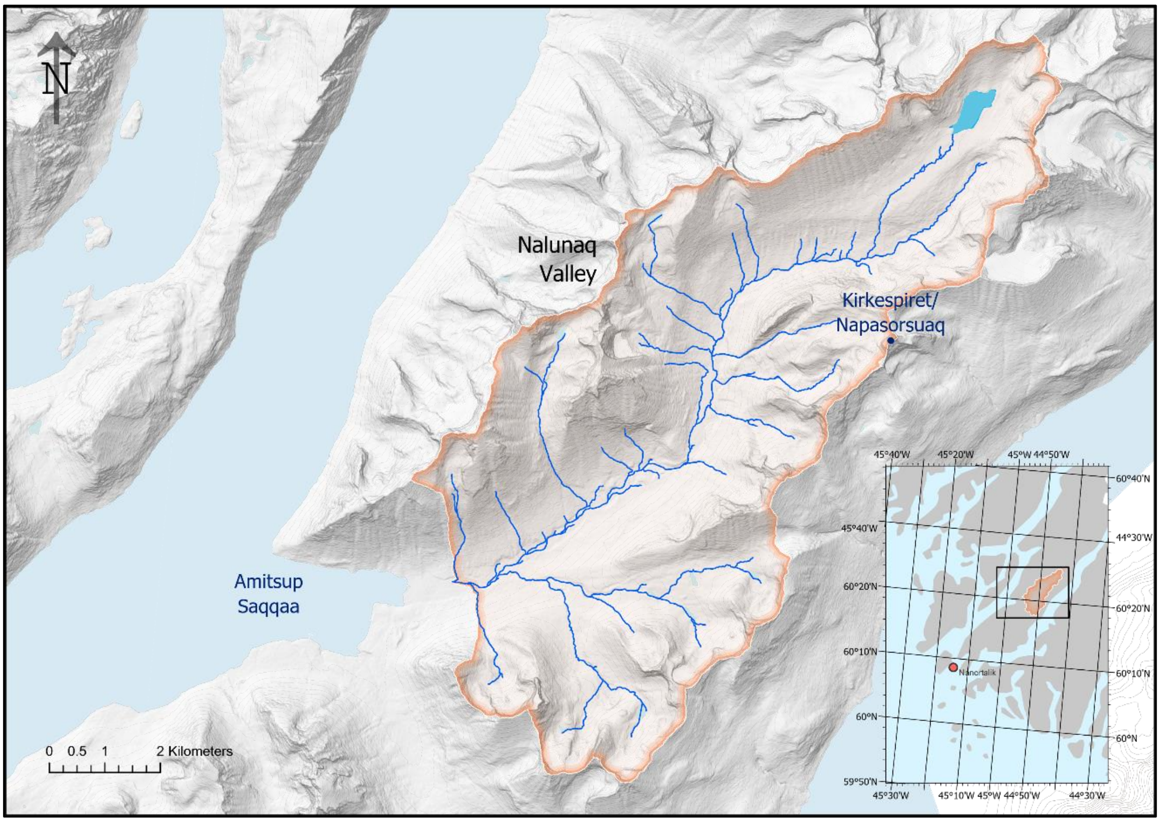
Water resource in Nalunaq Valley
Desktop study



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Introduction

Nalunaq A/S wish to quantify the water resource in Nalunaq Valley with a view to evaluating the feasibility to utilize the water for hydropower. Therefore, Nalunaq A/S has asked Asiaq – Greenland Survey to estimate the water resource based on existing data.

This version 2 of the report includes additional plots of monthly distribution of the water resource for four points along the main river in Nalunaq Valley.

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Content

Data files

File name	File type	Content
nalunaq_valley_arctic_dem_utm22n_geoid.tif	GeoTIFF	Digital elevation model used for the analysis
nalunaq_valley_river_network.shp	ArcGIS Shapefile	River network with attributes for water resource etc.
nalunaq_valley_watershed.shp	ArcGIS Shapefile	Watershed for the whole valley
nalunaq_valley_subcatchments.shp	ArcGIS Shapefile	Subcatchments for Nalunaq Valley

1 Nalunaq Valley

Nalunaq Valley is situated around 30 km Northeast of Nanortalik town in Southwest Greenland, Figure 1.1.

Nalunaq Valley consist of a main valley surrounded by steep mountains up to 1575 meter (Kirkespiret/Napasorsuaq). A river flows 14 km along the bottom of the main valley from its source at the main valley's only lake (0.3 km^2) found at 747 meter above sea level to its mouth at the sound Amitsup Saqqaa. Tributaries from a few smaller side valleys feed water to the main river along its course.

