FINNISH METEOROLOGICAL INSTITUTE

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Ph.D., Hydrology, Russian State Hydrometeorological University, St Petersburg, Russia (2001)
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Career

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Research Scientist, Finnish Meteorological Institute (2014->)

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Retention time of lakes in the Larsemann Hills oasis, East Antarctica

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Epiglacial and land-locked lakes in the Larsemann oasis, Queen Elizabeth Land, East Antarctica.

Climatology (1988–2010).
Annual air temperature: –10.9 < –9.7 < – 7.8 °C;

relative humidity: 58.2 < 60.4 < 63.8 %;

average wind speed: 5.0 < 6.0 < 6.8 ms^{-1}.

Annual precipitation amount over 2003–2016 is 166 mm yr^{-1} (Yu et al., 2018).

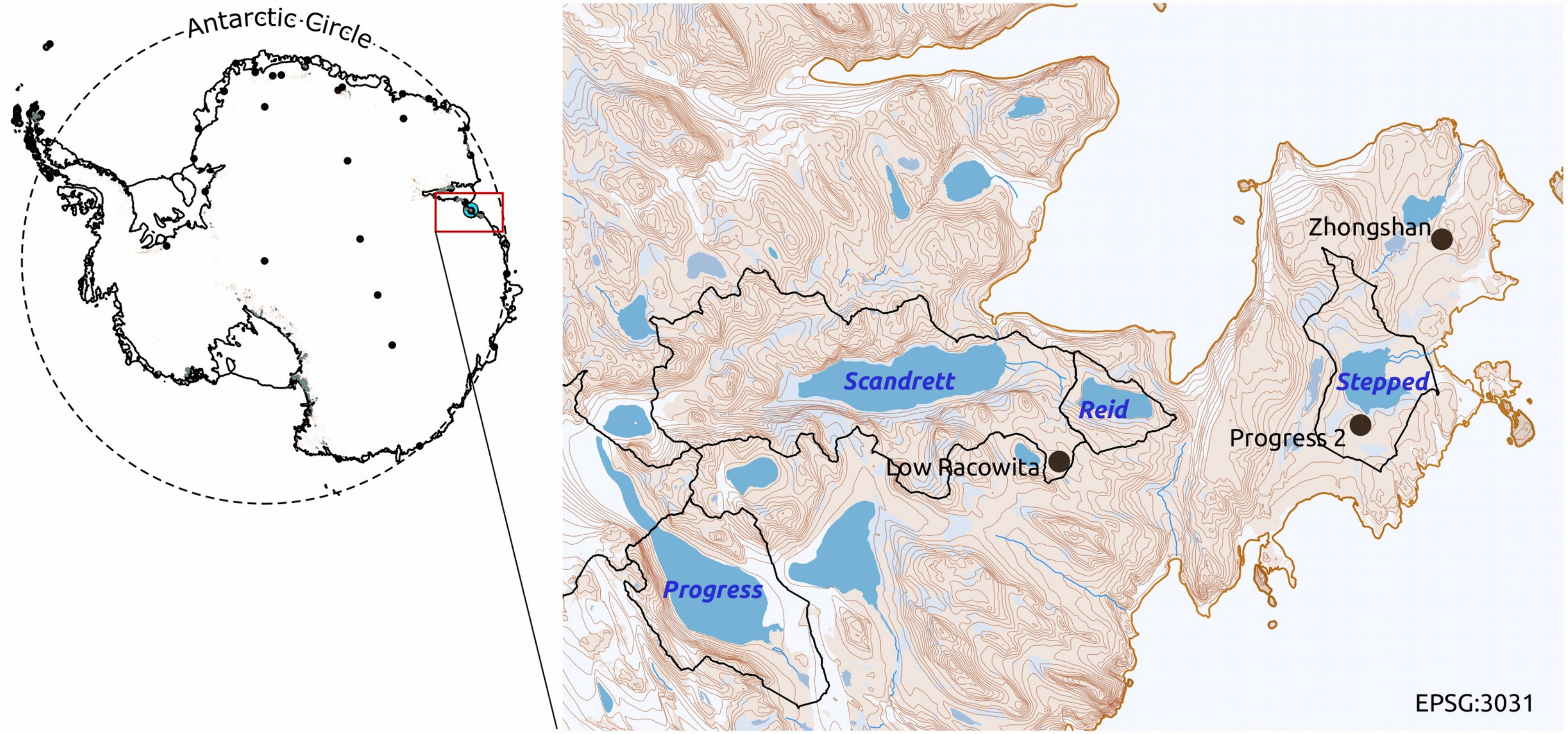


Table 1. The volume (*V*, x10^3 m^3) and area (*A*, x10^3 m^2), of five lakes located in the Larsemann Hills oasis: estimated after (Shevnina and Kourzeneva, 2017) / (Pryakhina et al., 2020). No estimations are indicated by "–" .

Parameter	Epiglacial lakes		Land-locked lakes		
	Lake Progress /LH57	Lake Nella/Scandrett /LH72	Lake Stepped \/LH68	Lake Reid /LH70	Lake Sarah Tarn / LH71
