MORPHOLOGICAL AND HYDROLOGICAL POSSIBILITIES FOR THE DEVELOPMENT OF WATER POWER AT ANGMAGSSALIK

A case study of applied physical geography

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Scientific results from a field station belonging to the Department of Geography, University of Copenhagen, have been applied to determine the possibilities for development of water power at Angmagssalik, Eastern Greenland. It is shown that the potential power production of the area is about 10-15 GWh/year or, enough to cover a substantial part of the local requirements.

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INTRODUCTION AND SCOPE

Hydrological investigations have been carried out by the Department of Geography, University of Copenhagen, at its field station situated near Angmagssalik, East Greenland. Some of the results have been published earlier by H. Valeur (1959) and B. Hasholt (1972). The main purpose of these investigations is of a scientific nature (a.o. mass balance studies of a glacier), but in the light of the global energy crisis it has been convenient to use the scientific results for the practical purpose to determine the possibilities of energy production at the town of Angmagssalik.

The purpose of this investigation is:

1. To investigate the morphological conditions for the development of water power at Angmagssalik Ø.
2. To calculate the amount of water that can be utilized for power production.
3. To make preliminary calculations of the possible power production.
4. To select the most suitable sites for the power production.

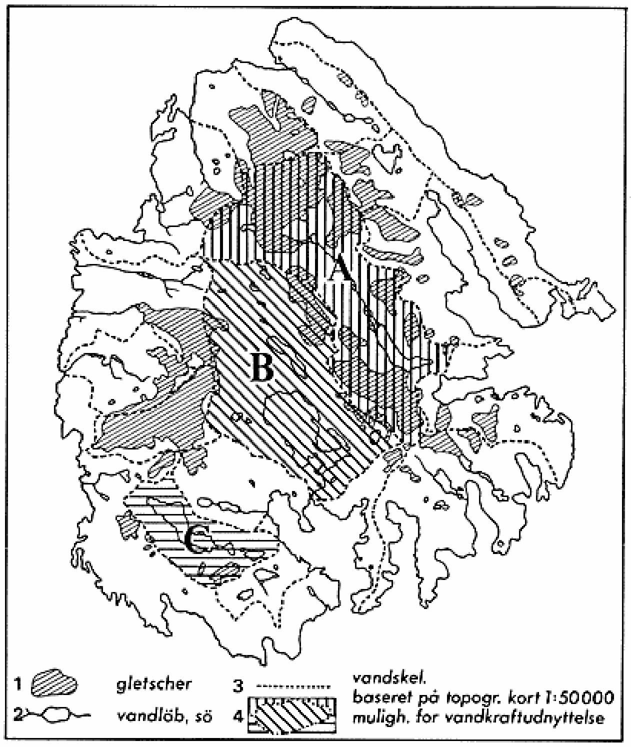

Fig. 1. Survey map 1:250.000 (after map 65 Ø I from Geodetic Institute, Copenhagen).
1: Glacier. 2: Watercourse, lake. 3: Watershed.
4: Selected drainage basins.
Fig. 1. Oversigtskort 1:250.000 (65 Ø I).
1: Gletscher. 2: Vandløb og sø. 3: Vandskel.
4: Udvalgte nedbørsområder.

DATA

Morphological data

The basic maps were surveyed by the Geodetic Institute in 1932-33 and appear at 1:50,000 with 50-m contour intervals. A few photogrammetrically drawn maps from the vicinity of Angmagssalik are available. The maps were surveyed in 1963 and drawn in scale 1:10,000 and 1:20,000 with contour intervals varying from 10 to 50 m. A map of the Midtluaqkat glacier was surveyed for the Department of Geography 1972 at 1:10,000 with 5-m contour intervals.

Depth curves near Angmagssalik are shown on harbour plan No. 2351 elaborated by Søkortarkivet, Copenhagen. Furthermore the morphology can be studied on various aerial photographs from the period 1943-1972.

A systematic coverage of the area has not been made, and some of the existing pictures are oblique. It can be mentioned that many stretches of the drainage divides have been checked in the field in connection with geographical expeditions in the area.

Fig. 2. Detailed map of drainage basin (A), B and C.
Fig. 2. Detailkort over område (A), B og C.
Geodetic Institute. Copyright (A 173/80).

