Greenland case study: water supply

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NEEDS FOR AND PURPOSES OF PREDICTIVE TECHNIQUES

There is at present a great interest in developing hydropower projects in West Greenland. Many of the basins identified as possible sites for development have a high degree of glacier cover (Olesen & Weidick, 1977). Measured runoff series are all very short as measurements, except for the 1967-71 Narssaq runoff series (Larsen, 1973), only started in the mid-1970s as part of a program of preliminary investigations by the Greenland Technical Organization (GTO, 1979). Methods of predicting runoff from glacierized areas have therefore a great practical importance for Greenland.

All the projects under serious consideration involve storage of summer runoff in multi-year reservoirs formed by damming natural lakes for year-round electricity generation using moderate to high hydraulic heads. There are no proposals for low-head river power stations, and suggestions for water intakes at high elevations on the Inland Ice are impractical. The earlier proposals (Arctic Consultant Group & Vattenbyggnadsbyroen, 1975) mainly related to large basins at the margins of the Inland Ice with a high productivity which could be used to supply new industries. However interest has recently focussed on smaller coastal basins to generate hydropower for local consumption (ACG, 1979).

No hydropower station has been built yet, although decisions may be made within the next few years on several projects where runoff measurements have been started. This means that hydrological models are presently needed for localizing possible sites (regional models) and will soon be needed for design purposes (site-specific models). The hydrological information required mainly consists of runoff estimates on a year-to-year and seasonal basis for calculations of yield, hydropower potential and necessary reservoir capacity. When hydropower stations come into operation, models for seasonal forecasting will also be needed for determining policy.

As many of the proposed hydropower projects would use a high proportion of glacial waters, problems of sediment load, such as filling up of reservoirs and wear on hydraulic equipment, must be considered. A number of proposed reservoirs will be partly fed by ice-dammed lakes, draining annually or once every few years, so the
hydrological effects of such lakes also need consideration, for example in design of spillways.

DATA CURRENTLY BEING COLLECTED

Meteorological observations

Figure 1 shows the location of test sites in Greenland. Long-term meteorological observations are rather scattered, with most stations located in townships along the west coast of Greenland. These measurements, the longest of which extend back about one hundred years, are mainly carried out by the Danish Meteorological Institute (DMI) for the purpose of providing routine weather service. Some shorter records are available from ice cap stations, while a number of expeditions have made observations over short periods, usually only in the summer.

Since 1977, about twenty automatic climate stations have been established by the GTO within basins being considered as possible sites of hydropower projects. The Geological Survey of Greenland (GGU) is also manning climate stations in connection with their glaciological field programs in Greenland. For these measurements, the emphasis is placed upon recording of simple climatic elements,
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e.g. air temperature, humidity, wind speed and direction, sunshine duration and precipitation. The data will be used both for developing runoff models and for assessing climatic conditions for building and operating hydropower stations.

Few measurements of energy-balance have been made in Greenland, the most complete one being by Ambach (1963), but it is hoped that some studies will be made in the future. Simple measurements of pan evaporation are also being made by the GGU at two stations.

Streamflow observations

The oldest streamflow measurements in Greenland on a multi-year basis were made by the GGU in the Narssaq basin in South Greenland (Larsen, 1973). However, since the mid-1970s more than twenty stream-gauging stations have been established in a number of basins on the west coast. The majority of these are operated by the GTO, with further stations run by Krvolitselskabet oresung A/S, the Geographical Institute, University of Copenhagen, the GGU and Greenex A/S.

Glacier inventory

Weidick & Olesen (1980) have prepared a basin inventory for West Greenland on the basis of available topographic maps. The work is now being expanded to a full glacier inventory according to TTS World Glacier Inventory specifications (Weidick, 1981). The first part has already been published (Knudsen & Weidick, 1981). The inventory will include extra information about the hypsographic distribution of glaciers, in addition to standard parameters recommended by the TTS.

Glacier fluctuations

Some information about past glacier fluctuations have been compiled by Weidick (1959 & 1968) from historical sources and geological evidence. The work has now been extended to include regular field measurements of mass balance on several glaciers: the Nordbogletscher (Olesen & Weidick, 1978; Clement, 1980 & 1981), Narssaq Brae (started 1981), Qamanârssûp sermia (Olesen, 1981) and Manitsup sermilia (started 1981). As far as possible, the observations are being made according to international specifications and include measurements of complete mass budget as well as collection of simple climatic data at the main sites.

