National Energy Authority

Gunnlaugur H. Jónsson:

HYDRO

-A Dynamic Simulation Program for Optimization of Hydropower Sites and Simulation of Hydropower Plants.

Preprint of a paper presented at the Nordic Hydrological Conference, Vemdalen, Sweden, August 10-16th 1980.

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INTRODUCTION

Iceland has considerable hydropower of which about 30 to 40 TWh annually are considered economically and technically feasible for development. To date only about 10% of this potential has been developed. With the advent of the energy crisis further development of the remaining hydropower has become extremely important for the future development of the Icelandic economy (Fig. 1).

The development of hydropower however is a very complex problem and calls for the simultaneous application of many academic disciplines such as: hydrology, engineering, surveying, economics, geology and engineering geology. The problem is compounded by the fact that very often the development of a particular area's hydropower is most economically achieved by the diversion of rivers and combining of rivers into one in order to achieve the economy of scale which is inherent in all hydroelectric power projects (Fig. 2).

The National Energy Authority (NEA) has for a long time been aware of the need for a computing tool or procedure for quick comparison between the numerous options which are available for the development of a particular river system and for comparing the economy of one system with another.

The computer code "Hydro" was developed to meet this need. "Hydro" accepts data on hydrology, topography, surface geology and hydropowerplant structure; i.e. dams, tunnels, canals, turbines etc. The code simulates the hydrosystem using normally a 14 day series of runoff and annual load demand data obtaining the firm energy of the system as a function of reservoir storage and installed capacity. Built into the code is common engineering practice in building earth dams, tunnels, canals etc. Using derived volumes of materials the program calculates a standard cost of all components of the hydrosystem. The cost of these components will in most cases be an indirect function of storage volume in dams, head and flow rates through tunnels, canals and turbines.

Unit cost of the project components has been evaluated for NEA by Consulting Engineers Thoroddsen and Partners.

Fig.1

WATER POWER SITES* IN ICELAND

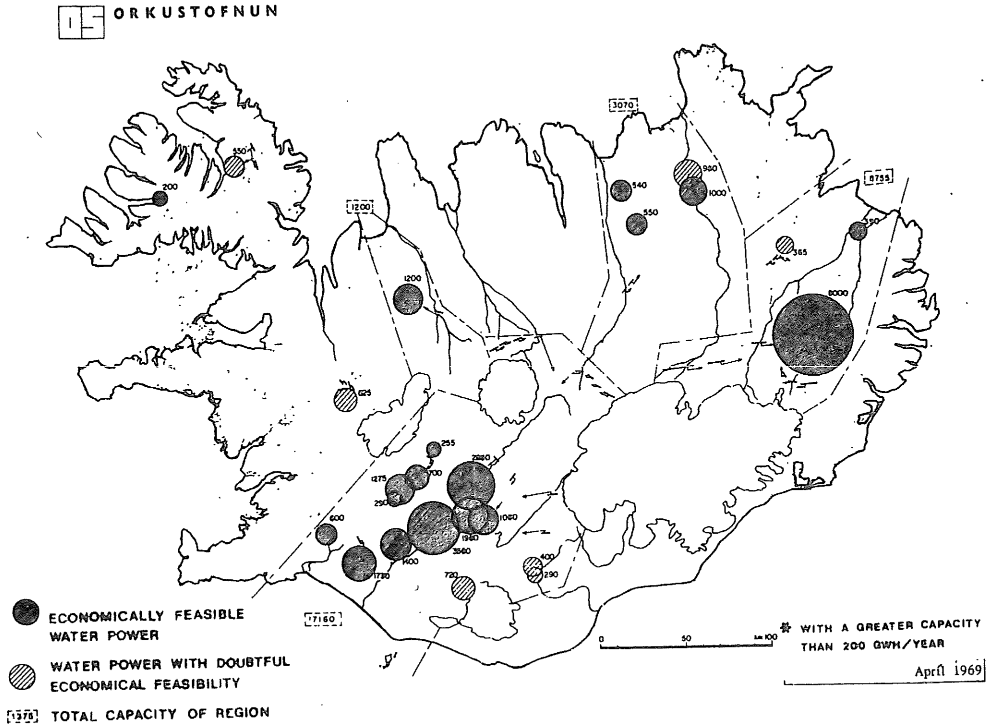
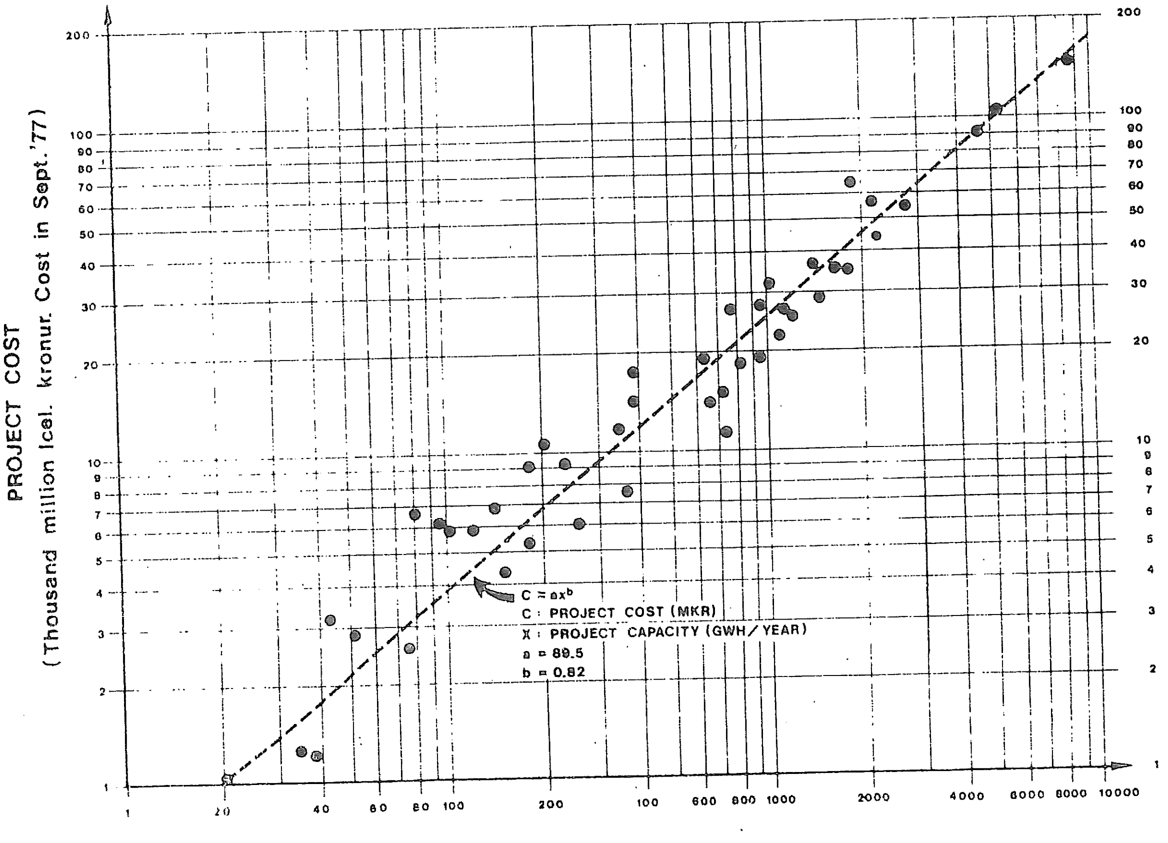


Fig. 2

ECONOMIES OF SCALE FOR WATER POWER PROJECTS IN ICELAND



By giving a value to the electric energy generated, and associating a cost to capital and energy not served (e.n.s.) by the hydro system (normally much higher than the value of electric energy, to reflect the high cost of energy shortage and energy produced from oil), it is possible to find the optimum development plan, that is the plan giving the greatest difference between the value of the electric energy and the associated cost of capital and e.n.s. by the hydro system. Included in the optimum solution is the total storage required and its distribution between reservoirs, capacity and dimensions of tunnels and canals etc.

HISTORY OF HYDROSIMULATION IN ICELAND

The first models for simulating hydro systems were developed at the NEA in 1966 with assistance from Professor Hveding from Norway who at that time was a United Nations adviser on power system analysis.

At that time two models were developed, the single plant model and the multiple plant model. These models, especially the multiple plant model, have been greatly refined since 1966, and have been used for simulating the energy potential of hydro systems.

GENERAL DESCRIPTION OF HYDRO

As stated previously Hydro was developed mainly to enable the NEA to campare quickly and consistently different alternatives for the development of a particular river system, in order to find the optimum developmentplan. A secondary benefit is the calculated firm energy for the development, and the possibility of camparing the economy of one river system´s development with another.

