NAALAKKERSUISUT

GOVERNMENT OF GREENLAND

GREENLANDIC ICE CAP WATER

– hydrological studies and data collection

Greenlandic Ice Cap Water

Drinking water of high quality is becoming a scarce resource worldwide. As the world population grows, demand is rising while the supply is under pressure from the impact of climate change.

In Greenland, pure meltwater running off the Greenlandic Ice Sheet provides the solution. As the annual hydrological cycle intensifies with rising temperatures in the Arctic, the available water resource only increases. Unlike mountain glaciers which are vanishing globally, the Greenlandic Ice Sheet is vast, containing 2.85 million cubic kilometres of pure glacier ice providing a freshwater reservoir without equal in the northern hemisphere.

The Greenlandic Ice Sheet covers most of the land in Greenland with rivers transporting the meltwater through the mountains to the fjords through the largely uninhabited country. In southwestern Greenland, the fjords provide access to the mouths of the meltwater rivers with opportunities for direct access by ship.

The Government of Greenland actively supports the prospect of drinking water export from this immense resource. To attract investments from the industry, an extensive effort has been launched to map possible extraction locations, assess the quality of the meltwater and review the existing ice and water export legislation.

Mapping and water quality assessments are undertaken by the Geological Survey of Denmark and Greenland (GEUS) adhering to the highest international standards. GEUS has been charged by the Government of Greenland to identify suitable locations for extraction of drinking water from meltwater rivers, conduct field investigations and water sampling, and subsequently carry out water quality assessments in certified laboratories. GEUS is the National Data Centre for water quality information for all of Denmark's more than 280,000 drinking water wells and has carried out extensive geoscientific fieldwork in Greenland since 1946.

The largest and most pristine freshwater reservoir in the Northern Hemisphere

The Greenlandic Ice Sheet has covered Greenland for the last 2.5 million years, growing during the ice ages and shrinking in the warm periods like the present. Each year, fresh snow settles on the 1.7 million square kilometres of inland ice, eventually compacting under the weight of new layers of snow to become glacier ice. With enough weight on top, ice crystals deform, recrystallize and slide causing the glacier ice to move. Over millennia, the ancient snow is transported through the ice sheet from the great white plains of the interior to the ice margin. Here it breaks off as icebergs into the fjords or melts, causing new fresh layers of ice to resurface constantly. The age of the ice that melts spans the whole period of the human civilization and before.

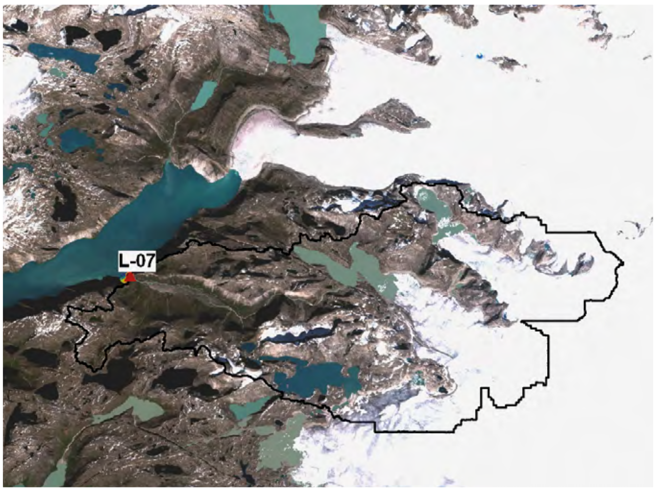
The Greenlandic Ice Sheet provides an abundant source of meltwater on a seasonal basis. Thus, an important

factor is the length of the melting season, which is most extensive in southwestern Greenland lasting from late May to mid-September. This part of Greenland is accessible by ship throughout the year with occasional icebergs dotting the horizon. A variety of fjord water depth measurements are available and the waters covered by regular nautical charts will expand significantly over the next few years under under contract with the Danish Government. Generally speaking, Greenland fjords are very deep, but the ice sheet is slowly eroding the underlying rock, producing sediment that when transported to the fjords, may cause shallower waters in some locations.

The meltwater and its sediment are transported to the ocean via rivers, but the majority of the rivers investigated here are intersected by one or more lakes on their way from the ice sheet margin to the ocean. This allows for a large fraction of the sediment to settle, reducing the filtering needs.

