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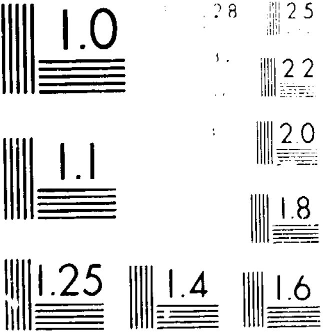
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Distr.
LIMITED

ID/WG.329/3
7 October 1980

ENGLISH

United Nations Industrial Development Organization

Second Seminar-Workshop/Study Tour in the
Development and Application of Technology for
Mini-Hydro Power Generation (MHG)

Hangzhou, China, 17 October - 1 November 1980

Manila, Philippines, 3 - 8 November 1980

SMALL HYDRO IN SWEDEN*

by

Thorild Persson **

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** Swedish Power Association.

1. Introduction

About 70 % of the total energy requirement in Sweden has to be imported as fuel oil. This is one of the main problems of the Swedish economy as it is for many other countries.

Electric power supply amounts to roughly 20 % of the total energy demand. In the year 1979 92 TWh electric energy was produced. Until the mid of the 1960s the power supply was practically completely based on hydro power. After that thermal power has taken a growing part of the increase in the power demand. In 1979 hydropower accounted for 65 %, nuclear power for 22 %, oil fired backpressure plants for 10 % oil fired condensing plants and gasturbines for 3 % of the production.

The installed generating capacity at the end of 1979 was 14200 MW in hydroelectric plants and 11600 MW in thermal plants The last figure includes six nuclear units of 3710 MW, 3010 MW oil fired condensing plants, 3100 MW back pressure plants and 1780 MW gasturbines. Four nuclear units of together 3630 MW are ready for test operation after the positive result of the nuclear referendum in March 1980. Another two nuclear units are under construction and will be taken in operation during the 1980s.

The production of power is practically equally divided between the government through the State Power Board and power companies owned by industries, municipalities and other non-governmental bodies. The latter are joined in the Swedish Power Association.

The total hydro power production now amounts to around 61 TWh during a normal year of precipitation. Plants now under construction will give a further 1 TWh. On the basis of data relating to the topography and runoff, the total natural hydro potential has been estimated to 200 TWh per year. Considering inevitable losses, effeciency of machinery and waterways, unfeasible sites etc, it has been judged technically possible to develop about 130 TWh per year.

On several occasions throughout the years studies have been made to investigate to which extent hydro power are economically worth development. Each new estimation has produced a higher figure than the preceding. The latest study was made in 1974 and gave the figure 95 TWh per year as economical feasible. The evaluation of the potential is continually changing as a consequense partly of technological and economical development in design and construction and partly of costs of alternative power production.

In the fifties and sixties the evaluation was made in comparison with oil-based production of power. The latest estimate is based on comparison with nuclear power, which according to present judgements is the cheapest alternative. Another alternative for the future may be coal-based power. This would probably result in a further uprating of the economically developable hydro resources.

With an economically feasible potential of at least 95 TWh per year, of which 62 TWh is developed today, an additional resource of 33 TWh per year should thus remain to be used.

However, under pressure from environmental groups, the government has decided that most of these resources must remain untouched. The actual plans aims at a hydro power production of only 65 TWh per year in 1990.

2. Background for small hydro power plants

Electric light was first demonstrated in Sweden in the 1880s. The power was then produced in small steam plants fuelled by coal or oil. The first generating stations based on hydro were opened in the 1880s. These plants were usually built where there previously had been directly driven machinery for mills, saws, hammers etc. The plants were small and essentially intended for supplying power to industries and communities in the immediate vicinity. They were most often built in small watercourses but sometimes in the large rivers too. In the latter case, however, only a small part of the waterflow was used for the plants.

Many hundred of such small local hydroelectric plants were constructed during the end of the nineteenth and the beginning of the twentieth century. As the technique of transmitting power by the alternating current method was developed in the beginning of 1900 it became possible to exploit more remote waterfalls. Gradually the power networks grew larger and a countrywide power system was established. The techniques at the design, construction and operation of large hydro-stations were developed in such a way that the power from these plants became much cheaper than the power from the old small plants. The main part of the country's power was at last produced in the large stations, the costs of wich were determining for the power tariffs. The consequence was that the revenues from the small hydro plants were not high enough for defraying the costs for reconstruction when the plants became worn out and out-of-date. The small power plants were therefore laid down at an increasing rate.

3. Energy potential in small hydro

Because of the oilcrisis in the 1970s and the marked rise in energy prices the Swedish Power Association took the initiative in 1974 in a development scheme for small hydro plants. In order to investigate the energy potential in closeddown small stations a nation wide survey was carried out. Power companies and electric utilities were asked about both closeddown small hydroplants and small hydro plants still in operation but which were judged to require a complete renovation in the immediate future. The survey was restricted to plants with capacities from 100 kW to 1500 kW. The limits were chosen with respect to the assessment that power stations with a capacity of less than 100 kW would require unreasonably high restoration costs whereas very few stations with a capacity of more than 1500 kW had been dismantled.

