Chapter

Water Balance and Thermal Regime of Lakes in Antarctic Oases

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Abstract

The chapter aims to revise the capabilities of a water balance modelling approach to be applied on climate-related or practical studies of lakes located in specific conditions of Antarctica. The seasonal water balance equation (WBaL) of a lake was suggested for the lakes located in the vicinity of the Antarctic scientific stations: Bellinshausen, Progress and Maitri. First, the methods and models used to evaluate the income and outcome terms of the WBaL from minimal observational datasets are considered. Then the historical observations available on the lakes Kitezh, Priyadarshini, Stepped, Nella, Progress and Reid are described based on the technical reports of the Finnish, Indian and Russian Antarctic research programmes and from open source publications. Finally, practical recommendations on improving temporal hydrological network are formulated to give a simple solution for the seasonal water balance studies of the Lake Priyadarshini.

Keywords: Antarctic oasis, lakes, freshwater resource, climate change, water quality and quantity, human activity, water supply

1. Introduction

Ice-free areas named oases provide a home for numerous lakes in Antarctica. The size of the lakes vary from small, shallow ponds to big, deep natural reservoirs; however, these lakes are very sensitive to changes of the physical parameters of the near-surface atmosphere. The precipitation and air temperature are among the climate variables affecting the liquid water storage of the Antarctic lakes. The water balance of lakes is an important indicator of changes in climate, and it includes various sets of freshwater inflow and outflow terms depending on the time scale of the physical processes considered. On a seasonal scale, an increase of freshwater outflow from the Antarctic continent leads to changes of ocean water salinity and can affect the Southern Ocean circulation [1]. At the same time, an increase of air temperature leads to an increase in the ratio of evaporation to precipitation for a lake surface, which reduces the number of small ponds in the Antarctic oases [2]. In turn, the drying lakes may accelerate local warming in the oases. Recently, the decrease in the number and volume of small lakes is mentioned by [2–4].

While a majority of studies discuss the observed and expected changes in an air temperature regime and ice and snow cover evolution on the continent [5], the knowledge of surface hydrology and freshwater resources is still limited to the lakes in Antarctic oases [6]. This is due to the remoteness of the continent, which results in the high cost of the hydrological observational network. In this situation, a modelling approach provides the only opportunity to study regional specifics of the Antarctic lakes.

The water balance equation of a lake (WBaL) is among the traditional models used to study a quantity of freshwater accumulated in lakes [7]. The equation provides a relationship between inflow and outflow terms (precipitation, evaporation, surface inflow and outflow, etc.) and includes different components depending on lake type, a human factor or a time scale of physical processes to be accounted for. The WBaL also allows for the optimisation of the total amount of water withdrawal for human needs. This task has become interesting for the study of lakes located in the vicinity of scientific stations. In this chapter, the applicability of the WBaL to evaluate the seasonal freshwater cycle for the lakes was considered.

Models need observations to be calibrated, validated and corrected. In Antarctica, the atmospheric forcing data available for evaluations of the WBaL terms are usually limited to the standard meteorological observations within the World Meteorological Organisation (WMO) network, and temporary hydrological observations operate during summer field campaigns. The temporary hydrological observations are supported by national Antarctic programmes, and the content of data may vary year to year. Since only observations with consistent measurement techniques and instruments can be used for climate-related studies, it is important to have uniform programmes to study the water balance components of lakes in Antarctica. Then, specifics of the polar environment as well as features of logistic operations can be accounted for in solutions of the network to monitor the lake's water balance components. In this chapter, the historical hydrological observations are analysed from the technical reports of the three national Antarctic programmes and open source publications.

This chapter aims to revise the capability of the water balance modelling approach to be applied in climate-related or practical studies of lakes located in specific conditions of Antarctica. The seasonal water balance equation was suggested for the lakes located in the vicinity of the Antarctic scientific stations Bellinshausen, Progress and Maitri. First, the methods and models used to evaluate the income and outcome terms of the WBaL from minimal observational datasets are considered. Then, the historical observations available on the lakes Kitezh, Priyadarshini, Stepped, Nella, Progress and Reid are described based on the technical report of the Finnish, Indian and Russian Antarctic research programmes and previous publications. Finally, practical recommendations for the temporal hydrological network for the water balance studies of Lake Priyadarshini are formulated as an example of a simple solution.

