

Hydrological Background of a Glacier-Influenced Hydropower Station in Greenland

Paper presented at the 7th Northern Res. Basins Symposium/Workshop
(Ilulissat, Greenland May/June – 1988)

Claus Kern-Hansen

Greenland Technical Organization, Copenhagen, Denmark

For planning a hydropower station at Paakitsup Akuliarusersua in West Greenland, some unusual hydrological studies were required. The basin is situated about 45 km north-east of Ilulissat/Jakobshavn (69° 30'N latitude) at the Greenland Inland Ice and is hence strongly ablation-influenced. As only sparse hydrological measurements had been obtained from the actual basin, it was necessary to base the calculations on historical data from Ilulissat/Jakobshavn. This work included among other things preparation of a suitable hydrological ablation model, detailed analyses of data to establish time series for the simulation work, sensitivity analyses of the hydro-glaciological prerequisites, and analysis and evaluation of periodic elements in the time series.

Introduction

In 1982 it was decided that the energy supply to a number of Greenlandic towns should be changed over to hydropower. The first of these powerplants will be built to supply Ilulissat/Jakobshavn.

The hydropower station will be set up at Paakitsup Akuliarusersua, and the plant should be ready for use in the early 90'ies. In the working plans, one of the first elements was the preparation of a hydrological basis for dimensioning the hydropower station which, on account of the other stages of the planning work, had to be ready for the planners in early 1985.

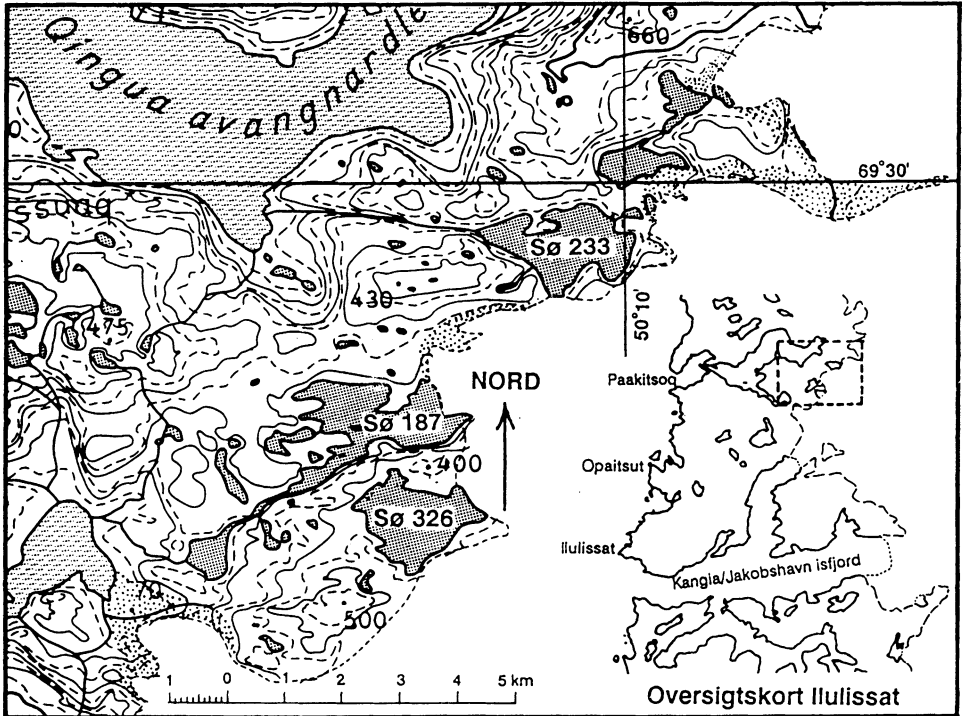


Fig. 1. Drainage basin at Paakitsup Akuliarusersua.

Location

The Paakitsup Akuliarusersua basin is situated 45 km to the north-east of Ilulissat/Jakobshavn, at the edge of the Greenland Inland Ice (Fig. 1). The catchment area covers approximately 325 sq.km, of which only 40 are ice free, the rest of the area lies below the Inland Ice. The ice free area is found between 187 m and 600 m above sea level, whereas the surface of the icecovered area is situated between 190 m and more than 1,700 m above sea level.

The catchment area can be divided into three parts: the main catchment area of the lake Sø 187, and two minor catchment areas (the catchment areas of Sø 233 and Sø 326 respectively), both of which flow independently into lake 187.

