through: • water resources planning • management of upstream conservation • water quality • water utilization • control of destructive water • operation and maintenance • rehabilitation • construction/development	• Water flow monitoring.
Center Research of Water Resources	Research on water resources management	• Research, analysis, and data on water quantity and quality.
Ministry of Marine Affairs and Fisheries	Formulates and implements policies on: • marine and freshwater fisheries and aquaculture	• Aquaculture is a polluter and employer.
Ministry of Agriculture	Formulates and implements policies on: • agricultural infrastructure and facilities • increasing production of meat, rice, corn, soybeans, sugarcane, and other crops • enhancing added value, competitiveness, quality, and marketing	• Agriculture is an employer and a polluter.
Ministry of Industry	Formulates and implements policies on industries	• Local industries are polluters and employers.
Ministry of State-Owned Companies	Implements: • water resource commercialization • water resource services • provision of guarantee for water resource services/operation • maintenance and development of water infrastructure • technical advice to water resource managers • implementation of operation and maintenance of infrastructures (prior to hand over to private operators)	• State-owned companies around Lake Toba (e.g., PJT1). • The ministry can collect fees from water users.
Lake Toba Tourism Area Management Authority	Stimulating tourism through: • preparation of Master Plan and Detailed Plan of Development of Tourism Area of Lake Toba • coordination and policy strengthening of planning, development, management, and control of tourism area • formulation of operational strategy of tourism development • assistance to development of tourism in the area • facilitation and stimulation of tourism growth • licensing and non-licensing business centers and areas in the region of approximately 500 ha • determining how to solve problems in planning, development, management, and control of area	• Preparation of detailed Master Plan.[87] • Coordinating implementation of Master Plan. • Management of 500 ha tourism area. • Supports momentum for water quality improvement.
Investment Coordinating Board	National level coordination for investment (for large domestic and foreign investors)	• Licensing for investors (e.g., in aquaculture).

(continues)

TABLE 10. Continued

Provincial level		
Institution	**Activities**	
Provincial Environmental Agency of North Sumatra	- Monitors water quality and pollutant sources - Determines pollution quality standard for the main sources - Prevents pollution through information, isolation, and termination of pollutant sources - Provides pollution recovery through cleaning, remediation, rehabilitation, and restoration - Enforces regulation on pollutant sources - Develops and empowers communities on waste management - Oversight of facilities and infrastructure for sewage treatment - Determines carrying capacity and environmental capacity - Determines environmental quality standards - Monitors and conserves biodiversity	
(planned) Special Body for Lake Toba Geopark	Not yet applicable.	
Coordinating Agency for Lake Toba Ecosystem Management	Coordination for ecosystem, including water quality.	
Watershed Forum *(Daerah Aliran Sungai)*	Coordination forum for upstream catchment.	
Provincial Public Works Agency	Takes care of river basins that belong to the province (Permen MoPWH 4/2015).	
District level[88]		
Institution	**Activities**	
Head of District	Licensing authority for fish cages and hotels, based on technical recommendation from related agencies.	
Regional Planning Agency	Coordinates planning from all sectors at district level.	
District Public Works Agency	Takes care of river basins that belong to the district.	
Other major stakeholders		
Institution	**Activities**	**Involvement**
NGOs and CSOs	Depending on area of work	- Some do water quality monitoring.
Regional Water Utility Company, PDAM Tirtanadi	Drinking water and wastewater company	- Manages wastewater treatment plant Parapat.
Electricity Companies	Hydropower (e.g., BDSN, INALUM, PLN)	- Water user.
Toba Pulp Lestari	Pulp company	- Polluter and employer.
PT Aquafarm Nusantara	Aquaculture	- Polluter and employer.
PT Suri Tani Pemuka	Aquaculture	- Polluter and employer.
National Water Resources Council	Preparation of national water resources policy	- Water quality is key policy priority.
Basin Council	Coordinates basin water resources management; endorses strategic and master planning; allocates yearly water allocation; hydrogeology and hydroclimatology; and implements monitoring programs and activities	- Water quality is one aspect of water resources conservation.

Governance

A strengths, weaknesses, opportunities, and threats (SWOT) analysis was undertaken with the Reference Group to better understand governance and capabilities in implementing, monitoring, and enforcing regulations and programs. The key parameters considered in the SWOT analysis were: resources (labor, capital, technology, etc.); physical environment (climate, extreme events, pests, etc.); infrastructure (roads, water infrastructures, etc.); and economic (markets, tourism, etc.) and social factors (attitudes, institutions, etc.).

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87 It has been agreed between government agencies/ministries that RIDA of MPWH will prepare the Integrated Tourism Master Plans.

88 In 2016 there were no agencies at the district level for forestry, environment, and aquaculture.

The SWOT shows that the agenda and momentum for realizing Lake Toba's tourism potential are key strengths and opportunities for improving water quality (Figure 22). The tourism agenda for Lake Toba is pushed at the national level, from the president, through to ministries and the Lake Toba Rescue Initiative. This agenda provides a window of opportunity to accelerate funding and interventions for water quality improvements.

The major bottleneck is at the district level where monitoring and law enforcement efforts stall. Stronger commitment is needed from district heads, coupled with strengthened capacity of district agencies. Required interventions include governor regulations for district level commitments and provincial monitoring of district compliance. For example, the Ministry of Home Affairs has proven effective in instructing district heads to build sanitation facilities. Direct implementation by provincial agencies to take over management roles is seen as positive since provinces have more capacity, human resources, and budgets for operations compared to districts.

Residents, including civil society organizations and non-governmental organizations, express support for programmatic and legal compliance. This includes farmers who have shifted from horticulture to aquaculture for example. Though they operate without a license, they have expressed keen interest in alternative livelihood options. There are also active NGOs engaging with residents and voicing concerns on livelihoods. Residents have a strong attachment to Lake Toba for its cultural value.

FIGURE 22. **SWOT analysis of water quality monitoring and management of Lake Toba**

Water Quality Management and Monitoring of Lake Toba

Strengths

- Momentum created by designating Lake Toba a priority tourism destination current administration
- Wastewater treatment facilities and regulations were set up and enhanced in anticipation of tourism
- Increased and strong demand for clean water (reflected in construction, initiatives, programs)
- Decentralization is increasing resources and capacity for O&M at provincial level
- Provincial agency now handles solid waste management
- Reference and guidance for Lake Toba management is available through Lake Rescue Initiative and other studies
- Increasing participation of communities and NGOs

Weaknesses

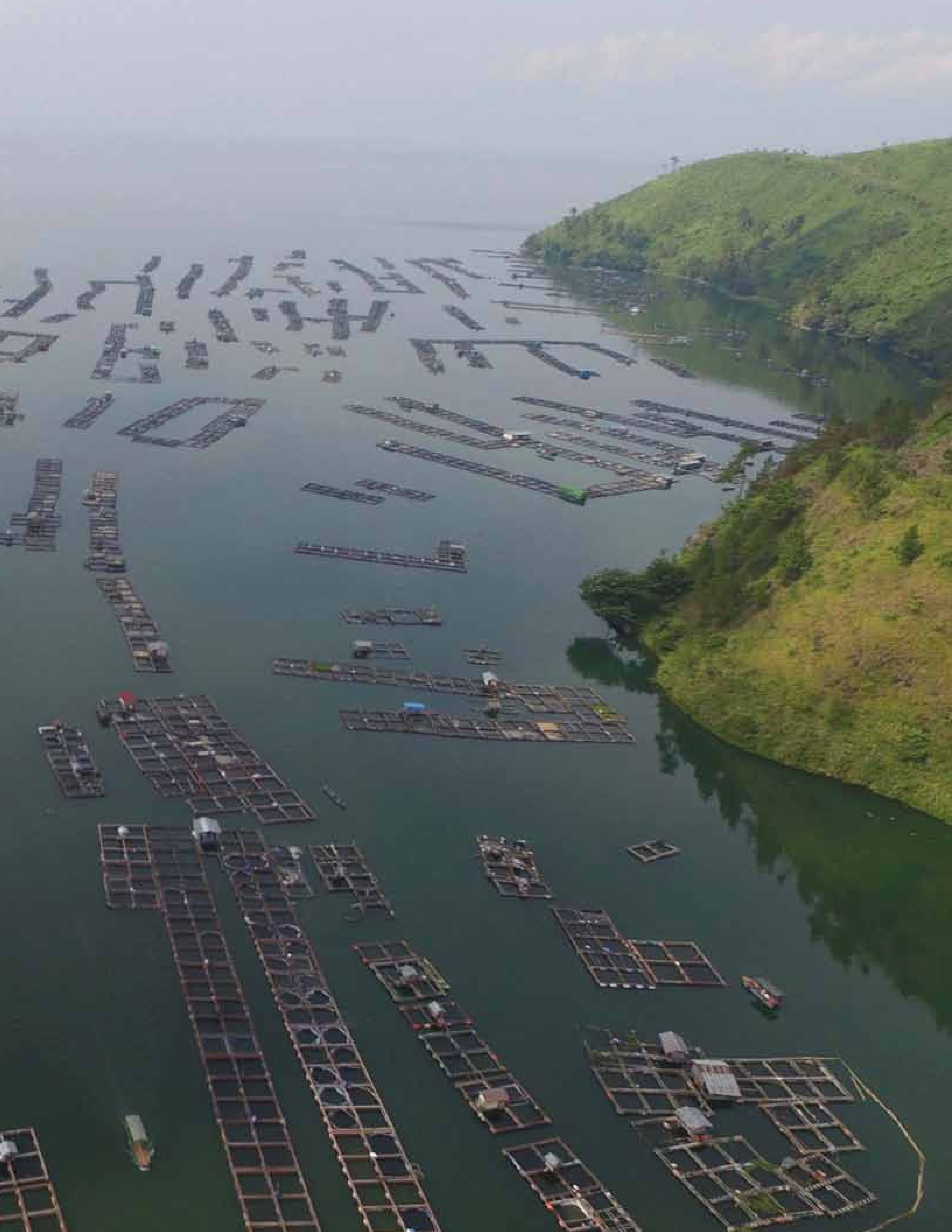
- Not all 7 districts have formally committed
- Gaps between initiatives at central level and implementing bodies at district level
- Limited monitoring and law enforcement capacity
- Poor condition of wastewater treatment plants
- Low coordination between license issuing agencies and technical services at the district level
- Lack of legally binding regulations for the Lake Toba Rescue Initiative to implement a management program
- Diffuse responsibilities because of overlapping institutional mandates

Opportunities

- National programs incentivizes better management (e.g., Adipura, Social Forestry Program)
- Interest at highest levels of government could encourage involvement of wide range of central government ministries/agencies and subnational governments
- Attention given to Lake Toba as a National Strategic Region
- Lake Toba Tourism Area Management Authority Board has specific mandate
- Government is preparing an Integrated Tourism Master Plan
- The presence of local community support groups could improve information sharing, advocate better management, and promote new interventions
- Willingness of community to change jobs, especially to tourism

Threats

- Cultural significance of most land surrounding the lake means any changes in land use need customary (often lengthy) approval
- Lake Toba Tourism Area Management Authority is exploring land conversion, including currently classified "protected forests" posing a threat of further erosion
- Limited fish production will impact jobs, livelihoods, and social stability
- Political changes at national and provincial level could affect strong commitment to the lake
- Potential conflict of interests when government officials are involved in industry, such as fishing industry or paper mills



CHAPTER 4

Pressures and Drivers: Sources of Nutrient Inputs

To inform the development of a roadmap for improving the water quality of Lake Toba, the key pressures and drivers relating to nutrient loading were assessed using the Sumatra Spatial Model (SSM). The SSM has been used in several strategic studies on water resources[89] and was used to assess potential sources of nutrient emissions, estimate the nutrient loading of the lake, and determine the concentration of key parameters (see Appendix F for further details on the SSM). The output of the analysis includes nutrient load calculations and evaluation of point and non-point sources.

Nutrient loads were calculated in the model to quantify and compare current sources of nitrogen and phosphorous. The calculations consider socioeconomic development, future land use, and corresponding nutrient and waste loads (i.e., waste loads encompass nutrients and other pollution emissions into the water). The emission estimates, from point (specific locations) and non-point sources (diffused emissions) across the compartments[90] of the lake, were used to investigate the drivers of nutrient loading in 2015. While it is important to distinguish the sources in order to identify appropriate solutions for reducing nutrient loads, the distinction is less important for the model because each nutrient loading is assumed to be immediately dispersed in a compartment (Figure 15) up to the thermocline layer. After loads were calculated, total nitrogen and total phosphorous concentrations were calculated for each compartment using a simple budget water quality model.[91]

Nutrient Load Calculations

The emissions from aquaculture were calculated as the product of annual fish production (tons of fish per year) and the nitrogen or phosphorous loss to the environment per ton of fish production. The nutrient emissions are assumed to be the same across commercial and small-scale operators. The nutrient emissions were estimated at 15.98 kg of phosphorous per ton of fish[92] and 74.78 kg of nitrogen load per ton of fish.[93] The estimated yearly fish production used in the model was 84,800 tons of fish for 2015[94] (Table 11). The total nutrient load was distributed over the various lake model compartments based on the ratio of their surface. A Geographic Information Systems (GIS) analysis was performed to determine the location and number of fish cages in Lake Toba (Figure 23). Because the use of fish cages varied over time outside Haranggaol Bay, a weighing factor of 0.5 has been applied to estimate the number of cages. The total production of 84,800 tons was proportionally distributed over the fish cages with the assumption that commercial fish cages produce twice the amount of small-scale production.

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[89] The same spatial model has been applied in Indonesia to predict impacts on water resource systems in earlier studies, such as the Java Spatial Model developed for the ADB study for the six rivers around Jakarta (6Ci study); the World Bank-financed Java Strategic Water Resources Study *(Studi Strategis Sumber Daya Air (pulau) Jawa);* and the Korean study for Strategic Water Resources of Sulawesi.

[90] See horizontal lake circulation and zonation in Chapter 1.

[91] See Appendix F.

[92] By applying a food conversion ratio of 1.9 to the values estimated by Oakley 2015 (Table 1).

[93] Taken as six times the phosphorous loss based on Table 4 in Gyllenhammar and Håkanson, 2005.

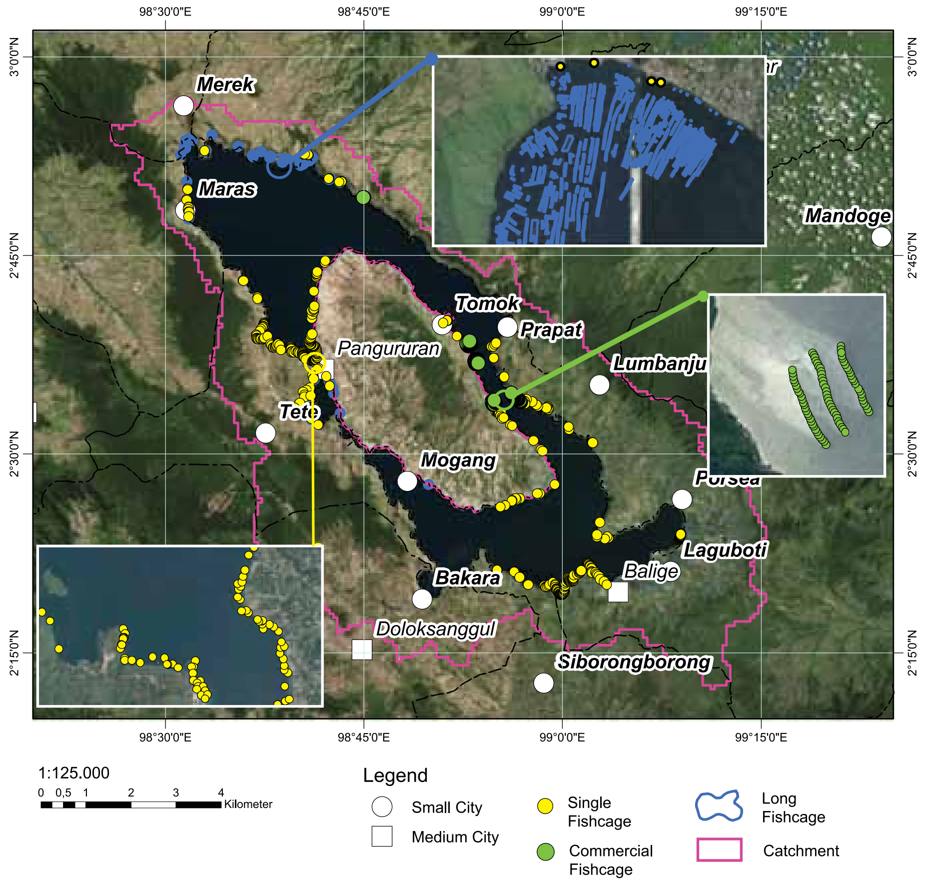
[94] The Provincial Environmental Agency for North Sumatra (Dinas Lingkungan Hidup, DLH-SU).

TABLE 11. Estimated aquaculture fish production in Lake Toba per producer and compartment 2015 (tons/year)

Producers	**Estimated production 2015**					
Lake compartments	North	South	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	14,000	22,000		22,000		**36,000**
PT Suri Tani Pemuka	9,700	0				**9,700**
Haranggaol Bay small-scale operators	22,700	0				**22,700**
Other small-scale operators	6,500	9,900	3,300	4,900	1,700	**16,400**
Total	**52,900**	**31,900**	**3,300**	**26,900**	**1,700**	**84,800**
Percentage production	*62%*	*38%*	*4%*	*32%*	*2%*	
Percentage emission	*60%*	*40%*	*8%*	*28%*	*4%*	

Note: See Figure 15 for lake compartment delineation.
Source: Total production estimates by DLH-SU, and geographical distribution according to Figure 23.

FIGURE 23. Locations of aquaculture fish cages on Lake Toba 2008 to 2015



Note: The dots represent clusters of individual fish cages as mapped from Google Earth images.
Source: Observations in Google Earth for the period 2008–2015.

Each fish cage could be considered as a separate point source. Mitigating measures can be taken at farm and individual cage levels. The locations of long fish cages (blue), commercial fish cages (green) and individual single cages (yellow) are shown in Figure 23. Clusters of long fish cages are mainly found in the Haranggaol Bay area.

The emissions[95] from wastewater were calculated as the product of population, emission factors per inhabitant, and the runoff factor (Table 13). The population estimates comprise the residents of the Lake Toba catchment area and are based on the Sumatra Spatial Model and national census data.[96] The population growth estimates were kept conservative and not calibrated in the Sumatra Spatial Model (SSM) despite an overestimation compared to official statistics data. In the SSM, annual population growth between 2010 to 2015 for the catchment was overestimated by 3 percent compared to district growth estimates from the Indonesia Statistics (*Badan Pusat Statistik,* BPS, Table 12). For the seven Lake Toba districts, however, the annual population growth estimates in SSM and BPS are 2 and 1 percent respectively. Also, the drivers of growth in the SSM reduce rapidly after 2015. The 1 percent difference in population growth estimates occurs early in the projection period.[97] Therefore, the water quality model slightly overestimates the nutrient loads and thus provides a conservative projection. In addition, the nutrient emissions from tourism are estimated from 5 million tourist nights per year.[98]

TABLE 12. **Comparison of 2015 BPS and Sumatra Spatial Model (SSM) population estimates**

District	2015 population estimates		Estimate difference
	BPS statistics	SSM	SSM/BPS (%)
Tapanuli Utara	293,399	301,609	102.8
Toba Samosir	179,704	189,917	105.7
Asahan	706,283	739,829	104.7
Sima Lungun	849,405	899,582	105.9
Dairi	279,090	296,631	106.3
Karo	389,591	391,915	100.6
Humbang Hasundutan	182,991	185,717	101.5
Samosir	123,789	132,155	106.8
Total	**3,004,252**	**3,137,355**	104.0 (average)

Source: BPS (2015) and SSM.

TABLE 13. **Modelled nutrient emissions for domestic wastewater**

	Emissions (g/person/day)		Number of days per year	Runoff factor
	N	P		
Urban population	15	2.55	365	0.5
Rural population	15	2.55	365	0.5

Excessive emissions from wastewater enter the lake because of a predominant use of pit latrines and because the area's only wastewater treatment facility is operating at 10 percent capacity. Most sanitation facilities are on-site facilities at household or community levels and can be classified as pit latrines. This means that nutrients easily enter the groundwater (in contrast to septic tanks) and enter surface waters when latrines overflow during floods or high rainfall events. In combination with the underperforming wastewater treatment plant at Parapat, polluted water enters the lake. Wastewater is a nonpoint source of pollution that matches population density (Figure 24).

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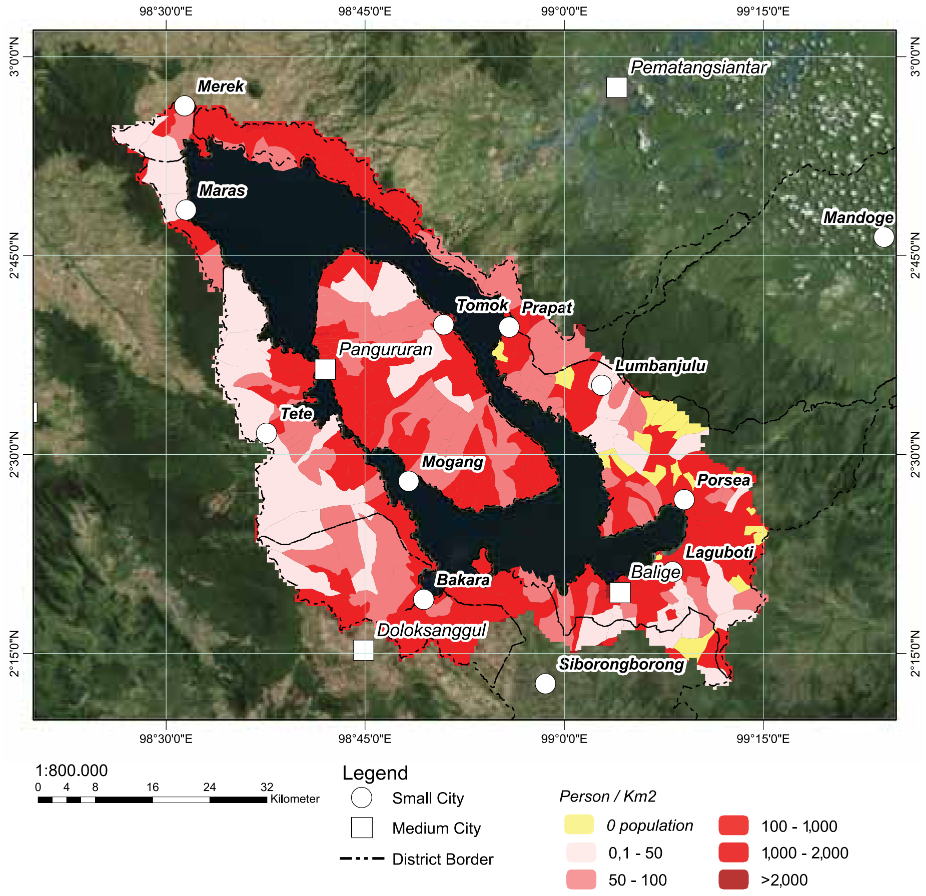
[95] Emission factors were taken from DLH-SU, 2017 and Deltares & TNO, 2016.

[96] See Appendix F.

[97] A proper comparison can be made in the next population census.

[98] Total tourist nights are spread between the compartments based on Horwath HTL, 2017.

FIGURE 24. Lake Toba catchment population density by village (desa) in 2015



Source: SSM 2017.

The emissions from tourism are comparatively small because of the relatively low number of tourists. However, tourists are concentrated in a limited number of village areas (Figure 25). Hotels are generally small and often without adequate sanitation facilities. The contribution of individual hotels can be compared with a cluster of houses and classified as a nonpoint source.

Emissions from livestock and agriculture were calculated using standard coefficients relative to total numbers and cultivated areas. Livestock counts are related to population numbers, with the population estimates per sub-catchment providing growth factors to estimate future loads from livestock. The agricultural emissions were calculated as the product of cultivated areas, emission factors per crop or culture type, and the number of growing seasons per year (Table 14). Emissions from other land uses[99] were calculated as the product of land use areas and emissions factors per land use class (Table 15).

Nutrient loads from livestock manure are classified as nonpoint sources as emissions primarily enter the lake via surface runoff and groundwater. The numbers of animals[100] used in the model were estimated from population growth estimates. Figure 26 shows livestock densities[101] (matching population densities and minor nutrient contributions from agriculture and other land uses).

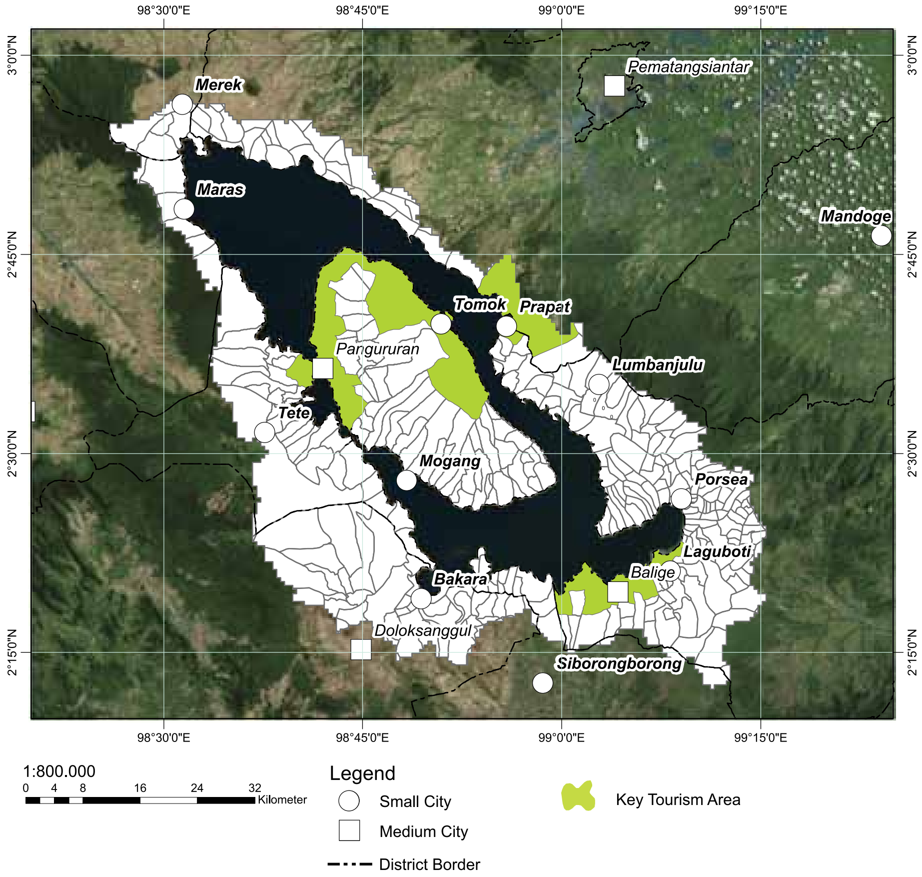
---

[99] Phosphorous and nitrogen emission factors were based on Iskandar, 2013.

[100] Note that data was available for some desa and district level areas, and no data was available for some areas.

[101] Based on data from DLH-SU, 2017.

FIGURE 25. Main tourism areas around Lake Toba in 2015



Source: Horwath HTL, 2017.

TABLE 14. Modelled nutrient emissions for agriculture

	Emissions (g/ha/season)		Number of seasons	Runoff factor
	N	P[102]		
Total paddy area (ha)	20	10	3	1
Other agriculture (ha)	10	5	1	1
Plantation (ha)	3	1.5	1	1

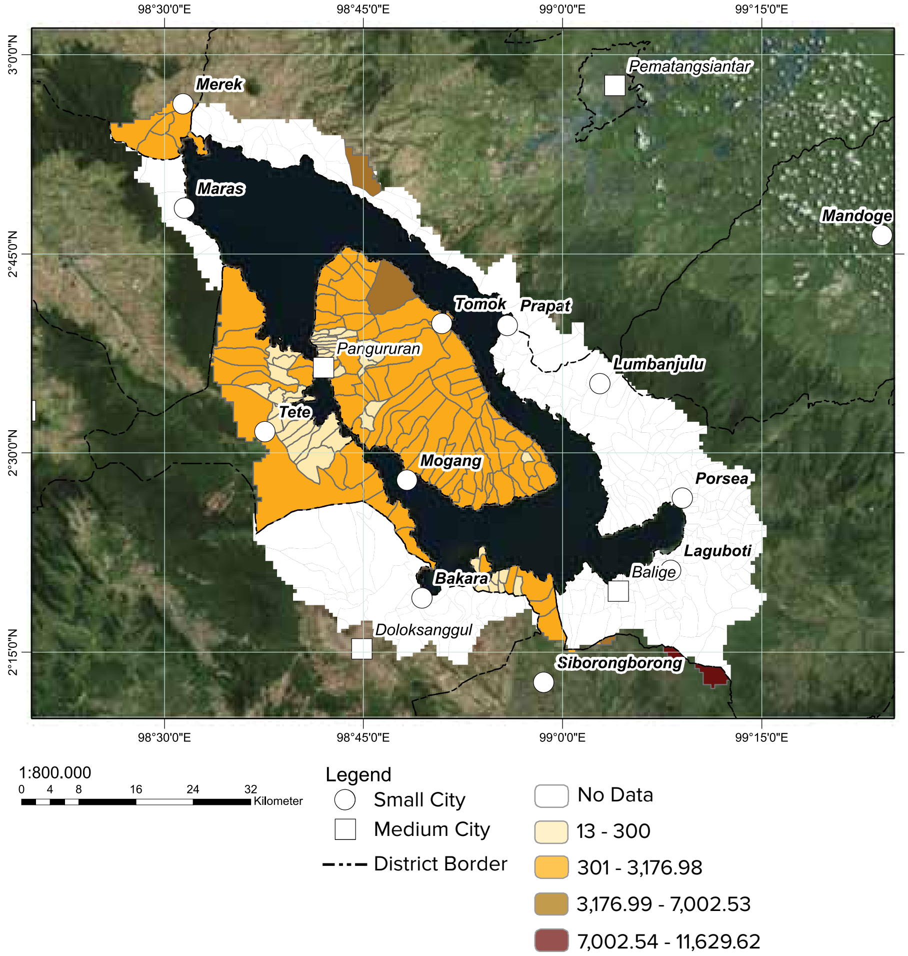
TABLE 15. Modelled nutrient emissions for other land uses

	Emissions (g/ha/year)	
	N	P
Grass/other (ha)	2.46	0.246
Shrub (ha)	2.46	0.246
Forest (ha)	1.94	0.194

---

[102] Emission factors based on Iskandar, 2013.

FIGURE 26. Livestock densities around Lake Toba



Source: DLH-SU, 2017.

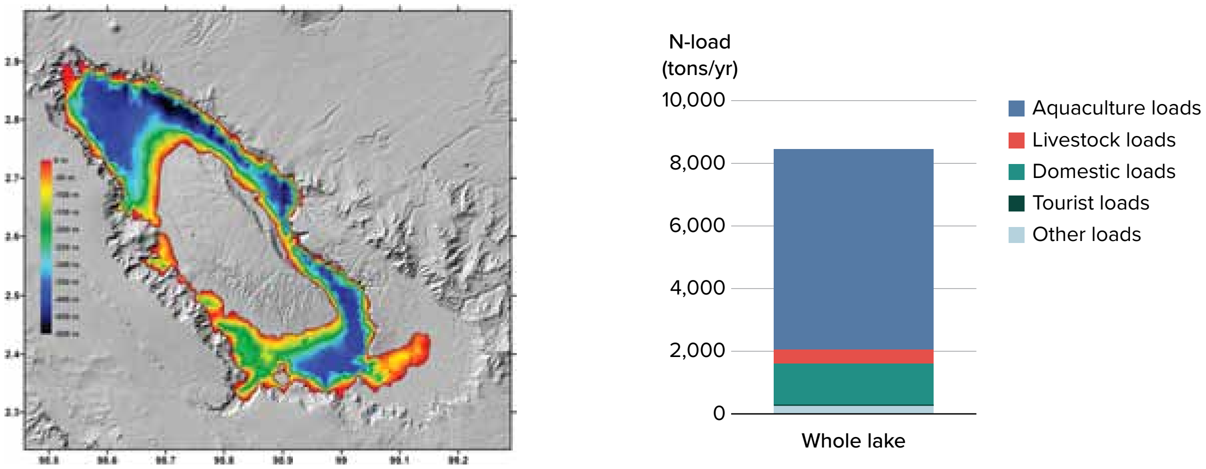
Total and Relative Nutrient Loads

Aquaculture is the main source of nutrient loading, contributing 76 percent of total nitrogen and 68 percent of total phosphorous loads into the lake based on model estimates. The second largest source is domestic wastewater contributing 15 percent of total nitrogen and 11 percent of total phosphorous loads. The third is livestock, with 5 percent of nitrogen and 19 percent of phosphorous load contribution. The location and relative distribution of main sources in 2015 are shown in Figure 27 and Figure 28. Other sources of nutrients include forests, meadows, tourism, rice paddies (sawah) and other agricultural activities. Collectively, these minor sources contribute 4 percent of total nitrogen and 2 percent total phosphorous. The minor contribution of tourism as part of wastewater is illustrated in Figure 30.

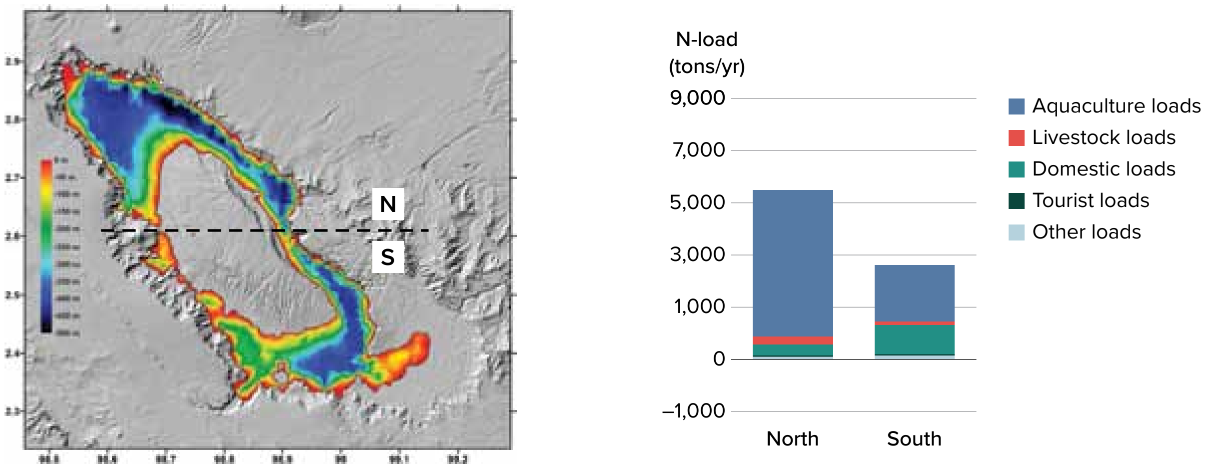
The local near-field affect is likely underestimated in the four-compartmental modelling, and eutrophic and hyper-eutrophic deterioration can emerge locally in the short-term. The nutrient loads presented above are based on mixing in the four lake compartments used in the model. Long-term and far-field effects are averaged and not very large in the model. However, there can be significant real local effects that are not captured for the short-term and local near-field effects albeit temporary. Near-field effects estimates, carried out by the Indonesian Institute of Sciences (LIPI), show that water quality can deteriorate locally to eutrophic and even hyper-eutrophic states with increasing densities of fish cages, such as along the northeastern coast (Table 16).

FIGURE 27. Relative contributions of total nitrogen load across lake compartments and source in 2015

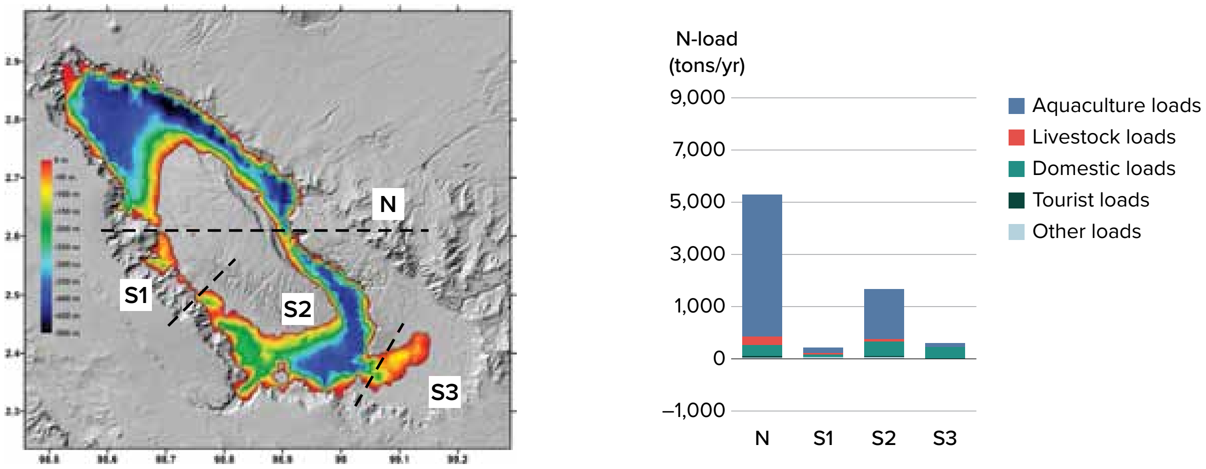
Nitrogen loads in 1 compartment



Nitrogen loads in 2 compartments



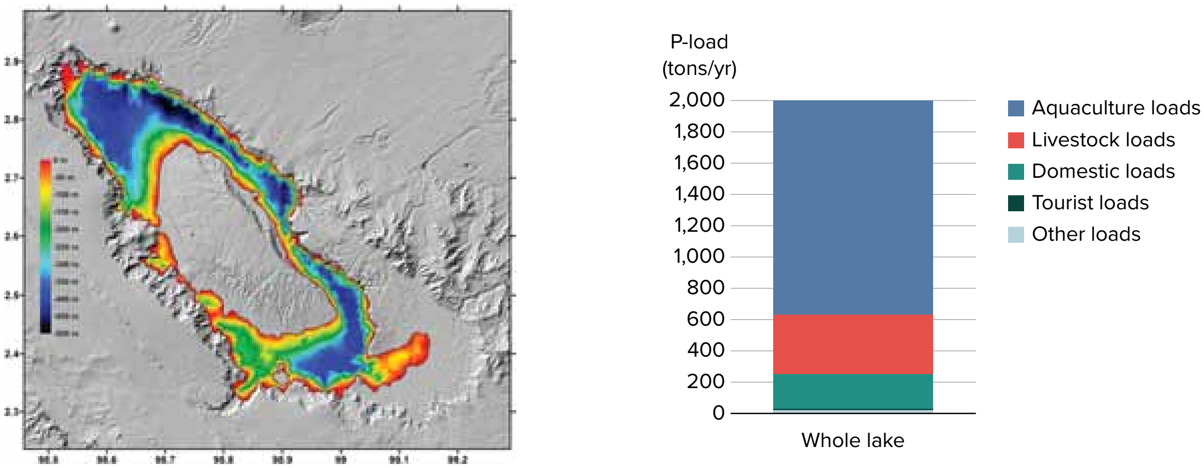
Nitrogen loads in 4 compartments: 1 north, and 3 in the south (S1, S2 and S3)



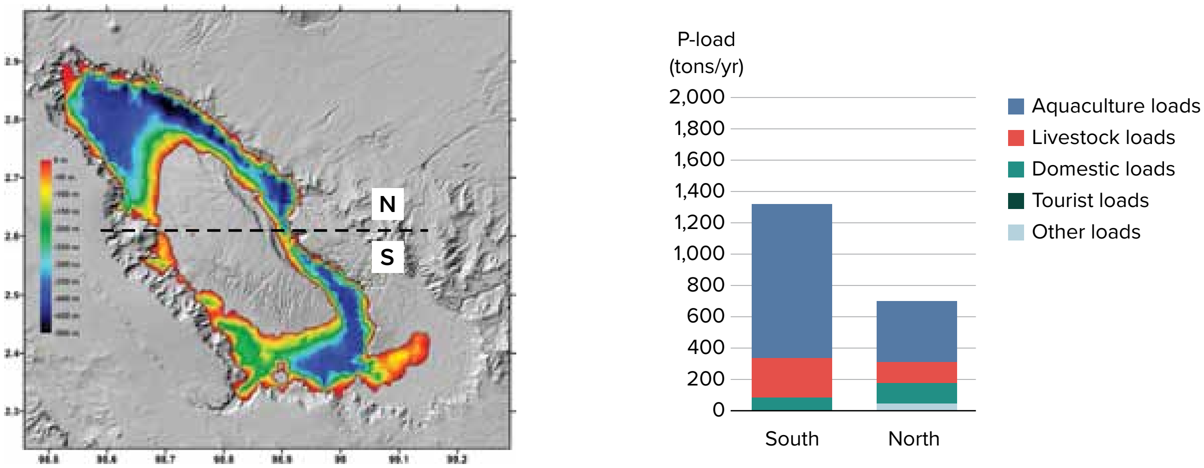
Source: Load calculations based on land use and underlying SSM model.

FIGURE 28. Relative contributions of total phosphorous load across compartments and source in 2015

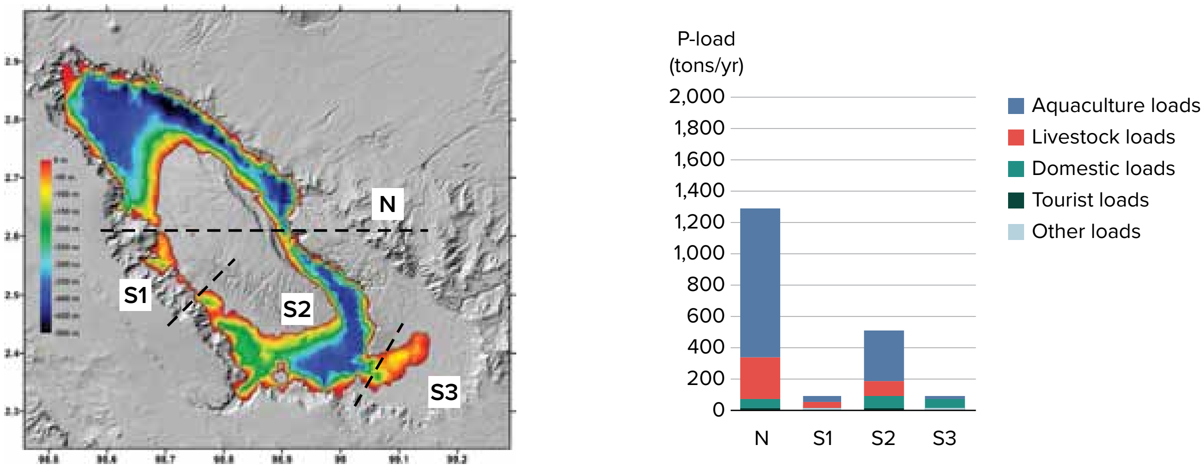
Phosphorous loads in 1 compartment



Phosphorous loads in 2 compartments

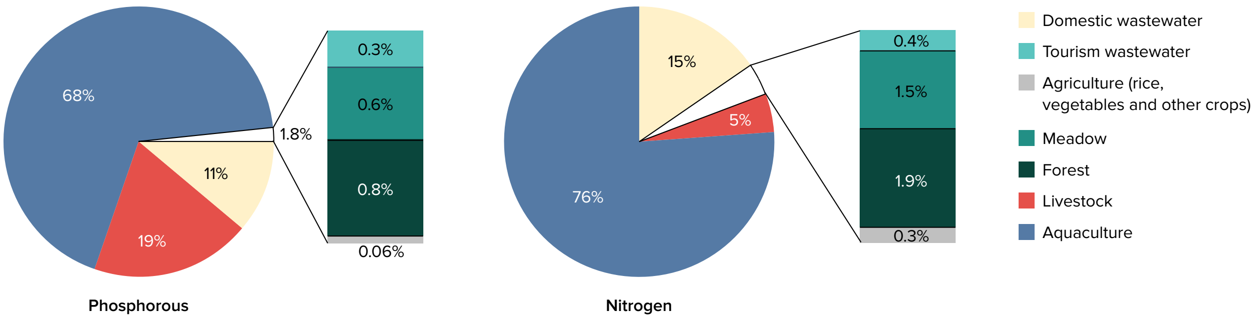


Phosphorous loads in 4 compartments: 1 north, and 3 in the south (S1, S2 and S3)



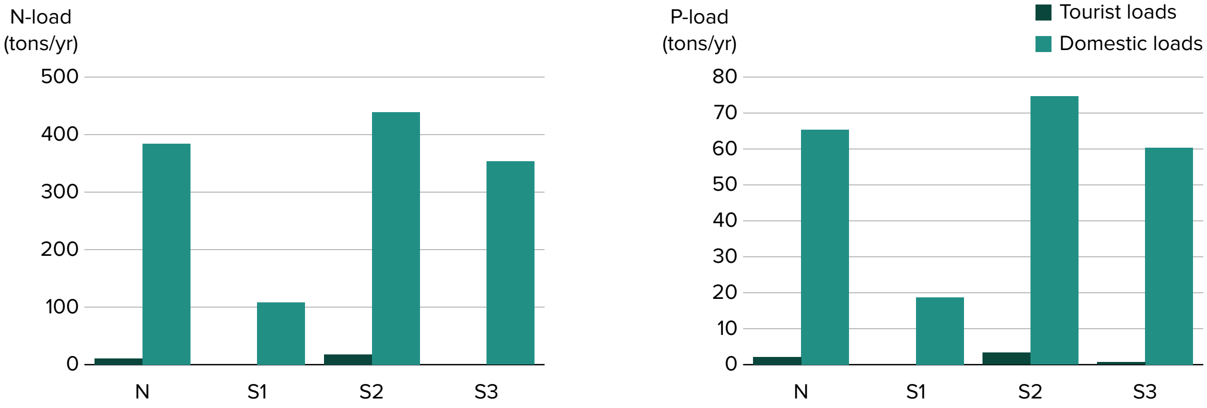
Source: Load calculations based on land use and underlying SSM model.

FIGURE 29. **Relative contributions of total phosphorus (left) and total nitrogen (right) loads into Lake Toba in 2015**



Source: Results from Deltares water quality model for calculating nutrient loads.

FIGURE 30. **Relative contributions of resident wastewater (domestic loads) and tourists (tourist loads) for nitrogen (left) and phosphorous (right) in four compartments of Lake Toba**



Phosphorous Loading

Phosphorous loading is the most critical factor in the nutrient load pathways in Lake Toba. Different carrying capacity studies for Lake Toba have been summarized by the Provincial Environmental Agency of North Sumatra (DLH-SU).[103] Although other parameters are important, interventions proposed in the model focus on phosphorous as the main determinant for eutrophication. The phosphorous loads per source and year are shown in Figure 31. Other parameters and chemicals also cause eutrophication and can have serious local impacts on human health and the environment, such as biochemical oxygen demand, inorganic compounds, pesticides, and pathogens.[104]

The rate of daily phosphorous contribution from aquaculture doubled between 2012 and 2016. The nutrient load from livestock[105] increased by approximately 25 percent, while minimal changes occurred in the domestic wastewater pollution load in the same period. Nutrient inflows from agriculture, forest areas, or erosion are relatively immaterial for eutrophication in the model and thus have not elaborated in detail.

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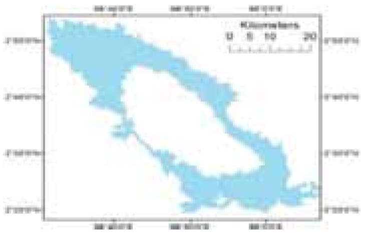
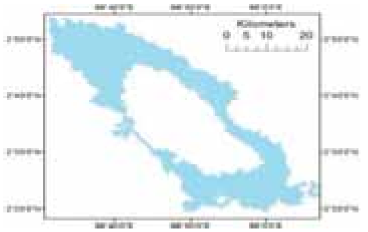
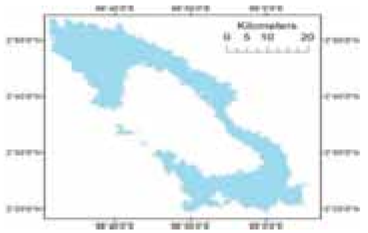
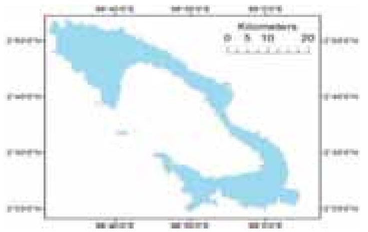
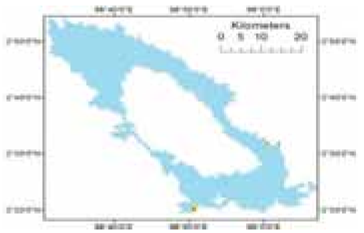
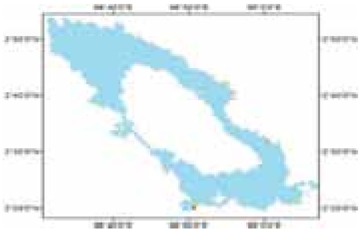
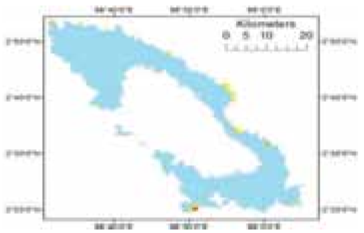
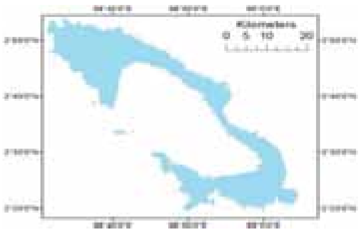
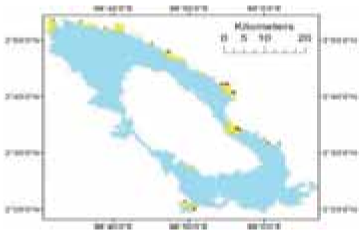
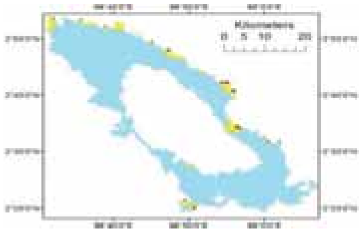
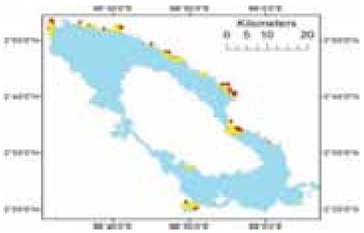
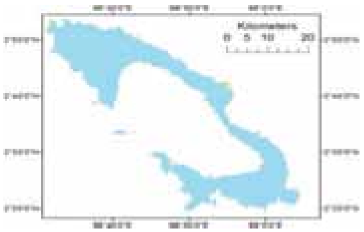
[103] DLH-SU, 2017.