2. Lakes in the Antarctic oases

This chapter presents an overview of the observations available to evaluate the seasonal water balance for the lakes located in the vicinity of the three Antarctic bases. Kitezh Lake is located on the Fildes Peninsula, on King George Island, and serves the water supply of the Russian Bellinshausen and the Chilean Presidente Eduardo Frei Montalva stations year-round. The Fildes Peninsula is an ice-free area, and only the northeast edge is covered by Collins Glacier. The surrounding landscape is formed by hills; the bedrock is composed of volcanic deposits mostly of basalts, tuffs and andesites [8, 9].

Lake Priyadarshini is situated on the Schirmacher Oasis, Dronning Maud Land, and it provides water for the Indian Maitri station with about 25 people on a winter crew. During the summer, the number of people doubles. The Schirmacher Oasis is located approximately 80 km from the sea coast and has the ice-free area elongated in a narrow strip around 17 km long and 3 km wide located between two glaciers. The relief of the oasis is typically hill rocks and moraines with local depressions occupied by more than a hundred lakes of different types: small, shallow ponds, big, deep lakes and shallow lakes [10, 11].

Lakes Stepped, Nella, Progress and Reid are among more than 150 surface freshwater lakes located in the Larsemann Hills, Princess Elizabeth Land [12, 13]. Lake Stepped provides the technical water supply of the Russian Progress station, which has year-round operations with 25 people, and gives the additional inflow to the water supply system of the Chinese Zhongshan station. Drinking water is extracted from the Lake Progress located within several kilometres of both stations, and it is delivered by vehicles once a week during the summer. Lake Nella is located about half as far from the stations as Lake Progress, and its water resources may be an alternative water supply to both stations. In case of an increase in activities on the Australian Low/Racowita Antarctic station, Lake Nella can become a good source of water for this station as well.

2.1 Models

2.1.1 Water balance equation of a lake

The water balance equation of a closed lake (WBaL) generally includes two terms [7]:

$$\Delta V = I - O \tag{1}$$

where ΔV is the volume change per time unit and I and O are the input and output terms correspondingly. The input and output terms consist of a number of water balance components depending on a time interval of changing in a volume. In fact, the shorter time interval requires a higher number of water balance components to be accounted for due to the inclusion of physical processes of smaller scales. On seasonal scales, the input terms of WBaL are precipitation and surface groundwater inflow runoff, while the output terms are evaporation and surface/groundwater outflow runoff. The number of terms in the WBaL also depend on the lake type, for instance, the only output term for endorheic lakes is evaporation. This type of lake is among the most common in the Antarctic oases. The human factor should also be accounted for among the output terms of the WBaL for the lakes serving the water supply for Antarctic stations.

Figure 1 shows the seasonal terms of WBaL for lakes that are used or may potentially be used as the water supply of the three Antarctic stations. The WBaL can be written as follows:

$$\Delta V = P - E \pm Y \pm G \pm W \tag{2}$$

where V is the volume of a lake, P is the precipitation (input term), Y is the surface inlet/outlet runoff (input/output terms), E is the evaporation (output term), G is the sub-surface inflow/outflow runoff (input/output terms) and W is a term connected to the human activity (a pure water consumption or a wastewater utilisation). Two terms, P and E, are related to the lake surface.

To finalise the WBaL, each term should be estimated from specific observations or modelled from standard observations. In Antarctica, it is a challenge to organise