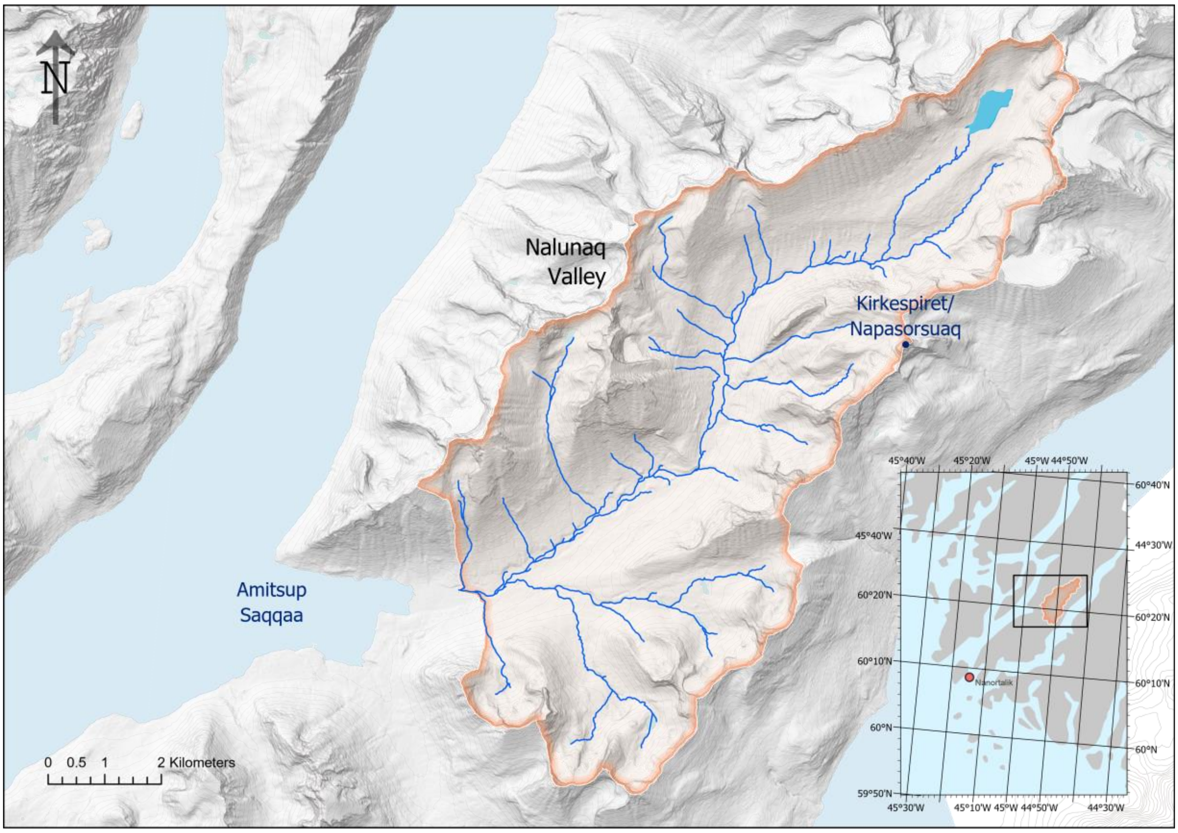

Figure 1.1 Nalunaq Valley Watershed. Catchment defined with orange border and stream network with blue lines.

2 Method

The water resource in Nalunaq Valley has not been measured directly. In order to estimate the water resource we therefore combine an estimate of the specific water resource (q_{mean} [mm/year]) with the catchment area (A [m^2]) for the valley. Due to the limited data from Nalunaq Valley we use one estimate of q_{mean} for the entire valley i.e. any variation in specific water resource within the catchment area is not estimated.

Furthermore, we will estimate the typical year-to-year variations and the typical monthly distribution of the annual water resource throughout the year. The latter will describe how many percent of the annual water resource is expected to be available in each month (assuming no reservoir for storing water).

2.1 Assessment of specific mean annual water resource

The assessment of the specific mean annual water resource will be based on a number of available secondary data sources.

Measured water resource data

The water resource at Hydropower potential 01.A (HP01.A) was monitored in the period 1980-1990. Some data gaps exist in the time series, which thus gives the basis for determining the annual water resource for eight full years.

With HP01.A situated around 15 km southwest of Nalunaq Valley (see Figure 2.1) the climatic-hydrological conditions are similar and a strong correlation can be expected between the water resource at the two sites. However, due to the region's mountainous terrain with Nalunaq Valley situated further inland, Nalunaq Valley is expected to experience less precipitation and thus have a smaller specific water resource than HP01.A.

Measured precipitation data

Precipitation has been measured in Nalunaq Valley (station 623), at HP01.A (station 124) and in Nanortalik town (station 501). The position of the stations are shown in Figure 2.1 and the periods of operation for the precipitation measurements are shown in Table 2.1. From the measured time series we extract monthly values of precipitation.

The precipitation measurements in Nalunaq Valley do not overlap in time with the measurements at HP01.A (Table 2.1); thus, in order to evaluate the ratio between precipitation in Nalunaq Valley and HP01.A we utilize that precipitation measurements in Nanortalik town overlaps with the data series from both sites.

By assuming that the ratio between specific water resource for Nalunaq Valley and HP01.A is the same as the ratio between precipitation at Nalunaq Valley and HP01.A, we can adjust the specific water resource measured at HP01.A to estimate the specific water resource in Nalunaq Valley.

Site	Station no.	Period of operation	Data overlap with station 501, months
Nalunaq Valley	623	1997-2002	11
HP01.A	124	1982-1990	16
Nanortalik	501	1987-present	

Table 2.1 Period of operation of precipitation measurements at the three stations near Nalunaq Valley

Irregular data gaps in the three time series of precipitation reduces the number of monthly values that overlap, which together with the necessity of using Nanortalik data to link the datasets from Nalunaq Valley with HP01.A increases the uncertainty of the estimated ratio. Consequently, we see a need to include regional climate model output as an independent data source in the analyses.