The following background information about the Icelandic electric system may be useful in understanding some of the underlying assumptions of the program:

1. The Icelandic electric system is for obvious reasons an isolated system with no interconnection to other systems.
2. Under normal conditions no thermal power generation is planned.
3. Normally sufficient reservoir capacity will be economically available in future developments for seasonal and some annual storage.

4. When thermal generation is 5 to 10 times more expensive than hydro generation and reservoirs cover all seasonal needs and some annual storage requirements the steady state optimum market for a hydro system is equal to the firm energy of the system, that is the energy available under the worst conditions on record, assuming that the records cover no more than 25 to 50 years.

The information required for the use of the program Hydro is mainly the following:

1. Hydrological data for the river system. In Iceland we normally simulate using 25 years with 26 periods of 14 days. By 1981 this will probably be extended to 30 years. Often this data is synthesized from nearby gaging stations and meteorological data.
2. Accurate topographical maps of the area. We use at this preliminary stage maps of 1:20.000 with 5 m contour lines.
3. Geological information, particularly on the overburden and depth to sound rock for dams, canals and other surface structures and rock conditions for tunnels and other underground structures.

The first stage consists mainly of map reading looking for suitable storage opportunites, dam sites and diversions of rivers to increase the potential of the main river development. The second stage is to compile all the reasonable alternatives for development and select for further study those most promising. The river system can now be divided into nodal points or collection points as we call them. A collection point consists normally of a dam or a diversion structure from which the water is conveyed to another collection point through a system of structures such as a dam, intake, canal, tunnel, headrace tunnel, powerstation, tailrace tunnel and canal. Associated with each collection point is an unregulated natural riverflow and all the structures necessary to harness that flow and convay it to another collection point.

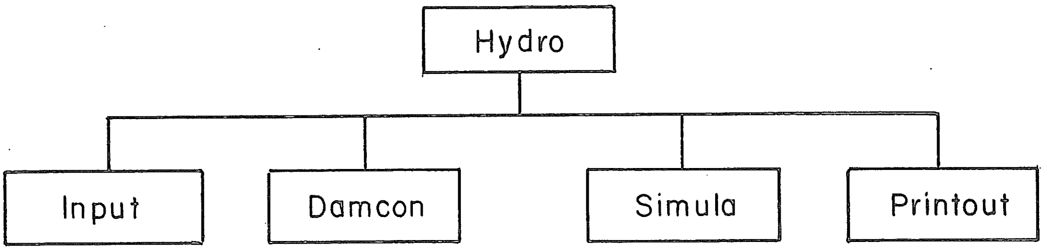
Some of the collection points are common to more than one alternative for development, but the dimensions of the associated structures may vary from one alternative to another depending on how much water is diverted through the collection point from other collection points, and also depending on how and where the water is taken to the next collection points.

I will describe later what information is required for each collection point and for each structure in order to calculate its associated cost. In general it is true however that surface structures such as dams and canals require topographical information read from maps and overburden geological maps. Some other structures such as tunnels, powerhouse, turbines and generators require much less detailed information, their cost being mainly a function of maximum flow and head.

The optimum development plan for a particular system of rivers is in theory one of an infinite number of possible plans, each of which has a range of possible values for storage and generation capacity. Any practical solution to the problem is therefore very dependant upon the people working on the problem being able to identify the most likely optimum solutions and being able to grasp the important features of the topography and the hydrology which make an economical hydro-project. Some of the most important of these are favourable reservoir sites (collection points).

Hydro in its present form consists of a main program Hydro and four subprograms, Input, Damcon, Simula, Printout (Fig. 3). Hydro calls on the subprograms and controls the simulation until the optimum market (firm energy) is found for each of a number of reservoir sites.

Figure 3



The structure of Hydro

INPUT

The input subroutine accepts general data on the system to be simulated and the file names of the collection points to be used, and the hydrological series.

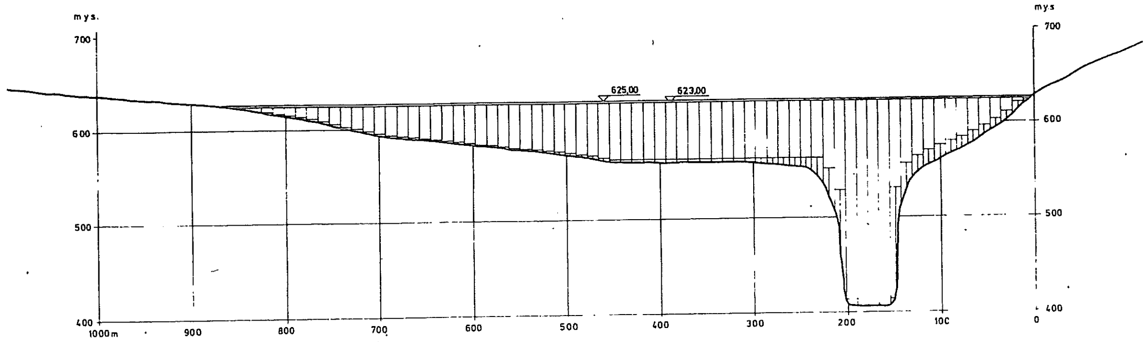
The input program does not only accept input from terminals and files. It also calculates the hydrological series to be used for each collection point, the average flow, the associated energy and the regulation capacity required in each year of the hydrological series to maintain the average energy of the system throughout the year. The regulation energy needed in the worst hydrological year is called the systems regulation index, and is used as a guide to the required reservoir size. Normally the optimum regulation is 0.9 to 1.2 times the systems regulation index.

Some of the power projects in Iceland have very limited regulation, and their limited regulation is not affected by and does not affect the regulation of other projects. In this case it saves a lot of computer time to calculate the run of river energy from these projects once and for all for each of the periods to be simulated. This energy is stored in the computer and when the system is simulated in Simula it is viewed as a corresponding reduction in load. This calculation of preproduced energy allows storage in each project but the release from storage is unregulated, as the stored water is used immediately when the river flow drops below the station capacity.

DAMCON

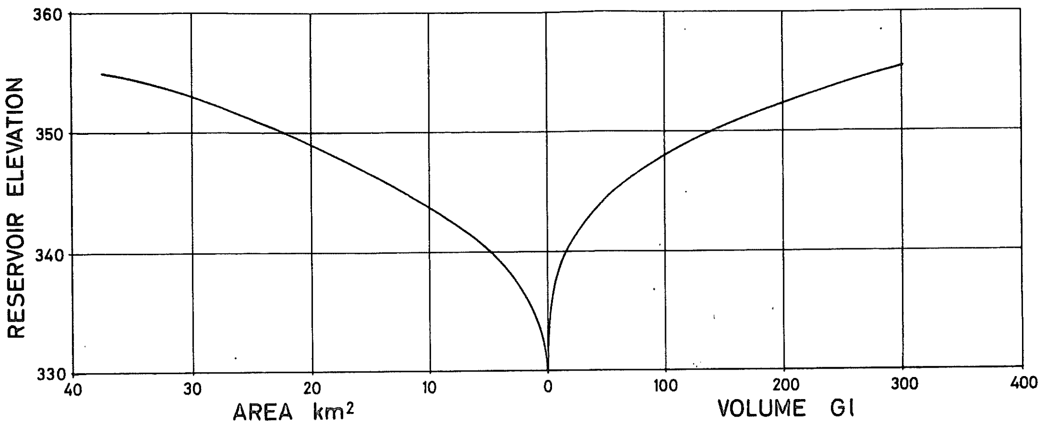
The subroutine Damcon reads from files information about the dams associated with each collection point. The most important information being:

1. The profiles of the dams. The profiles are defined by specifying the distance between contour lines, and their elevation. The profile is specified high enough to cover the highest likely reservoir elevation (see fig. 4).
2. The elevation-area curve of the reservoir. For each contour line the area of the potential reservoir is obtained by planimeter. See fig. 5.