V, x10^3 m^3	1812.4 / 1526.75	1033.2 / 1490.7	40.5 / 51.03	25.5 / 40.45	10.5 / –
A, x10^3 m^2	160.6 / 125.7	155.9 / 157.9	47.3 / 44.4	33.1 / 35.5	6.1 / –

<u>The study aims</u> to evaluate water transport scale for lakes located in the Larsemann Hills oasis.

Question: How fast water is re-new in local lakes?

LRT is among others important parameters for chemical/eutrophication models.

<u>Method.</u>

A first order description of water transport processes occurring in lakes namely a lake “retention time” (LRT, year) or a lake “residence” time or a “flushing” time:

$$LRT\left[year\right]=\frac{Volume\ of\ lake\left[m^{3}\right]}{Volumetric\ Outflow\ Rate\left[m^{3}\ year^{-1}\right]}$$

<u>It needs to know lakes’ physiography as well as long-term observations on water level/stage and water discharges in outlets</u>

Water balance equation of a lake:

$$\frac{dV(t)}{dt} = Q_{\text{in}}(t) - Q_{\text{out}}(t) + \left(P(t) - E(t)\right)A(t) \pm \ldots,$$

where Q_{in} and Q_{out} are the income and outcome surface runoff (m^3 s^{-1}), P and E are precipitation and evaporation (m s^{-1}) over the lake surface area A (m^2). This equation is usually applied in the integrated form, with integration time period depending on application, e. g. one year time period:

$$\frac{\Delta V}{\Delta t} = Q_{\text{in}} - Q_{\text{out}} + (P - E)A \pm \ldots, \tag{2}$$