Hydrological Problems and Data Base

In the case of Paakitsup Akuliarusersua, there were several important problems to consider:

- how large is the catchment area of each individual lake on the inland ice, and what does the bottom topography of the ice look like? Could a small retrogression of the ice cause a cutoff of a considerable volume of water for the hydropower station?
- the preparation of a hydrological layout should be based on long time series, and their representativeness with respect to the general climatic changes must be evaluated.

The data base of measurements from the actual basin was extremely sparse. A continuous registration of the runoff from the main lake was not started until 1980, and first in 1983 a small climate station was established. But there are measurements of air temperature and precipitation at the town of Jakobshavn (carried out by the Danish Meteorological Institute) back to 1873.

It would thus be possible to prepare a hydrological basis by means of a hydrological model simulation based on the long climatic time series from the town, if a suitable parameter transfer could be devised.

The primary data base is shown in Table 1.

With respect to catchment areas and their delimitation on the inland ice, Greenland Technical Organization (GTO) has cooperated closely with the Geological Survey of Greenland (GGU) who for a start worked out appropriate maps of catchment areas on the basis of local knowledge as well as interpretation of satellite pictures. These catchment area delimitations were later revised on the basis of the runoff results during the model calibration, and have finally been adjusted simultaneously with an analysis of the bottom topography of the ice in a recent project carried out by GGU (Thomsen, Thorning and Braithwaite 1986).

Hydrological Model Work

The Model

For the simulation work an ordinary precipitation runoff model was not sufficient. The well-known NAM model (Nielsen and Hansen 1973), used in other parts of Greenland that are little influenced by ablation (*i.e.* Christensen and Hansen 1978, GTO 1983), was therefore redesigned into a proper Hydrological Ablation Model to describe ablation-dominated areas. This deterministic model has been described in detail by Thomsen and Jørgensen (1984). The model structure with the routing principle used for Paakitsup Akuliarusersua is shown in Fig. 2.

Parameter Transfer

To be able to use the around-the-clock values of airtemperatures measured at Ilulissat in the simulation for the basin, it was necessary to describe a transfer model between Ilulissat and the basin, and then between the basin and the glacier areas, respectively.

Table 1 – Hydrological databasis and catchment areas, Paakitsup Akuliarusersua hydropower project.

Year	Parameter	Measured at	Measured by	Time step	Catchment	Icefree area	Icecovered area*)	Lake area
1980-84	Runoff	Basin sØ 187	GTO	daily	SØ 233	17.7 km ²	234 km ²	2.2 km ²
1983-84	Airtemp.	Basin sØ 187	GTO	daily	SØ 187	11.6 km ²	47 km ²	3.2 km ²
1982-84	Ablation	Icecap	GGU	yearly	SØ 326	4.1 km ²	4 km ²	2.3 km ²
1961-84	Airtemp.	Ilulissat	MI	daily	TOTAL	33.4 km ²	285 km ²	7.7 km ²
1961-84	Precipitation	Ilulissat	MI	daily				
1873-1960	Airtemp.	Ilulissat	MI	monthly				
1873-1960	Precipitation	Ilulissat	MI	monthly				

*) areas adjusted on the basis of model calibration

Table 2 – Yearly distribution of heating factor.

Month	jan.	feb.	mar.	apr.	may	jun.	jul.	aug.	sep.	oct.	nov.	dec.	(m)
Heating _m	0.0	0.5	0.8	1.0	1.5	2.3	0.8	0.3	÷0.5	÷1.0	÷1.0	÷1.0	°C