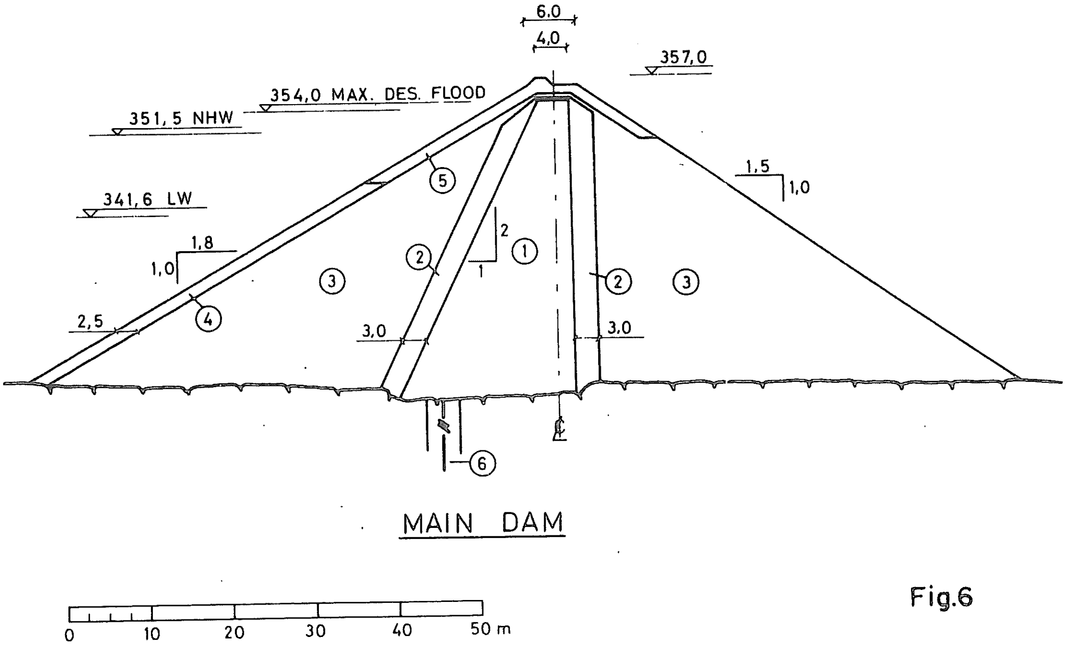
PROFILE OF THE DAM AT HAFRAHVAMMAR LOOKING DOWNSTREAM. IN DAMCON THE PROFILE IS INPUT NUMERICALLY.

Fig.4



RESERVOIR AREA-VOLUME CURVE

Fig.5



MAIN DAM

Fig.6

3. Engineering information about the dam such as: The width of the crown, upstream and downstream slope and the freeboard, Fig. 6.
4. Geological information about depth of pervious overburden.

The program calculates the following for a range of dam crest elevations: Reservoir storage volume in GL, average expected gross head utilized in downstream powerstations, total energy stored in reservoir, volume of dam, length of dam, cross-sectional area of dam, area of reservoir, and the average and instrumental cost of the dam in physical units. These physical units are defined as volume of dam in cubic meters over the energy contained in the dam, as measured by the product of reservoir volume in GL, and gross utilized head in meters.

For comparison when no information is available about the construction material it is normal to use a crown width of 6 m, upstream slope of 1.8 downstream slope of 1.6 and a freeboard of 4 m. Using this data the most favourable reservoir sites in Iceland have a cost of 3 to 12 cubic meters dam volume per GL reservoir volume and meter in head. Typically the average cost is high at small reservoir volume, while the incremental cost is low. As the size of the reservoir increases, the average cost decreases while the incremental cost increases, until they cross and both start to increase. See figure 7.

During simulation, when the above calculation is done for all the collection points for a particular initial height of dams, the program checks to see if the required regulation is achieved. (This requirement is expressed as a fraction of the regulated energy required to produce continously the average run of the river energy in the dryest year on record). If not the program automatically increases the storage in the reservoir with the lowest incremental cost, taking into account constraints such as permissible maximum storage (possibly due to limited inflow) and in some cases a required difference in reservoir levels to ensure that the water flows in the right direction. When it becomes necessary to raise the elevation of such a downstream reservoir the program automatically calculates the weighted average incremental cost of all reservoirs, whose level is affected.

SIMULA

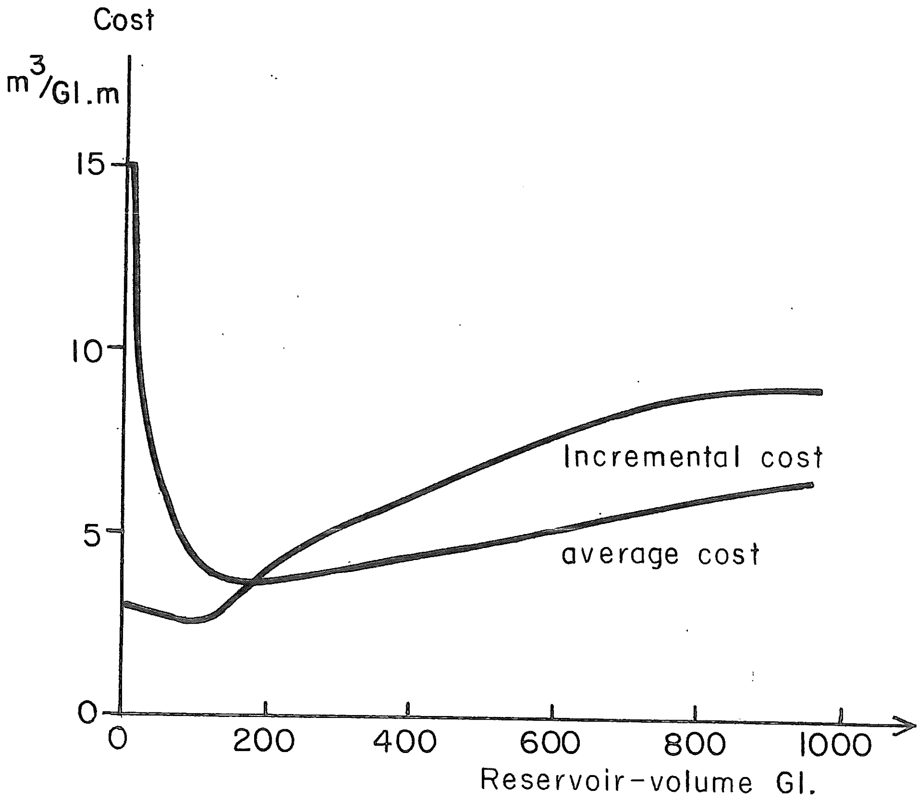
The module contains the dynamic program which simulates the operation of all the collection points which make up the system. This module uses the hydrological series produced for each collection point by the input module and information about lenght of tunnels, rated capacity, gross head and water consumption at rated capacity to calculated economic diameter of water conduits and the friction constant. From Damcon the module uses information about the relationship between reservoir level and reservoir volume.

Simula uses reservoir rule curves to guide the operation of reservoirs. These curves show the desired reservoir level as a fraction of full capacity for each of the 26 periods of the year. These rule curves differ from one reservoir to another, depending on the characteristic and purpose of the reservoir. In a typical storage reservoir the rule curve resembles a sinusoidal wave with a peak in the autumn (September-October) of 0.9 and a low in spring (April-May) of 0.1. Some reservoirs contribute considerably to the head of the associated powerstation. In that case it is desirable to keep the reservoir relatively full all year, and the rule curve may be a constant of 0.9. Often the reservoir of a collection point is relatively small, with a bigger reservoir upstream. In that case the reservoir is mainly used to regulate the limited natural unregulated flow and pick up daily load changes. The desired level of this type of reservoir is typically half full, giving a rule curve of 0.5.

For any collection point one can imagine an infinite number of rule curves, but at this preliminary investigation stage we have found it sufficient to use a combination of 5 rule curves as the solution is not very sensitive to the rule curves as long as they are reasonably selected (Figure 8).

For each period Simula calculates the deviation index from the rule curve for each collection point. This deviation index as shown in fig. 9 is calculated as the fraction "a" over "b", where "a" is the deviation from the rule curve in GL of storage and "b" the difference between the rule curve and a full reservoir when "a" is positive, and the difference between the rule curve and an empty reservoir when "a" is negative.

Figure 7



Eyjabakkar reservoir, cost volume relationship

This reservoir deviation index has a value of minus one when the reservoir is empty and plus one when the reservoir is full, when the reservoir follows the rule curve its value is zero.

Simula controls the release of water from reservoirs in such a way that the reservoir deviation indexes are about equal for all the reservoirs in each period. However, there are physical limitations on the flow from each collection point and these will be described now. The program checks the flow for the following constraints:

1. Flow must be less than the rated capacity of waterconduits and/or the associated powerstation.

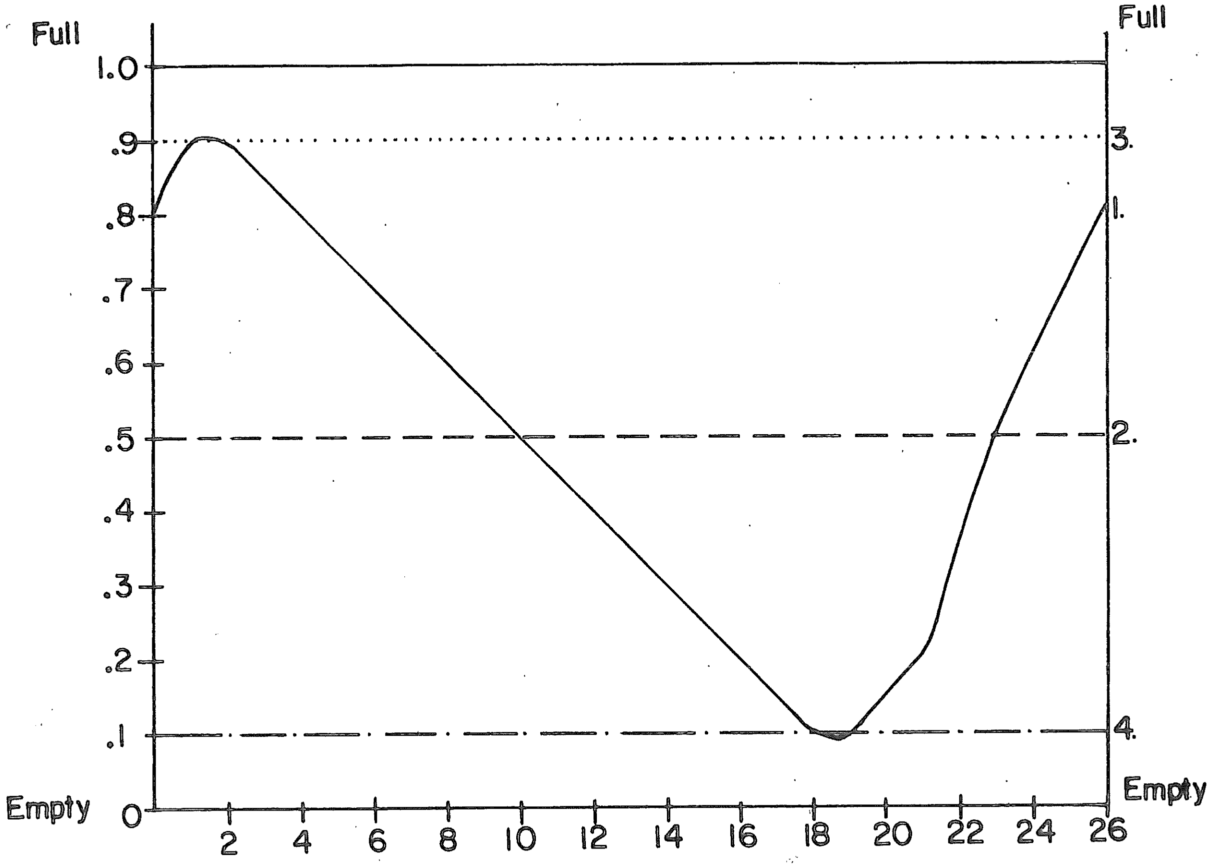


Fig. 8 Some typical reservoir rule curves

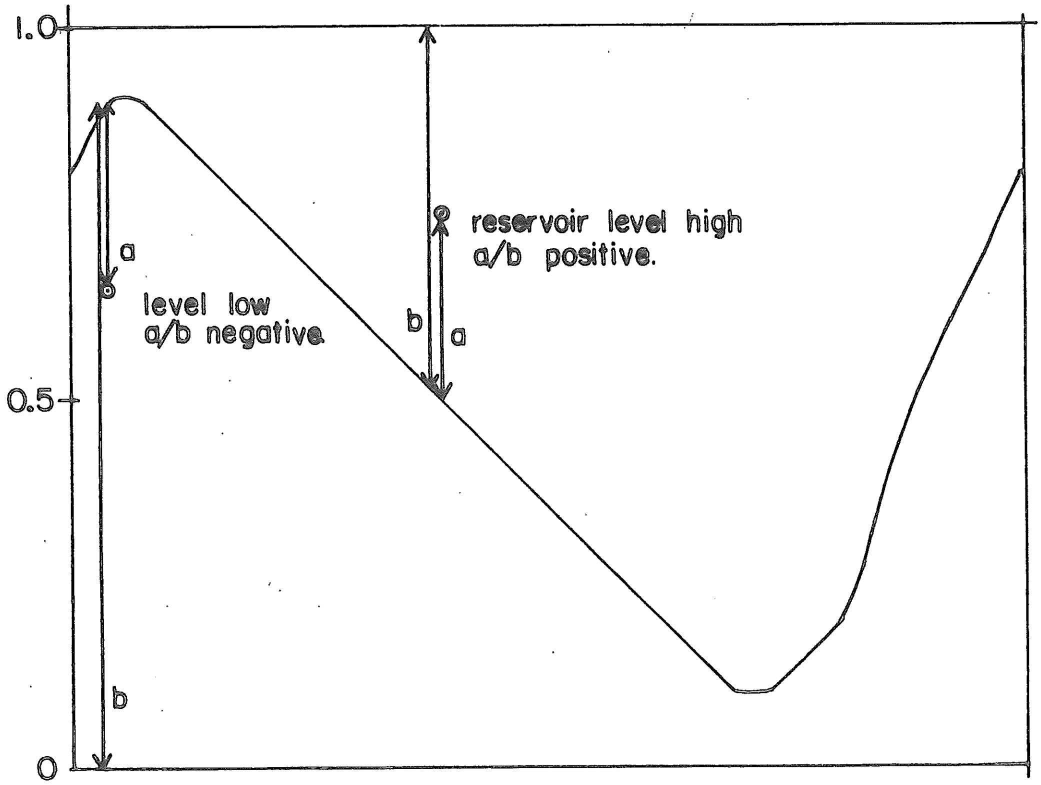
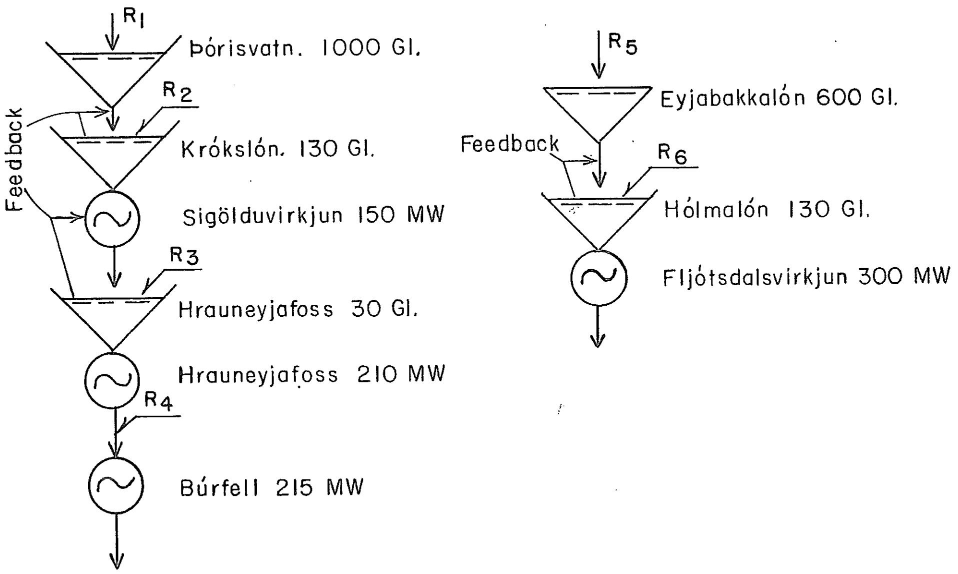


Fig. 9 Deviation index is equal to a over b.

2. Flow must not exceed the water available from runoff and storage.
3. In diversion tunnels waterflow may be limited by the head available to drive the flow. This head is a function of the level in the upstream reservoir at one end and the downstream reservoir or the tunnel exit (which ever is higher during the particular period) at the other end.
4. A limit may be put on water velocity in diversion tunnels to prevent erosion.
5. To minimize spillage, those reservoirs which are overflowing have a priority on release, which is consistant keeping the deviation index equal for all the collection points.

Figure 10



Downstream reservoirs give feedback to upstream controls

The aggregate level of release from all the reservoirs is controlled by the demand for power in each period, and this demand follows a yearly cycle, being greatest in Dec. Jan. and lowest in July. The market in Iceland is composed of: 50% power consuming industries with constant demand, 35% general load and 15% space heating. The aggregate of this gives a load which grows from 85% of the avarage demand in July to 113% of the average in Dec.-Jan.

To control not only the aggregate level of release but also the division between collection points, Simula uses the deviation from the rule curve, and a double feedback loop. The program calculates for each period the average deviation for all the collection points. Those points which have a relatively high deviation index increase their release relative to those which have a low deviation index. This makes up the primary feedback loop. Experience showed that this loop did not give enough stability to the system, when simulating two or more parallel systems with serially connected reservoirs. In some periods big upstreams reservoirs were starving a small downstream reservoir and at other times they were overfilling them.

To overcome this instability it was necessary to introduce a secondary feedback loop. This secondary feedback loop gives direct feedback from a downstream reservoir to the next upstream reservoir. When the deviation index of the downstream reservoir is higher, then the upstream reservoir reduces release, and when the downstream reservoirs index is lower it increases release. This secondary feedback prevents oscillations in serially connected reservoirs which may be operated parallel with other river systems. See figure 10.