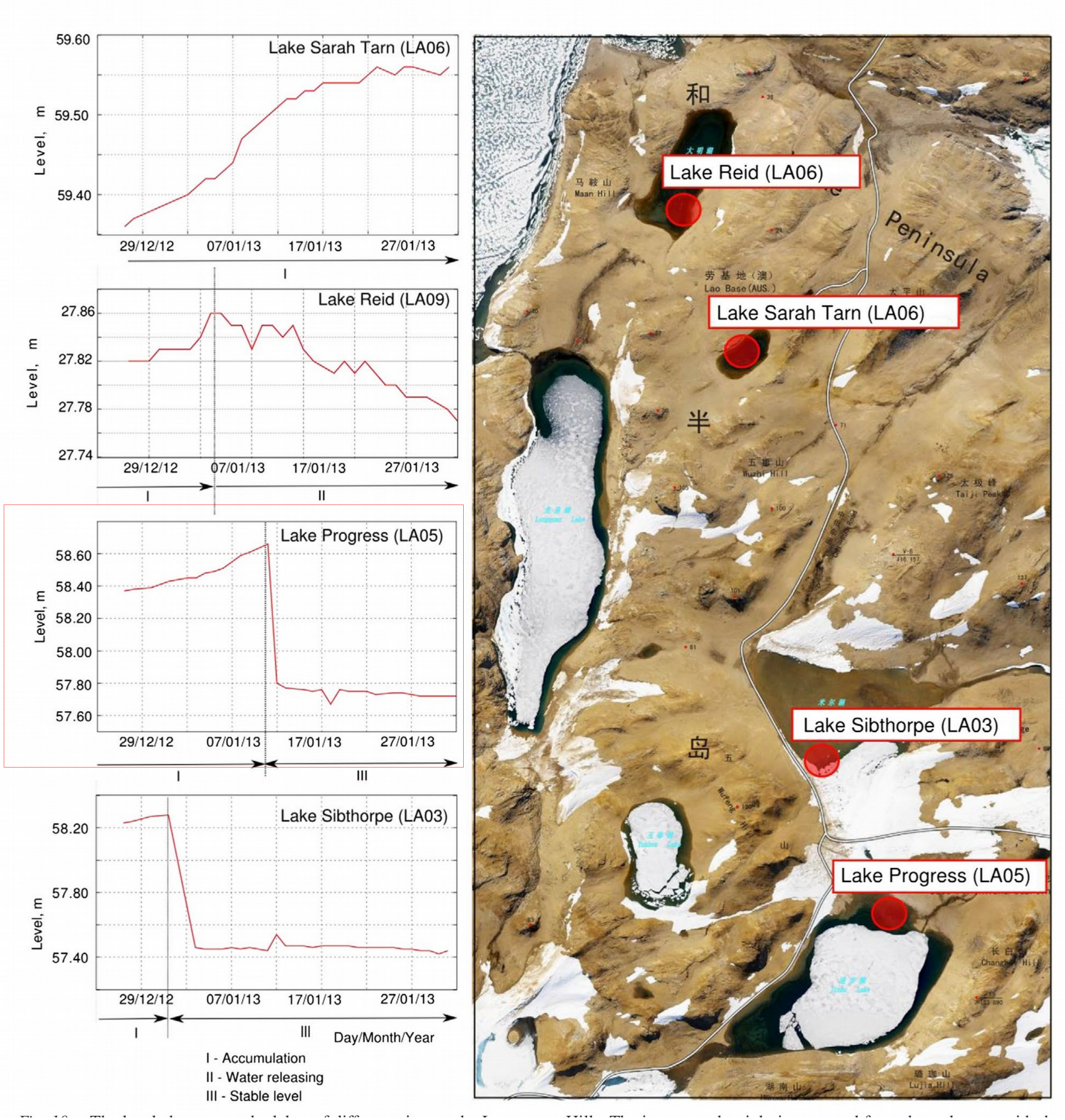
where now ΔV (m^3) is the volume change during the time period Δt (e.g. 1 year), Q_{in} and Q_{out} are the income and outcome surface runoff per this time period (e.g., yearly income and outcome surface runoff), P and E are precipitation and evaporation during this time period (e.g. annual precipitation and evaporation).

Assumptions:

1 year time period was referred to the seasonal ice-free observations of the outflow surface runoff for the whole year, suggesting no water flux during the frozen period for the lakes.

Ground inflow/outflow, and evaporation during the frozen period are small.

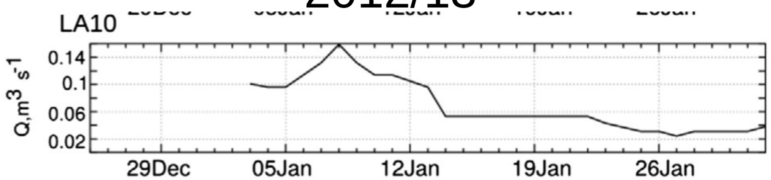
Epiglacial lakes: Progress and Scandrett/Nella



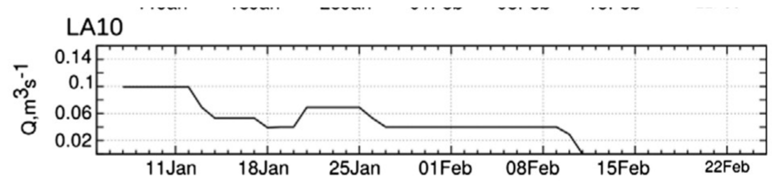
$$LRT^{o} = \frac{\bar{V}}{Q_{\text{out}} + Q_{\text{abr}} + E \cdot A}$$

$$Q_{\text{abr}} = A \Delta h$$

2012/13



2013/14



<u>Evaporation</u>
is calculated from measurements of the water temperature from the energy balance and by empirical Dalton type equation.