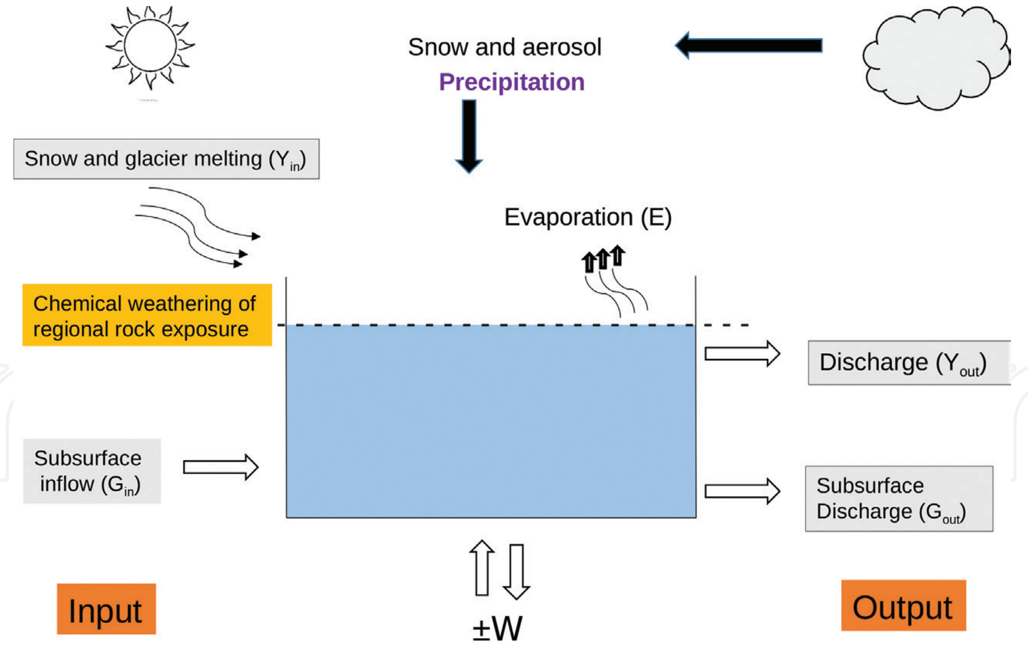

Figure 1.
The components included in the water balance equation of the lakes.

the regular observational network for monitoring the terms of water balance due to high supporting costs; thus, the modelling approach is only a way to study climate-related changes in lakes located on Antarctic oases. Modern hydrology provides numerous models to evaluate terms of the WBaL, such as surface/sub-surface inflow/outflow runoff or evaporation; however, the models still need measurements for testing experiments.

2.1.2 WBaL: the input terms

For the lakes studied, to estimate the seasonal precipitation amount, the direct measurements are available at the nearest meteorological station operating with the World Meteorological Organisation (WMO). The stations use standard methods and instruments to measure the precipitation as well as the air temperature, relative humidity, wind, solar radiation, soil temperature, etc. These meteorological observations are available for a long-term period; thus, they serve as a good source for the forcing variables to model the WBaL terms, and the inflow/outflow (both surface and sub-surface) runoffs are among the other known sources.

Melting water from a seasonal snow cover produces a surface stream flow network to transport water, sediments and dissolved minerals into a lake during a summer season. To simulate the surface/sub-surface runoff from standard meteorological observations, physically based distributed hydrological models are common [14]. These models require datasets on climatology as well as detailed soil type maps on height resolution, which do not exist for Antarctica. A spatial dimension of the local surface runoff network and the size of watersheds are too small to be described by the physically based distributed hydrological models. To use this type of models, the special geodesic measurements and geological studies are needed to reproduce the details of the local digital elevation model (DEM) and soil types [15].

The lumped hydrological models provide an alternative for the physically based models to evaluate surface runoff in climate-related and practical studies. In this case, the surface runoff is also simulated from the standard meteorological variables, and the simulations are not required on the detailed DEM or soil type data. However, the direct measurement of the river water discharges is needed to calibrate and verify the models. In seasonal water balance calculations, the sub-surface runoff inflow term can be neglected, as it was assumed in this study. The precipitation and surface inflow terms are connected to biogeochemical processes going on in lakes, as they are chief contributors of the water input to the lakes and also provide a reaction medium for terrestrial weathering. These processes ultimately affect the lake water biogeochemistry.

2.1.3 WBaL: the output terms

The evaporation from a lake surface term remains among the poorly studied variables for the lakes located in the Polar Regions. The direct measurements of evaporation are difficult to organise even in low latitudes since techniques usually require very specific instruments. Indirectly, the Dalton-type empirical equations are usually used to calculate the evaporation from standard meteorological observation [16]. In hydrology, the daily evaporation rate (mm/day) is calculated as follows:

$$E = 0.14(e_0 - e_{200})(1 + 0.72w_{200}) \tag{3}$$

where e_0, hPa is the water vapour pressure at the saturation point; e_{200}, hPa is the screen level water vapour pressure and w_{200}, ms^{-1} is the wind speed. The equation is obtained using measurements with the "pan evaporation technique" on lakes located in the north of Russia [16]. Thus, this equation may give noised results in the estimation of the evaporation rate [4].