The survey yielded the following results:

	Number of units	Capacity MW
Closeddown plants	510	235
Plants built before 1950 still in operation	684	290
Miscellaneous objects	156	25
	1 350	550

If the closeddown plants according to this study were restored and if we assume an average annual utilization time of 4000 hours, we should have an energy production of the magnitude of 1 TWh per year. The renewal of plants still in operation would mean no additional energy, but if no measures were taken it would be necessary to reckon on a loss of energy amounting to about 1 TWh per year. The aggregate potential energy output of small hydro in Sweden is thus approximately 2 TWh per year.

To be observed is that in this figure no new sites for small hydro are included. Without doubt there are many such sites in Sweden. However, it has been judged that these projects will be much more uneconomic than the still remaining unharnessed waterfalls in the large rivers. It is also certain that an exploitation of new sites for small hydro will meet a strong opposition från environmental groups and organizations.

4. Legal aspects

Although there are large regions of plains in the south of Sweden, the country as a whole is a land of lakes and rivers with vast woods in between. As settlers moved inland and more and more northernly they followed the watercourses where tillable soil was to be found and the water itself became their help for transports and communication. They also got fish for food, bog-ore for tools and reeds for winterfodder to the cattle. Smaller affluents afforded mechanical power to mills for grinding and sawing. On such a background already the early middle-age provincial laws stated that use of water was based on private right. In most countries the waterways belong to government or local authorities. In Sweden, however, they are still possessed by the owners of the riverbanks, which sometime may be the government. This is an explanation why most of the small power plants are owned by private companies or individuals.

Permission according to the water law and construction law is necessary to build a hydropower plant. The experiences, especially from the last years, indicate that the judicial trial often is very complicated, timeconsuming and expensive. Even a small plant, if it is a site which has not been harnessed previously, may have many appelants.

At restoring older closeddown plants, however, the judicial trial normally should not be too complicated. This is specially the case if the right to store and regulate the water can be referred to older legal permissions.

One condition which always must be met is that the economic advantage of the hydro plant must be greater than the capitalized costs of the plant. The advantage is calculated in conformity to special rules stated in the water law.

5. Development programme

The amount of energy forthcoming from restored renovated small hydro plants in Sweden does not represent a very impressive figure. It is, however, on the other hand a domestic energy resource which in a significant way may restrict the use of imported expensive fuel oil. The Swedish Power Association therefore considered it worthwhile to try reduce the costs for small hydro to secure the continued operation of these plants and also to put disused plants back into service.

The aim of the development programme was:

1. To renew plants still in operation. This may require rather comprehensive measures, for instance a complete new head race tube and exchange totally or partly of the mechanical and electrical equipment.

2. To add new units to existing plants in order to increase as well the capacity as the energy production.

3. To restore plants which have previosly been closed down. This will usually require quite much of construction work and new mechanical and electric equipment.

4. To build new small power plants in small watercourses, which up to now have not been harnessed.

The conditions are very different for the four categories. Category 1 will probably be the most favourable one concerning both ecomomy and possibilities to get the legal permissions which are necessary. Category 4 is not of immediate interest and will not come to fore until a greater part of unharnessed large rivers has been utilized.

The development programme was directed towards reducing costs of installations as well as costs of maintenance and operation. The idea was by means of simplification and standardization to reduce capital costs and by means of automation to reduce operation costs.

The survey mentioned above showed that the development programme should comprise units for heads between 2 and 30 m. The capacity of the units should be in the range 100 - 1500 kV.

The survey also indicated that most of the closeddown plants were situated not far from distribution networks 10 - 20 kV. It was therefore decided to dispence with turbine regulator and voltage regulation for the proposed turbines. It was also decided that the regulation of water trough the turbines should be made in the simplest possible way.

6. Prototype installations

In order to test various technical solutions a number of prototype units were designed. The design and construction of these prototypes was done in cooperation between the power companies and the manufacturing industries in Sweden. Some of the costs of the prototypes were defrayed by government grants. The development work has been carried on in two stages.

Stage 1:

This first stage comprised six propeller turbines with fixed guide vanes and fixed runner blades. These prototypes have been in operation since the beginning of 1977.

Stage 2:

The second phase comprised two units. These turbines were also equipped with fixed guide vanes but had adjustable runner blades. They have been in operation since late in 1979.

Some dates of the prototype units are shown in figure 1.

The protptype units have functioned rather well. In appendix 1, however, some problems are described which ought to be taken in consideration for future installations.

