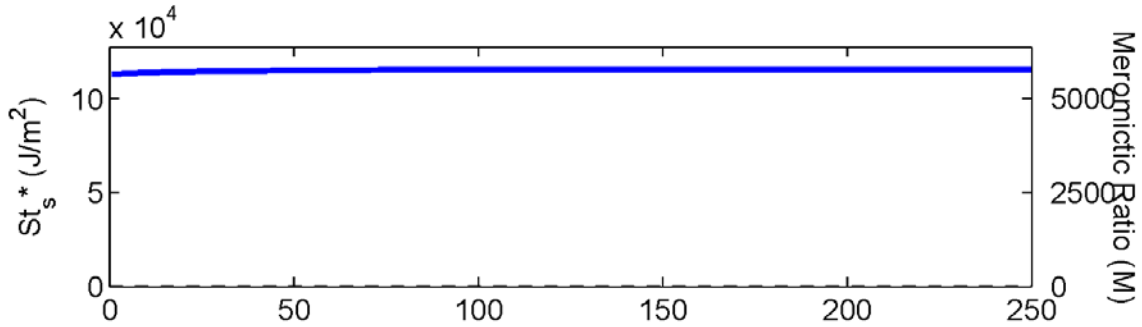
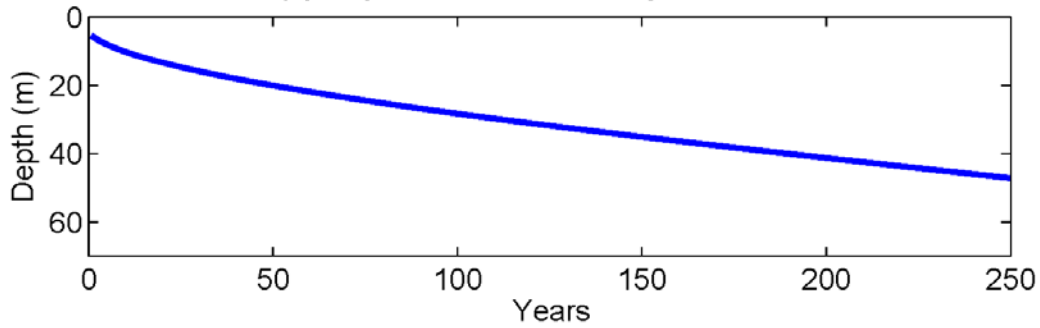


Figure 5 Scenario 2A, Llama pit lake
(a) Salinity stability (St_s^*) and Meromictic ratio (M) at August 31



(b) Depth of the surface layer at ice on



(c) Salinity of surface layer at ice on (RED)

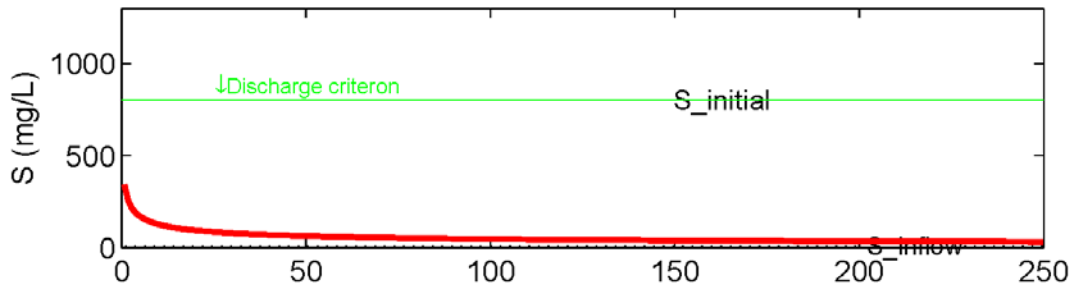


Figure 5 Scenario 2A Two layer stratification with surface layer at the discharge criterion and $\Delta St_s = 20 \text{ J/m}^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