[104] Close monitoring of non-nitrogen and phosphorous parameters are recommended, and subsequent studies on water quality in Lake Toba could consider these in greater detail.

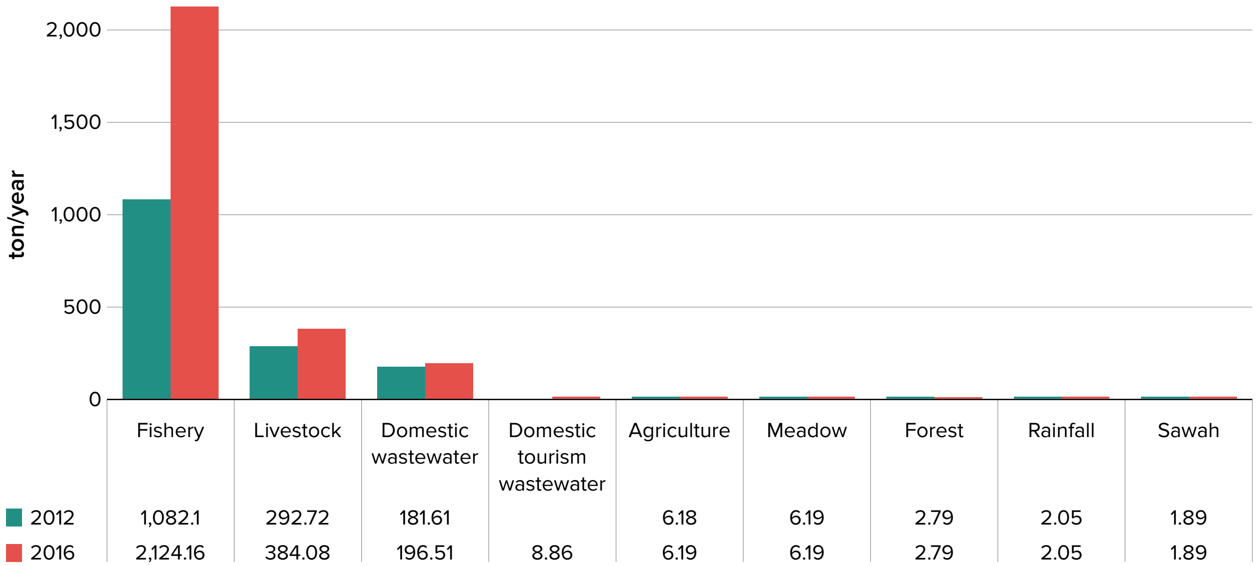
[105] Taken as three times the phosphorous load based on Buckley and Makortoff, 2004.

TABLE 16. Short-term and near-field effects of nutrient loads resulting from aquaculture at various depths

Density of fish cages	Depth			
	1m	2m	10–15m	40–50m
0 cages/segment				
20 cages/segment				
100 cages/segment				
Each segment (pixel) is 250 × 250 m	🟦 Oligotrophic 🟨 Mesotrophic	🟥 Eutrophic 🟫 Eutrophic	⬛ Hyper-eutrophic	

Source: Figure provided as is by LIPI.

FIGURE 31. **Phosphorous loads to Lake Toba in tons per source and year (2012 and 2016)**



	Fishery	Livestock	Domestic wastewater	Domestic tourism wastewater	Agriculture	Meadow	Forest	Rainfall	Sawah
🟩 2012	1,082.1	292.72	181.61		6.18	6.19	2.79	2.05	1.89
🟥 2016	2,124.16	384.08	196.51	8.86	6.19	6.19	2.79	2.05	1.89

Source: DLH-SU, 2017.

CHAPTER 5

State and Impact: Lake Assessment

The state of Lake Toba and the impact of nutrient loading were assessed based on the key pressures and drivers. A water quality system analysis was performed using existing data on: basin hydrology,[106] water quality data,[107] point and nonpoint sources of pollution and their emissions estimates, load calculations, and nutrient concentrations. The assessment focuses on the primary pollution related to eutrophication, specifically nitrogen and phosphorous loads.[108]

Data quality depends on the consistency and adequacy of laboratories used for water quality monitoring, allowing for the necessary comparison over time. Information on quality control, however, was only available from the literature and interviews. The Indonesian Institute of Sciences (LIPi) and Provincial Environmental Agency of North Sumatra (DLH-SU) use government labs and perform regular quality tests of their equipment. PT Aquafarm Nusantara (PTAN) uses its own on-site laboratory.

Physical and Chemical Parameters

The major water quality variables and their development between 2006 and 2017 were reviewed. The primary data source was PTAN as it had the highest sampling frequency. Supplemental data from DLH-SU and LIPI were also included. In addition, multispectral remote sensing[109] using publicly available earth-observation data (Table 17) was analyzed to provide additional insights into the water quality dynamics (illustrated in Figure 32). This included a time-series estimate of turbidity, chlorophyll a, and vegetative cover;[110] long-term changes in water quality[111] across the lake and specific changes in land-use in the Aek Manira watershed; and an assessment of discrete historical events aimed at illustrating the potential application of remote sensing techniques as part of the strategy for improving water quality monitoring.

Temperature

Water temperatures vary between 25°C and 28°C and have been stable overall between 2006 and 2017 (Figure 33, Figure 34, and Figure 35). A minor increase was, however, recorded at the beginning of 2016 when surface water temperatures peaked above 28°C. Temperature determines the depth of the thermocline, in turn setting the boundary conditions that separate the epilimnion and hypolimnion.

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[106] Hydrology of the Lake Toba basin as modelled in the Basin Water Resources Management Plan (BWRMP) project (Vernimmen, 2015).

[107] In collaboration with LIPI, DLH-SU, and PTAN.

[108] See discussion on biochemical processes in Lake Toba for rationale behind the focus on nitrogen and phosphorous.

[109] Multiple sensors are needed since temporal coverage is limited by atmospheric conditions and overpass schedule (LS8/S2A 'land' sensors: 5 ~ 10 days; S3A: ~1 day but lower spatial resolution).

[110] From Sentinel-2A, Landsat-8, MERIS, MODIS, Landsat-5/7.

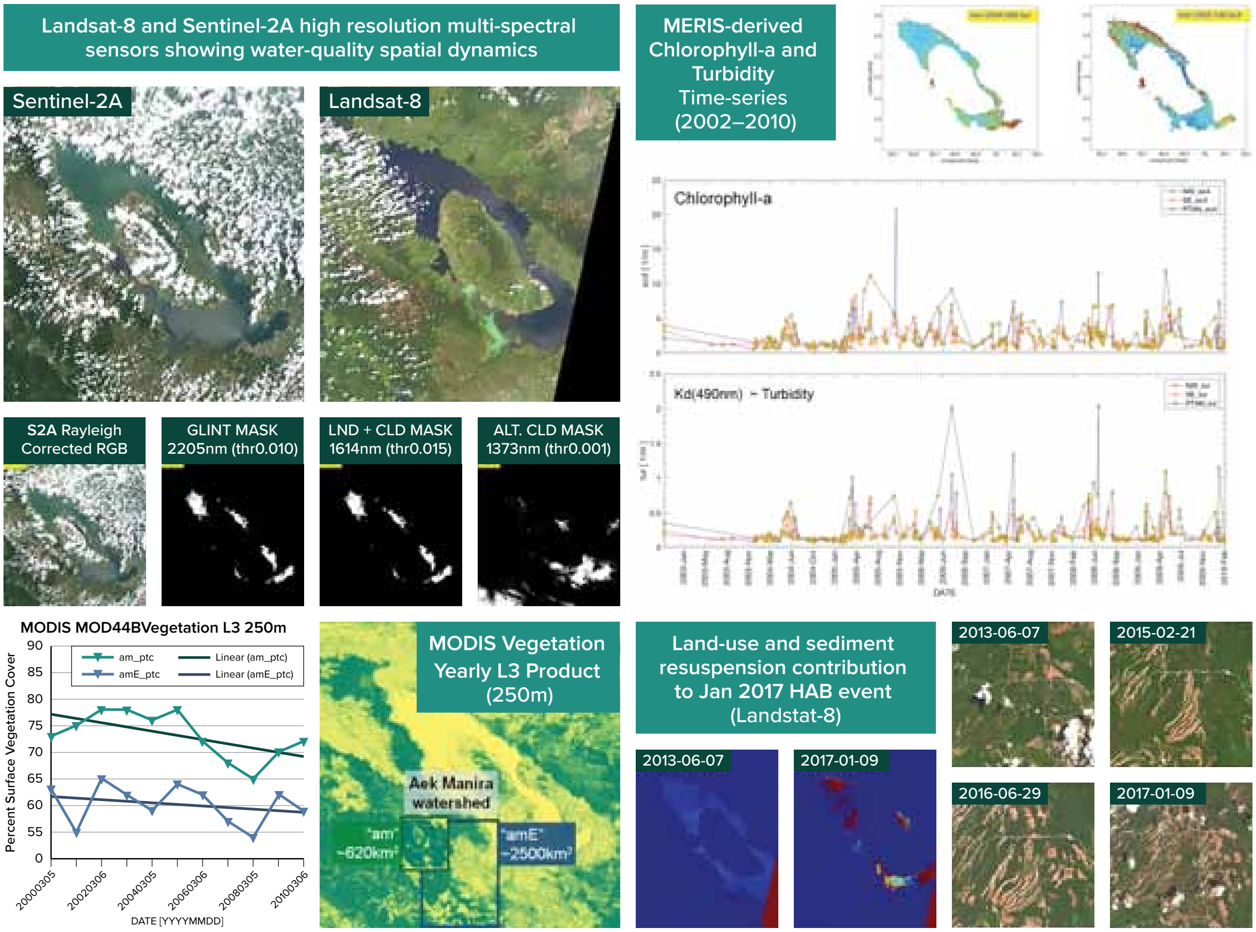
[111] MERIS time series ~2006.

TABLE 17. High-resolution multispectral instruments supplemented with other atmospheric/land/ocean color missions used in the water quality analysis

Satellite	Agency	Temporal coverage	Revisit frequency (1/day)	Resolution (m)	Notes
Landsat-8 (OLI)	USGS/NASA	2013–present	~1/16	30	Pan~15 m
Sentinel-2A (MSI)	ESA	2015–present	~1/10	10	
Sentinel-2B (MSI)	ESA	2017–present	~1/10	10	2A+2B~5days
Envisat (MERIS)	ESA	2002–2012	~3	300	
Sentinel-3A (OLCI)	ESA	2016–present	~2	300	3A+3B~1 day
EOS Aqua/Terra (MODIS)	NASA	2000–present (T) 2002–present (A)	1~2	250~500	3 hrs offset
SNPP-JPSS (VIIRS)	NOAA/NASA	2015–present	~1	~375	
Himawari-8 (AHI)	JAXA	2015–present	~60 (10 mins)	~1000	Geostationary

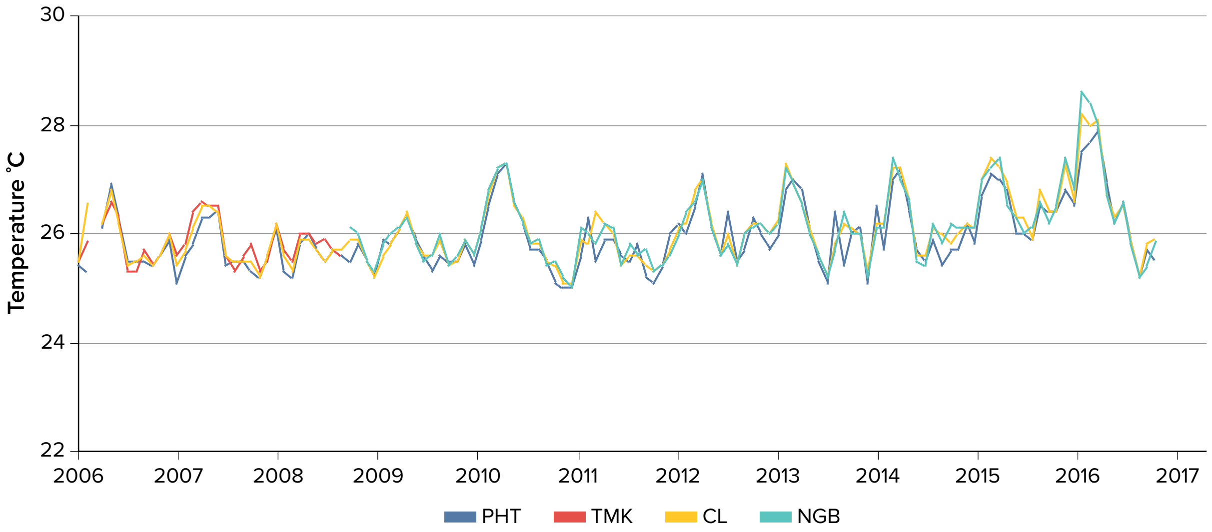
Note: Satellites in pink shade indicate sensors for which atmospheric and Rayleigh corrected images and movies were produced; yellow shades indicate sensors for which top of the atmosphere images and movies of example dates were produced.

FIGURE 32. Combination of sensors and analysis illustrated to gain detailed insights on water quality dynamics



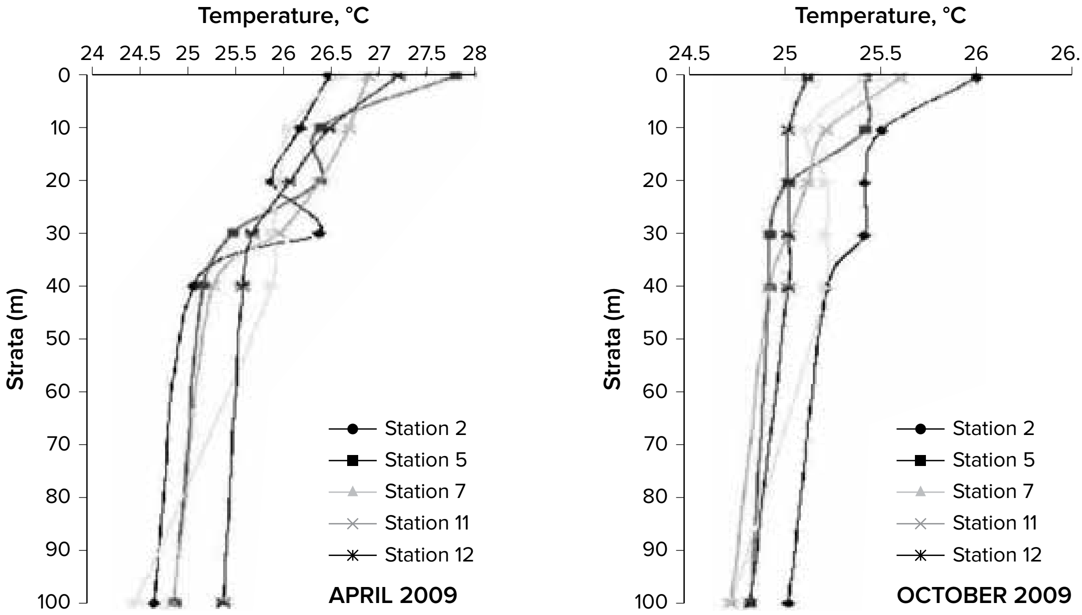
Source: USGS/NASA Landsat-8, 2017; Badan Informasi Geospasial 2013, Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGA, AeroGRID and IGN.

FIGURE 33. Temperature measured at 2 meters depth at the four PTAN monitoring locations 2006 to 2017 (°C)



Source: PTAN, 2017.
Note: The locations are PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

FIGURE 34. Temperatures measured in April and October 2009 along a depth profile of 100 meters

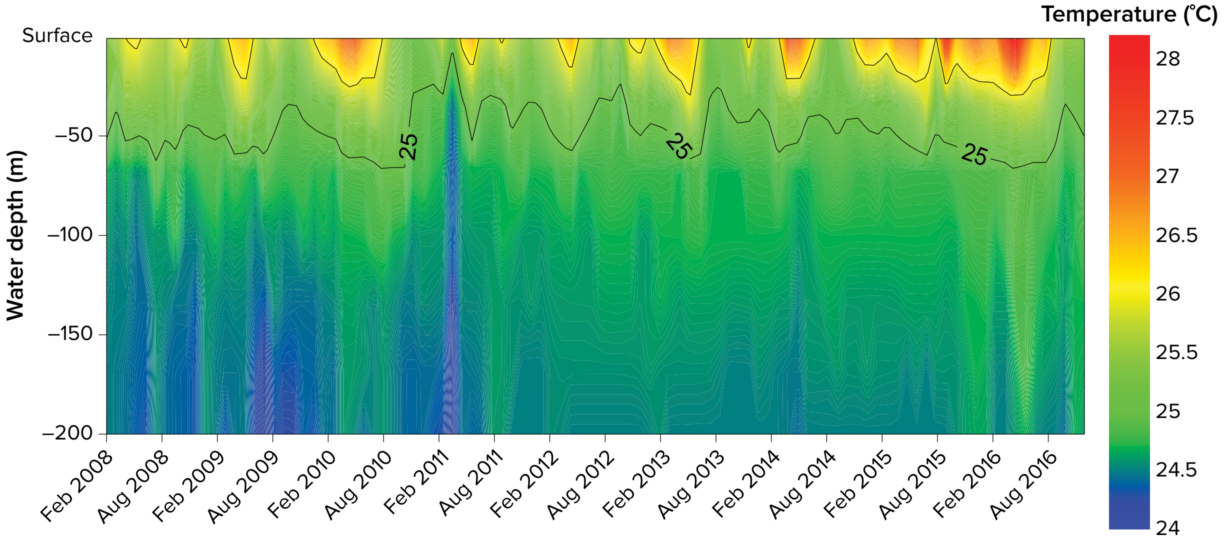


Source: Recorded data at LIPI stations 2, 5, 7, 11, and 12 in 2009. Lukman and Ridwansyah, 2010.

Dissolved oxygen

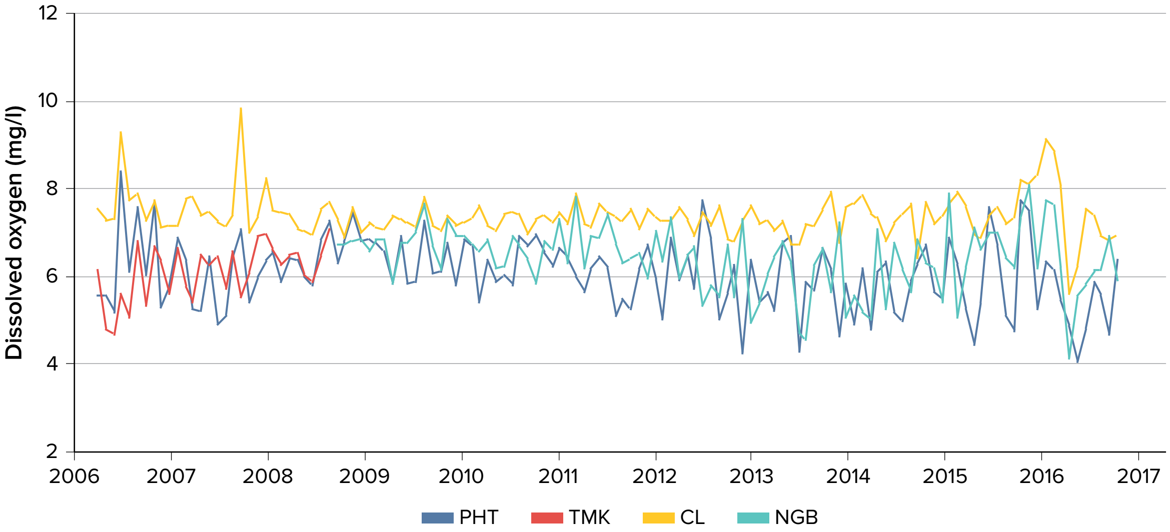
Stations near fish farms have lower dissolved oxygen (DO) which fluctuates more within and between years compared to samples at the control reference location in the lake (Figure 36). Importantly, changes in dissolved oxygen can be an indicator and/or result of eutrophication (i.e., the buildup of nutrients in the water body) rather than a driver of eutrophication. Control measurements show a peak in DO in 2006, 2007, and again in 2016. Otherwise DO values are stable. DO values decline steadily as depth increases and then even out after 200 meter depths (Figure 37). The LIPI depth profile measurements of DO are similar to the PTAN values (Figure 38).

FIGURE 35. Temperature dynamics along depth profiles sampled monthly 2008 to 2016 at field station Pangambatan (meters below surface)



Source: PTAN, 2017.

FIGURE 36. Dissolved oxygen measured at 2 meters depth at four PTAN locations 2006 to 2017 (mg/l)[112]



Source: PTAN, 2017.
Note: The locations are PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

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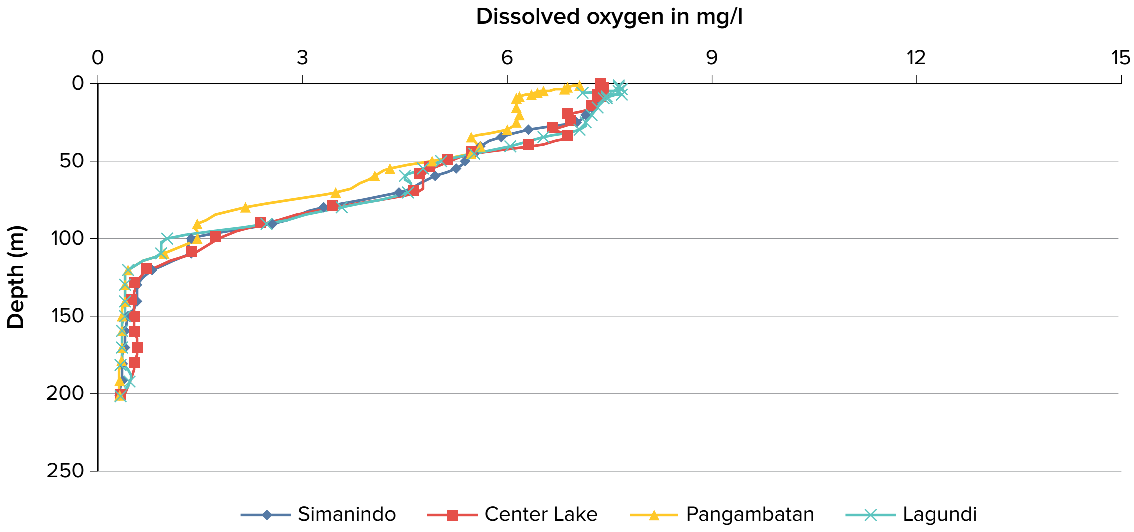
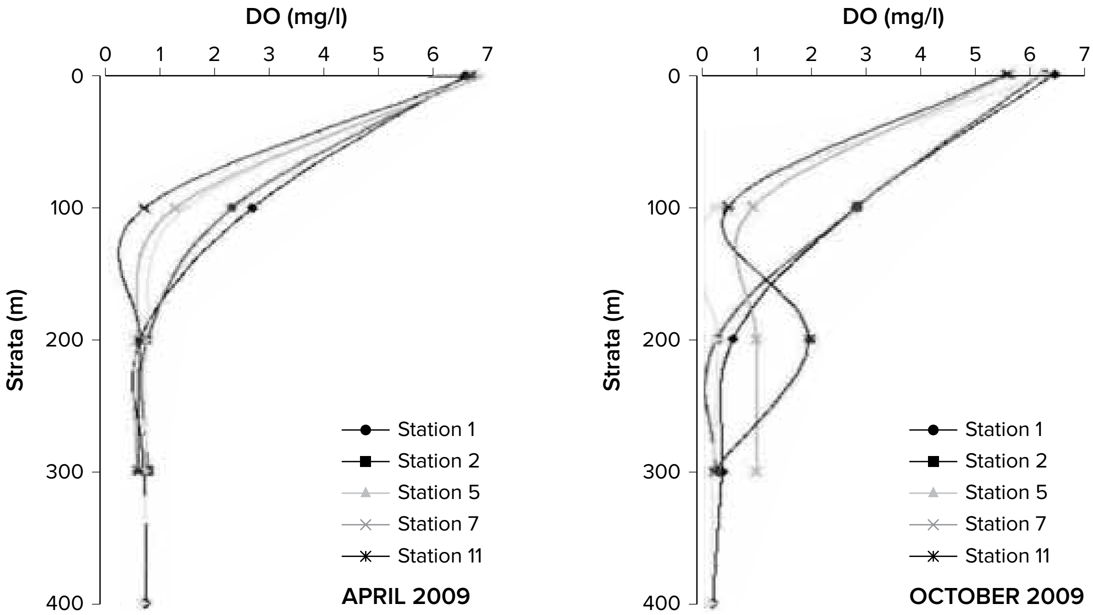
112 Milligrams per liter.

FIGURE 37. Dissolved oxygen profiles measured at the PTAN locations (mg/l)



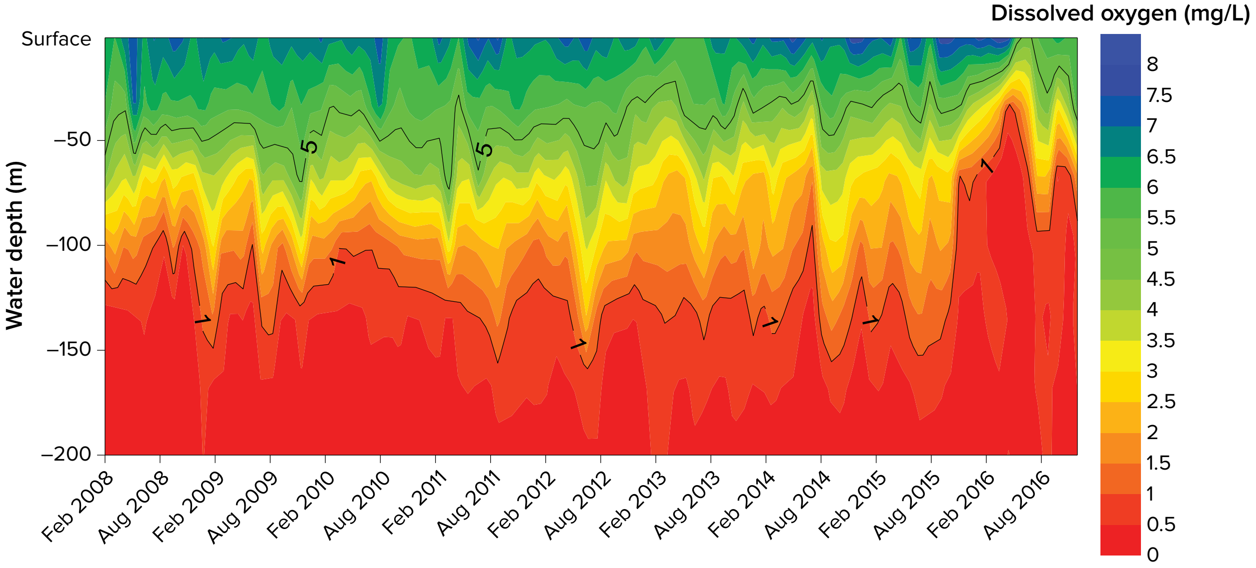
Source: Beijer, 2017.

FIGURE 38. Dissolved oxygen along a depth profile of 400 meters (mg/l)



Source: Recorded data at LIPI stations 2, 5, 7, 11, and 12 in April (left) and October (right) 2009. Lukman and Ridwansyah, 2010.
Note: The anomaly in October at 200 meters depth could be caused by local thermal vents or measurement error.

FIGURE 39. Oxygen dynamics along depth profiles sampled monthly 2008 to 2016 at Pangambatan (meters below surface)

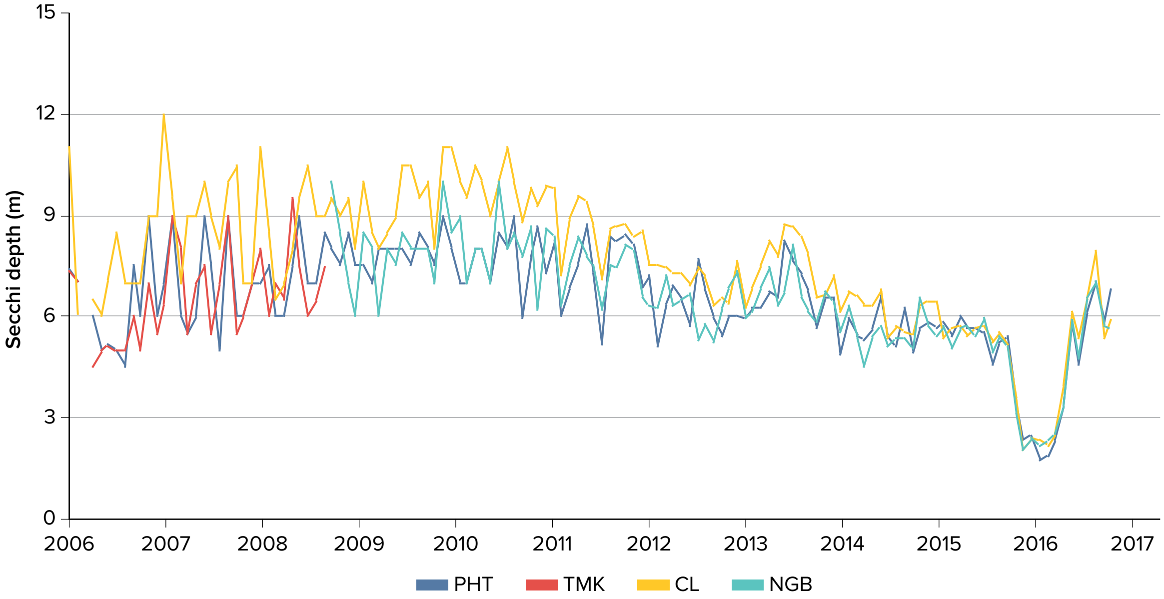


Source: PTAN, 2017.

Transparency

The transparency of the lake's water remains an average 6 meters—but a drastic drop in visibility is recorded in 2016. The depth of visibility and transparency in Lake Toba is measured through visible depth using a Secchi-dish and consistently averages 6 meters. This corresponds to the definition of ultra-oligotrophic lake conditions according to the classification of Chapman (1996). As shown in Figure 40, the transparency depth at the control station is deeper, which is to be expected at deeper lake locations. The recordings of visibility above 10 meters is rare (i.e., above what is acceptable for Aquaculture Stewardship Council certification).

FIGURE 40. Secchi depth measured at the four PTAN locations 2006 to 2017 (meters)



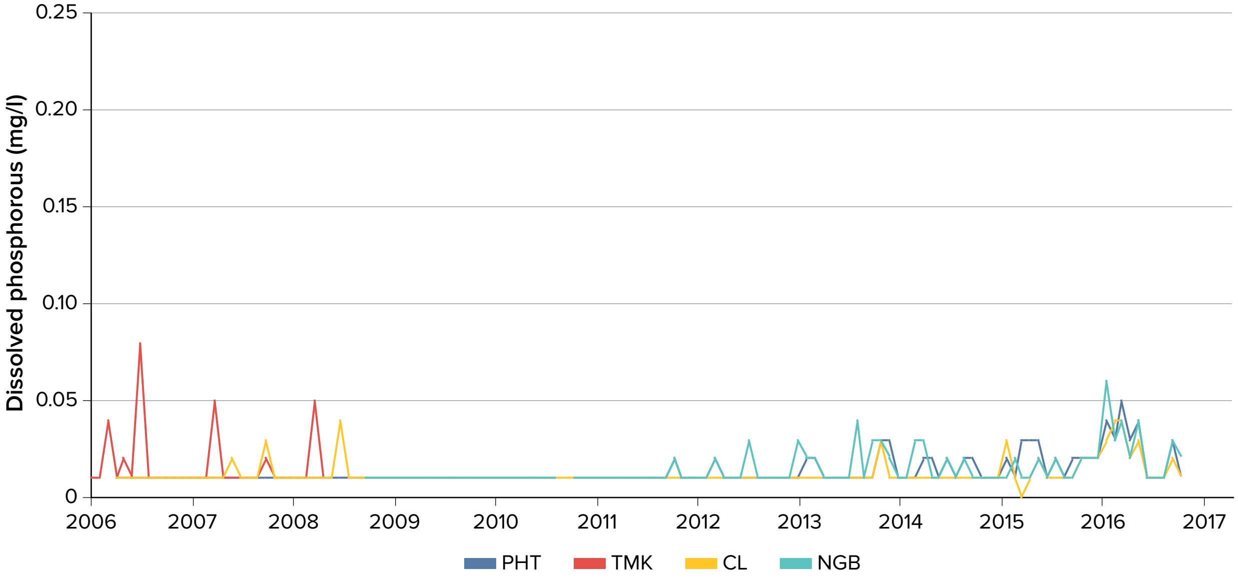
Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

Nutrients

Phosphorous

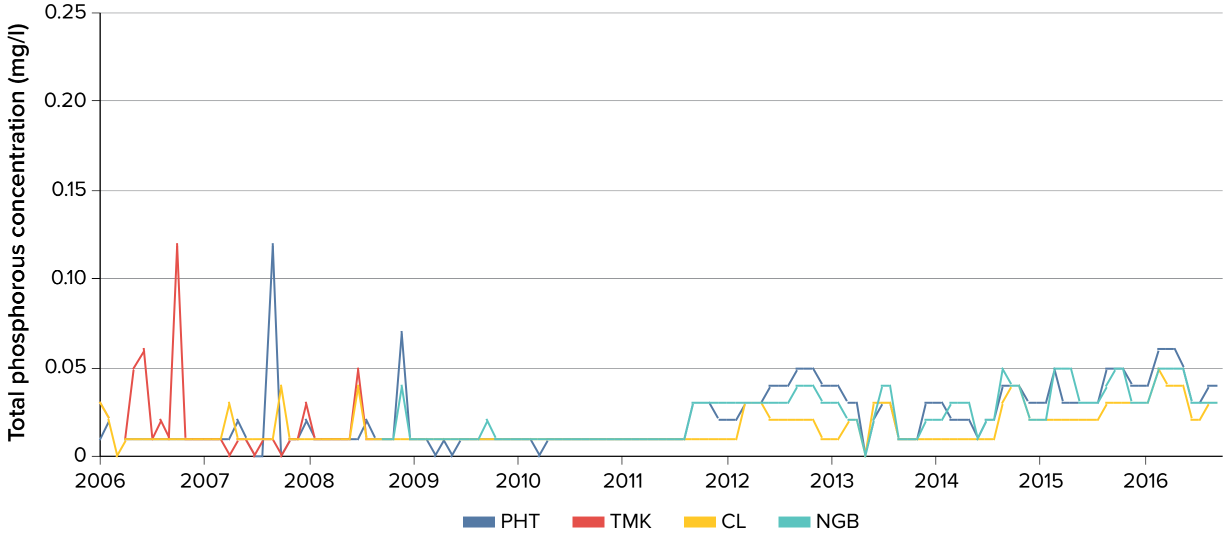
After a period of low concentrations, phosphorous concentrations rise after 2012 and peak in 2016 (Figure 41). After measurements started in 2006, phosphorous concentrations were on average low, around 0.01 mg/l. The 2016 anomaly matches those of other parameters. Temporal variation in total phosphorous is higher than the spatial variation. The average measurements per moment were taken and plotted over time (Figure 43) showing that concentrations are mainly below 0.04 mg/l. The DLH-SU data, however, show an additional peak in 2014 at which moment they reach levels higher than those in the PTAN data (Figure 42). The trophic conditions of the measuring locations are oligotrophic between 2008 and 2012 and mesotrophic between 2012 and 2016.

FIGURE 41. Dissolved phosphorous concentration at the four PTAN locations 2006 to 2017 (mg/l)



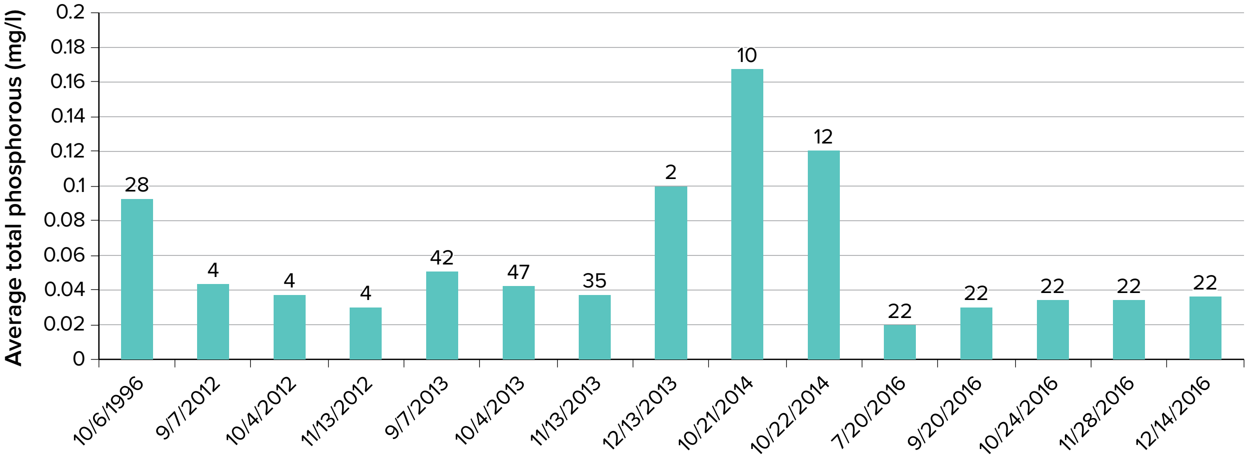
Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

FIGURE 42. Total phosphorous concentration measured at the four PTAN locations 2006 to 2017 (mg/l)



Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

FIGURE 43. **Total phosphorous averaged over all DLU-SU sampling locations in 1996, 2012, 2013, 2014, and 2016**

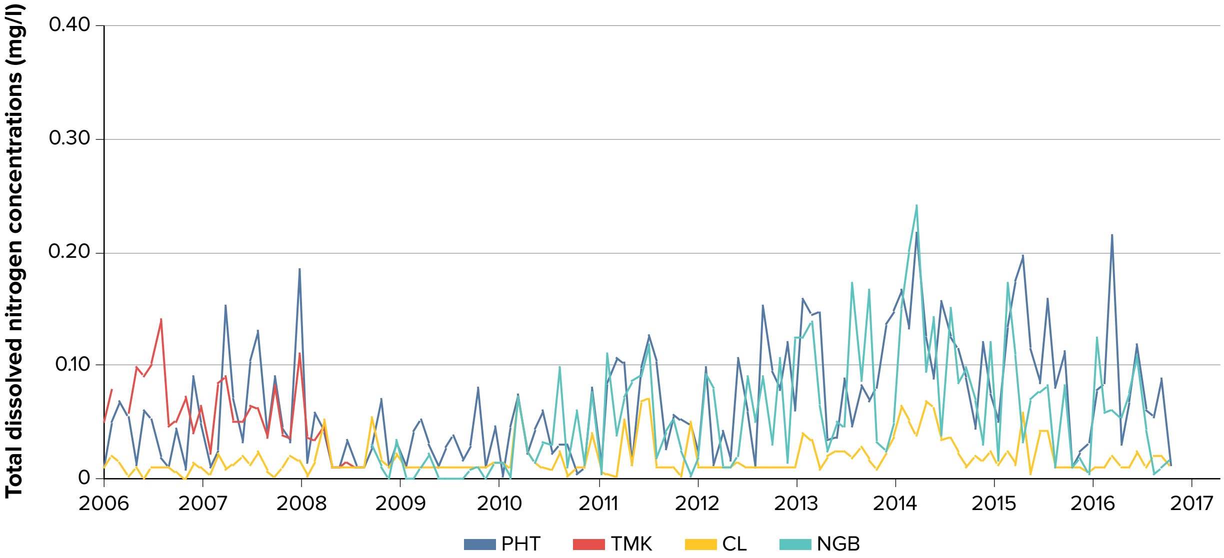


Note: Numbers at the top of each bar indicate the number of locations sampled.
Source: DLU-SU, 2017.

Nitrogen

Total nitrogen values are relatively constant at PTAN's control station and lower than at their fish farm stations, besides minor peaks (Figure 44). Total nitrogen values are lowest between 2009 and 2014, and measured total nitrogen concentrations do not differ between PTAN's control and fish farm monitoring sites. A study conducted by LIPI in 2013 at 19 sampling sites showed that total nitrogen varied between 0.075 and 0.374 mg/l and were on average lower than measurements in their earlier 2010 study. The measured total nitrogen concentrations at the field stations correspond to oligotrophic conditions, as they are mostly below the most conservative threshold of 350 µg/l,[113] and only very occasionally exceed the most lenient threshold of 650 µg/l (Figure 45).

FIGURE 44. **Total dissolved nitrogen concentrations measured at the four PTAN locations 2006 to 2017 (mg/l)**



Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

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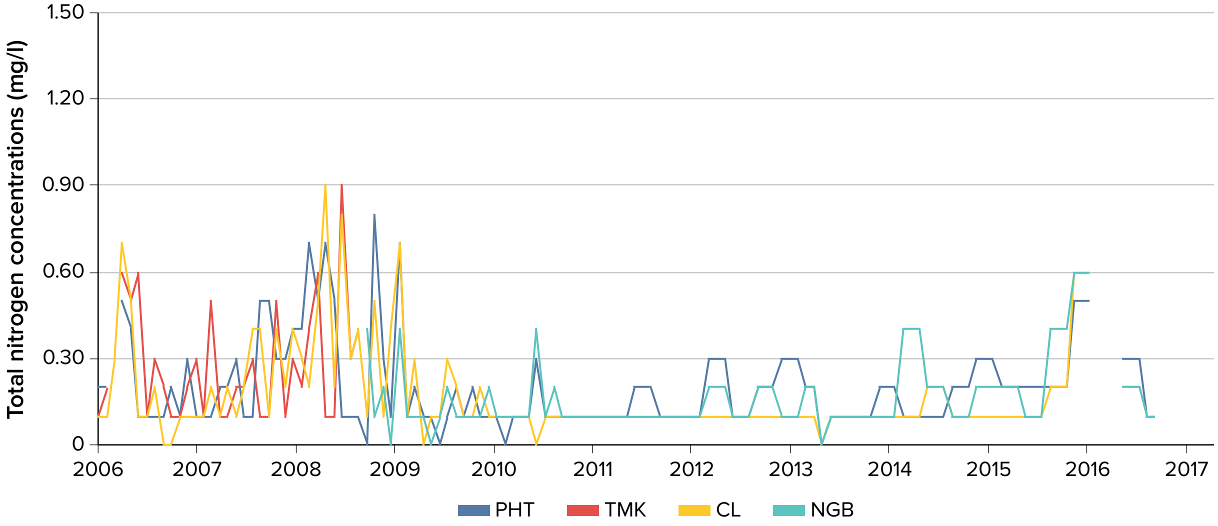
[113] Micrograms per liter; KLH, 2009.

FIGURE 45. Total nitrogen concentrations measured at the four PTAN locations 2006 to 2017 (mg/l)



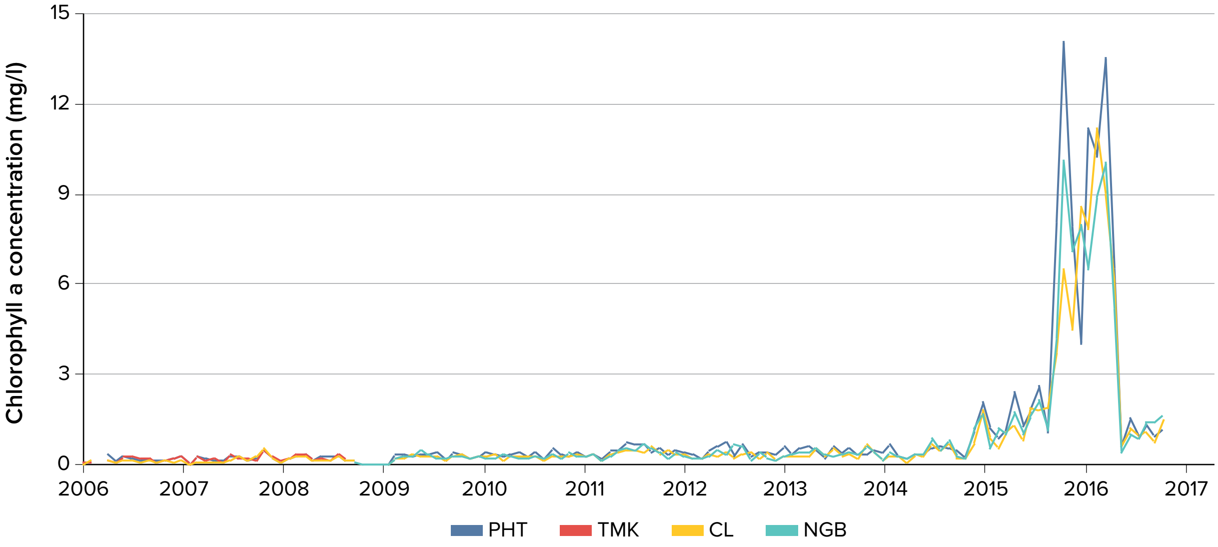
Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

Organic Content

Chlorophyll a values show little difference between stations with a sudden peak in 2016. Chlorophyll a concentration and dry weight show similar trends at all stations (Figure 46 and Figure 47). Dry weight values for the control station, however, are lower compared to fish farm stations. The chlorophyll a concentrations are within the thresholds of ultra-oligotrophic lakes until the end of 2014. Between February and August 2016, chlorophyll a concentrations rose to 12 µg/l and the lake became mesotrophic.

The remote sensing time series from MERIS (satellite instrument scanning the earth's surface[114]) shows evidence of natural and human-induced eutrophication. MERIS data show that chlorophyll a concentrations doubled since 2006 with a corresponding two-fold increase in light attenuation (i.e., a reduction of light intensity caused by an increase in

FIGURE 46. Chlorophyll a concentration measured at the four PTAN locations 2006 to 2017 (mg/l)



Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

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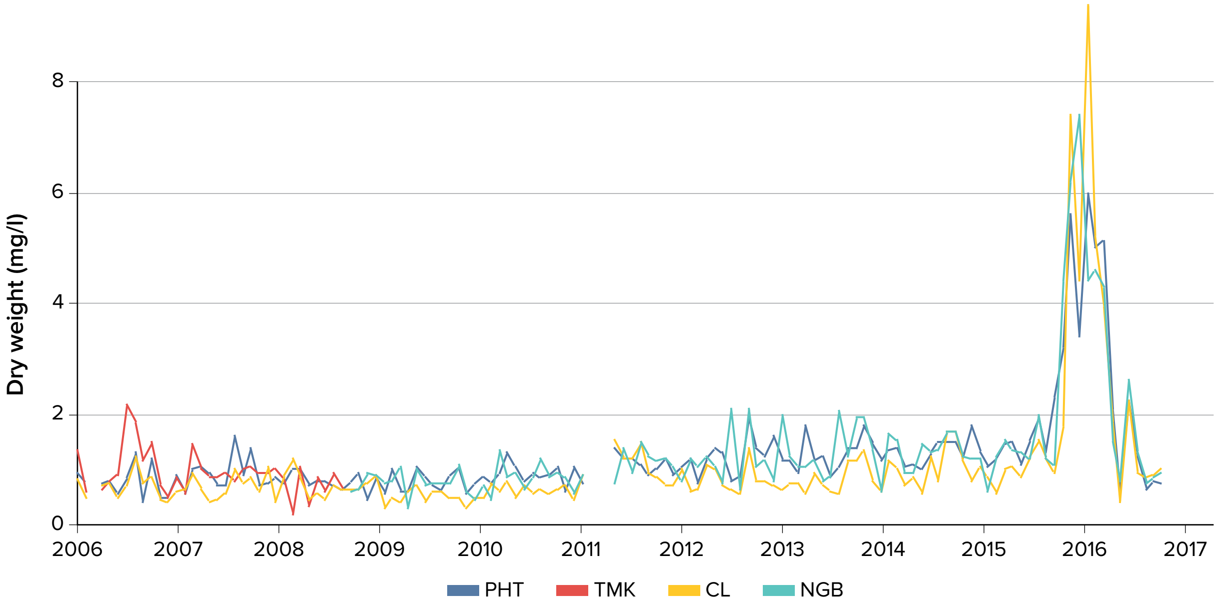
[114] MERIS is a "programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range." European Space Agency, 2018.

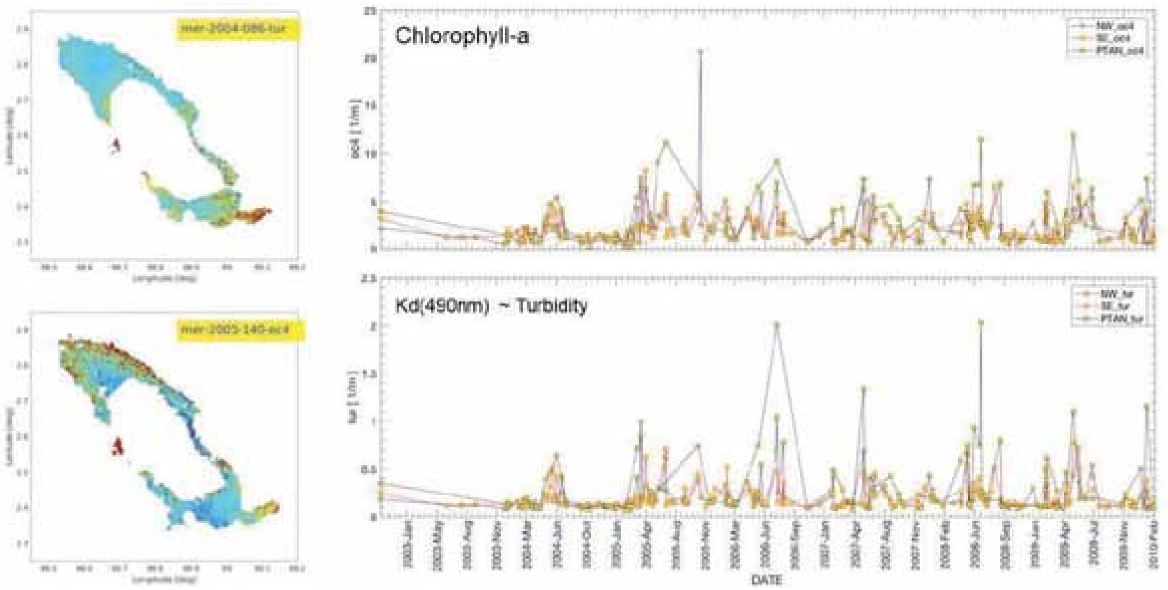
particulate matter, also referred to as turbidity).[115] Maximum biological productivity, as determined by concentrations of chlorophyll a, is even higher at certain locations. Supplemental remote sensing data show a significant increase in spatial and temporal variability in both chlorophyll a and turbidity (Figure 48).[116]

FIGURE 47. Dry weight measured at the four PTAN locations 2006 to 2017 (mg/l)



Source: PTAN, 2017.
Note: PHT = Panahatan, TMK = Tomok (closed 2008), NGB = Pangambatan, and CL = Control Location.