The ice sheet margin is retreating in many places, potentially creating a changing runoff pattern as the surface lowers. However, as the majority of the meltwater is produced close to the ice sheet margin, the discharge from the larger catchments under investigation is rather insensitive to ice elevation changes.

As Greenland is mostly uninhabited, river discharge is generally only known from hydrological models. Only a few catchments of interest for hydropower have been



Catchment delineation example for a location L-07 between Nuuk og Paamiut.

gauged, and these show a strong increase in the amount of meltwater of up to 80 % over the recent decade.

Locations of interest

The Government of Greenland has initiated a comprehensive mapping of prospective locations, effectuated by GEUS. The initial assessment of locations is based on a three-level approach: accessibility, abundance and water quality, where each level is dependent on the former.

At each level, a number of different criteria is identified and assigned a weight in the assessment with the goal to single out the most promising locations to visit in the field.

The accessibility criteria includes proximity to infrastructure, marine chart coverage, availability of bathymetry data, river slope, and abundance of sea ice and icebergs.

The abundance criteria relates to water discharge, length of the melt season, existence of proglacial lakes, risk of outburst floods, upstream catchment changes, total ice cover within the catchment, and ice cover relative to catchment size.

Finally the water quality criteria focuses on origin of the water, age of the source ice, expected sediment concentration in the meltwater, and other issues from contact with naturally occurring minerals.

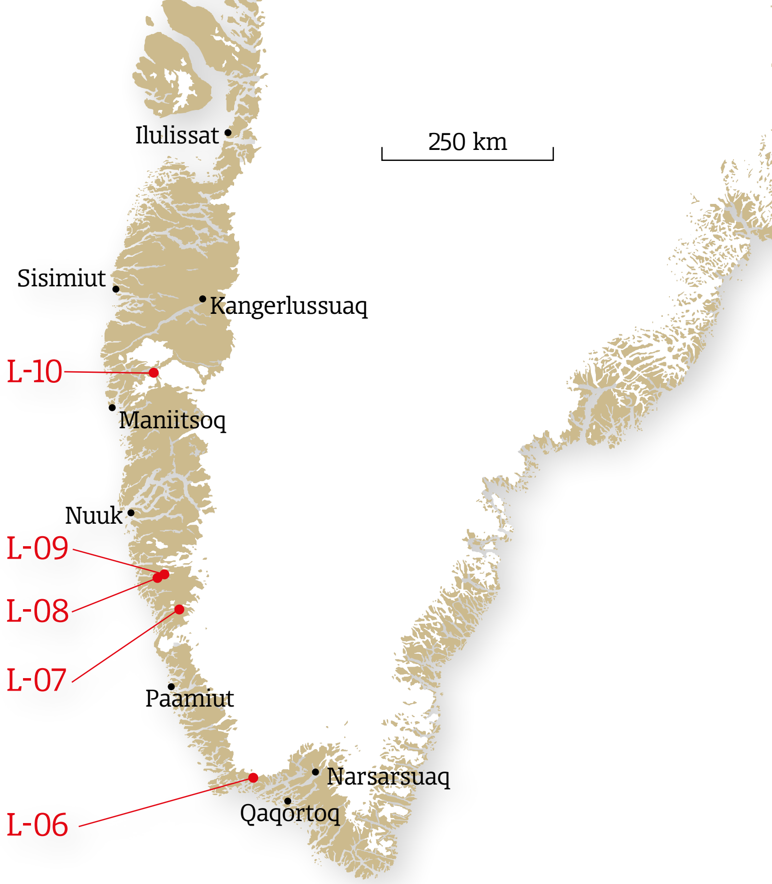
Each location is meticulously examined and rated with respect to the 18 criteria from the considerable geospatial, geological, and geochemical datasets available to the Government of Greenland and GEUS.

Locations are defined as outlets of a significant meltwater river to accessible fjords in the southwestern part of Greenland, to minimize potential sea ice and iceberg interference.

Catchments for each location or river outlet were derived employing advanced hydrological methods, using the most recent elevation models available.