Land-locked lakes: Reid, Sarah Tarn and Stepped

$$\frac{\Delta V}{\Delta t} = Q_{in} - Q_{out} + (P - E) A \pm \ldots$$

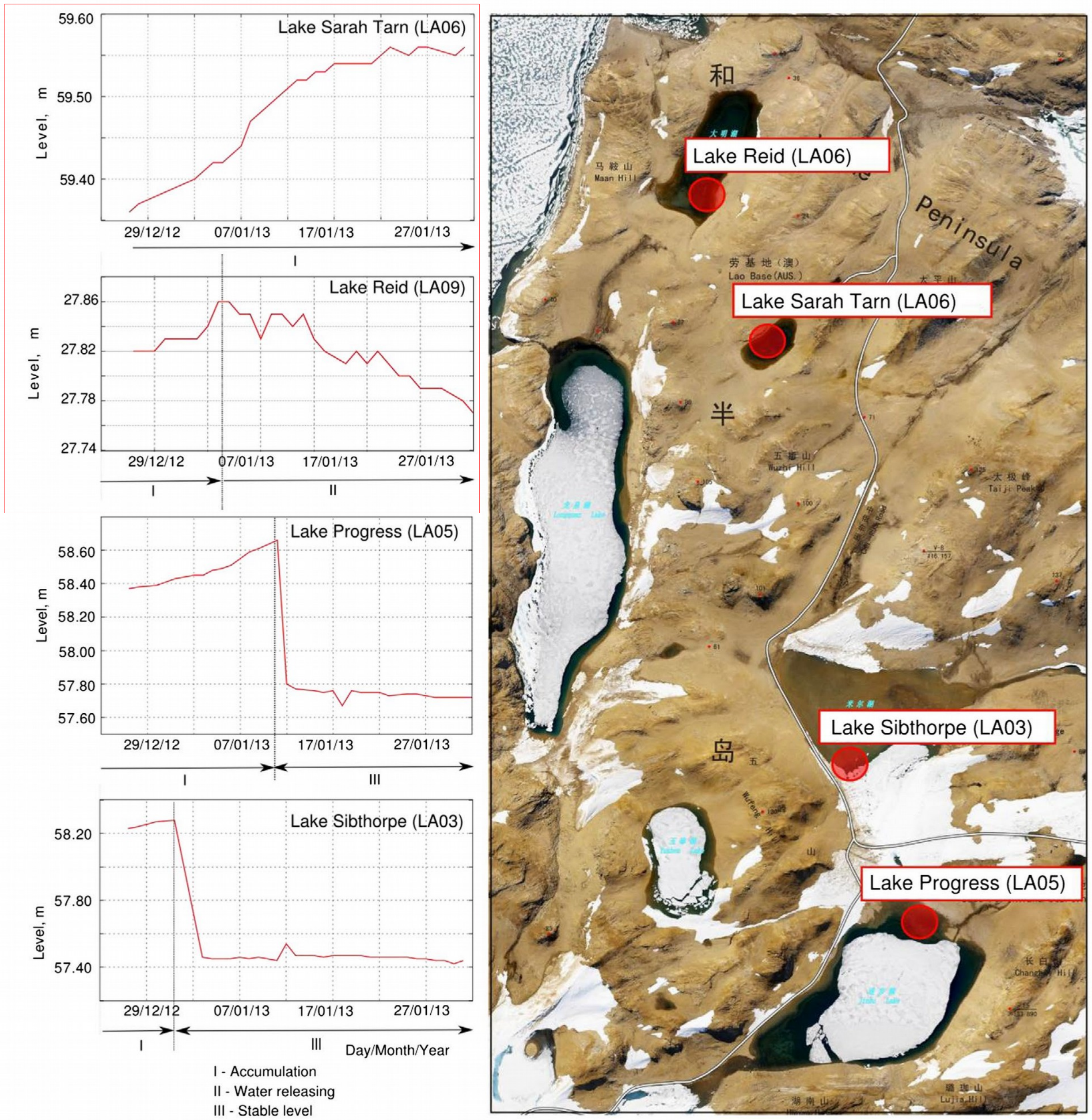
A: annual volume of the land-locked changes do not exceed 1–2 %

$$0 = M - Q_{out} + (P - E) A \pm \ldots$$

where M, (m^3) is the amount of water due to snow melting per this time period (e.g. per a year).