FIGURE 48. MERIS images and time series of turbidity and chlorophyll a for different parts of Lake Toba



Source: NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Medium Resolution Imaging Spectrometer (MERIS) L1B FRS Data; NASA OB. DAAC, Greenbelt, MD, USA. Accessed in Q3 2017; processed using Sentinels Applications Platform (SNAP) [Software, v5.0] (2017): http://step.esa.int/main/toolboxes/snap/

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[115] An approximately two-fold increase in regionally-averaged chlorophyll a from 1 ~ 2 mg/m^3 to 2 ~ 6 mg/m^3 and corresponding two-fold increase in light attenuation at 490 nm (turbidity) were observed. Mesotrophic to eutrophic lake conditions with chlorophyll-a concentrations of 4 ~ 30 mg/m^3 were also derived from Landsat-8/Sentinel-2A imagery with complex local variability.

[116] To improve the quality of data retrievals, cloud-glint data masking refinements and further regional tuning are required. Additionally, the long-term MERIS time series and imagery as well as high-resolution (Sentinel-2A/Landsat-8) imagery show a significant increase in variability (temporal and spatial) for both chlorophyll a and turbidity.

Thermocline Depth

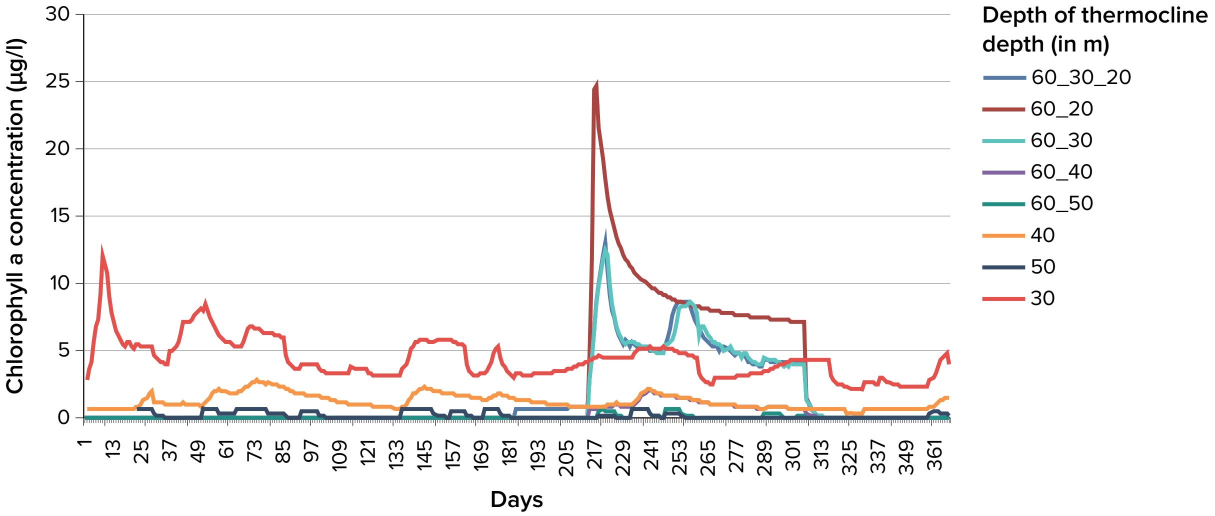
The thermocline depth determines the volume over which the incoming nutrients are diluted. Deeper thermoclines mean that concentrations may be lower as dilution occurs in a larger volume of water. Thermoclines therefore act to regulate algae blooms. The relation between thermocline depth (as modelled for Lake Toba)[117] and chlorophyll a concentration is shown in Figure 49. The different lines correspond to different thermocline depths or sequences thereof.[118]

The results of the model show that maximum chlorophyll a concentrations depend on whether the thermocline depth is assumed to occur instantly or whether it is achieved stepwise in time. This is because algal growth and sedimentation may affect the loss of nutrients from the surface layer (epilimnion) and therefore change the nutrient availability over time.

The model suggests that the default thermocline depth in Lake Toba occurs at around 50 meters. At this depth, the modelled chlorophyll a concentrations best match the observed chlorophyll a concentrations (Figure 46). The 50 meters thermocline depth aligns roughly with observed stratification profiles (Figure 36). A sensitivity analysis of the thermocline depth showed that phosphorous concentrations lowered from about 60 µg/l at the 20 meters thermocline depth to about 20 µg/l at 60 meters.

The thermocline depth in 2016 probably rose to a depth of 30 meters, or in a more stepwise manner to 20 meters. At the shallower thermocline depths, the modelled chlorophyll a matches best with the observed chlorophyll a peak at the time (Figure 46). Note that this change in thermocline depth probably corresponds to a change in, or occurrence of, the secondary thermocline since the observed 25°C level (i.e., primary thermocline) is not shifted to shallower depths (Figure 35).

FIGURE 49. Chlorophyll a concentrations over time when the thermocline depth is assumed to occur instantly or achieved stepwise over time (µg/l/days)



Source: Deltares, 2017.
Note: The purple 60_40 line indicates that the thermocline will occur in two steps: the first step at 40 meters depth and the second at 60 meters depth.

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[117] The depth of the thermocline in Lake Toba was determined with a simple 1Dv Delft3D-WAQ model assuming the mixed layer to be fully mixed and a background extinction rate of 0.4 (which corresponds to a Secchi depth of ~5 m). Also, initial total nitrogen was 0.2 mg/l and total phosphorous was 0.02 mg/l.

[118] 60, 30, and 20 means that the thermocline depth starts at 60 m but is changed at day 211 to 30 m and at day 241 to 20 m.

Hydrothermal Stability and Mixing Events

Mixing events are interlinked with the biogeochemistry of the lake. The observed patterns in the temperature and oxygen profiles at the PTAN sampling site Pangambattan (i.e., narrow passage east of the Samosir peninsula) prompted a brief analysis of the hydrothermal status of the lake. That is, the action of water under conditions of different temperatures. In Figure 50, the white vertical lines represent anoxic conditions (i.e., oxygen depleted waters) occurring at greater depths and the black lines represent anoxic conditions occurring at shallower depths. Anoxic conditions correlate to thermal stratification, meaning that shallow anoxic levels coincide when surface waters are warm, and deeper levels coincide with a period of deeper mixing with cooler surface waters.

The hydrothermal dynamics of Lake Toba were simulated using the Deltares 1DV model[119] with input on meteorological conditions from Sene et al. (1991).[120] The upper panel in Figure 51[121] shows air temperature (black) together with the simulated surface water temperature (red). The middle panel shows wind magnitude with a biannual increase in wind speed. The lower panel shows stratification of water temperatures in the top 100 meters with biannual periods of deeper mixing due to increased wind speed.

The observed patterns of changing water temperatures (Figure 50) suggest biannual mixing and re-stratification events in the upper 10 to 20 meters, driven by monsoon winds and occurring in most years. These mixing events do not create deep mixing (i.e., surface water is not mixed downward beyond 50 meter depth). It appears therefore, that Lake Toba develops a warmer top layer of marginal stability.

The absence of deeper mixing creates enduring anoxic conditions beyond 150 meter depths. In periods of thermal stratification with warm surface water, the upper level of anoxic water rises to shallower depths (shown by the black lines in Figure 50). This does not appear to be caused by strong upwelling events.[122] Instead, these are interpreted as oxygen-rich water being mixed downward from the water surface, or oxygen-depleted water being created in the absence of vertical mixing given that some oxygen is consumed. In periods of deep mixing with cooler surface water, the upper boundary of anoxic water descends to greater depths (white lines in Figure 50).

Infrequent upwelling events are the likely cause behind instances of deep cooler waters (i.e., the 24°C shown in blue in Figure 50). The cooler waters do not extend to the surface in the observed period. The upwelling events potentially originate from the deeper parts of Lake Toba, bringing cooler water into the narrow passage east of the Samosir peninsula. The cause of the upwelling events could not be explained by downward mixing of water or internal seiches.[123] Possible causes include: rare stormy events elsewhere in Lake Toba creating very deep mixing beyond 200 meter depths, cooler river inflow that sinks to greater depths, and/or subaquatic sources of cooler water.[124]

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[119] Based on the same methodology as the 3D hydrodynamic and transport code Delft3D-FLOW of Deltares (Deltares, 2014).

[120] Sene et al. (1991) provide insight into the typical conditions for wind, air temperature, and humidity over a short period of 42 days in January and February 1989 near Pulo Tao island (1 km north of Samosir, the large central peninsula). From this reference, meteorological observations in the period 2003–2010 were adjusted and the air temperature was reduced by 3°C accordingly.

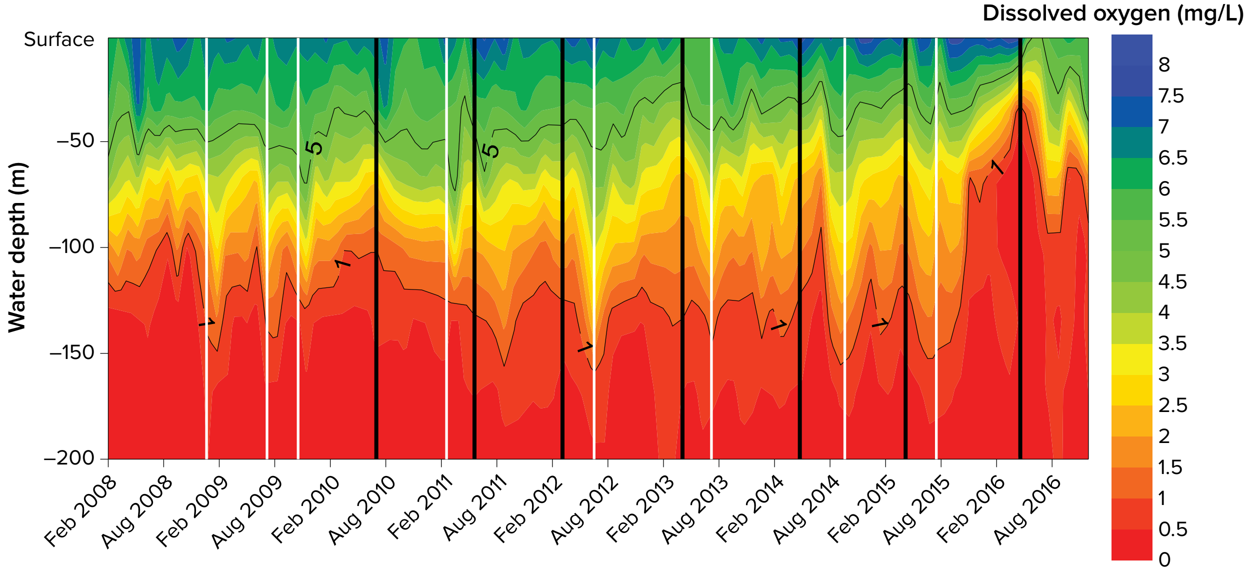
[121] There is little available published information on the hydrothermal dynamics and meteorological conditions of Lake Toba.

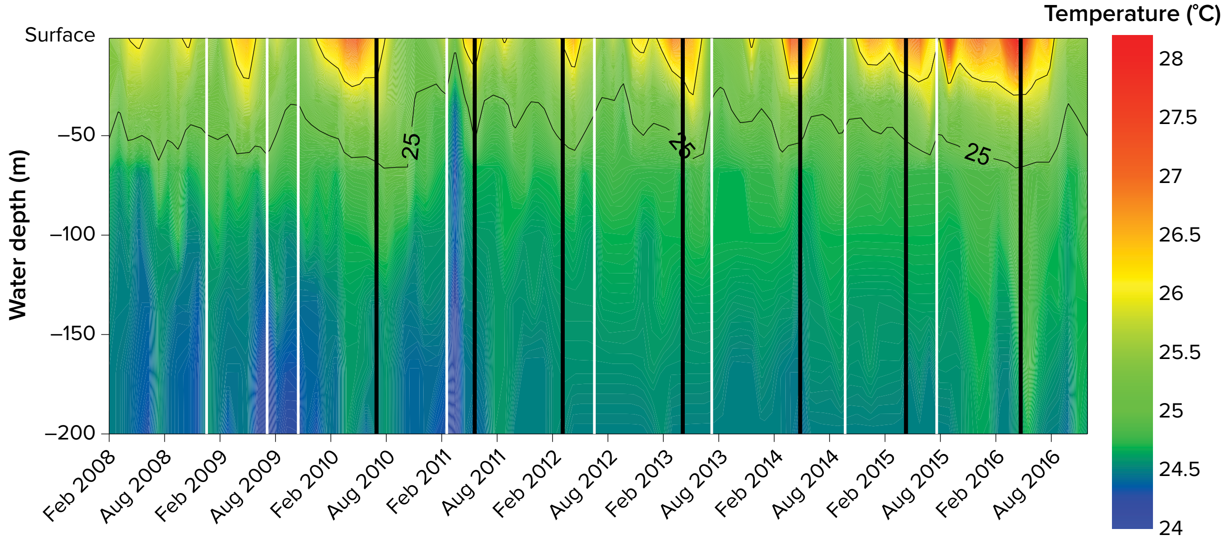
[122] Since the observed 25°C level is not equally shifted upward with the dissolved oxygen isoline.

[123] A standing wave that oscillates in time, but its peak amplitude profile does not move in space.

[124] Such as are present in Lake Kivu, Rwanda (Ross et al., 2015).

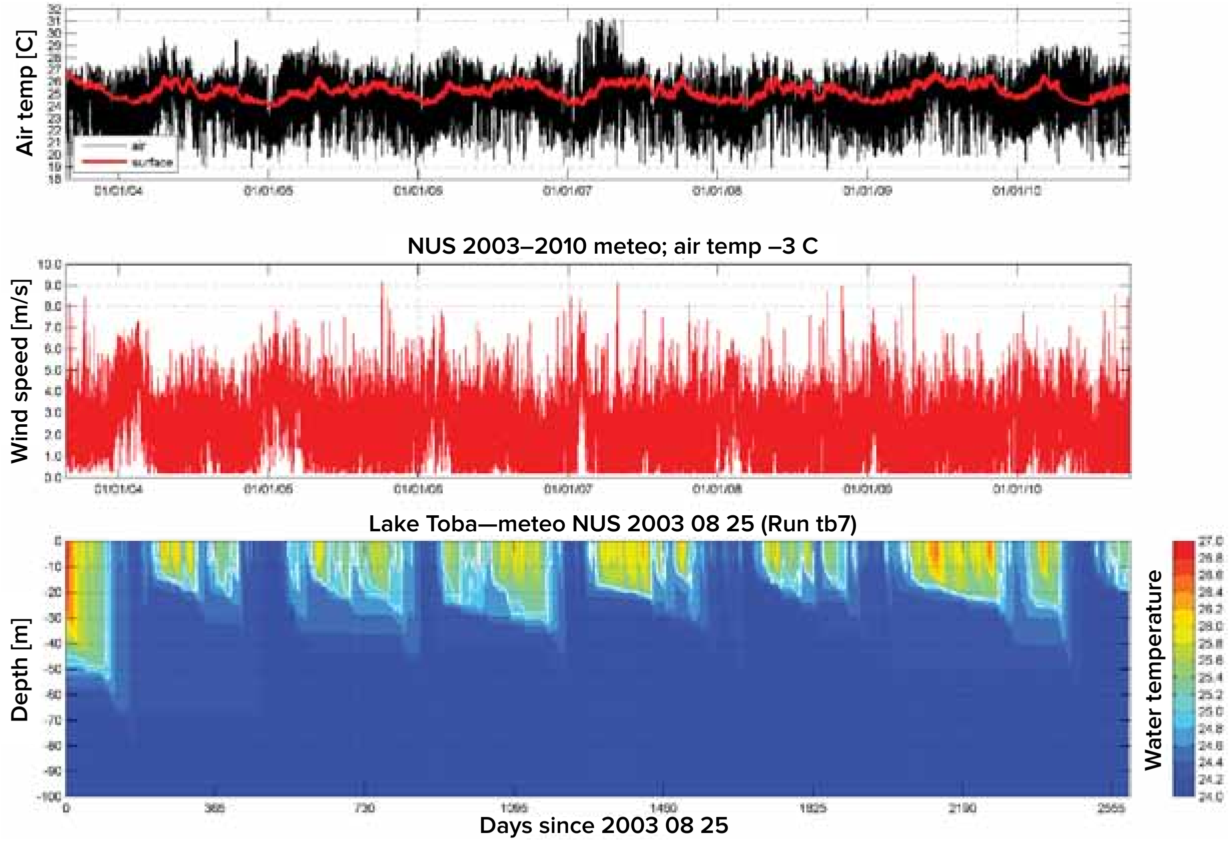
FIGURE 50. Oxygen and temperature dynamics in Lake Toba 2008 to 2017





Source: PTAN, 2017.

FIGURE 51. Simulated air and water temperature, wind magnitude, and water temperature of top 100 meters using Deltares 1DV model



Note: The 1DV model was run based on Delft3D-FLOW code with 100 nonequidistant layers over its maximum 505 meter depth and meteorological forcing from National University of Singapore (2003–2010) and with air temperature reduced by 3°C (Sene et al., 1991).

Historical Trends

Comparing current and historical data from 1930 shows a long-term deterioration in the water quality of Lake Toba. In 1930, Ruttner conducted a series of water quality measurements in Lake Toba. A comparison between Ruttner's data and current data is indicative of long-term changes (Table 18).

TABLE 18. Comparison between current and Ruttner 1930 data

Parameters	Ruttner 1930 data	Current data	Note
Total phosphorous concentrations	0.005 mg/l	0.01 PO4–P (mg/l) (2013, PTAN)	Doubled; ten-fold increase compared to peak in 2016 of 0.05 PO4–P (mg/l).
Phosphorous at 150 m depth	0.012–0.18 PO4–P (mg/l)	0.04 PO4–P (mg/l)	More than two-fold increase
Oxygen concentrations: surface	—	—	Appear to remain constant
Oxygen concentrations: 150 m+ depths	5.35–5.40 mg/l	below 0.5 mg/l (2008–2017, PTAN)	Lower concentrations compared to historical
Transparency	7.5–11.5 m	~6 m	Lower average visibility of 1.5 m compared to historical

Source: Ruttner, 1931; PTAN, 2017.

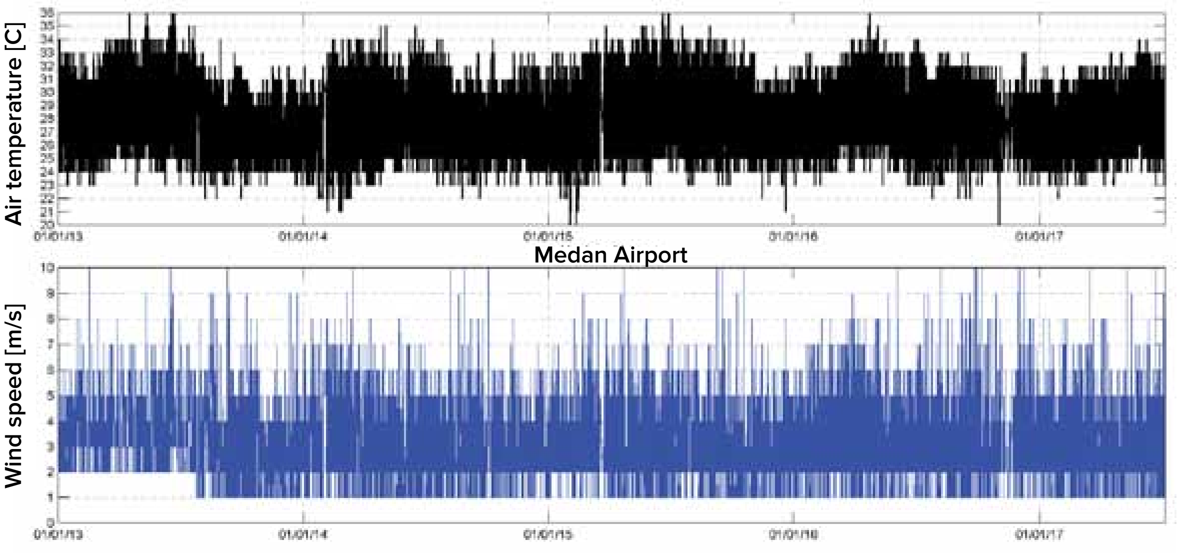
Recent Anomalies

The extreme values at the start of 2016 suggest an algae bloom and that Lake Toba entered a mesotrophic state. At the beginning of 2016, all water measurements show extreme deviation. The temperatures of the lake and surface waters increased, and dissolved oxygen concentrations at shallower depths dropped significantly (February to August, Figure 39). This coincided with a preceding drop in visibility and phosphorous, and a sudden peak in chlorophyll a concentration. The anomaly is also visible as a thermal stratification event between February and August. The rise of the upper level of anoxic waters was also particularly strong.

The 2016 anomaly appears to be caused by long cloudless weather conditions. Temperature and wind speed recorded at Medan, 80 km north of Lake Toba, do not suggest windy or hot events in February 2016 (Figure 52). However, these measurements may not be fully representative of the Lake Toba area. Instead, this period was reported to be, at least locally, particularly cloudless.[125] This cloudless period could explain the relatively long and strong (secondary) temperature stratification. This, in turn, may have caused the exceptionally strong algae bloom (Figure 46) creating high concentrations of detritus and correspondingly large oxygen consumption. However, other causes may have influenced the temporary rising of anoxic water as well.

Analyses of remote sensing images in January 2017 were able to detect the manifestation of a pollution event. On January 9, 2017, conditions in the southeastern Bakara/Baktiraja region led to hypoxia (i.e., oxygen depletion) and the death of tons of fish. Figure 53 illustrates how satellite images from remote sensing can provide data of such events. Elevated levels of chlorophyll a[126] and evidence of resuspended bottom sediments are visible from satellite imagery. The sediment resuspension is possibly caused by vertical (advective) mixing of the lake caused by significant rainfall and discharge from the Aek Manira/Silang watershed. Meteorological conditions on the following day, January 10, 2017, show significantly reduced harmful algae bloom activity (also visible from the Japanese weather satellite Himawari-8). This correlates with the reported dissolved oxygen measurements.[127]

FIGURE 52. Temperature and wind speed recorded at Medan 80 km north of Lake Toba



Source: Reliable Prognosis, available at: https://rp5.ru

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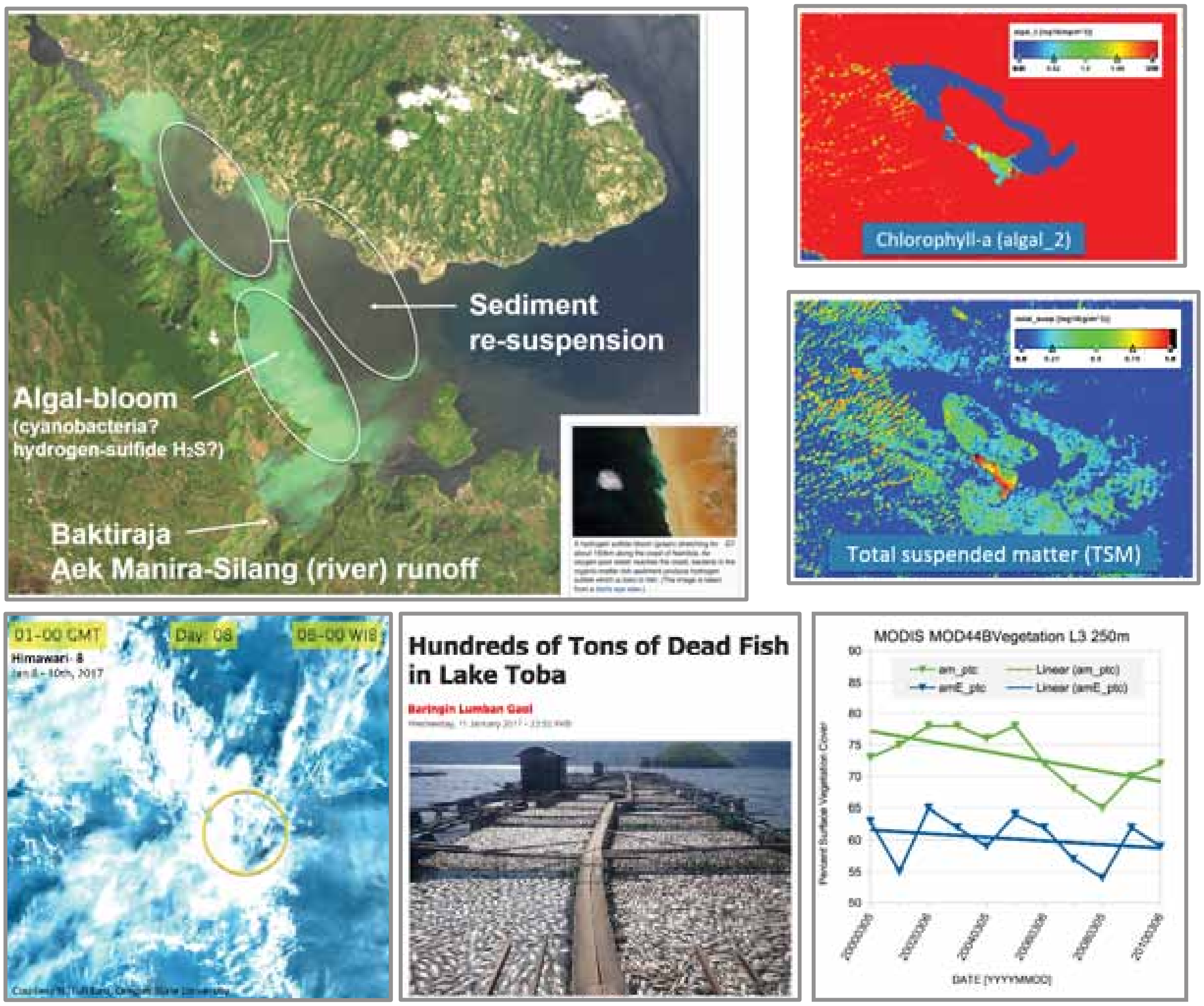
[125] Personal observations by JanJaap Brinkman. The meteorological station is far from Lake Toba and data on cloud cover are not available.

[126] Reaching more than 10 mg/m^3 (>30 locally).

[127] At sub 1 ppm level, the common threshold supporting biological processes.

FIGURE 53. Hypoxia and harmful algae bloom event January 9, 2017



Source: Landsat-8, Himawari-8 and Sentinel-3A VIIRS not verified.

Lake Status

The most important determinant of lake water quality is the amount of dissolved nutrients. Water transparency, organic content (e.g., chlorophyll a), phosphorous, and nitrogen are key parameters that determine a lake's trophic state (Table 19). Oligotrophic conditions exist when the concentration of phosphorous is below the threshold of 10 µg/l and the concentration of nitrogen is below 350 µg/l. Mesotrophic conditions exist when the concentration of phosphorous is between 10 µg/l and the upper threshold of 30 µg/l, and the concentration of nitrogen is between 350 µg/l and the upper threshold of 650 µg/l. The observed values of Lake Toba show phosphorous and oxygen profiles that are consistent with mesotrophic conditions; while nitrogen, chlorophyll a, and transparency reflect oligotrophic conditions, they also reached levels associated with mesotrophic conditions (Table 20).

TABLE 19. Overview of trophic status of freshwater lakes

Lake status	Description
Oligotrophic	Lakes of low primary productivity and low biomass associated with low concentrations of nutrients (oligotrophic between 4–10 µg/l and 350 µg/l nitrogen) tend to be saturated with oxygen throughout the water column.
Mesotrophic	Less well-defined lakes compared to oligotrophic or eutrophic states (between 10–30 µg/l phosphorous and 350–650 µg/l nitrogen), thought to be in transition between the two states; some depression in oxygen occurs in the lower water layer (hypolimnion).
Eutrophic	Lakes with high concentrations of nutrients and associated high biomass production, usually with low transparency. Oxygen can get very low, often less than 1 mg/l in the hypolimnion during stratification.
Hypereutrophic	Lakes at the extreme end of the eutrophic range with very high nutrient concentrations and associated biomass production. Complete oxygen loss often occurs in the hypolimnion during stratification.

Source: Chapman, 1996.

TABLE 20. Lake Toba trophic classification and status of selected water quality parameters

Parameter	Status
Phosphorous	Oligotrophic between 2008 to 2012; mesotrophic from 2012 to 2016.
Nitrogen	Oligotrophic conditions as concentrations are mostly below the conservative threshold of 350 µg/l, and infrequently exceed the most lenient threshold of 650 µg/l.
Chlorophyll a	Ultra-oligotrophic until end of 2014. Mesotrophic between February and August 2016 when chlorophyll a concentrations rise to 12 µg/l.
Transparency	Oligotrophic until 2016 when water transparency drops in correspondence with algae bloom. There are events during which transparency is above a 10 m depth which is very rare for any type of lake.
Temperature	Temperature profiles show clear stratification. Water surface temperatures range from 25–28°C and were stable 2006–2016. A minor increase occurs early in 2016 peaking at over 28°C.
Oxygen	Dissolved oxygen steadily declines with depth and remains constant beyond 200 m. Peak concentrations occur in 2006, 2007, and 2016 (otherwise stable). Fish farm stations report lower and more fluctuating values. At one station, oxygen increases at around a 200 m depth, possibly due to thermal vents or error.

Source: Deltares with input from DLH-SU, LIPI, and PTAN (state assessments from 2016, trend assessments for 2006–2016).

CHAPTER 6

Future Pressures and Lake Status

Growth projections were assessed to determine the impact of future pressures on the water quality status of Lake Toba. The Sumatra Spatial Model (SSM)[128] was used to project the scale and impact of future population growth, changes in land use, and increasing tourism to the area. It was assumed that there will be no future growth in the total aquaculture production and so the primary source of input data on future growth projections was derived from the Indonesia Statistics (*Badan Pusat Statistik,* BPS). Growth projections were forecast for 2018, 2022, and 2042 as inputs to the scenario development based on the following input data:

- Administrative units: island, provinces, districts, subdistricts, and villages (2010).
- Drivers: population growth scenario, economic growth scenario (historic trend data), and production and consumption of rice, palawija (i.e., secondary crops), and vegetables (2010).
- Unit load scenario for water demand, biochemical oxygen demand, and waste load emissions.[129]
- Situation data (2010 population census):
    - Population, households, and employment by village,
    - Land use: Rupa Bumi Indonesia (Geospatial Information Agency, *Badan Informasi Geospasial*) and *Peta Audit Baku Sawah* paddy field maps (Ministry of Agriculture),
    - Gross Regional Domestic Product by district and sector,
    - Provincial level spatial plans from provincial planning agency *Bappeda/PU Tata Ruang*, and
    - Road development plans.

Population and economic growth projections

The population data used in the SSM are at village level (desa) and were derived from the 2010 population census. Population projections were made by BPS per province from the period 2010–2035. Figure 54 shows the annual multiplier for population growth per five-year period.

Provincial economic growth averaged 3.7 percent between 2000 and 2013, with North Sumatra experiencing among the highest growth rates. National economic growth has averaged 5 percent for the last 50 years.[130] Economic growth by province data in Sumatra is shown in Figure 55 and provided the basis for long-term growth projections.[131]

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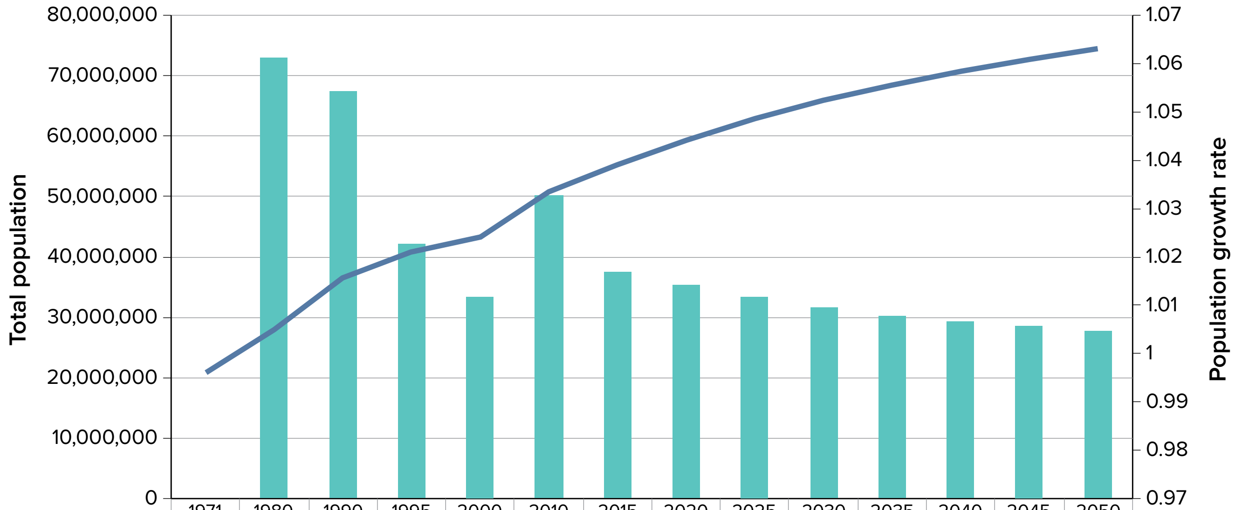
[128] Indra Karya, 2015.

[129] Waste load is the term used encompassing nutrients and other pollution in the water, such as Biochemical Oxygen Demand (BOD).

[130] BPS, 2016.

[131] Long-term analysis was done in close cooperation with the Ministry of Public Works and Housing in Sumatra Water Resources Strategic Study (Indra Karya, 2015).

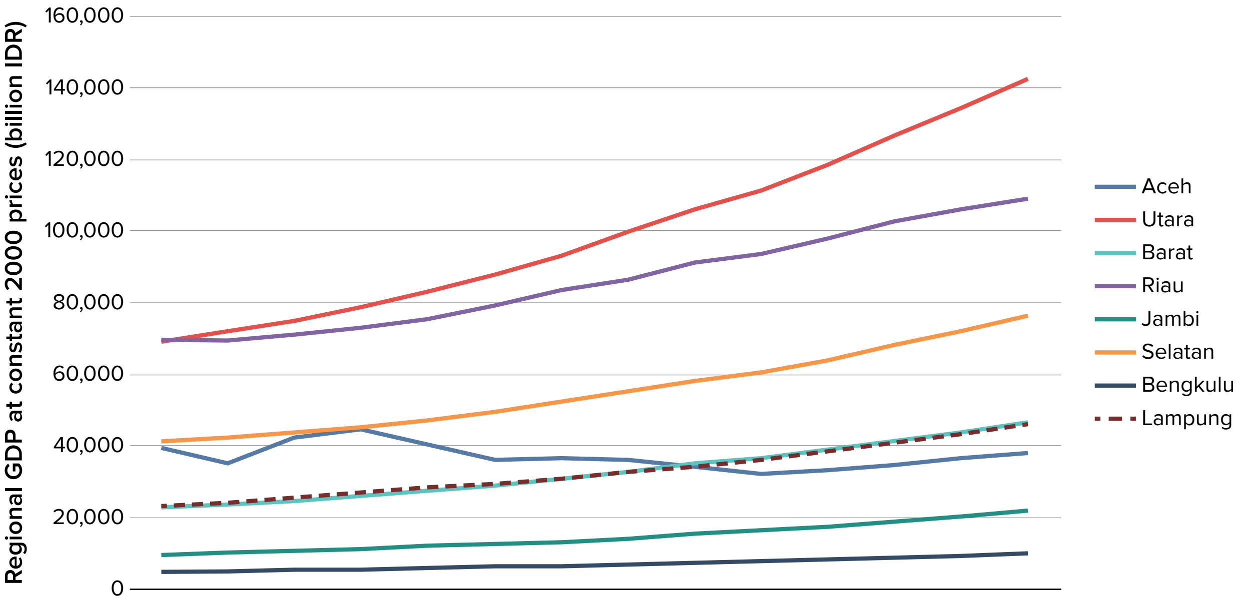
FIGURE 54. Past and projected population growth on Sumatra 1971 to 2050



	1971	1980	1990	1995	2000	2010	2015	2020	2025	2030	2035	2040	2045	2050
🟩 Annual multiplier		1.0613	1.0544	1.0226	1.0119	1.0327	1.0168	1.0143	1.0117	1.0095	1.0077	1.0066	1.0056	1.0046
― Sumatra ('000)	20,808	28,016	36,506	40,830	43,309	51,000	55,000	59,000	63,000	66,000	69,000	71,000	73,000	75,000

Source: BPS for data until 2035, SSM for data 2035 to 2050.

FIGURE 55. Economic growth by province in Sumatra 2000–2013

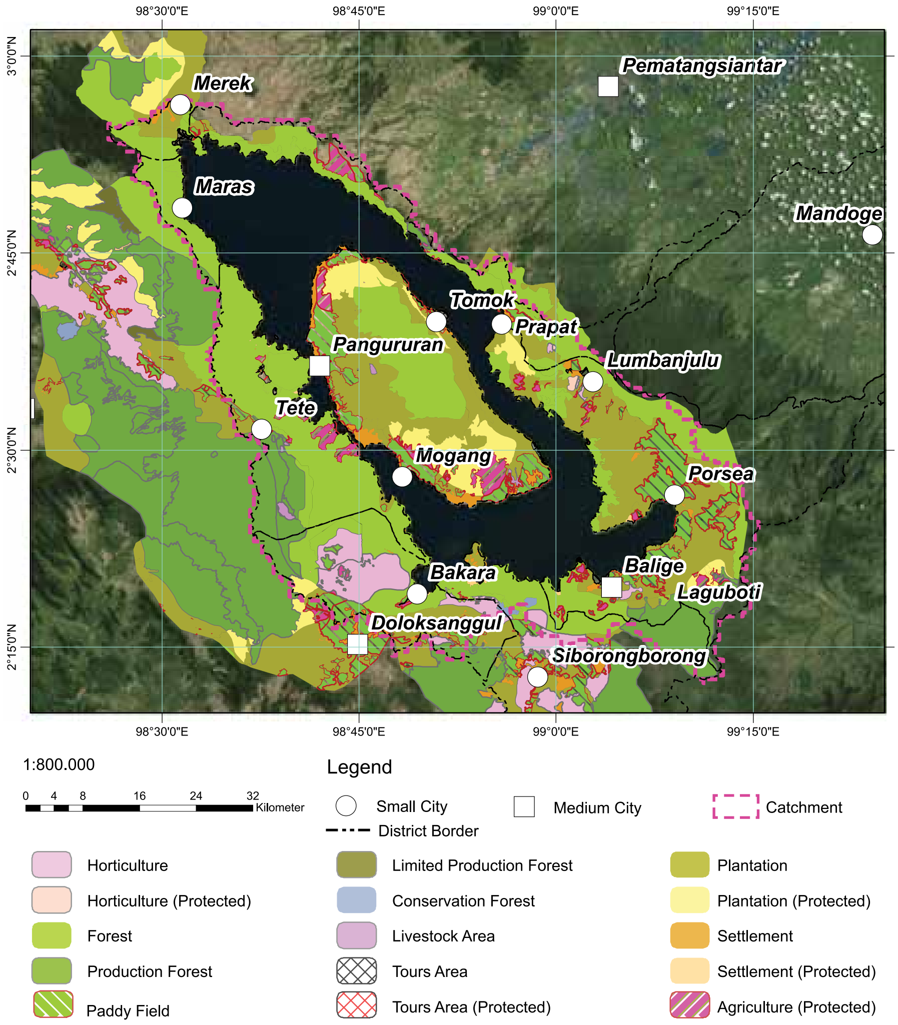


Source: BPS, downloaded from https://www.bps.go.id, November 2014.
Note: The graph illustrates the regional GDP for the eight provinces of Sumatra (official number) over the same years that have been included in the Sumatra Spatial Model.

Spatial development plan

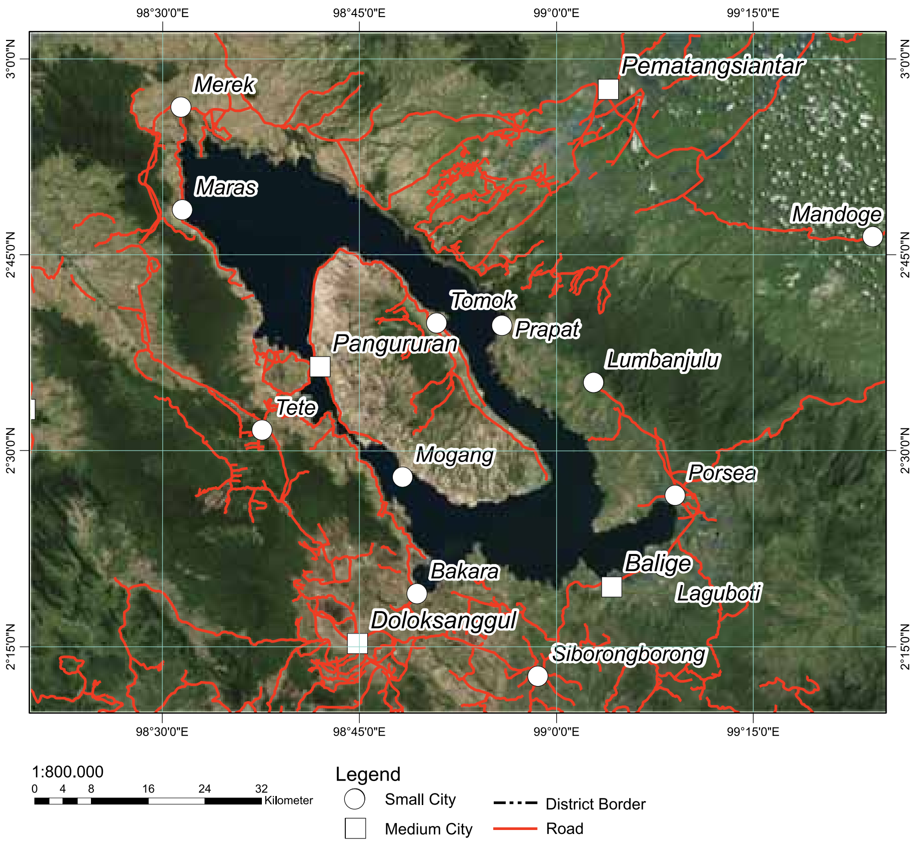
A key input to the Sumatra Spatial Model is the Lake Toba Spatial Plan (Figure 56). The spatial plan shows that part of the area around Lake Toba is protected land and should not be converted to urban areas. Road development was included in the SSM because increased accessibility stimulates infrastructure development near planned roads, especially toll roads (Figure 57).

FIGURE 56. Lake Toba Spatial Plan



Source: Sumatra spatial plan (provincial regulation No. 7/2003). Deltares, 2017.

FIGURE 57. Toll Road Development Plan 2009



Source: Ministry of Public Works and Housing, 2009.

Projections

The estimated future nutrient loads were based on population and employment projections for 2010 to 2050 and land use change projections for 2010 to 2050. These projections are available at village (*desa*), subdistrict (*kecamatan*), district (*kabupaten*), province, and island levels. The projections were then converted to the catchment area in the Lake Toba simulation model using the SSM post-processor. This is a sub-model that calculates indicators as inputs to basin water resource management planning and other sectoral resource impact assessments. The projections start with the 2010 population census data.[132] The impact of short-term investments is assessed over a period of five years and the long-term impacts after twenty-five years (results are thus analyzed for 2018, 2022, and 2042).

Wastewater

Unit wastewater load data and projected population numbers (by both districts in the catchment and the entire lake) were used to calculate waste loads. Population numbers for areas within districts that drain into the lake were combined with unit waste load data to calculate the waste loads for the total lake and individual compartments. The waste load encompasses nutrient and other pollutants released into the water. The actual nutrient loads to Lake Toba, however, could be lower because of losses during transport in local sewers or surface runoff. A correction factor for runoff losses was integrated into the model.[133] The population densities were projected for 2018 (Figure 24) and 2042 (Figure 58) at

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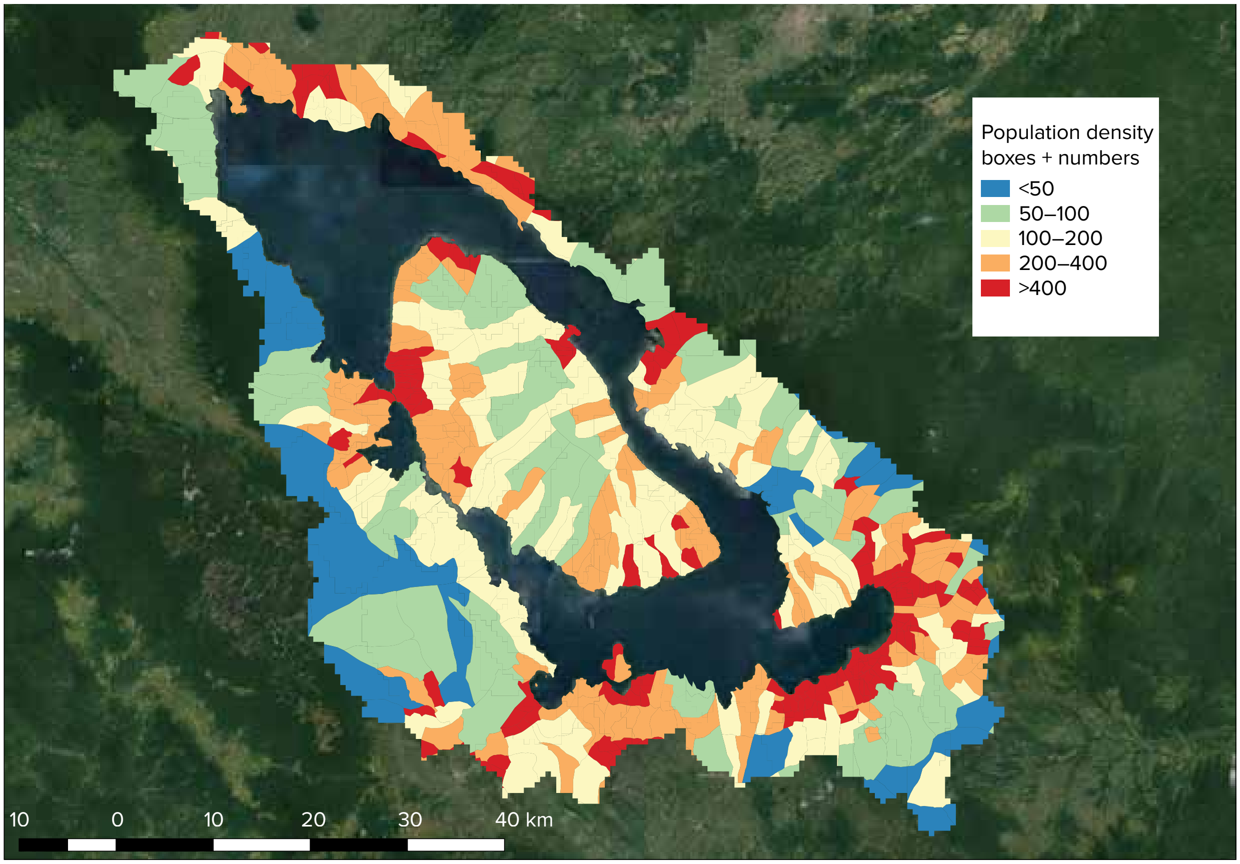
[132] The most reliable population dataset for the intermediary years was used (BPS data on birth, death, and migration statistics are less reliable).

[133] Deltares & TNO, 2016.

FIGURE 58. Population density projections by village for 2042



Source: GIS mapping by Poul Grashoff, 2017.

village levels in the catchment. The population growth rate, based on the difference between 2018 and 2042 projections, is shown in Figure 59.

Sanitation strategies and plans for each regency in the catchment provided the initial inventory of existing and planned wastewater and sewerage infrastructures. The sources included: the District Sanitation Strategies (BPS), the City Sanitation Strategies (*Strategi Sanitasi Kota,* SSK), the Sanitation Sector Program Memorandum (*Memorandum Program Sanitasi,* MPS), and the 2015 Urban Sanitation Development Program (*Program Pengembangan Sanitasi Perkotaan,* USDP). The options for wastewater infrastructures were informed by the 2009 TTPS Reference Book (*Buku Referensi*),[134] promoting solutions that are low cost and reduce risks to human health and the environment. An assumption of average wastewater flows based on full water supply coverage was included in the scenario estimates. Calculations were made for all villages (*desa*) in catchment areas draining into Lake Toba (i.e., not for the entire regency, *kabupaten*). The peak numbers of visitors were calculated as: 300,368 in 2018 for all scenarios; 343,114 in 2022 and 384,500 in 2042 for Scenarios A and B; and 368,623 in 2022 and 568,363, for Scenarios C, D, and E.

Land use

Changes in land use were projected as proportionate to changes in the village (*desa*) area with respect to urbanization, paddy field areas, and plantations. Land use data were calculated for each time interval at the village level and were converted for the relevant district surface area to calculate waste loads.

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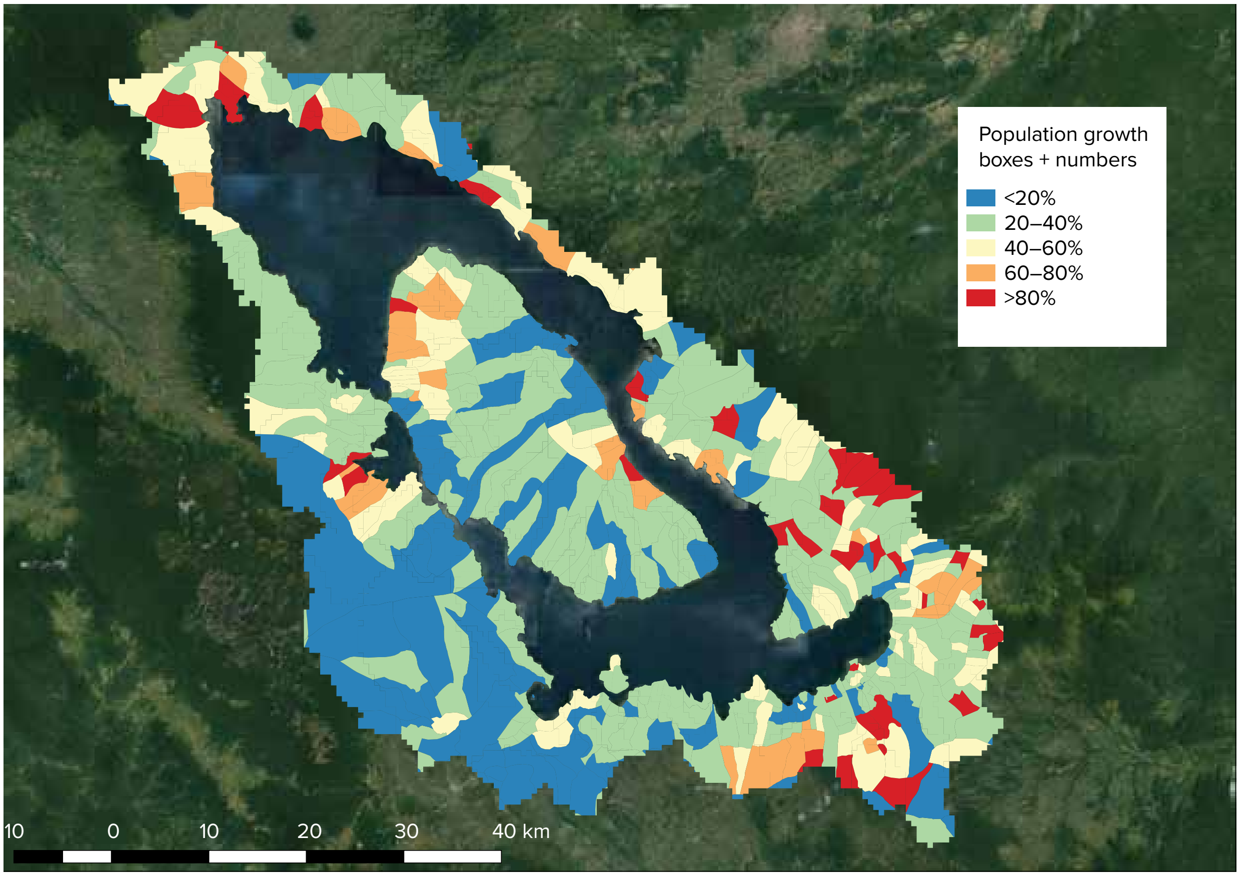
[134] TTPS, 2009. Sanitation system and technology options (originally in Indonesian Opsi Sistem dan Teknologi Sanitasi). Jakarta, Indonesia: Government of Indonesia. Technical Team for Sanitation Development (TTPS), led by Bappenas, in collaboration with the World Bank's Water and Sanitation Program—East Asia and the Pacific (WSP-EAP).

