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Hydrological modelling in Greenland in connection with hydropower

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There is still interest in the possibility of using runoff for the generation of hydroelectric power in Greenland. However, systematic investigations of the hydrological conditions in the country are relatively recent. For example, the longest runoff series were only started in 1976, while measurements were started even later at potentially attractive sites near to Jakobshavn, Christianshåb, Godthåb, Frederikshåb, and Angmagssalik.

A knowledge of hydrological conditions, especially with respect to annual runoff and its variability, is naturally one of the important components in the planning of hydropower

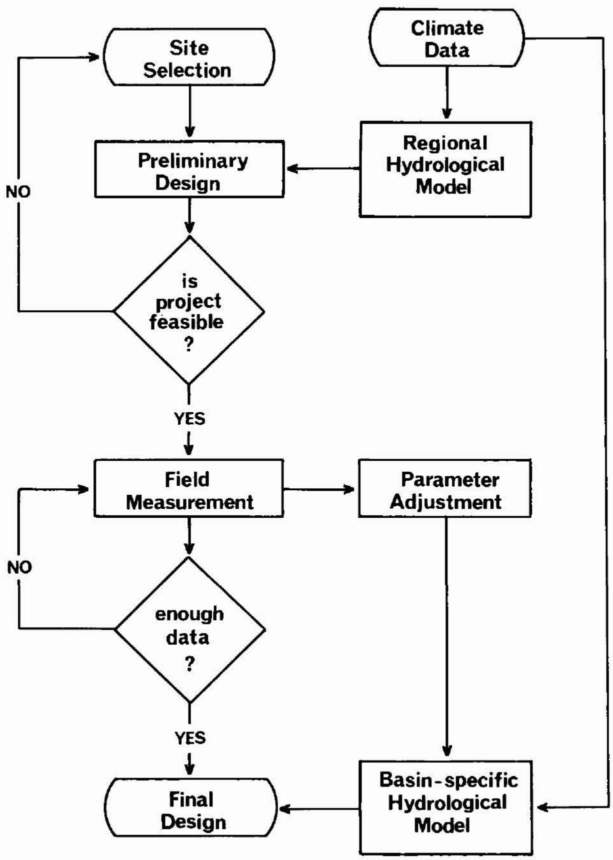

Fig. 37. Relationship between design stages of a hydropower project and hydrological models.

projects. However, the sparsity of hydrological data in Greenland means that the identification and evaluation of possible hydropower sites must be made initially in the complete absence of any measurements of runoff in the area. Once a site has been judged to be potentially attractive, measurements of runoff will, of course, be started there. Such measurements will continue for a few years but one cannot afford to wait for several decades to assemble a statistically representative measurement series before making any decision about the feasibility of the project.

The solution to this shortage of hydrological data at crucial decision stages is to use models to generate surrogate runoff data from climate data at coastal weather stations, combined with the study of basin topography from maps.

Two different kinds of climate-runoff model are required. For the initial evaluation of a possible hydropower site (the pre-feasibility study) a regional hydrological model is required which must be based solely upon climate data from the coast as no runoff data will be available from the actual basin. Such a model cannot, in the nature of things, be highly accurate but it only needs to be accurate enough to avoid making serious mistakes about the hydropower potential of the basin. After a few years of runoff data have been collected, a more detailed evaluation of the basin's potential will be made (feasibility study) using a basin-specific model. The few years of runoff measurements, together with parallel climate data from the coast, will be used to test and calibrate the model. The calibrated model will then be applied to older climate data, i.e. pre-dating the start of runoff measurements, to estimate past runoff variations which will be used in preparing more detailed designs of the hydropower project.

The relationship between the feasibility-design stages of hydropower projects and the two kinds of hydrological model, i.e. regional and basin-specific, is illustrated in fig. 37.

An important part of GGU's hydrological programme in the last few years has been to develop models of both kinds, with especial emphasis on runoff from glaciers (Braithwaite, 1981a). A brief review of two GGU models is given in the following sections.

The simple model of runoff from ungauged basins

This has been described by Braithwaite (1982), while examples of its application are given in Braithwaite (1981b) under the name Model II, and in Braithwaite (1981c) in a modified form.

Essentially the model calculates the mean and the coefficient of variation of mean specific annual runoff for a basin with any degree of glacierization. All glaciers are assumed to have a long-term mass balance of zero, although year-to-year fluctuations in mass balance are taken into account, while the evaporation from glacier-free areas is frankly a guess. An illustration of the results is given in Table 4 which lists mean specific runoff as a function of latitude and degree of glacierization. The total runoff for a basin is obtained by multiplying the mean specific runoff by the basin area.

The model cannot be very accurate for several reasons. For example, in addition to the uncertainties in the evaporation, precipitation at coastal stations must be used as a surrogate for the basin precipitation which is unknown at the stage when the model will be applied. A further drawback is that the total basin area must be known. This is no great problem for coastal basins with only a moderate degree of glacier cover but can be extremely difficult for basins including sectors of the Inland Ice because of the problems in delineating the higher parts of such basins.