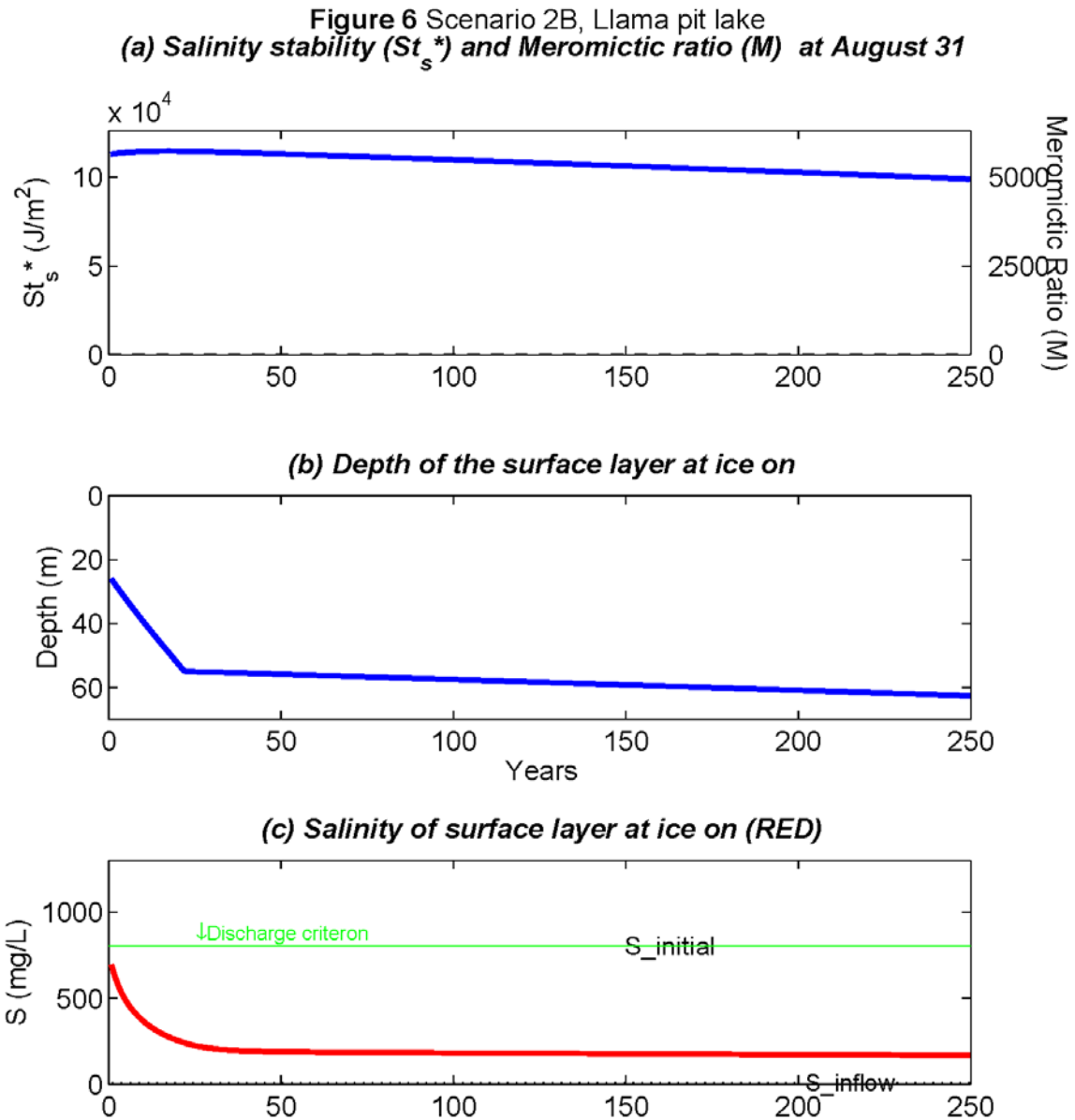


Figure 6 Scenario 2B Two layer stratification with surface layer at the discharge criterion and $\Delta St_s = 200 J/m^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

Figure 7 Scenario 3A, Llama pit lake
(a) Salinity stability (St_s^*) and Meromictic ratio (M) at August 31