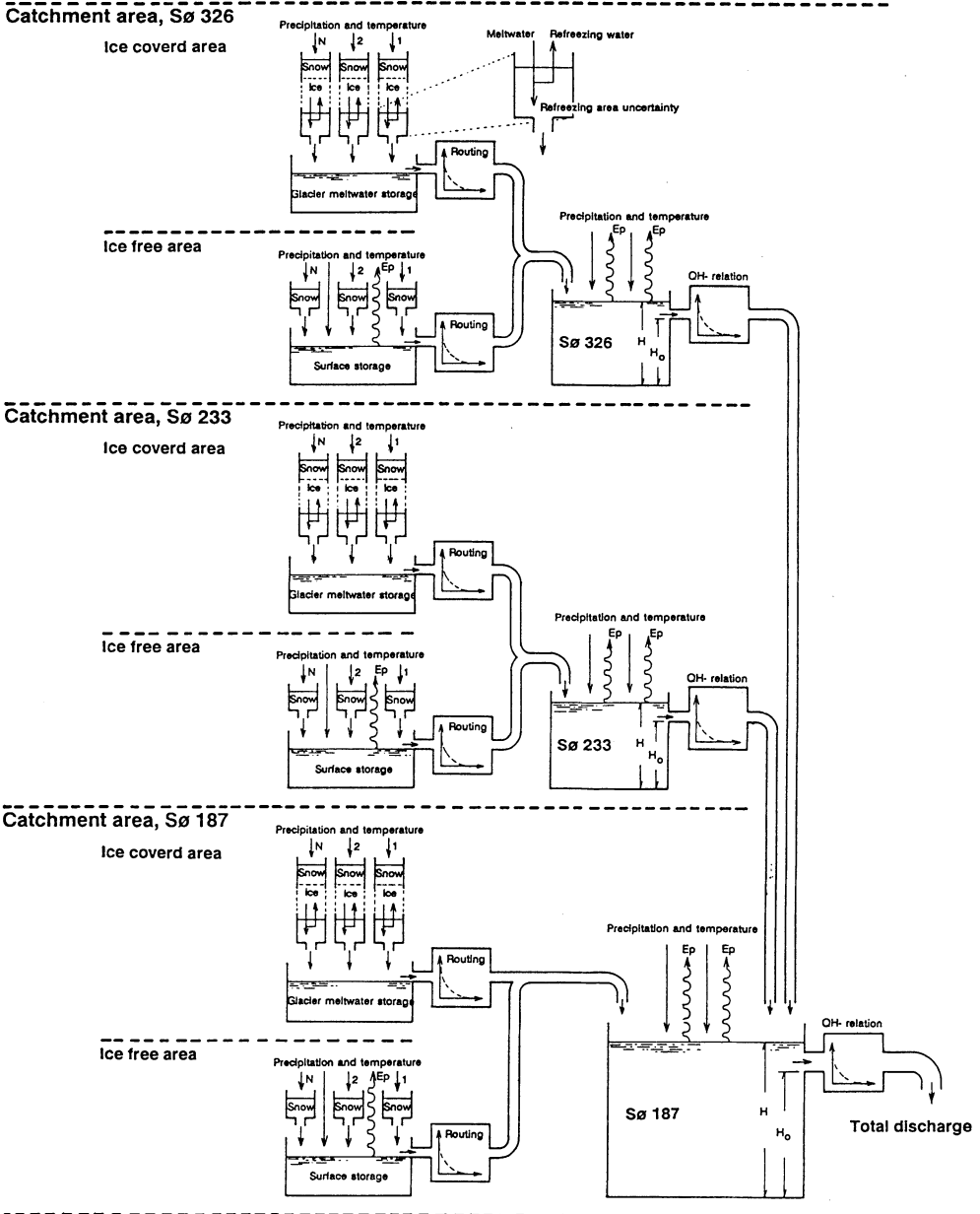


Fig. 2. Hydrological ablation model structure.

For the period from September 1983 to September 1984 it was possible to compare temperatures measured at Ilulissat and temperatures measured at SØ 187. Similarly, there was a very brief period (four months) with simultaneous measurements of air temperatures at SØ 187 and on the inland ice at an altitude of 500 m above sea level.

The temperature transfer between town and basin has been worked out as a combination of a lineary regression formula and a heating factor, the latter determined on a monthly basis. As winter temperatures are of little significance for the runoff, it is primarily the temperature transfer during the melting period that is important in the analytical work.

Based on analyses of several possible combination forms, the following temperature transfer between town and basin was established:

$$T_d(\text{basin}) \equiv 0.7 T_d(\text{town}) + \text{Heating}_m$$

where:

$T_d(\text{basin})$ - 24-hour mean temperature, calculated for the basin

$T_d(\text{town})$ - 24-hour mean temperature, measured at Ilulissat

Heating_m - monthly heating factor, cf. Table 2.

The temperature transfer between basin and glacier was established on the basis of two assumptions:

- The glacier has an inherent cooling effect, *i.e.*, the air temperature measured at a given altitude in the ice free part of the catchment area is higher than the air temperature measured at the same altitude near the edge of the glacier (Braithwaite 1980).
- A linear cooling takes place in consequence of the altitude level.