The energy produced in each collection point during a particular period is a function of three factors, the average flow, net head, and the efficiency of the turbine. We have described how the flow is regulated. The net head is a function of: 1. The upstream reservoir level, 2. The downstream reservoir level or the tailrace control level, whichever is the higher in a period, 3. The frictional losses in the conduit, which are calculated for each period, by using a previously calculated friction constant and the square of the water flow.

The efficiency of the turbines is assumed to be constant for each station. The elevation of each reservoir is calculated as a function of the average storage of the reservoir for the period. A change in the release from reservoirs therefore affects the net head both through changes in water levels and through frictional losses in conduits. To produce exactly the energy required in each period and to control the release of the water from each reservoir effectively the program has to make a few iterations for each collection point.

Simula has the ability to simulate production of secondary energy in addition to primary energy, when the reservoirs are relatively full. The criteria for producing secondary energy is some average deviation of the reservoirs above the rule curves, normally some number between 0.0 and 1.0. If the number is 1.0 then secondary energy is only produced when all reservoirs are full. If the number is greater than one no secondary energy is produced.

When water is diverted from a lower level reservoir to an upper level reservoir and when the collection point includes a power station, then this station is treated as a pumping station. The associated electrical energy is negative, the conduit losses contribute to the energy, and the electrical energy is greater than the rise in potential energy of the water as the efficiency of the pumping station is about 85%.

Most of the output from Simula is retained in memory for use by the Printout subroutine, but there is an option to print for each period one or more of the following for each collection point.

1. Reservoir deviation index.
2. Water released.
3. Average water level at collection point.
4. Average water level downstream.

If any of the above information is requested the program also prints out the energy shortage if any for each period and the cumulative annual overflow at each collection point in GWh.

All other information is reserved for printing out by the subroutine Printout.

PRINTOUT

The output from Printout can be divided into two main parts:

1. Information about individual collection points (Figure 11).
2. Information about the whole system (Figure 12).

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VEITA   8 TIL   9                    HOLMALON
------------------------------------------------------------------------------------------------
RUMM.STIFLU = 0.705 GL  LANGSKURDARFL  32495.M2    LENGD  =  4591. M  MEDALKOSTN =  43.76 M3/GL M
BREYTILKOSTN = 44.37 M3/GL M   HAESTA MIDLUN = 613.0 MYS  LAEGSTA MIDLUN = 605.0 MYS   LONRYMI =  28.5 GL
OFODRUD GONG =  2.00 KM   THVERMAL =  6.15 M   FODRUD GONG =  1.40 KM   THVERMAL =  3.99 M
FALLGONG =  0.60 KM   THVERMAL =  2.92 M   ADKOMUGONG =  2.00 KM THVERMAL =  6.00 M
INNTAKSHAED AAETLUD = 610.0 MYS   UNDIRVATNSHAED =  41.3 MYS   SKURDUR =  0.00 KM
MEDALRENNSLI = 34.65 M3/S   Q V/KREIKN = 54.64 M3/S   STUDULL VAR =  1.58  EIGID MQ =  0.51M3/S
ORKUUTREIKNINGAR   25 ARA   TIMABIL 2 VIKUR.    MIDLUNARTHORF   16. ARS VAR1937.1 GWH
LON TAEMDIST   25 SINNUM, LON FYLLTIST  181 SINNUM A   25 ARUM
VATN I LONI I UPPHAFI =  14.2 GL   VATN I LONI I LOK UTREIKN =  28.5 GL
FRAMLEIDD ORKA = 929.6 GWH   FRAMLEIDD AFGANGSORKA =   0.0 GWH   FRAMHJA ORKA 154.4 GWH  FALLTOP I GONGUM =   7.7 GWH
AFL I MW = 264.8   NYTINGARSTUNDIR A ARI 3511.

                    MANNVIRKJAKOSTNADUR I MKR

          JARDSTIFLUR...........  1221.3 MKR
          YFIRFOLL..............    16.4 MKR
          BOTNRASIR.............    19.8 MKR
          INNTOK OG LOKUR.......   320.9 MKR
          OFODRUD GONG..........   735.6 MKR
          FODRUD GONG...........  1071.6 MKR
          FALLGONG..............  1307.8 MKR
          SKURDIR...............     0.0 MKR
          STODVARHUS............  1151.7 MKR
          ADKOMUGONG............   706.0 MKR
          VELAR OG RAFBUNADUR...  5461.6 MKR
          ANNAD.................   200.0 MKR
                                 -----------
            SAMTALS............. 12212.8 MKR
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Fig. 11   Information about collection point no. 8

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ORKUSTOFNUN, RAFORKUDEILD          FLJOTSDALUR MED LANDSKERFI
+ + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +

VID REIKNINGA VAR NOTAD,  MIDLUNARSTUDULL = 1.00   ORKUSTUDULL = 0.720   SEM GAF ORKUTHORF = 5111.9 GWH

NAEMNISTUDULL = 0.50   HAESTI BREYTILEGUR KOSTN =25.000 AFGANGSORKUSTUDULL  1.1

N I D U R S T A D A.. FRAMLEIDD ORKA = 5056.2 GWH  ORKUSKORTUR = 55.797 GWH   UMFRAMORKA  0.049 GWH

AFL =  820.5 MW   FRAMLEIDD AFGANGSORKA    0.0 GWH  OG A HVERJU ARI I GWH...

     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0

ORKUSKORTUR I PROMILLE  11.03   FRAVIK FRA 1 PROSENT I ORKU VAR51. SINNUM OG A HVERJU ARI I GWH...
   86.5    58.2     6.6     0.6     0.1     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.1
    0.0   163.8   390.7   382.8   260.5     0.0     8.5     0.0     0.0     0.0     0.0    37.8

                    MANNVIRKJAKOSTNADUR I MKR

          JARDSTIFLUR...........  5658.5 MKR
          YFIRFOLL..............  1057.0 MKR
          BOTNRASIR.............   504.0 MKR
          INNTOK OG LOKUR.......  3879.9 MKR
          OFODRUD GONG..........   735.6 MKR
          FODRUD GONG...........  1071.6 MKR
          FALLGONG..............  2106.3 MKR
          SKURDIR...............     0.0 MKR
          STODVARHUS............  3925.2 MKR
          ADKOMUGONG............   706.0 MKR
          VELAR OG RAFBUNADUR... 16007.0 MKR
          ANNAD.................  1200.0 MKR
                                 -----------
            SAMTALS............. 36851.1 MKR

REIKNADUR ARLEGUR HAGUR AF VIRKJANANETINU ER =  6826.3 M KR
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Fig. 12   Information about the whole system

I For each collection point the following information is printed out:

1. Name of collection point.
2. Where controlled water is diverted.
3. Dam and reservoir information: volume, cross-sectional area and length of dam; reservoir volume, high and low water level, average and incremental cost of reservoir in cubic meters of dam volume per GL reservoir and meter of gross head.
4. Tunnel information: length and diameter of headrace tunnels, pressure tunnels, tailrace tunnels and access tunnels.
5. Expected average headwater and tailwater level.
6. Average total flow, divided into average unregulated flow and average flow diverted from other collection points.
7. Design flow of the station and tunnels associated with collection points.
8. Number of times when reservoir was full and empty during simulation.
9. Initial and final volume of water in reservoir in simulation.
10. Average energy produced each year, average secondary energy, average spilled energy, average loss in tunnels.
11. Power of the associated powerstation if any and the load factor in hours per year.

The cost of the following structures is calculated:

1. Dam as a function of volume, cross sectional area (to reflect cost of leakage control) and length.
2. Spillway as a function of basin area and surface area of reservoir.
3. Bottom outlet and diversion as a function of basin area and length of outlet.
4. Intakes and gates as a function of capacity.
5. Unlined tunnels as a function of capacity, diameter and length.
6. Lined tunnels as a function of capacity, diameter and length.
7. Steel lined head race tunnels as a function of capacity, diameter, length and head.
8. Canals as calculated by an auxiliary program.
9. Power house as a function of capacity, maximum flow, head and number of units.
10. Machinery as a function of head, capacity and number of units.
11. Access tunnel as a function of diameter and length.
12. Other unspecified cost as an input constant.

II The system printout contains the following information:

1. Storage index of the whole system, as discribed in Input module.
2. Total electrical load on the system in GWh and its fraction of the average annual energy of the system.
3. Average annual production of the system.
4. Yearly energy shortage and average annual shortage.
5. Average and annual production of secondary energy.
6. The total construction cost of the system, which is equal to the sum of the cost for individual collection points.
7. Expected net yearly benefit from the system. This net benefit is the objective function which is used to compare alternative development schemes. The net benefit is the value of electrical energy produced minus the annual average cost of capital invested, operation and energy shortage.