FIGURE 59. Population growth as the difference between projected populations in 2018 and 2042



Source: GIS mapping by Poul Grashoff, 2017.

Urban areas are projected to grow by approximately 66 percent in the Lake Toba catchment between 2018 and 2042 (Figure 60). Only 4 percent of the Lake Toba catchment area is categorized as urban as of 2018, and the rate of urbanization is estimated to be low in the immediate years thereafter. The change is more significant when projected for the longer time horizon of 2042.

Significant land use changes have occurred in the southwest areas of Lake Toba since 2000. Remote sensing data reveal that the southwestern Aek Manira/Silang watershed experienced approximately 1 percent reduction in vegetative cover per year between 2000 and 2010.[135] Qualitatively, more significant changes occurred between 2013 and 2017[136] (Figure 61). Land use change at catchment levels however, showed limited large-scale changes in overall vegetation cover between 2000 and 2010.[137]

Tourism

Tourism projections to inform the calculation of wastewater (assigned at village levels) are based on an assessment of tourism market demand carried out in 2017.[138, 139] The data enabled the projection of equivalent inhabitants and estimation of peak numbers for the years 2022 and 2042 (Table 21). These are yearly figures and not all visitors visit at the same

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[135] MODIS PTC.

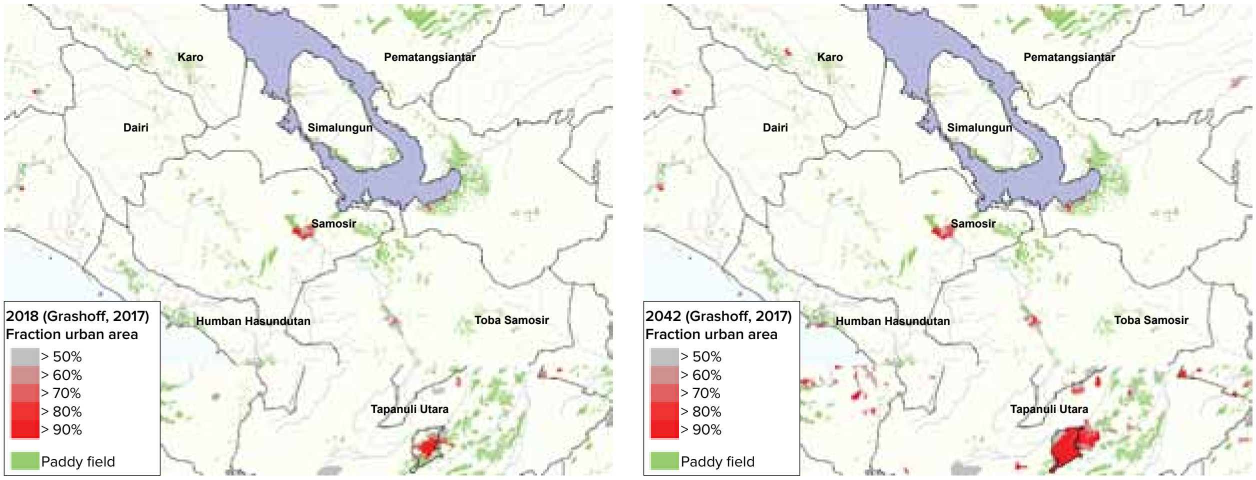
[136] Landsat-8.

[137] NASA MODIS Annual Products.

[138] Horwath HTL, 2017.

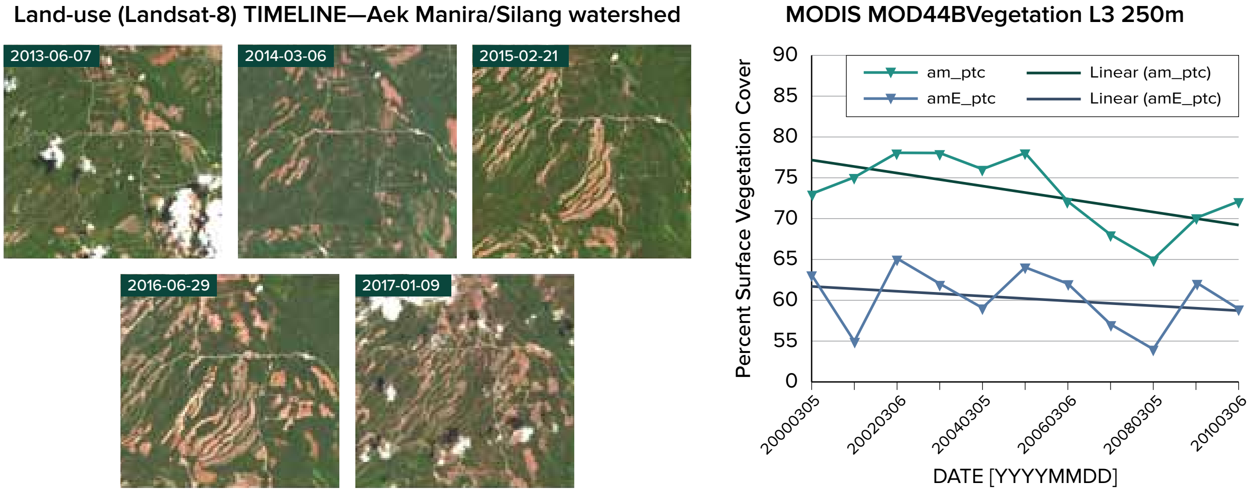
[139] The SSM does not include tourism as a sector in terms of population.

FIGURE 60. Urban area portion by village in 2018 (left) and 2042 (right)



Source: GIS mapping by Poul Grashoff, 2017.

FIGURE 61. Illustration of land use change analysis in the Aek Manira/Silang Watershed (2013–2017) and decline of the vegetation cover (2000–2010)


Land-use (Landsat-8) TIMELINE—Aek Manira/Silang watershed

MODIS MOD44BVegetation L3 250m

Source: Badan Informasi Geospasial 2013; Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGA, AeroGRID and IGN.

TABLE 21. Current and projected number of tourists

Parameters	Baseline	Business-as-usual scenario		Best-case scenario	
Year	2015	2022	2042	2022	2042
Number of visitors					
Domestic	1,743,500	1,978,279	2,210,500	2,125,128	3,083,500
Foreign	58,709	80,408	87,300	86,610	264,900
Total Lake Toba	**1,802,209**	**2,058,686**	**2,297,800**	**2,211,739**	**3,348,400**
Average length of stay (days)					
Domestic	2.7	2.6	2.7	2.7	2.6
Foreign	2.1	2.1	2.1	2.1	2.3
Equivalent inhabitants	13,426	14,816	16,612	16,115	23,930
Peak number of visitors at one time	**300,368**	**343,114**	**384,500**	**368,623**	**568,363**

Source: Horwath HTL, 2017.

time. A maximum of a sixth of the total annual number of visitors is estimated to be present at the same time. However, there will be peaks in the number of visitors, which is less important for the wastewater load calculations, but crucial in the design of required sanitation infrastructures. The focus of future tourism development will be in the subdistricts Balige, Girsang Sipangan Bolon, Simandindo, and Pangururan.[140]

Total Nutrient Concentration Projections

Total nitrogen (TN) and total phosphorous (TP) concentrations were calculated for 2022 and 2042 for each of the lake compartments based on nutrient load calculations (Chapter 4). The parameters used for the budget model used to quantify the concentrations are listed in Table 22 and Table 23. The thermocline depth was set at a 50 meter depth, and at 20 to 30 meter depths for February through August 2016. The model results were then calibrated with the lake's residence time[141] (i.e., the time water stays in the lake system). Resulting TN and TP concentrations, and links to thermocline depths, are shown in Figure 62.

The projected TN and TP concentrations for the north compartment are equivalent to those for the whole lake, higher in the South 1 (S1) compartment, and lower in the South 2 (S2) and South 3 (S3) compartments. The thermocline depths influence the concentration of nutrients. The smaller volume of water of a shallow thermocline means higher nutrient concentrations and vice versa. At a thermocline depth of 50 meters, the total nutrient concentrations over the whole lake averaged 224 µg/l TN and 26 µg/l TP (both within the observed ranges of 2015). At a thermocline depth of 20 meters, the total nutrient concentrations more than doubled to 467 µg/l TN and 59 µg/l TP (corresponding to observations in 2016). Results varied when calculations were done per compartment (Figure 63) due to local differences of the compartment properties (Table 22 and Table 23) and different loadings.

Resulting nutrient concentrations represent the eventual equilibrium that will be reached in the whole lake compartment over time. An example of how a nutrient load would lead to increased concentrations over time, until a certain equilibrium concentration is reached, is shown in Figure 64. The equilibrium would shift up with continuous loads. The time required to reach equilibrium is not known but could be decades. When loads are reduced, the resulting concentration slowly decreases over time until a new equilibrium is reached (Figure 65).

TABLE 22. **Whole lake and two compartment (north and south) parameters for carrying capacity calculations**

		Two compartments	
	Whole lake	**North**	**South**
Area (m^2) ('000)	1,240,000	660,000	584,000
Average depth (m)	228	206	206
Thermocline depth (m)	50	50	50
Outflow (m^3/s)	110	50	110
Volume (m^3) ('000)	284,000,000	136,000,000	120,000,000
Epilimnion volume (m^3) ('000)	62,200,000	33,000,000	22,900,000

Note: Surface area and volume estimates are simplified for modelling purposes.

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[140] Horwath HTL, 2017.

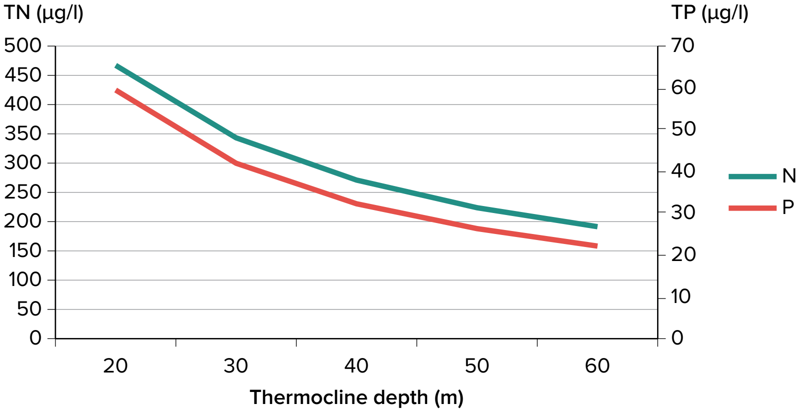
[141] The resulting total nitrogen and total phosphorous concentrations match best with the present state when assuming retention rates of 0.001 and 0.002 for nitrogen and phosphorous respectively.

TABLE 23. Four compartment parameters for carrying capacity calculations (north, S1, S2, and S3)

	Four compartments			
	North	South 1	South 2	South 3
Area (m^2) ('000)	660,000	27,800	468,000	88,300
Average depth (m)	90	200	100	80
Thermocline depth (m)	50	50	50	50
Outflow (m^3/s)	50	10	110	110
Volume (m^3) ('000)	59,400,000	5,560,000	46,800,000	7,060,000
Epilimnion volume (m^3) ('000)	33,000,000	1,390,000	23,400,000	4,420,000

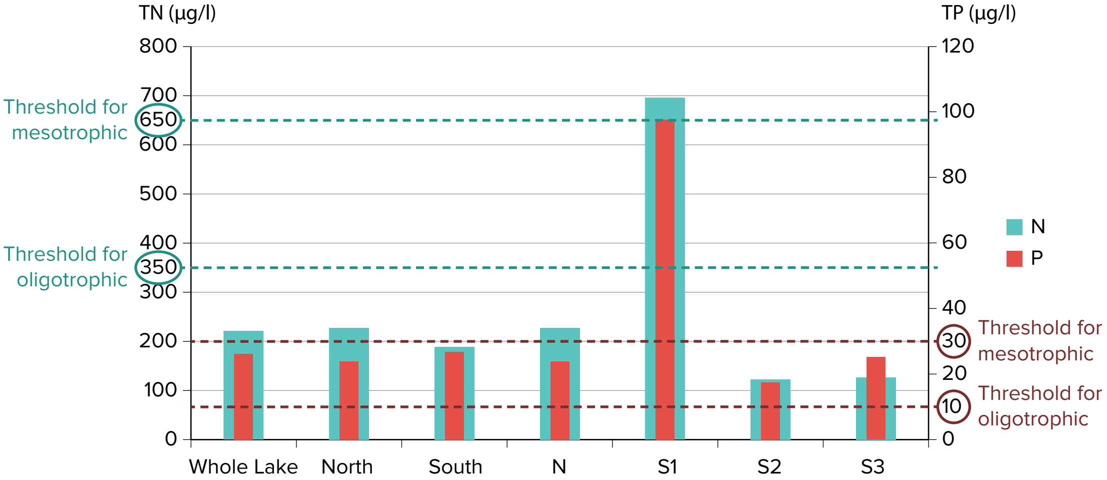
Note: Surface area and volume estimates are simplified for modelling purposes.

FIGURE 62. Relation between thermocline depth and TN and TP concentrations for the whole lake in 2015



Source: Calculated by the water quality budget model.

FIGURE 63. TN and TP concentrations across lake compartments in 2015 assuming a thermocline depth of 50 meters



Source: Calculated by the water quality budget model.
Note: The thresholds for oligotrophic status are 10 µg/l phosphorous and 350 µg/l nitrogen; and for mesotrophic state, 30 µg/l phosphorous and 650 µg/l nitrogen.

FIGURE 64. Nutrient concentration over time resulting from a load

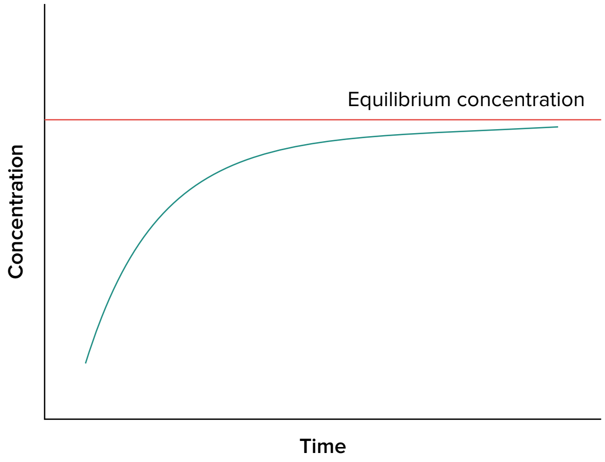
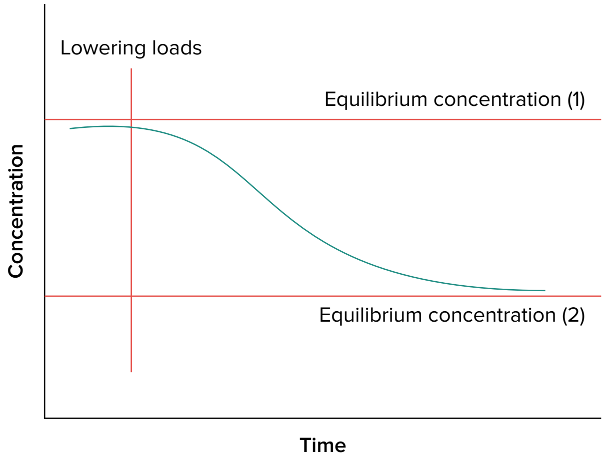


FIGURE 65. Shift in nutrient concentration over time resulting from a reduction in nutrient load



CHAPTER 7

Water Quality Management Scenarios

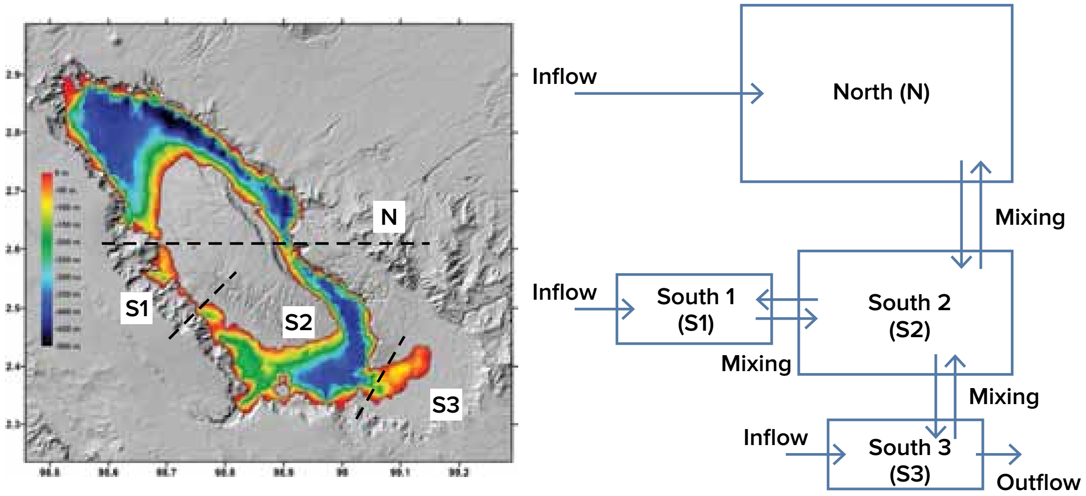
Scenario Definition

A range of options for improving the management of water quality in Lake Toba were assessed. The Sumatra Spatial Model (SSM) was used to quantify the impact of the five scenarios designed based on a range of different interventions that are aimed at mitigating nutrient loading from the key drivers, including aquaculture, livestock, and wastewater (detailed in Table 24). These account for 98 percent of the total phosphorous loads (68 percent, 19 percent, and 11 percent, respectively).

Future growth and drivers[142] of nutrient loading were based on population and land use projections for the catchment area of Lake Toba (Chapter 6) and not the full regency (*kabupaten*) surrounding the lake. Resulting nutrient concentrations in the lake were calculated based on the water quality budget model. This does not consider the accumulated nutrients already present in the lake or the complexity of physical and biogeochemical processes, and their variability in time and space. Therefore, they do not account for long-term effects that could be aggravating (because of accumulation effects) or improving (because of natural purification processes) the water quality of the lake.

Each scenario was subsequently costed according to the specific interventions. The scenarios were applied to the whole lake and the four compartments (north, S1, S2, and S3 as shown in Figure 66) in order to model the impacts of the

FIGURE 66. **Overview of the four compartments of Lake Toba used for the scenario analysis**



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[142] In the Sumatra Spatial Model, autonomous growth is a projection of population growth that would occur without any intervention.

TABLE 24. Scenario interventions to reduce nutrient loads into Lake Toba

Source	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Level of intervention	*Baseline*	*Low*	*Intermediate*	*High*	*Optimized*
Aquaculture (tons of fish produced)					
	Extrapolation of 2015 levels (FCR 1.9)	**Growth to maximum potential (FCR 1.9)**	**Gradual reduction (FCR 1.9)**	**Ambitious reduction (FCR 1.2)**	**Ambitious reduction (FCR 1.2)**
2018	84,800	106,000	64,000	64,000	64,000
2022			50,000	10,000	10,000
2042			10,000	10,000	10,000
Livestock (% conversion of manure into biogas)					
2018	Extrapolation of levels based on population growth	Extrapolation of levels based on population growth	1	5	5
2022			20	30	30
2042			40	60	60
Wastewater (% coverage from intervention)					
	No intervention	**Slow implementation**	**Implementation as planned**	**Accelerated implementation**	**Implementation as planned**
2018	On-site: 50	On-site: 50	On-site: 50	On-site: 50	On-site: 50
2022		On-site: 66 Off-site: 1	On-site: 85 Off-site: 2	On-site: 69 Off-site: 31	On-site: 85 Off-site: 2
2042		On-site: 94 Off-site: 6	On-site: 94 Off-site: 6	On-site: 50 Off-site: 50	On-site: 94 Off-site: 6
Tourism (number of tourists/year)					
Scenario	**Business as usual**	**Business as usual**	**Best-case**	**Best-case**	**Best-case**
2018	1,802,200	1,802,200	1,802,200	1,802,200	1,802,200
2022	2,059,000	2,059,000	2,212,000	2,212,000	2,212,000
2042	2,307,000	2,307,000	3,410,300	3,410,300	3,410,300

Note: FCR = food conversion ratio, the ratio of input feed transformed into output biomass.

interventions on the nutrient loading. Measures to reduce the minor loads from other sources are explored at the end of the chapter because of the potential benefits to the environment, health, and tourism.

Scenario A

Scenario A is the *baseline* scenario. It does not project any external interventions to reduce nutrient loads. Scenario A assumes:

- Aquaculture production of 84,800 tons of fish per year as in 2015 (with a Food Conversion Ratio, FCR, or the ratio of input feed transformed into output biomass, of 1.9);
- Autonomous growth for livestock and population pressures (based on SSM projections);
- No change to current wastewater facilities; and
- Business-as-usual forecast for the number of tourists.

Scenario B

Scenario B is the *low* intervention scenario. It projects a low level of interventions to reduce nutrient loads from wastewater. Scenario B assumes:

- Aquaculture production growth to a maximum level of 106,000 tons of fish per year (FCR of 1.9);
- Autonomous growth for livestock (based on SSM projections);

- Slow implementation of planned water and sanitation investments, increasing access to on-site sanitation facilities (e.g., septic tanks) (from 50 percent of the population in 2018 to 66 percent in 2022 and 94 percent in 2042),[143] alongside increased off-site sewerage system (i.e., centrally managed wastewater treatment facilities) coverage to 1 percent of the population by 2022 and 6 percent in 2042; and
- Business-as-usual forecast for the number of tourists (without additional sanitary facilities). Because water quality of Lake Toba will decline in Scenario B, the growth of visitors will eventually slow down.

Scenario C

Scenario C is the *intermediate* intervention scenario. It projects an intermediate level of interventions to reduce nutrient loads from aquaculture, livestock, and wastewater. Scenario C assumes:

- Aquaculture production levels of 64,000 tons of fish per year in 2018, 50,000 tons by 2022, and 10,000 tons by 2042 through expiration of the one remaining license, judiciary enforcement combined with alternative livelihood options for fish farmers without licenses (FCR of 1.9);
- Conversion of livestock manure into biogas (1 percent by 2018, 20 percent by 2022, and 40 percent by 2042);
- Implementation of planned water and sanitation investments, increasing access to on-site sanitation facilities (from 50 percent of the population in 2018, to 85 percent by 2022 and 94 percent by 2042)—alongside increased off-site sewerage system coverage to 2 percent of the population by 2022 and 6 percent in 2042 (open defecation decreases from 50 percent in 2018 to 13 percent by 2022 and 0 percent by 2042); and
- Best-case forecast for the number of tourists (without additional sanitary facilities).

Scenario D

Scenario D is the *high* intervention scenario. It projects a high level of interventions to reduce nutrient loads across aquaculture, livestock, and both domestic and tourist wastewater. Scenario D assumes:

- Aquaculture production of 10,000 tons of fish per year in 2022 and in 2042 through accountability measures on licensed production with improved fish feeding practices in remaining cages (enabling FCR of 1.2);
- Conversion of livestock manure into biogas (5 percent by 2018, 30 percent by 2022 and 60 percent by 2042);
- Accelerated and better financed water and sanitation investments (beyond planned interventions) increasing access to on-site sanitation facilities (from 50 percent of the population in 2018, to 69 percent by 2022, and then dropping to 50 percent by 2042)—alongside a greater increase in off-site sewerage system coverage to 31 percent of the population by 2022 and 50 percent by 2042 (open defecation decreases from 50 percent in 2018 to 0 percent by 2022 and 2042); and
- Best-case forecast for the number of tourists (with wastewater management coverage).

Scenario E

Scenario E is the *optimized* intervention scenario. It projects a high level of interventions to reduce nutrient loads across aquaculture and livestock (same as in Scenario D), but a lower level of interventions in wastewater (same as in Scenario C). Scenario E assumes:

- Aquaculture production of 10,000 tons of fish per year in 2022 and in 2042 through accountability measures on licensed production with improved fish feeding practices in remaining cages (enabling FCR of 1.2);

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[143] Considering projected population growth.

- Conversion of livestock manure into biogas (5 percent by 2018, 30 percent by 2022 and 60 percent by 2042);
- Implementation of planned water and sanitation investments, increasing access to on-site sanitation facilities (from 50 percent of the population in 2018, to 85 percent by 2022 and 94 percent by 2042)—alongside increased off-site sewerage system coverage to 2 percent of the population by 2022 and 6 percent in 2042 (open defecation decreases from 50 percent in 2018 to 13 percent by 2022 and 0 percent by 2042); and
- Best-case forecast for the number of tourists (without additional sanitary facilities).

Aquaculture

Interventions

The interventions in aquaculture are aimed at assessing the impact of enforcing the carrying capacity established under the government regulations. As of the beginning of 2018, none of the aquaculture producers, with the exception of PT Aquafarm Nusantara, were reported as having formal licenses. It is unclear whether PT Aquafarm Nusantara's license will expire prior to 2022. The scenarios assess the impact of the status quo and an increase in production on nutrient loading, along with different approaches to reducing the production capacity. These approaches have potential social, economic, financial, and legal implications and so are considered separately.

Further analyses and information are needed to determine the exact extent, validity, and limitations of issued licenses. Future interventions, such as those for the intermediate level of interventions in Scenario C, would require improved compliance monitoring and enforcement (e.g., distance from the shore, minimum water depth, and maximum visibility) which in turn requires better information on current aquaculture production (e.g., location and ownership of fish cages and how they are operated). Achieving Scenario D and Scenario E could potentially require revoking the license and/or require immediate compliance enforcement with no further renewals or new licenses to be issued.

A combination of efforts would be needed to regulate and improve the operations of small-scale owners. This would include technical advice and capacity building to improve efficiencies (e.g., for food conversion ratio of 1.2) and compliance (e.g., operating at least 10 meters from shore and at 100 meter depth locations).[144] Regulating small-scale and commercial operations would require better enforcement of legal requirements on production. Civil servant investigators (e.g., from the Ministry of Marine and Fisheries and Ministry of Public Works and Housing) play a key role in acting on the data collected through monitoring and surveys, and in legally prosecuting nonlicensed and noncompliant production. Local leaders (*Tokoh Adat*) also play important roles in monitoring.

Alternative livelihood opportunities will be needed to offset the potential impact of reducing aquaculture production. Many owners of small-scale operations have other sources of livelihoods, including horticulture farming. There are also other livelihood options that could emerge, such as through a more diversified fish market (e.g., building on the potential of the native and more nutritious fish *batak* or *jurung* compared to *tilapia*), organic farming and tourism. This transition needs to be properly supported by government through livelihood restoration that may include support to training and skills development (e.g., through agricultural extension centers), as well through financing mechanisms, social safety nets, and transition mechanisms. Local foundations and civil society organizations could play a role in supporting the transition to alternative livelihoods. For example, Yayasan Bina Sarana Bakti located in Ciawi, Bogor, could provide incentives for organic farming.[145] While the carrying capacity of Lake Toba is restricted to control the processes

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[144] As specified in Presidential Regulation No. 81/2014.

[145] Yayasan Bina Saran Bakti (BSB) is a pioneer in organic farming in Indonesia (since 1984). The foundation provides in-situ training on their farm which is not limited to technical knowledge of organic farming only, but also includes business operations such as managing supply chains.

of eutrophication, it will be essential to further understand key stakeholders and opportunities for expanding alternative livelihood options and the role that stakeholder consultations can have to support such opportunities. This requires a livelihoods restoration plan to assess socioeconomic impacts, options for alternative livelihoods with detailed planning, and costing of livelihood restoration.

Improving the efficiency of current aquaculture production could help offset some of the losses from interventions aimed at reducing nutrient inputs from aquaculture. The Food Conversion Ratio (FCR) compares the amount of feed transformed into output biomass to provide a measure of aquaculture production efficiency. The model assumes an FCR of 1.9 based on available information. However, there are four main contributing factors that determine FCR: genetics, environment, husbandry, and feeds. The intersection of these parameters is complex and subject to interactions with environmental factors, particularly oxygen saturation and temperature, but present opportunities for further research and improvement. Fish feeding efficiencies could be achieved at aquaculture farms on Lake Toba by breeding different types of fish, changing the stock-to-feed ratio, and by using alternative feed. The interventions could make the local industry more profitable and investment costs would be borne by owners. Such improvements are considered in Scenarios D and E.

Cost estimates and production levels

Scenario A assumes the same total production of fish as in 2015 and is kept constant for 2018, 2022, and 2042. However, the distribution across compartments has shifted as PT Aquafarm Nusantara has moved cages from the northern compartment of the lake to the S2 compartment (Table 25). Cost estimates for Scenario A do not incorporate possible economic losses to commercial and small-scale producers.

TABLE 25. **Projected fish production in 2018, 2022, and 2042 for all scenarios (tons/yr)**

Scenario A (baseline)					
Producer	**Estimated production 2018, 2022, and 2042 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	10,800		25,200		**36,000**
PT Suri Tani Pemuka	9,700				**9,700**
Haranggaol Bay small-scale operators	30,900				**30,900**
Other small-scale operators	3,300	1,600	2,400	900	**8,200**
Total	**54,700**	**1,600**	**27,600**	**900**	**84,800**
Percentage[146] production (%)	*65*	*2*	*33*	*1*	
Percentage emission (%)	*72*	*3*	*24*	*1*	
Scenario B (low)					
Producer	**Estimated production 2018, 2022, and 2042 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	10,800		25,200		**36,000**
PT Suri Tani Pemuka	30,000				**30,000**
Haranggaol Bay small-scale operators	31,800				**31,800**
Other small-scale operators	3,300	1,600	2,400	900	**8,200**
Total	**75,900**	**1,600**	**27,600**	**900**	**106,000**
Percentage production (%)	*72*	*2*	*26*	*1*	
Percentage emission (%)	*79*	*1*	*20*	*1*	

(continues)

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146 Because of rounding, percentages in tables may not exactly add up to 100%. The model applies the calculated, nonrounded percentages.

TABLE 25. Continued

Scenario C (intermediate)					
Producer	**Estimated production 2018 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	9,000		21,000		**30,000**
PT Suri Tani Pemuka	4,000				**4,000**
Haranggaol Bay small-scale operators	23,100				**23,100**
Other small-scale operators	3,000	1,000	2,000	900	**6,900**
Total	**39,100**	**1,000**	**23,000**	**900**	**64,000**
Percentage production (%)	*61*	*2*	*36*	*1*	
Percentage emission (%)	*69*	*1*	*29*	*1*	
Producer	**Estimated production 2022 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	9,000		21,000		**30,000**
PT Suri Tani Pemuka	0				**0**
Haranggaol Bay small-scale operators	13,100				**13,100**
Other small-scale operators	3,000	1,000	2,000	900	**6,900**
Total	**25,100**	**1,000**	**23,000**	**900**	**50,000**
Percentage production (%)	*50*	*2*	*46*	*2*	
Percentage emission (%)	*58*	*2*	*39*	*2*	
Producer	**Estimated production 2042 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara			0		**0**
PT Suri Tani Pemuka	0				**0**
Haranggaol Bay small-scale operators	5,000				**5,000**
Other small-scale operators	2,100	0	2,000	900	**5,000**
Total	**7,100**	**0**	**2,000**	**900**	**10,000**
Percentage production (%)	*71*	*0*	*20*	*9*	
Percentage emission (%)	*80*	*0*	*14*	*6*	
Scenario D (high) and E (optimized)					
Producer	**Estimated production 2018 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara	9,000		21,000		**30,000**
PT Suri Tani Pemuka	4,000				**4,000**
Haranggaol Bay small-scale operators	23,100				**23,100**
Other small-scale operators	3,000	1,000	2,000	900	**6,900**
Total	**39,100**	**1,000**	**23,000**	**900**	**64,000**
Percentage production (%)	*61*	*2*	*36*	*1*	
Percentage emission (%)	*69*	*1*	*29*	*1*	
Producer	**Estimated production 2022 and 2042 (tons)**				
Compartment	North	South 1	South 2	South 3	**Total**
PT Aquafarm Nusantara			0		**0**
PT Suri Tani Pemuka	0				**0**
Haranggaol Bay small-scale operators	5,000				**5,000**
Other small-scale operators	2,100	0	2,000	900	**5,000**
Total	**7,100**	**0**	**2,000**	**900**	**10,000**
Percentage production (%)	*71*	*0*	*20*	*9*	
Percentage emission (%)	*80*	*0*	*14*	*6*	

Scenario B assumes unregulated growth in aquaculture production from 2018 to 2042, up to 106,000 tons. This is reflected through a relatively low number of limited interventions to reduce nutrient emissions. PT Aquafarm Nusantara is assumed to produce 36,000 tons per year according to its license and PT Suri Tani Pemuka to increase production to 30,000 tons per year (i.e., the level of the original license). Aquaculture at Haranggaol Bay is assumed to increase to 31,800 tons while total production of other small-scale operators remains at 8,200 tons per year (Table 25).

Scenario C represents a gradual reduction of commercial aquaculture production (while small-scale operators do not immediately abandon remaining cages) at a cost of IDR 9.7 billion (USD 0.72 million). Table 25 provides a detailed overview of the projected production of fish per year for Scenario C across the different lake compartments and by producer. Scenario C would involve continued production of 30,000 tons by PT Aquafarm Nusantara in 2018 and 2022, while PT Suri Tani Pemuka will phase out production from 4,000 tons in 2018 to none by 2022. Aquaculture farmers in Haranggaol Bay would reduce production from 23,100 tons in 2018 to 13,100 by 2022, and 5,000 by 2042. Other small-scale operators would produce 6,900 tons in 2018 and 2022, and 5,000 tons by 2042. No aquaculture activities would be allowed in the small compartment S1 by 2042. Table 26 outlines the operational expenditures to achieve target production of 50,000 tons by 2022 in Scenario C.

Scenario D and Scenario E require rapid reduction of commercial aquaculture through actions against unlicensed farming, no new or renewed licenses, and total small-scale production of 10,000 tons—at a cost of IDR 34.15 billion (USD 2.53 million). The one remaining license for PT Aquafarm Nusantara would either expire before 2022 or be revoked beforehand. Compliance with legal requirements for aquaculture would be actively enforced, and most small-scale operators would abandon remaining fish cages. Aquaculture farmers at Haranggaol Bay and other small-scale operators could continue aquaculture at a maximum of 5,000 tons per year respectively. No aquaculture activities would be allowed in the small compartment S1 by 2022. More efficient production practices would result in a better food conversion ratio of 1.2 compared to the other scenarios. The specific implications of Scenario D and Scenario E on fish production are shown in Table 25. The operational expenditures to achieve 10,000 tons fish per year by 2022 are provided in Table 26.

TABLE 26. Estimated costs for target aquaculture production of 50,000 tons in Scenario C, and 10,000 tons in Scenarios D and E by 2022 (million IDR)

Interventions	Scenario C	Scenarios D and E	Responsibility	Duration (years)
	OPEX (m IDR)			
Infrastructure				
Better feed purchases	0	50	Aquaculture companies, small-scale operators	5
Institutional				
Coordination	200	400	Ministry of Marine and Fisheries, local government	5
Law enforcement: monitoring	100	200	Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (ATR/BPN), Ministry of Marine and Fisheries, BWS Sumatera II, traditional leaders	5
Law enforcement: investigation	50	100	Civil servant investigators under ATR/BPN, Ministry of Marine and Fisheries, and Ministry of Public Works and Housing	5
Training: fisheries	600	4,000	Ministry of Marine and Fisheries	3
Training: organic farming	1,200	4,000	Ministry of Agriculture, local foundations	3
Training: tourism	600	4,000	Ministry of Tourism	3
Market development	500	4,000	Local government, tourism industry	5
Information				
Guiding studies	1,500	4,500	Ministry of Marine and Fisheries	1.5
Awareness campaign	4,950	12,900	Ministry of Environment and Forestry, Ministry of Marine and Fisheries	3
Total (million IDR)	**9,700**	**34,150**		
USD equivalent	*718,785*	*2,530,567*		

Note: OPEX = operational expenditure/running costs. ATR: The Ministry of Agrarian Affairs and Spatial Planning (*Kementerian Agraria dan Tata Ruang*), BPN = National Land Agency, Agrarian and Spatial Planning Ministry (*Badan Pertanahan Nasional AgrariaTata Ruang*).

Impact on nutrient loads

The impacts of aquaculture production were quantified to illustrate the relative contributions of the scenarios on improving the water quality of Lake Toba. The high and increasing nutrient loads of the *baseline* Scenario A and the maximized production of the *low* levels of interventions in Scenario B are evident in Figure 67. Also, the difference in scale of impact between pursuing a gradual reduction of nutrient load (Scenario C, intermediate level of interventions) versus a rapid reduction (Scenario D and Scenario E, high and optimized level of interventions) is also apparent—especially for the near future of 2024.

A large reduction in nutrient loads can be achieved in the northern compartment and the S2 compartment. Figure 67 also shows the nitrogen and phosphorous loads and long-term concentration under the five scenarios, allowing for a comparison on impact across the lake. All lake compartments would experience a drop in long-term phosphorous concentrations below the oligotrophic threshold of 10 µg/l in Scenario C by 2042 and by 2022 in Scenario D and Scenario E. The maximum production level of 10,000 tons of fish per year on its own would therefore not threaten long-term oligotrophic conditions. However, continued loads would still contribute to long-term bioaccumulation and local eutrophication effects.

Livestock

Interventions

The interventions in the livestock sector are aimed at assessing the opportunities for converting livestock manure to biogas energy, reducing nutrient emissions into Lake Toba and providing a source of revenue. The Indonesian Domestic Biogas Program (*Biogas Rumah,* BIRU[147]) promotes the use and market of biogas plants as local and sustainable sources of energy.[148] The BIRU program is implemented by Yayasan Rumah Energi and had built over 16,000 biogas plants in nine provinces in Indonesia by 2016.

For a low-maintenance biogas plant, a household would need manure from at least two cows or seven pigs or 170 poultry to produce gas for daily cooking and lighting needs.[149] The estimated useful life of the biogas asset is 15 years and construction cost is IDR 6.0–7.5 million. The choice between an individual household or communal biogas plant depends on the distance between houses. A successful pilot is suggested in a minimum of three areas and should be supported with advocacy and training to accelerate wider uptake. The proposed construction of 17 biogas plants is included under Scenario C and 22 plants in Scenarios D and E. Upscaling over time based on demonstrable results is suggested, doubling the efforts to ensure 20 percent uptake in Scenario C and 30 percent uptake in Scenarios D and Scenario E by 2022.

An action plan for the management of pollution from livestock covering all municipalities around Lake Toba is recommended to facilitate uptake and consistency. This action plan could focus on identifying piloting sites and training activities and be facilitated by the Livestock and Animal Health Agency of North Sumatra Province in cooperation with related agencies in each regency (*kabupaten*) and the Lake Toba Tourism Area Management Authority. Partnering with local agencies and NGOs could improve implementation and uptake. The training and institutional efforts of Scenario D and Scenario E are 1.5–2.0 times of those required for Scenario C.

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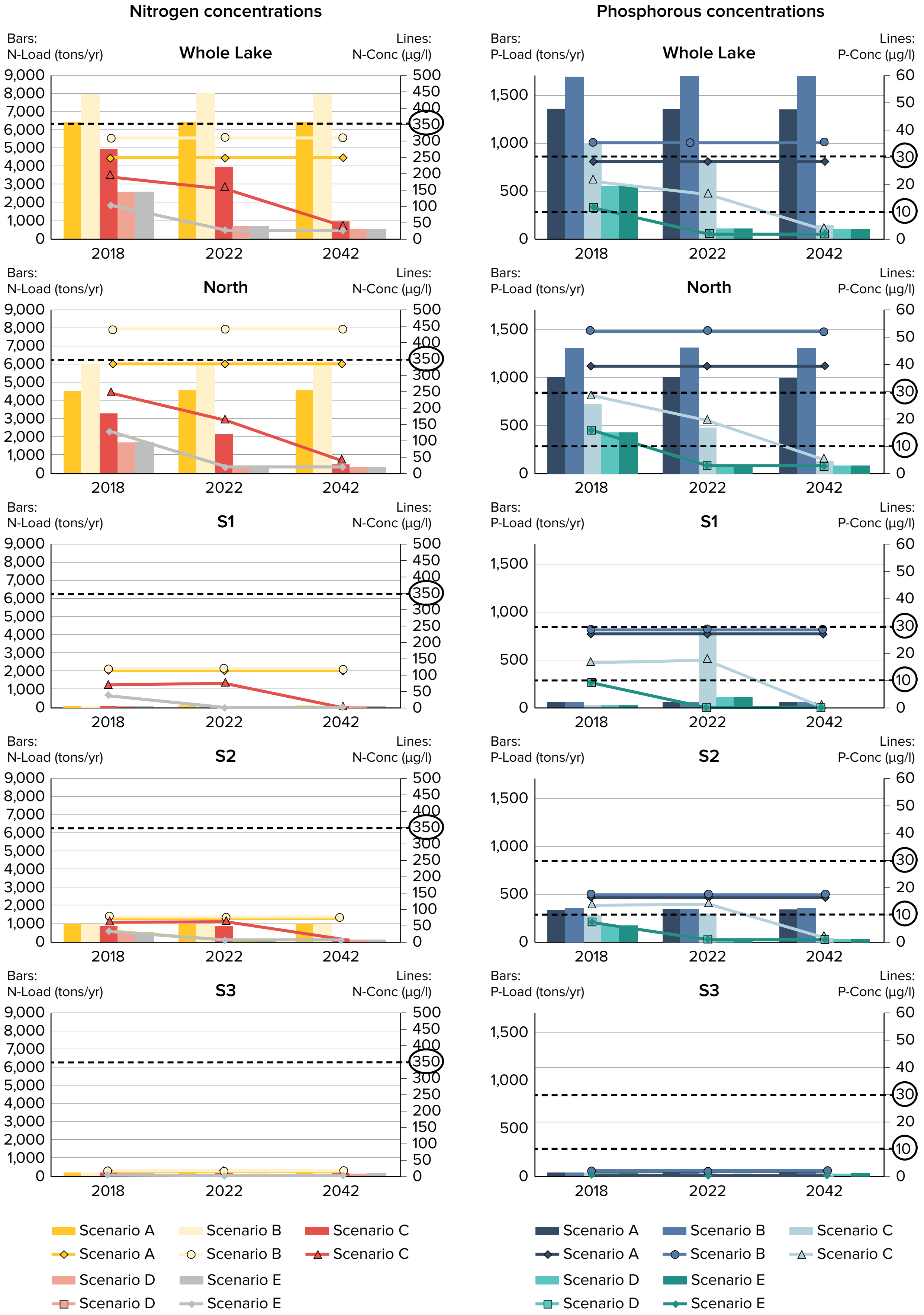
[147] Meaning biogas for the home.

[148] Initiated by the NGOs Hivos and SNV.

[149] www.biru.or.id

FIGURE 67. Projected impact of aquaculture in all scenarios on long-term nitrogen and phosphorous concentrations by the whole lake and by lake compartment against oligotrophic and mesotrophic concentration thresholds



Note: The nutrient concentration levels represent the long-term result of a load in a year, assuming that aquaculture is the only source of nitrogen and phosphorous. The threshold for oligotrophic (10 µg/l phosphorous and 350 µg/l nitrogen) and mesotrophic conditions (30 µg/l phosphorous) are marked by black circles.[150]

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[150] Nürnberg, 1996.

Cost estimates

The estimated costs to reduce nutrient emissions through livestock biogas amounts to IDR 12.92 billion (USD 0.96 million) for Scenario C and IDR 18.77 billion (USD 1.39 million) for Scenario D and Scenario E (Table 27). The cost estimates were grouped for infrastructure, institutional, and communication interventions. More details on proposed activities and costing are provided in Appendix G.

TABLE 27. **Estimated costs of converting 20 percent in Scenario C, and 30 percent in Scenarios D and E of livestock manure into biomass by 2022 (million IDR)**

	Scenario C		**Scenarios D and E**			
	CAPEX	**OPEX**	**CAPEX**	**OPEX**		
Interventions	**(m IDR)**				**Responsibility**	**Duration (years)**
Infrastructure						
Pilot project biogas	340	26	440	33	Dinas Peternakan at 7 kabupaten—coordinated by Dinas Peternakan & Kesehatan Hewan (DPKH) provinsi	0.5
Upscaling biogas installations	5,000	1,000	7,000	1,400		4
Institutional						
Coordination		300		400	DPKH Province Sumatera Utara	5
Training		2,500		4,000		5
Information						
Guiding studies		3,000		4,500	DPKH Kabupaten & Province Sumatera Utara	0.5
Campaign		750		1,000		
Subtotal	*5,340*	*7,576*	*7,440*	*11,333*		
Total (million IDR)	**12,916**		**18,773**			
USD equivalent	*396,000*	*561,000*	*551,000*	*840,000*		
USD equivalent	*957,000*		*1,391,000*			

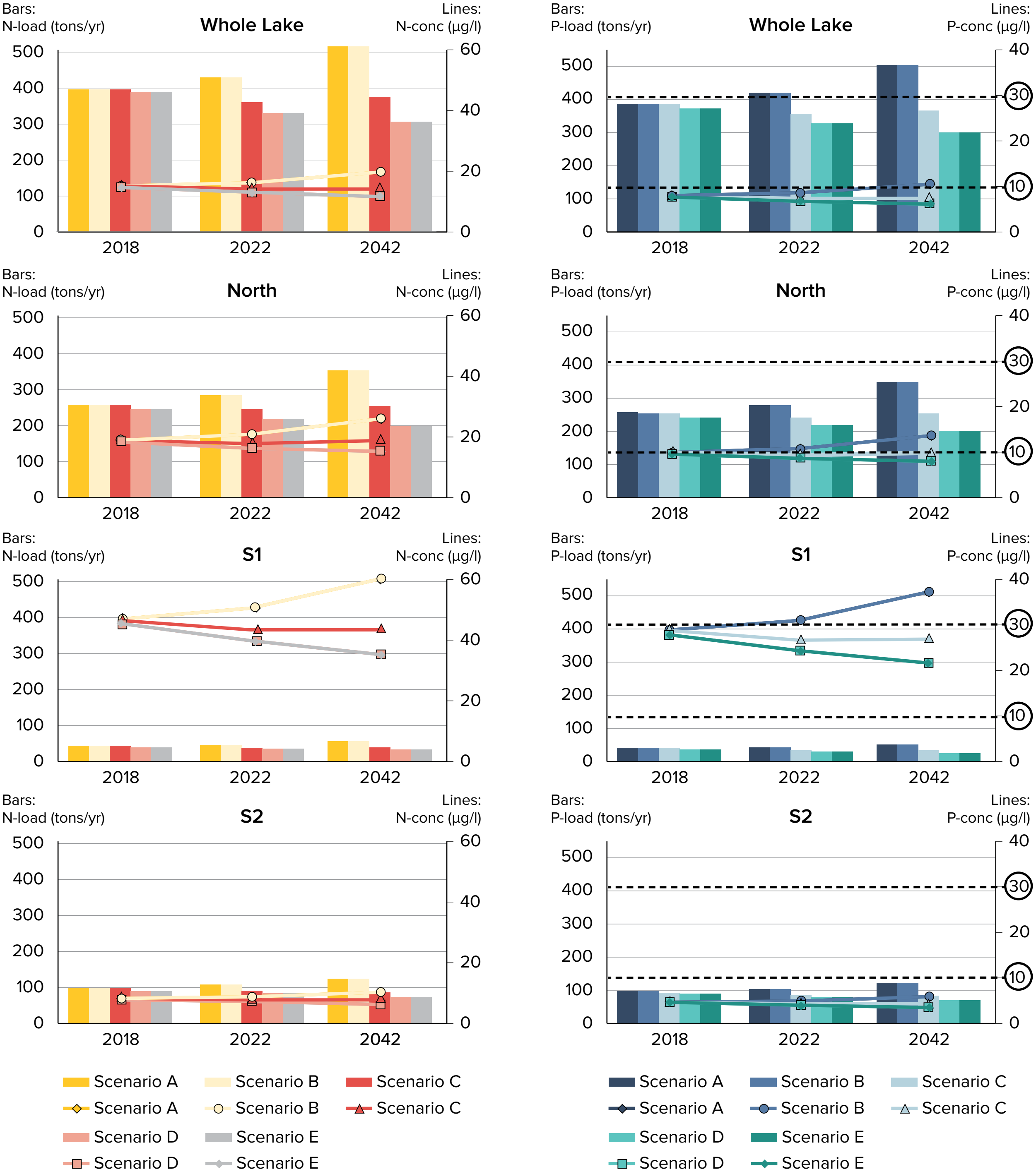
Note: OPEX = operational expenditure/running costs. CAPEX = Capital Expenditures.

Impact on nutrient loads

The impacts of using livestock manure for biogas were quantified to illustrate the relative contributions for improving the water quality of Lake Toba. Future autonomous growth of livestock is based on population and land use projections in the Sumatra Spatial Model. The proposed interventions to reduce nutrient emissions are only proposed in Scenarios C, D, and E. In Scenario C, there is a 1 percent conversion of livestock manure in 2018, rising gradually to 20 percent by 2022 and 40 percent by 2042. In Scenario D and Scenario E, the conversion of livestock is more ambitious, resulting in 5 percent uptake in 2018, 30 percent by 2022, and 60 percent by 2042. All scenarios assume an efficiency of 70 percent reduction of nitrogen and phosphorous. In Figure 68, the comparative impact is shown for Lake Toba.