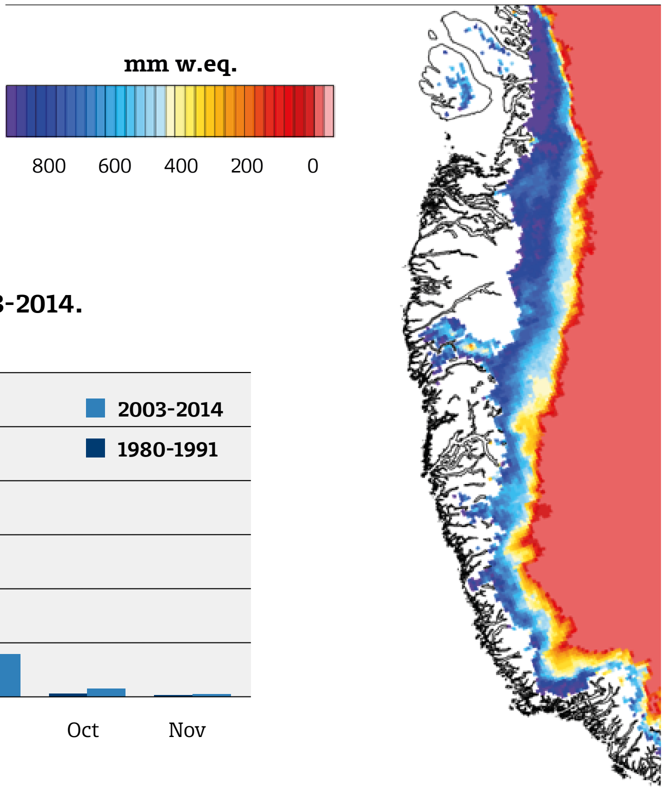
Subsequently, results from a regional climate model were used as input to a glacio-hydrological model to calculate the average monthly discharge expected at each location from precipitation and meltwater leaving the catchment. A similar method was also used to examine the change in discharge over the last few decades, showing an overall melt increase of more than 50 % for the region.

Five locations were visited by boat to sample the water and collect additional data. The visits were conducted in early summer and early fall, respectively, to capture the seasonal variability of the water quality. Two locations

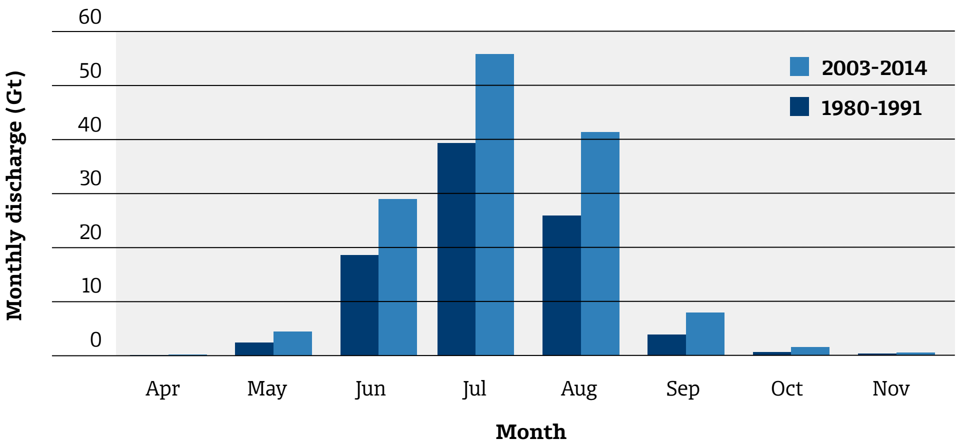


Overview of five locations identified as prospective sources of drinking water.

The increase in the ice sheet melt between 1980-91 and 2003-2014 given in mm water equivalent.



Monthly intensification of the ice sheet melt in Southwest Greenland between 1980-91 and 2003-2014.



drain ice sheet catchments and three locations drain catchments with local mountain glaciers. An extensive analysis of chemical, physical, and microbiological parameters was performed on the water samples. Some types of analyses had to be performed on-site, some were performed at GEUS laboratories and some at certified commercial laboratories.

The geology of Greenland is rich and diverse, adding to the unique nature of the meltwater from the ice sheet, but also requiring attention to the inorganic content such as metal ions and radioisotopes. The analysis thus included a screening for radioactivity and potentially toxic trace metals such as arsenic, cadmium and nickel, as well as fluoride, which serves as an indicator. The

Table 1. Analytical program for chemical, sediment and microbiological parameters.