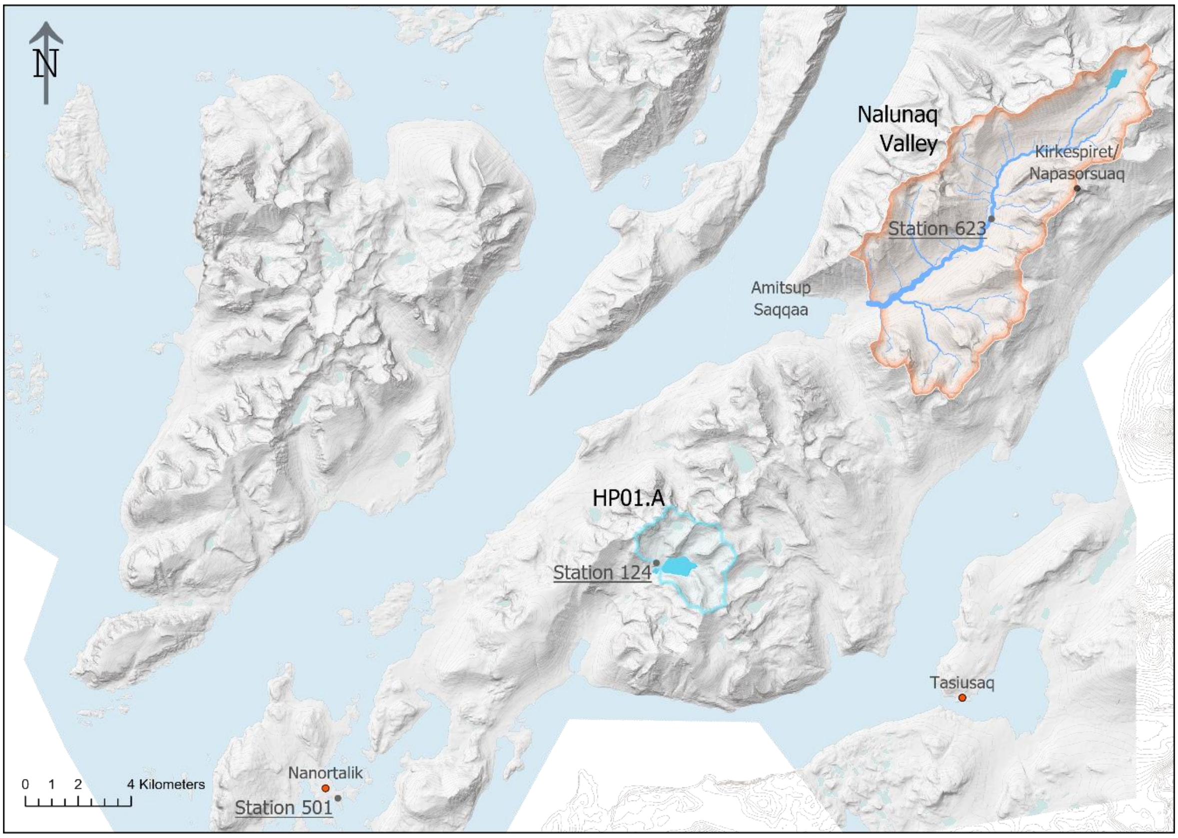

Figure 2.1 Precipitation has been measured at the three stations 501, 124 and 623. The water resource for the catchment area of HP01.A (light blue outline) has been measured, too. The catchment of Nalunaq Valley (orange outline) and the river network in Nalunaq Valley (blue lines) is shown.

Regional climate model output

HIRHAM is a regional climate model run by the Arctic and Climate Research section at the Danish Meteorological Institute (DMI). HIRHAM is run at a horizontal resolution of 0.05 degrees (~5km) covering all of Greenland. The ERA-Interim reanalysis produced by the European Centre for Medium Range Weather Forecasting was used as climatic forcing on the model boundaries. We utilize the model output in the form of monthly values of specific runoff and precipitation covering the period 1980-2014.

The HIRHAM model covers Nalunaq Valley and thus gives runoff values for the valley directly. However, our research have shown that although the model normally gives a good description of the year-to-year variation (high correlation coefficients with measured data), it typically overestimate the annual water resource considerably (Research project ‘Evaluation of HIRHAM5 estimates of water resources’ carried out by Asiaq and financed by the Greenland Research Council).

We have estimated a correction factor to apply to the modelled runoff. The factor was estimated in two ways. Firstly, we have compared measured precipitation data from Nalunaq Valley with HIRHAM precipitation data for Nalunaq Valley. Secondly, we have compared measured yearly water resource values for HP01.A with HIHRAM runoff values for the HP01.A catchment. The second estimate assumes that the model correction factor is the same in Nalunaq Valley as for HP01.A.

Furthermore, we use the model output to give an independent estimate of the ratio between specific water resource for Nalunaq Valley and HP01.A. Catchment areas for Nalunaq Valley and HP01.A were delineated as described below in section 2.2. For each catchment, we extracted HIRHAM model outputs for all HIRHAM grid cells that overlap the catchment and a weighted mean was calculated. Weights being the ratio of the area of the catchment within the grid cell divided by the total catchment area.

Finally, we use the HIRHAM runoff values for the HP01.A catchment to evaluate how well the eight years, from which measurements exist, represent a long-term mean.