As previously mentioned Iceland´s electrical energy is almost exclusively (97%) produced by hydro power. The results of simulations show that as the level of regulation in the system increases the optimal market for the electrical system becomes equal to the firm energy of the system, that is the profit of the system increases with increased demand until the optimum market is reached and the need arises to produce the first kWh from a thermal power plant. Figure 13 shows for Jökulsá í Fljótsdal the increased benefit of storage up to 500-600 GL. It also shows how the optimum market becomes equal to the firm energy as the storage increases. The reasons for this are the following:

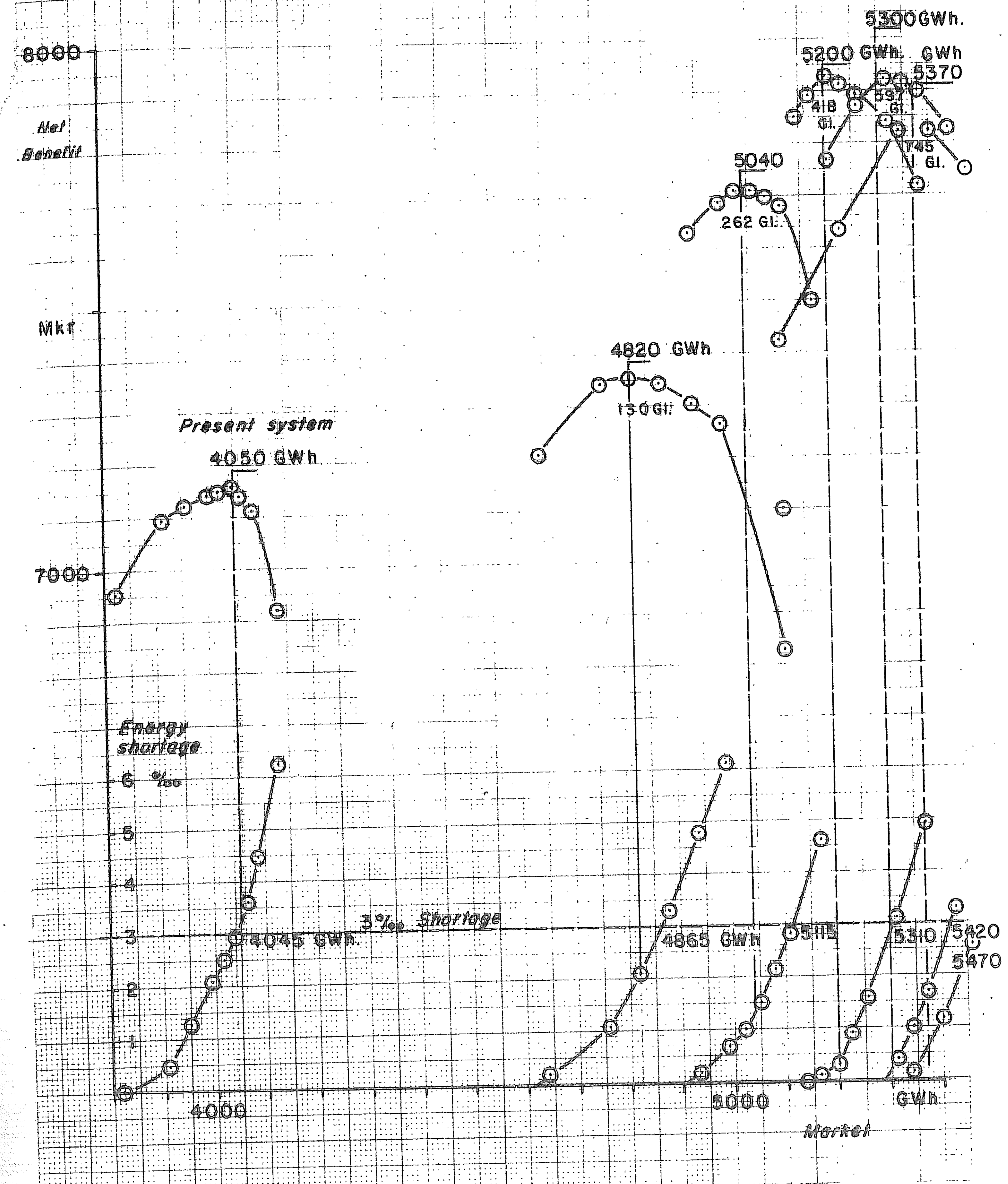
1. Hydrological data cover only 25 years.
2. At a high regulation level many years may pass from the time reservoirs overflow untill they are empty.
3. When energy demand rises above firm energy all additional demand during a period from reservoir spillage to reservoir recovery has to be produced in a thermal plant or treated as a shortage. When the regulation is high this period becomes such a large fraction of the total time simulated, that the incremental cost of thermal energy outweighs the incremental benefit of hydropower which would be produced during the periods from recovery to spillage or one spillage to another. See figure 14.

ORKUSTOFNUN
Raforkudeild

'79.12.13. G.J. /Ó.D.

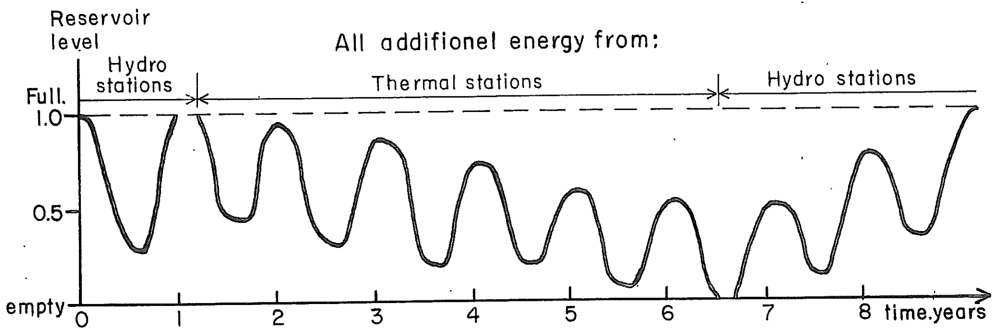
Jökulsá á Fljótsdal

Fig.13



As the system in Iceland is isolated and because the level of regulation will increase significantly in the future it follows that the optimum steady state market for the hydrological system becomes equal to its firm energy as derived from the relatively short hydrological records available.

Figure 14

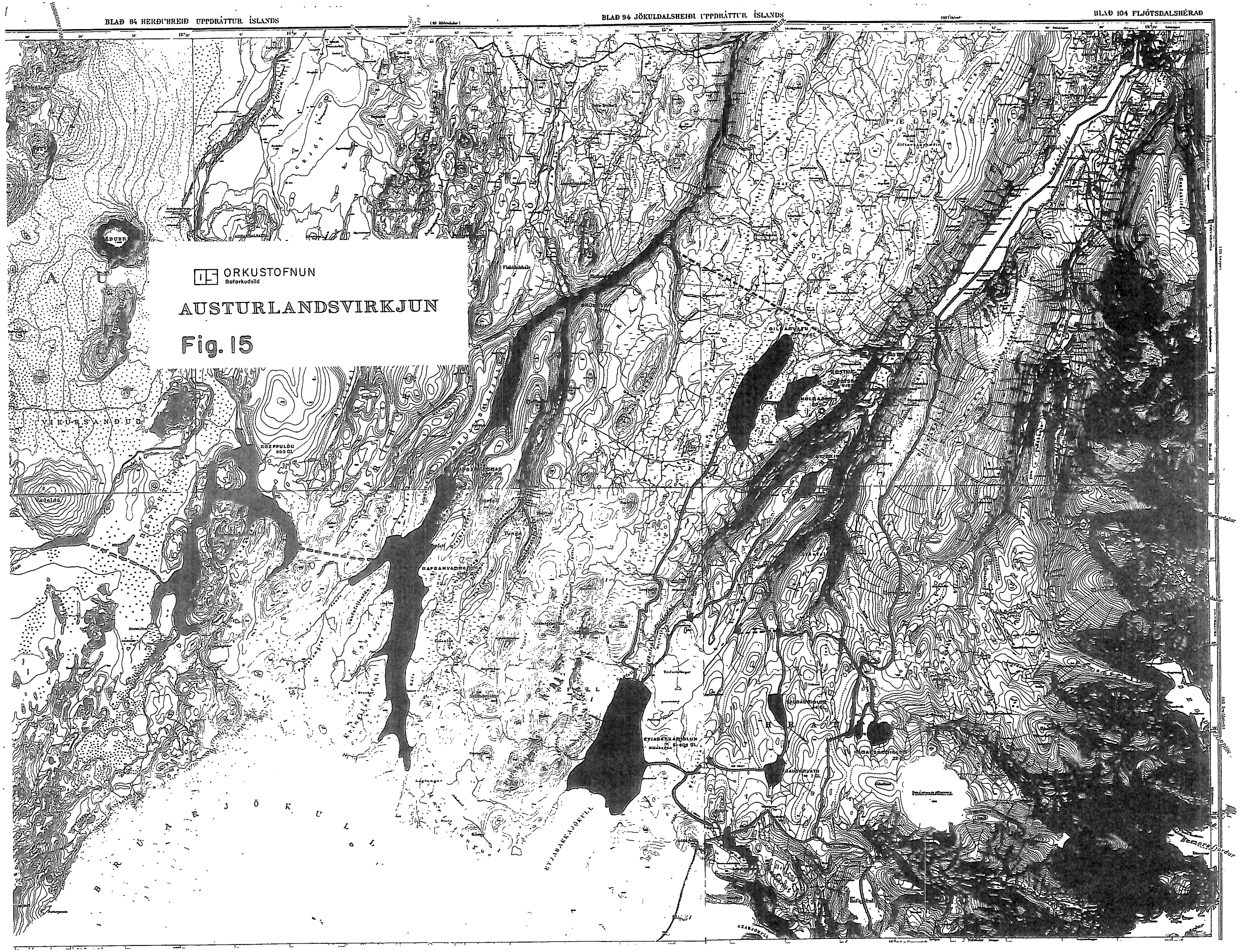


With large reservoirs the optimum market is equal to the firm energy of the system.