Parameter	Type of analysis	Place of analysis	Container	Comment
pH	Electrode	On-site	n/a	
Conductivity	Electrode	On-site	n/a	
Anions[1] + cations[2]	Ion chromatograph	GEUS	20 mL plastic	Filtered, kept cold
Trace metals[3]	DS/EN ISO 17294m:2016 ICP-MS	Eurofins	30 mL plastic	Acid conservation, filtered and unfiltered
Radioactivity[4]	ISO 10704+13168:2015	Eurofins	250 mL plastic	Unfiltered
Microcystins[a)]	ISO 20179 mod. LC-MS/MS	Eurofins	100 mL plastic	Added thiosulfate, kept cold
Sediment[5]	Gravimetric + Malvern	GEUS	1 mL plastic	Four replicates
Total CFU	3M Petrifilm Aqua 5 × 1 mL	On-boat	22°C incubator 68h	Undiluted + 10-fold diluted
Thermotolerant CFU[b)]	3M Petrifilm Aqua 5 × 1 mL	On-boat	36°C incubator 44h	Undiluted
Coliform bacteria	3M Petrifilm Aqua 5 × 1 mL	On-boat	36°C incubator 21h	Undiluted
Enterobacteriaceae	3M Petrifilm Aqua 5 × 1 mL	On-boat	36°C incubator 21h	Undiluted

1 Fluoride, chloride, bromide, sulfate, nitrate, phosphate.
2 Sodium, potassium, calcium, magnesium.
3 Aluminum, Antimony, Arsenic, Barium, Lead, Boron, Cadmium, Chromium, Cobalt, Copper, Mercury, Nickel, Selenium, Zink.
4 Total indicative dosis, total alpha-activity, total beta-activity, tritium activity.
5 Concentration and grain size distribution.
a) Analyzed only in September 2018.
b) Method developed for total CFU but adapted to thermotolerant CFU.

results indicate mineral water of high quality in all five areas.

The meltwater runs off the glaciers, through vast glacial forelands and dramatic gorges, rich in wild Arctic flora and fauna. While this voyage shapes the distinctive character of the water at each location, it also implies that biology is a factor requiring consideration. The analysis thus included counts of enterobacteria and total heterotrophic bacteria. As expected for natural surface water, microbial counts suggest that gentle treatment with UV light is advisable.

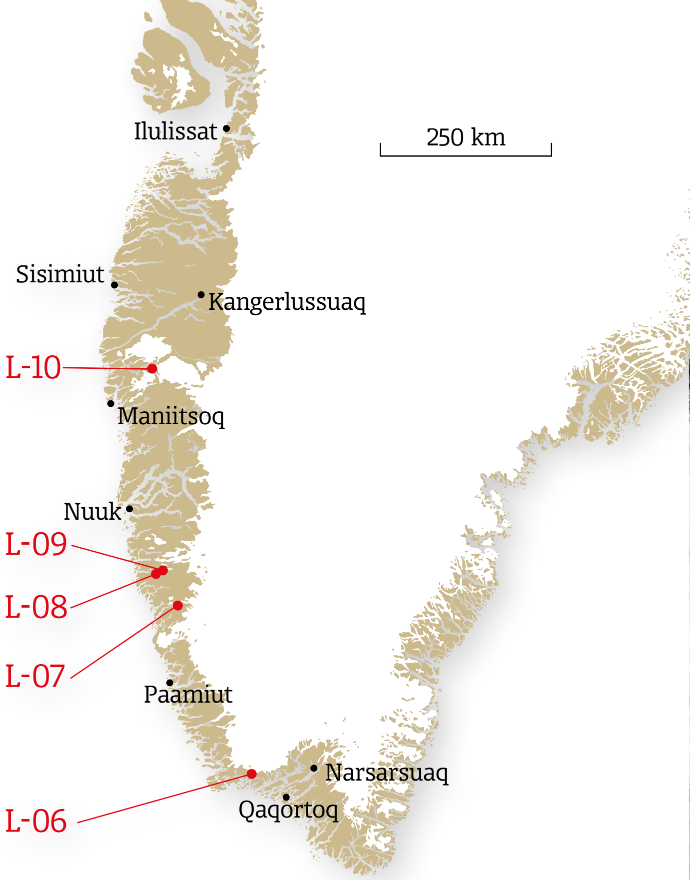
While the water quality can be expected to vary over the season, the results provide a strong indication of the potential for export of drinking water from meltwater rivers in Greenland.

A detailed technical report is available with a full description of the analysis design and sampling strategy, including a water quality evaluation of the results.*

Table 2. Content of inorganic ions and trace metals at the five locations visited. For trace metals the value is for filtered (0.45 µm) samples.