A long-term programme of deep drilling on the Inland Ice has been carried out by the Geophysical Institute University of Copenhagen (Reeh et al., 1978) to determine past climatic fluctuations, such as accumulation rate and temperature.

Sediment transport and glacier floods

Some studies of sediment transport have been made, for example, Hasholt & Thomsen (1980) carried out measurements of suspended load
in the Nordboso fed by the Nordbogletscher, South Greenland. One of the GGU stream gauges is placed in a stream feeding an ice-dammed lake at the side of Nordbogletscher. As the water level in the lake is also being recorded, it is possible to document the filling and draining cycle.

THE MODELS BEING USED

Introduction

There is no network of long-established stream gauging stations in Greenland. One station was operated near Narssaq in the period 1967-71 as part of the Danish IHD Programme (Larsen, 1973), while all the present runoff stations were established after their localities were identified as possible sites for hydropower projects. The localization of these sites can only be made in the first place, therefore, by the use of very simple regional models based upon climatic generalizations and even guesswork. Naturally, such models cannot be highly accurate, but they only need to be sufficiently accurate to provide a basis for decisions as to which localities are worth further investigation, especially by establishment of runoff and local climate stations. After a few years of data collection from these stations, the records can be used in conjunction with site-specific models to generate long-term runoff simulations for project design.

Regional models

ACG/VBB (1975) estimated the annual runoff of sixteen large basins in West Greenland using a very simple regionally-lumped model. The area from latitude 60° to 69°N was treated as three zones, for each of which altitudinal distributions of annual ablation and precipitation were estimated. The annual runoff of each basin was then calculated by applying these curves to the hypsographic distributions of the basins as determined by planimetry of 1:250 000 scale maps. The assumed increases of precipitation with altitude and decrease with distance from the coast were based upon the little data available, while the ablation model was based upon unpublished data collected in 1974 in the Isukasia area. No explicit estimates of year-to-year or seasonal variability of the runoff were made.

Weidick & Olesen (1980) prepared an inventory of hydrological basins in West Greenland which includes estimates of water balance together with basin physiography. However, in their case, the estimates refer to natural basins terminating at sea level rather than basins feeding possible reservoirs. Basin precipitation was estimated from maps of precipitation in coastal areas and of accumulation on the Inland Ice. This was combined with a generalized curve of mass balance derived from measurements made by the Wegener and EGIG expeditions in the Umanak and Disco Bugt areas. Both runoff and iceberg calving were considered and it was
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found that calf-ice production was a major water sink so that the theoretically useable runoff in West Greenland only constitutes about 41% of the total precipitation income.

Braithwaite (1980) calculated the regional distribution of ablation in West Greenland using degree-day factors extrapolated from coastal weather stations. However, the ablation appears to be overestimated at higher elevations, probably due to neglect of refreezing, while effects of land-heating are not accounted for. A regional runoff model has also been developed (Braithwaite, submitted) using precipitation data extrapolated from coastal weather stations and assuming that all glaciers are in equilibrium. Results for the annual runoff are roughly similar to those calculated by ACG/VBB (1975) and have an estimated error of 30% to 40%. However, additional calculations of year-to-year variability are also made which indicate that the effect of glacier cover is to reduce year-to-year variations in runoff. A further development of the model to include explicit calculations of mass balance variations is now being attempted (Braithwaite, 1981), although there are still problems to be solved.

All of the above attempts suffer from the fact that the network of climatic stations in Greenland is biased to coastal locations, while there were too few measurements of glacier ablation and almost no measurements of evaporation. The delineation of drainage basins from available topographic maps is also problematic, especially for areas fed by runoff from Inland Ice sectors.

Site-specific models

The NAM-II model is a site-specific model developed by the Institute of Hydrodynamics and Hydraulic Engineering (ISVA), Technical University of Denmark, for application to arctic areas. It is a development of an earlier model described by Christensen & Hansen (1980). The main purpose of the model is to extend existing short-term runoff series in Greenland by the use of long-term climatic variables to provide a basis for design of hydropower projects. As the network of climatic stations in the country is sparse, the input data requirements for the model are purposely designed to be flexible. For example, the melting of the snow and ice cover is calculated by either a degree-day approach, using only air temperature, or by an energy-balance approach requiring wind speed, humidity and cloud cover or sunshine duration as additional data inputs. The model works on a day-to-day basis, i.e. daily means of climatic data are fed into the model which computes daily runoff.

