

PAPER • OPEN ACCESS

## Bathymetric survey of lakes Maninjau and Diatas (West Sumatra), and lake Kerinci (Jambi)

To cite this article: C Bouvet de Maisonneuve *et al* 2019 *J. Phys.: Conf. Ser.* **1185** 012001

View the [article online](#) for updates and enhancements.

### Recent citations

- [The sediments of Lake Singkarak and Lake Maninjau in West Sumatra reveal their earthquake, volcanic and rainfall history](#)  
Kathleen Wils *et al*



**IOP | ebooks™**

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

# Bathymetric survey of lakes Maninjau and Diatas (West Sumatra), and lake Kerinci (Jambi)

C Bouvet de Maisonneuve<sup>1,2\*</sup>, S Eisele<sup>1,2</sup>, F Forni<sup>1,2</sup>, Hamdi<sup>3</sup>, E Park<sup>1</sup>, M Phua<sup>1,2</sup>, and R Putra<sup>3</sup>

<sup>1</sup>Earth Observatory of Singapore, Nanyang Technological University, Singapore

<sup>2</sup>Asian School of the Environment, Nanyang Technological University, Singapore

<sup>3</sup>Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Indonesia

\*carolinebouvet@ntu.edu.sg

**Abstract.** Determining the bathymetry of lakes is important to assess the potential and the vulnerability of this valuable resource. The dilution and circulation of nutrients or pollutants is largely dependant on the volume of water and the incoming and outgoing fluxes, while the degree and frequency of mixing depends on the water depth. The bathymetry of lakes is also important to understand the spatial distribution of sediments, which in turn are valuable archives of natural hazards and environmental change. We thus conducted a bathymetric survey of lakes Maninjau and Diatas in West Sumatra and lake Kerinci in Jambi (Indonesia) using a sonar. We found maximum water depths of 168 m, 55 m, and 105 m and minimum volumes of 9.79 km<sup>3</sup>, 0.32 km<sup>3</sup>, and 1.57 km<sup>3</sup> for lakes Maninjau, Diatas and Kerinci respectively. Although lake Maninjau is the largest, it is vulnerable due to the low water fluxes in and out of it, and is thus currently threatened by increasing levels of cultural eutrophication. Lake Diatas is smaller but surrounded by less human settlements and is thus less impacted by related human activities. Lake Kerinci is relatively voluminous, has larger incoming and outgoing water fluxes, and doesn't appear to be suffering greatly from surrounding human activities. Given the sizes and inlets of these lakes, Maninjau and Diatas likely have the highest potential for hosting a long-term sediment record built from low sedimentation rates.

## 1. Introduction

Lakes are valuable resources for people in a variety of ways; e.g. as freshwater for household consumption or crop irrigation, as a food resource through their natural biodiversity or the development of aquaculture [1], and as popular recreation and vacation spots given their nice scenery. Depending on their specific geographical configuration, the water in lakes comes from precipitation, melting ice (although not for the lakes under study here), streams, and groundwater seepage. Most lakes are thermally stratified, with (1) a shallow, warm upper surface layer, (2) a middle layer where the temperature declines rapidly (the thermocline), and (3) a deeper, cooler body of water. The water in shallow lakes mixes annually, whereas in deeper lakes, a full turnover may only happen once or twice a year (seasonally), or less frequently [2, 3, 4]. A healthy lake contains a reasonable amount of oxygen and nutrients (nitrogen and phosphorus), which enable algae to grow and in turn will feed other organisms. When a lake gets too many nutrients because of sewage from towns, phosphorus-based fertilizers from farms, or excessive fish food from fish farms, the growth of algae, plankton and



aquatic weeds can get out of control leading to an algal bloom [5]. When these aquatic plants die, their breakdown causes oxygen depletion and lake eutrophication (or death as no organism is able to survive) [6, 7, 8]. The physical properties of lakes, i.e. their depth, geometry, and water inflow / outflow thus control the temperature stratification of the lake [9, 10], the chemical characteristics of the water, and the spatial distribution and potential for dilution of nutrients. It is therefore important to know the bathymetry and volume of a lake in order to assess the potential and vulnerability of it as a resource.