2.2 Catchment delineation and river network

The watershed area of Nalunaq Valley was delineated based on the Arctic Digital Elevation Model Mosaic[1] (Arctic DEM). The newest version 3 has been obtained with a resolution of 2x2 meters. So far, vertical accuracy tests[2] show average values between -0.01 ± 0.07 m in comparison to other sources of height information from satellite. Before any hydrological analyses are being undertaken, the DEM is reprojected to the WGS 1984 UTM Zone 22N (EPSG: 32622) projection with a Greenlandic geoid. This is, among other things, to compare with the elevation model from the Nalunaq Valley 2019 Asiaq drone survey.

GIS analyses were carried out using a suite of ArcGIS (hydrological) tools. Below is a basic description of the steps that were performed in the process.

Firstly, the Arctic DEM might contain sinks and imperfections; this was filled/repaired in order to make the flow direction calculation step work properly.

The calculation starts from the upper most parts of the DEM and calculates the flow direction to its downslope neighbors. This results in a raster file containing the values for the direction of the hydrological flow for each grid cell. Based on the flow direction grid a flow accumulation grid is calculated, which for each grid cell holds information about the number of upstream cells contributing water to that grid cell.

Then, the flow accumulation grid is filtered, so that it only contains cells that holds values over a chosen threshold. In the physical world, this represents the rivers and tributaries. A vector river network is established from this.

A pour point is created at the outlet of Nalunaq Valley towards the sea. This marks the downstream end-point for the catchment. Furthermore, sub-catchments for the larger tributaries and the segments of the main river between confluence points are generated.

[1] Polar Geospatial Center: http://data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/mosaic/v3.0/2m/
[2] ArcticDEM Validation and Accuracy Assessment https://ui.adsabs.harvard.edu/abs/2017AGUFM.C51A0951C/abstract

The previously calculated flow accumulation grid is used for computing the mean annual water resource flowing through each grid cell. By multiplying the specific mean annual water resource [m^3 water per m^2 per year] with the flow accumulation grid and the area of the Arctic DEM pixels a mean annual water resource grid is obtained. The vector river network is divided into segments of maximum 10 meters. Each line segment is assigned the maximum value from the cells in the mean annual water resource grid that the line segment crosses. This then creates a segmented river network, containing values for the mean annual water resource at each river segment. Other attributes include height and slope for the line segment. A list of attributes and their units is given in Appendix A.

3 Results

3.1 Specific mean annual water resource

Because of the lack of direct measurements of the water resource in Nalunaq Valley, we calculated four estimates of the specific mean annual water resource for Nalunaq Valley based on the available data sources.

Two of the estimates uses the measured water resource at Hydropower potential 01.A (HP01.A) as starting point:

Based on the regional climate model we found that the eight years from which measurements of the water resource at HP01.A exist, represent the long-term mean well (mean of the eight years/mean of 34 years = 0.96). The long-term mean annual water resource for HP01.A was found as the mean of the eight years of measured data divided by 0.96.

The long-term specific mean annual water resource for HP01.A was converted to the specific mean annual water resource for Nalunaq Valley by multiplying with the ratio of the specific water resource between Nalunaq Valley and HP01.A. The ratio was estimated in two ways:

- A ratio of 0.32 was computed based on correlations between precipitation data measured in Nalunaq Valley and Nanortalik (R^2=0.85) and in Nanortalik and HP01.A (R^2=0.81)
- A ratio of 0.42 was computed based on HIRHAM runoff outputs from Nalunaq Valley and HP01.A (R^2=0.95)

The two other estimates uses the modelled water resource (runoff) in Nalunaq Valley from the regional climate model HIRHAM as starting point:

The model output was adjusted by multiplying with a correction factor to account for uncertainties of the HIRHAM output. The correction factor was estimated in two ways:

- A correction factor of 0.6 was computed based on the ratio between measured and modelled precipitation in Nalunaq Valley (R^2=0.71)
- A correction factor of 0.69 was computed based on the ratio between measured and modelled water resource at HP01.A (R^2=0.69)

The four estimates of the specific mean annual water resource falls in the interval between 590 and 770 mm/year. A mean of the four values constitute our best estimate for the specific mean annual water resource in Nalunaq Valley:

Specific mean annual water resource in Nalunaq Valley: 690 mm/year

3.2 Catchment and river network

The river network and catchment area of Nalunaq Valley was calculated based on a digital elevation model of the area, Figure 3.1. The river network consist of a main river and a number of approximately 20 small tributaries. The catchment area for the entire valley is 67.9 km^2.