The evaporation term provides a connection between the thermal and water balance of a lake. Since the evaporation is connected with the latent heat flux from the lake surface, it can also be calculated using the lake heat balance and thermodynamic lake models. In this case, a thermodynamic lake model is forced by standard meteorological observations, namely by the air temperature, specific humidity and the wind speed. Downward short-wave and long-wave radiation, if not measured, may be estimated from cloudiness observations, using astronomical formula and empirical methods [17, 18]. Evaporation, as well as other turbulent fluxes, may then be calculated by an atmospheric surface layer block of a lake model from the simulated lake surface temperature and atmospheric variables. The example of the calculation for the evaporation in Antarctica using the thermodynamic lake model may be found in [4]. In this study, the lake model FLake [19] is used to simulate lake water temperature profiles and the turbulent fluxes from a lake surface, including the evaporation, for the lakes in the Larsemann Hills and the Fildes Peninsula. The results are sensitive to the parameters of lakes, namely, to the lake depth and the lake water transparency.

The surface outflow term can be estimated only from direct observations, since this term of the WBaL depends on both morphological features of a lake and on meteorological variables. The water withdrawal/releasing form a human factor could be estimated only from direct measurements. In water management, these two terms allow regulation of a lake's storage in an accumulation/releasing water resources depending on human needs.

2.1.4 Volume of a lake

A bathymetrical map of a lake is among the tools to evaluate the basic morphometrical characteristics of a lake including the width, the depth (average and maximum), the surface area and the volume of water storage. To obtain the bathymetry, the space-distributed measurements on lake depth are needed. Presently, the estimates on the length, the width, the surface area and depth are published for a number of lakes on the Antarctic oases [3, 4, 7, 8, 12, 20]; however, there are still minimal data

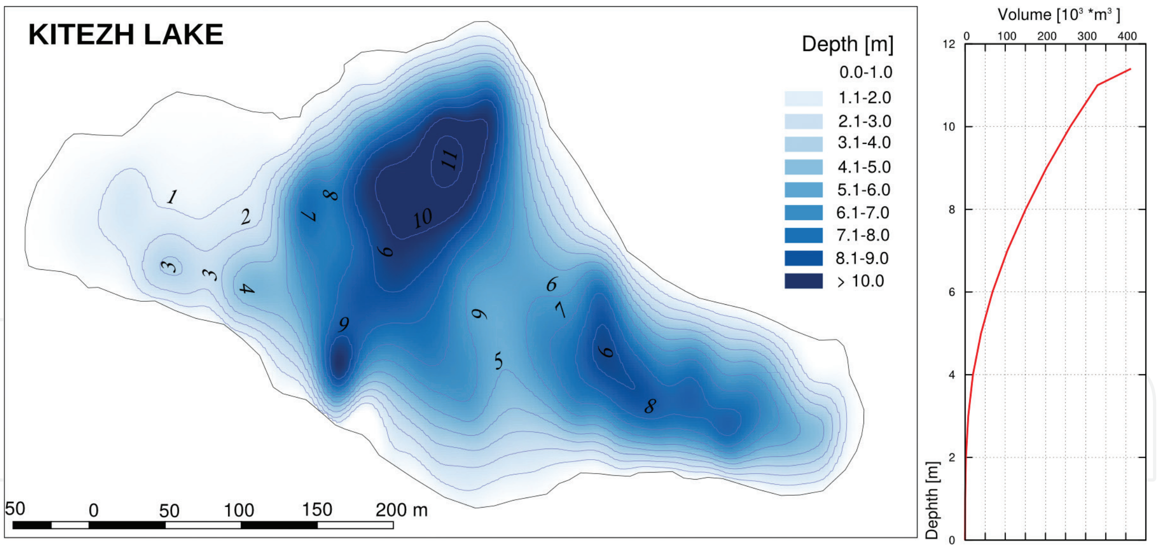

Figure 2.
The bathymetry (left) and volumetric curve (right) of Lake Kitezh [23].

on the volume of lake storage. The volume of a lake can be also evaluated from the high-resolution digital elevation model as suggested in [21]. However, the uncertainties of such estimations with freely available DEMs are still unclear [22].

To finalise the water balance of a lake, the sum of the terms should be equal to the volume changes during the selected time step (day, decade, month, season, etc.). For that, the measurements on the water level-named stage (H, m) are required together with a lake's volumetric curve (see **Figure 2** for the example). The volumetric curve is a unique lake attribute; however, there are also theoretical models allowing evaluation of lake bathymetry from the remote sensing data [22].

2.2 Observations

In modern times, the water balance components of a lake are measured occasionally, and only during the summer season (December–March) on a number of lakes located in the vicinity of the Antarctic bases. However, the content on the hydrological datasets vary year by year as well as spot by spot and in terms of a number of lakes, the location of hydrological gauges and instruments used for measurements. In this part of the chapter, we analysed the technical reports on the filed campaigns 2011–2018 published by the Finnish, Indian and Russian national Antarctic research programmes as well as more early publications in an attempt to understand whether we have measurements to support climate studies on the seasonal water balance of the lakes used for human water supply for the selected spots in Antarctica.