APPLICATIONS OF HYDRO IN EAST ICELAND

North of Vatnajökull, the largest glacier in Iceland, there are three main glacial rivers. These rivers emerge from Vatnajökull at an elevation of 600-700 m. The combined hydro potential of the three rivers is of the order of 10 TWh with an installed capacity of 1700 MW.

The first application of Hydro was to help find the most economical total solution to the development of these rivers. Working with the NEA were three engineering consultants, who made separate estimates of cost from more thorough engineering studies. After comparing about ten different solutions, including separate development of the rivers and pumping from one reservoir to another an optimum solution was found. Figure 15 shows the solution which consists of diverting the river Jökulsá á Fjöllum ($100\ m^3/s$) east into Fagradalsreservoir (600 GL) which is created in the tributary river Kreppa at an elevation of 635 m. This reservoir is connected with a tunnel to Hafrahvammar-reservoir (2000 GL) in the river



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Raforkudeild

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Fig. 15

Jökulsá á Brú at an elevation of 620 m. The Hafrahvammar-reservoir is the center of the development because of its size and great natural inflow (115 m^3/s). Associated with the Hafrahvammas-collection point is also the biggest dam ever contemplated in Iceland with a height of about 225 m and a volume of some 8 million m^3 in the main dam and 2 million in auxiliary dams.

The simulations showed that the storage in Hafrahvammar was essential for the economy of the optimum solution. In earlier plans (Figure 16) the intention was to divert this water to the east into Gilsárvötn (630 m). This required a much higher dam at Hafrahvammar and did not allow the draw-down to 550 m which is now planned. Pumping of the water did not prove economical.

The lowering of the Hafrahvammar reservoir also allowed the diversion of Jökulsá á Fjöllum from the west further downstream which greatly reduced the potential leakage through the lavaflows covered by the previous site.

Water from the Hafrahvammar-powerstation (500 MW) discharges into a downstream reservoir at an elevation of 390 m. The dam was originally planned about 20 km downstream from Hafrahvammar, but it was found to be economical to move the dam 10 km downstream as the shorter tunnel and increased inflow more than made up for the increased cost of the dam. Of significant value was the reduced energy loss in the shorter tunnel which discharges into Jökulsá í Fljótsdal some 20 km to the east. The powerstation which has a gross head of 368 m and a mean flow of 250 m^3/s will have an installed capacity of some 900 MW and produce 5300 GWh annually.

Jökulsá í Fljótsdal, which is furthest to the east of the three glacial rivers is also by far the smallest one, only 20 m^3/s by the Eyjabakkar dam site. It is economical to divert the water from Eyjabakkar to Hafrahvammar by tunnel. However the separate development of Jökulsá í Fljótsdal with associated small local rivers provides more flexibility and more phased construction, and a size which is more appropriate to the Icelandic electricity market.

This study showed there was no disagreement between the result obtained by Hydro and that obtained using the cost estimate of the consultants and the energy from a previously developed simulation model.