In this case the temperature comparisons produced the following temperature regressions for the 24-hour values:

$$T(\text{edge of glacier}) \equiv -0.20 + 0.83 T(\text{basin})$$

$$T(\text{glacier, alt. 500}) = -1.45 + 0.83 T(\text{basin})$$

As about 90% of the runoff in the basin derives from ablation, and as there were not simultaneous measurements of precipitation in town and basin, the transfer of the precipitation data from Ilulissat to the basin was not considered overly important. For the period 1961-84 the measured daily sums were used, whereas only monthly sumvalues were available for the years from 1874 to 1960. The latter were evenly distributed on the days of the month, which is not physically correct, but adequate from the model-technical point of view.

The precipitation recorded as point measurements at Ilulissat was corrected to the estimated »true« precipitation for the area. Based on detailed precipitation

Hydrology in Greenland

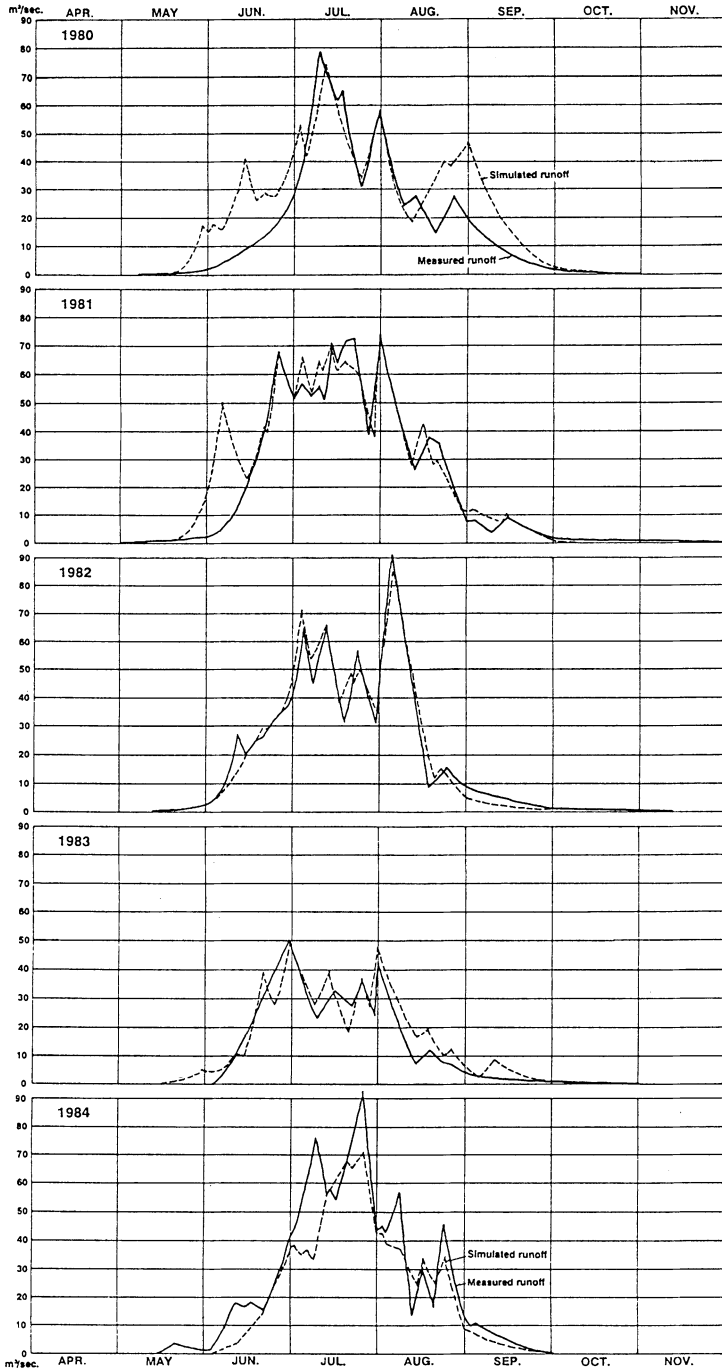


Fig. 3. Measured and simulated runoff 1980-84, Paakitsup Akuliarusersua.

analyses from other parts of Greenland (GTO 1983), the correction was made by multiplying by 1.70 for snow, and by 1.15 for rain.