2.2.1 WBaL: the input terms

For Lake Priyadarshini, the measurements on the surface runoff inflow/outflow as well as snow cover measurements were not founded or do not exist. Generally, the hydrological observations on Lake Priyadarshini usually consist of the water temperature profiles and chemistry [10, 11]. A similar situation was founded for Lake Kitezh, where the measurements of water balance components are limited by one season year, 2011–2012 [23]. The temporal hydrological network on the watershed of Lake Kitezh included discharge gauges on inlet/outlet rivulets as well as snow cover extent, thickness and density. The preliminary modelling results of the surface inflow suggest that one-/two-degree "black-box" hydrological models show a good fit to the observations of the discharges on the inlet gauges.

The hydrological observations on the input terms of the WBaL for the lakes Stepped, Nella, Progress and Reid (the Larsemann Hills) usually cover the period of 1–2 months. During these periods, the temporal gauges to observe the water stage/discharge are placed in the inlet rivulets of all of these lakes. The daily river discharges are usually estimated from the water stage/discharge curve.

The seasonal observations of snow cover properties (snow depth, extent and density) are available for Lake Stepped for four summer seasons (2011–2012; 2013–2014; 2013–2014 and 2016–2017), and the preliminary results suggest that surface/sub-surface water inflow due to seasonal melting of snow contributes more than 5–7% of the total volume of storage [24–26]. The seasonal surface inflow due to snow melting is also estimated for the lakes Nella and Reid; however, the detailed study is still needed to model the surface inflow runoff term of the WBaL of these lakes.

2.2.2 WBaL: the output terms

The evaporation from open surface of Lake Priyadarshini measured during the period of January 2018 [2] with the method of eddy covariance [27]. The preliminary results of the campaign suggest that the daily values of evaporation rate ranged from 0.9 to 1.6 mm/day and strongly depend on wind speed, air temperature and lake water temperature. The results of this field experiment will be presented in a separate study in cooperation with Miguel Potes and Daniela Franz. The direct observations of evaporation were not founded on other lakes, including Kitezh, Stepped, Progress, Nella and Reid.

2.2.3 Volume and water level

The bathymetry of lakes Kitezh, Priyadarshini, Stepped, Progress and Reid are evaluated from GPS and depth measurements [4, 11, 23]. The volume of Lake Nella ($103.3\ m^3 \times 10^4$) is estimated after [21]; however, the bathymetric map of Lake Nella has not been published or ever done. Only two datasets on the Nella Lake depths were found; however, the results are only on the lake depth profiles [12, 24].

Table 1 gives the length of the observational period, the date and the resolution of the measurements of the lake water level for the period 2011–2018. The water level (stage) is measured on the lakes selected; however, the temporal hydrological network contains a different number of the observational gauges.

The measurements on the water level/stage are available daily or once every 3 days for the summer seasons 2012–2014 and 2017 in the Larsemann Hills. These data look promising to be applied in the seasonal water balance calculations and the simulation of water balance terms. However, the temporal hydrological networks on the lakes Stepped, Progress, Nella and Reid are relocated yearly, and the datasets on water level (stage) observations have a different "zero level". This "zero-level" issue makes an inconsistence in the year by year datasets for the water level/stage observations [23, 24, 28]. This problem is solved during the field campaign 2016–2017 [26].

The survey of the technical reports and publications shows that the hydrological observations of the water balance components of the lakes in the Antarctic oases occur occasionally and cover mostly only the summer season. The measurements are often inconsistent in terms of gauges' location, instruments used and measurement techniques applied. This issue is inherent in the measurements on the lakes that are provided a water supply. In this context, some harmonisation of the measurement methods and tools is needed to support climate-related study of a water balance of lakes in the Antarctic oases. Further, the hydrological observational network will be discussed, for example, on Lake Priyadarshini (the Schirmacher Oasis).

Spot	Period	Number of the gauges/measurement points or profiles/ samples					
		E	SR	LST	SC	GR	CS
FA	05.01.2012–05.04.2012	0	6	12	3	0	25
SH	28.12.2017–08.02.2018	1	1	3	0	0	3
LA	27.12.2011–05.02.2012	0	3	9	1	0	48
	21.12.2012–28.01.2013	0	4	10	1	4	25
	25.12.2013–03.03.2014	0	2	6	1	0	38
	05.01.2016–20.02.2017	0	0	5	4	0	67

Note: E, the evaporation; SR, surface runoff; LST, the lake stage and water temperature; SC, snow cover; GR, sub-surface runoff and CS, the chemistry sampling.