In addition to the social and ecological importance of lakes, lake sediments are fantastic archives of geological processes (floods, landslides, volcanic eruptions, earthquakes) and environmental change (climate change and change in land use) [11 – 15]. Volcanic ash can travel far and forms well-preserved tephra layers in quiet, low-energy sedimentary environments such as lakes. Long term hydrological variations are recorded as changes in sedimentology, geochemistry and biological proxies. Lake sediments thus provide high resolution palaeoenvironmental data for variations and interactions of the monsoons, El Nino Southern Oscillation, Indian Ocean Dipole, floods and droughts, and human activities. The bathymetry of a lake and its water inflow/outflow will control the distribution of sediments within a lake and can thus inform about a lake's potential as an environmental archive. A bathymetric survey is a first fundamental step before the collection of lake sediments through coring.

Lakes Maninjau, Diatas and Kerinci are large, natural lakes in the highlands of West Sumatra and Jambi (Indonesia; Fig. 1). They were built by magmatic and/or tectonic processes and receive their water from precipitation and streams mainly [16]. They are important hosts of inland aquaculture, supply many neighboring communities with water, and are some of the most touristic destinations in the region. Many people thus inevitably rely on the health of these lakes. In addition, these lakes lie in close proximity to active volcanoes (e.g. Marapi, Singgalang, Talang) and the active Sumatran strike-slip fault. Their sediments thus have a high potential of recording the frequency and magnitude of volcanic eruptions and earthquakes in the region.

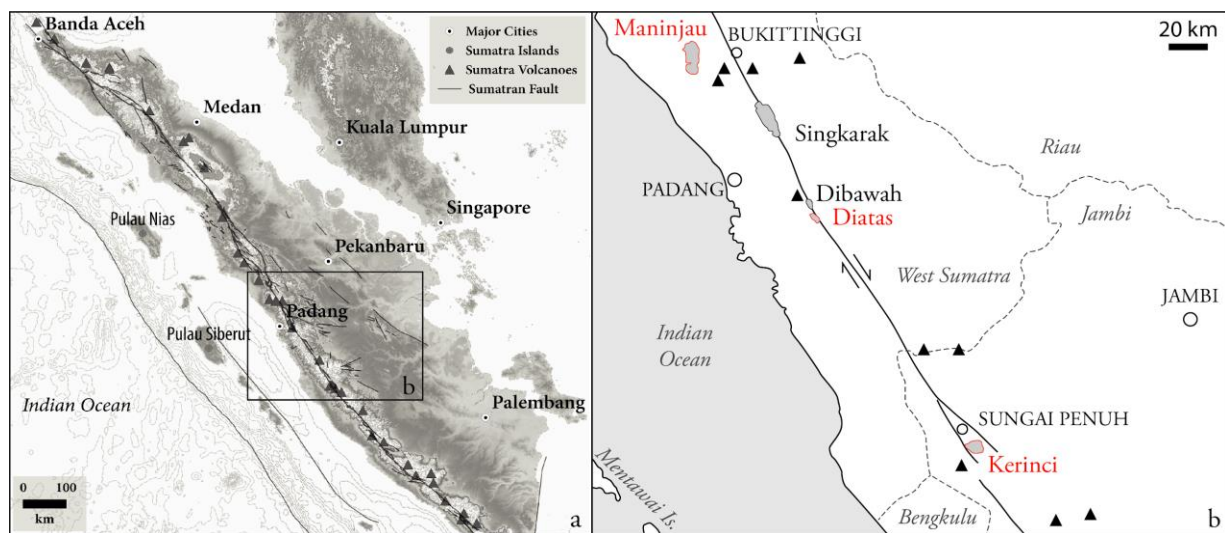


Figure 1: (a) regional map showing the location of Sumatra and the Malay peninsula in the Indian Ocean and the distribution of the volcanic centers on Sumatra along the Sumatran Fault; (b) detail of the study area displaying the location of the surveyed lakes.

In an inventory of major lakes and reservoirs in Indonesia, Geisen [17] and Lehmusluoto et al. [16] suggest a maximum depth of 169 m for Lake Maninjau, 44 m for Lake Diatas, and 107 m for Lake Kerinci. During a bathymetric survey, we collected sonar data to build a bathymetric map and investigate the spatial distribution of water depths. At a later stage, the data will be used to investigate the sedimentary archive of these three lakes. We hope that this data will be useful for hydrological

calculations and the careful assessment of the potential of these lakes for aquaculture and other activities.