$$Q_{out} + E \cdot A = M + P \cdot A$$

$$\boxed{LRT^{o} = \frac{\bar{V}}{Q_{out} + E \cdot A} \qquad LRT^{i} = \frac{\bar{V}}{M + P \cdot A}}$$



Data:

The observations collected during four seasonal field campaigns:

- the bathimetric surveys in the lakes Stepped and Progress in 2011/12;
- the hydrological measurements on lakes and streams in 2012/13, 2013/14;

Table 8. Water balance components of the studied lakes in the Antarctic. (Shevnina and Kourzeneva, 2017).

Lake name	Season	dV, 10^3, m^3	P, 10^3, m^3	E/E^{FLake}, 10^3, m^3	Y_{in}, 10^3, m^3	Y_{out}, 10^3, m^3	M/M^{FLake}, 10^3, m^3	D/D^{FLake}, 10^3, m^3	Terms in D
Mirage (FA00)	2012	0.09	0.18	0.07/0.10	–	–	0.11/0.08	–0.02/0.01	$-G_{out} + G_{in}$
Kitezh (FA05)	2012	–17.4	23.2	11.5/14.6	332.0	379.0	–35.3/–38.4	17.9/21.0	$-G_{out} + G_{in}$
Dlinnoe (FA11)	2012	–2.3	2.9	0.9/1.4	–	142.1	–140.1/–140.6	137.8/138.3	$-G_{out} + G_{in}$
Glubokoe (FA22)	2012	–26.5	9.0	3.9/3.9	9.8	–	14.9/14.9	–41.4/–41.4	$-G_{out} + G_{in} - W$
Stepped (LA01)	2013	–1.4	1.3	n	–	[26.6]	[–25.3]	[23.9]	$-G_{out} + G_{in} - W - E$
	2014	–1.4	0.6	4.6/5.5	–	20.7	–24.7/–25.6	23.3/24.2	$-G_{out} + G_{in} - W$
Progress (LA05)	2013	–151.0	3.5	n	–	[150.2]	[–146.7]	[–4.3]	$-G_{out} + G_{in} - E$
	2014	–134.9	2.1	7.7/18.8	–	[128.3]	[–133.9]/[–145.0]	[–1.0]/[10.1]	$-G_{out} + G_{in}$
Sarah Tarn (LA06)	2013	1.2	0.1	n	–	–	0.1	1.1	$-G_{out} + G_{in} - E$
	2014	1.3	0.1	0.5/0.7	–	–	–0.4/–0.6	1.7/1.9	$-G_{out} + G_{in}$
Scandrett/Nella (LA08)	2013	–6.4	3.4	n	n	203.8	–200.4	194.1	$-G_{out} + G_{in} + Y_{in} -$
	2014	–4.7	2.0	7.6/18.3	n	170.9	–176.5/–187.2	171.8/182.5	$-G_{out} + G_{in} + Y_{in}$
Reid(LA09)	2013	–1.3	0.7	n	–	–	0.7	–2.1	$-G_{out} + G_{in} - E$
	2014	–1.7	0.4	3.2/4.0	–	–	–2.8/–3.6	1.1/1.9	$-G_{out} + G_{in}$

Note: dV = the seasonal volume changes; P = the amount of precipitation over open water surface; E and E^{FLake} = the amount of evaporation fr open water surface calculated following Odrova (1978) and by FLake; Y_{in} and Y_{out} = the volume of runoff per period; $M/M^{FLake} = (P + Y_{in} - Y_{($ E/E^{FLake}); $D/D^{FLake} = dV - M/M^{FLake}$. Dash means no inflow or outflow, value in brackets means estimated approximately, n means not estimatec

- the snow surveys during seasons 2011/12 and 2016/17.