Table 1.
The summary for the direct measurements of the water balance components on the lakes located in the Fildes Peninsula (FA), the Larsemann Hills (LA) and Schirmacher (SH) oases.

2.3 Optimisation of the temporal hydrological network

The hydrological measurement campaign to study the water balance components of Lake Priyadarshini was carried out during summer season 2016–2017. The campaign was mostly focused on evaporation [2], while the additional hydrological observations were organised on the temporal hydrological network on the watershed of Lake Priyadarshini (**Figure 3**).

The water level and temperature gauge named Parwati was equipped with the temperature and water level sensor HOBO by Onset. The evaporation gauge named Irgason was equipped with the Integrated CO_2 and H_2O Open-Path Gas Analyser and 3-D Sonic Anemometer by the Campbell Scientific and temperature sensor iButton by Maxel. The water discharges were only measured episodically on the gauge named West Inflow with the micro-current metre (GR-55) by the Gidrometpribor for reasons to be discussed in a separate paper. However, continued discharge measurements are needed to apply the modelling approach to estimate the water balance component of Lake Priyadarshini.

Figure 3 provides an example of a simple solution for the location of the temporal hydrological gauges on the watershed of the Antarctic lakes; however, the network must also include the snow measurement profiles, groundwater level gauges, etc. The good examples of the temporal hydrological network on the watershed of Lake Stepped are given in [23–26].

2.3.1 WBaL: the input terms

The input terms of the WBaL of Lake Priyadarshini are formed by the surface/sub-surface inflow runoff and wastewater that come from the Maitri station. To evaluate the surface/sub-surface runoff, a simple hydrological "black-box" model can be applied; however it should be calibrated against measurements. In this context, the field measurements of the snow cover and soil properties in the watershed of Lake Priyadarshini are important in the modelling of water balance income terms. It should be noted that for the seasonal water balance, calculations on the field measurements are needed since remote sensing observations still remain coarse for such calculations for watersheds of a small size. In addition to snow and soil measurements, the gauges named West/East Inflow and Outflow gauges should be equipped with water temperature, level and discharge sensors. The water input

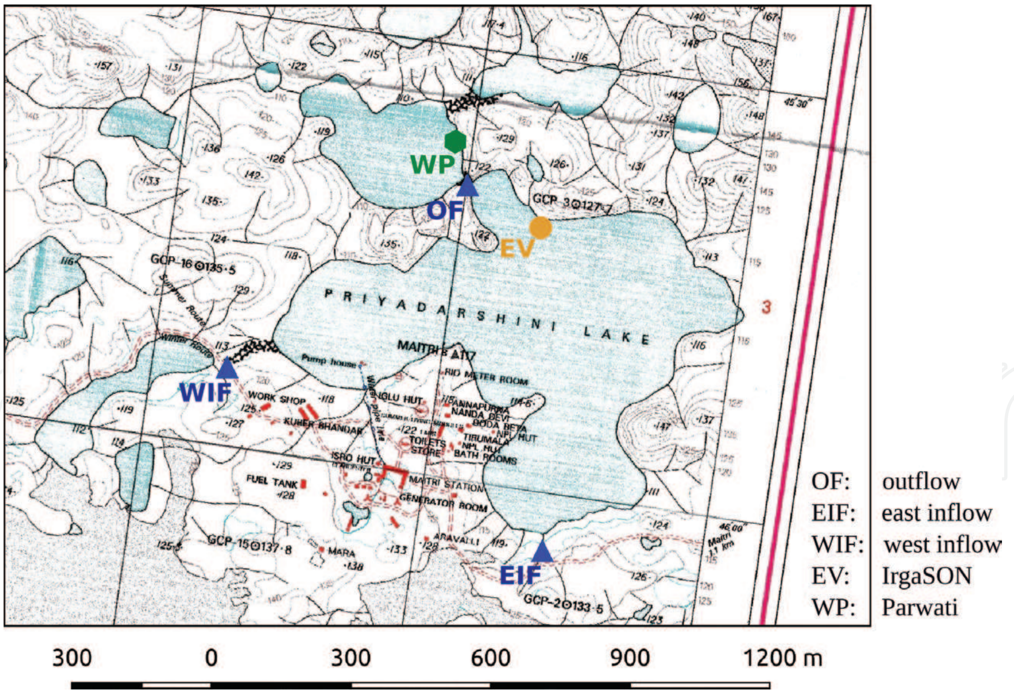

Figure 3.
The temporal hydrological network on the watershed of Lake Priyadarshini (from the field campaign of 2017–2018): the green hexagon is the water level and temperature gauge; the blue triangles are the discharge gauges on inlet/outlet streams, and the yellow circle is the evaporation gauge.

to Lake Priyadarshini due to human activity would be recommended to measure the outlet of the water purification system of the Maitri station.