## 2. Methods

We conducted a bathymetric survey of Lakes Maninjau, Diatas and Kerinci between April and May 2018 using a Humminbird Helix 10 CHIRP SI GPS G2N digital sonar, with the transducer mounted at the back of a small motorboat. A large number of randomly oriented, obliquely cross-cutting profiles were obtained from each lake (Figs 2-4). The Humminbird Helix 10 digital sonar operates in two main frequencies (83 Hz and 200 Hz) and has a maximum depth penetration of approximately 460 m. The exact profile location was recorded by the built-in GPS, using World Geodetic System 1984 (WGS-84) as the datum. Depth soundings were collected and recorded at a ping rate of about 2 s, with an average travel speed of 5-6 km/h in order to maximize the recovered signal. A total of about 970,000 depth soundings were collected at Lake Maninjau, 250,000 at Lake Diatas and 360,000 at Lake Kerinci. Raw data is available upon request from the corresponding author.

The recorded depth soundings were then used to create a continuous bathymetric map using the open source QGIS 2.18 software (Figs 2-4). Spatial interpolation of the depth soundings were conducted using the interpolation method - Inverse Distance Weighted (IDW), which is a deterministic interpolation method that estimates depths at unsampled points using a linear combination of depths at sampled points weighted by an inverse function of the distance from the point of interest to the sampled points [18]. This method assumes that points closer to each other will have similar depth values [19]. We also took into account the surrounding topography of the lakes in the interpolation procedures through the data fusion of our recorded depth soundings and the 1 Arc-Second Shuttle Radar Topography Mission (SRTM) elevation data, a common enhancement technique conducted at the landscape-scale [20].

## 3. Results

### 3.1. Lake Maninjau

Lake Maninjau is a caldera lake that formed after a violent explosive eruption which occurred ~50 ka and caused the collapse of an older volcanic edifice (Alloway et al., 2004). The lake has a surface area of 97.9 km<sup>2</sup> and is located at 459 m elevation [16]. Our bathymetric survey confirmed a maximum depth of 168 m over a relatively flat area in the southern half of the lake. The map reveals similar slopes in the water as on the mountain flanks around the lake, with a steeper gradient in the south and to the west than in the north and to the east (Fig. 2). The northern third of the lake has a mean depth of ~100 m, gently dipping to the south, with a relatively rough surface similar to the agricultural land just north of it. The minimum bulk volume of the lake is close to 9.79 km<sup>3</sup>.