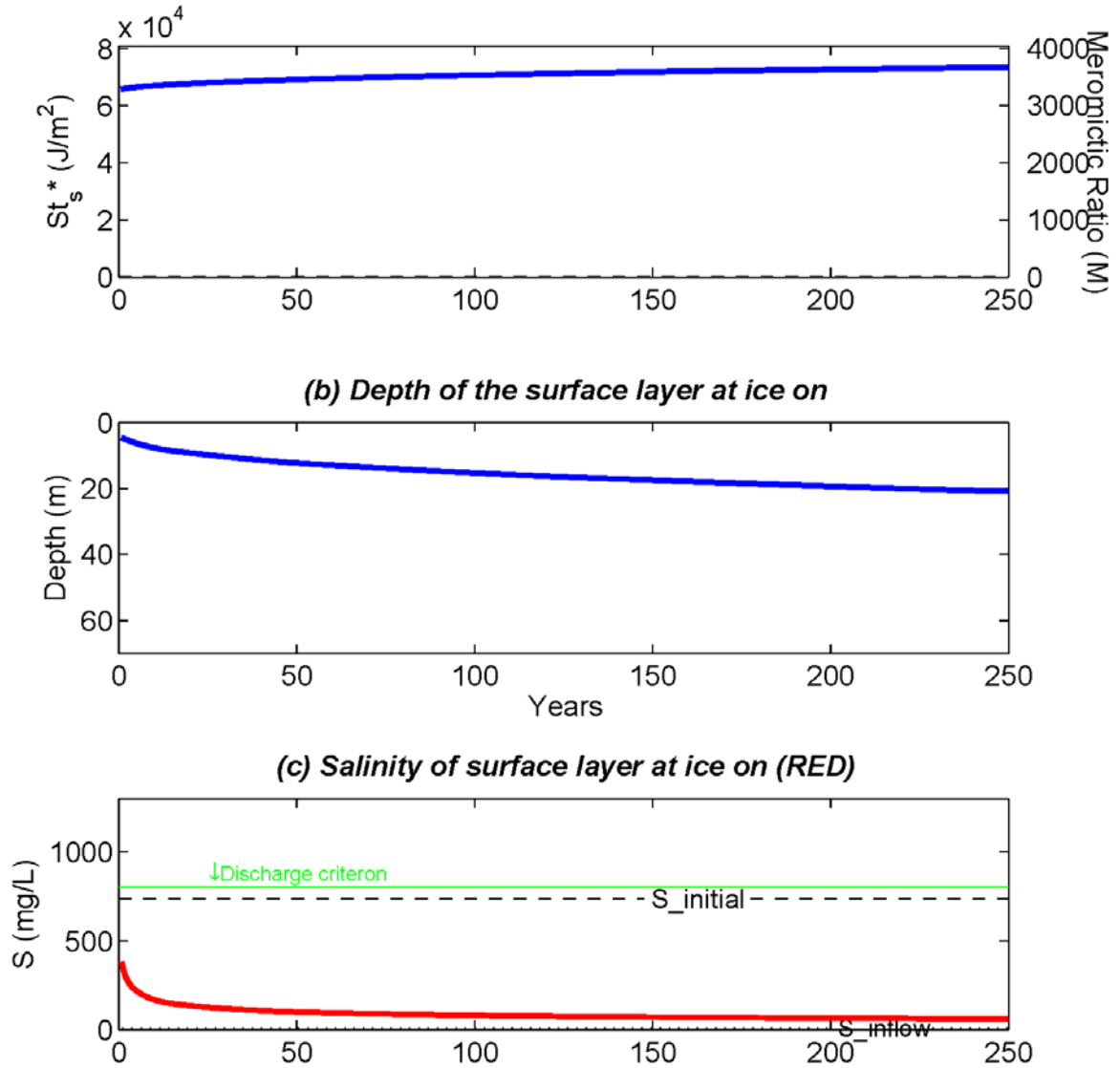


Figure 7 Scenario 3A Linear stratification with $\Delta St_s = 20 J/m^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

Figure 8 Scenario 3B, Llama pit lake
(a) Salinity stability (St_s^*) and Meromictic ratio (M) at August 31