The impact of converting livestock manure into biogas is limited at the lake level (but not locally in the S1 compartment). The nitrogen and phosphorous loads of Scenarios C, D, and E are shown alongside baseline Scenarios A and B (i.e., no intervention) in Figure 68 for the whole lake and for three lake compartments (north, S1, and S2). No modelling could be performed for compartment S3 due to insufficient data. Scenario C can compensate for autonomous growth. For phosphorous, the impact is more pronounced, particularly for Scenario D and Scenario E. In the northern compartment, the reduction of phosphorous loads in Scenarios D and E would eventually lead to concentrations below the oligotrophic threshold. In the S1 compartment, the low loads are predicted to lead to concentrations at the mesotrophic level even when manure is converted into biogas in all three scenarios. Without interventions, the increasing loads would contribute to a eutrophic state in S1.

FIGURE 68. Projected impact of livestock in all scenarios on long-term nitrogen and phosphorous concentrations[151] against oligotrophic and mesotrophic concentration thresholds



Note: The nutrient concentration levels represent the long-term result of a load in a year, assuming that livestock are the only source of nitrogen and phosphorous. The threshold for oligotrophic (10 µg/l phosphorous) and mesotrophic conditions (30 µg/l phosphorous) are marked by black circles. Nitrogen levels remained below the 350 µg/l limit for the mesotrophic classification.[152]

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[151] As Scenarios A and B are the same, the concentrations for Scenario A are not visible; these are the same as for Scenario B.

[152] Nürnberg, 1996.

Wastewater

Interventions

The interventions in wastewater are aimed at assessing the benefits of improved water supply and sanitation on nutrient emissions into Lake Toba but would also contribute to important social improvements. Water plays an important part of the overall human capital, with improved water quality and sanitation contributing to the reduction of many infectious diseases and improving the overall quality of life.

The only wastewater treatment (WWT) plant in the Lake Toba area, in Parapat, is operating at 10 percent capacity, serving 200 connected households.[153] Only three out of 45 hotels near Lake Toba are connected to the system—meaning that most hotels (with restaurants) discharge their wastewater directly into the lake. The plant is managed by the Regional Water Utility Company (*Perusahaan Daerah Air Minum,* PDAM Tirtanadi) and has been operational since 2000. It has a conventional system consisting of aeration ponds, facultative ponds, and maturation ponds, all equipped with aerators. The sewerage system also covers 15,000 meters of pipeline equipped with 128 manholes and three pump rooms. The plant has a capacity to treat 900–2,000 m^3 per day (equivalent of 3,000 household connections). The system is in significant need of rehabilitation, which would provide a cost-effective intervention to immediately improve the control of nutrient emission from wastewater in the Lake Toba area. With rehabilitation, new efficiencies and technologies could be introduced, and the system's land and environmental footprints could be reduced. Additional WWT facilities are planned for Balige and Toba Samosir Districts, although budgets and timelines have not been set and there are delays in the land acquisition processes.

Achieving improved sanitation coverage gradually, according to government plan or through accelerated planned investments, is assessed in Scenarios B, C, D, and E. Scenario B assumes the slowest improvements to sanitation services with lengthy processes for securing permits and financing. Scenario C and Scenario E propose sanitation investments as outlined in the 2015 Urban Sanitation Development Program (USDP).[154] Scenario D, however, proposes an accelerated implementation of the USDP (i.e., the 100 percent coverage target would be achieved by 2022 instead of 2042). Specifically, Scenario D proposes additional sanitation facilities and a shift to off-site centralized sewerage for the main tourism areas on the southern and eastern lake shores (were population densities are higher). For tourism projections, the estimated number of visitors is assumed to be business-as-usual in Scenario B, best-case numbers in Scenario C and Scenario E (with no additional sanitation infrastructures), and best-case numbers with additional sanitation facilities in Scenario D.

The appropriate type of sanitation service for each scenario was determined by nationally agreed targets and criteria (Table 28). Scenarios B, C, and E build on community-based sanitation systems (e.g., *Sanitasi Berbasis Masyarakat,* SANIMAS) and individual septic tanks[155] for rural areas. For urban areas, off-site centralized sewerage systems would provide coverage for 5 to 10 percent of the population by 2042 in the three scenarios. In all, the majority of domestic wastewater will not be treated to reduce nutrient emissions. In Scenario D, an accelerated shift toward centrally managed off-site sewerage system is achieved whereby half the population is covered by 2042. The remaining half will have advanced treatment, including nutrient removal.

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[153] PDAM Tirtabadi communication, November 2017.

[154] The original budget in the Asian Development Bank study turned out to underestimate the costs of off-site sanitation; in the scenarios presented here, this has been corrected.

[155] City Wide Sanitation Investment Program, 2016.

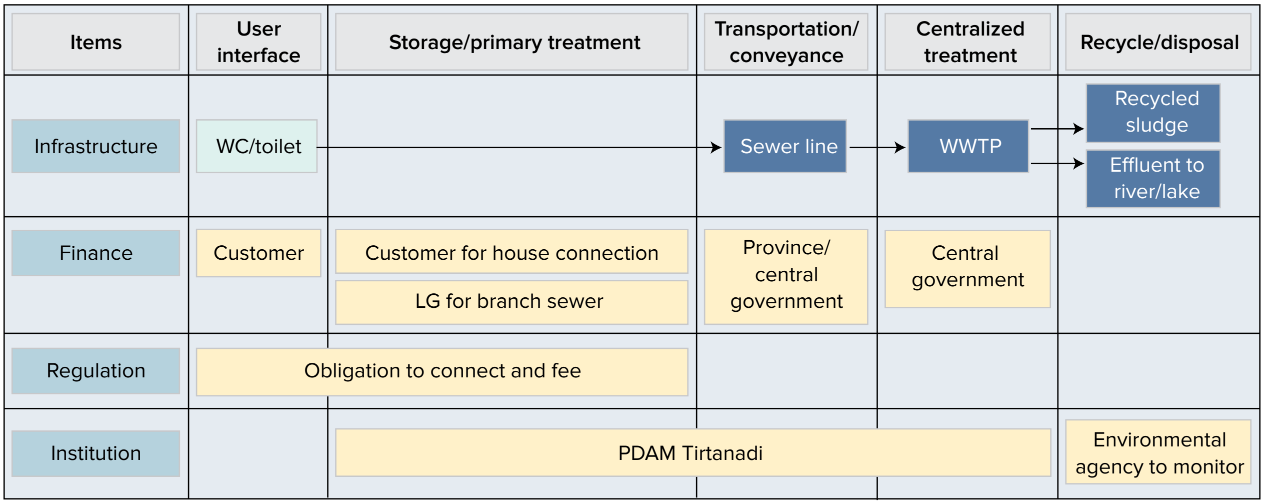
TABLE 28. Selection criteria for sanitation alternatives

	Criteria									
Population density (pp/ha)	<25		25–100		100–175		175–250		>250	
Urban function/planned sanitation service level (BPSan, RTRW)	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
On-site facility (e.g., pit latrine)	▨	▨	▨	1						
Community based *(Sanimas)*					▨		▨		2	
Off-site (centrally managed, > 10,000 households)										
District WWT *(Kawasan)*				1				▨	2	
Center WWT *(Terpusat)*										3

Note: 1 = On-site systems for existing areas, district WWT (kawasan) for new areas; 2 = Community-based and district WWT for high density rural areas; and 3 = No clear distinction between district (kawasan) and centralized (terpusat) WWT, off-site capacity of > 10,000 households. BPSan = District Sanitation Strategy; RTRW = Spatial Plan for national, province, city and districts; Rencana Tata Ruang Wilayah Nasional/Provinsi/Kota/Kabupaten.

Achieving the projected results for wastewater management will require incentives, institutional cooperation, and clear mandates.[156] Incentive programs supported by provincial and national governments could help local governments align wastewater programs and on-site sanitation solutions.[157] The wastewater section of PDAM Tirtanadi has the institutional mandate, and the institutional arrangements for managing and sustaining the plant in Parapat were outlined in 2008 (Figure 69). These remain relevant and could inform management of future WWT plants. Financial mechanisms such as subsidies for connection to the system could improve household uptake. Communal systems are managed by the community, and on-site systems such as septic tanks are usually owned by each household.

FIGURE 69. Supply chain for best wastewater scenarios at Parapat



Items	User interface	Storage/primary treatment	Transportation/ conveyance	Centralized treatment	Recycle/disposal
Infrastructure	WC/toilet →	→	Sewer line →	WWTP →	Recycled sludge Effluent to river/lake
Finance	Customer	Customer for house connection LG for branch sewer	Province/ central government	Central government	
Regulation	Obligation to connect and fee	Obligation to connect and fee			
Institution		PDAM Tirtanadi	PDAM Tirtanadi	PDAM Tirtanadi	Environmental agency to monitor

Source: Tilley et al., 2008.

To achieve the benefits projected in the scenarios, it is recommended that the City Sanitation Working Group for Lake Toba is reactivated and that they develop an action plan for improving wastewater management to protect Lake Toba. For all sanitation interventions, it is important that multiple government agencies and stakeholders are active and cooperate. In the case of Lake Toba, this would include: the local Public Works Agency *(PU Dina)* for overall planning mandate; the Health Agency *(Dinas Kesehatan)* and the Communication and Information Agency *(Dinas Kominfo)* for advocacy and campaigns; the local National Development Planning Agency (*Badan Perencanaan Pembangunan*

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[156] USDP, 2015.

[157] An outline of steps, timelines, and activities for strategic level sanitation planning (as developed by the 2016 City-Wide Sanitation Program) can be found in Appendix H.

Nasional, BAPPENAS) for programs and budget allocations; and the utility PDAM Tirtanadi for operations. To take part in the National Accelerated Sanitation Development for Human Settlements Program (*Program Nasional Percepatan Pembangunan Sanitasi Permukiman,* PPSP), a municipality must establish a City Sanitation Working Group. The Ministry of Home Affairs requires the group to be chaired by the municipal secretary. The City Sanitation Working Group for Lake Toba could play a central role in improving wastewater management in the area.

Cost estimates

Investments and prioritization of centralized sewerage systems in Scenario D require more financing than the other scenarios but at a lower direct cost for communities. Cost estimates for Scenarios B, C, D, and E were determined based on capital expenditure investments (CAPEX) and operational expenditures (OPEX) for running and managing the investments, using both public and private financing. The costs for sewer systems in new areas are expected to reduce by 50 percent[158] compared to investments in existing areas. The cost for a WWT plant is assumed to be the same in existing and new areas. Costs were determined based on unit cost per person over five years (Table 29). The estimates show that Scenario D is costlier (especially up front) but brings a decrease in direct cost to community users (~0.4x) compared to Scenario A. The investment costs in wastewater could be discouragingly high and reduce the appeal of Scenario D. Scenario E provides an optimized combination of interventions from the perspective of long-term impact on nutrient loading.

TABLE 29. **Estimated costs of domestic wastewater interventions (including tourism) in Scenarios B, C, D, and E (million IDR)**

	Scenario B		Scenarios C and E		Scenario D		
	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	
Interventions	(m IDR)						Responsibility
Infrastructure							
On-site systems	86,000	66,215	203,000	75,434	219,000	76,652	Users/community, national and local government
Community-based systems	474,000	22,965	848,000	41,097	349,000	16,914	
WWT	76,000		103,000		102,000		National and local government
Medium centralized	95,000	10,925	236,000	18,655	3,693,000	240,932	National and local government
Institutional and information are included in OPEX							
Subtotal	731,000	100,105	1,390,000	135,185	4,363,000	334,498	
Reserved	730,472	100,105	730,472	100,105	730,472	100,105	
Extra investment required (10^6 IDR)	528	0	659,528	35,081	3,632,528	234,393	
Total (million IDR)	**529**		**694,610**		**3,866,922**		
USD equivalent	*39,000*	*0*	*48,872,000*	*2,600,000*	*269,176,000*	*17,369,000*	
USD equivalent	*39,000*		*51,472,000*		*286,545,000*		

Note: OPEX = operational expenditure/running costs; CAPEX = capital expenditures.

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[158] Based on data of the Dutch situation it is found that more than half of the costs of the sewer system in existing areas are related to the opening and closing of existing roads and pavements. In new developments, the opening up of the streets is not needed and the construction of pavement is considered part of the general development, so a 50 percent factor for sewer system development is applied.

Impact on nutrient loads

The impacts of improving wastewater management were quantified to illustrate the relative contributions of the scenarios on improving the water quality of Lake Toba. The estimated nutrient reduction and assumed interventions and number of visitors is presented in Table 30. Notably, many urban on-site sewerage solutions do not comply with the definition of a septic tank but instead resemble pit latrines, with implications for nutrient leakage into the groundwater.[159] Local improvements to on-site facilities (e.g., septic tanks and community-based systems) would translate into a 5 percent nutrient reduction. Off-site centralized systems are more effective and are estimated to remove 67 percent of nutrients.[160]

TABLE 30. Access to sanitation services and corresponding reduction in nutrient emissions per scenario (%)

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
2018					
On-site (%)	0	0	0	0	0
Centralized (%)	0	0	0	0	0
Peak number of tourists	300,368	300,368	300,368	300,368	300,368
Total nutrient reduction (%)	**0**	**0**	**0**	**0**	**0**
2022					
On-site (%)	0	66	85	69	85
Centralized (%)	0	1	2	31	2
Peak number of tourists	343,114	343,114	368,623	368,623	368,623
Total nutrient reduction (%)	**0**	**4**	**6**	**24**	**6**
2042					
On-site (%)	0	94	94	50	94
Centralized (%)	0	6	6	50	6
Peak number of tourists	384,500	384,500	368,623	368,623	368,623
Total nutrient reduction (%)	**0**	**9**	**9**	**36**	**9**

Although the impact of reducing nutrient loads through wastewater will be low for the lake as a whole, local effluents can give rise to local deterioration. Most people live in non-urban areas and will continue to use septic tanks (i.e., 50 percent are assumed to use on-site solutions by 2042 in Scenario D). These on-site systems have a limited effect on nutrient emissions at the basin level (Figure 70) but local effects however, could be higher. There are also a range of broader benefits to human health and social well-being to be derived from improvements in sanitation.

The projected nutrient emissions from wastewater show increasing loads from population growth in all scenarios except Scenario D due to its high level of interventions in wastewater treatment. The target of having 50 percent connected to centralized sewerage systems by 2042 in Scenario D would bring nutrient emissions below 2018 levels, despite population growth. In the large northern and S2 compartments, the long-term phosphorous concentrations do not go beyond the threshold for oligotrophic conditions. In compartment S3, only Scenario D could maintain oligotrophic conditions; all others would bring mesotrophic conditions. In the small S1 compartment, however, concentrations would go beyond the mesotrophic threshold in all scenarios.

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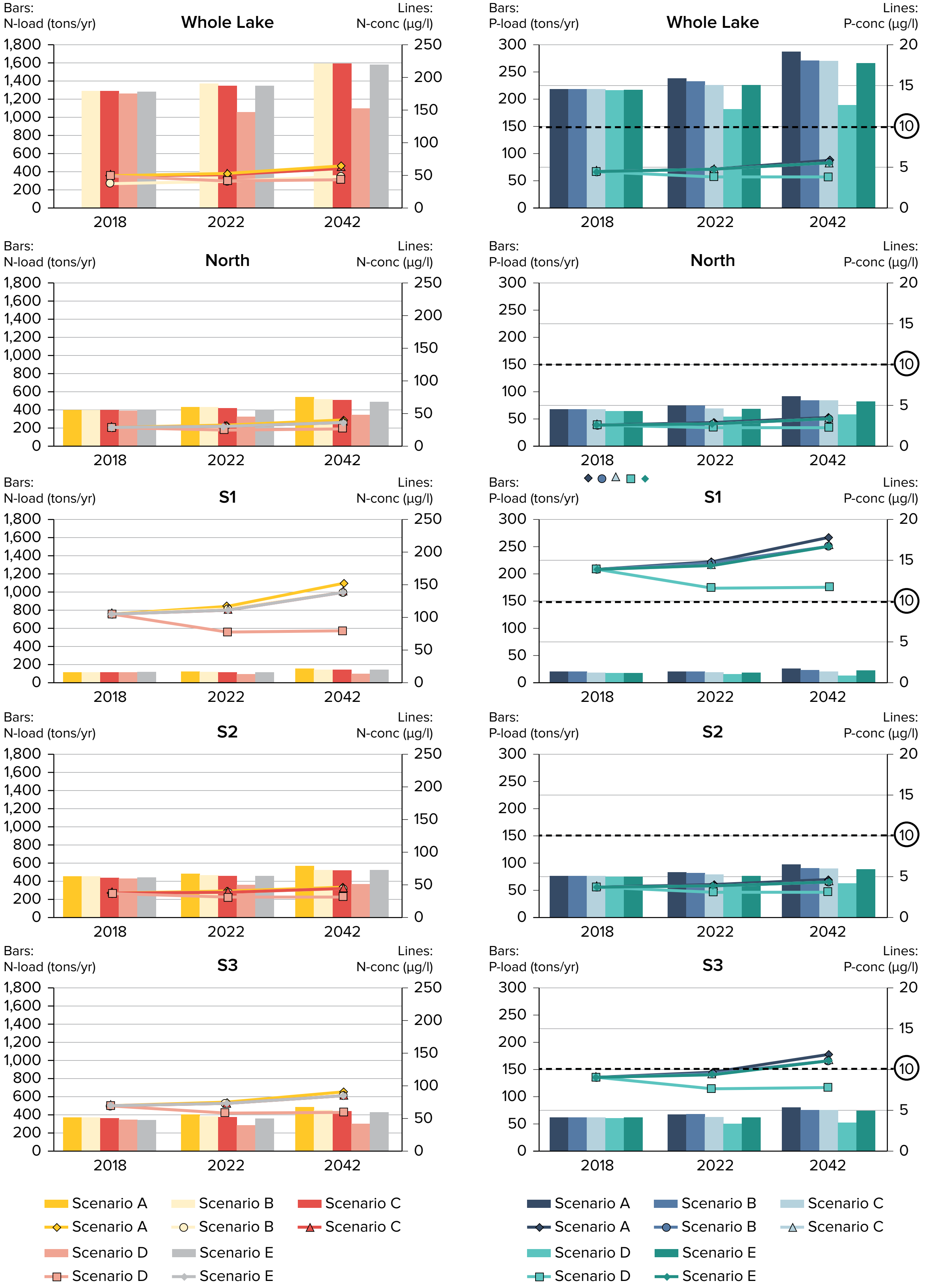
[159] Kearton et al., 2013.

[160] Kerstens et al., 2015.

FIGURE 70. Projected impact of wastewater loads in all scenarios on long-term nitrogen and phosphorous concentrations[161] (whole lake) against oligotrophic and mesotrophic concentration thresholds



Note: The nutrient concentration levels represent the long-term result of a load in a year, assuming that wastewater is the only source of nitrogen and phosphorous.

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161 As Scenarios A and B are the same, the concentrations for Scenario A are not visible; these are the same as for Scenario B.

Other Interventions

A range of other potential sources of nutrient emissions were assessed but show relatively little impact on total nutrient loads. For example, the estimated impact of reductions in the total phosphorous load from agriculture, solid waste, and erosion is 2 percent.[162] However, these interventions could bring additional benefits beyond the impact on nutrient loading and improvements in the water quality of Lake Toba. This could include a range of economic opportunities, alternative livelihoods, enhancements to tourism, sustainability of the broader catchment, and improvements to human capital. Specific investment decisions and interventions should therefore be considered through a multicriteria assessment framework that considers the broader range of potential benefits and possible costs.

Agriculture

Creating market opportunities for organic farming could mobilize a reduction of synthetic pesticides and fertilizers. The promotion of organic farming would require capacity building and training, along with strengthened supply chain and marketing. A way to encourage the shift toward organic farming, for both conventional farming and aquaculture, is through pilot projects and government subsidies. Small local organizations have expressed interest in supporting improved agricultural farming practices and irrigation, such as the Water User Associations (WUA) during the stakeholder consultations at Laguboti (June 14, 2017).

Solid waste

Developing solid waste management services will be increasingly important with growing populations and tourism. Solid waste does not currently emit significant pollution into Lake Toba. However, solid waste could increasingly become a threat to tourism, health, environmental services, and the aesthetic appeal of the area if left unmanaged.

Based on the 2015 USDP,[163] larger areas would be serviced, and interventions would include landfills, truck trash collection, and the 3Rs (reduce, reuse, recycle) facilities. The available data on planned solid waste services was scaled down to the Lake Toba catchment area and updated with population and spatial projections in the SSM with separate input on tourism. However, interventions will service larger areas than the catchment and are organized at higher administrative levels. Additional costs for servicing catchments outside Lake Toba were not included. Further recommendations are detailed in Appendix I.

The projected levels of access to collection and to final disposal and 3R facilities are detailed in Table 31 with cost estimates presented in Table 32. Scenario B projects a slower implementation of planned solid waste services. Scenario C and Scenario E project implementation according to government plans and timelines. Scenario D represents accelerated implementation reaching 100 percent coverage by 2022.

TABLE 31. Access to solid waste disposal facilities and services in all scenarios (%)

Year	Solid waste service	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
2018	Final disposal and 3R facilities (%)	0	0	0	0	0
	Collection activities (%)	0	0	0	0	0
2022	Final disposal and 3R facilities (%)	0	10	12	100	12
	Collection activities (%)	0	11	12	100	12
2042	Final disposal and 3R facilities (%)	0	95	95	100	95
	Collection activities (%)	0	93	93	100	93

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[162] Roads, hydropower, and telecom are excluded from the estimates.

[163] National Accelerated Sanitation Development for Human Settlements Program (PPSP-2 USDP; USDP, 2015) prepared an assessment of the countrywide solid waste funding and facilities required in the period of 2015–2019 (and beyond) for the National Medium-Term Development Plan 2015–2019 (RPJMN 2015–2019).

TABLE 32. Estimated costs to reduce nutrient emissions from solid domestic waste (including tourism) by 2022

	Scenario B		Scenarios C and E		Scenario D	
	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
Solid waste investment	(m IDR)					
Infrastructure						
Final disposal and 3R facilities	106,000	18,112	120,000	20,696	295,000	135,756
Collection activities	5,000	62,915	8,000	71,271	113,000	472,554
Institutional, information (included in OPEX)						
Subtotal	111,000	81,027	128,000	91,967	408,000	608,310
Reserved	111	81,025	111	81,025	111	81,025
Extra investment required (million IDR)	110,889	2	127,889	10,942	407,889	527,285
Total (million IDR)	**110,891**		**138,831**		**935,174**	
USD equivalent (000, split)	*8,217,025*	*141*	*9,476,751*	*810,811*	*30,225,176*	*39,072,612*
USD equivalent (000, total)	*8,217,166*		*10,287,562*		*69,297,788*	

Note: OPEX = operational expenditure/running costs; CAPEX = capital expenditures.

Erosion

Erosion in the Lake Toba catchment is largely driven by land conversion and deforestation, resulting in lost top soil and higher inflow of sedimentation and nutrients into Lake Toba. There are several ways erosion can be reduced through reforestation,[164] natural infrastructures,[165] and restoration of degraded land. Such interventions can also be beneficial in terms of mitigating and controlling floods. Other options include agro-industry and agro-tourism, providing livelihoods and income opportunities for local communities. Alternatives are presented and approximately costed in Table 33 and discussed in detail in Appendix I.

TABLE 33. Erosion control measures and total costs for scenarios (USD/ha)

Erosion control measures	Costs (USD/ha)	
	Best practice interventions	Minimal interventions
Infrastructure		
Natural infrastructure (reforestation)	1,150	x
Erosion control structures	x	
Restoration of degraded lands		x
Institutional		
Develop agro-industry and agro-tourism	x	
Promote best planting practices	859	
Strengthen regulations and institutional aspects		x
Information		
Adapt Global Forest Watch Water	x	
Monitor land-use conversion		x

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[164] The Ministry of Environment and Forestry, together with the Provincial Forest Service, is implementing a reforestation program.

[165] For example, containment dam and gully plugs in the upper watershed, controller dam and terraces in the central part of the watershed, and infiltration wells in the lower watershed.

Combined Impact and Costs of Scenarios

Nutrient loads

The combined impact of reducing nutrient emissions in aquaculture, livestock, and wastewater for all scenarios was quantified to illustrate their relative effect. The projected impacts for the whole lake and by lake compartment are shown in Figure 72 (graphs show loads and concentrations at fixed scales to enable comparisons between compartments).

Without interventions, Scenario A and Scenario B, the nutrient concentrations will rise to long-term eutrophic conditions for phosphorous and mesotrophic conditions for nitrogen in the north and S1 compartments. The deterioration in the north and S1 is due the nutrient loads from aquaculture. The S2 and S3 compartments would remain mesotrophic for phosphorous and oligotrophic for nitrogen.

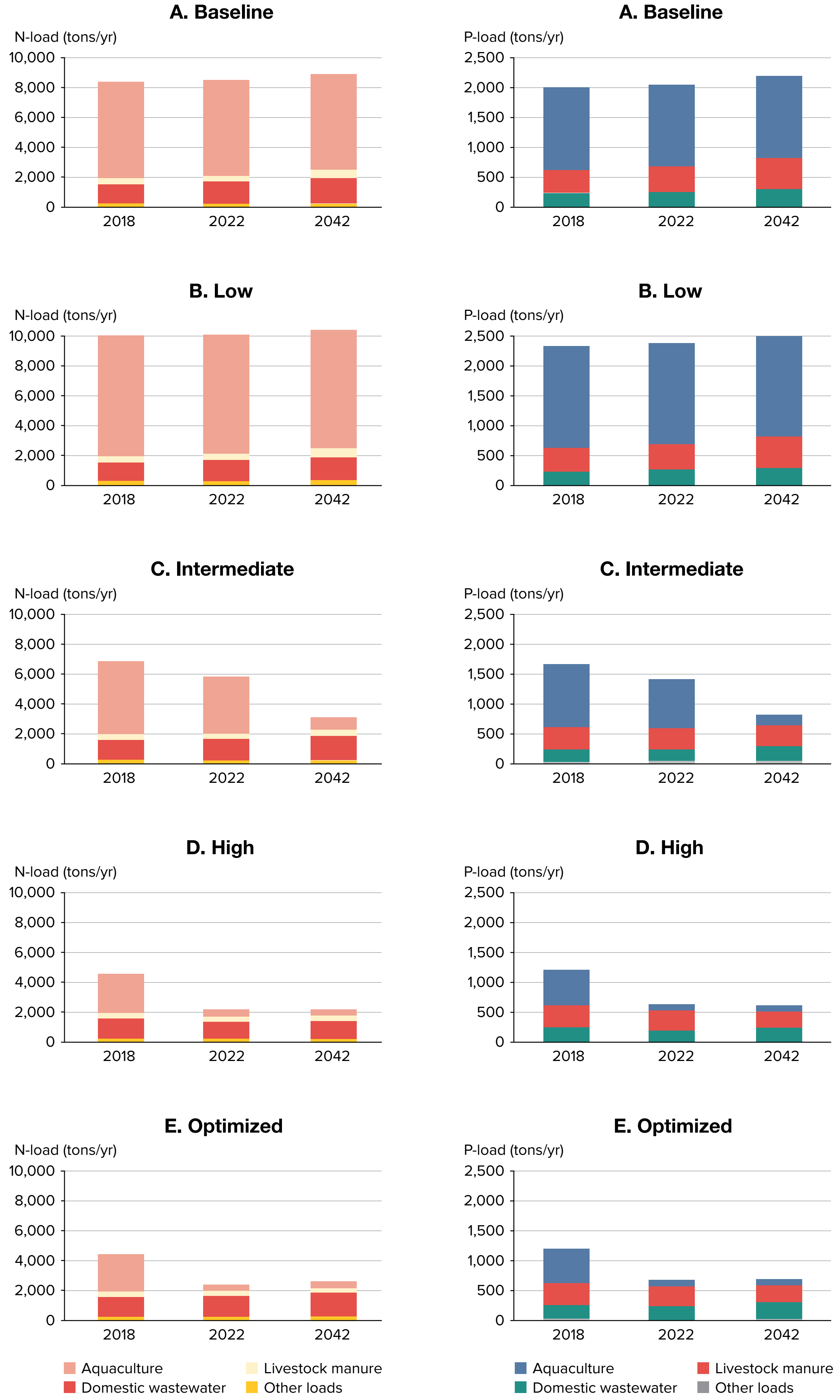
The intermediate (Scenario C) and high-level interventions (Scenario D and Scenario E) have the most substantial impact on reducing nutrient loading to improve Lake Toba's water quality. The contribution of each of the scenarios on nitrogen and phosphorous were quantified (Figure 71) to illustrate the relative impacts of interventions. The analysis shows that livestock and wastewater interventions have minimal impact on nutrient loads but relatively higher impact on phosphorous loads. The most significant reductions in nitrogen and phosphorous are only derived, however, when aquaculture production volumes are reduced (i.e., blue bars).

The optimized Scenario E was modelled to explore a combined level of wastewater interventions while maintaining ambitious emission targets for aquaculture and livestock. The interventions to reduce nutrient emissions from aquaculture and livestock manure have high impacts for relatively low costs compared to wastewater interventions. Scenario E, therefore, proposes a balanced and financially optimized alternative to Scenario D. Overall, the resulting long-term nutrient concentrations of Scenario E are comparable to those of Scenario D (except for the S3 compartment and for nitrogen in the S1 compartment). Compartment S3 is the only place where the alternative Scenario E leads to long-term phosphorous concentrations that would change the eventual conditions from oligotrophic to mesotrophic.

Although no scenario would lead to oligotrophic conditions in terms of phosphorous for the whole lake, Scenario D could result in oligotrophic conditions in S3 to the benefit of the Asahan River. In Scenario D, the reduction of phosphorous loads from 2022 onward in the S2 and S3 compartments would eventually bring their phosphorous concentrations from mesotrophic conditions down to just below the oligotrophic threshold. If Scenario D is achieved, oligotrophic water will eventually flow out of compartment S3 into the Asahan River benefitting downstream users. Concentrations in the northern compartment would slowly go down below the threshold for mesotrophic conditions, based on the loads in 2022 and 2042 in Scenario C and in all years in Scenario D and Scenario E.

Aquaculture coupled with high population and livestock densities means the S1 compartment will continue to experience very high, long-term nutrient concentrations. Although aquaculture is reduced in Scenarios C, D, and E, the loads from livestock and wastewater separately bring long-term phosphorous concentration to levels above the oligotrophic threshold (Figure 72). Combined, loads surpass the mesotrophic threshold and reach phosphorous concentrations associated with eutrophic conditions even under Scenarios C, D, and E.

FIGURE 71. Total nitrogen and phosphorous loads of all scenarios (whole lake) for 2018, 2022, and 2042



A. Baseline

B. Low

C. Intermediate

D. High

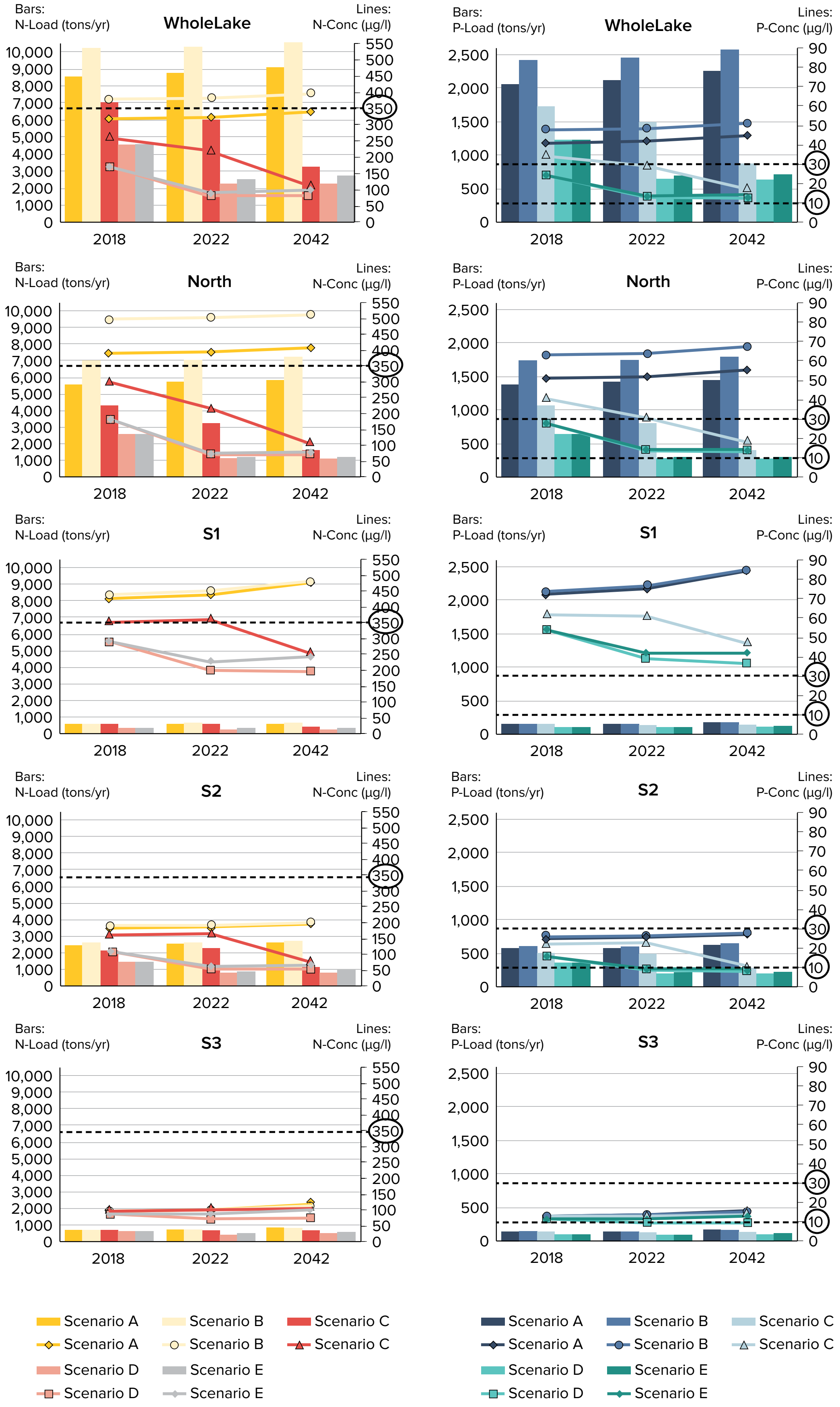
E. Optimized

Cost estimates

The total costs for interventions in aquaculture, livestock, and wastewater, coupled with investments in water quality monitoring, are presented in Table 34 for each scenario. The five-year costs for the most ambitious reduction in nutrients of Scenario D would be IDR 3,919.8 billion (USD 290.5 million). Combined with the IDR 433.8 billion (USD 32.1 million) cost estimate for improving water quality monitoring with *statistical* function, the total costs would be IDR 4.354 billion (USD 322.6 million). However, the considerable cost difference between Scenario C and Scenario D is due to the projected investments in wastewater infrastructure (i.e., IDR 694.6 billion/USD 51.5 million in Scenario C, and IDR 3,866.9 billion/USD 286.6 million in Scenario D).

The optimized Scenario E requires a combination of significant interventions in aquaculture and livestock with intermediate interventions for wastewater. The total five-year costs of water quality management interventions in Scenario E would be IDR 747.5 billion (USD 55.4 million), which is not significantly higher than Scenario C (IDR 717.2 billion/USD 53 million). Combined with the cost for improving water quality monitoring with *statistical* function, the total costs for both water quality management and monitoring of Scenario E will be IDR 1.181 billion (USD 87.5 million).

FIGURE 72. Projected impact of all scenarios on long-term nitrogen and phosphorous concentrations by the whole lake and by compartment, against oligotrophic and mesotrophic concentration thresholds



Note: The threshold for oligotrophic (10 µg/l phosphorous and 350 µg/l nitrogen) and mesotrophic conditions (30 µg/l phosphorous) are marked by blue circles and dotted lines.[166]

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[166] Nürnberg, 1996.

TABLE 34. Summarized targets and costs for all scenarios and five-year interventions, 2018–2022 (m IDR, USD)

	Scenario A	Scenario B		Scenario C		Scenario D		Scenario E	
	(m IDR)								
	n/a	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
Water quality management (m IDR)									
Targets									
Fish production (tons)	84,800	106,000		50,000		10,000		10,000	
Conversion of manure into biogas (%)				20		30		30	
Peak tourist numbers	343,114	343,114		368,623		368,623		368,623	
Access to:									
On-site and community-based systems (%)	0	66		85		69		85	
WWT systems (%)									
Access to:		1		2		31		2	
Centralized WWT systems (%)									
Investments (m IDR)									
Aquaculture					9,700		34,150		34,150
Livestock				5,340	7,576	7,440	11,333	7,440	11,333
Wastewater[167]		528		659,528	35,081	3,632,528	234,393	659,528	35,081
Subtotal		**528**		**664,868**	**52,357**	**3,639,968**	**279,876**	**666,968**	**80,564**
Total (CAPEX + OPEX in million IDR) for 5 years		529		717,225		3,919,845		747,533	
Water quality monitoring (m IDR)									
Function	*n/a*	*Signaling*		*Exploratory*		*Statistical*		*Statistical*	
Total (million IDR) for 5 years		**78,966**		**227,978**		**433,775**		**433,775**	
Total water quality management and monitoring for 5 years (milion IDR)	n/a	**79,495**		**945,203**		**4,353,620**		**1,181,308**	
	Scenario A	**Scenario B**		**Scenario C**		**Scenario D**		**Scenario E**	
	USD equivalent								
	n/a	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
Water quality management (USD)									
Fish production (tons)	84,800	106,000		50,000		10,000		10,000	
Conversion of manure into biogas (%)				20		30		30	
Peak tourist numbers	343,114	343,114		368,623		368,623		368,623	
Access to:									
On-site and community-based systems (%)		66		85		69		85	
Centralized systems (%)									
Access to:		1		2		31		2	
Centralized WWT systems (%)									
Investments									
Aquaculture					719,000		2,531,000		2,531,000
Livestock				396,000	561,000	551,000	840,000	551,000	840,000
Wastewater		39,000	0	48,872,000	2,600,000	269,176,000	17,369,000	48,872,000	2,600,000
Subtotal		**39,000**	**0**	**49,268,000**	**3,714,000**	**269,727,000**	**20,739,000**	**49,423,000**	**5,970,000**
Total (CAPEX + OPEX in USD) for 5 years		39,000		52,982,000		290,466,000		55,393,000	
Water quality monitoring (USD)									
Function	*n/a*	*Signaling*		*Exploratory*		*Statistical*		*Statistical*	
Total (USD) for 5 years		**5,849,359**		**16,887,237**		**32,131,511**		**32,131,511**	
Total water quality management and monitoring for 5 years (USD)	n/a	**5,888,359**		**69,869,237**		**322,597,511**		**87,524,511**	

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[167] For wastewater management, net required investments (minus reserved funds) are listed.

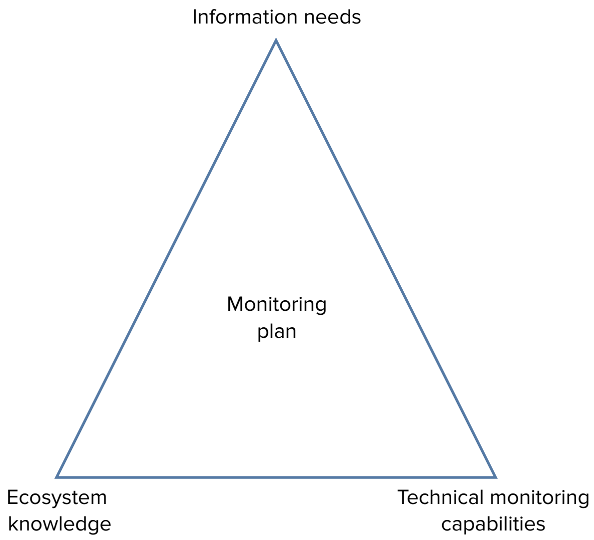
CHAPTER 8

Water Quality Monitoring Scenarios

Pillars for Formulating a Monitoring Plan

A range of options for improving the monitoring of water quality were assessed as an important pre-requisite for adaptive management and continuous improvement of the water quality in Lake Toba. The design priorities of effective water quality monitoring rest on three important pillars:[168] ecosystem knowledge; information needs; and technical monitoring capabilities (Figure 73). The detailed characteristics of the pillars need to be identified and contextualized in a multi-stakeholder process. This should inform a structured, iterative process of robust decision making given the uncertainties around the complex hydrodynamics associated with water quality in Lake Toba. Improving the underlying data and information informing management decisions will help to reduce the uncertainty over time and improve the long-term outcomes.

FIGURE 73. **The three pillars needed to formulate a monitoring plan**



Source: By Deltares, 2017.

Ecosystem knowledge

Ecosystem knowledge represents the lake ecosystem dynamics and issues that prompt water quality monitoring. Given the economic and political priorities associated with the potential eutrophication of Lake Toba, the most important

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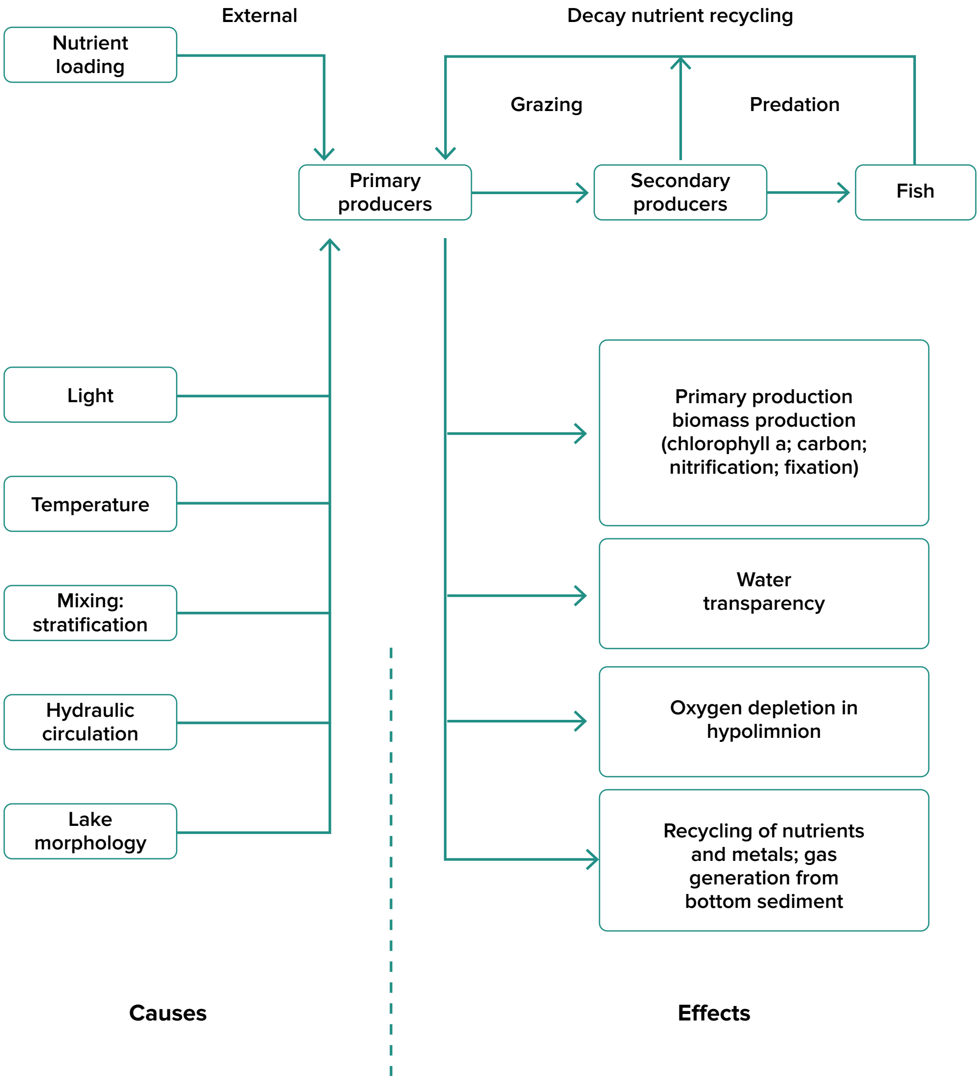
[168] Buijse and Noordhuis, 2012; Figure 76.

FIGURE 74. Eutrophication causes and effects



Source: Chapman, 1996.

parameters to monitor are those that provide insights on the causes and effects of eutrophication (Figure 74). First, this requires monitoring changes in nutrient concentration and primary producers. This will provide a signaling function. Second, monitoring should be targeted to the circumstances where negative effects occur, providing a predictive function. The latter will give rise to more parameters requiring monitoring.

Conceptualizing the lake system in the context of the catchment can help identify and build consensus on monitoring priorities with multiple stakeholders. The Indonesian Institute of Sciences (LIPI) has focused on advancing a hydrodynamic-ecological model that is used to inform policy recommendations on the management of water quality in Lake Toba (Box 3). This approach leads LIPI to identify water quality hotspots in the lake and provides the architecture for continuous development and improvement to provide a more comprehensive catchment model that can account for all the potential sources of nutrients in Lake Toba (as conceptually shown in Figure 75).

Information needs

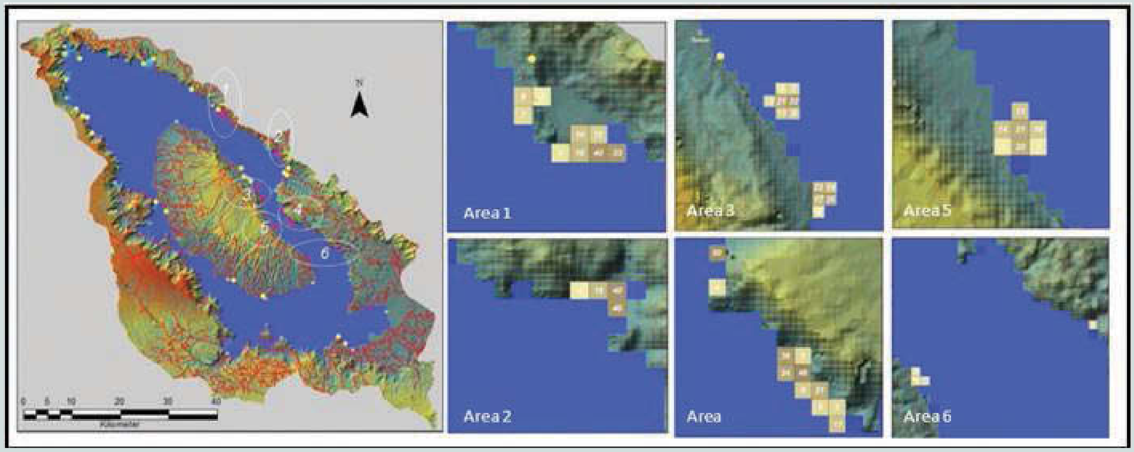
Information needs represent the prioritized data needed for management decisions and for the longer term development of a dynamic water quality model. This includes data that signal if something is wrong, that provide insight on policy implementation progress, and that provide information about the lake as a system. This analysis identifies phosphates,

BOX 3. Research Center for Limnology (Pusat Penelitian Limnologi) of the Indonesian Institute of Sciences (Lembaga Ilmu Pengetahuan Indonesia, LIPI)

The Research Center for Limnology of LIPI has a long history of research into the hydrodynamics, ecology, and water quality issues of Lake Toba. Recent research has focused on advancing the hydrodynamic-ecological model to inform policy recommendations on the management of water quality in Lake Toba. This approach leads LIPI to identify water quality hotspots in the lake.

The model's findings conclude that the floating cage fishery industry is the primary driving factor driving the eutrophication of Lake Toba. To achieve the Government of Indonesia's official objective of retaining the lake's oligotrophic status, the model can be used to inform decisions around the number and spatial distribution of fish cage units. Such information needs to be integrated within social, economic, and other environmental considerations within the framework of the prevailing legal and regulatory regime.

LIPI is committed to a continuous process of improvement. This includes further development of the hydrodynamic-ecological model to refine the level of understanding at greater resolution and confidence in delineation of compartments. LIPI is also committed to collaborating for a publicly accessible information management platform that can integrate real-time monitoring data, incorporating remote sensing data and other technologies, to improve the forecasting capabilities related to water quality and make the model widely available for users.



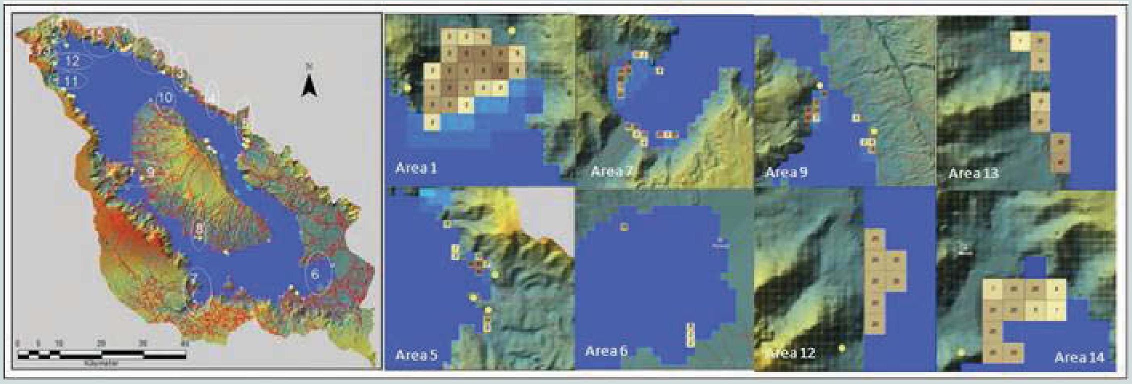
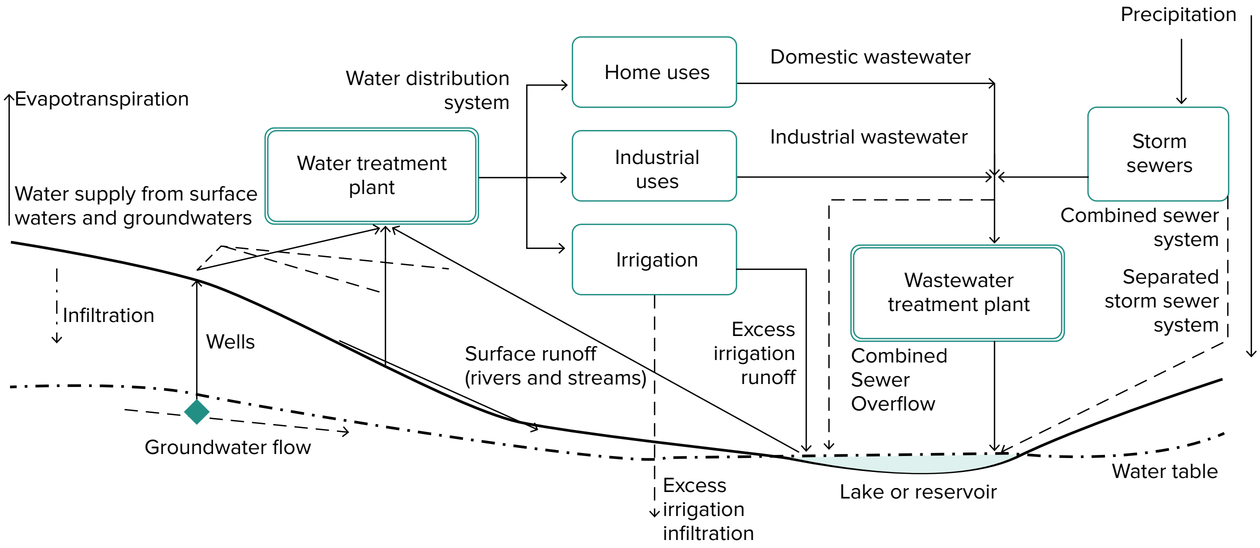


FIGURE 75. Conceptual model of a catchment



Source: Lehr et al., 2005.

and to a lesser extent nitrogen, as main determinants of eutrophication. Other relevant parameters to consider in further development of the model's capabilities and monitoring include, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), inorganic compounds, pesticides, and pathogens.