The NAM-II model may be categorized as a conceptual, semi-distributed model. Thus the model facilitates the division of basins into sub-areas, which makes it possible to take into account the areal variability of meteorological conditions within the basin. However, the routing of water through the basin is performed by means of two different conceptual lumped models, one for ice-free areas and one for glacierized areas, based on linear reservoir theory. Some details of model structure are given by Gottlieb (1980a).
So far, no restrictions in the applicability of the model have been discovered except for the limitations set by the quality of the input data. The model has up to ten parameters which require re-calibration for each new basin to which the model is applied. This is done by comparing observed and calculated runoff during the measuring period. The quality of the calibration depends, of course, on the length and quality of the measured series. In general, about four or more years of measured runoff data will result in an acceptable calibration for many practical purposes. Up to now, the NAM-II model has been applied to the following basins:

- Narssaq River, South Greenland (unpublished)
- Johan Dahl Land, South Greenland (Gottlieb, 1980a)
- Taserssuaq-Holsteinsborg, West Greenland (Gottlieb & Iversen, in press)
- Peyto Glacier, Alberta, Canada (Gottlieb, 1980b)
- W-3 Sleepers River, Vermont, USA (Gottlieb et al. 1980)
- Joekulsa a Fjotsdal, Fjorsa River & Tungnaa River, Iceland (Gottlieb & Einarsson, in press)

PERCEIVED GAPS IN DATA AND MODELLING PROCEDURES

Although it must be admitted that there is still relatively little experience of modelling glacier runoff in Greenland, it is suggested that limitations in predictive techniques are not the most serious problems. The most serious problems are related to the lack of basic data, e.g. insufficient measuring sites and short series, although field programs are now underway to remedy these deficiencies.

There are long-term weather stations on or near the coast and a few stations on the Inland Ice have moderately long climatic records. The poorest coverage in terms of fewest stations and shortest records is of the Inland Ice ablation area and marginal zone, which are important regions for hydropower.

Because of the large scale of available maps (1:250 000) and the difficulties of mapping the Inland Ice, even the delineation of surface drainage patterns is uncertain. To this must be added that there is almost no information about intra- or sub-glacial drainage. A systematic programme of radar echo-sounding in all areas of interest would be desirable to determine bottom topography.

Very few direct measurements of radiation and heat balance have been made yet, so that the main climatic input to present ablation models must be air temperatures extrapolated from coastal weather stations. Questions of assigning lapse rates and assessing coastal/inland effects must be considered.

Systematic measurements of mass balance have only recently started in a few areas so that the net contribution of glacial waters to runoff is little understood as yet. For example, it seems that refreezing of meltwater as superimposed ice is a significant effect in many places, whilst ice-dammed lakes are common.
Observations of glacier tongue fluctuations have been compiled but they are difficult to interpret directly in terms of mass balance because of the typically long response times of most Greenland glaciers.

Because hydrological measurements have only been started recently, there are still problems with instrumentation, selection of measuring sites and data analysis. For example, some published runoff data are liable to be updated as improved rating curves are obtained. Problems of a technical nature or due to the harsh environment have also been encountered with automatic recording instruments.

REFERENCES


Gottlieb, L. & Einarsson, K. Experience with hydrological
modelling of Icelandic basins (in press). *Nordic Hydrology.*
a snow routine and applications to runoff simulation. 6th
inst. Rapport 52, 67-82.
Hasholt, B. & Thomsen, T. (1980) Sedimenttransport i oplandet til
52.
Larsen, L.B. (1973) Water balance investigations in the Narssaq
river basin, South Greenland. Unpubl. thesis, Copenhagen
University. 159 pp.
Olesen, O.B. & Weidick, A. (1977) Vandkraft i Gronland -
Olesen, O.B. & Weidick, A. (1978) Glaciological investigations in
Olesen, O.B. (1981) Glaciological investigations at Qamanarssup
105, 60-61.
Reeh, N., Clausen, H.B., Dansgaard, W., Gunderstrup, N., Hammer,
Weidick, A. (1959) Glacial variations in West Greenland in
Weidick, A. (1968) Observations on some Holocene glacier
Unders.* 73, 202 pp.
Weidick, A. (1981) Status of the West Greenland glacier inventory
Weidick, A. & Olesen, O.B. (1980) Hydrological basins in West