Parameter	Unit	L-06		L-07		L-08		L-09		L-10		Guideline limit
Date of sampling	Date	Jun. 2018	Sep. 2018	Jun. 2019	Sep. 2018	Jun. 2019	Sep. 2019	Jun. 2019	Sep. 2019	Jun. 2019	Sep. 2019	-
pH_{field}	-	7.04	6.78	6.9	6.81	6.26	6.56	6.6	6.58	6.95	7.34	6.5-8.0
$Conductivity_{field}$	mS/m	2.83	1.23	0.82	0.88	1.19	0.76	1	0.65	1.05	3.07	< 250
$Temp_{field}$	°C	5	6.3	5.7	4.3	6.7	7.4	5.2	6.8	5.6	1.6	-
$Alkalinity_{lab}$	meqv/L	0.1	0.08	0.07	0.07	0.039	0.04	0.035	0.03	0.067	0.22	-
F^-	mg/L	0.08	0.05	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	1.5
Cl^-	mg/L	3.6	0.64	0.18	0.15	1.47	0.48	1.41	0.46	0.23	0.27	250
NO_3^-	mg/L	0.09	< 0.05	0.07	0.06	< 0.05	< 0.05	0.079	< 0.05	< 0.05	0.08	44
PO_4^{3-}	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-
SO_4^{2-}	mg/L	1.62	0.67	0.41	0.43	1.08	0.78	1.08	0.78	0.76	3.88	250
Na^+	mg/L	1.87	0.57	0.25	0.23	0.91	0.49	0.75	0.35	0.25	0.06	175
K^+	mg/L	0.51	0.3	0.41	0.38	0.24	0.21	0.11	0.08	0.45	0.22	-
Ca^{2+}	mg/L	2.32	1.37	0.89	0.98	0.78	0.66	0.71	0.61	1.1	0.32	-
Mg^{2+}	mg/L	0.43	0.19	0.12	0.11	0.21	0.16	0.22	0.11	0.24	0.11	50
Aluminum (Al)	µg/L	15	17	3.4	5.1	4.3	8.8	3	3.8	2.8	4.9	200
Antimony (Sb)	µg/L	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	5
Arsenic (As)	µg/L	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.036	5
Barium (Ba)	µg/L	7.5	4.2	1.5	1.3	< 1	< 1	< 1	< 1	3.8	9.6	700
Lead (Pb)	µg/L	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	0.038	0.11	< 0.025	< 0.025	< 0.025	10
Boron (B)	µg/L	5.3	1.3	< 1	2.2	< 1	< 1	< 1	< 1	< 1	< 1	300
Cadmium (Cd)	µg/L	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	0.0035	< 0.003	< 0.003	< 0.003	< 0.003	3
Chromium (Cr)	µg/L	0.069	< 0.03	< 0.03	< 0.03	< 0.03	0.1	< 0.03	0.05	< 0.03	0.17	50
Cobalt (Co)	µg/L	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.1	< 0.04	< 0.04	< 0.04	5
Copper (Cu)	µg/L	0.37	0.26	< 0.03	0.13	< 0.03	0.62	< 0.03	0.24	< 0.03	0.19	1000
Nickel (Ni)	µg/L	0.049	0.066	< 0.03	< 0.03	0.067	0.24	0.062	0.15	0.1	0.47	20
Selenium (Se)	µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.061	< 0.05	< 0.05	< 0.05	0.071	10
Zink (Zn)	µg/L	0.4	< 0.3	4.2	< 0.3	0.55	1	23	< 0.3	6.7	0.4	100

*) Results of the analysis and all other information in relation thereto are provided "as is" and are only a general indication of the quality of the water at the place and time of the sampling of the water. The actual quality of the water may be different and may vary in different places and over time. The Government of Greenland and GEUS shall not have any obligation or liability for the analysis or their results or other information provided related to water, including among others the quality of the water and the estimated annual mean runoff. Companies applying for a licence to exploit water must therefore perform their own analysis of the water and matters in relation to the water. Companies granted an exploitation licence should therefore perform their own analysis of the water and matters in relation to the water before exploiting it.



Water quality sampling at the five locations visited.

The Self-Government of Greenland
Tel +299 34 50 00
www.businessingreenland.gl · www.naalakkersuisut.gl
P.O. Box 1601 · 3900 Nuuk · Greenland

Geological Survey of Denmark and Greenland
GEUS

Authors: Andreas P. Ahlstrøm
and Christian Albers, GEUS
Photographs: GEUS • January 2020