1 Supplementary information “Water balance and its intra-annual variability in a permafrost catchment: hydrological interactions between catchment, lake and talik”

1.1 Meteorological data

Results from the local Automatic Weather Station (AWS) at TBL show that almost 60% of the 2012 annual P was recorded during the active period (May to September) with maximum monthly P in September, 84 mm. This is more than three times the recorded P for the active period in 2011. The corrected annual P 2012 in Kangerlussuaq was 346 mm, which is significantly higher than the long term mean of 173 mm. On annual basis, the P is slightly higher at TBL compared to Kangerlussuaq and the short time series from the TBL catchment is considered to be comparable with the long term mean values from Kangerlussuaq.

Based on the 36 y time series from the DMI station in Kangerlussuaq a rain of 24 h duration with a return period of one year was defined to be approximately 13 mm/day. The largest 24-hour rain for the 36-year period was 30 mm /day. In the TBL catchment, two rain events with a rain intensity higher than 13 mm/day were recorded during the studied hydrological year, indicating that rain events with high intensity at TBL are in the same order of magnitude as high intensity rains in Kangerlussuaq. The rain events at the TBL catchment are characterized by relative long duration and low intensity.

Data from the AWS on shortwave in- and out- going radiation, long wave in- and outgoing radiation, albedo, air temperature, relative humidity and wind speed was used to calculate the potential evapotranspiration (PET) of the site, using the Penman-Montieth equation (Penman 1947). The total calculated PET for the hydrological year is 413 mm and the mean daily PET during the active period is 2.5 mm/day in 2011 and 2.4 mm/day in 2012.

The mean hourly wind speed was 2.1 m/s with a maximum mean hourly wind speed of 18.6 m/s. During winter, the threshold wind speed for snow drift is exceeded 106 times, indicating snow drift might be an important process and component of the water balance of the catchment area. Snow accumulation and snow melt was calculated with a degree day method using air temperature and precipitation data from the AWS. The snow model was verified with photos from the time lapse camera. The threshold temperature for snow melt/accumulation was set to 0°C and the degree day coefficient was set to 2 mm/day/°C. Snow depth measurements in three transects, one in a valley along the lake, one on the lake ice and one on a hillside, were performed in April 2011. The mean snow depth in the three transects ranged from 11 cm on the hillside to 24 cm in the valley. The mean snow depth on the lake was 17 cm.

In April 2013, sublimation was measured at three sites in the TBL catchment during a period with temperatures between -14 to -2 °C, moderate winds in the range from 2-5 m/s and clear sky. At each site, 5 boxes were filled with snow, weighted and left out for three consecutive days. The weight loss in each box was observed every 24 h. The measurements stopped after three days due to snow fall. The measured sublimation averaged to 2.75 mm/day ranging from 1.8 to 4.2 mm/day depending on the location of the measurements.

1.2 Active layer and lake ice

The thickness of the active layer was measured with a soil probe at a number of locations in 2008, 2010 and 2011 (Clarhäll 2011). The survey resulted in a mean active layer thickness of 0.69 m. The maximum and minimum depths were found to be 0.94 m and 0.55 m respectively. In the stream depression at the lake outlet the active layer was measured to 0.90 m. Soil temperature is monitored every 0.25 m down to 2 m depth at one location in the catchment. During both monitored seasons, 2010 and 2011, the uppermost sensor at 0.25 m depth has been freezing in October and no positive temperatures have been recorded between November first and mid-May, Figure 3 (lower left). The uppermost TDR sensors, placed at 5 cm and 10 cm depth, indicate that the uppermost 5-10 cm of soil freezes in early October and thaws in the first half of May.

1.3 Lake level measurements

Data from the pressure transducers (Level TROLL 700) was corrected for barometric effects using air pressure data from the AWS. The total amplitude of lake pressure for the observed period is approximately 440 mm with lowest values during the summer of 2011. In 2010 the lake level was measured to be 180 mm below the lake threshold for surface water runoff. Measurements were performed with a leveling instrument. The threshold for groundwater outflow in the active layer, i.e. the depth of the active layer in the lake outlet, was in the summer of 2010 situated 90 cm below ground surface. During the studied hydrological year the net change in lake water pressure was an increase with 73 mm. In general, the amplitude of pressure changes are 30 mm during the frozen period when ice and snow covers the lake and approximately one order of magnitudes higher in the active period. For both seasons 2011 and 2012 a pressure increase was observed as response to snow melt with larger increase in 2012.