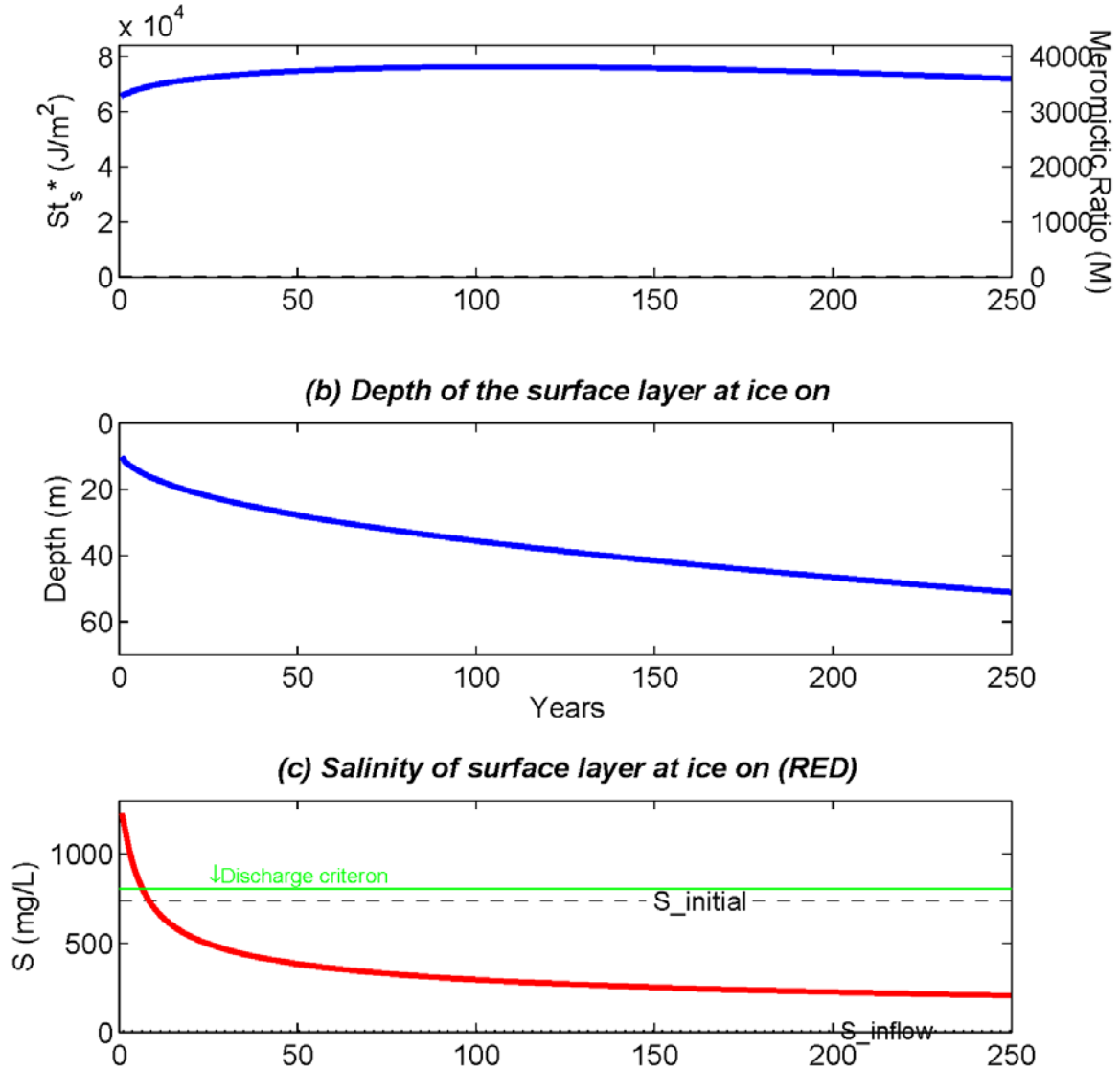


Figure 8 Scenario 3B Linear stratification with $\Delta St_s = 200 \text{ J/m}^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

Figure 9 Scenario 4A, Llama pit lake
(a) Salinity stability (St_s^*) and Meromictic ratio (M) at August 31