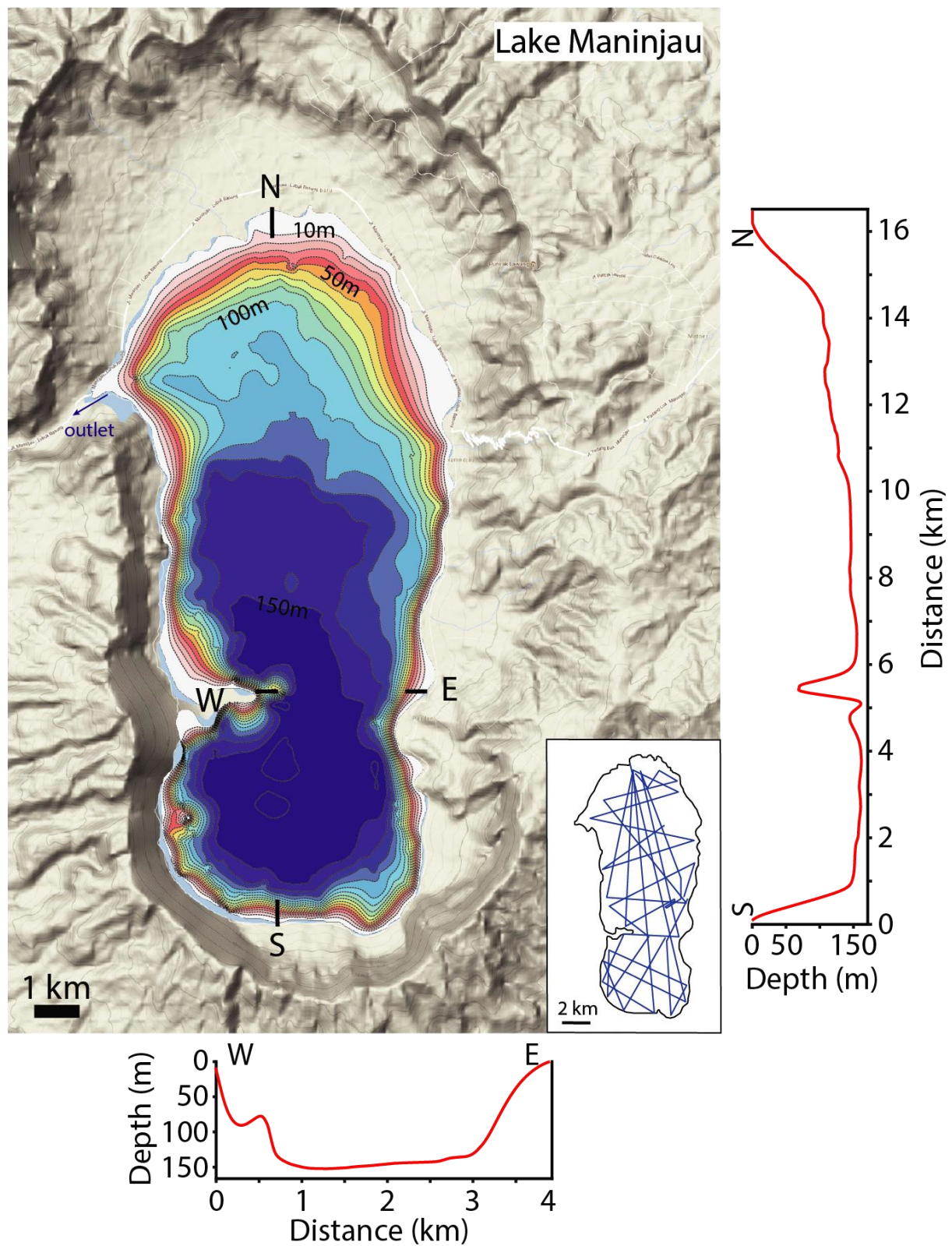


Figure 2: combined terrain and bathymetric map of Lake Maninjau showing the location of the main outlet in the north-western side of the lake and the N-S and W-E depth profiles. Inset: outline of Lake Maninjau displaying the runlines covered during the survey.

### 3.2. Lake Diatas

Lake Diatas is a tectonic depression on the trace of the Sumatran fault. It has a surface area of 12.3 km<sup>2</sup> and is located at 1531 m elevation [16]. The bathymetric survey revealed that most of the lake has a flat base at 35 m depth and a deeper zone (with a maximum depth of ~55 m) aligned with the Sumatran fault on the eastern rim.

This deeper zone is about 100-200 m wide and ~1 km long. The eastern margin of the lake is the steepest (reaching the maximum depth within <100m), while the northern margin has the most gentle slope (reaching 35 m within ~1 km) (Fig. 3). The minimum bulk volume of the lake is close to 0.32 km<sup>3</sup>.