1.4 Soil moisture data and porosity

In total 44 TDR sensors (Campbell CS616) measuring soil moisture content were installed in three clusters. Two clusters containing 4*4 vertical profiles with TDR sensors equally distributed from the ground surface down to the bottom of the active layer. Additionally TDR sensors were placed in a transect at three sites, each site containing a vertical profile of 4 sensors evenly distributed from ground surface to the bottom of the active layer. TDR data were evaluated in order to determine the change in total water content in the active layer over the hydrological year, Table S1. For each cluster of sensors 1-3 (Figure 1) the mean value of the soil moisture content at each individual depth was calculated for the start and end of the hydrological year and the annual difference in water content for each depth was determined and expressed in mm of water, Table S1. All individual values were summed in order to determine the total change in water storage for each profile. TDR cluster number 2 and 3 are installed in the regolith type “peaty silt” and cluster number 3 is placed in the regolith type “Eolian silt-fine sand” (Figure 1). The TDR sensors are installed in relatively wet areas within the catchment. The regolith type “peaty silt”, covering 2% of the total catchment area, is only present in small areas close to the lake, i.e. in topographically low areas within the catchment where water is accumulating and the soil moisture is assumed as higher than the mean soil moisture content in the catchment area. “Eolian silt-fine sand” is the dominating type of regolith in the area covering 51% of the catchment land area and is present in areas ranging from the catchment boundary to the lake, but still in relatively low lying areas. It is assumed to represent the mean soil moisture of the catchment area. The high altitude areas of the catchment are covered by till or bedrock outcrops (Figure 1). The water content in these areas is very low and an eventual difference of soil water content over the year can be neglected.

A mean value of the change in soil water content was calculated for TDR 2 and 3, both representing the QD-class “Peaty silt” and the total storage change over the hydrological year in this QD-class was calculated by multiplying the storage change with the area of the QD-class resulting in a total storage change over the hydrological year of 2196 m^3. The change in water content determined from TDR number 1 representing QD-class “Eolian silt-fine sand”, 15358 m^3, was calculated in the same way. The total storage change over the hydrological year is 17555 m^3.

1.5 Borehole data

The DH-GAP01 borehole is packed off and instrumented with a U-tube multi-sensor system (Freifeld 2009) located at a vertical depth interval corresponding to 130-140 m. This system allows for water sampling and monitoring of in situ pressure (M), temperature (T) and electrical conductivity (EC). The M/T/EC sensors (AquaTROLL 200) are located below the inflatable packer at vertical depth of 138.57 m (relative to the top of casing), and are connected to the surface via a non-vented cable. The amplitude of the measured head during the observed period is 1.4 m. A detailed description of the drilling and installation of the U-tube multi-sensor system is described in SKB (2010).

The hydraulic gradient between the lake and the bedrock was calculated using pressure data from the DH-GAP01 borehole and the pressure transducer on the lake bottom. The height difference, dz, between the pressure transducer in the lake and the sensors in the bore hole is 128.1 m. The mean difference in hydraulic head over the year is 1.85 m, ranging from 1.21 m to 2.47 m. The mean hydraulic gradient was calculated to 0.014 ranging from 0.019 to 0.009. However, the gradient is continuously directed downwards. The hydraulic gradient between the lake and the borehole is increasing over the studied hydrological year, i.e. the net increase in lake pressure is reflected as an increased hydraulic gradient between the two domains.

2 References supplementary material

Clarhäll A (editor). 2011. SKB studies of the periglacial environment – report from field studies in Kangerlussuaq, Greenland 2008 and 2010. P-11-05. Svensk Kärnbränslehantering AB.

Penman, H.L., 1948. Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London 193, 120–145.

SKB, 2010. The Greenland Analogue Project, Yearly Report 2009. SKB R-10-59, Svensk Kärnbränslehantering AB.

3 Tables Supplementary Material

Table S1. Soil moisture data at start and end of the hydrological year, table 4A. Total change in water content in the catchment is presented in table 4B.

A

TDR1 (Postglacial silt-fine sand)	Water content, % 2011	Water content, % 2012	Difference, %	Difference, mm water*
0-10 cm	0.42	0.42	0.00	0.00
10-20 cm	0.37	0.38	0.01	0.01
20-30 cm	0.38	0.41	0.04	0.04
30-70 cm	0.36	0.41	0.05	0.14
			SUM:	0.19
TDR2 (Peaty silt)				
0-5 cm	0.33	0.81	0.48	0.24
5-15 cm	0.45	0.68	0.23	0.23
15-20cm	0.52	0.66	0.14	0.07
20-25 cm	0.47	0.53	0.06	0.03
25-30cm	0.48	0.56	0.08	0.04
30-70 cm	0.50	0.57	0.06	0.22
			SUM:	0.82
TDR3 (Peaty silt)				
0-10 cm	0.47	0.61	0.14	0.14
10-20cm	0.46	0.53	0.07	0.07
20-30cm	0.47	0.53	0.05	0.05
30-35cm	0.50	0.54	0.04	0.02
35-45cm	0.47	0.53	0.07	0.07
45-55cm	0.34	0.45	0.12	0.17
			SUM:	0.52

*mm water calculated as water content in %= mm of water in 10 cm of soil

B

	Mean difference of water, mm	Area, m^2	Mean difference of water, m^3
Postglacial silt-fine sand	19.00	808328	15358
Peaty silt	67.00	32781	2196
		SUM:	17555