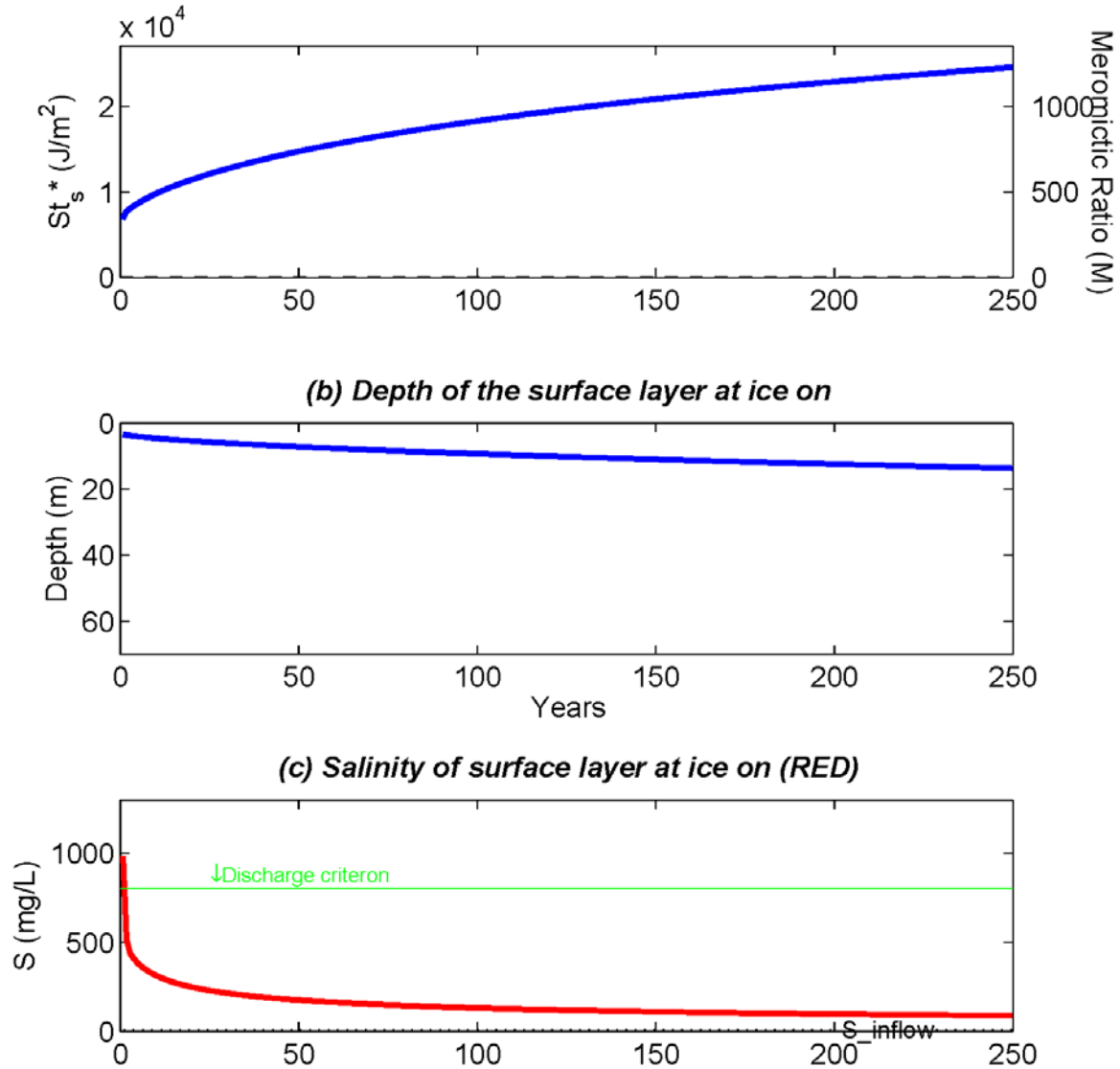


Figure 9 Scenario 4A Fully mixed with $\Delta St_s = 20 J/m^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

Figure 10 Scenario 4B, Llama pit lake
(a) Salinity stability (St_s^*) and Meromictic ratio (M) at August 31