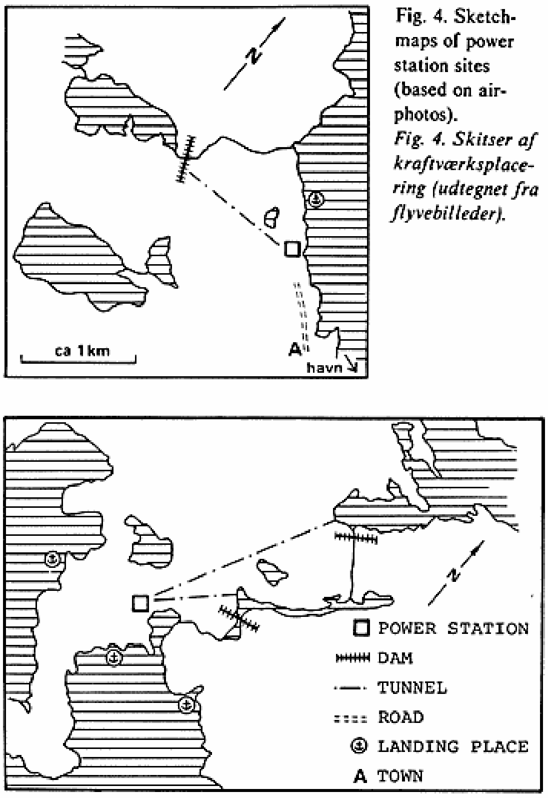

Fig. 4. Sketch-maps of power station sites (based on air-photos).
Fig. 4. Skitser af kraftværksplacering (udtegnet fra flyvebilleder).

Hydrological data
Since 1897, climatological observations have been collected at Angmagssalik. With a few exceptions during World War II, precipitation has thus been measured since this year. Moreover, the Meteorological Institute has measured temperature, humidity, air pressure and other variables.

At the Sermilik Station the same variables are measured when the station is manned, so to say in the summer period only, due to the severe climatological conditions and heavy transport problems.

Since 1977, the potential evapotranspiration has been measured with a »Knudsen evaporimeter« placed 0.75 m above the ground. Snowmelt and discharge from the glacial stream have been measured during the melting periods 1977 and 1978. Single observations from other watercourses have also been collected. Measurements of sediment transport in the glacial stream have been made, supplemented by single measurements from other watercourses.

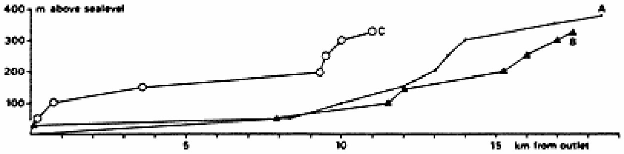

Fig. 3. Length profiles of drainage basins A, B and C.
Fig. 3. Længdeprofiler af A, B og C.

MORPHOLOGICAL CONDITIONS
The drainage divides from the whole island appear on maps in scale 1:50,000. The main divides are shown on the map 1:250,000, fig. 1. It is seen that the eastern two thirds of the island are characterized by deep glacial valleys with a main direction from NV-SE. The main drainage divide is placed rather near the Sermilik Fiord. Most of the drainage basins are rather small, the largest basin area is about 100 sq.km. On the survey map three drainage basins are shown, all of them located within a short distance from Angmagssalik and covering a relatively large area. They will be described in greater detail in the following. The other existing drainage basins are considered too small or too far away to be of any significance for a production of water power.

On fig. 2 the basins A, B, and C are shown. Only the lowermost part of A is seen, however.

The respective fall heights can be seen on the crude length profiles drawn along the main watercourse for each area, fig. 3. Basin A has a very flat profile in the lower part, but a minor threshold near the outlet cannot be excluded due to the great distance between the contours. Basin B has a

Table 1

1. drainage basin	2. area sq.km	3. lake %	4. glacier %	5. effective area of drainage basin ca. sq.km	6. storage basin area sq.km	7. threshold fall height meter	8. threshold fall height + 20 meter
A	93.8	3	45	93	2.7	0-50	20
B	92.5	15	8	92	10.5	30	50
C	26.5	16	7	25	3.6+0.7	100	120

Basic hydrological data.
Hydrologiske basisdata.

waterfall a few hundred m above the outlet into the sea, the fall height is here at least 25-30 m. In basin C the water is falling about 100 m along a 7-800 m stretch near the outlet.