2.3.2 WBaL: the output terms

The output terms of the WBaL of Lake Priyadarshini are the evaporation, surface/sub-surface outflow and water withdrawal for the needs of the Maitri station. The evaporation can be calculated from thermal balance of the lakes or from Dalton-type equations using the standard meteorological observations. The FLake model [19] simulates the evaporation rate from the open lake surface; however, this model is not yet tested against direct measurements of evaporation. The experiment on the Irgason evaporation gauge 2017–2018 (**Figure 4**) was designed to measure the evaporation rate to be used in modelling experiments with the FLake model. The preliminary results show that the daily values of the evaporation rate ranged from 0.9 to 1.6 mm/day and strongly depend on wind speed, air temperature and lake water temperature [2]. At the same time, the observational period for the campaign was too short, which may contribute limitations to the model testing results. Thus, the experiment would be interesting to continue further. The surface/sub-surface outflow should be measured as mentioned above. The water withdrawal should be measured on the inlet of the water pumping station of the Maitri station.

2.3.3 Volume and water level

The detailed study of the volume of Lake Priyadarshini is reported by [11] about 20 years ago; thus, the volume of the lake may differ. The actual GPS survey and the lake depth measurements may contribute to the actual state of the lake bedrock. The water level/stage gauge with temperature sensor (or profiled sensors) and water level data logger should be deployed on Lake Priyadarshini for the year-round operation.