Future monitoring should increase the number of sampling sites close to pollutant sources for better insights into the nature and extent of emissions. For example, the Jasa Tirta 1 Public Corporation (PJT1) recorded increasing values for BOD and COD between May 2016 and July 2017 in Lake Toba. These results, together with the observation showing decreased dissolved oxygen, indicate that water quality continues to deteriorate further. Reducing uncertainty around physical and wind conditions would improve the understanding of the complex hydrodynamics and inform improved water quality management. The meteorological station at Medan airport used to inform current monitoring is 80 km north of Lake Toba and does not adequately monitor conditions at the lake. It is recommended that the capacity for meteorological monitoring is strengthened through the installation of four on-lake meteorological stations—one each in the central north and central south of Samosir peninsula, along with one in the west and another in the east in the lake.

Other hydrological conditions to monitor include hydrothermal dynamics, dissolved gases, and bacteria. An improved hydrothermal analysis could provide insights on upwelling events and the lake's water balance. Monitoring dissolved gases (e.g., carbon dioxide (CO_2) and methane (CH_4) and their sources) is recommended as such gases can be introduced through groundwater in areas of active volcanoes. Dissolved CO_2 can reduce the lake thermal stability (e.g., with turnover events as in Lake Nyos, Cameroon) whereas high concentrations of dissolved CH_4 can enhance lake stability. Bacterial fermentation could accelerate with more wastewater and potentially unused fish food as well.

Technical monitoring capabilities

Technical monitoring capabilities represent the institutional capacities and technologies that determine what can be measured, the level of accuracy, and at what costs. The following main institutions perform monitoring of water quality for different purposes, mandates, and resources:

- **The Provincial Environmental Agency for North Sumatra** (*Dinas Lingkungan Hidup-Sumatra Utara*, DLH-SU) has 22 near-shore sampling sites for monitoring signals and long-term lake status trends;
- **The Indonesian Institute of Sciences** (*Lembaga Ilmu Pengetahuan Indonesia*, LIPI) has 12 sampling sites in the middle of the lake for exploratory and statistical monitoring to better understand lake functions, depth profiles and for their 3D hydrodynamic model;

- **The Jasa Tirta 1 Public Corporation** (*Perusahaan Umum Jasa Tirta*, PJT1[169]) has 20 sampling sites for water quality (including a mid-lake reference site) and are advancing plans for a water quality laboratory near Parapat; and
- **PT Aquafarm Nusantara** (PTAN) has four sampling sites near the major fish farms.

Integrated Water Quality Monitoring Plan

The optimal water quality monitoring program represents one that minimizes the costs while maximizing the benefits. Once the technical priorities for monitoring water quality have been identified based on the three pillars (Figure 73), adjustments need to be made with respect to cost-effectiveness and financial sustainability. Following this order allows for a better understanding of what can technically be achieved with respect to available financing. The objectives of a monitoring plan need to be clear in this context, especially if it is implemented by multiple institutions. A collaborative stakeholder process can facilitate consensus on goals, outputs, and adjustments of the program.

Developing an Integrated Water Quality Monitoring Plan for Lake Toba will help integrate and advance monitoring capabilities. Setting up a Working Group for water quality monitoring with the main institutions DLH-SU, LIPI, PJT1 and PTAN (and primary interest groups) would provide a first step to reaching consensus on monitoring priorities and appropriate implementation arrangements. The Working Group could jointly develop an Integrated Water Quality Monitoring Plan for Lake Toba that sets out the key parameters, sampling locations, and frequencies. The Plan would also need to confirm the roles and responsibilities of the different agencies, including protocols for the exchange of data and information management, estimate the financing requirements, and identify sustainable financing mechanisms. Such a plan could be cost effectively developed in six months (Table 35).

TABLE 35. Estimated budget for developing a Water Quality Monitoring Plan

Description	Output	Investments (USD)	Time (days)
Setting up WQ Working Group (priorities, roles and responsibilities/ tasks). Result: joint workplan for developing a WQ Monitoring Plan	1 meeting and workplan description	1,000	5
Chapter I: Update and reach consensus on conceptual catchment and lake system description.	1 meeting and written chapter	4,000	20
Chapter II: Agreement on the information needs that joint WQ monitoring should meet.	2 meetings, interviews and written chapter	4,000	20
Chapter III: Inventory of existing monitoring programs and technology capabilities of all stakeholders.	1 meeting, gather and rank information	2,000	10
Chapter IV: Based on chapters I, II, and III, list lake system parameters that need to be monitored, the ideal spatial distribution and frequency of sampling. Draft template data and information to illustrate benefits.	1 meeting, template analysis to show benefits	4,000	20
Chapter V: Operational program. Allocate monitoring tasks to active institutions and illustrate budget requirements.	1 meeting. written chapter	2,000	10
Chapter VI: Information management. Document agreed data and information procedures, ownership and central database management.	Written chapter	2,000	10
Chapter VII: Open community. Explore and plan for data contribution from citizens (e.g., mapping fish cages, reporting algae blooms, etc.)	Written chapter	1,000	5
Chapter VIII: Confirm benefit and links to scientific community	Written chapter	1,000	5
Closing presentation	Stakeholder consultation	200	2
Total costs and time for devising a monitoring plan (USD, days)		**21,200**	**107**

Note: The cost estimates are based on personnel, commercial laboratory analyses, and equipment costs. Staff time of local experts is set at USD 200/day flat rate. Laboratory costs combine capital and operational expenses into unit prices as per standard water analyses.

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[169] PJT1 can collect revenue for lake management, providing opportunities to finance long-term monitoring.

Key Parameters and Sampling Frequency

The three pillars (Figure 73) used to define the monitoring program require different inputs and resources. An initial list of proposed water quality parameters to be monitored at 40 (of the 54) sites have been identified for the different functions (Table 36) and for the different background and depth profiles (Table 37). Signaling monitoring is typically carried out on a monthly basis for background information, requiring minimum investments. Statistical function monitoring is typically carried out on a weekly basis for background monitoring and for aquatic life, fishery, and recreation. Monitoring for exploration is the same as statistical, but at a lower frequency for expensive analyses (thus requiring intermediate level of investments). These three options for water quality monitoring by function are described in detail in Table 38.

TABLE 36. Sampling frequency at 40 sites of lake water quality parameters with function and price/sample

Parameter	**Frequency/month**			
Monitoring function	**Signal**	**Exploratory**	**Statistical**	**Unit price/sample (IDR)[170]**
General parameters				
Temperature	1	4	4	52,990
Color	1	4	4	148,372
Odor		4	4	52,990
Suspended solids	1	4	4	211,960
Turbidity/transparency	1	4	4	127,176
Conductivity	1	4	4	105,980
Total dissolved solids		4	4	211,960
pH	1	4	4	52,990
Dissolved oxygen	1	4	4	105,980
Hardness		4	4	190,764
Chlorophyll a	1	1	4	572,291
Nutrients				529,899
Ammonia	1	4	4	211,960
Nitrate/nitrite	1	4	4	423,919
Phosphorous	1	4	4	317,939
Organic matter				
Total organic carbon	1	1	4	529,899
Chemical oxygen demand	1	4	4	476,909
Biochemical oxygen demand	1	4	4	476,909
Major ions	1	4	4	317,939
Sodium	1	4	4	
Potassium	1	4	4	
Calcium	1	4	4	
Magnesium	1	4	4	
Chloride	1	4	4	
Sulphate	1	4	4	
Other inorganic variables				
Fluoride		4	4	211,960
Boron		4	4	169,568
Cyanide		1	4	529,899
Trace elements		1	4	582,889

(continues)

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170 The price per sample includes capital and operational expenses as per usual practice of commercial laboratories.

TABLE 36. Continued

Parameter	Frequency/month			Unit price/sample (IDR)[170]
Monitoring function	Signal	Exploratory	Statistical	
Heavy metals		1	4	317,939
Arsenic and selenium		1	4	
Organic contaminants				
Oil and hydrocarbons		1	4	847,838
Organic solvents		passive sampling		2,755,475
Phenols		1	4	635,879
Pesticides		passive sampling		1,907,636
Surfactants		1	4	0
Microbiological indicators				
Fecal coliforms		4	4	370,929
Total coliforms		4	4	370,929
Pathogens		1	4	3,285,374
Dissolved gasses (CO_2/CH_4)		1	4	1,483,717

Note: Prices per sample have been used to account for differences between laboratories and support separate calculations for signal, exploratory, and statistical monitoring as well as for depth profiles in Table 38.
Source: Chapman, 1996, for list of proposed parameters to be monitored.

TABLE 37. Sampling frequency of water quality parameters for background and depth profiles

	Background monitoring	Depth profiles
General parameters		
Temperature	x	x
Color	x	
Suspended solids	x	x
Turbidity/transparency	x	x
Conductivity	x	x
pH	x	x
Dissolved oxygen	x	x
Chlorophyll a	x	x
Nutrients		
Ammonia	x	
Nitrate/nitrite	x	
Phosphorous	x	
Organic matter		
TOC	x	
COD	x	x
Biochemical oxygen demand	x	x
Major ions		
Sodium	x	
Potassium	x	
Calcium	x	
Magnesium	x	
Chloride	x	
Sulphate	x	

Source: Chapman, 1996.

TABLE 38. Outline of monitoring with signal, exploratory, and statistical functions

Monitoring function	Signal	Exploratory	Statistical
Monitoring working group	Monitoring plan	Monitoring plan	Monitoring plan
In-lake water quality analysis	Table 36 and Table 37	Table 36 and Table 37	Table 36 and Table 37
River outflows	—	10 river lake inflows; monthly, background WQ package	20 river lake inflows, weekly, background WQ package
Depth profiles	10 sites, monthly; WQ package depth profile, 10 depths/site	10 sites, weekly; WQ package depth profile, 10 depths/site	20 sites, weekly; WQ package depth profile, 10 depths/site
Passive samplers: pesticides, (vet) medicines	—	10 sites, dry and wet season	20 sites, dry and wet season
Meteorology stations and fixed sensors	2 online meteorology stations; 4 continuous online depth profiles; basic WQ	4 online meteorology stations; 8 online continuous online depth profile; basic WQ	4 online meteorology stations; 16 online continuous online depth profiles; basic WQ
Mapping and surveys	Survey of aquaculture: mapping locations, supply chain sales, stocking densities	Signal parameters and mapping farmers	Exploratory parameters and mapping domestic interventions
Toba research fund	1 PhD study	5 PhD studies	10 PhD studies

Note: WQ = water quality.

It is important to establish standard field and laboratory protocols to address common errors in water quality sampling. These range from sample contamination to uncalibrated operations. Protocols can help staff overcome errors and provide consistency across sampling. If contracting subcontractors for monitoring, these standard protocols should be included in the Terms of Reference. The International Organization for Standards (ISO) sets concrete monitoring standards, including sampling procedures and laboratory analyses (i.e., ISO standard 5667, parts 1 to 24, for sampling and ISO standard 17025 for water quality laboratories).

Remote Sensing Capabilities

Remote sensing can provide comprehensive, relatively low-cost data and a directly transferable resource for water quality monitoring across Indonesia's lakes and reservoirs. Producing an accurate representation of biogeochemical processes with input from remote sensing is a complex undertaking requiring validation with in-situ data. This notwithstanding, provides a comprehensive and cost-effective complement to future improvements to water quality monitoring of Lake Toba. Furthermore, the skills and resources developed through building remote sensing capabilities across government and scientific research institutions will be directly transferable to the management of other water resources across Indonesia. A brief overview of the capabilities in remote sensing of water quality at the Indonesian National Institute of Aeronautics and Space (LAPAN) are provided in Box 4.

The number of publicly available remote sensing applications for water quality monitoring are increasing. The global satellite infrastructures that enable remote sensing are long-term assets that are continuously being developed to provide improvements in areal coverage, accuracy, and data availability. Examples of available platforms on the Internet for accessing remotely sensed data on water quality are listed below. Several of these platforms and databases provide downloadable data and training materials. For example:

- The World Water Quality Portal managed by UNESCO (www.worldwaterquality.org);
- The GEOSS Platform of the European Space Agency and the National Research Council of Italy (www.geoportal.org); and
- Aquawatch (www.geoaquawatch.org).

Combining data from several multispectral sensing platforms gives optimal coverage of atmospheric conditions in the tropics. These include high-resolution sources (e.g., Sentinel 2A/2B, Landsat-8); moderate-resolution sources (e.g., MERIS,

BOX 4. Remote sensing capabilities for water quality at the Indonesian National Institute of Aeronautics and Space (LAPAN)

The Indonesian National Institute of Aeronautics and Space (LAPAN) was formed in 1963 and supports a range of sectors, from wildfire monitoring to naval operations. LAPAN has developed advanced capabilities to integrate, atmospherically correct, calibrate, and process satellite imagery for operational water quality monitoring using several earth observation satellite platforms, as well as aerial (drone) multispectral imagery.

LAPAN currently provides yearly 'operational' Landsat-8 mosaics for 15 lakes across Indonesia, including Lake Toba. This includes total suspended matter and light attenuation, but not chlorophyll α. Based on these capabilities LAPAN has the demonstrated capacity to produce maps on a finer time basis for specific areas of interest using Landsat-8. The data and results of the 'operational' water-quality system could provide an important foundation for interagency collaboration and should ideally be shared with the public domain.

LAPAN does not routinely access Sentinel-2 (A/B) or Sentinel-3 data. However, this capability should follow a similar processing chain as is currently used for Landsat-8 and is relatively straightforward. To advance LAPAN's capabilities, greater data storage space is needed (e.g., expanded server capacity through cloud services for example) along with implementation of specific processing chains for water quality. These will involve engineering and staff resources (estimated at three to six months for one to two GIS experts).

Recommendations for developing LAPAN's role in water quality monitoring

LAPAN could pilot its capabilities in water quality monitoring of Lake Toba by defining a processing chain for remote sensing of a limited list of water quality products and sensors in order to produce regular outputs (including uncalibrated outputs)—particularly for chlorophyll a and turbidity. Utilizing its Landsat-8 capabilities, LAPAN could set up the product archiving/indexing of all new processed images and a web-browsing interface (e.g., one-week latency period from USGS's scene availability). Such data could be presented alongside in-situ sampled water quality data. Subsequently, the next remote sensing list of products should prioritize Sentinel 3A/3B and Sentinel 2A/2B, as well as inclusion of three-band chlorophyll-a products.

A pilot on 'operational' implementation of product and time-series generation using the USGS Landsat-8 (OLI) and ESA Sentinel 3 and Sentinel 2A and 2B (OLCI/MSI) sensors to obtain turbidity and chlorophyll α uncalibrated products, would provide a cost-effective demonstration of LAPAN capabilities and a valuable input into the monitoring of water quality in Lake Toba. In parallel, establishing an open system for data sharing with other agencies, and potentially the public, could be useful for early detection of conditions leading to fish-kill events, and quantitative changes in water quality, particularly when coupled with other plans for in-situ instrumentation and near real-time water quality monitoring around the Lake Toba basin.

S3A OLCI); and low-resolution geostationary sources (e.g., Himawari-8). With upgraded capacities of Sentinel 2B, five to eight cloud-free images per year are feasible. Sentinel 3B performs daily Ocean and Land Color Instrument revisits. Five multispectral sensors are online for enhanced temporal coverage of Lake Toba: three high spatial-resolution sources (Sentinel 2A/2B, Landsat-8) enabling fingerprint of lake surface and water quality dynamics on a monthly to seasonal basis; and two moderate-resolution sources (S3A OLCI and S3B 2018) with daily to weekly dynamics and long-term continuity, multiyear/decadal monitoring (MERIS time series).

Integration of instruments could be a key part of comprehensive monitoring strategy (NASA Aqua/Terra MODIS and ESA Sentinel-3A/3B OLCI). A higher rate of data sampling from lower-resolution sensors (e.g., ESA MERIS) can overcome atmospherically-clear pixel availability and generate high-value product maps and movies. Further optimization of the constant threshold filtering or masking of data based on SWIR/NIR bands is needed to remove atmospheric (haze/clouds/marine layer) and optical artifacts (glint), and to improve quality and quantity of valid pixels.

Scenarios and Recommendations

Three scenarios were developed to estimate the cost of investments and operations of three corresponding options for water quality monitoring by function. The three functions are: signal, exploratory, and statistical. Cost estimates were done using costs presented in Table 36 and Table 39 and the costs of the Water Quality Working Group and a research fund. For the first five years, IDR 80.0 billion (USD 5.8 million) would be required for the scenario for signal function monitoring, IDR 227.9 billion (USD 16.9 million) for the exploratory, and IDR 433.8 billion (USD 32.1 million) for the statistical (Table 40). These estimates do not account for the existing costs associated with ongoing monitoring programs. The sustainable financing of water quality monitoring will be a prerequisite for achieving the benefits of integrated lake management informed by the adequate level of water data (Box 5).

TABLE 39. Estimated annual costs of signaling, exploratory, and statistical water quality monitoring

	Annual costs		
Parameter ***Monitoring function***	**Signal**	**Exploratory**	**Statistical**
General parameters	661	2,696	3,520
Nutrients	458	1,831	1,831
Organic matter	712	2,086	2,849
Major ions	153	610	610
Other inorganic variables		987	1,750
Trace elements		280	1,119
Organic solvents		712	2,849
Microbiological indicators		3,001	7,732
Dissolved gasses (CO_2/CH_4)		712	2,849
Total (million IDR)	**1,984**	**12,915**	**25,109**
USD equivalent	*147,000*	*957,000*	*1,861,000*

TABLE 40. Cost scenarios for implementing an Integrated Water Quality Monitoring Plan (IDR & USD, 2018–2022)

Intervention ***Monitoring function***	**Signal**	**Exploratory**	**Statistical**
Annual operating costs			
Monitoring working group	280	561	1,966
Water quality analyses	1,984	12,915	25,109
Depth profiles	3,244	14,059	28,118
River outflows		228	1,977
Passive samplers		1,262	2,524
Meteorological stations and fixed sensors (excl. CAPEX)	8,000	12,000	18,000
Mapping and surveys	80	160	240
Research	1,338	2,676	5,352
Subtotal (million IDR/year)	**14,926**	**43,861**	**83,286**
Investment costs			
Meteorological stations and sensors (CAPEX one off purchase)	4,336	8,673	17,345
Subtotal (million IDR/year)	**4,336**	**8,673**	**17,345**
Total for 2018–2022 (million IDR), including investment cost	**78,966**	**227,978**	**433,775**
USD equivalent/year	*1,105,630*	*3,248,963*	*6,169,333*
USD equivalent, investment cost	*321,211*	*642,422*	*1,284,844*
USD equivalent for 2018–2022	*5,849,359*	*16,887,237*	*32,131,511*

Note: The costs are based on personnel, commercial laboratory analyses, and equipment costs. CAPEX = Capital Expenditures.

BOX 5. Sustainable financing—a prerequisite for water quality monitoring of Lake Toba

Successfully improving the water quality in Lake Toba and addressing the challenges of sustainable water resource management and the surrounding catchment requires sustainable financing mechanisms to support a range of interventions. These include measures associated with both the monitoring and the management of water quality. In addition to project-related capital investments there is a need for sustainable financing mechanisms that can support recurrent costs associated with necessary operation and maintenance.

Sustainable sources of financing can be derived through three principle mechanisms: (i) “tariffs” which are the cash flows from the sale of water and revenues from service users; (ii) “taxes” which are cash flows provided by domestic taxpayers through governments and subsequently diverted to the water sector, commonly referred to as subsidies; and (iii) “transfers” which are non-repayable cash flows provided in the form of grants or in-kind contributions from external sources, such as through Official Development Assistance. Tariffs, taxes, and transfers provide a useful tool in helping to unlock an understanding of the sources of the funds which underpin sustainability.

There are a range of options to ensure financial sustainability by realizing the full range of benefits associated with water that can be used to share prosperity and economic benefits while contributing to the protection and restoration of ecological systems. PTJ1 as a state-owned enterprise is mandated with operational responsibilities to support the conservation efforts for Lake Toba and has the authority to collect revenues from specific water users. However, these are mostly limited to downstream industries and not reflective of the full range of environmental benefits and services that can be derived from the lake and its waters. There are other types of sustainable financing such as: (i) extending the definition of water user fees to include environmental services; (ii) enforcing the ‘polluters pay’ principle whereby the party responsible for producing or contributing to pollution is responsible for paying the operation cost for pollution prevention and control measures; and (iii) exploring payment for environmental services where the beneficiary or user of an ecosystem service (such as tourism) makes a direct or indirect payment to the provider of that service.

Such revenues could be channeled through a special Lake Toba Water Fund to finance the costs associated with water quality monitoring and the management interventions aimed at improving the overall water quality of the lake. Water funds are financing mechanisms that gather investments, such as revenues from water users and direct beneficiaries, and direct the funding toward measures aimed at securing the protection and restoration of the water resources. Water funds vary from place to place depending on local opportunities and regulations but can provide an effective mechanism to ensure long-term sustainable and dedicated financing for water quality monitoring in Lake Toba.

There are several opportunities to make current monitoring at the 54 identified sites more efficient. For example, some of the total 54 identified stations of DLH-SU, LIPI, and PJT1 are close together and could be merged (e.g., DLH-SU and LIPI stations providing full shoreline and mid-lake coverage). Yearly evaluation of the number and locations of sampling sites is useful to reassess their value and efficiency. Further improvements could be achieved through real-time monitoring at priority sites. For comprehensive understanding of the lake and catchment dynamics, it will also be necessary to monitor environmental variables such as aquaculture production and livestock densities.

Statistically accurate information on drivers affecting the Lake Toba catchment will need to be sourced from relevant government entities. The cost for monitoring parameters, such as population, livestock, and fish production are not included in the cost estimates because data collection is performed by other government entities. The externally sourced data will need to include: certified aquaculture production data; certified livestock data per type at village level; number of livestock in small-scale to large industrial scale operations; locations of large-scale farms; records of wastewater treatment plants; and records of licensed hotels, industries, and other businesses.

The proposed installation of four on-lake meteorological stations would provide continuous data on temperature, rainfall, and wind strength and direction at an estimated unit cost of IDR 1,349 million (USD 100,000). Forecasts from available databases and models (e.g., DEWS/FEWS at the Meteorology, Climatology, and Geophysical Agency, BMKG) could also be integrated into the monitoring plan.

Trade-offs can be achieved between cost and frequency of monitoring and should be planned for in designing the Integrated Water Quality Monitoring Plan. For example, monitoring the lake's upper surface layer (epilimnion) should be done weekly, but can be done monthly for depth profiles at fewer locations. Parameters that are expensive to monitor could be sampled monthly with those depth profiles only. Some parameters (e.g., temperature, dissolved oxygen, conductivity, and salinity) can be monitored at a high frequency and across a depth profile.

Passive sampling is a cost-effective way to monitor the presence of toxic substances. Passive sampling methods absorb micropollutants during their deployment in water (e.g., silicon sheets). They will absorb a time-averaged amount of the micropollutants, optimally four weeks worth. The passive samplers are subsequently analyzed in laboratories for pesticides, medicine, and hormones (e.g., fish and human antibiotics). Hence, a single analysis will yield a time-averaged concentration.

There are several opportunities to integrate Internet and mobile phone technologies in water quality monitoring systems. The existing coverage of 4G telecommunication facilities, Internet access, and data services around Lake Toba and core tourism areas is extensive.[171] Real-time data relay from sensors and measuring stations to data management systems online and/or on-site is fully feasible. The best coverage is provided by the operator TELKOMSEL, followed by ProXL and Smartfren. A low-cost LoRa[172] mesh network (i.e., wireless technology for long-range communication performance in large areas) could be set up as a cheap and complimentary alternative for real-time data transfer.

Building remote sensing capabilities as part of the monitoring plan could improve understanding of key parameters and the dynamics of Lake Toba, such as suspended particles and algae blooms (Table 41). Regional models can, using remote sensing from several satellites, provide a compliment to in-situ data. Comprehensive training would be required. The capabilities for the monitoring of Lake Toba could:

- Refine analysis, using specific sampling sites and transects, to better understand changes in water quality observed around 2005 (MERIS data) using additional data from MODIS (Aqua/Terra);
- Perform focused multi-sensor analysis to determine specific conditions leading to acute water quality events on record (May 4, 2016, and Jan 9, 2017);
- Refine atmospheric correction, glint, speckle, and masks to improve data quality;
- Incorporate processing of two recently launched satellites (Sentinel 2B and 3A); and
- Define detailed remote sensing monitoring (i.e., sensors, processing chains, and algorithm settings).

TABLE 41. **Summary of action items and costs for remote sensing of water quality in Lake Toba**[173]

Action item	Cost estimate (USD)
Refinement of spatial data analysis	20,000
Multi-sensor data analysis for acute water quality events (2016, 2017)	30,000
Improving remote sensing data quality	20,000
Incorporate new remote sensing platforms (Sentinel 2B and 3A)	30,000
Develop approach for remote sensing data use as part of Water Quality Monitoring Plan	25,000
Training on the use of remote sensing methods and data for water quality monitoring	25,000

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[171] Horwath HTL, 2017.

[172] https://www.lora-alliance.org/technology

[173] The cost estimates in Table 41 are one-time expenses required to develop and implement remote sensing capabilities for the duration of one year. The annual operating costs can be estimated based on staff, institutional, and other costs.

CHAPTER 9

Conclusions and Recommendations

Lake Toba is a unique natural asset of global significance with a rich cultural heritage. In addition to providing a wide range of environmental goods and services, the lake has the potential to be one of Indonesia's growing tourism destinations. It is estimated that better managed tourism in Lake Toba could generate almost 5,000 additional jobs and an increase in annual tourism spending of IDR 2,200 billion (USD 162 million) by 2041. However, environmental degradation has emerged as a key risk to the growth and success of Indonesia's tourism industry, and realizing the potential of Lake Toba as a tourism destination is contingent on addressing sources of pollution and improving water quality.

The continued deterioration of water quality in Lake Toba undermines the potential for long-term sustainable benefits. Lake Toba has largely been a destination for local tourism, but several challenges have led to its declining appeal. With improvements in environmental sustainability, accessibility, and activities, Lake Toba has the potential to become an attractive destination for a wider variety of domestic visitors and specific segments of the international market. Recognizing these challenges, the government has launched the Indonesia Tourism Development Program with the aim of improving the quality of, and access to, tourism-relevant basic infrastructure and services and strengthening local economy linkages to tourism, as well as attracting private investment. Lake Toba is one of three destinations support by the Program.[174]

A roadmap is required to secure improvements in the water quality of Lake Toba and realize the potential for sustainable economic development. The objective of this analysis was to inform the development of such a roadmap by understanding the key drivers of deteriorating water quality in Lake Toba and identifying a range of investment scenarios for reducing nutrient inflows to sustainable levels. The roadmap is intended to inform the Integrated Tourism Master Plan for Lake Toba that will provide a framework for effective and sustainable tourism development in and around the lake. It also aims to guide recommendations for water quality management and monitoring to ensure sustainable water resources development.

Functioning and Trophic Status of Lake Toba

The water quality dynamics in Lake Toba are informed by a long residence time (80 years) and nonhomogenous mixing. The theoretical residence time assumes homogenous mixing of the lake; however, using such generalized conditions in water quality modelling can risk underestimating the local impact of pollution concentrations. In reality the hydrodynamics are influenced by spatial variations in topography, bathymetry, circulation flow directions, and velocities, along with hydrometeorological conditions. Mixing and nutrient concentrations are also influenced by thermoclines. While these hydrodynamic processes result in nonhomogenous mixing and create discrete compartments within the lake, most assessments of nutrient loading have been based on whole lake estimates. This can result in a much longer residence time and have

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[174] The other two being: Lombok in West Nusa Tenggara Province and Borobudur-Yogyakarta-Prambanan in Central Java Province. Additional destinations may be added over time.

important implications for estimating the nutrient loading. Continuous research, model refinement, and improved data inputs are required to increase the delineation of such compartments and inform appropriate recommendations.

Introducing discrete hydrological compartments to the water quality model for Lake Toba provides new insights into localized impacts as well as the key drivers. Four theoretical compartments were constructed for the purposes of the model. These were based on the topography and bathymetry of the lake to provide for a differentiated assessment of the key drivers. The model examined the lake as a whole, split between two discrete hydrological compartments and four compartments separating the northern part of the lake from three compartments in the southern part. While the delineation of these compartments needs to be validated through continued monitoring and modelling, with the possibility of increasing resolution through additional compartments, the modelled values for the year 2015 lie well within the ranges observed in the lake.

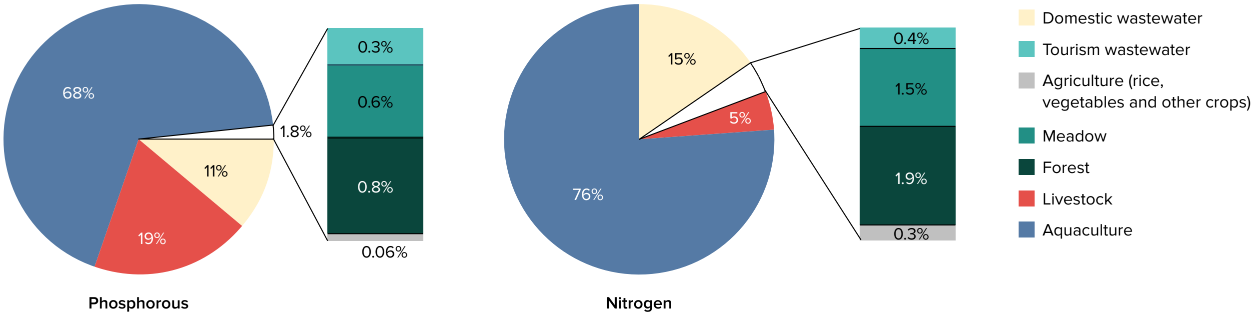
The model results show that the concentrations of phosphorous and dissolved oxygen in Lake Toba reflect mesotrophic conditions. While concentrations of nitrogen and chlorophyll a, along with transparency, in Lake Toba typically indicate oligotrophic conditions, these also occasionally rise to levels associated with mesotrophic conditions. The current state reflects a continuous process of deterioration in water quality despite numerous government initiatives aimed at maintaining Lake Toba in an oligotrophic state as stated as in the Governor's Regulation 1/2009. The mesotrophic conditions and continued deterioration due to increased nutrient loads lead to localized events, such as algae blooms and depleted oxygen levels, resulting in negative environmental outcomes that undermine the tourism potential of the area and the provision of other environmental goods and services.

Key Drivers—Findings from Investment Scenarios

The key driver contributing to the deterioration of water quality in Lake Toba is excessive nutrient loading from aquaculture. The model analysis shows that the process of eutrophication in Lake Toba is primarily driven by nutrient emissions from aquaculture, which is responsible for over two-thirds of total phosphorous loads (Figure 76). Other land-based sources of nutrient emissions, such as from livestock manure and domestic wastewater, contribute to the deterioration of water quality but are not in themselves key drivers.

The scenario analysis identifies the type and level of investment required to reduce nutrient loading and improve the water quality of Lake Toba. A total of five scenarios (A–E) were defined based on different levels of interventions associated with aquaculture, livestock manure, and wastewater. These were complemented by improvements to water quality monitoring (as detailed in Table 34). The impact of each scenario on nitrogen and phosphorous emissions was quantified for the whole lake and the different compartments to illustrate relative impacts of combined interventions (Figure 72).

FIGURE 76. **Relative contributions of total phosphorus (*left*) and total nitrogen (*right*) loads into Lake Toba (2015)**



Source: Results from Deltares water quality model for calculating nutrient loads.

The scenario analysis concluded that:

1. Reducing nutrient emissions from aquaculture is essential to improving the water quality and lake status of Lake Toba—measures to reduce emissions from other sources will have a marginal impact on the lake's trophic state;
2. Nutrient concentrations will rise to long-term eutrophic conditions for phosphorous and mesotrophic for nitrogen in the north and S1 compartments in the absence of interventions (Scenarios A and B);
3. Substantial reductions in nutrient loads and concentrations, and sustained oligotrophic conditions can only be achieved through a reduction in aquaculture emissions (Scenarios C, D, and E);
4. Sustained oligotrophic conditions in terms of phosphorous are only possible under Scenario D and Scenario E in the S2 compartment (and only Scenario E for the S3 compartment);
5. A balanced and financially viable alternative to the ambitious targets across all three main sources of nutrient loading is provided in Scenario E; and
6. The S1 compartment will experience high long-term nutrient concentrations even if aquaculture is halted completely, because of high population and livestock densities.

The assessment of the available data concludes that a comprehensive water quality monitoring plan is required to inform adaptive management in response to changing circumstances and monitor the outcomes of any intervention. Indonesia is currently not fully benefitting from the data that is collected, from alternative data sources (such as remote sensing), or from improved data transparency through initiatives such as citizen observations science. This undermines the efficacy of existing efforts and limits the utility of existing data to inform adaptive management measures aimed at restoring the water quality of Lake Toba. The most important parameters would need to be covered and collective sampling streamlined. Five-year cost estimates for three scenarios envisaging different levels of monitoring were estimated. The first water quality monitoring scenario would provide a *signaling* function, based on monthly monitoring for background information and requiring capital investments in two meteorological stations and four sensors for a total estimated cost of IDR 80.0 billion (USD 5.8 million). The second water quality monitoring scenario would provide an *exploratory* function, based on the same monitoring as the third statistical scenario but at a lesser monitoring frequency and with capital investments in four meteorological stations and eight sensors for a total estimated cost of IDR 228 billion (USD 16.9 million). The third water quality monitoring scenario would provide a *statistical* function based on weekly monitoring, along with sampling for background monitoring and for aquatic life, fishery, and recreation; as well as capital investments in four meteorological stations and 16 sensors. The total estimated cost for the third statistical function scenario is IDR 433.8 billion (USD 32.1 million).

The optimal solution for the management of water quality in Lake Toba represents a combination of specific interventions and cost considerations. Scenario E represents the optimized alternative, enabling significant interventions in aquaculture and livestock with intermediate interventions in wastewater. The total five-year cost of water quality management interventions in Scenario E would be IDR 747.5 billion (USD 55.4 million), which is not significantly higher than Scenario C (IDR 717.2 billion/USD 53 million) but achieves larger reductions in nutrient emissions. Combined with investments in a comprehensive water quality monitoring program that would provide the best *statistical* function to improve the management capacity, the total costs are estimated to be IDR 1,181 billion (USD 87.53 million) over five years.

Water quality can only achieve oligotrophic conditions by reducing nutrient emissions from aquaculture production. Government regulations stipulate this to be equivalent to 10,000 tons of fish per year or less, as was modeled under Scenarios C, D, and E. Achieving better water quality requires increased enforcement of existing policies, improved monitoring and compliance, and addressing license mechanisms, coupled with training and support for alternative livelihoods. Interventions in livestock manure and wastewater management can complement nutrient reductions from aquaculture but not substitute them. The five-year cost to reduce production from 64,000 tons of fish in 2018 to 10,000 tons of fish per year by 2022 is estimated to be IDR 34.2 billion (USD 2.5 million) and around IDR 9.7 billion (USD 0.72 million) for a more gradual reduction by 2042. This would reduce nutrient loading by 72 percent for phosphorous and 67 percent for nitrogen.

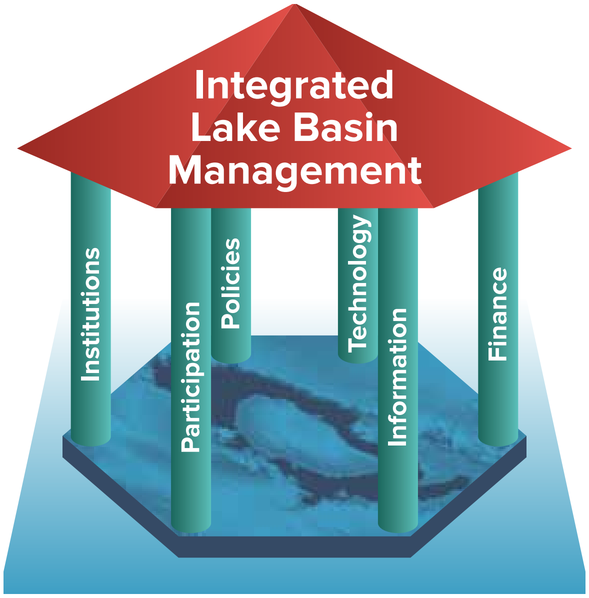
Interventions in livestock manure and wastewater management can complement nutrient reductions from aquaculture but not substitute them. These interventions are particularly important in the northern compartment and in the S1 compartment. The long-term concentrations of phosphorous would still reach levels above the oligotrophic limit in the north and mesotrophic in S1. Converting 20 percent of livestock manure into biogas by 2022 (Scenario C) would require IDR 12.9 billion (USD 957,000) and 30 percent by 2022 (Scenarios D and E) would require IDR 18.8 billion (USD 1.4 million). For wastewater management, Scenario C proposes construction of individual and community-based on-site systems, based on septic tanks, for 85 percent of the population by 2022 at the cost of IDR 694.6 billion (USD 51.5 million). Scenario D proposes larger investments in centralized sewerage systems for 31 percent of the population by 2022 for IDR 3,866.9 billion (USD 286.5 million).

Key Recommendations

The long-term sustainable management of Lake Toba requires development and implementation of an Integrated Lake Basin Management Platform. Lakes and their catchments are a single interacting and interdependent management unit that needs to be managed through an integrated framework to respond adequately to lake catchment management. This creates a variety of challenges, particularly because the boundaries of lake basins rarely coincide with established political systems. An Integrated Lake Basin Management Platform takes into consideration the biophysical factors of the lake and provides a framework for stakeholders to account for the complex dynamics associated with different development scenarios to ensure sustainable management of the lake and its resources. Such a platform is built around six pillars, including: policies, information, institutions, participation, technology, and sustainable financing (Figure 77).[175]

An Integrated Water Quality Monitoring Program is required to improve the data for determining long-term trends in Lake Toba and informing government planning and management. Addressing the challenges of lake basin management requires due consideration of the information requirements to inform timely decisions, the appropriate institutional and policy requirements, stakeholder participation, and targeted investments to ensure effective management responses. There is a need to optimize the design and implementation of the monitoring program to balance trade-offs between cost, extent, and frequency of monitoring. This includes the addition of more signal, exploratory, and statistical functions to improve data interpretation and outcomes from modelling. The minimum investment costs for an initial five-year integrated monitoring program with signaling function are estimated to be IDR 80.0 billion (USD 5.8 million). For a monitoring program with exploratory function, the estimated total costs are IDR 228 billion (USD 16.9 million), and for the most appropriate program with statistical function, the total estimated costs are IDR 433.8 billion (USD 32.1 million) due to

FIGURE 77. **Conceptual model for integrated lake management and monitoring**



Source: International Lake Environment Committee Foundation, 2018.

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[175] International Lake Environment Committee Foundation, 2018.

a higher monitoring frequency and higher capital investments in sensors. Building remote sensing capabilities and capitalizing on existing capacity (such as within LAPAN) will improve the understanding of key parameters and the dynamics of Lake Toba, such as suspended particles and algae blooms, and provide an important supplement to traditional in-situ measurements. These cost estimates do not account for the existing expenditures across the range of agencies currently undertaking data collection in Lake Toba, and efficiency gains could be realized by enhancing coordination and alignment of the 40 stations currently monitored by DLH-SU, LIPI, and PJT1. These should be coupled with the installation of at least four on-lake meteorological stations and the integration of Internet and mobile phone technologies to provide cost-effective solutions that are capable of providing continuous data on temperature, rainfall, and wind strength and direction. Investments in data collection should be accompanied by increased efforts to increase data transparency and encourage citizen engagement through web-based, publicly available data and information that can be used to monitor outcomes and inform management.

A Lake Basin Management Plan should be prepared to inform zonation of the lake for different purposes. Activities within the lake are currently concentrated in particular areas creating localized issues due to the specific hydrodynamic conditions. More sophisticated modelling supported by better data could help improve in estimating the inflow/outflow of nutrient based on the local boundary conditions. This could be used to inform a consultative process of spatial planning and supporting interventions. For example, much of the owner operator aquaculture is located in sheltered areas near shore due to logistical constraints and safety concerns. This concentration can create localized effects that could be mitigated in part through broader distribution of cages or relocation to deeper offshore waters. These would entail different production characteristics, and a transition process with supporting resources could provide the incentives and sense of security to encourage owner operators to participate in such a transition.

The recommended investment scenario to reduce nutrient emission and improve water quality of Lake Toba is estimated at IDR 1,181 billion (USD 87.5 million) over five years. This optimized investment Scenario E involves enforcement of carrying capacity limit (10,000 tons per year by 2022) and improved fish feeding practices in the remaining cages, conversion of manure into biogas (gradually to 60 percent by 2042), wastewater investments as planned (50:50 on-site/off-site), and improved monitoring. Any investments would need to include sufficient provisions for the project-related capital investments and sustainable financing mechanisms that can support recurrent costs associated with necessary operation and maintenance. Innovative financing mechanisms could be implemented to capitalize on the full range of benefits provided by improved water and catchment management using a strategic combination of tariffs, taxes, and transfers. Consideration should be given to the establishment of a Lake Toba Water Fund to crowd in revenues from water users and direct beneficiaries to provide sustainable sources of funding toward measures aimed at securing the protection and restoration of Lake Toba.

Improved institutional coordination and cooperative mechanisms are needed to capitalize on the capacity for sustainable management of Lake Toba. The success of any interventions to address the challenge of sustainable development of Lake Toba relies on the contributions of several different agencies across various sectors and levels of government and a wide range of different stakeholders with a strong interest in the management of the lake. However, the complex arrangements and responsibilities for water quality management often overlap, creating a complex institutional framework for the management of Lake Toba. Enhanced coordination arrangements across a broad range of stakeholders are required to facilitate a more effective and coordinated response, reduce policy incoherence (such as when issued licenses exceed the government-regulated carrying capacity), and reduce institutional complexity derived from overlapping mandates. This could be facilitated through an integrated platform to share data, improve transparency, increase knowledge, and enhance citizen engagement.

Political commitment, increased law enforcement, monitoring, possible license revocation, and support for alternative livelihoods are required to facilitate the reduction in aquaculture production.[176] Only by reducing aquaculture production to 10,000 tons of fish per year or less and improved fish feeding practices in the remaining cages can water quality be expected to improve, with long-term concentrations dropping below the threshold for oligotrophic conditions.

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[176] The need for possible license revocation could increase these costs. The costs for enabling alternative livelihoods are estimated and subject to a livelihoods generation plan.

Implementing a reduction strategy will impact each of the districts around Lake Toba differently, with those districts affected by reductions in aquaculture production not always the same as those districts that could benefit from increased tourism growth. Similarly, tourism job gains and aquaculture job losses will not be evenly distributed. Most of the estimated 9,000 jobs in cage fishing along with revenues from *Red Tilapia* (representing about USD 54 million in wholesale prices[177]) would be lost. If better managed, tourism could potentially bring 5,000 additional direct jobs and contribute an estimated USD 162 million extra expenditures per year by 2041. The government's agenda thus requires recognition and quantification of trade-offs, which can be eased by measures, such as revenue-sharing arrangements between districts, alternative livelihoods (possibly through intensified training opportunities), and a phased implementation.

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[177] Assuming a *Red Tilapia* wholesale price of USD 1,000/ton.

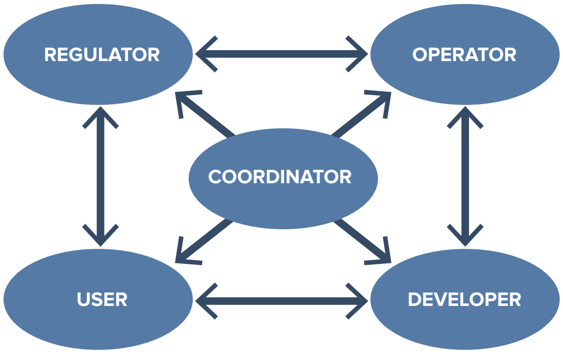
APPENDIX A

Stakeholder Consultations and Assessment

Methodology

Stakeholder roles and functions

FIGURE 78. Stakeholder roles



Five categories of widely accepted stakeholder roles are: regulator, coordinator, operator, developer, and user. These are identified in the 2004 Indonesian Water Resources Law, the Strategic Water Resources Management Framework Plan (*Pola*) and Master Plan for River Basin Management (*Rencana*). The roles are shown in Figure 78 and detailed in Table 42. The fulfilment of these roles is particularly important at the 46 lower subdistrict level (*Kecamatan*) for the water quality management and monitoring interventions in the Lake Toba area.

Social network analysis

The social network analysis highlighted which stakeholders are important for influencing policy, initiating actions, or facilitating information and knowledge transfer. The outcome of the two Network maps (NetMap) produced during the two meetings held in Jakarta on May 17, 2017, and in Laguboti, Sumatra, on June 14, 2017, represent a subjective reality that helps understand the social landscape.

TABLE 42. Detailed stakeholder roles

Stakeholder role	Description
Regulator	The government creates the enabling environment for efficient and effective water resources management. Laws and regulations guide the actions of others. No distinction is made between water quality management and monitoring.
Coordinator	The coordinating role is held by several agencies to achieve balanced, safe, and sustainable utilization and preservation of water. Coordination also involves non-water agencies whose actions and interests impact water resources (e.g., Ministry of Environment and Forestry, *Kementerian Lingkungan Hidup dan Kehutanan,* for conservation and pollution control; Ministry of Energy and Mineral Resources, *Kementerian Energi dan Sumber Daya Mineral,* for licensing of groundwater abstraction; and the National Land Agency at the Agrarian and Spatial Planning Ministry, *Badan Pertanahan Nasional-Kementerian Agraria dan Tata Ruang,* for flood management through spatial planning and land-based infrastructure).
Operator	The operator role is held by agencies mandated with daily operation of infrastructure assets to manage and monitor water. In most basins the role is carried out at the levels of provincial and district government. No distinction is made between water quality management and monitoring.
Developer	The role is held by any agencies involved in the development of physical infrastructure for the utilization of or protection against water (e.g., dams, levees, irrigation canals, water supply or wastewater treatment facilities, aqueducts, etc.). The role is often carried out by (semi-) government or publicly-owned organizations (e.g., the Basin Water Resources Management Council, *Tim Koordinasi Pengelolaan Sumber Daya Air;* the Regional Water Utility Company, *Perusahaan Daerah Air Minum;* and the National Corporation for Basin Management *Perusahaan Umum Jasa Tirta*).
User	The role covers a wide range of agencies and actors, from large-scale to individual (e.g., water supply utilities, pulp mills, hydropower plants, etc.).

The identified actors were grouped according to the categories: national government agencies, subnational government agencies, non-governmental organizations, local communities, academic institutions, and the private sector. Once mapped, interrelations based on authority and flow of information/coordination, as well as in/formality were outlined. The data was entered into NodeXL (software that can be integrated with Excel) for further analysis.

Stakeholder Observations and Discussions

The network analysis illustrated that management of water quality in Lake Toba is complex and dynamic. Moreover, participants emphasized that several actors need to be involved to foster a change in pollutant loading. For example, reducing agriculture and livestock waste requires the involvement of the Agriculture District Services *(Dinas Pertanian)* as they coordinate and guide Agriculture Communities *(Komunitas Tani),* and reducing pollutant loads from aquaculture requires the involvement of the Fisheries Services *(Dinas Perikanan).* Participants also emphasized that the many linkages connected to central, government-level actors do not necessarily translate into a similar number of programs by each actor. In principle, subnational governments should be able to influence management decisions of Lake Toba water quality compared to the national government.

At the second NetMap exercise, participants proposed the map be adjusted to separate levels of actors at the subnational level into provincial level and district level to better visualize the connection between levels and identify potential gaps. The second map shows a lack of connections (and thus isolation and lack of coordination) at provincial levels and especially at district levels, and that connections at these subnational levels are mostly with other government agencies and rarely with the private sector, academia, or others. In summary, a lack of local linkage and embedment between the national-provincial-district levels is a bottleneck to efficient implementation of well-formulated and urgently required interventions and programs.

The maps did not illustrate a clear champion among coordinating bodies (Forum DAS, TKPSDA, and BKEPDT) in the management and monitoring of water quality at Lake Toba. These actors were also said to be governed primarily at the central level with weaker alignment and integration at district levels. Civil society organizations are highly interconnected (e.g., Yayasan Pencinta Danau Toba, WALHI, Alusi Tao Toba, KSPPM, and local communities represented through the local fishermen's association, DAERMA) and emphasized that when interests were not well received by district services, they would go directly to the relevant ministries at the national level. Participants at both meetings expressed the need for a clear leader and champions.

List of Stakeholders

Table 43 lists all identified stakeholders. Those marked as regulator and/or operator play a role in water quality monitoring. Table 44 lists the members of the Reference Group, and Table 45 provides an overview of the institutions that provided data for the analysis.