The development of the model involves the paradox that it is intended to be applied to

Table 4. Estimated specific runoff in West Greenland as a function of latitude and degree of glacierization, based on Braithwaite (1982)

	DEGREE OF GLACIERIZATION					
LATITUDE	0.0	0.2	0.4	0.6	0.8	1.0
60	0.6	0.7	0.7	0.7	0.8	0.8
62	0.7	0.5	0.6	0.6	0.7	0.7
64	0.5	0.5	0.5	0.6	0.6	0.6
66	0.4	0.4	0.4	0.5	0.5	0.5
68	0.3	0.3	0.3	0.4	0.4	0.4
70	0.2	0.3	0.3	0.3	0.3	0.3

(Units are m water equivalent rounded-off to nearest 0.1 m) basins where no runoff measurements have been started, while it can only be rigorously tested in areas where a few years of measurements exist. Despite this, there are indications that the model is accurate to within 30 to 40 per cent (Braithwaite, 1982) which is probably good enough at the pre-feasibility stage of a hydropower project. The optimum conditions for applying this model are probably in smaller local basins near to the coast, rather than basins including large Inland Ice sectors.

From the calculations of coefficient of variation of runoff by the model, it appears that a moderate amount of glacier cover in a basin has the effect of smoothing year-to-year variations in runoff compared to unglacierized basins. This has the consequences of reducing the relative sizes of reservoirs for multi-year storage, and of shortening the periods for which measurements have to be made to achieve any prescribed level of statistical quality.

The model is primarily intended as a regional hydrological model although it can also be applied to basins with little glacier cover as a crude basin-specific model as carried out by Braithwaite (1981c).

The advanced model

The advanced model involves separate treatment of glacier-covered and glacier-free areas by two different sub-models; MB1 (mass balance 1) and SM1 (snowmelt 1), respectively. These models calculate specific values of various water balance elements (e.g. accumulation, ablation and rainfall) as a function of elevation (presently at 200 m intervals). Specific runoff values from the two models are then passed into a third sub-model RO1 (runoff 1) which calculates total basin runoff. An early example of the approach is given by Braithwaite (1981b) under the name Model III, while the MB1 model has also been used for estimating mass balance variations over the last century in the Jakobshavn area (Reeh, 1983).

The model is a distributed model in contrast to the simple runoff model which is a lumped model. This, together with the separation of the model into the three sub-models, makes it particularly easy to experiment with different choices of areal distribution for the basin. This is a very useful facility when applying the model to basins including Inland Ice sectors.

The MB1 model. This is a natural development from the regional ablation model described by Braithwaite (1980). The 'ablation' calculated by the earlier model, from extrapolated temperature data, is now treated as 'potential' ablation which, together with rain, may be refrozen again. The model includes precipitation which, on the basis of temperature, is divided into rainfall and snowfall for the different elevations. New snow is added to the glacier surface which may be either bare ice or old snow, while meltwater and rainfall are absorbed into the snow cover by refreezing until its density reaches a specified critical density value, after which runoff is allowed to occur. The time increment for the calculation is one month, and running totals of the different water balance elements are stored and used for calculating annual balance elements, e.g. annual ablation and accumulation or winter balance and summer balance. The annual equilibrium line altitude (ELA) is also calculated and has been used for diagnostic purposes. For example, it has been found that reasonably realistic ELA values can be achieved if the critical density is set at 900 kg m^{-3}, i.e. if runoff is only allowed from ice, while calculated ELAs are generally much too high if the critical density is set at only 300 kg m^{-3}, i.e. if runoff is also allowed from settled snow.

The SM1 model. This is rather similar to the MB1 model except that there is only snow ablation and no ice ablation.

The RO1 model. The area-elevation relations must be specified separately for the glacier-covered and glacier-free parts of the basin. The evaporation from the glacier-free parts is estimated by specifying a runoff coefficient, i.e. the ratio of runoff to liquid water available. The total runoff from the basin is then calculated by integrating the specific runoff values from the MB1 and SM1 models over the appropriate areas. The calculation is made on a monthly basis for as many years as there are climate records as input data.

The advanced model can be used as either a regional or basin-specific model, and it can be applied to basins containing Inland Ice sectors as well as conventional basins. In the first round of calculations, the model uses only climate data from coastal stations (regional model). The calculated runoff can then be compared with any available runoff observations to produce a new series of calibrated runoff data (basin-specific model). Making the calculations in two stages like this gives the model greater flexibility than more conventional basin-specific models which fit model parameters directly to runoff records.

Outlook

During the 1983–1984 winter, the advanced model will be applied to several basins where the Greenland Technical Organisation (GTO) has measured runoff for a few years. The model will be tested and used to estimate runoff variations over several decades as a basis for evaluating present proposals for these basins. Further testing of the simple model will also be made at the same time.

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