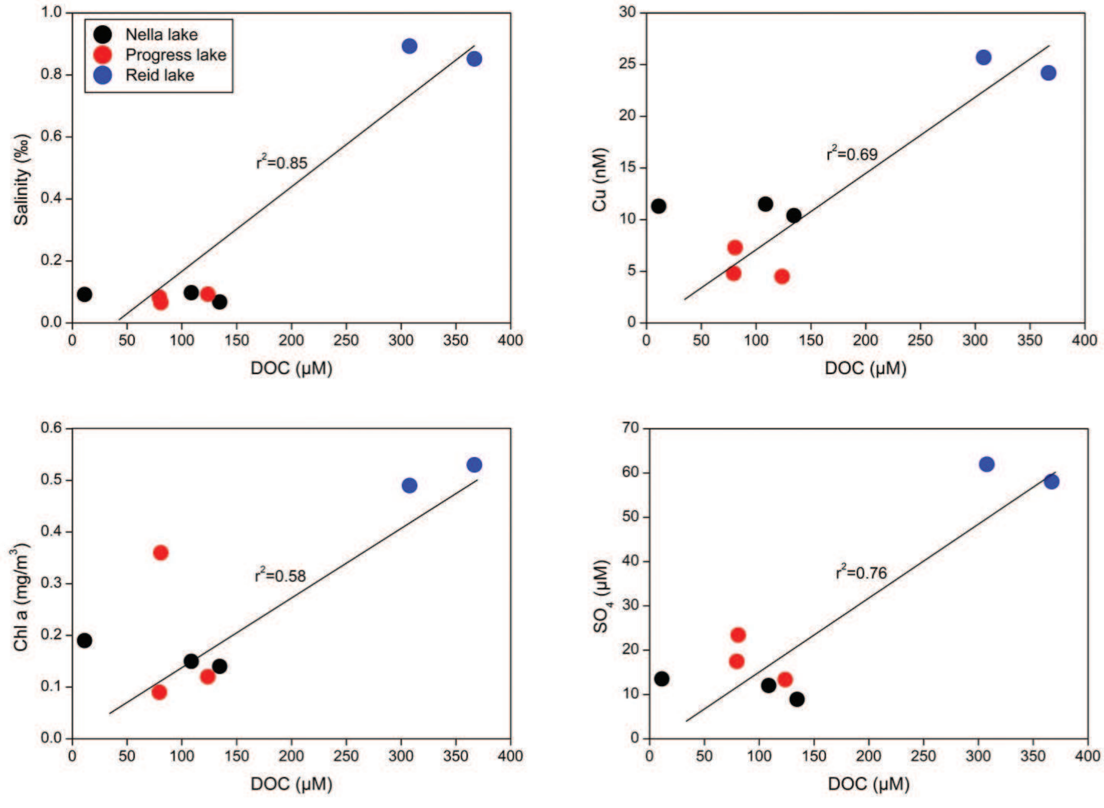

Figure 4.
Correlations between salinity, chlorophyll (Chl-a), dissolved sulphate (SO_4) and dissolved copper (Cu) and dissolved organic carbon (DOC) for water samples collected during January and February 2017 from the lakes of Larsemann Hills, East Antarctica.

2.4 Antarctic lakes: archive for terrestrial and biogeochemical processes

There is meagre knowledge on a well-developed river system in Antarctica unlike in the tropical and temperate regions; however, the Larsemann Hills regions of the East Antarctic peninsula, an ice-free oasis, has almost 150 surface freshwater lakes [12, 13]. Lakes in the region are exposed with highly metamorphosed granitic gneiss and a thin layer of sediment patches [29]. Chemical and physical weathering of the exposed lithology is pathways for nutrient supply to the lake water primary produces. Among them, silicate weathering is one of the major processes which control the atmospheric CO_2 draw down and in turn governs the long-term climatic changes [30–32]. Since then, Antarctica has been assumed to be pristine; these lakes can be a suitable archive to study the terrestrial and biogeochemical processes.

2.4.1 Sampling and analysis

To understand the terrestrial and biogeochemical processes in the region, Antarctic lakes have been studied under an Indian Antarctic expedition in a seasonal field campaign from December 2016 to February 2017. The lake water samples were collected from three surface freshwater lakes in the Larsemann Hills in East Antarctica named Nella, Progress and Reid. Every possible measurement has been taken during the sample collection and processing to avoid contamination. The water samples have been analysed for dissolved trace metal concentrations using Quadrupole-ICP-MS, macro nutrients (silicates, phosphates, nitrate and nitrite); analysis using auto analyser and chlorophyll-a (Chl-a) was measured using flourometer. Dissolved organic carbon (DOC) was analysed following standard methods [33]. Analytical precision within limits for each parameters and analysis was obtained.

2.4.2 Results

In this study, we have found that the major ion chemistry of the lakes in the Larsemann Hills is largely controlled by silicate weathering followed by atmospheric dust and seawater. Dissolved Cu plays an important role as a micronutrient that shows a strong correlation with DOC (**Figure 4**).

The sub-nanomolar concentration of trace metals indicates an insignificant impact of human activities on lake water chemistry, as also reported by earlier workers [34, 35]. Lakes are oligotrophic as indicated by Chl-a, and for most of the samples, the values are not more than 0.6 mg/m^3. The strong correlation between salinity, dissolved sulphates, dissolved Cu concentration, Chl-a and DOC plays the significant role of primary productivity, despite their lower concentration.

3. Conclusion

The chapter contributes to an understanding of the seasonal water balance of lakes located in Antarctic oases. The results and hydrological datasets from the technical reports were critically considered on the consistency of the variables measured as well as for uniforming methods and instruments applied during the measurement campaigns of 2011–2018. It was found that the hydrological observations remain more or less similar year by year for the methods and instruments used. However, the sets of the observed variables vary year by year even for a single lake; thus the multi-year datasets do not provide the similar dataset for the water balance components. The harmonisation of the seasonal hydrological programme is greatly needed to collect suitable datasets and to apply a modelling approach in climate-related and practical studies.

To prepare the uniformed programme of hydrological observations, the location of the temporal hydrological network was suggested for Lake Priyadarshini. The technical reports of the Finnish, Indian and Antarctic research programmes and previous publications allow for the recommendation of optimal solutions for the measurements, including locations of the gauges as well as a set of required instruments for the lakes Kitezh, Stepped, Nella, Progress and Reid.

The water balance is connected to the thermal and chemistry balances. The income and outcome terms of the water balance equation allow for evaluation of a lake retention time, which shows a strong correlation with trace metals like Zn, Cd, Co, Mn and Cu, thus playing an active role in lake water chemistry and primary productivity. The theoretical retention time is defined as a result of the division of a lake volume by inflow or outflow. In specific Antarctic conditions, the inflow/outflow on lakes only occurs during the summer. Thus, the retention time can be evaluated for warm and cold seasons separately and could be the topic of a future study.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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