TABLE 43. Stakeholder institutions and roles (*Reference Group members)

	Roles				
Institutions	**Regulator**	**Operator**	**Developer**	**Coordinator**	**User**
National					
Coordinating Ministry of Maritime Affairs*	R			C	
Coordinating Ministry of Economy	R				
Ministry of Tourism	R			C	
Ministry of Home Affairs (cq Directorate General of Regional Development)	R				
National Development Planning Agency/BAPPENAS (Sub Dit., River, Coastal, Reservoir, Lake)	R			C	
Ministry of Finance	R				
Ministry of Environment and Forestry*	R				
Ministry of Agraria and Spatial Planning	R				
Ministry of Public Works and Housing	R	O	D		
— Regional Infastructure Development Agency*	R			C	
— DG Human Settlements—PPLP	R				
— DG Highways	R				
— DG Water Resources (cq Dit Rivers and Coastal)	R				
— Center of dam/reservoir (cq Lake, Situ, Embung division)	R		D	C	
— Center of raw water and ground water	R				
— BWS Sumatera II*	R	O	D		
— Center Research of Water Resources	R				
Ministry of Transportation	R				
Ministry of Marine Affairs and Fisheries	R				
Ministry of Energy and Mineral Resources	R				
Ministry of Manpower	R				
Ministry of Administrative and Bureaucratic Reform	R				
Secretary of Cabinet/Presidential Chief of Staff office	R				
Ministry of Agriculture	R				
Ministry of Industry	R				
LIPI Research Center of Limnology*	R				
Agency for the Assessment and Application of Technology (BPPT)*	R				
PJT1		O			
Meteorology, Climatology, and Geophysical Agency (BMKG)		O			
National Board for Disaster Management (BNPB)	R	O			
Lake Toba Tourism Area Management Authority*		O	D	C	U
Province					
Governor of North Sumatra	R				
Regional Development Planning Agency/*BAPPEDA Provincial*	R			C	
Provincial Forestry Agency	R	O			
Provincial Environmental Services*	R	O		C	
Provincial Water Resources Services	R	O			
Provincial Human Settlements TR Services	R	O			
Land Cadaster/bpn atr Provincial	R	O			
Provincial Services of Transportation	R	O			
Provincial Agriculture	R	O			
PPL *(Petani Penyuluh Lapangan)*		O			
Provincial Fisheries Services	R				
PPL *(Penyuluh Lapangan Perikanan)*		O			
Provincial Tourism Services	R	O			
Badan Penanggulangan Bencana Daerah (BPBD)		O			
Badan Pengelola Geopark Kaldera Danau Toba		O		C	U
Kabupaten/districts					

(continues)

TABLE 43. Continued

	Roles				
Institutions	**Regulator**	**Operator**	**Developer**	**Coordinator**	**User**
Head of District	R				
Regional Planning Agency/*BAPPEDA Kabupaten*	R			C	
Kabupaten Forestry	R	O			
Kabupaten Environmental Services	R	O		C	
Kabupaten Water Resource Services	R	O			
Kabupaten Human Settlements TR Services	R	O			
Land Cadaster/bpn atr District	R	O			
Kabupaten Services of Transportation	R	O			
Kabupaten Agriculture	R	O			
PPL *(Petani Penyuluh Lapangan)*		O			
Kabupaten Fisheries Services	R				
PPL *(Petani Penyuluh Lapangan)* Perikanan		O			
Kabupaten Tourism Services	R	O			
State Owned, private sector, civil society, NGO					
Perhutani		O			U
Masyarakat Adat (Batak)					U
AMAN *(Aliansi Masyarakat Adat Nasional)*					U
WALHI North Sumatra					U
Yayasan Pencinta Danau Toba					U
Community Masyarakat Peduli Danau					U
Forum Komunikasi Danau Toba					U
KSM *(Kelompok Swadaya Masyarakat)*					U
PKK *(Pembinaan Keluarga Sejahtera)*					U
Forest communities (upstream conservation)					U
Other NGOs (KSPPM, Alusi Tao Toba, Hutan Rakyat Institute)					U
Fishermen’s Association (DAERMA) and others					U
Tourism communities					U
Rivers communities					U
Universities/Perguruan Tinggi–USU (North Sumatra University)–UNIMED, Nomense–*Universitas Simalungun*					U
URI (University Rhode Island)					U
Electricity company: INALUM + PLN + others					U
Bajradaya Sentranusa (BDSN)					U
Industrial group/area industry					U
TPL (Toba Pulp Lestari)					U
PT Aquafarm Nusantara					U
PT Suri Tani					U
Kelompok Tani					U
Kelompok Pembudidaya Ikan					U
Asosiasi Peternak					U
Irrigation Commission/Komisi Irigasi					U
WUA/Group WUA/Federation WUA					U
Komunitas transportasi air					U
Penambang Galian C					U
DMO Toba					U
Public Water Supply Company/PERPAMSI—PDAM					U
Coordination Body					
Coordinating Body on Capital investment/BKPM				C	
National Water Resources Council/*Dewan Sumber Daya Air Nasional*				C	
Provincial Water Resources Council/*Dewan Sumber Daya Air Provinsi*				C	
BKPEDT				C	
Basin Council/*Tim Koordinasi Pengelolaan Sumber Daya Air Wilayah Sungai*				C	
Forum DAS *(Daerah Aliran Sungai)*				C	

TABLE 44. Members of the Reference Group

Institution	Name	Position	Office
CMMA	Ridwan Djamaluddin	Deputy *Minister*	Deputy for Infrastructure
CMMA	Dr. Rahman Hidayat	Director *Asisten Deputi*	Department for Navigation, Fisheries and Tourism Infrastructure *(Departemen Infrastruktur Pelayaran, Perikanan, dan Pariwisata)*
CMMA	Velly Asvaliantina	Deputy Director	Sector Nautical and Tourism Infrastructure *(Bidang Infrastruktur Pariwisata Bahari)*
MoPWH	Hadi Sucahyono	Head *Kepala*	Regional Infrastructure Devleopment Agency *(Badan Pengembangan Infrastruktur Wilayah, BPIW)*
MoPWH	Raymond Tirtoadi	Representative *Wakil*	Center for Strategic Areas *(Pusat Pengembangan Kawasan Strategis)*
LIPI	Dr. Fauzan Ali	Head *Kepala*	Center of Limnology *(Pusat Penelitian Limnologi)*
LIPI	Dr. Ir. Lukman MSi.	Researcher *Peneliti*	Center of Limnology *(Pusat Penelitian Limnologi)*
BPPT	Dr. Ir. Rudi Nugroho	Director *Directur*	Center for Environmental Technology *(Pusat Teknologi Lingkungan)*
BPPT	Prof. Dr. Titin Handayani	Representative *Wakil*	Center for Environmental Technology *(Pusat Teknologi Lingkungan)*
KLHK	Dr. Budi Kurniawan	Representative *Wakil*	Directorate for Water Pollution Control *(Direktorat Pengendalian Pencemaran Air)*
KLHK	Hermono Sigit	Representative *Wakil*	Directorate for Watershed and Aquatic management *(Direktorat Pengendalian Kerusakan Perairan Darat)*
DLH-SU	Dr. Ir. Hj. Hidayati	Head *Kepala*	Provincial Environmental Agency North Sumatra *(Badan Lingkungan Hidup Sumatera Utara)*
BWS Sumatera II	Baru Panjaitan	Head *Kepala*	River Basin Management Organization Sumatra II *(Balai Wilayah Sungai Sumatera II)*
BWS Sumatera II	Novita R	Section Head *Kepala Seksi*	Operation and Maintenance *(Operasi & Pemeliharaan)*
BOPDT	Arie Prasetyo	Head *Kepala*	Lake Toba Tourism Area Management Authority *(Badan Otorita Pariwisata Danau Toba)*

TABLE 45. Overview of Data Collected by Stakeholders of Lake Toba

Lake data	Consultant	LIPI	KLHK BLH-SU BPDas	PUPR BWSS2 PusAir PJT1	MMAF	KATR	BPS	BPPT	PLN	BMKG Parapat	Inalum	Center for Isotopes and Radiation Application-BATAN	Eastern Illinois University	Tourism demand analysis	Aquafarm	TPL	PT Suri Tani Pemuka	Walhi	From literature	Unavailable, will be collected by consultant	Outside consultancy scope
Bathymetry		x											x						x		
Hydrology, rainfall	x			x					x	x	x								x		
Water balance and operation	x			x							x								x		
Meteorology										x											
Hydrological model	x			x																	
Water balance model	x			x																	
Catchment characteristics (GIS elevation, land use, environment, water system, infratructure, water utilization, etc.)	x	x	x			x		x													
Lake Toba Atlas—GIS	x (iwrm)		x			x															
Water supply	x			x																	
Temperature (including profile)		x (x)	x	x					x			x			x (x)		x				
Ph, Salinity		x (x)	x	x				x (x)							x (x)		x				
Circulation (horizontal)		x																			
Oxygen (including profile)		x (x)	x	x	x			x (x)	x						x (x)						
Nitrogen (including profile)		x (x)	x	x				x	x						x (x)		x				
Phosphorus (including profile)		x (x)	x	x				x	x						x (x)		x				

Lake data	Consultant	LIPI	KLHK BLH-SU BPDas	PUPR BWSS2 PusAir PJT1	MMAF	KATR	BPS	BPPT	PLN	BMKG Parapat	Inalum	Center for Isotopes and Radiation Application-BATAN	Eastern Illinois University	Tourism demand analysis	Aquafarm	TPL	PT Suri Tani Pemuka	Walhi	From literature	Unavailable, will be collected by consultant	Outside consultancy scope
Chlorophyll-a (including profile)		x (x)	x	x				x							x (x)		x				
Aquatic flora and fauna		x						x (x)													
Pesticides															x (x)						
Secchi depth (turbidity)		x (x)	x (x)					x (x)							x (x)		x (x)				
Sediment quality															x						
Isotope profiles												x									
Satellite interpretation								x													
Conservation and deforestation	x		x													x		x			
Erosion	x		x																		
Pollutant source analysis	x	x	x	x	x														x		
Fisheries	x	x	x		x										x		x		x		
Carrying capacity analysis	x	x	x		x										x		x		x		
Population (including scenarios)	x (x)		x	x		x	x							x (x)					x		
Tourism (including scenarios)		x				x	x							x (x)					x		
Lifestock and agriculture (including scenarios)	x (x)		x	x		x	x							x (x)					x		

Received raw data

Available, processed data already received including 2017

Based on agreement between LIPI and Menko Maritime, data from LIPI only includes published articles and published data in the public domain. LIPI indicated it will share preliminary interpretations of ongoing research with the Consultant. LIPI has also indicated that it prefers not to make available and share more recent data that has not been published.

Stakeholder Meetings

The group and individual meetings and interviews held during 2017 are shown in Table 46.

TABLE 46. Stakeholder meetings and interviews (2017)

Meetings			
Date	**Place**	**Participants**	**Topic**
Mar 16	Jakarta	Reference group	Kick off meeting
May 10	Jakarta	Reference group	Inception
May 17	Jakarta	Reference group and additional key stakeholders	Present initial stakeholder mapping; discuss draft legal, institutional and political economy assessment, first NetMap exercise
June 14	Laguboti, North Sumatra	Reference group Local level participants	Second NetMap exercise; present initial findings of Lake and Catchment Assessment
Aug 7	Jakarta	Reference group	Presentation and discussion of final Lake and Catchment Assessment
Aug 24	Medan, North Sumatra	Reference group Local level participants	Presentation of final Lake and Catchment Assessment Presentation of preliminary recommendations
Sep 28	Jakarta	Reference group	Draft recommendations
Interviews			
Date	**Institutions**		**Name**
18–20 Mar	BPDAS-Forestry		Bp. Fauzi
22 Mar	PLTA Renun		Bp. Gunawan, Bp. Giovandi Siahaan
23 Mar	LH Province North Sumatera		Ibu Hidayati, Ibu Bayu Nasution, Bp. Umanda
25 Apr	MoPWH Central Reservoirs (including lake)		Ibu Made Sumiarsih
25 Apr	KLHK		Bp. Samsuhari, Ibu Inge
25 Apr	USDP		Bp. Mees Krimpen, Bp. Amrizal, Bp. Dhanang Wuryandoko, Bp. Arief
18 May	Ministry of Agrarian Affairs and Spatial Planning/ National Land Agency (ATR/BPN)		Bp. Wisnu, Bp. Ludfie
5 June	Bappeda North Sumatra		Bp. Yosi Sukmono
6 June	Human Settlements North Sumatra		Bp. Kusriadi replace by Ibu Dolphin
6 June	KKP (Perikanan) North Sumatra		Ibu Retno
6 June	LH Sampah North Sumatra		Bp. Indra, Bp. Hendro
7 June	PDAM Tirtanadi WWT plant division (field officer)		Bp. Bonar Tampubolon, Bp. Dipman, Bp. Sirait, Bp. Simanjuntak
21 June	Ministry of Agrarian Affairs and Spatial Planning/ National Land Agency (ATR/BPN)		Bp. Wisnu

APPENDIX B

Theoretical Background on Lake Functions

Theory of Residence Time

The concept of water residence time (or *turnover time*) is particularly important for Lake Toba as it is a large water body with a relatively small outflow. The residence time of lakes may range from a few days to many tens of years, or even to a century or more. A simple form of residence time can be calculated by dividing the lake volume by the outflow (Chapman, 1996). Lake Toba's theoretical residence time is approximately 80 years: (256,200,000,000 m^3)/[100 $m^3/s \times (60 \times 60 \times 24 \times 365)] = 81.2$ years. Importantly, the theoretical residence time assumes homogeneous mixing of the lake. Stratified lakes (such as Lake Toba) have a much longer residence time than the theoretical value (Meybeck, 1995).

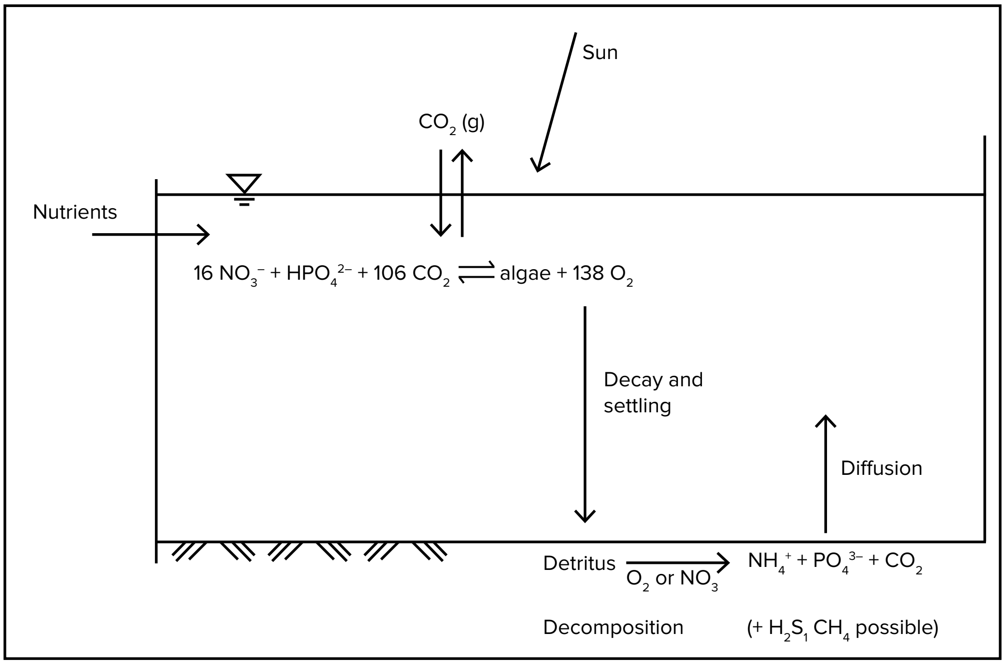
Theory of Biochemical and Algae Processes

A simplified view of the biogeochemical processes in lakes is shown in Figure 79. Nutrients enter the system via river discharges and runoff, percolation through the soil, and from direct input such as aquaculture. Nutrients are taken up by algae (phytoplankton) who produce oxygen through photosynthesis and consume oxygen through respiration. This results in a daily oxygen variation, with oxygen concentrations increasing during daytime and decreasing during night-time. When the algae die, they change into detritus which settles into the deeper lake layers. Detritus can accumulate in the hypolymnion (bottom layer of the water column). There, it could be mineralized back into inorganic nutrients. Since the mineralization process consumes oxygen, this decreases the oxygen concentrations in the deeper layer of the lake. Also, fermentation processes may lead to the local accumulation of methane or carbon dioxide.

In deep lakes, such as Lake Toba, algal growth is typically limited by light. This is because of the large epilimnion depth (surface layer of the water) over which the algae are being mixed. During their travels over the epilimnion they experience light conditions that are on average too small to result in a positive production flux. Occasionally, however, the depth over which the algae are being mixed is decreased, due to a change of the primary or secondary thermocline depth. Once the light limitation is removed, an algal bloom may occur. Therefore, the thermocline depth is a key factor determining the occurrence of algal blooms. Also, thermocline depth determines the volume over which the nutrients are diluted. Because of its (twofold) importance, thermocline depth is a key factor.

The peak biomass concentration of the algal bloom is determined by the availability of nutrients. Nutrient addition from runoff and direct input from aquaculture lead to higher nutrient concentrations in the upper layer above the thermocline. This may thus lead to higher algal biomass in the event of an algal bloom.

FIGURE 79. Simplified biogeochemical processes in a lake



Nutrient addition in the form of organic waste however may sink to the bottom layer, the hypolimnion, where it is mineralized, thus leading to higher nutrient concentrations and lower oxygen concentrations, mainly in the deeper parts of the lake. Once arrived in the deeper waters, these nutrients will not directly affect the epilimnion anymore. Since the volume of the hypolimnion is so large, the increase in nutrient concentration may increase very slowly, at a pace that only becomes visible when assessed over large periods of time.

Although nutrient loading of the hypolimnion does not affect the epilimnion directly, it does entail risks. During mixing events, nutrients from the hypolimnion may be returned to the epilimnion and support larger algal biomass peaks. Also, when the hypolimnion is anoxic the oxygen concentrations in the epilimnion may drop substantially during a mixing event. This may have a large impact on all biology in the epilimnion, and in some cases even lead to mass mortality events. Even worse may be events of mixing during which large amounts of CO_2 are brought up, which in Lake Nyos in Cameroon suffocated 1,746 people and 3,500 livestock in nearby towns and villages (Giggenbach, 1990).

Trophic Level Classification

A qualitative classification based on trophic level (Table 20) represents a continuous range of nutrient concentrations and associated biomass production (Carlson, 1977). The quantitative boundaries of nutrient and chlorophyll a concentrations with which to define the trophic levels vary between scientists and organizations (Table 47). Some classifications are based on additional variables (Table 48). The Provincial Environmental Agency for North Sumatra (DLH-SU) uses the KLH (2009) boundaries. Most boundaries are similar, although the KLH nitrogen boundaries are relatively high, with the oligotrophic-mesotrophic boundary of 650 µg total N per litre being almost twice the value of the other boundaries. It is therefore recommended to use the other classification boundaries.

TABLE 47. Total P, N, and Chlorophyll a concentrations (µg/l) for different trophic states (*cut-off values proposed by Nürnberg 1996 were applied in the analysis)

Variable	Oligotrophic-mesotrophic	Mesotrophic-eutrophic	Eutrophic-hypereutrophic	Reference
P	10	30	100	Nürnberg (1996)*
	15	25	100	Forsberg and Ryding (1980)
	10	25	100	Jones and Knowlton (1993)
	10	30	100	KLH (2009)
N	350	650	1,200	Nürnberg (1996)*
	400	600	1,500	Forsberg and Ryding (1980)
	300	500	1,200	Jones and Knowlton (1993)
	650	750	1,900	KLH (2009)
Chlorophyll a	3.5	9	25	Nürnberg (1996)*
	3	7	40	Forsberg and Ryding (1980)
	3	7	40	Jones and Knowlton (1993)
	2	5	15 (hyp. > 200)	KLH (2009)

TABLE 48. Nutrient levels, biomass, and productivity of lakes for trophic classes

Trophic category	Mean total phosphorous (mg m^{-3})	Annual mean Chlorophyll a (mg m^{-3})	Chlorophyll a maxima (mg m^{-3})	Annual mean Secchi disc transparency (m)	Secchi disc transparency minima (m)	Minimum oxygen (% sat)*
Ultra-oligotrophic	4	1	2.5	12.0	6.0	<90
Oligotrophic	10	2.5	8	6.0	3.0	<80
Mesotrophic	10–35	2.5–8	8–25	6.0–3.0	3.0–1.5	40–89
Eutrophic	35–100	8–25	25–75	3.0–1.5	1.5–0.7	40–0
Hypereutrophic	100	25	75	1.5	0.7	10–0

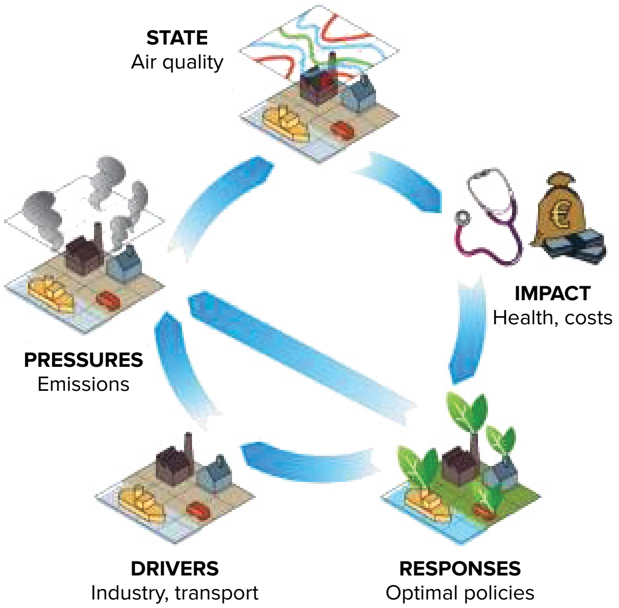
Source: Chapman, 1996.
Note: *The percentage saturation in bottom waters depending on mean depth.

APPENDIX C

The DPSIR Concept

The Driver, Pressure, State, Impact, Response (DPSIR) concept enables systematic analysis of complex issues and streamlining insights and appropriate responses within large groups of stakeholders. The concept is illustrated in Figure 80 and detailed in Table 49.[178]

FIGURE 80. Driver, pressure, state, impact, and response concept



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[178] For more information about systems thinking and the DPSIR concept, see https://archive.epa.gov/ged/tutorial/web/html/index.html

TABLE 49. Descriptions for driver, pressure, state, impact, and response

Element	Description
Driver	*Drivers* are the social, demographic, and economic developments in societies and corresponding changes in life styles, overall levels of consumption, and production patterns. Drivers are often defined as socioeconomic sectors that fulfil human needs for food, water, shelter, health, security, and culture. Driving forces can originate and act globally, regionally, or locally.
Pressure	Drivers function through human activities which may exert *Pressures* on the environment. Human activities that exert pressure include: land use changes; resource consumption; release of substances; and physical damage through direct contact. Pressures depend on the kind and level of technology involved in source activities and can vary across geographic regions and spatial scales.
State	The pressures exerted by society may lead to unintentional or intentional changes in the *State* of the ecosystem. Usually these changes are unwanted and negative (damage, degradation). The pressures exerted by society may directly impact the ecosystem, such as harvesting or dredging, or may be transported and transformed through a variety of natural processes to indirectly cause changes in ecosystem conditions. The State is the condition of the abiotic and biotic components of the ecosystems in a certain area in terms of: physical variables (the quantity and quality of physical phenomena such as temperature or light availability); chemical variables (the quantity and quality of chemicals such as atmospheric CO_2 concentrations or nitrogen levels): and biological variables (the condition at the ecosystem, habitat, species, community, or genetic levels, such as fish stocks or biodiversity).
Impact	Changes in the quality and functioning of the ecosystem have an *Impact* on the welfare or well-being of humans through the provision of ecosystem services. Ecosystem goods and services are ecosystem functions or processes that directly or indirectly benefit human social or economic drivers or have the potential to do so in the future. Ecosystem processes benefit humans through: provisioning of food, timber, and water; regulation of air quality, water quality, or disease; cultural benefits including aesthetic or recreational value; and indirect supporting processes that maintain the ecosystem. The value of ecosystem services depends on human need and use (e.g., market value).
Response	Humans make decisions in *Response* to the impacts on ecosystem services or their perceived value. Responses are actions taken by groups or individuals in society and government to prevent, compensate, ameliorate, or adapt to changes in the state of the environment by seeking to: control drivers or pressures through regulation, prevention, or mitigation; directly maintain or restore the state of the environment; deliberately "do nothing"; and/or decision-making processes occur at a variety of scales, from individuals to local management to federal government.

Source: Environmental Protection Agency, USA.

APPENDIX D

Legislation Overview

The legislation, regulations, and decrees that are relevant for the management and monitoring of Lake Toba's water quality are presented in Table 50.

TABLE 50. Laws, regulations, and decrees relevant to Lake Toba

Legal instrument	Name
In English	
Acts	Act No. 5 of 1990 on the Conservation of Biological Natural Resources and Its Ecosystem
	Act No. 41 of 1999 on Forestry
	Act No. 26 of 2007 on Spatial Planning
	Act No. 32 of 2009 on Environmental Protection and Management
	Act No. 23 of 2014 on Regional Government
Government Regulation	Government Regulation No. 82 of 2001 on Water Quality Management and Water Pollution Control
	Government Regulation No. 44 of 2004 on Forest Planning
	Government Regulation No. 45 of 2004 on Forest Protection
	Government Regulation No. 26 of 2008 on National Spatial Planning
	Government Regulation No. 42 of 2008 on Forest Planning
Presidential Regulation	Presidential Regulation No. 81 of 2014 on spatial planning of Lake Toba and its surrounding
	Presidential Regulation No. 49 of 2016 on the Management Authority of Lake Toba Tourism Area
Presidential Decree	Presidential Decree No. 32 of 1990 on Protected Areas Management
	Presidential Decree No. 2 of 2014 on the addition of Jasa Tirta 1 Company's working area in Toba Asahan River, Serayu Bogowonto River and Jrantunseluna River
Ministerial Regulation	Ministry of Health Regulation No. 416/1990 on the requirements of Water Quality Supervision
	Ministry of Health Regulation No. 907 of 2002 on the Requirements and Supervision of Drinking Water Quality
	Ministry of Environment Regulation No. 111 of 2003 on the Guidance of Requirements and Licensing Procedures along with the Guidance on Waste Disposal to Water and Water Sources
	Ministry of Environment Regulation No. 28 of 2009 on the capacity of pollution load on Lake and Reservoir Water
	Ministry of Public Work and Public Housing Regulation No. 4 of 2015 on River Area Criteria and Stipulation
	Ministry of Public Work and Public Housing Regulation No. 9 of 2015 on Water Resources Utilization
	Ministry of Public Work and Public Housing Regulation No. 10 of 2015 on Planning and Technical Planning of Water Governance and Irrigation System
	Ministry of Public Work and Public Housing Regulation No. 28 of 2015 on the stipulation of River border line and Lake border line
	Ministry of Public Work and Public Housing Regulation No. 37 of 2015 on the license of Water and/or Water sources use
	Ministry of Environment and Forest Regulation No. 68 of 2016 on Water Waste Quality Standard
	Ministry of Public Work and Public Housing Regulation No. 4 of 2017 on the implementation of Domestic Water Waste Management System
North Sumatra Governor Regulation	North Sumatra Governor Regulation No. 30 of 2008 on the Management Coordination Board of Lake Toba ecosystem area
	North Sumatra Governor Regulation No. 1 of 2009 on the water quality standard of Lake Toba in North Sumatra Province
	North Sumatra Governor Regulation No. 18 of 2009 on the Preservation Coordination Board of Lake Toba ecosystem area

(continues)

TABLE 50. Continued

Legal instrument	Name
North Sumatra Governor Decree	North Sumatra Governor Decree No. 062.05/255/K/2002 on the Preservation Coordination Board of Lake Toba ecosystem area
	North Sumatra Governor Decree No. 614/468 of 2008 on the formation of Asahan-Toba watershed Management Forum
	North Sumatra Governor Decree No 188.44/209/KPTS/2017 on Lake Toba trophic status
	North Sumatra Governor Decree No. 188.44/213/KPTS/2017 on the Capacity of Lake Toba pollution load and carrying capacity for fisheries cultivation
	Regional Regulation No. 7 of 2003 on North Sumatra Spatial Planning is currently (July 2017) being updated and still in the process of legalization in the Governor's office
In Bahasa Indonesia	
Undang-Undang	Undang-Undang Nomor 5 Tahun 1990 tentang Konservasi Sumber Daya Alam Hayati dan Ekosistemnya
	Undang-Undang Nomor 41 Tahun 1999 tentang Kehutanan
	Undang-Undang Nomor 32 Tahun 2004 tentang Pemerintahan Daerah
	Undang-Undang Nomor 26 Tahun 2007 tentang Penataan Ruang
	Undang-Undang Nomor 32 Tahun 2009 tentang Perlindungan dan Pengelolaan Lingkungan Hidup
Peraturan Pemerintah	Peraturan Pemerintah Nomor 82 Tahun 2001 tentang Pengelolaan Kualitas Air dan Pengendalian Pencemaran Air
	Peraturan Pemerintah Nomor 44 Tahun 2004 tentang Perencanaan Kehutanan
	Peraturan Pemerintah Nomor 45 Tahun 2004 tentang Perlindungan Hutan
	Peraturan Pemerintah No. 26 Tahun 2008 tentang Rencana Tata Ruang Wilayah Nasional
	Peraturan Pemerintah No. 42 Tahun 2008 tentang Perencanaan Kehutanan
Peraturan President	Perpres No. 81/2014—Peraturan President No. 81 Tahun 2014 tentang Rencana Tata Ruang Kawasan Danau Toba dan sekitarnya
	Perpres No. 49/2016—Peraturan President No. 49 Tahun 2016 tentang Badan Otorita Pengelola Kawasan Pariwisata Danau Toba
Keputusan President	Keputusan President Nomor 32 Tahun 1990 tentang Pengelolaan Kawasan Lindung
	Keppres No. 2/2014—Keputusan President Nomor 2 Tahun 2014 tentang Penambahan Wilayah Kerja Perusahaan Umum (PERUM) JASA TIRTA I di Wilayah Sungai Toba Asahan, Wilayah Sungai Serayu Bogowonto, dan Wilayah Sungai Jratunseluna
Peraturan Menteri	Peraturan Menteri Kesehatan Nomor 416/1990 tentang Syarat-Syarat Pengawasan Kualitas Air
	Keputusan Menteri Kesehatan Nomor 907 Tahun 2002 tentang Syarat dan Pengawasan Kualitas Air Minum
	Keputusan Menteri Negara Lingkungan Hidup Nomor 111 Tahun 2003 tentang Pedoman mengenai Syarat dan Tata Cara Perijinan serta Pedoman Pembuangan Limbah ke Air dan Sumber Air
	Peraturan Menteri Negara Lingkungan Hidup Nomor 28 Tahun 2009 tentang Daya Tampung Beban Pencemaran Air danau dan/atau Waduk
	Peraturan Menteri PUPR Nomor 4 tahun 2015 tentang Kriteria dan Penetapan Wilayah Sungai
	Peraturan Menteri PUPR Nomor 9 tahun 2015 tentang Penggunaan Sumber Daya Air
	Peraturan Menteri PUPR Nomor 10 tahun 2015 tentang Rencana dan Rencana Teknis Tata Pengaturan Air dan Tata Pengairan
	Peraturan Menteri PUPR Nomor 28 tahun 2015 tentang Penetapan Garis Sempadan Sungai dan Garis Sempadan Danau
	Peraturan Menteri PUPR Nomor 37 tahun 2015 tentang Izin Penggunaan Air dan/atau Sumber Air
	Peraturan Menteri Lingkungan Hidup Kehutanan Nomor 68 Tahun 2016 tentang Baku Mutu Air Limbah
	Peraturan Menteri PUPR Nomor 4 Tahun 2017 tentang Penyelenggaraan Sistem Pengelolaan Air Limbah Domestik
Peraturan Gubernur Sumatera Utara	Peraturan Gubernur Sumatera Utara No. 30 tahun 2008 tentang Badan Koordinasi Pengelolaan Ekosistem Kawasan Danau Toba
	Peraturan Gubernur Sumatera Utara Nomor 1 Tahun 2009 tentang Baku Mutu Air Danau Toba di Provinsi Sumatera Utara
	Peraturan Gubernur Sumatera Utara Nomor 18 Tahun 2009 tentang Badan Koordinasi Pelestarian Ekosistem Kawasan Danau Toba
Keputusan Gubernur Sumatera Utara	Surat Keputusan Gubernur Sumatera Utara Nomor 062.05/255/K/2002 tentang Badan Koordinasi Pelestarian Ekosistem Kawasan Danau Toba
	Surat Keputusan Gubernur Sumatera Utara No. 614/468 tahun 2008 tentang Pembentukan Forum Pengelolaan Daerah Aliran Sungai Asahan-Toba
	Surat Keputusan Gubernur Sumatera Utara Nomor 188.44/209/KPTS/2017 tentang Status Trofik Danau Toba
	Surat Keputusan Gubernur Sumatera Utara Nomor 188.44/213/KPTS/2017 tentang Daya Tampung Beban Pencemaran dan Daya Dukung Danau Toba untuk Budidaya Perikanan
	Peraturan Daerah Nomor 7 Tahun 2003 tentang Rencana Tata Ruang Wilayah Provinsi Sumatera Utara is currently (July 2017) being updated and still in the process of legalization in the Governor's office

APPENDIX E

Sample of Water Quality Data (PJT1)

A collection of water quality data from the Jasa Tirta 1 Public Corporation (*Perusahaan Umum Jasa Tirta,* PJT1), a state-owned enterprise of water resource management, is shown in Table 51 to illustrate data availability and levels. PJT1 started monitoring water quality at 20 sampling sites in the Toba Asahan basin in 2016 (Figure 19) together with the Sepuluh Nopember Institute of Technology, Surabaya. Data from these sites were not available for roadmap modelling.

TABLE 51. Water quality data at eight sampling sites by PJT1 in 2016 and 2017 (mg/l)

			Location							
Parameter	**Date**	**Water quality standard**	**Reference point**	**Bakkara**	**Nainggolan**	**Hilir Danau**	**Simalungun**	**Sipiso-piso**	**Dairi**	**Tomok**
Dissolved oxygen	May 2016	4	6.6	6.6	—	4.8	5.4	5.2	4.3	4.7
	Sep 2016	4	—	—	—	7.5	6.6	6.4	6.5	5.6
	Jan 2017	4	5.6	5.6	5.5	5.0	5.5	4.8	5.1	5.2
	Apr 2017	4	5.6	5.2	5.4	5.3	5.4	5.1	4.9	5.1
	Jul 2017	4	4.9	4.2	4.0	4.0	4.8	4.2	4.0	4.0
Biochemical oxygen demand	May 2016	3	5.1	3.9	—	3.8	9.2	4.9	9.4	9.0
	Sep 2016	3	—	—	—	3.2	3.1	3.2	3.4	3.2
	Jan 2017	3	6.5	5.5	13.6	6.3	4.7	4.3	4.9	12.0
	Apr 2017	3	3.89	6.91	2.54	3.20	3.59	4.75	2.01	3.54
	Jul 2017	3	5.55	4.55	4.80	6.35	6.30	7.35	4.45	4.75
Chemical oxygen demand	May 2016	25	17.28	7.70	—	7.04	21.23	13.10	22.30	20.27
	Sep 2016	25	—	—	—	7.15	9.32	8.62	8.95	8.51
	Jan 2017	25	23.08	23.56	38.91	21.17	14.12	12.34	14.80	37.62
	Apr 2017	25	14.37	29.63	8.30	13.02	12.67	12.94	7.56	14.66
	Jul 2017	25	18.22	17.32	15.37	16.31	17.40	16.39	12.92	14.48

APPENDIX F

Lake Assessment Methodology

The Sumatra Spatial Model

Background

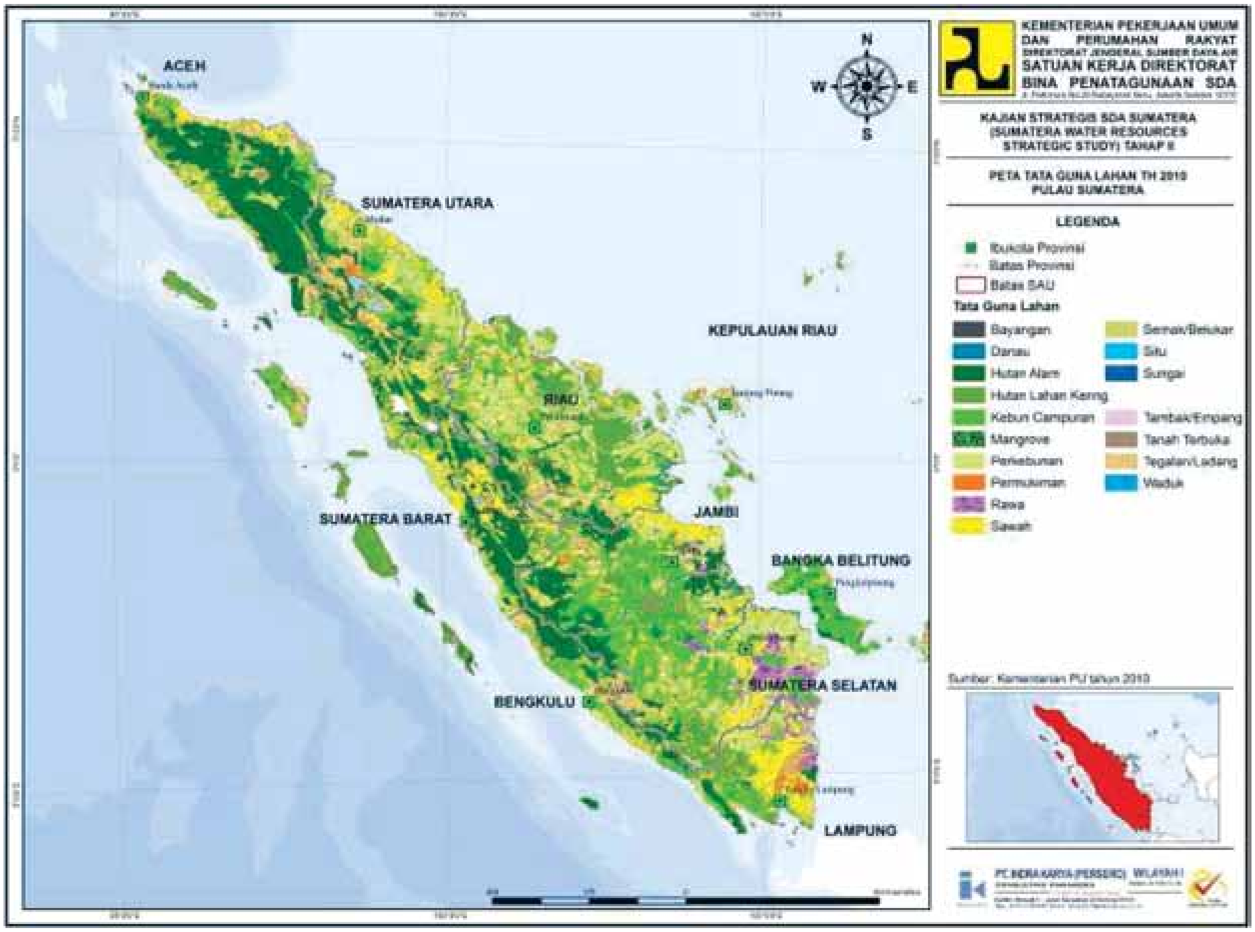
Demographic changes and economic activities over the next 25 years will increase pressures on land, water, and environmental resources. Adverse impact on water runoff is already occurring (e.g., higher peak flows and lower low flows with associated floods and impact on water supply), and competition for fertile irrigable land is increasing. Effective protection through spatial zoning and regulation will be necessary to protect and balance different sector interests. The Spatial Law Nr 26 (2007) incorporates the sustainable management and protection of resources and provides a framework to develop and implement spatial planning within Indonesia (Figure 81). For example, the law has set a minimum target of maintaining 30 percent of forests in catchment areas.

Land use data in the Sumatra Spatial Model (SSM) (Figure 82) comes from the Indonesia terrain maps from the Geospatial Information Agency (*Badan Informasi Geospatial,* BIG). Parts of their datasets were out-of-date and corrections were made for paddy fields (based on the 2010 Peta Audit Baku Sawah from the Ministry of Agriculture) and urban areas (Google Maps). Some of the categories near Lake Toba needed correction to get a representative starting point for land use per village *(desa).* Any large land claims for a sector will impact other land consuming sectors. A quantitative approach can model spatial changes in population, employment, urban land use, and associated changes in land use to understand and predict such trade-offs.

The SSM provides internally consistent future projections of:

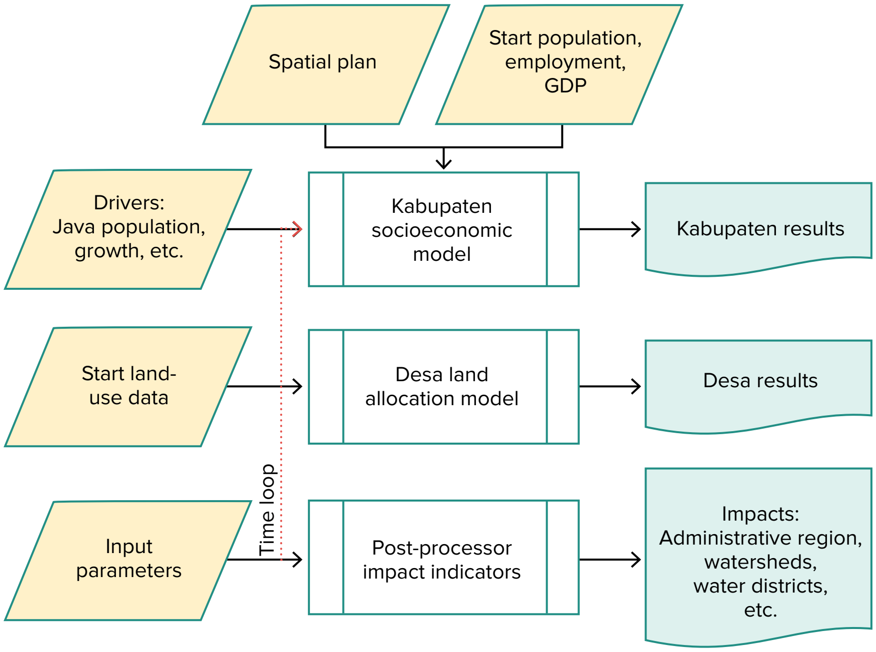
- The spatial distribution at village level of the population and employment;
- The urban area growth needed to accommodate human activities; and
- The land-use changes caused by the urban area growth.

FIGURE 81. Land use on North Sumatra



Source: Rupa Bumi (BIG).

FIGURE 82. Overview of the Sumatra Spatial Model



Note: As originally applied to Java.

The SSM provides consistent projections of urban/rural land use and consequences on total water demand, water quality, and ecology based on:

- Socioeconomic projection of population and employment at the district level based on economic growth scenarios;
- Spatial allocation of population and land use for Java at the village level; and
- Calculation of impacts, such as water demands, and pollutant emissions at different geographic levels (the river basin territories or parts thereof, catchment area, province, districts, subdistricts and villages) based on existing Ministry of Public Works (MPW) guidelines for river basin studies.[179]

Land-use changes

Transformation of nonurban areas into urbanized land is driven by changes in housing, labor, and transportation markets. Predicting drivers, such as demographic changes, are important to project the demand on land. Key drivers for additional urban land use include: domestic land-use change (i.e., population growth, household size reduction, and increasing use of land resources per household as wealth grows); and municipal and industrial land-use changes (i.e., economic growth, employment growth, and changes in economic structure).

Drivers of land use change underpins the SSM design. The key design principles are: a two-step approach to capture different spatial trends of centralization at an interregional *(kabupaten)* level and decentralization at the levels within a region *(desa);* dynamic modelling using time steps of one year, reflecting the incremental nature of spatial changes (which enables modelling of time path dependency of developments); and capability to calculate the impacts on the spatial distribution of residents/employment and associated land-use changes of different socioeconomic and demographic scenarios and/or policies at the *desa* level.

Sub-models and variables

The model consists of three sub-models (Figure 83).

Sub-model 1: Socioeconomic sub-model by kabupaten. Calculates population growth and migration at district *(kabupaten)* level. Sum of population of all districts on the island (Sumatra) is kept equal to available official population projections[180] and economic growth scenarios.

The socioeconomic sub-model handles the projections of population and industrial activities. It uses four model sectors: population, employment, housing, and industry (interrelated and representing major urban developments). Between the three economic sectors of agriculture, industry, and services, there are various feedbacks that influence the rates of change within the sectors. The distribution of the (growing) population and migration depends on the attractiveness of an area (e.g., number of available jobs) and is constrained by limited resources (e.g., land). These two assumptions mean that growth is limited in the end by available land. A key data source for calibration of the sub-model is the Dalam Angka data and Census 1990/2000 data of Statistics Indonesia (*Badan Pusat Statistik,* BPS). Data was collected for the time period 1990 to 2010. Census 2010 data were obtained for calibration at the district *(kabupaten)* level.

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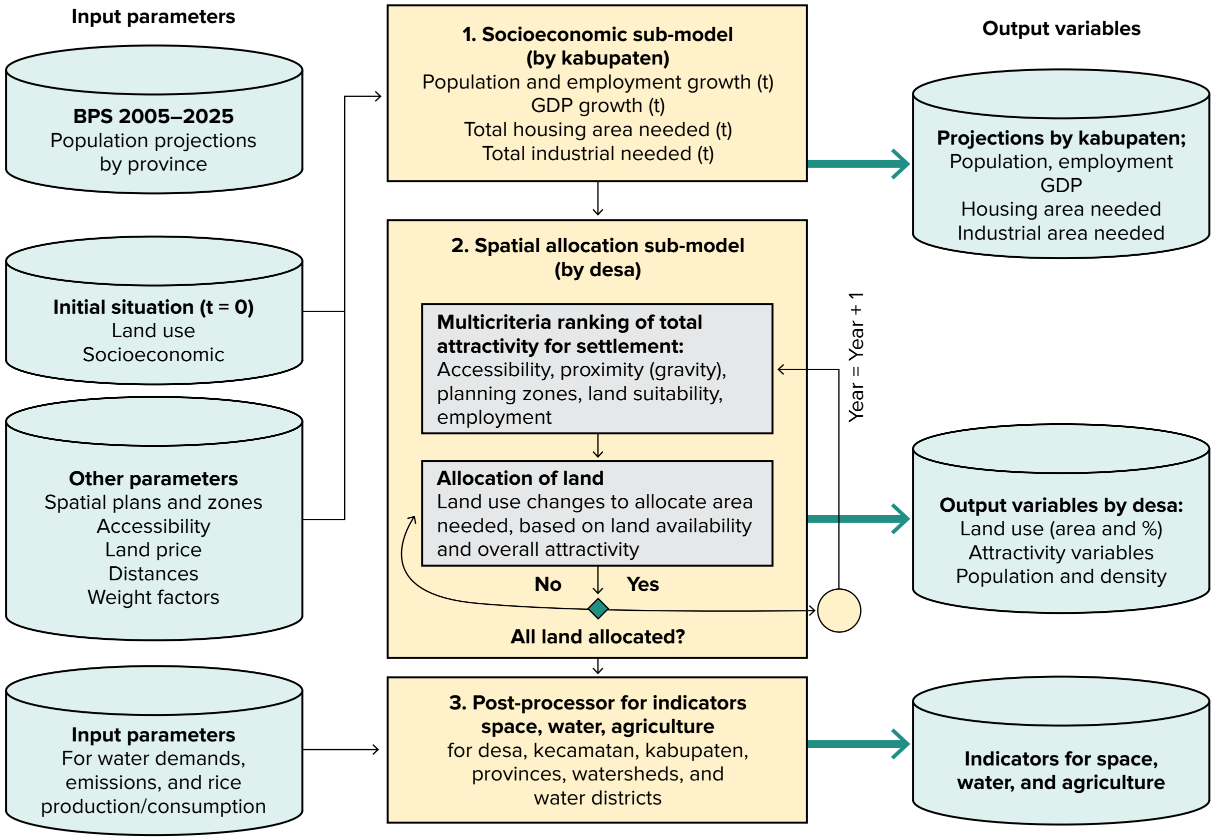
[179] In 2015 and 2016 the Sumatra Spatial Model was applied to Sumatra in the Sumatra Water Resources Strategic Study and to Sulawesi in the Sulawesi Water Resources Strategic Study (SulSM).

[180] BPS and National Development Planning Agency/BAPPENAS.

FIGURE 83. The Sumatra Spatial Model



Sub-model 2: Spatial allocation sub-model by desa. Allocates space demand at the kabupaten level to desa level based on preferences of residents and zoning policy.

The sub-model predicts how the calculated growth of activities of the socioeconomic sub-model is spatially distributed within the study area and what the resulting land-use changes are. The available land in the different areas (cells) will be the subject of inventory and the attractiveness of this area for the land demanding activities. The available land for the allocation process depends on the land use in the area. The attractiveness of an area for a specific activity is a combination of the characteristics of the area (accessibility, access to work, proximity, planning zones, land price and land development costs, and aesthetic value) and the preferences of the activities. This parameter is called the attractiveness potential of an area. New activities are allocated to the areas at every time step. After the allocation, the new situation will be stored in the database and will function as a starting point of the next time step.

Sub-model 3: Postprocessor for indicators space, water, and agriculture (i.e., indicators on land-use changes at different administrative levels, water resources impacts, agricultural and food supply impacts, and ecological impacts).

The sub-model calculates indicators as inputs to Basin Water Resources Management Planning and other sectoral resources impact assessments. Outputs of the sub-model include:

- Spatial indicators (directly from the allocation module)
  - Population and population density
  - Fraction of areas by land-use class

- Water demands
  - Domestic, municipal, and industrial demand (DMI)
  - Irrigation
- Biochemical Oxygen Demand
  - Domestic, municipal, and industrial emissions
  - Irrigated paddy
- Biodiversity
  - Mean species abundance (MSA) loss due to urbanization
  - Rice, vegetable, and palawija crop production, consumption, and self-sufficiency
  - Spatial results by compartment and year

Spatial Results

Spatial results in 2018, 2022, and 2042 for Lake Toba as a whole and by compartment are presented in Table 52.

Calculation of Nutrient Concentration Trajectories

Total nitrogen (TN) and total phosphorous (TP) concentrations are calculated in a simple water quality budget model approach that is a modification of the models in previous Lake Toba carrying capacity studies (Oakley 2015; LIPI, EPANS, CFM, 2014). The budget model approach is an oversimplification of reality, which does not take into account the complexity of physical and biogeochemical processes, nor their variability in time and space. Therefore, the model does not provide any system understanding, nor provide any predictions about future changes in physical or biogeochemical processes. The compartment approach addresses some of the spatial variability present in Lake Toba. Also, the sensitivity for the thermocline depth is explored. For more precise computations and predictions, it is recommended to use a 3D ecosystem model.

TN concentration in a water body is determined by the loading, the lake's surface area, the lake's mean thermocline depth, the flushing rate, and the fraction of nutrients retained in the water column. The calculation is: $C = L/(Q + k * A * d)$. In which: C = the calculated concentration (µg/l), L = the nutrient load as calculated in the section above (µg/d), Q = outflow (m^3/d), k = retention rate (1/d), A = surface area (m^2), and d = thermocline depth (m). The outflow varies between 90 and 140 m^3/s,[181] and is set at 110 m^3/s in the model (i.e., a combination of long-term average and extrapolation of trends). The exact value of outflow has minimal impact on resulting concentrations. The effect is the same in the compartments.