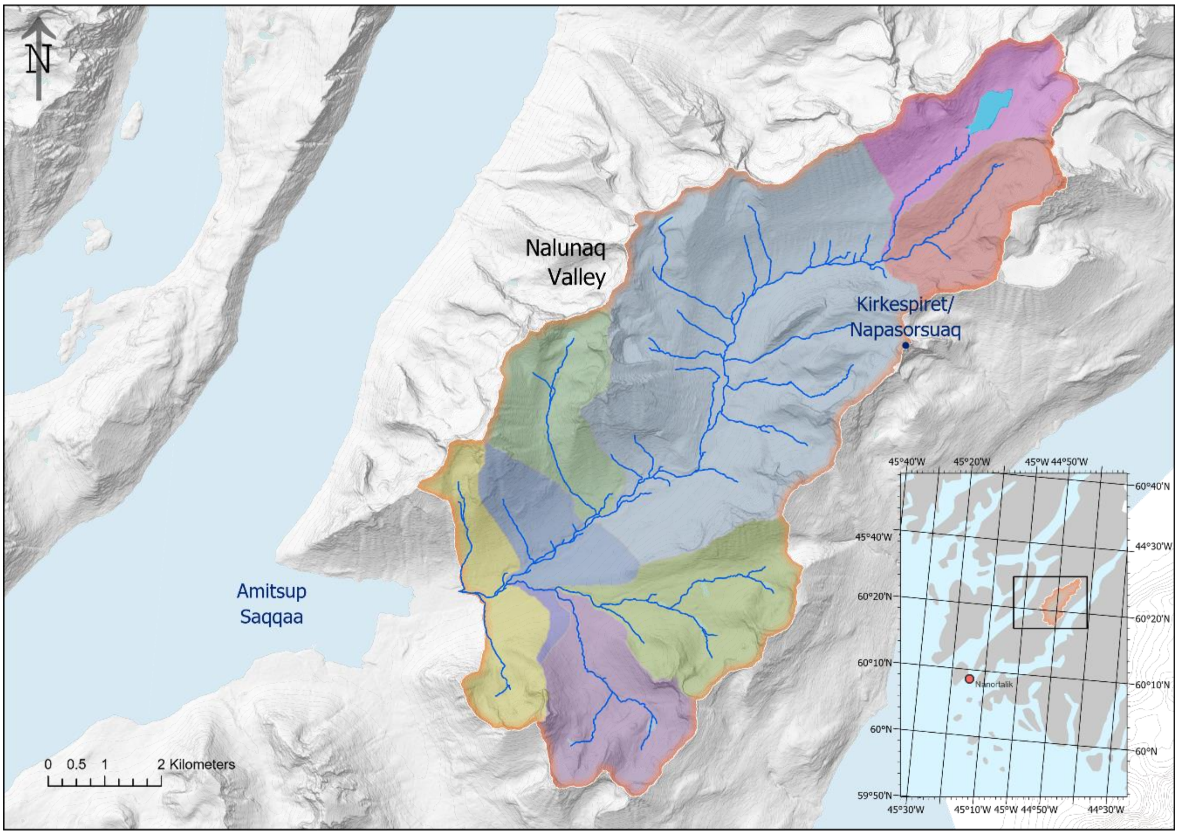

Figure 3.1 Nalunaq Valley with its river network (blue lines). Catchment for the entire valley is shown (orange border) together with sub-basins (areas in different colour).

3.3 Water resource

Combining the specific mean annual water resource with the upstream area feeding water to the river we have calculated the mean annual water resource along the river network, Figure 3.2. The mean annual water resource increases along the river from 2 mill. m^3/year at the river source to 46 mill. m^3/year at the mouth of the river.

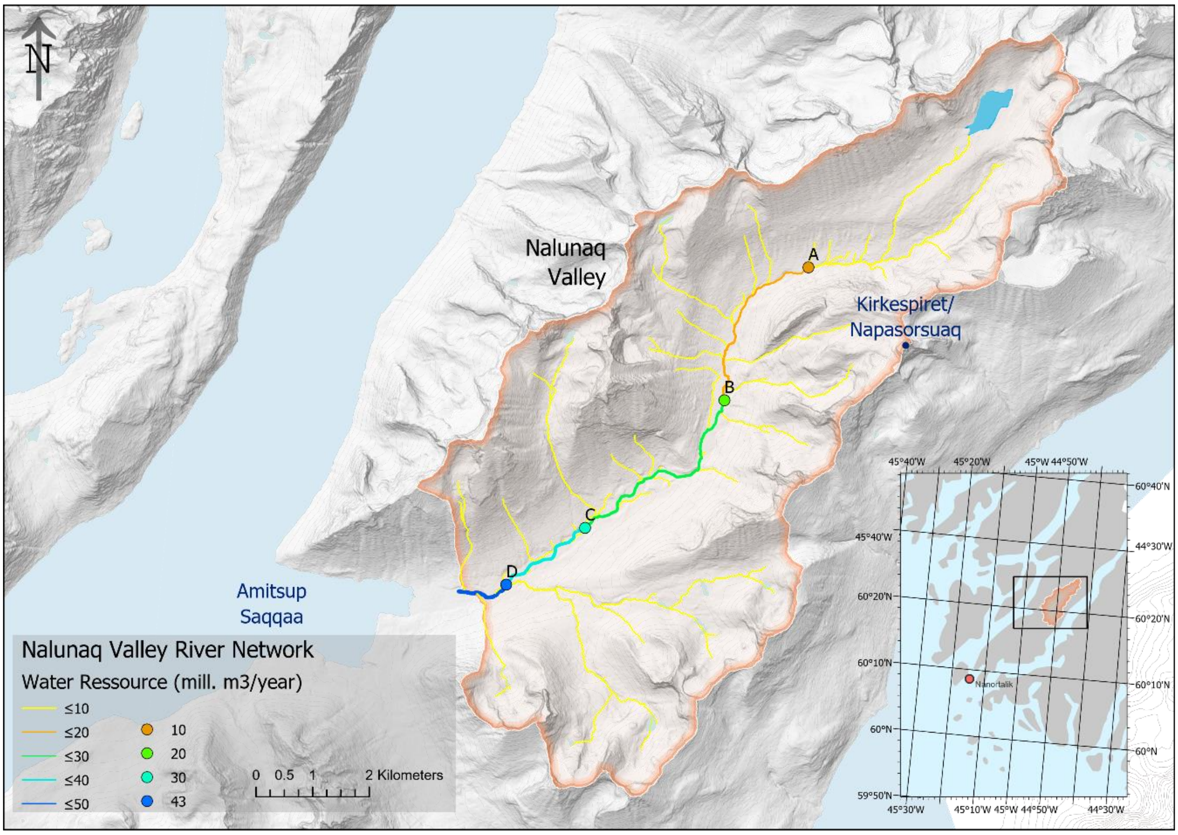

Figure 3.2 Mean annual water resource along the river network in Nalunaq Valley. As examples, water resource data is extracted for four points A, B, C and D along the river.