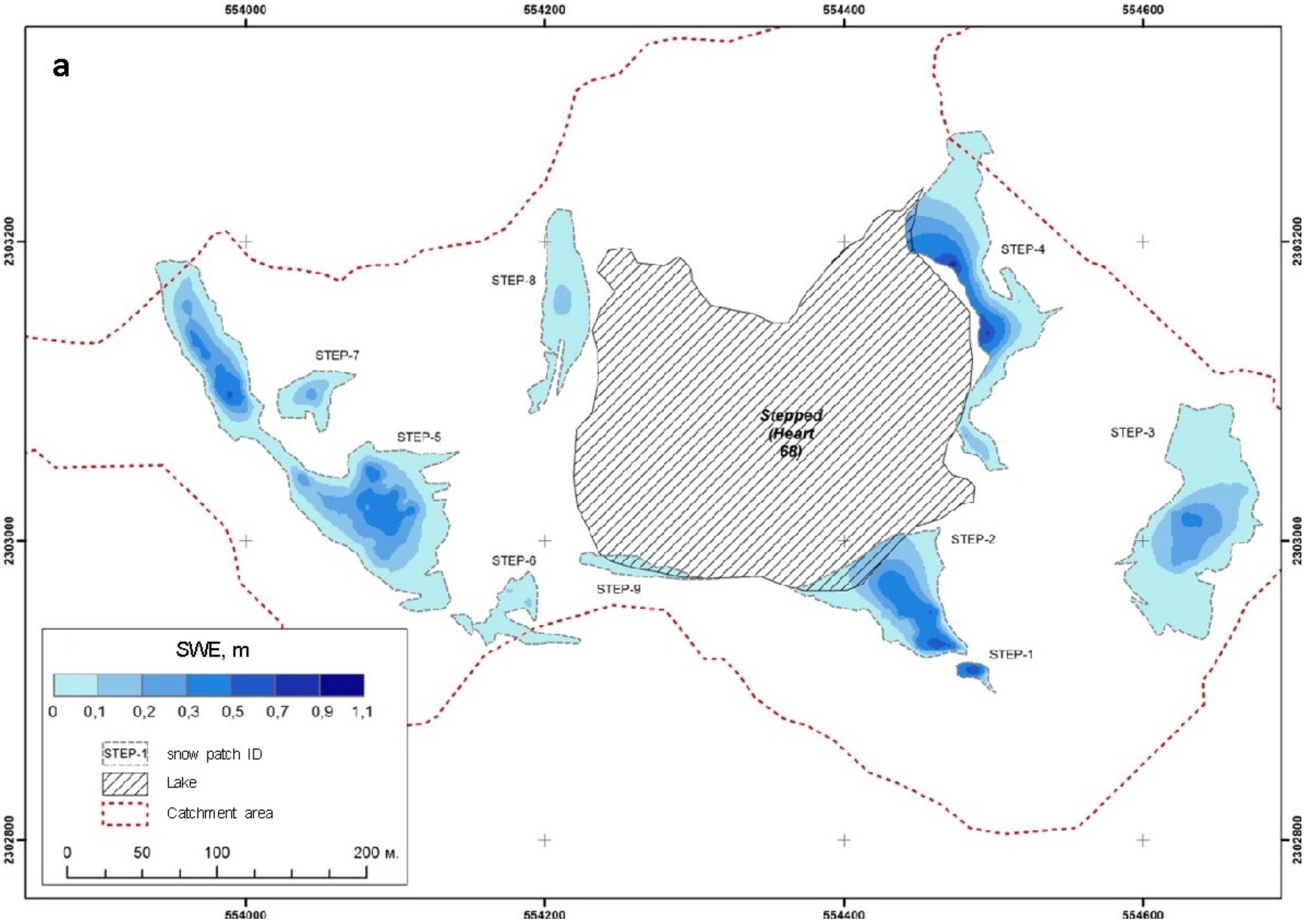
(Fedorova et al., 2012; Dvornikov and Evdokimov, 2017).

Data:

- the snow surveys during seasons 2011–2012 and 2016–2017.

Measured:
Snow depth;
Snow density;
Snow extent

Calculated:
Snow Water Equivalent (SWE) and volume of melted water



The map of SWE calculated from the snow surveys of 08–10.01.2017 over 9 stand-alone snow packs on the watershed of Lake Stepped (Dvornikov and Evdokimov, 2017).