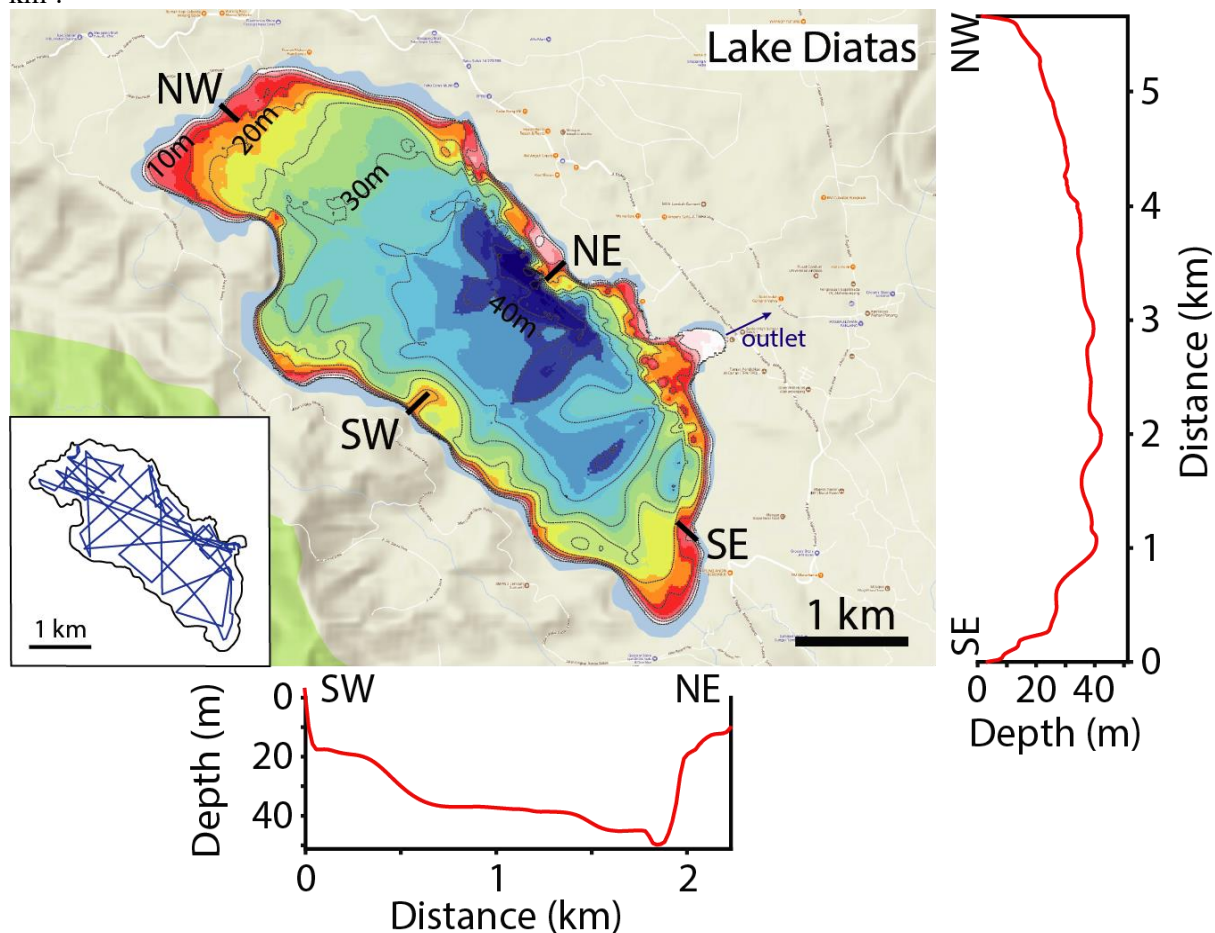


Figure 3: combined terrain and bathymetric map of Lake Diatas showing the location of the main outlet in the south-eastern side of the lake and the SE-NW and SW-NE depth profiles. Inset: outline of Lake Diatas displaying the runlines covered during the survey.

### 3.3. Lake Kerinci

Lake Kerinci is a tectonic/volcanic depression on the trace of the Sumatran fault. It has a surface area of 46 km<sup>2</sup> and is located at 710 m elevation [16]. The bathymetric survey confirmed a maximum depth of ~105 m in a north-south elongated, central depression surrounded by steep slopes (Fig. 4). The northwestern and northeastern sides of the lake outside of this depression are very shallow, around 10 m depth. The western side of the depression is partly arcuate, while the eastern side of the depression is more linear and in continuation with the trace of the Sumatran fault (Fig. 4). The minimum bulk volume of the lake is close to 1.57 km<sup>3</sup>.