A considerably year-to-year variation in the water resource will occur depending on the natural variation in the weather. Based on HIRHAM model output from the period 1980-2014 for Nalunaq Valley the water resource in dry years can be as low as 50% of the mean annual value, and in wet years the water resource can be 150% of the mean annual value.

The typical monthly distribution of the annual water resource for Hydropower potential 01.A (HP01.A) is shown in Figure 3.3. In Nalunaq Valley the available water resource in autumn, winter and spring (September to December and January to April) may be less than indicated here, due to a smaller storage capacity in the form of lakes in Nalunaq Valley compared to HP01.A. In this case, the percentage of the water resource available in the remaining months (May to August) will of course be correspondingly higher.

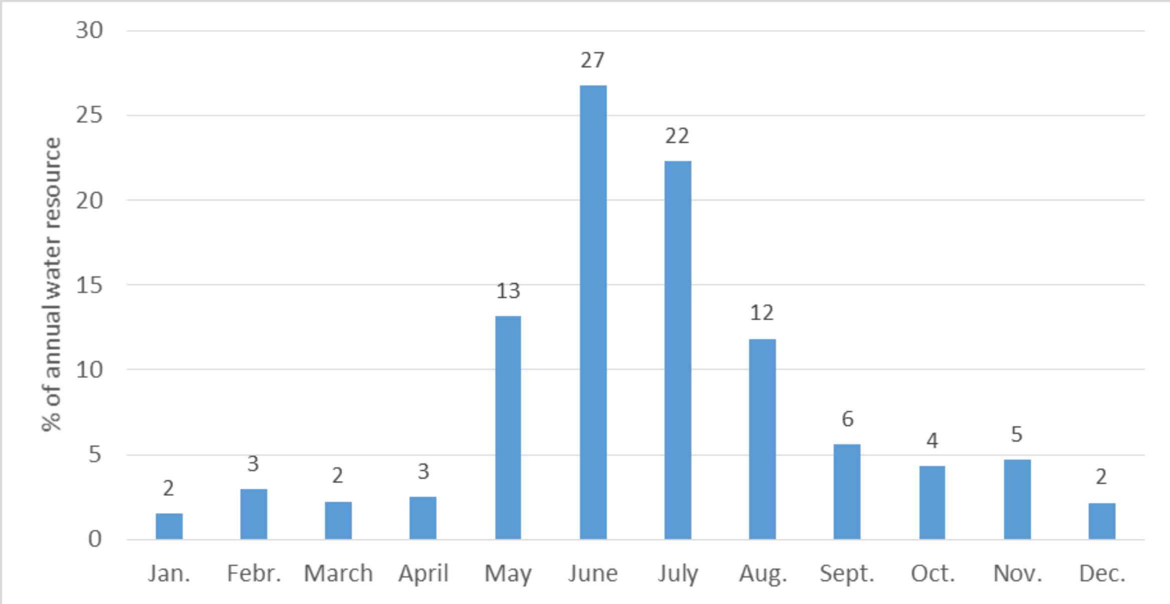

Figure 3.3 Typical monthly distribution of the annual water resource based on data from Hydropower potential 01.A. In Nalunaq Valley the available water resource in autumn, winter and spring (September to December and January to April) may be less than indicated here, due to a smaller storage capacity in the form of lakes in Nalunaq Valley compared to HP01.A.

Using the monthly distribution from HP01.A we have calculated the water resource per month for four points (A, B, C and D) along the river for an average year as well as for years with minimum and maximum water resource, see Figure 3.4 to Figure 3.7. The position of points A-D is shown in Figure 3.2.