Results: the epiglacial lakes.

Table 2. The LRT^{o} (years) of two epiglacial lakes, calculated from the measurement campaign data of years 2012–2013 and 2013–2014, the measured outcome surface runoff $Q_{out}+Q_{abr}$ (x10^3 m^3 per season) and evaporation from the lake surface $E \cdot A$ in the volumetric rate (x10^3 m^3 per season) calculated after (Odrova, 1978) / (Mironov et al., 2005). No observations are indicated by "–".

Lake	Year of campaign	$Q_{out}+Q_{abr}$	$E \cdot A$	$Q_{out}+Q_{abr}+E \cdot A$	LRT^{o}
Nella/Scandrett/LH72	2012–2013	246	–	~246	4
	2013–2014	190	7.6 / 18.3	198 / 209	5 / 5
Progress/LH57	2012–2013	150	–	~150	12
	2013–2014	128	7.7 / 18.8	136 / 147	13 / 12

The values of LRT can be over-estimation due to the assumption on the negligible amount of sublimation during the frozen period, which can be a significant term of WB for the lakes located in the polar regions (Huang et al., 2019; Faucher et al., 2019)

Results: the land-locked lakes.

Table 3. The LRT^{o} (years) of three land locked lakes, calculated from the measurement campaign data of years 2012–2013 and 2014, the measured outcome surface runoff Q_{out} (x10^3 m^3 per season) and evaporation from the lake surface $E \cdot A$ in the volumetric rate (x10^3 m^3 per season) calculated after (Odrova, 1978) / (Mironov et al., 2005). No observations are indicated by "–".

Eq. (2.a)

Lake	Year of campaign	Q_{out}	$E \cdot A$	$Q_{out} + E \cdot A$	LRT^{o}
Stepped/LH68	2012–2013	26.6	–	26.6	1.5
	2013–2014	20.7	4.6 / 5.5	25.3 / 26.2	1.6 / 1.6
Reid/LH70	2013–2014	0	3.2 / 6.4	3.2 / 6.4	8 / 4
Sarah Tarn/LH71	2013–2014	0	0.5 / 0.7	0.5 / 0.7	21 / 15

Table 4. The LRT^{i} (years) of three land-locked lakes, calculated from the measurement campaign data of years 2011–2012 and 2016–2017, the income water due to melting of snow cover estimated from the snow surveys M (x10^3 m^3 per season) and annual precipitation over the lake surface $P \cdot A$ in the volumetric rate (x10^3 m^3 per season).

Lake	Year of campaign	M	$P \cdot A$	$M + P \cdot A$	LRT^{i}
Stepped/LH68	2011–2012	0.55	1.18	1.73	23
	2016–2017	2.56	1.32	3.88	10
Reid/LH70	2016–2017	1.02	0.92	1.95	13
Sarah Tarn/LH71	2016–2017	0.14	0.17	0.31	34

Eq. (2.b)

Conclusions:

This study suggests the first estimations for water transport scale characteristic, namely the lake retention time (LRT) for five lakes located in the Larsemann oasis, East Antarctica. The LRT was evaluated depending on the lake type: separately for epiglacial and land-locked lakes.

The estimated LRT of two epiglacial lakes Progress/LH57 and Nella/Scandrett/LH72 is 12–13 and 4–5 years, respectively. Different methods applied to calculate the evaporation do not affect the estimates of the LRT for the epiglacial lakes, since the surface outflow runoff for these lakes is much larger than the evaporation. Some under-estimation may be expected due to lack of data in the begging and end of the warm season.

For the land-locked lakes Stepped/LH68, Sarah Tarn/LH71 and Reid/LH70, our results show a big difference in the LRT calculated from the outflow and inflow terms of the water balance equation, depending on the methods and errors inherent to them. On our opinion, such difference is caused by the quality of the hydrological observations available to the analysis. We suggested to rely on the estimations from the outflow surface runoff since they are based on the hydrological measurements collected during longer periods (60–66 days).

To improve these estimates, the hydrological observations are needed to monitor the lakes and streams during the warm season with an uniform observational program.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