The areas of the selected drainage basins have been measured with a planimeter and are correct within ± 2‰; subareas of minor glaciers and lakes are less exact determined. Therefore the percentages of lakes and glaciers are correct within ±1%. The most important morphological characteristics for the basins are given in table 1. Basin A has a very significant percentage of glaciated area while basin B and C have a high lake percentage. This might indicate that the precipitation conditions differ rather much in the three basins, perhaps there is more precipitation in basin A.

From the above it is seen that exploitation of the water power theoretically is possible for all three basins. It is however necessary to build dams to establish fall height and storage basins. The dams drawn on fig. 2 are preliminary based solely on the contour intervals and not - as they must be - on geotechnical investigations.

HYDROLOGICAL CONDITIONS

Precipitation

In Angmagssalik the yearly precipitation consists of 62% snow. The corrected yearly precipitation must therefore be at least 20% higher (if the normal correction value from southern Denmark is used). The normal precipitation for the period 1921-50 is 749 mm (Lyshede 1969), in this publication the great variations in the precipitation at Angmagssalik are pointed out. Maximum and minimum precipitation for the same period is 422 mm and 1043 mm respectively. The precipitation recorded from 1898-1976 is shown in fig. 5. It is seen that for the period 1921-50 there is a remarkable absence of the relative high values that were recorded both before and after.

In the following computations the value from the period 1940-70 is used, fig. 7, together with the values from 1921-50 and 1931-60. The distribution of the yearly values in the 30-years period is shown on fig. 6. It is seen that the distribution is skewed. The median is 815 mm and the average is 826 mm. About 73% of the values are above 700 mm/year. The seasonal distribution can be seen in fig. 7, there is a minimum from April to August of about 50 mm per month. In the same figure the monthly maxima and minima for the respective years are shown together with percentage of days with snow.

Evapotranspiration

The simple version of Turc's formula has been used for a preliminary computation of the actual evapotranspiration. Climatological data from Angmagssalik are used. The yearly evapotranspiration is 273 mm, when the temperature is —0.5°C (1921-50) and the precipitation is 815 (median). In a technical report on water power in Western Greenland by ACG/VBB for GTO, the annual evapotranspiration in three zones: 60°-63°, 63°-66°, and 66°-69° is 200 mm, 120 mm, and 60 mm respectively.

At the Sermilik Station the potential evapotranspiration is measured with a »Knudsen Evaporimeter« placed 0.75 m above the ground. In 1976 the evapotranspiration was 52 mm from 12/7-18/8. In 1977 the value was 118 mm from 29/5-7/8. In 1978 a value of 10 mm was observed from 27/7-7/8. The yearly values are not measured, but it is assumed that if the above measured values are reasonably indicative for the summer evapotranspiration, a yearly value of about 150-200 mm is a realistic one.

Discharge and runoff

The discharge is registered continuously at the outlet of the Midtluaqkat glacial stream. During the summer the discharge often varies between 1-10 m³/sec., the corresponding run-off values are 60 and 500 l/sec/km² respectively. In 1972 the mean run-off from 19/7-1/9 was 190 l/sec/km² with significant daily variations. From the drainage basin at

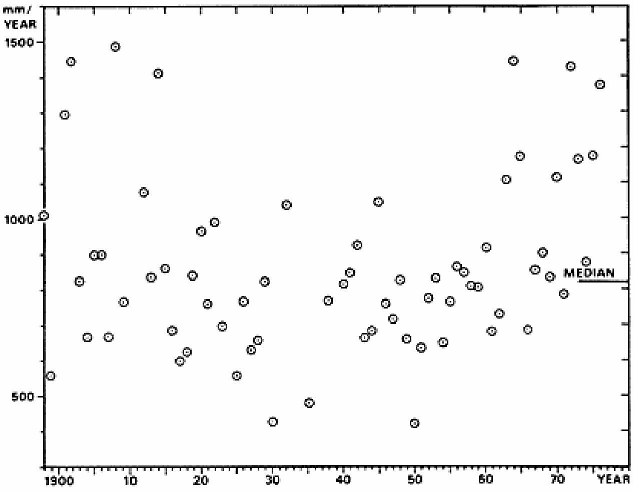

Fig. 5. Yearly precipitation values.
Fig. 5. Årlig nedbør.