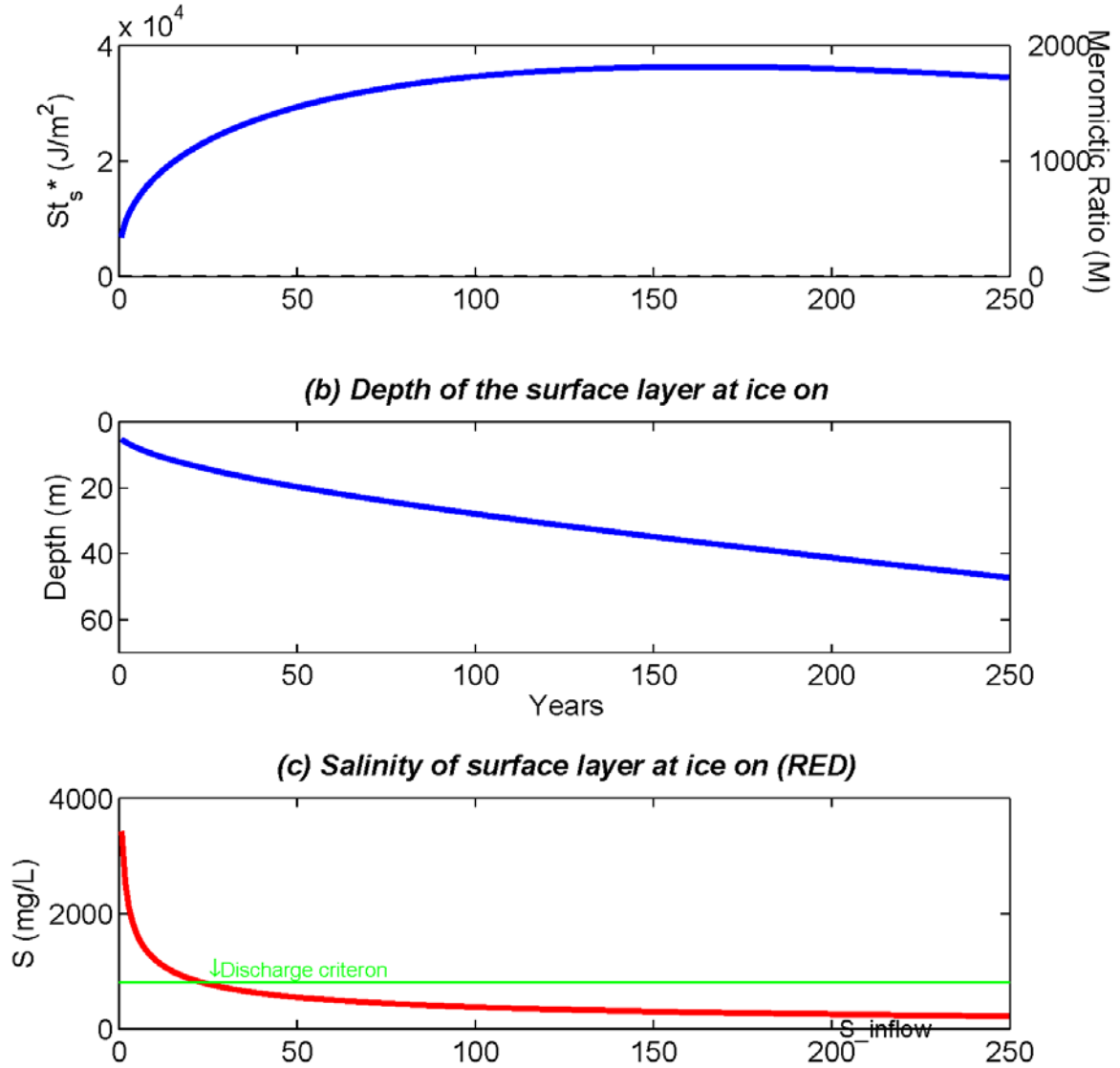


Figure 10 Scenario 4B Fully mixed with $\Delta St_s = 200 \text{ J/m}^2$. **(a)** Salinity stability shown on two different scales: the salinity stability at the end of August (St_s^*), and the meromictic ratio (M). **(b)** Depth of the surface layer at the time of ice-on. **(c)** Salinity of the surface layer at ice-on (red), the initial salinity of the surface layer (dash line), the mean salinity of all inflow (dotted line), and the discharge criterion (green).