Model Calibration

The redesigned deterministic hydrological ablation model was calibrated on the basis of the four years of recorded runoff from the basin, Fig. 3.

The calibration was primarily carried out on the annual runoff balance, and secondly on the fitting of peaks and recession elements. Finally in the model calibration, emphasis was put on the starting time and volume of the runoff. The melting (degree-day) factors for the ice-covered areas were calibrated on the basis of ablation measurements over a two-year period, and finally it was possible, based on brief, simultaneous runoff series from each of the three lakes, to adapt the model calibration to the internal distribution of water from the three part catchment areas.

After that, the calibrated model could be used for a preliminary simulation with daily values of precipitation and temperatures measured at Ilulissat 1961-84. The simulation was based on the assumptions found for catchment area sizes etc. for 1984, and produced the following result: mean yearly discharge = 328.6 ± 72.9 mio. m^3 .

Extended Temperature Series

As mentioned earlier, the greatest uncertainty factor in the hydropower station project is its dependence on the ablation from the inland ice. It is therefore necessary to see if the period from 1960 to 1984 is representative. To this end it was necessary to establish daily temperature series that was longer than the measured series. This synthetic temperature series was constructed on the basis of monthly mean temperatures measured at Ilulissat from 1873 to 1960, and daily mean temperatures measured at Ilulissat in the period 1960-84.

The series was calculated on the basis of the following formula

$$T_{d,m,y}^g = \bar{T}_{m,y} + S_{d,m} F_{m,y}$$

where

subscript d – Day 1-31

subscript m – Month 1-12

subscript y – Year 1875-1960

$T_{d,m,h}^g$ – Generated 24-hour mean temperature, day d , in month m , year y .

$\bar{T}_{m,y}$ – Measured monthly mean temperature, month m , year y ,

$S_{d,m}$ – St. dev. (day-to-day deviations from the monthly mean value of month m). All 12 representative average months have been found in the historical material.

$F_{m,y}$ – Factor calculated for month m , year y .

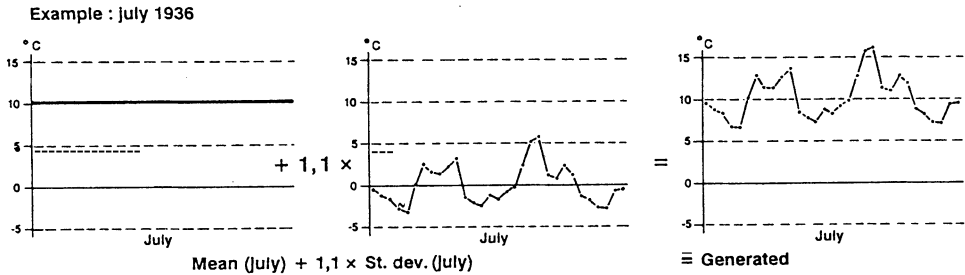


Fig. 4. Principle for generation of around-the-clock temperatures: July 1936, when the mean temperature and factor are special for this month of July, whereas the superimposed standard deviation is identical for all months July.

so that the monthly mean value from the 76-year series was superimposed with the statistical data from the daily series. The principle is illustrated in Fig. 4.

The validity of the generated series was verified by comparing a hydrological model simulation for the years 1961-84 with a similar simulation for the same period, based on measured data. This synthetic temperature series was subsequently used for analysing the climatological trends during the past 110 years. While the catchment area characteristics for 1984 (glacier catchment areas etc.) were reckoned to be stationary, the temperature and precipitation data were changed to correspond to the period 1874-1984.

The conclusion of these analyses was that the simulated runoff for the period 1960-84 is near the average for the 110-year series (1874-1984), and that the probable development for the 25-year period 1985 to 2009 will more likely correspond to the period 1875-1899 (which is the coldest 25-year period in all the data material) than the conditions reigning in 1960-84.

Model Simulation Results

In addition to the future temperature changes, the following possible sources of error in the hydrological work were analysed:

- the stage-discharge relation
- temperature transfers
- input data
- glacier catchment areas
- the model
- uncertainty in statistical adaptation
- uncertainty relative to ablation measurements and simulations

Based on a number of sensitivity analyses of each individual relation and parameter, and on statistical considerations of each of the uncertainty factor's effect on the final result, two 50-year series were composed for the final simulations.