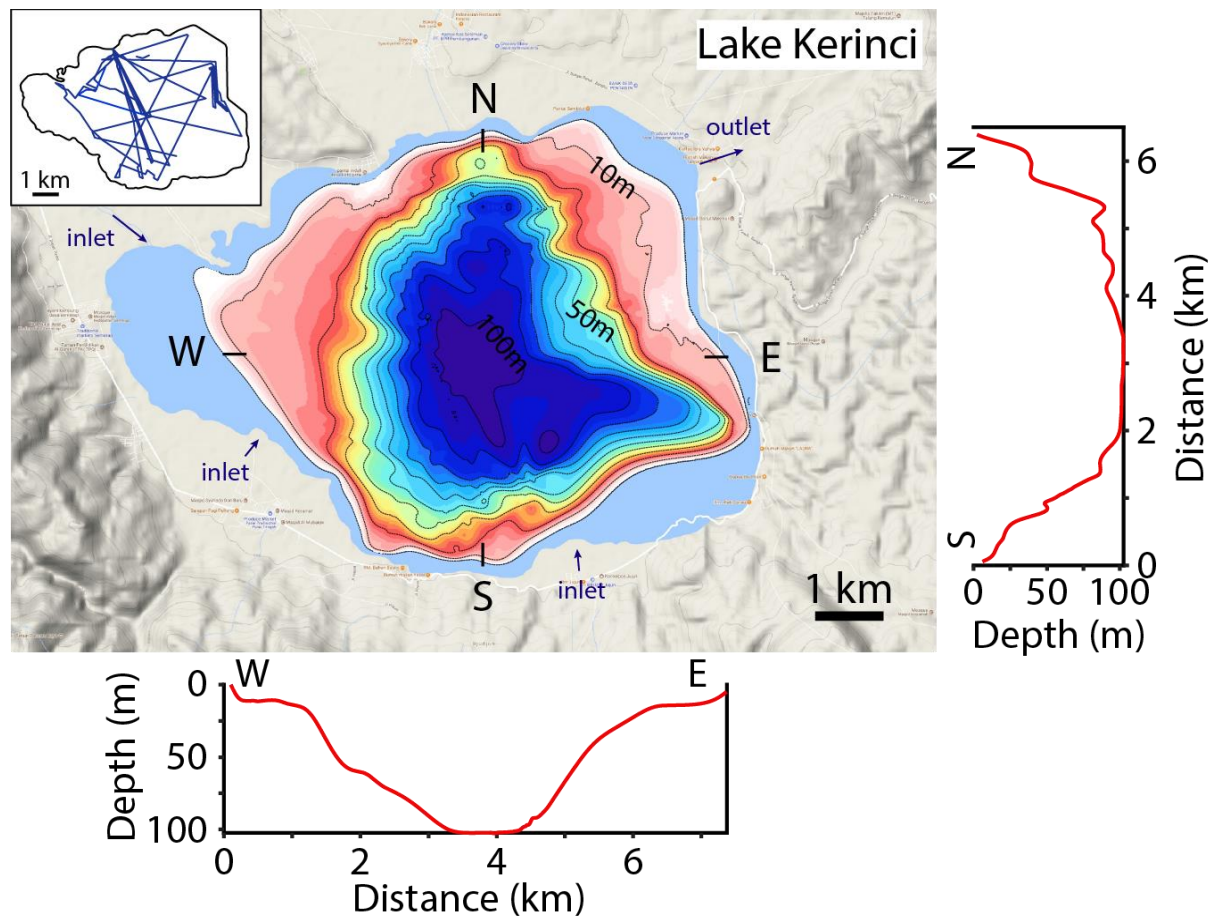


Figure 4: combined terrain and bathymetric map of Lake Kerinci showing the location of the main inlet in the north-west, two minor inlets in the south and south-west and the a major outlet in the north-eastern side of the lake, together with N-S and W-E depth profiles. Inset: outline of Lake Kerinci displaying the runlines covered during the survey.

## 4. Discussion

### 4.1. Lake Maninjau

Lake Maninjau has one major outlet to the NW (Batang Antokan river; Fig. 2) with a control dam (Lehmusluoto et al., 1997) but no major inlet and is thus essentially infilled by precipitation. Yearly precipitation rates are 3,122 mm/yr on average in Bukittinggi (Climate-Data.org), implying a minimum influx of 0.3 km<sup>3</sup>/yr, and thus a maximum water residence time of approx. 50 years assuming the lake is in a steady state. Sediments are only brought to the lake by surface runoff or wind transport, likely yielding low sedimentation rates. The present day bathymetry of the lake thus mostly resulted from volcanic processes.

Bathymetric information is important for habitat assessments, particularly for the benthic communities, which are the organisms living at the bottom of the lake near the sediment-water interface. The lake is currently under a serious threat due to algae blooming mainly in response to high population density, neighboring agriculture and increases in fish farming activities particularly concentrated around the northern part of the lake where it is generally shallower (Fig. 2). This was seen from the strikingly green color of the water and the total absence of fish recorded by the side scan sonar at the time of the survey (during the onset of the dry season). Early signs of cultural eutrophication were already reported by Lehmusluoto et al. [16] and by emphasized by Syandri et al. [8]. Algae blooming affect habitability and decrease oxygen level by reducing light penetration, and

also degrade water quality for local consumption [7]. Therefore, a proper management strategy for Lake Maninjau is necessary and bathymetric information can essentially serve as a basis for the assessment of the environmental vulnerability of the lake through calculations of hydrological fluxes and dynamics, and water residence times.