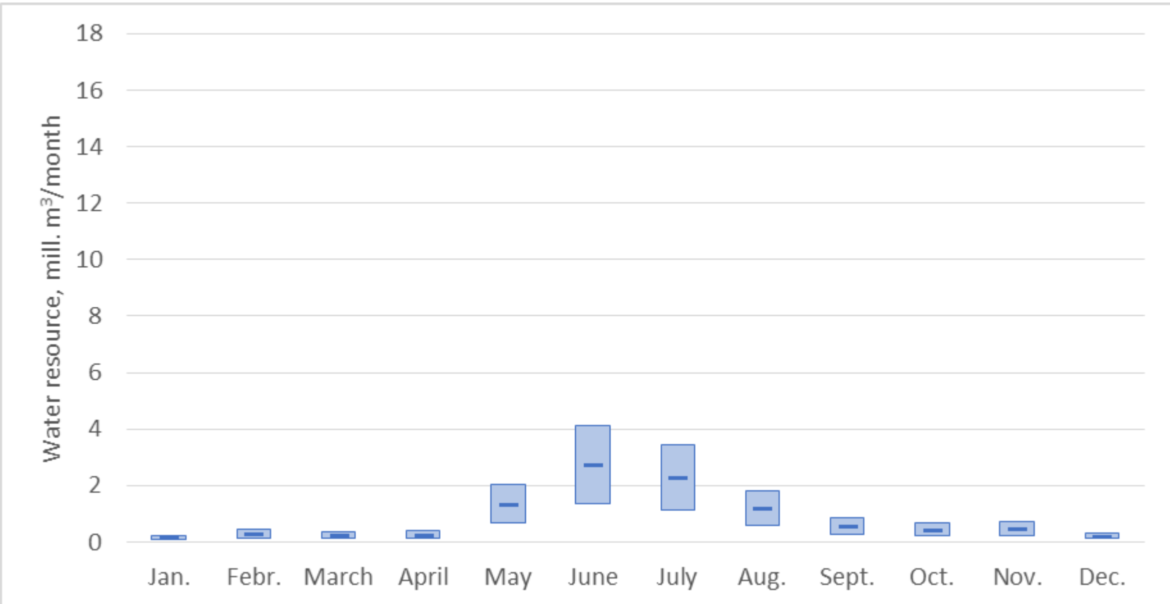

Figure 3.4 Monthly water resource at point A. Columns illustrate the interval from minimum (dry year) to maximum (wet year), horizontal strokes within the columns are mean values. Note that year-to-year variations in monthly distribution is not taken into account.

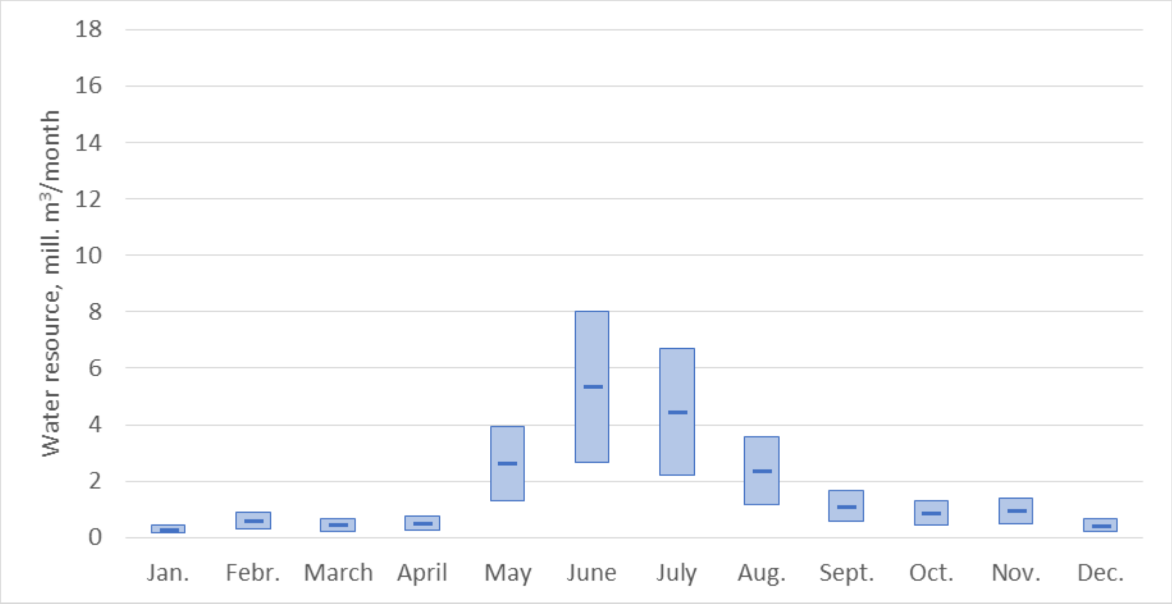

Figure 3.5 Monthly water resource at point B. Columns illustrate the interval from minimum (dry year) to maximum (wet year), horizontal strokes within the columns are mean values. Note that year-to-year variations in monthly distribution is not taken into account.