Comparison to LIPI Data

Results from the Sumatra Spatial Model were compared to 2010 findings from the Indonesian Institute of Sciences (LIPI). The PTAN data compared well with LIPI's observed values of 2010 study (describing trophic state of 19 different sampling sites along the coastline of Lake Toba).

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[181] Vernimmen, 2015.

TABLE 52. Overview of spatial results in 2018, 2022, and 2042

Variables	Whole lake			North			South			South 1			South 2			South3		
Year	2018	2022	2042	2018	2022	2042	2018	2022	2042	2018	2022	2042	2018	2022	2042	2018	2022	2042
Metropolitan population	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large town population	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medium town population	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small town population	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kecamatan city population	42,468	43,547	46,896	19,138	19,770	21,740	0	0	0	4,844	4,960	5,317	3,668	3,761	4,035	14,818	15,056	15,804
Desa population	438,622	475,637	585,531	124,803	137,582	175,930	23,330	23,777	25,155	35,847	38,672	47,115	160,417	171,956	203,774	117,555	127,426	158,712
Employment	209,528	223,243	338,761	65,208	69,478	105,950	313,819	338,055	409,600	20,666	22,026	33,413	83,023	88,394	132,849	40,631	43,345	66,550
Households	118,610	129,903	173,747	35,522	39,133	53,465	144,321	153,765	232,812	10,130	11,094	14,791	39,572	43,081	56,103	33,388	36,595	49,387
Housing (ha)	10,964	12,155	16,628	3,712	4,323	6,635	83,089	90,770	120,282	1,021	1,088	1,337	3,606	3,942	5,152	2,624	2,802	3,503
Other buildings (ha)	1,534	1,751	4,105	521	622	1,693	7,252	7,832	9,992	174	190	362	445	514	1,271	394	426	779
Rainfed paddy (ha)	0	0	0	0	0	0	1,012	1,130	2,411	0	0	0	0	0	0	0	0	0
Technical irrigated paddy (ha)	17,188	17,062	16,443	2,187	2,156	2,012	0	0	0	944	942	930	6,731	6,687	6,475	7,326	7,276	7,026
Semi-technical irrigated paddy (ha)	11,459	11,374	10,962	1,458	1,438	1,341	15,001	14,905	14,431	629	628	620	4,488	4,458	4,317	4,884	4,851	4,684
Other agriculture (ha)	80,397	79,876	77,480	21,592	21,331	20,188	10,001	9,937	9,621	11,600	11,551	11,302	40,560	40,376	39,507	6,645	6,618	6,483
Grass/other (ha)	10,871	10,748	10,243	2,938	2,847	2,485	58,805	58,545	57,292	1,543	1,539	1,518	4,403	4,382	4,289	1,987	1,981	1,951
Shrub (ha)	54,168	53,950	52,831	17,330	17,218	16,652	7,933	7,901	7,758	5,652	5,632	5,529	25,401	25,327	24,939	5,785	5,773	5,712
Forest (ha)	62,406	62,305	61,795	27,005	26,933	26,565	36,838	36,732	36,180	10,784	10,782	10,772	18,151	18,132	18,031	6,465	6,459	6,427
Ponds (ha)	0	0	0	0	0	0	35,401	35,373	35,229	0	0	0	0	0	0	0	0	0
Plantation (ha)	32,627	32,407	31,403	3,632	3,522	3,061	0	0	0	1,404	1,400	1,383	6,699	6,668	6,520	20,892	20,817	20,440
Water (ha)	3,575	3,575	3,575	1,626	1,626	1,626	28,995	28,885	28,342	130	130	130	1,589	1,589	1,589	231	231	231
Total urban area (ha)	12,497	13,906	20,732	4,233	4,945	8,329	1,949	1,949	1,949	1,195	1,278	1,700	4,051	4,456	6,422	3,018	3,228	4,282
Total irrigated paddy area (ha)	28,647	28,436	27,405	3,645	3,594	3,353	8,264	8,961	12,404	1,573	1,569	1,551	11,219	11,146	10,792	12,210	12,127	11,710
Sum of remaining area available for land-use change (ha)	197,534	196,125	189,299	53,089	52,378	48,994	25,002	24,842	24,052	18,598	18,515	18,093	81,817	81,411	79,445	44,031	43,821	42,767
Total area (ha)	294,052	294,052	294,052	90,217	90,217	90,217	144,445	143,748	140,305	33,946	33,946	33,946	112,591	112,591	112,591	57,297	57,297	57,297
Total population	481,090	519,184	632,426	143,941	157,352	197,670	203,835	203,835	203,835	40,691	43,632	52,432	164,086	175,717	207,809	132,372	142,482	174,515
House area needed (ha)	0	0	0	0	0	0	337,149	361,831	434,756	0	0	0	0	0	0	0	0	0
Industry area needed (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
House area vacated (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry area vacated (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 53. LIPI data set from April 2010

Station	Total organic matter (mg/l)	Dissolved organic matter (mg/l)	Particulate organic matter (mg/l)	Total nitrogen (mg/l)	Dissolved oxygen (mg/l)	Temp (°C)	pH	Conduct. (µS/cm)
1	15.22	7.97	7.25	0.484	8.467	27.3	8.900	0.205
2	15.22	5.80	9.42	0.452	8.250	27.1	8.227	0.162
3	20.02	10.14	9.88	0.516	8.320	27.3	8.220	0.162
4	12.17	10.14	2.03	0.452	8.293	27.4	8.200	0.163
5	18.26	10.87	7.39	0.484	8.300	26.9	8.408	0.163
6	18.26	12.17	6.09	0.387	7.900	27.0	8.190	0.162
7	14.49	10.14	4.35	0.484	7.950	27.1	8.020	0.163
8	15.22	10.14	5.07	0.581	7.680	27.4	8.113	0.167
9	12.17	6.92	5.26	0.452	7.330	27.1	7.848	0.166
10	8.30	6.52	1.78	0.484	7.710	27.2	7.757	0.164
11	12.17	5.07	7.10	0.484	7.810	27.0	7.890	0.165
12	19.78	9.89	9.89	0.484	7.910	27.0	7.990	0.162
13	10.87	5.80	5.07	0.452	7.690	27.0	8.027	0.161
14	12.93	9.89	3.04	0.484	7.820	27.2	8.220	0.160
15	22.82	13.69	9.13	0.419	7.670	26.7	8.000	0.164
16	12.93	8.69	4.24	0.161	7.550	26.5	8.320	0.162
17	12.17	2.77	9.41	0.581	7.750	26.7	8.050	0.162
18	7.25	6.22	1.02	0.581	7.630	26.6	8.100	0.163
19	11.41	5.80	5.62	0.323	7.750	26.7	8.050	0.163

Source: Badjeori, 2013.

Available Data and Their Quality

Several stakeholders provided data for this study that were assessed in terms of different functions. The data included catchment-wide GIS data on land use, population statistics, agricultural statistics, or lake monitoring data such as nutrient concentrations, water transparency, and chlorophyll a concentrations.

When comparing the data from DLH-SU, LIPI, and PTAN with the monitoring guideline set up by Chapman (1996), it became clear that the DLH-SU data set is currently the most comprehensive data set compared to LIPI and PTAN. Also, only few of the relevant parameters are missing (hardness, conductivity, sodium, potassium, calcium cyanide, arsenic and selenium, organic solvents, phenols, pesticides, surfactants), of which for Lake Toba probably only the organic contaminants (solvents, phenols, pesticides) are of relevance. The PTAN and LIPI data sets are less 'complete' with respect to their set of parameters, as compared to the Chapman guideline.

The spatial vertical distribution of the datasets from DLH-SU, LIPI, and PTAN confirms the different purposes of data collection. Both DLH-SU and LIPI aim to cover the whole lake. DLH-SU focuses on parameters near the shore, probably connected to local pollutant sources, and LIPI on characterizing the lake itself by selecting only mid-lake monitoring points. PTAN is focusing on their aquaculture farms and has one reference point. For whole lake monitoring, the combination of DLH-SU and LIPI monitoring locations seems a good and nonoverlapping match.

As for horizontal distribution (profiles), the DLH-SU data set does not contain depth information, but a safe assumption would be that samples are taken directly below the water surface in the upper epilimnion. Both the LIPI and PTAN data contain depth profiles for 100 meter and 200 meter depths, respectively. For the lake assessment, the profile data up to at least a 200 meter depth are necessary, especially on temperature and oxygen, to fully cover the transition of epilimnion to the hypolimnion.

The temporal distributions of the data sets vary. PTAN data are most consistent, with monthly data. DLH-SU monitors one to two times a year. LIPI data covers 2009 only, though more unpublished data might be present. Monthly data can be regarded as the minimum requirement for exploratory and statistical monitoring.

TABLE 54. Data assessment based on three functions (1 = signal, 2 = exploratory, and 3 = statistically conclusive)

Lake data	Monitoring function	Trophic status	Water balance	Hydrodynamic model	Nutrient loading	Carrying capacity	Erosion	Remarks
Bathymetry	Statistically conclusive	3	3	3	3	3	3	
Hydrology, rainfall	Statistically conclusive	3	3	1	3	3	3	• Level 3 for general ecological analysis • Level 1 for lake stratification (hourly data required for lake stratification modelling, including wind force and direction)
Water balance and operation	Statistically conclusive	3	3	3	3	3	3	
Hydrological model	Statistically conclusive	3	3	3	3	3	3	
Water balance model	Statistically conclusive	3	3	3	3	3	3	
Catchment characteristics (GIS elevation, land use, environment, water system, infrastructure, water utilization, etc.)	Statistically conclusive	2	3	3	2	3	2	• More detailed digital elevation model would yield better results for smaller sub-catchments • More land use classes will improve load estimates, only if those classes are mapped >70% accuracy • Detailed soil maps improve results
Lake Toba Atlas—GIS	Same as above							
Water supply	Signal		1					
Temperature (including profile)	Exploratory	2	2	2	2	2	2	No year-round data available in a spatially stratified sampling scheme, borders on level 1
Circulation (horizontal)	Signal	1	1	1	1	1	1	No data available, only calibrated model (LIPI) based on level 2 data that are not year round
Oxygen (including profile)	Signal	1	1	1	1	1	1	Some profiles available from a few locations, year-round or multiyears for grouped locations (PTAN)
Nitrogen (including profile)	Signal	1	1	1	1	1	1	
Phosphorus (including profile)	Signal	1	1	1	1	1	1	
Chlorophyll a (including profile)	Signal	1	1	1	1	1	1	
Aquatic flora and fauna	Exploratory	2	2		2	2	2	
Pesticides	Not encountered							
Transparency (Secchi depth)	Exploratory	2	2	2	2	2	2	
Isotope profiles	Data not available							
Satellite interpretation	See catchment characteristics							
Conservation and deforestation	Exploratory	2	2		2	2	2	• Locations known • Unknown if other data exist, such as exact ecological status, landscape ecological quality, status of conservation targets
Erosion	Exploratory	2	2		2	2	2	• Estimates are available from modelling
Pollutant source analysis	Exploratory	2	2		2	2		• Emissions are estimated (common practice) • No direct measurements in discharges or rivers or from fields available
Fisheries	Exploratory	2	2		2	2		
Carrying Capacity analysis	Exploratory	2	2		2	2	2	• Based on other parameters • Modelling is generally exploratory but can inform policy alternatives
Population (including scenarios)	Statistically conclusive	3	3		3	3	3	
Tourism (including scenarios)	Exploratory	2	2		2	2	2	
Livestock and agriculture (including scenarios)	Signal	1			1	1		• Livestock numbers not always available at village level • Administrative statistics have low internal consistency

Note: The assessment is given for overall and for six applications. Not all data may apply to all applications.

APPENDIX G

Recommendations on Livestock

The promotion of biogas production can be accelerated with the following measures:

- Incentivize increased use of biogas (e.g., funding for dry fermentation and efficient retreatment technologies, and support for co-digestion of slurry and solid manure).
- Manure-based biogas plants utilizing waste and by-products as co-substrates (energy crop utilization should be justified to avoid negative impact on the environment and market).
- Manure-based biogas plants with clear plans to optimize the entire manure management chain (proper solutions for substrate collection, plant design, and operation; and storage, spread, and potential post processing of the digestate to avoid pollution swapping between different steps).
- Energy efficient use of biogas as a criterion for environmental permit and financial support (best local utilization needs to be determined at planning stage).

The following considerations should be made:[182]

- Raise awareness of proper manure management (e.g., spread of livestock disease to humans).
- Put in place legislation to prevent discharge of animal manure (including liquids) to surface waters (irrigation and drainage channels, rivers, ponds, and lakes).
- Discourage livestock production in semi-urban environments.
- Develop and adapt technologies for effective manure management as appropriate for local livestock production systems, and introduce legislation for effective uptake of technologies.
- Survey current manure application practices within crop production systems and the effects of manure applications on crop yield and soil quality (use of manure as a source of organic matter in poor and degraded soils should be given attention by farmers, extension personnel, and those persons responsible for land management).
- Improve cooperation between researchers, legislators, and NGOs from across sectors and areas of expertise because animal manure management lies at the interface between animal production, soil science, and plant production.
- The greatest potential is achieved through an integrated system for using organic manure and inorganic fertilizers while minimizing environmental pollution and developing confidence among farmers in the use of animal manures.
- Combined use of animal manures with inorganic fertilizers is likely to result in increases in crop and forage production, resulting in economic benefit for farmers, as well as environmental benefits.

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[182] Adopted from “Guidelines for Sustainable Manure Management in Asian Livestock Production Systems;” IAEA-TECDOC-1582; May 2008.

- Develop pilot/demonstration farms (incorporating appropriate levels of technology) as an effective way of promoting positive messages on manure management at the local level.
- Develop decision support software that assists in manure management system design and in improved understanding of nutrient fluxes following manure application.
- Design and provide training courses on nutrient budgets and improved manure management practices.
- Provide communication materials (e.g., information sheets/pamphlets) on ‘best practices’ of manure management for extension workers and farmers.
- Initiate programs to reward farmers for carrying out sustainable manure management activities as an effective way of motivating other farmers to adopt ‘best’ manure management practices.

APPENDIX H

Recommendations on Wastewater

An inventory of existing and planned wastewater infrastructures informed the database used for the water quality modelling (derived from local sanitation strategies[183] as part of the PPSP[184] supported by the USDP)[185] in conjunction with updated and scaled population and development projections from the Sumatra Spatial Model.

More than 30 percent of people living around Lake Toba practice open defecation (except at Karo, 12 percent). This is higher than national figures for urban areas (23 percent of poor households and 7 percent of non-poor households).[186] For most Lake Toba households, temporary on-site or communal facilities will provide appropriate improvements in the short run (especially in the absence of piped running water). For the investment scenarios for 2018, 2022, and 2042, the projection assumed that households eventually be connected to off-site sewerage systems when: population density criteria were met, the number of connected households at district or village level exceeded 10,000 (i.e., 50,000 people), and the district or village GPD reached USD 3,000. The selection criteria for wastewater management systems is presented in Table 55. The locations of interventions of Scenario C and Scenario E, representing an intermediate level of wastewater management improvements in accordance with government plans and strategies, can be seen in the map in Figure 84. Cost figures for off-site systems were updated from the Waste Water Management Investment Roadmap,[187] and a comparison of required unit investment costs is illustrated in Figure 85. Table 56, Table 57, and Table 58 show the target interventions, split of budgetary responsibilities for financing interventions among national and local level authorities and users, and breakdown of costs for the different time horizons for Scenario C and Scenario E (showing for example approximately 30 percent of the costs would need to be borne by communities and users). The analysis recommends that cross-district solutions will be financially and administratively more attractive. Two key recommendations for improving existing conditions for wastewater, both requiring active community engagement and campaigns, are: remove poorly performing septic tanks that pollute surface water and groundwater, and instead connect to a sewerage collection system (e.g., at the time of house renovation); and intercept and treat effluent septic tank water and greywater before point of discharge into surface water and gradually move the point of interception closer to the house.

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[183] District Sanitation Strategy (*Buku Putih Sanitasi,* BPSan); City Sanitation Strategy (*Strategi Sanitasi Kota,* SSK); and Sanitation Sector Program Memorandum (*Memorandum Program Sanitasi,* MPS).

[184] National Accelerated Sanitation Development for Human Settlements Program or Program *(Nasional Percepatan Pembangunan Sanitasi Permukiman);* www.ppsp.info

[185] The Urban Sanitation Development Program (USDP) is a technical support project, within Accelerated Sanitation Development for Human Settlements Program or Program Percepatan Pembangunan Sanitasi Permukiman (PPSP). USDP took a role to facilitate and further strengthen the government institutions at the national, provincial and, indirectly, at the local level to be involved in implementing the program. USDP supports over 400 cities and regencies throughout Indonesia with technical, institutional, and health-related services (http://www.usdp.or.id/).

[186] BPS, 2010.

[187] City Wide Sanitation Investment Program, Waste Water Management Investment Roadmap; Asian Development Bank, May 2016. BE1344/R001/MvK/Indo

The specific interventions for improving the Parapat wastewater treatment (WWT) plant are listed and costed in Table 59 and recommend:

- Repair the existing sewer line, either fully or in the commercial area at a minimum;
- Construct additional sewer lines to connect more customers;
- Improve processes in the existing WWT plant;
- Connect septic tank effluents to the sewer line (as part of future Kawasan WWT system);
- Design and construct the additional Kawasan WWT plant; and
- Construct reliable public toilets including belowground structures at tourism hotspots.

TABLE 55. Selection criteria for wastewater facilities

BPSan criteria	Population density (pp/ha)	Area	WWT system	Examples
Rural	< 100	Rural areas	On-site systems	Septic tank
Rural	>100	Peri urban	Community based	Communal WWT plant
Urban	< 25	Very low-density urban areas	On-site systems	Septic tank
Urban	25–100	Low-density urban areas	Existing houses on-site; new infrastructure: off-site	Existing: septic tanks; new infrastructure: Kawasan WWT
Urban	100–250	High-density urban areas	Off-site systems	Kawasan WWT plant
Urban	>250		Off-site systems	Terpusat WWT plant

Note: BPSan = District Sanitation Strategy.

FIGURE 84. Indicative development of new wastewater systems in the period 2018–2022 for Scenario C and Scenario E

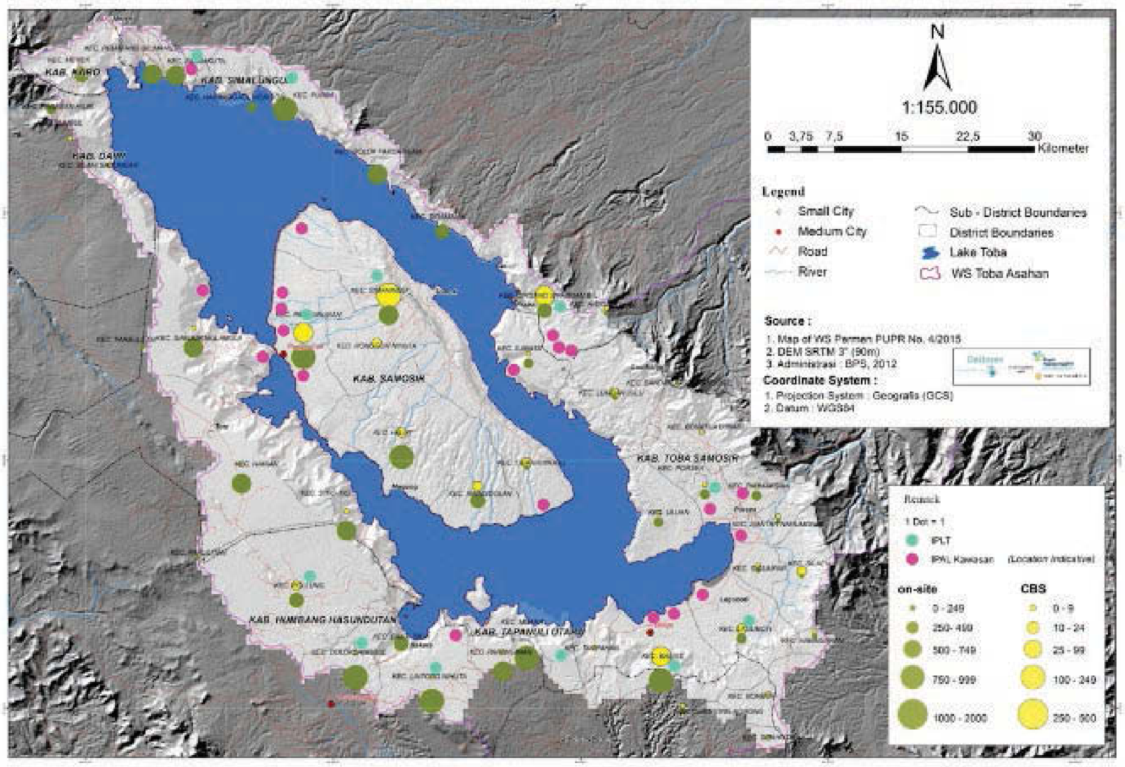

FIGURE 85. Applied unit cost rates for wastewater facilities (million IDR/person)

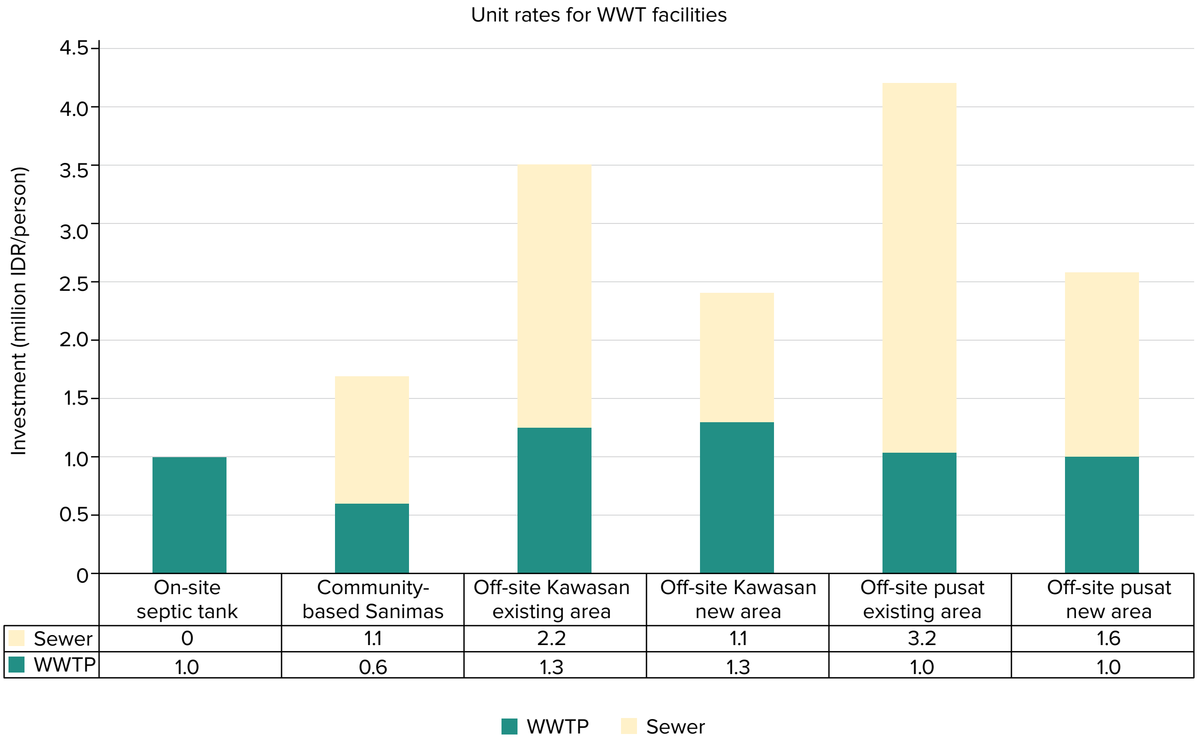

TABLE 56. Target wastewater management interventions for 2022 and 2042 in Scenarios C, D, and E

	On-site facilities	Community-based systems	Sludge treatment facilities	Kawasan WWT plant
Scenario C and Scenario E—intermediate level interventions per government plan				
2022	22,845	644	16	15
2042	40,718	1,446	26	31
Scenario D—high level of interventions, accelerated implementation of government plans				
2022	24,593	276	17	92
2042	33,666	379	25	206

TABLE 57. Budgetary responsibilities for wastewater interventions

	On-site facility						Community-based system						Kawasan WWT Plant					
	%	*Level and mandate*					*%*	*Level and mandate*					*%*	*Level and mandate*				
		N	**Lo**	**U**	**PU**	**AE**		**N**	**Lo**	**U**	**PU**	**AE**		**N**	**Lo**	**U**	**PU**	**AE**
Studies																		
Master plan													0.25	▨			░	
LARAPAMDAL, FS													0.25		▨		░	
Design																		
Guidelines							1	▨			░		1	▨			░	
Detailing							4			▨			3	▨			░	
Campaign advocacy, socialization																		
General (activity)	5	▨				░	2	▨			░		0.5		▨			░
Kabkot (activity)	5		▨			░	4		▨			░	2		▨			░
Land acquisition (land)						░	11			▨			3		▨			
Construction activities (infrastructures)																		
House connection	9			▨			24			▨			13		▨			
Sewer, onsite sludge tr.	1	▨			░		22	▨			░		43	▨			░	
Treatment	80			▨			32	▨			░		34	▨			░	
All	**100**						**100**						**100**					

Note: Gray indicates levels of budgetary responsibilities: N = national, Lo = local (provincial, district, village) and U = user. Pink indicates department responsibilities: PU = public works or construction, AE = Advocacy and empowerment of the Ministry of Health.

TABLE 58. Budget by level and time horizon for wastewater investments in Scenario C and Scenario E

Period	Source of finance	WWT	IDR
Total 25 years (2018–2042)	*Investments*		
	National	1,779	billion
	Local government (Kabkot+Prov)	259	billion
	Users/community	1,041	billion
	Total	**3,079**	**billion**
	OPEX	48,768	million/yr
Total 4 years (2018–2022)	*Investments*		
	National	774	billion
	Local government (Kabkot+Prov)	122	billion
	Users/community	493	billion
	Total	**1,389**	**billion**
	OPEX	27,037	million/yr
Total 4 years (2018–2022)	*Investments national division*		
	Infra (public works)	688	billion
	Design and studies (public works)	20	billion
	CA/instit. (health + bangda)	66	billion
	Total	**774**	**billion**
Total 4 years (2018–2022)	*Investments local division (provincial/Kabupaten)*		
	Infra (public works)	73	billion
	Design and studies (public works)	1	billion
	CA/instit. (health + bangda)	49	billion
	Total	**122**	**billion**

TABLE 59. Investment cost alternatives for improved wastewater management at Parapat (USD)

	Total costs (USD)		
	Low	**Intermediate**	**High**
Infrastructure			
Repair existing sewer lines in Parapat		150,000	750,000
Additional sewer line to receive more customers			2,700,000
Improve the process in the wastewater treatment plant			4,000,000
Connect septic tank effluents to the sewer line		80,000	
Construct reliable public toilet including the below-structure (septic tank)	150,000		
Institutional			
Local regulation for customers to connect to sewer	25,000		
Enforce the hotels and restaurants to connect to sewer			20,000
Prepare local regulation to construct septic tank in accordance to technical standard	20,000		
Assign PDAM Tirtanadi with O&M	5,000		
Assign responsible institution for the operation of the public toilet	5,000		
Information			
Open contact with private companies	5,000		
Set the performance of the public toilet	5,000		
Total of each scenario (USD)	**215,000**	**950,000**	**7,470,000**

Note: Improvements to WWT plant processes mean it will operate at a higher capacity on less land. Currently there is a cleaning pond (aerated lagoon system) that takes up a lot of space which could be converted to a conventional active sludge system that also removes N and P.

APPENDIX I

Recommendations on Solid Waste and Erosion

Solid Waste

Management of solid waste is the mandate of the Environmental District Services since 2016 (Government Regulation 18/2016). Full implementation of the reformed mandates is pending, and district services are not in operation. There are informal garbage disposal sites in the Lake Toba area where open dumping is practiced and there are no formally managed landfills or waste transportation services. There are also no set targets for solid waste management coverage (apart from urban area targets in BAPPENAS 2015–2019). Although the relative contribution from solid waste to nutrient loading is low, it poses significant risks to tourism. The methodology for analyzing solid waste was the same as for wastewater. The estimated costs for improving solid waste management in the Lake Toba area under Scenario C and Scenario E are shown in Table 60 and are 12–30 percent that of wastewater investments. The cost difference between achieving high and base case targets are very small. The breakdown in budgetary responsibilities is shown in Table 61 with time horizons in Table 62.

The specific recommendations for interventions are:

- Urban and rural priorities:
    - Improvements in urban areas should be prioritized for the medium-term future in line with the National Development Planning Agency/BAPPENAS.
    - Additional investments and facilities/services will be required as population densities increase in rural areas (more than 25 pp/ha) in the long-run.
    - Short-term priorities for rural areas should promote reducing, reusing, and recycling (3R) and home composting, and management of any facilities by the sanitation services (*Dinas Kerbersihan*).
- Landfills and solid waste collection services
    - Collection of waste can be done by garbage transportation and final disposing in a sanitary landfill. Landfill investments can be done with phased approach with the initial capital investments being higher than subsequent upgrading.
    - Explore private sector solutions to enable collection and transportation of waste.
    - Strengthen management and facilitate systems for waste sorters at waste sites (incorporating recycling opportunities).
- Reduce, Reuse, Recycle (3Rs)
    - Management of communal 3R stations should be shifted to a Dinas because of current low success and usage rate (30 percent).
    - Centralized 3R facility is suitable for urban areas (e.g., large-scale facilities in Banda Aceh, Bima, and Cijantung).
- Communication
    - Strengthen message on the linkages between solid waste and tourism to political and corporate audiences.

TABLE 60. Solid waste targets and investment costs of Scenario C and Scenario E (IDR/unit cost per person)[188]

Subsector				
System	**IDR**	**Collection activities**	**Final disposal and 3R facilities**	**Total**
New investments (2018–2042)	billion	157	869	1,025
Targets access to safe waste disposal				
0–4 yrs (2018–2022)	%	12	12	12
5–10 yrs (2023–2027)	%	92	94	92
11–15 yrs (2028–2032)	%	92	95	92
16–25 yrs (2033–2042)	%	93	95	93
Investment planning				
Inv.: 0–4 yrs (2018–2022)	billion	8	120	128
Inv.: 5–10 yrs (2023–2027)	billion	116	460	576
Inv.: 11–15 yrs (2028–2032)	billion	11	125	136
Inv.: 16–25 yrs (2033–2042)	billion	22	164	186
Operational expenditures (OPEX)				
OPEX: at 4 yrs	million/yr	14,254	4,139	18,393
OPEX: at 10 yrs	million/yr	102,414	28,379	130,793
OPEX: at 15 yrs	million/yr	110,806	30,717	141,523
OPEX: at 25 yrs	million/yr	127,588	35,393	162,982

TABLE 61. Budgetary responsibilities for solid waste interventions

	Collection-transfer-transport						**Treatment**					
	%	*Level and Mandate*					*%*	*Level and Mandate*				
		N	**Lo**	**U**	**PU**	**AE**		**N**	**Lo**	**U**	**PU**	**AE**
Studies												
Master plan	3	▨			░		1.5	▨			░	
LARAPAMDAL, FS	1		▨		░		1		▨		░	
Design												
Guidelines	2	▨			░		2	▨			░	
Detailing	2		▨		░		3		▨		░	
Campaign advocacy, socialization												
General (activity)	1	▨				░	0.5	▨				
Kabkot (activity)	2		▨			░	1		▨			
Land acquisition (land)	10		▨				20		▨			
Construction and procurement (infrastructures)												
Construction and procurement	53		▨		░		55	▨				
Design								civil				
Collection/treatment	26			▨			16		▨		░	
All	**100**						**100**					

Note: Gray indicates levels of budgetary responsibilities: N = national, Lo = local (provincial, district, village) and U = user. Pink indicates department responsibilities: PU = public works or construction, AE = Advocacy and empowerment of the Ministry of Health.

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[188] Table presents the investments required to reach 80 percent collection/treatment urban, none for rural by 2022 and 100 percent collection/treatment for urban and rural by 2042. Total coverage does not reach 100 percent because some rural areas do not qualify for collection/disposal even in the long-term.

TABLE 62. Budget by level and time horizon for solid waste investments in Scenario C and Scenario E

Period	Origin of funds	WWT	IDR
Total 25 years (2018–2042)	*Investments*		
	National	541	billion
	Local government (Kabkot+Prov)	445	billion
	Users/community	39	billion
	Total	**1,025**	**billion**
	OPEX	162,982	million/yr
Total 4 years (2018–2022)	*Investments*		
	National	74	billion
	Local gov't (Kabkot+Prov)	52	billion
	Users/community	2	billion
	Total	**128**	**billion**
	OPEX	18,393	million/yr
Total 4 years (2018–2022)	*Investments national division*		
	Infra (public works)	67	billion
	Design and studies (public works)	5	billion
	CA /instit. (health + bangda)	2	billion
	Total	**74**	**billion**
Total 4 years (2018–2022)	*Investments local division (provincial/Kabupaten)*		
	Infrastructure (public works)	9	billion
	Design and studies (public works)	40	billion
	CA/institution (health + bangda)	3	billion
	Total	**52**	**billion**

Erosion Reduction

Erosion control, forest rehabilitation, and better land-use management are necessary to reverse land degradation of already fragile soils in the Lake Toba catchment and the contribution of erosion to the reduced water quality of the lake. Lake Tobas is frequently identified and targeted in national programs for land forest protection and afforestation.[189] Implementation challenges have been linked to a lack of local and community ownership, illegal logging, and regulatory accountability.

The recommendations for reducing erosion in the Lake Toba catchment are:

- Promote cheaper and more effective 'green' natural infrastructures such as establishing conservation zones, and encouraging agroforestry and other sustainable forestry practices;
- Construction of simple structures (e.g., containment dam and gully plugs in the upper watershed, controller dam and terraces in the central part of the watershed, and infiltration wells in the lower watershed); and
- Forest and land restoration through community forestry schemes (estimated to cost USD 60/ha with high benefit-cost ratios and internal rates of return)[190] allowing local communities to develop agroforestry and agro-tourism (e.g., the NPV of coffee agroforestry was USD 1,000/ha, USD 787/ha for rubber, and USD 434/ha for benzoin on Sumatra in a 2013 feasibility study).[191]

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[189] E.g., the National Movement for Rehabilitation (GN-RHL/Gerhan) launched in 2003 and the One Billion Trees program launched in 2011; and the current national target to rehabilitate up to 5.5 million hectares of 'critical land' nationally by 2019.

[190] World Resources Institute Indonesia and World Agroforestry Center (ICRAF) study in the Musi Watershed of South Sumatra (unpublished).

[191] http://www.worldagroforestry.org/sea/Publications/files/paper/PP0342-14.pdf

References

Acreman M., Meigh J., and Sene K. J. 1993. *Modelling the decline in water level of Lake Toba, Indonesia*. Advances in Water Resources. Vol. 16. pp. 207–222.

Badjeori M. 2013. *Distribusi spasial bakteri perombak nitrogen di perairan Danau Toba, Sumatera Utara*. LIMNOTEK Vol. 20. Issues 1. pp. 89–99.

Beijer J. 2017. *Lake Toba: where we are and where to go?* Presentation to Indonesian Aquaculture Society, Medan on July 10, 2017.

Bisnis.com. 2017. *Perda RTRW Sumut Akhirnya Diketok Dewan*. Available at: sumatra.bisnis.com/read/20170113/2/66022/perda-rtrw-sumut-akhirnya-diketok-dewan

BKPEKDT. 2005. *The Beginning: Lake Toba Ecosystem Management Plan*. Indonesia: Coordinating Agency for Lake Toba Ecosystem Management (BKPEKDT).

Borja Á., Galparsoro I., Solaun O., Muxika I., Tello E., Uriarte A., and Valencia, V. 2006. *The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status*. Estuarine, Coastal and Shelf Science. Vol. 66(1). pp. 84–96.

BPS Provinsi Sumatera Utara. 2016. *Provincsi Sumatera Utara Dalam Angka* (Sumatera Utara province in figures). ISSN 0215.2053. Publication number 12560.1601

Buckley K., and Markortoff M. 2004. *Phosphorus in Livestock Manures*. Available at: http://www.farmwest.com/node/953

Carlson R. 1977. *A trophic state index for lakes*. *Limnology and Oceanography.* Vol. 22(2). pp. 361–369. doi:10.4319/lo.1977.22.2.0361

Chapman D. (Ed.). 1996. *Water quality assessments: a guide to the use of biota, sediments, and water in environmental monitoring. Second Edition*. UN-WHO. E&FN Spon.

Chesner C. 2012. *The Toba Caldera Complex*. *Quaternary International.* Vol. 258(C). pp. 5–18. doi:10.1016/j.quaint.2011.09.025

City Wide Sanitation Investment Program. 2016. *Waste Water Management Investment Roadmap*. Ref. BE1344/R001/MvK/Indo. Manilla: Asian Development Bank.

Damage Control Directorate of Aquatic Ecosystems. 2017. *Toba Lake Rescue Movement North Sumatra*. Jakarta: Ministry of Forestry and Environment, Government of Indonesia.

Danaparamita A. August 30, 2016. *Why did millions of fish turn up dead in Indonesia's giant Lake Toba?* Mongabay. Available at: news.mongabay.com/2016/08/why-did-millions-of-fish-turn-up-dead-in-indonesias-giant-lake-toba/

Deltares. 2014. *Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments*. Delft3D-FLOW User Manual. Delft: Deltares.

Deltares & TNO. 2016. *Factsheet Emission Estimates for domestic effluents*. Available at: http://www.emissieregistratie.nl/

Dillon P., and Rigler F. 1974. *A test of a simple nutrient budget model predicting the phosphorus concentration in lake water*. *Journal of the Fisheries Board of Canada.* Vol. 31(11). pp. 1771–1778.

Direktorat Pengendalian Kerusakan Perairan Darat. 2017. *Gerakan Penyelamatan Danau Toba*. KLHK.

DLH-SU. 2017. *Penentuan status trofik dan daya tampung beban pencemaran Danau Toba* (Determination and carrying capacity of trophic state of Lake Toba due to pollution loads). Powerpoint presentation on March 10, 2017. Sumatra: Provincial Environment Department of North Sumatra, Government of Indonesia.

FAO. 2016. *Forest landscape restoration for Asia-Pacific forests*. Rome: Food and Agriculture Organization.

Fritz V., Kaiser K., and Levy B. 2009*. Governance and Political Economy Analysis. Good Practice Framework*. Washington D.C.: The World Bank.

Fritz V., Levy B., and Ort R. (Editors). 2014. *Problem-driven Political Economy Analysis. The World Bank's Experience.* Washington D.C.: The World Bank.

Giggenbach W. 1990. *Water and gas chemistry of Lake Nyos and its bearing on the eruptive process*. *Journal of Volcanology and Geothermal Research.* Vol. 42(4). pp. 337–362.

Global Forest Watch. 2016. Interactive map. Available at: www.globalforestwatch.org/map

Grindle, MOS. 2004. *Good Enough Governance: Poverty Reduction and Reform in Developing Countries*. Governance. Vol. 17 (4). pp. 525–548. doi:10.1111/j.0952-1895.2004.00256.x

Gumelar G. 2017. *Investor Singapura dan China Tertarik Garap Wisata Danau Toba*. Available at: www.cnnindonesia.com/ekonomi/20170612160628-92-221171/investor-singapura-dan-china-tertarik-garap-wisata-danau-toba/

Gunawan A. March 16, 2016. *Forest burning continues in Lake Toba area. The Jakarta Post.* Available at: www.thejakartapost.com/news/2016/03/16/forest-burning-continues-lake-toba-area.html

Gyllenhammar A., and Håkanson L. 2005. *Environmental consequence analyses of fish farm emissions related to different scales and exemplified by data from the Baltic—a review*. Marine Environmental Research. Vol. 60(2). pp. 211–243. doi:10.1016/j.marenvres.2004.10.005

Hadinaryanto S., Karokaro A., Nugraha I. and Saturi S. May 8, 2014. *Special Report: Lake Toba indigenous people fight for their frankincense forest*. Mongabay. Available at: news.mongabay.com/2014/05/special-report-lake-toba-indigenous-people-fight-for-their-frankincense-forest/

Hargreaves G., and Allen R. 2003. *History and evaluation of Hargreaves evapotranspiration equation*. *Journal of Irrigation and Drainage Engineering.* Vol. 129(1). pp. 53–63.

Horwath Hotel, Tourism and Leisure (HTL). 2017. *Lombok/Borobudur-Yogyakarta-Prambanan/Lake Toba: Baseline demand and supply, market demand forecasts, and investment needs*. prepared for the World Bank. Available at: bpiw.pu.go.id/uploads/20170302_Lake_Toba_Market_and_Demand_Assessment.pdf

Indra Karya. 2015. *Laporan Akhir. Kajian Strategis Sumber Daya Air* (Sumatera Water Resources Strategic Study). Tahap II. PT Indra Karya (Persero) Wilayah I.

International Monetary Fund. Representative Exchange Rates. November 3, 2017. Available at: www.imf.org/external/np/fin/data/rms_mth.aspx?SelectDate=2017–11–30&reportType=REP

Iskandar. 2013. *Inventarisasa & Identifikasi Sumber dan Beban Pencemaran Air*. Pengelolaan Kualitas Air. No. 50.

Kerstens S., Leusbrock I., and Zeeman G. 2015. *Feasibility analysis of wastewater and solid waste systems for application in Indonesia*. Science of the Total Environment. Vol. 530. pp. 53–65.

KLHK. 2017. *Gerakan Penyelamatan Danau Toba Provinsi Sumatera Utara*. Direktorat Pengendalian Kerusakan Perairan Darat.

Koesnadi Hardjosoemantri. 2003. *Good Governance Dalam Pembangunan Berkelanjutan di Indonesia*. Makalah untuk Lokakarya Hukum Nasional ke VIII. Bali: Indonesia.

Kompas.com. July 20, 2016. *Ikan Nila Hasil Budidaya di Danau Toba Diekspor ke ASEAN hingga AS.* Available at: ekonomi.kompas.com/read/2016/07/20/094900326/ikan.nila.hasil.budidaya.di.danau.toba.diekspor.ke.asean.hingga.as

Kumparan. 2017. *Investor China Tertarik Kembangkan Pariwisata Danau Toba.* Available at: kumparan.com/angga-sukmawijaya/investor-china-tertarik-kembangkan-pariwisata-danau-toba

Lehmusluoto, Pasi, and Badruddin Machbub. 1997. *National inventory of the major lakes and reservoirs in Indonesia*. General Limnology. Revised Edition (1) (1997).

Lehr J., Keeley J., and Kingery T. 2005. *Water encyclopedia. Water quality and resource development*. John Wiley & Sons. Hoboken, New Jersey: USA.

Lewis W. 2000. *Basis for the protection and management of tropical lakes*. Lakes & Reservoirs: Research & Management. Vol. 5(1). pp. 35–48. doi:10.1046/j.1440-1770.2000.00091.x

Lukman R., and Ridwansyah I. 2010. *Study on morphometry conditions and multiple parameter water stratification of Lake Toba*. Limnotek Journal. Vol. 17(2). pp. 158–170.

McDowell R., Monaghan, R., Dougherty W., Gourley C., Vibart R., and Shepherd M. 2017. *Balancing water-quality threats from nutrients and production in Australian and New Zealand dairy farms under low profit margins*. Animal Production Science. Vol. 57(7). pp. 1419–1430.

McDowell R., and Nash D. 2012. *A Review of the Cost-Effectiveness and Suitability of Mitigation Strategies to Prevent Phosphorus Loss from Dairy Farms in New Zealand and Australia*. Environmental Quality. Vol. 41. pp. 680–693. doi:10.2134/jeq2011.0041

Meybeck M. 1995. *Global Distribution of Lakes*. Physics and Chemistry of Lakes. pp. 1–35. Springer. Berlin, Heidelberg: Germany. doi:10.1007/978-3-642-85132-2_1

Ministry of Public Works and Housing. 2016. *Profil Kawasan Danau Toba*. Jakarta, Ministry of Public Works and Housing: Government of Indonesia. Available at: www.pu.go.id/uploads/services/infopublik20160330174236.pdf

Ministry of Public Works and Housing. 2018. *Pedoman Umum: Program Pembangunan Pariwisata Terintegrasi dan Berkelanjutan (P3TB).* Available at: bpiw.pu.go.id/uploads/itmp/Pedoman_Umum_P3TB.pdf

Nontji A. 2016. *Lake Toba* (in Bahasa Indonesia). Jakarta: Indonesia.

Nürnberg G. 1996. *Trophic State of Clear and Colored, Soft- and Hardwater Lakes with Special Consideration of Nutrients, Anoxia, Phytoplankton and Fish*. Lake and Reservoir Management. Vol. 12(4). pp. 432–447. doi:10.1080/07438149609354283

Oakley J. 2015. *Modelling the Aquaculture Carrying Capacity of Lake Toba, North Sumatra, Indonesia*. Master thesis Environmental Science and Management. University of Rhode Island: USA.

Prasetyo S., Hasiholan B., Hartomo K., Paseleng M., Nuswantoro B., and Wacana S. November 2013. *Geographic Information System of Critical Level of Land Degradation (Critical Land) Based on Agro-ecological Zone (AEZ) in Agricultural Areas with Recombination Method of Fuzzy Logic and Scoring.* IJCSI International Journal of Computer Science. Vol. 10(6) ISSN (print): 1694–0814; ISSN (online): 1694–0784.

PTAN. 2017. *Long term patterns of various water quality variables in Lake Toba*. PTAN Monitoring Program, Poster p. 8.

Ratman D. 2016. *Pembangunan Destinasi Pariwisata Prioritas 2016–2019*. Available at: www.kemenpar.go.id/userfiles/Paparan%20-%20Deputi%20BPDIP.pdf

Ross K., Gashugi E., Gafasi A., Wüest A., and Schmid M. 2015. *Characterisation of the subaquatic groundwater discharge that maintains the permanent stratification within Lake Kivu; East Africa*. PloS One. Vol. 10(3): e0121217. doi:10.1371/journal.pone.0121217

RPJMN. 2014. *Rencana Pembangunan Jangka Menengah Nasional (RPJMN) 2015–2019*. Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional. Ministry of National Development Planning: Government of Indonesia.

Rustini A., Lukman, and Ridwansyah I. 2014. *Estimation 2-dimensional flow pattern in Lake Toba.* Research Center for Limnology-LIPI. Limnotek. Vol. 21 (1). pp. 21–29.

Ruttner, F. 1931. *Hydrographische und hydrochemische Beobachtungen auf Java, Sumatra und Bali, Arch*. Hydrobiol. Suppl. 8. pp. 197–454.

Schmid M., Halbwachs M., and Wehrli B. 2005. *Weak mixing in Lake Kivu: new insights indicate increasing risk of uncontrolled gas eruption*. Geochemistry. Vol. 6(7). doi:10.1029/2004gc000892

Schmid M., Tietze K., and Halbwachs M. 2003. *How hazardous is the gas accumulation in Lake Kivu? Arguments for a risk assessment in light of the Nyiragongo volcano eruption of 2002*. Acta Vulcanologica. Vol. 15(1–2). pp. 115–122.

Sene K., Gash J., and McNeil D. 1991. *Evaporation from a Tropical Lake—Comparison of Theory with Direct Measurements*. Journal of Hydrology. Vol. 127(1–4). pp. 193–217.

Sianipar I. 2011. *Studi Deskriptif Gondang Sabangunan dalam Upacara Kematian Saurmatua pada Masyarakat Batak Toba di Kota Medan*. Universitas Sumatera Utara. Medan: Indonesia. Available at: repository.usu.ac.id/handle/123456789/29021

Sitanggang R. November 11, 2017. *Illegal logging rusak DTA Danau Toba*. Medan Bisnis Daily. Available at: www.medanbisnisdaily.com/news/read/2017/11/11/326098/illegal-logging-rusak-dta-danau-toba/

Soeprobowati T. 2015. *Integrated Lake Basin Management for Save Indonesian Lake Movement*. Procedia Environmental Sciences. Vol. 23.pp. 368–374. doi:10.1016/j.proenv.2015.01.053

Technical Team for Sanitation Development (TTPS). 2009. *Opsi Sistem dan Teknologi Sanitasi* (Sanitation system and technology options). BAPPENAS in collaboration with the World Bank's Water and Sanitation Program-East Asia and the Pacific (WSP-EAP). Jakarta: Government of Indonesia.

Tilley E., Ulrich L., Lüthi C., Reymond P., and Zurbrügg C. 2008. *Compendium of Sanitation Systems and Technologies, 2nd edition.* Swiss Federal Institute of Aquatic Science and Technology (EAWAG) and the International Water Association (IWA). Dubendorf: Switzerland.

Times Indonesia. August 1, 2016. *Danau Toba Tercemar Limbah*. Available at: m.timesindonesia.co.id/read/129651/20160801/192108/danau-toba-tercemar-limbah/

Toba Tilapia. August 29, 2016. *Toba Tilapia*. Powerpoint presentation.

UNEP. 2004. *Guidelines on Municipal Wastewater Management*. UNEP/GPA Coordination office. The Hague: United Nations Environment Programme.

Urban Sanitation Development Program (USDP). January 2015. *Sanitation Needs Assessment 2015–2019*. USDP-R-PIU.T-10083-2. Available at: www.usdp.or.id/

Verdegem M. 2013. *Nutrient discharge from aquaculture operations in function of system design and production environment*. Reviews in Aquaculture. Vol. 5. pp. 158–171.

Vernimmen R. 2015. *Hydrological analysis and modelling of the Toba-Asahan River Basin, Indonesia*. Report for the BWRMP project. Delft: Deltares.

World Bank. 2017. Indicators. Available at: data.worldbank.org/indicator

World Bank. 2018. *Indonesia—Integrated Infrastructure Development for National Tourism Strategic Areas Tourism Development Project*. Washington D.C.: The World Bank Group. Available at: documents.worldbank.org/curated/en/839781527910281861/Indonesia-Integrated-Infrastructure-Development-for-National-Tourism-Strategic-Areas-Tourism-Development-Project

World Economic Forum (WEF). 2017. *Travel and Tourism Competitiveness Report 2017*. Geneva: World Economic Forum. Available at: reports.weforum.org/travel-and-tourism-competitiveness-report-2017/

Young O. 2002. *The institutional dimensions of environmental change: fit, interplay and scale*. MIT Press, Cambridge, Massachusetts: USA.

Zajdband A., Peet C., Ethier V., and Voorhees T. September 10, 2015. *Farmed Tilapia, Oreochromis niloticus.* Monterey Bay Aquarium's Seafood Watch. Monterey, California: USA. Available at: www.seafoodwatch.org/-/m/sfw/pdf/reports/t/mba_seafoodwatch_tilapia_indonesia_report.pdf

Zomer R., Trabucco A., Bossio D., and Verchot L. 2008. *Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation*. Agriculture, Ecosystems & Environment. Vol. 126(1). pp. 67–80.

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