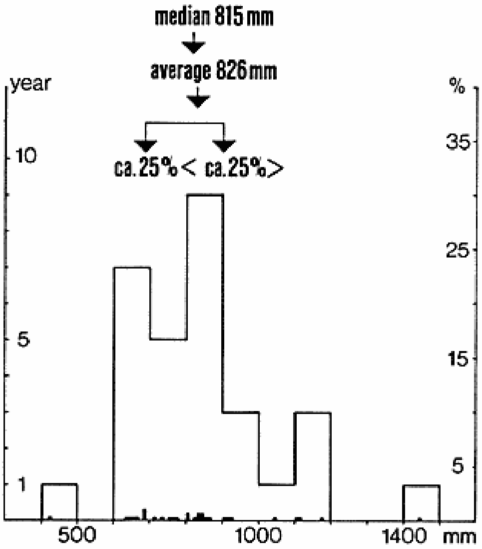

Fig. 6. Distribution of yearly precipitation for the 30-year period 1941-70. The small squares on the x-axis indicate exact yearly values.
Fig. 6. Fordeling af årsnedbør for 30-års perioden 1941-70. De små kvadrater angiver det enkelte års nøjagtige værdi.

Kugssuag, which has a relatively low amount of glacial meltwater, a run-off of 75-134 1/sec/km^2 has been measured at the beginning of August. Corresponding values from watercourses near Angmagssalik are about 80 1/sec/km^2.

It follows from the above that the discharge at the outlet of basin A, B and C in July-August will be about 9.9-2.5 m^3/sec.

The extreme value of 500 1/sec/km^2 is the result of heavy precipitation and melting on the glacier. A direct application of this figure in basin A, B and C gives the extreme discharge of about 45 m^3/sec. for A and B, and about 15 m^3/sec. for C. Because of the big lakes in basin B and C the realistic extreme values will be somewhat lower.

There are no measurements of the variations in discharge during a full year, the seasonal variations therefore have to be estimated. Mean monthly temperature at Angmagssalik is positive from May until October. During this period there will mostly be free water in the watercourses in contrast to the long periods the rest of the year when they are frozen up. Local observators, however, have ascertained drainage of water under the ice at the outlets of the larger lakes during winter. Positive daily maximum temperatures are measured in all months so that shorter periods of melt may occur.

The main thawbreak, however, occurs from medio May to medio July, somewhat later in higher-lying areas.

In 1977, the thawbreak started at the Midtluaqkat glacier at the end of May and culminated at the beginning of June. In 1978, it culminated at the beginning of July; but heavy thawbreaks have been seen still later, for example in 1972 when the extreme discharge appeared at the end of July.

In order to level out the seasonal variations and single, extreme discharges caused by heavy precipitation and snowmelt, possibilities must be found to store the water. Moreover, freezing and break-up of ice in the watercourses may cause troubles and require special technical precautions.

POTENTIAL POWER PRODUCTION

When making preliminary computations of the potential production certain assumptions, which are mentioned in the following, must be made.

The computation is based on the ordinary formula for potential energy:

$E = m \cdot h \cdot g \cdot e$

E: electrical energy (GWh/year), m: yearly discharge (10^6m^3/year), h: fall height (m), g: acceleration of gravity which together with e: the efficiency (85%) and an energy conversion factor are combined to a constant value of 0.00232.