#### 4.2. Lake Diatas

Lake Diatas has a minor outlet through the Gumanti river in the south (Fig. 3; [16]) and no major inlet so it is infilled by precipitation only. Yearly precipitation rates are 2,067 mm/yr on average in Alahan Panjang (Climate-Data.org), implying a minimum influx of 0.02 km<sup>3</sup>/yr, and thus a maximum water residence time of approx. 20 years assuming the lake is in a steady state. As for Lake Maninjau, sediments are generally brought to the lake by surface runoff or wind transport only, likely yielding low sedimentation rates. However, meter thick landslide deposits at the shore and the proximity of the lake indicate high accumulation rates during mass wasting events. The present day bathymetry of the lake thus mostly resulted from tectonic processes with a potential overprinting from landslides. An east-west shallow (~30 m deep) structure seems to propagate from the eastern coast in the southern part of the lake. However, this is an artefact of the interpolation method that artificially shallows the regions in between two acquisition profiles and must thus be ignored.

#### 4.3. Lake Kerinci

Lake Kerinci has a major fluvial inlet in the north-west, the Sungai Penuh river, two minor inlets in the south and south-eastern sides of the lake and a major outlet, the Segara Agung river, in the east (Fig. 4; [16]). As the influx of water at the inlet is not known, water residence times cannot be estimated. Sediments transported by the Sungai Penuh river seem to have largely filled in the Sumatran fault depression surrounding Lake Kerinci. The bathymetry of the lake is thus a result of sediment infill in addition to tectonic and/or volcanic processes.

Surface water samples collected in early May (i.e. close to the driest month; Climate-Data.org) at the lower reach of the river seem to have at least 150-200 mg/l of suspended sediment. Velocity at the river surface was relatively slow around 1 m/s, however hydraulic forces are much higher close to the river bed (average depth estimated around 3 m), enough to mobilize a rock of 20 cm diameter (our observation in the field), indicating that bedload transport rates might be substantially higher than the fine materials. Assuming a sediment concentration of 150 mg/l, at least close to the surface, the river may transport close to 1 million tons of fine materials in May. Given that the mean monthly rainfall of May is below the annual average (151 mm in May compared to a monthly average of 181 mm, and a maximum of 281 mm in January; Climate-Data.org), it can be assumed that the river may transport at least 10 million tons of fine sediment each year. A well-developed progradational deltaic submerged fan close to the river mouth (i.e. shallow water depths in the west-northwest) indicates a continuous and active sediment sourcing from the river (Fig. 4). Further grain size distribution analyses from the lake bed will corroborate influence of the fluvial inputs and redistribution mechanisms across the lake.

The low elevation land near the Sungai Penuh river and around Lake Kerinci is vulnerable to annual flooding during the wet season. The steep local gradient of the river is likely to introduce flash flooding. Discussions with the local people indicated that the river can frequently overbank flood over the surrounding flat landscape, which has resulted in several casualties in the past few decades.

## 5. Conclusion

We conducted a bathymetric survey of lakes Maninjau and Diatas (West Sumatra) and Kerinci (Jambi) using a sonar. Lake Maninjau has a maximum depth of 168 m and an average depth of 101 m. It has steep sides surrounding a flat bottom, slightly dipping southwards, which is the result of volcanic processes (caldera collapse ~50 ka; Alloway & al. 2004). Lake Diatas has a maximum depth of 55 m and an average depth of 28 m. It has a relatively flat bottom but a narrow trench-like feature in the northeast, which is the result of tectonic processes - namely the Sumatran strike-slip fault. Lake Kerinci has a maximum depth of 105 m in a subcircular depression in the center of the lake. It has very shallow regions on the northwestern and northeastern sides due to the input of sediments from the Sungai Penuh river. This bathymetric information is essential background knowledge for future



hydrologic, ecological, and sedimentary analyses for paleoenvironmental, paleoclimate and/or paleo-hazards purposes.

### Acknowledgements

The SUMATEPHRA team is grateful to Nur Fairuz Razali for managing the complicated logistics of the field campaign, as well as Prima Satria, Eko Mulyadi Saputra and Jon Rusmi for their essential assistance in the field. This work was funded by the National Research Foundation of Singapore, grant NRF-NRFF2016-04 awarded to CBdM.