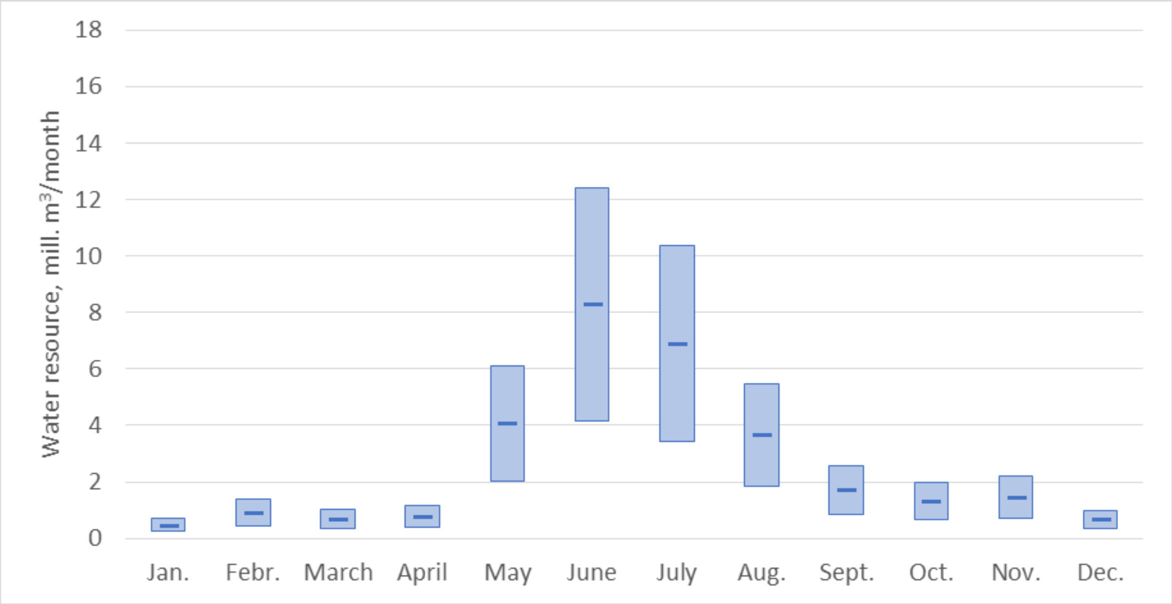

Figure 3.6 Monthly water resource at point C. Columns illustrate the interval from minimum (dry year) to maximum (wet year), horizontal strokes within the columns are mean values. Note that year-to-year variations in monthly distribution is not taken into account.

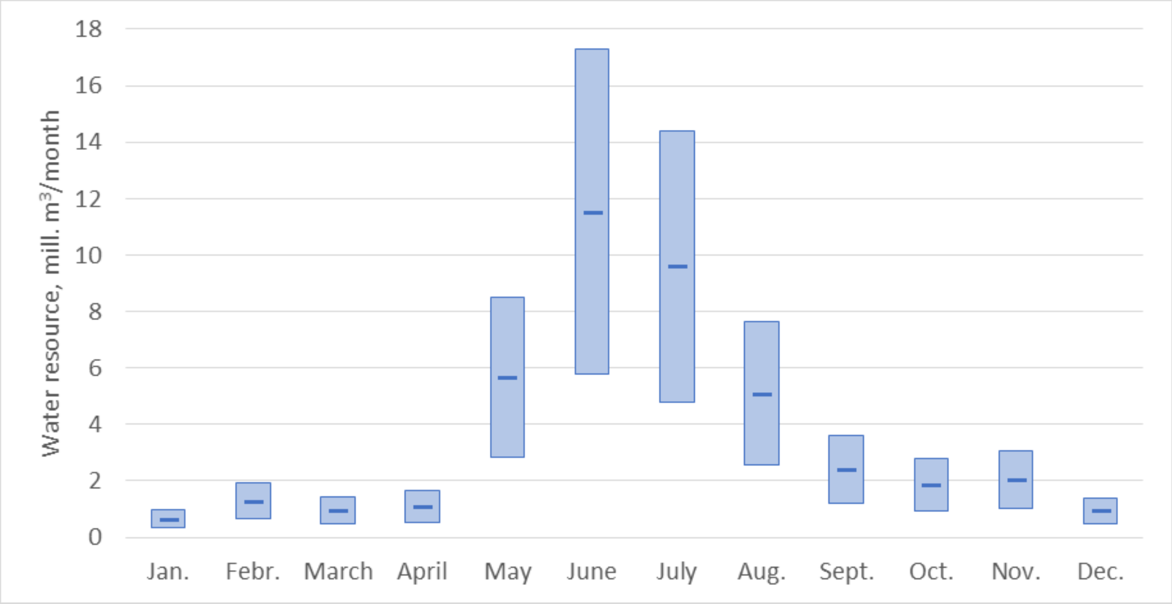

Figure 3.7 Monthly water resource at point D. Columns illustrate the interval from minimum (dry year) to maximum (wet year), horizontal strokes within the columns are mean values. Note that year-to-year variations in monthly distribution is not taken into account.

4 Conclusion and Recommendations

Based on existing data the specific mean annual water resource in Nalunaq Valley was estimated to 690 mm/year. Combined with the catchment area this gives a mean annual water resource along the river varying from 2 mill. m^3/year at the river source to 46 mill. m^3/year at the river mouth.

A considerably year-to-year variation in the water resource will occur depending on the natural variation in the weather. In dry years, the annual water resource can be as low as 50% of the mean annual value, and in wet years, the water resource can be 150% of the mean annual value.

Typical, the main part of the water resource, around 75%, will be available in the summer period during the months May, June, July and August.

Due to the uncertainty of the estimated water resource, it is recommended to measure the water resource in Nalunaq Valley for at least 3-5 years for verification of the results from this report before any large investment in hydropower.

Appendix A: Data file attributes

File name: **nalunaq_valley_river_network.shp**

Attribute name	**Unit**	**Explanation**
Z_Min	Meter above sea level	Minimum z-value
Z_Max	Meter above sea level	Maximum z-value
Z_Mean	Meter above sea level	Average z-value
Min_Slope	m (vertical change) per 100 m (horizontal distance)	Minimum slope
Max_Slope	m (vertical change) per 100 m (horizontal distance)	Maximum slope
Avg_Slope	m (vertical change) per 100 m (horizontal distance)	Average slope
Linelength	m (horizontal distance)	Horizontal length of river segment
Length3D	m (along the ground)	Length of river segment along terrain
Water_res	Million m^3 per year	Mean annual water resource

File name: **nalunaq_valley_watershed.shp**

Attribute name	**Unit**	**Explanation**
Area_m2	m^2	Area of catchment
name	-	Catchment name

File name: **nalunaq_valley_subcatchments.shp**

Attribute name	**Unit**	**Explanation**
Area_m2	m^2	Area of sub-catchment