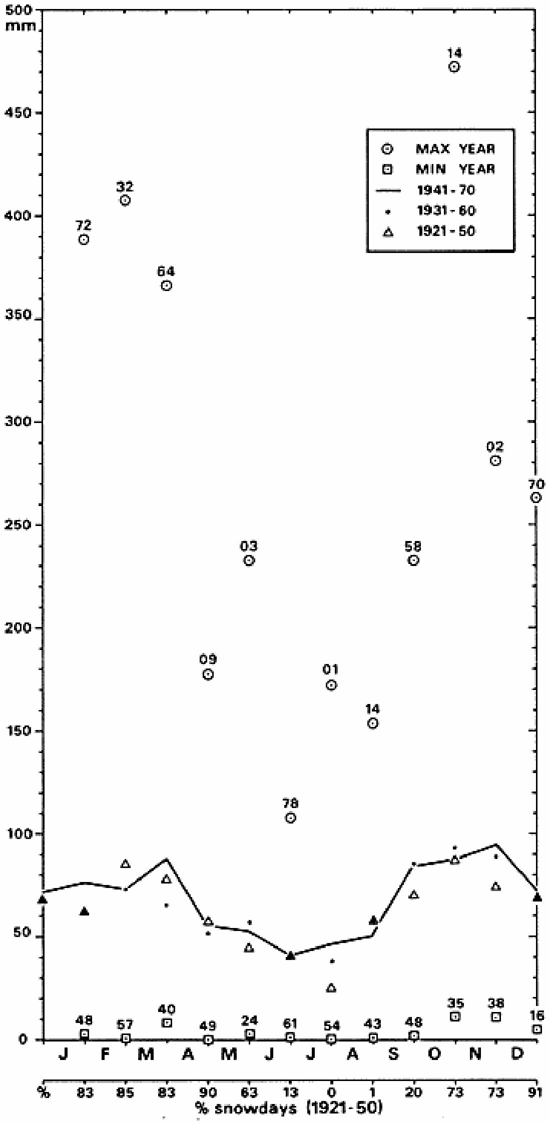

Fig. 7. Monthly precipitation for 30-years periods.
Fig. 7. Månedsnedbør for forskellige 30-års perioder.

Table 2

1. Precipitation median 1940-70	2. Ep mm *	3. Ea mm **	4. 1. - 2. mm	5. 1. - 3. mm	6. 1. x 1.2 - 2. mm	7. 1. x 1.2 - 3. mm
815 mm	150-200 mm	273 mm	615	542	778	705

* Ep mm = yearly evapotranspiration estimated on summer records.
** Ea mm = actual yearly evapotranspiration from Turc

Precipitation (measured and corrected) and evapotranspiration. Nedbør (målt og korrigeret) og fordampning.

The discharge values are stated above, discharges in mm are computed from the water balance and shown in table 2. The first figure is a very low value, the second is more realistic. The main uncertainty is due to the unknown precipitation conditions in the single basins. The underestimation due to snow is unknown and the variation of precipitation with height is unknown. Also the evapo-transpiration must be examined in more detail but there can be no doubt that the value is rather low.

The fall heigth is shown in table 1. The lowest value is the value found from the maps with the least distance between the contours. The other value is 20 m higher. The maximum possible fall height will be determined from the geotechnical conditions at the dam site and the construction costs. These must be known before final computations can be carried out.

The preliminary values of the power productions are shown in table 3, in basin B the value is about 8.3 GWh and for C about 5.4 GWh. The relatively low efficiency stated above is chosen because of the severe climatic conditions. Considering the uncertainties in the available basic data, the computed production values are thought not to be too optimistic. The basic values in the tables, however, make it possible to alter the computations when newer and more sufficient data are at hand. The best production possibilities are found in basin B, where also the storage is favourable.

OTHER LOCATION FACTORS

A considerable part of the costs will be construction of dams and tunnels whose size and length cannot yet be foreseen, however, because the final location of the power station will depend upon detailed investigations of relief and geotechnical conditions. So far some sketches have been elaborated on the basis of aerial photographs. Fig. 4 shows a possible location of dams and power stations for area B and C. For area C there is the alternative only to exploit the 17.4 km² large basin area of lake 168. This will, however, increase the lenght of the tunnel.

Transport of materials to the site is another economic factor of importance. To area C, the access is very favourable as there is a passable road up to 1 km from the site of construction. To area B there is roughly 8 km by land from Angmagssalik. Two minor streams have to be bridged; depending on location of the turbine, bridging of the stream at Qordlortoq will also be actual. The navigation conditions are good as the 10-m depth curve runs 25-100 m from the shore at both places. The distance by sea from Angmagssalik to the outlet of Qordlortoq lake (area B) is 4-5½ km. The shortest distance to Sangmileq (area A) is roughly 20 km, but hardly passable for heavier loads. By sea, there is roughly 35 km to the river-mouth. The transport conditions to area A are thus rather difficult compared to B and C.

The short distance to Angmagssalik makes it possible that the labour force can be resident here in case area B and/or C will be chosen. If more labour force will be needed than can be supplied from Angmagssalik, it will be necessary to construct some houses, but administration and health services are already there. Moreover, transport from residence to work-place can easily take place within 24 hrs. For area A it will be necessary to establish some houses at the working place.

It appears from the above that an exploitation of area A will involve considerably higher costs than the others.