APPENDIX 1

SCOPE OF WORK

Study Objective: Assessment of the stratification in the proposed Llama pit lake, Back River Project

The goal is to examine the stratification in the proposed Llama pit lake after it has been filled with both intercepted underground water and a fresh water cap to create two-layer stratification. There are two parts to the project:

1. Assess the likelihood of meromixis in Llama pit.
2. Assess the range of likely surface layer chloride concentrations given the initial two layer stratification.

To assess the likelihood of meromixis we will:

- briefly review key factors contributing to and working against meromixis,
- compare characteristics of the proposed Llama pit lake to a variety of existing pit lakes including existing pit lakes in the Canadian North,
- compute the stability of the proposed Llama pit lake, and
- determine whether or not the stability predicted for Llama lake in mid-summer is significantly greater than the anticipated change in stability due to wind and penetrative convection during the fall.

The chloride concentration in the outflow will be a balance of several processes, such as the upward flux of chloride from the erosion of the chemocline, the exclusion of chloride from the ice, and the flushing of chloride from the surface layer by inflow. To assess the range of likely surface layer chloride concentrations we propose using a simple compartment model. We anticipate that a key process will be erosion of chloride from below. We will estimate this flux in two ways. First, we will use changes in stability observed in other pit lakes to estimate the potential flux. Second, we will examine the upward flux based on diffusion, comparing to some observations in saline lakes – e.g. Powell Lake.

Future work:

If the surface layer chloride concentration estimated by this assessment is not within the targeted outflow concentration, then further work may be warranted to address the assumptions made. To reduce the scope of the analysis, the feasibility of establishing a two layer system will not be evaluated.

Appendix 2 Hydrograph of inflow to the pit lake

Month	Upstream Runoff (m3/month)
January	-
February	-
March	-
April	-
May*	25,976
June	427,355
July	155,858
August	77,927
September	100,554
October	51,951
November	-
December	-

* In the compartment model May inflow was included with June.

APPENDIX 3 SALINITY

1. Salinity of the lower layer

	meq/L	valence	mmol/L	g/mol	mg/L
Cl ⁻	1	1	1	35.5	35.50
Ca ²⁺	0.67	2	0.335	40.1	13.43
Na ¹⁺	0.26	1	0.26	23.0	5.98
Mg ²⁺	0.07	2	0.035	24.3	0.85
TOTAL					55.76

To convert chloride concentration [Cl] of the lower layer to salinity multiply by $55.76/35.50 = 1.57$.

2. Conversion between chloride concentration and salinity

Consider water with a chloride concentration, [Cl] (mg/L), composed of a fraction X of lower layer water and a fraction (1-X) of natural water (Table 2),

$$[\text{Cl}] = X \cdot (20,000 \text{ mg/L}) + (1-X) \cdot (1 \text{ mg/L})$$

Solving for X gives,

$$X = ([\text{Cl}] - 1) / (20,000 - 1)$$

The salinity is,

$$S = X \cdot (20,000 \cdot 1.57 \text{ mg/L}) + (1-X) \cdot (23 \text{ mg/L})$$

Substitution of X, and assuming $1 \text{ mg/L} \ll [\text{Cl}] \ll 20,000 \text{ mg/L}$ gives,

$$S \approx [\text{Cl}] \cdot 1.57 + 23$$

APPENDIX 4

ICE COVER

Ice melt can create a freshwater cap sufficient to prevent turnover (e.g. Pieters and Lawrence 2009a). Here we briefly describe the characteristics of ice important to this process and examine available data.

Black (or transparent) ice grows at the bottom of the ice sheet. Dissolved salts are excluded from black ice as it forms and black ice creates a fresh water cap at ice-off. White (or opaque) ice forms at the top of the ice sheet when snow overcomes the buoyancy of the ice and water floods the ice surface. In the formation of white ice, the salt of the lake water is generally incorporated into the ice or in the slush above the ice. The fresh water in the snow is included in the net precipitation.

Available ice data is given in Table A4-1. Ice thickness measured on Goose Lake at the Back River site was 2 m. The next closest site was Contwoyto Lake, 200 km east of the Back River site where a long record of ice thickness data averages 1.7 m. A total ice thickness of $h_i = 1.7$ m was used in the compartment model.

The proportion of black ice, p_b , ranges from 0.5 to 1.0, and the average of $p_b = 0.8$ was used in the compartment model.