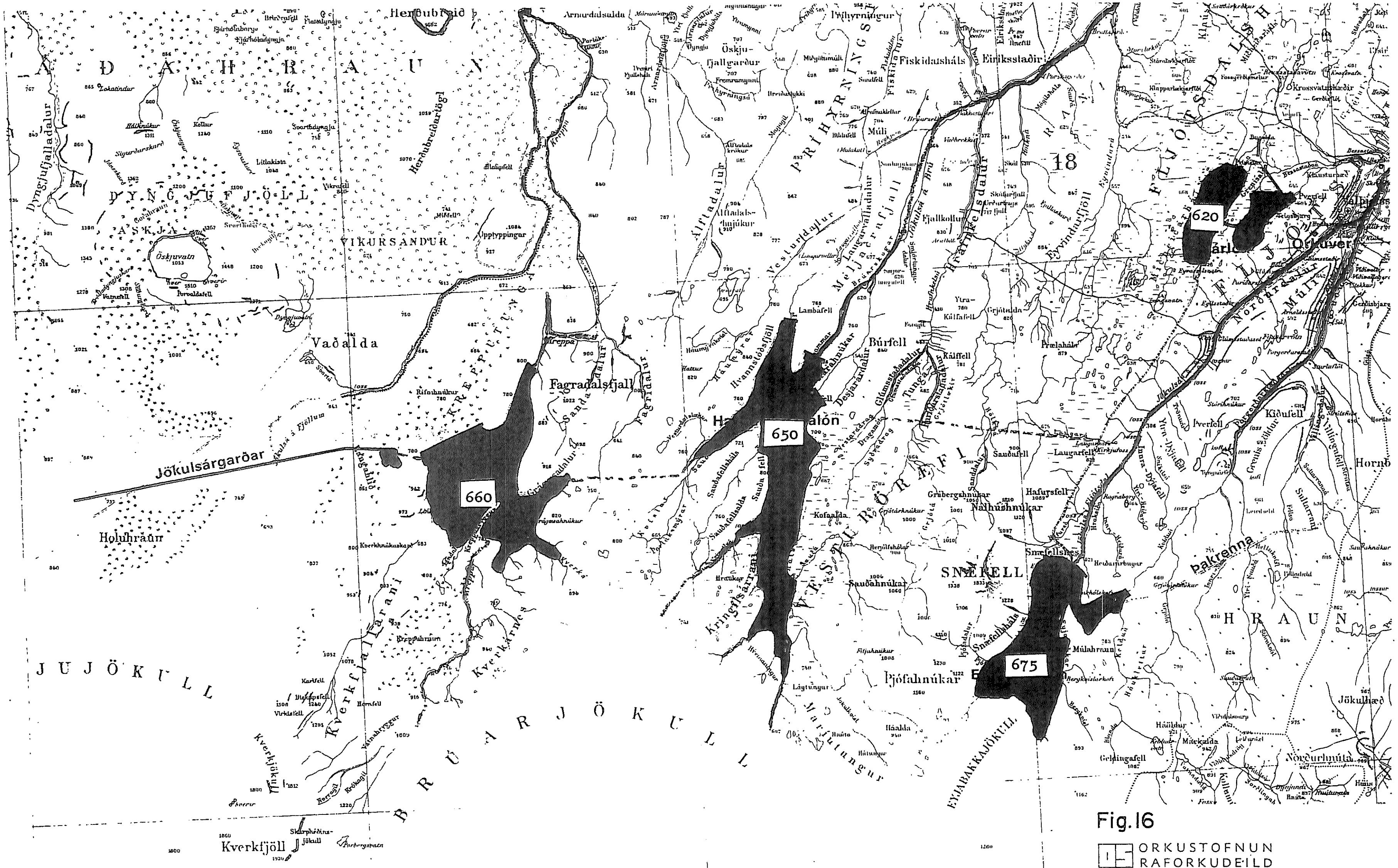

Fig.16

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Austurlandsvirkjun

Yfirlit yfir helztu mannvirki þegar virkjunin er fullgerð
Júlí 1969

- uppistoðulón
- skurður
- gong
- garður, stífla
- orkuver

Grunnkort: Aðalkort af Íslandi Mkv.: 1:250.000

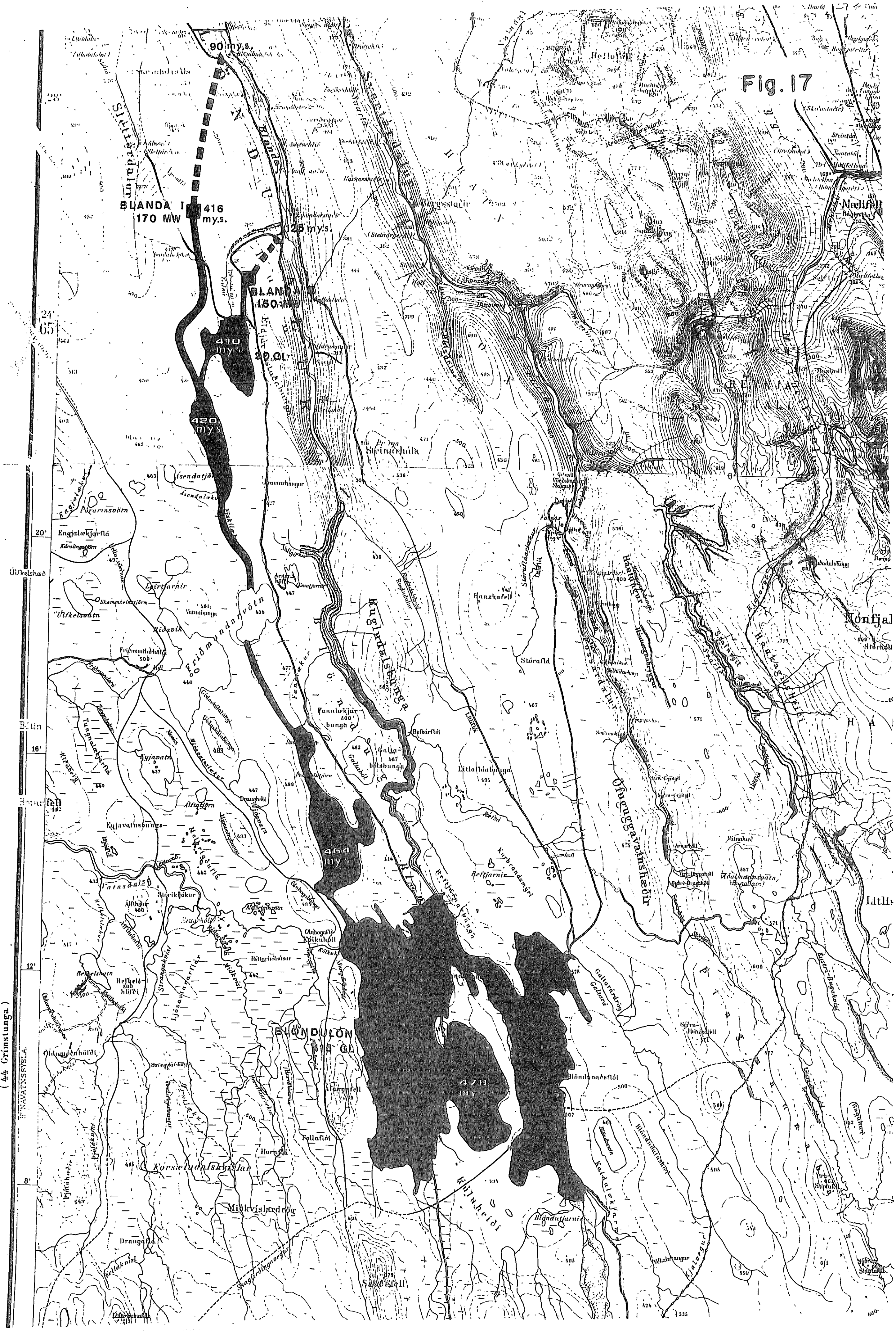
APPLICATION OF HYDRO IN NORTH-WEST ICELAND

Blânda is the largest river in North-West Iceland. Its development has been studied for about 20 years and intensively for the last 10 years. Figure 17 showes the alternative, Blanda I, which was favoured until recently. Using Hydro this alternative was studied together with some four others. This study showed that another alternative, Blânda II, is more feasible economically although its energy is about 100 GWh per annum lower at 750 GWh. This economy was achieved by reducing the length of the manmade canals and tunnels from about 12 km to less than 4 km at the loss of some 45 m out of 326 m in gross head. The net loss in head is somewhat smaller. The result of this study is shown in figure 18.

CONCLUSIONS

The dynamic simulation model Hydro and associated programs such as Canal allow a quick camparison between alternative developments when doing feasivility studies. Its results have been in agreement with more detailed engineering studies done by independent consultants. Its application to Blânda in North-West Iceland, which had been thoroughly studied for a number of years and had advanced beyond the feasibility study, lead to a more economic plan. The fact that the new plan will probably be more acceptable to local interest groups is also of real value.

Fig. 17


90 my.s.
BLANDA I
416 my.s.
170 MW
125 my.s.
BLANDA II
150 MW
410 my.s
20 Gl
420 my.s
464 my.s
478 my.s
BLÖNDULÓN
415 GL
Blanda
Sléttárdalur
Friðmundarvötn
Ruglurdalsbunga
Eldjárnsstaðabunga
Hanzkafell
Stórafld
Litlaflóabunga
Reftjarnir
Kurbrandsmýri
Ölfuggavatnsheiðar
Vatnsdalsá
Nónfjall
Mælifell
Úlfkelsvatn
Sauðafell
Mjóavatn
Korsiceðanskvíslar
Blöndudalsheiði
(44 Grímstunga)
HÚNAVATNSSÝSLA

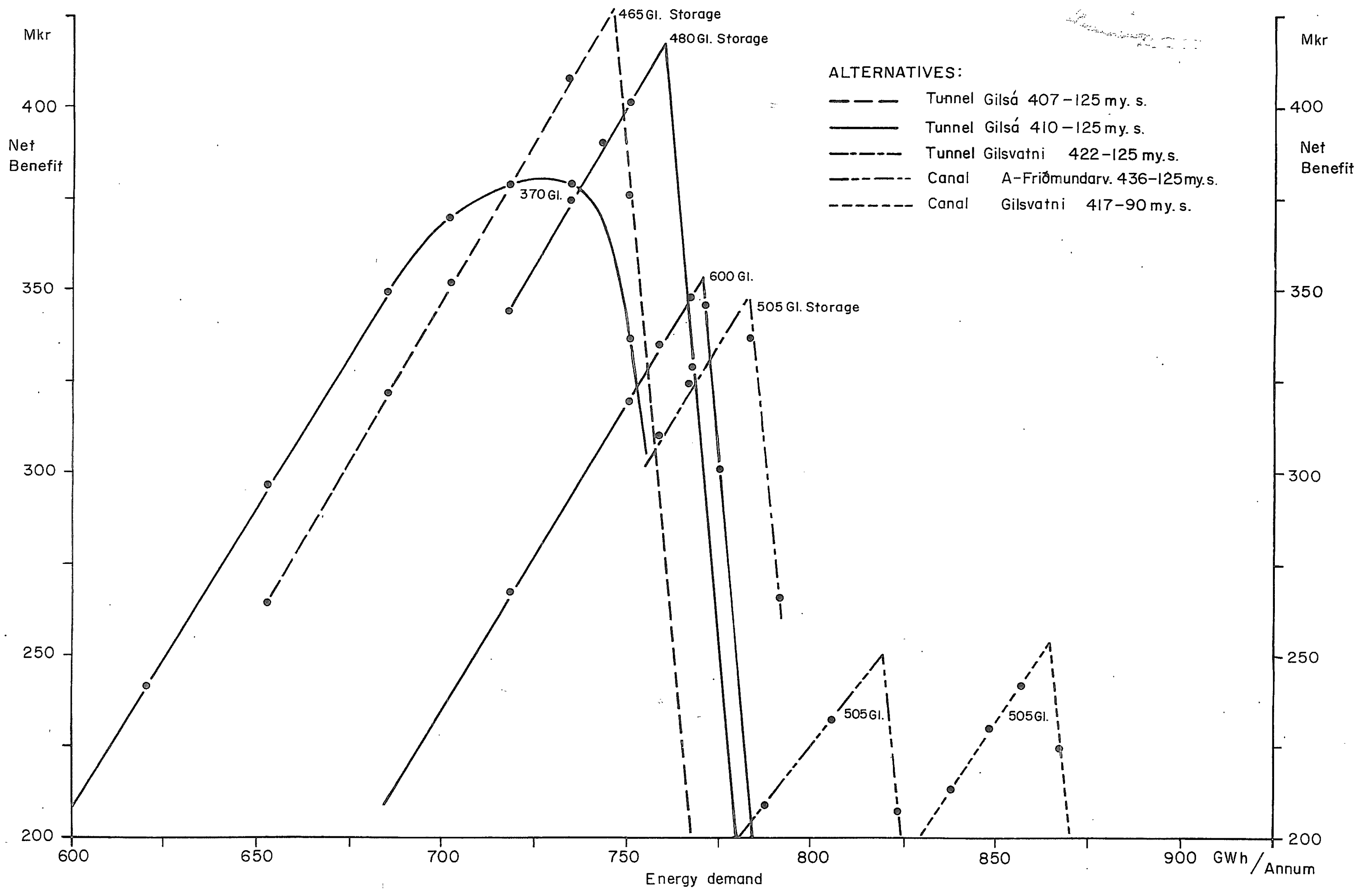


Fig. 18

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Blanda River Development
Simulated Net Benefit

9.2.1978 GJ/Gyða
T-168
B-86
F-16652