CONCLUSION

On the basis of the collected data and the foregoing rough calculation the following can be concluded:

1. The morphological conditions are present for an exploitation of water power in 2 or 3 precipitation areas on Angmagssalik Ø. The suitable areas are indicated on sketch map fig. 1, and, more detailed, in fig. 2.
2. The annual precipitation surplus calculated as mean precipitation minus actual evaporation (Turc) is 0,54 m. Calculated as corrected precipitation minus evaporation based on measurements during the summer period the precipitation surplus should be 0,78 m.
3. A rough calculation of potential water power production based on lowest surplus of precipitation and »threshold« fall height will give a minimum potential production for

Table 3

1. drainage basin	2. Q_1* 10^6 m³/year	3. Q_1 average m³/sec.	4. Q_2** 10^6 m³/year	5. Q_2 average m³/sec.	6. regulation height meter	7. production 1 GWH ***	8. production 2 GWH ****
A	50.4	1.60	72.4	2.30	26.8	0	3.4
B	49.9	1.58	71.6	2.27	6.8	3.5	8.3
C	13.6	0.43	19.5	0.62	4.5	3.1	5.4

* Q_1 = yearly runoff volume from table 2, column 5 and table 1, column 5.
** Q_2 = yearly runoff volume from table 2, column 6 and table 1, column 5.
*** production computed from table 3, column 2 and table 1, column 7.
**** production computed from table 3, column 4 and table 1, column 8.

Water-volume, discharge and power-production. Vandmængde, vandføring og kraftproduktion.

area A and B of approximately 3.5 GWh and for area C approximately 3.1 GWh. Based on corrected precipitation and fall height corresponding to threshold height, the production will be for A and B roughly 8,3 GWh and for C roughly 5,4 GWh.

4. Area B offers the best conditions for exploitation due to the size of the drainage basin and the favourable regulation possibilities. The distance to Angmagssalik is reasonable (by land roughly 8 km). The navigation conditions are good with about 10 m water depth near the shore. Area C has more than 100 m fall height, but a relatively small basin area. Regulation is less favourable as there are 2 reservoirs in different heights. With a distance by land of only 2,5 km, the location in relation to Angmagssalik is very favourable. Area A is the least suitable because of the many glaciers, the low fall height, and the great distance from Angmagssalik.

SOME CONCLUSIVE REMARKS AND SUGGESTIONS FOR FURTHER INVESTIGATION

In the end, an exploitation of the water power depends on the result of a cost/benefit analysis; to make this lies beyond the scope of this investigation, but it has been made clear that considerations of cost/benefit should be justified as there is enough available energy to make Angmagssalik self-supporting. In this connection it deserves notice that in southern Denmark power plants are working which have a production corresponding to the one discussed here. They were established in times of crisis as employment measures. In its report on the water power in Greenland, the Swedish Vattenbyggnadsbyrån states the cost price to be about 50-60 øre per kWh for a plant of same size at Holsteinborg. This is planned to be built about 30 km from the town, a distance which will increase the costs of transport and working camps compared with a plant at Angmagssalik.

If, on the present basis, a cost/benefit analysis should prove that a utilization of water power is profitable, it will demand further investigations in the area to make sure that the basis of the calculations is correct. These might be:

1. Sites for dams and power plants as well as storage basins should be surveyed and mapped in larger scale with denser contour intervals and supplemented by geotechnical investigations of the dam areas.
2. The distribution of precipitation must be investigated in greater detail, as measurements made at Sermilik and the very uneven distribution of glaciers hint that the records made by the meteorological station at Angmagssalik are not representative for the island as a whole. Especially for area B and C, snow surveys are needed.
3. Run-off and sediment transport in area B and C have to be investigated. The discharge at the areas' outlet should be measured regularly.

RESUME

Det forsøges i artiklen at anvende de hydrologiske data, som i videnskabeligt øjemed er indsamlet ved Geografisk Instituts feltstation (Sermilikstationen), til et praktisk formål. De indsamlede resultater indgår sammen med andre data i en vurdering af de morfologiske og hydrologiske forudsætninger for udnyttelse af vandkraften ved Angmagssalik.

På basis af en udtegning af samtlige nedbørsområder på Angmagssalik Ø udvælges tre områder: A, B og C til nærmere analyse, se fig. 1. De fundne morfologiske og hydrologiske basisdata samt den beregnede potentielle kraftproduktion fremgår af tabel 1-3. Det konkluderes, at der i områderne B og C, som er egnede til vandkraftproduktion, årligt kan produceres ca. 10-15 GWh. På fig. 2 og 4 er angivet forslag til en placering af kraftstationer og dæmninger. Det bemærkes endvidere at det hydrologiske datagrundlag bør forbedres. Endelig vil geotekniske undersøgelser være nødvendige for at kunne gennemføre rentabilitetsberegninger.

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