Exclusion of salt from black ice is not perfect (e.g. due to brine pockets) and the fraction of excluded salt ranges from $f_b = 0.5$ to 0.99. Belzile et al. (2002) reported salt exclusion from 6 Canadian Lake which ranged from $f_b = 0.78$ to 0.99, similar to that reported here. A value of $f_b = 0.8$ was used.

The effective ice thickness, which gives the equivalent thickness of pure ice is $h_i^{eff} = p_b f_b h_i$. The effective ice thickness used in the compartment model of Llama pit lake was $h_i^{eff} = p_b f_b h_i = 0.8 * 0.8 * 1.7 = 1.1$ m.

Table A4 Ice characteristics

Location/Stn	Ref	Date	Water C25 ($\mu\text{S/cm}$)	Total Ice Thickness (cm)	Black Ice Thickness (cm)	Fraction Black Ice, p_b (-)	Salt exclusion factor, f_b (-)	Effective Ice Thickness (cm)
Goose Lake	1	na	na	200	na	na	na	na
Waterline	2	Mar-03	1140	~70	na	na	0.68	38*
Faro	3	Jan 06	1200	55	44	0.80	0.93	41
Grum	3	Jan 06	1000	52	40	0.77	0.97	39
Vangorda	3	Jan 06	1600	45	39	0.87	0.98	38
Average				51	41	0.81	0.96	39
Zone 2 Pit	4	Mar-05	1155	85	75	0.88	0.99	74
Zone 2 Pit	4	Apr-06	1110	75	59	0.79	0.87	51
Tailing Lake	4	Mar-05	1530	90	80	0.89	0.99	79
Spot Lake	4	Mar-05	205	95	63	0.66	0.97	61
Paddle Lake	4	Mar-05	165	75	56	0.75	0.97	54
Average				84	67	0.79	0.96	64
Contwoyto Lake	5	68-81	na	1.2 -1.95	na	na	na	na

¹ SRK (2015), elevation ~295 m ASL.

² Equity Silver mine site, 30 km southeast of Houston B.C. (54.189 N, 126.263 W), elevation 1265 m ASL.

³ Colomac Zone 2 Pit, 250 km north of Yellowknife, NWT (64.397 N, 115.089 W), elevation 340 m ASL (Pieters and Lawrence, 2009a).

⁴ Faro mine site, 200 km north of Whitehorse, Yukon (62.353 N, 133.364 W), elevation 1120-1230 m ASL.

⁵ Contwoyto Lake, Nunavut (65.48 N, 110.37 W), elevation 564 m ASL, average 1.7 m ice (Leonormand 2002).

* Assuming fraction of black ice, $p_b=0.8$.

APPENDIX 5 EARTHQUAKE INDUCED MIXING

We briefly assess the potential effect of earthquakes on the stratification of the proposed pit lake by examining two cases of earthquake induced mixing, Table A5. In the first case, the Denali, Alaska earthquake was the largest in the interior of the US in 150 years. While this earthquake was far from Waterline pit lake in central British Columbia, it nevertheless broke the ice on the pit lake surface (Pieters and Lawrence 2014). However, the total mixing done by the earthquake was small: from the change in the moored temperature data we estimate that the change in the salinity stratification was approximately 3 J/m^2 . This change is much smaller than the stability of the proposed pit lake ($120,000 \text{ J/m}^2$).

In the second case, the earthquake was almost two orders of magnitude larger and the water body, Rapel Reservoir, Chile was much closer to the epicenter of the quake, Table A5. In this case, the intense motion of the ground caused a greater degree of mixing, 800 J/m^2 . Nevertheless, this was also far less than the stability of the proposed pit lake.

Based on the above examples, we conclude that it is unlikely that mixing due to a large earthquake would have a significant impact on the salinity stratification. Note that the proposed pit lake is situated in a region of low seismic risk (NRC 2010).

Table A5 Mixing induced by earthquakes

Earthquake	Date	Mag	Waterbody	Distance from epicenter	Estimated mixing
Denali, Alaska	Nov 4, 2002	6.9	Waterline pit lake	1600 km	3 J/m^2
Maule, Chile	Feb 27, 2010	8.8	Rapel Reservoir*	300 km	800 J/m^2

* de la Fuente et al. (2010)