### References

- [1]. Vadeboncoeur, Yvonne, Peter B. McIntyre, and M. Jake Vander Zanden 2011 "Borders of biodiversity: life at the edge of the world's large lakes." *BioScience* 61.7: 526-537.
- [2]. Hutchinson G.E. and Löffler H 1956 "The thermal classification of lakes." *Proceedings of the National Academy of Sciences* 42.2: 84-86.
- [3]. Lewis Jr, William M 1983 "A revised classification of lakes based on mixing." *Canadian Journal of Fisheries and Aquatic Sciences* 40.10: 1779-1787.
- [4]. Boehrer B. and M. Schultze 2008 "Stratification of lakes." *Reviews of Geophysics* 46.2.
- [5]. Hasler, Arthur D 1947 "Eutrophication of lakes by domestic drainage" *Ecology* 28.4 : 383-395.
- [6]. Steinberg, Christian EW, and Helga M. Hartmann 1988 "Planktonic bloom-forming Cyanobacteria and the eutrophication of lakes and rivers." *Freshwater Biology* 20.2 : 279-287.
- [7]. Schindler, David W., and John R. Vallentyne 2008 "The algal bowl: overfertilization of the world's freshwaters and estuaries". Edmonton: University of Alberta Press.
- [8]. Syandry H., Junaidi, Azrita, Yunus T. 2014 "State of aquatic resources Maninjau Lake West Sumatra province, Indonesia." *Journal of Ecology and Environmental Sciences*, 5-1, 109-113.
- [9]. Lewis Jr, William M 1996 "Tropical lakes: how latitude makes a difference." *Perspectives in tropical limnology* 4364 .
- [10]. Kraemer, Benjamin M., et al 2015 "Morphometry and average temperature affect lake stratification responses to climate change." *Geophysical Research Letters* 42.12 : 4981-4988.
- [11]. Beck, Christian 2009 "Late Quaternary lacustrine paleo-seismic archives in north-western Alps: Examples of earthquake-origin assessment of sedimentary disturbances." *Earth-Science Reviews* 96.4: 327-344.
- [12]. Waldmann, Nicolas, et al 2011 "Holocene mass-wasting events in Lago Fagnano, Tierra del Fuego (54 S): implications for paleoseismicity of the Magallanes-Fagnano transform fault." *Basin Research* 23.2 : 171-190.
- [13]. Kremer, Katrina, Guy Simpson, and Stéphanie Girardclos 2012 "Giant Lake Geneva tsunami in ad 563." *Nature Geoscience* 5.11 : 756.
- [14]. Smith, Victoria C., et al 2013 "Identification and correlation of visible tephras in the Lake Suigetsu SG06 sedimentary archive, Japan: chronostratigraphic markers for synchronising of east Asian/west Pacific palaeoclimatic records across the last 150 ka." *Quaternary Science Reviews* 67: 121-137.
- [15]. Coviaga, C., Cusminsky, G., Pérez, A.P., Schwalb, A., Markgraf, V., and Ariztegui, D 2018 "Paleoenvironmental changes during the last 3000 years in Lake Cari-Laufen (Northern Patagonia, Argentina), inferred from ostracod paleoecology, petrophysical, sedimentological and geochemical data" *The Holocene*, v. 28, no. 12, p. 1881-1893.
- [16]. Lehmusluoto, Pasi, et al 1997 "National inventory of the major lakes and reservoirs in Indonesia." *Expedition Indodanau Technical Report*, Edita Oy.
- [17]. Giesen W. 1994 "Indonesia's major freshwater lakes: A review of current knowledge, development processes and threats". *Internationale Vereinigung für Theoretische und Angewandte Limnologie: Mitteilungen*, 24:1, 115-128.
- [18]. Li, Jin, and Heap, Andrew D. 2008. *A Review of Spatial Interpolation Methods for Environmental Scientists*. Geoscience Australia, Canberra, Australia.

- [19]. Chuanfa Chen, Na Zhao, Tianxiang Yue, Jinyun Guo 2015 “A generalization of inverse distance weighting method via kernel regression and its application to surface modeling.” *Arabian Journal of Geosciences*, v 8, no. 9, p. 6623.
- [20]. Ettritch, G, Hardya, A., Bojang, L., Cross, D., Bunting, P., Brewer, P 2018 “Enhancing digital elevation models for hydraulic modelling using flood frequency detection” *Remote Sensing of Environment* 217 506–522.
- [21]. Eville G. and Boyce F.M 1989 "Influence of lake surface area and depth upon thermal stratification and the depth of the summer thermocline."