Table 3 – Statistical parameters for the two selected series.

50-year series	Mean yearly value (mio. m ³)	St. dev. (mio. m ³)	50-year min. (mio. m ³)	90 prob. (mio. m ³)
Most probable serie	302.8	70.7	158	205
Pessim. probable serie	203.6	54.1	103	135

These series were named »pessimistically probable series« and »most probable series«. The former corresponds to a development that may occur once out of 40 times. This series represents the smallest 50-year average inflow in 1875-1984, and an overall pessimistic view of the uncertainty with respect to the hydro-glacial series applied, including a pessimistic view of the glacier catchment areas. Similarly, the latter series represents the smallest average inflow during the 1875-1984 period, *i.e.* from 1875-1924 which is the coldest 50-year period, and at the same time the most likely 50-year series judged on the basis of the calibration data, and with allowance being made for periodicity phenomena.

The key figures for these two series are shown in Table 3, and these are the figures that were recommended for the continued planning work in mid-1985.

Future Work

In order to improve the data base at Paakitsup Akuliarusersua, an intensive collection of data has been commenced. The basin is now equipped with one central climate station, three smaller stations (recording precipitation, air temperatures, lake temperatures and the water levels of each of the three lakes), two temperature stations on the inland ice and a station erected halfway between Ilulissat/Jakobs-havn and the basin, plus a number of special stations.

Based on this network of stations it will be possible to describe the basin's hydro-glaciological conditions more accurately than earlier, and especially to obtain an improvement in relating time series measured in the basin to those recorded in the town.

Finally, it will be possible to obtain data for many other factors, *e.g.* ice and wind loads on transmissions lines and mast constructions, tidal conditions in connection with navigation, winds where a local helistop is to be built, rock temperatures in feeder tunnels, etc.

Acknowledgement

This paper is published by permission of the Greenland Technical Organization. The hydrological work was carried out and reported by Jørgensen, Norsker and

Thomsen (GTO 1985). As part of this work Roger Braithwaite and Henrik Højmark Thomsen, Geological Survey of Greenland, helped with the development of the hydrological ablation model.

References

- Braithwaite, R.J. (1980) Glacier energy balance and air temperature: comments on a paper by Dr. M. Kuhn, *Journal of Glaciology*, Vol. 25, no. 93.
- Christensen, M., and Hansen, E. (1978) Streamflow modelling for the Narssaq River Basin, Greenland. Paper presented at: The International Symposium on the Computation and Prediction of Runoff from Glaciers and Glaciated Areas. Tbilisi, Georgian S.S.R., 3-11 September 1978.
- Grønlands tekniske Organisation (1983) Forundersøgelser vandkraft 1982, Hydrologi, Buksefjorden, Nuuk/Godthåb, GTO-rapport.
- Grønlands tekniske Organisation (Jørgensen G.H., Norsker A.O. and Thomsen Th.) (1985) Forundersøgelser vandkraft 1984, Hydrologi, Paakitsup Akuliarusersua, Ilulissat/Jakobs-havn, GTO-rapport.
- Ministeriet for Grønland (1986) Vandkraft-bynære anlæg, Redegørelse for undersøgelser 1980-86; Rapport, Råstofforvaltningen.
- Nielsen, S.A., and Hansen, E. (1973) Numerical simulation of the rainfall runoff process on a daily basis, *Nordic Hydrology*, Vol. 4, pp 171-190.
- Selskabet for Arktisk Teknologi (1987) Energiforsyning i arktiske områder, SAT-rapport
- Thomsen, H.H. (1985) Arbejdsnotat vedr. afgrænsningen af dræningsarealer ved Paakitsup Akuliarusersua, GGU-arbejdsnotat.
- Thomsen, H.H., Thorning, L., and Braithwaite, R. (1986) Vurdering af de gletcher-hydrologiske forhold på Indlandsisen ved Paakitsup Akuliarusersua, Ilulissat/Jakobshavn, GGU-arbejdsnotat.
- Thomsen, Th., and Jørgensen, G.H. (1984) Hydrological Data-Model Work in Greenland, *Nordic Hydrology*, Vol. 15, pp 39-56.

Received: 1 August, 1988

Claus Kern-Hansen

Address:

Greenland Technical Organization,
Denmark Office,
Section of Hydro-Technical Investigation,
20 Hauser Plads,
DK-1127, Copenhagen K,
Denmark.