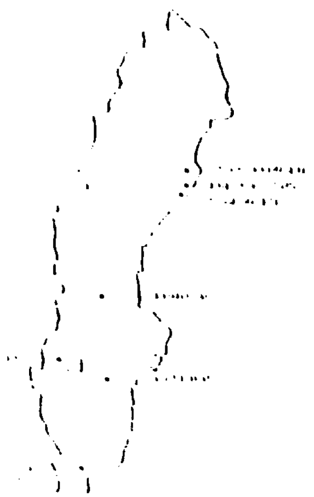
7. Standardized units

It has been judged feasible to design the standardized units as propeller turbines with fixed or alternatively with adjustable runner blades. The turbine is fitted with fixed guide vanes and thus no regulation of the guide vanes.

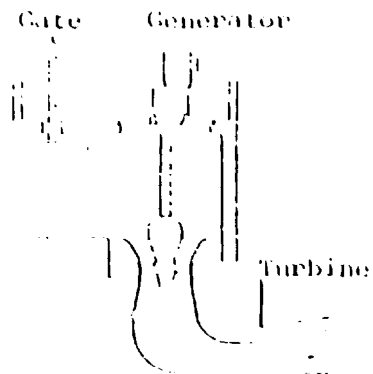
The turbine is normally connected to a standard asynchronous generator by means of a transmission gear. The generator is connected via a transformer to the local distribution net. The voltage of the generator is normally 400 V.

SMALL POWER PLANTS

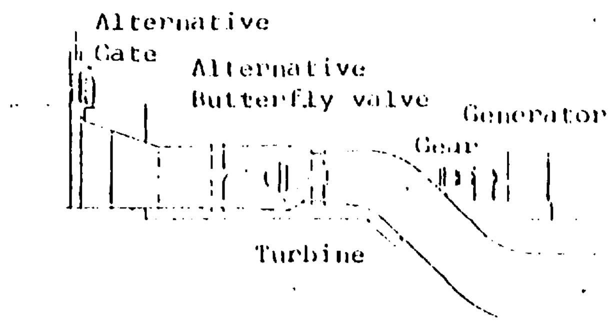
Prototype installation



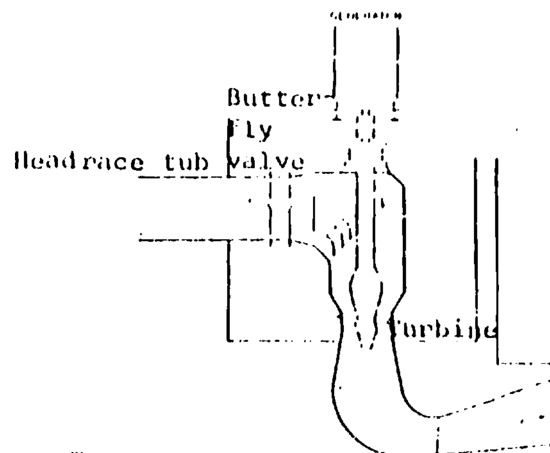
	Stage 1 (fixed runner blades)						Stage 2 (adjustable runner blades)	
Power plant	STORNYRFORSEN	FREDRIKSFORS	FURUDAL	KÅLSÄTER	HATTORP	KRUSEBOGE 1	KRUSEBOGE 2	[illegible]
Owner	SKELLEFTEÅ KRAFTVERK	MODOCELL AB	KORSNÄS-MARMA AB	BILLERUD AB	MOTALA STRÖMS KRAFT AB	KRUSEBOGE KRAFT AB	KRUSEBOGE KRAFT AB	SKELLEFTEÅ KRAFTVERK
Civil engineering	VBB	VBB	VBB	VBB	VBB	VBB	VBB	VBB
Supplier, turbine	KMW	KMW	KMW	BOFORS-NOHAB	BOFORS-NOHAB	BOFORS-NOHAB	BOFORS-NOHAB	KMW
Supplier, generator	ASEA	ASEA	ASEA	ASEA	ASEA	ASEA	ASEA	ASEA
Head	6.3 m	6.0 m	10.5 m	6.8 m	23.0 m	4.0 m	4.0 m	4.5 m
Capacity	400 kW (1200 kW)	470 kW	1000 kW	500 kW	750 kW	310 kW	315 kW	185 kW
Average production	2.0 GWh	1.8 GWh	9.3 GWh	2.3 GWh	1.8 GWh	2.4 GWh	0.9 GWh	1.9 GWh
Flow rate	8 m³/s (4 m³/s)	10 m³/s	12 m³/s	9 m³/s	3.9 m³/s	10 m³/s	10 m³/s	13 m³/s
Runner diameter	1.5 m	1.5 m	1.5 m	1.4 m	0.9 m	1.4 m	1.4 m	1.05 m
Speed turbine	273 r/min	273 r/min	425 r/min	306 r/min	765 r/min	273 r/min	237 r/min	190 r/min
Speed generator	765 r/min	765 r/min	765 r/min	765 r/min	765 r/min	765 r/min	765 r/min	765 r/min
Shaft	HORISONTELL	HORISONTELL	HORISONTELL	HORISONTELL	VERTIKAL	HORISONTELL	HORISONTELL	VERTIKAL
Closure	Butterfly	Butterfly	Butterfly	Gate	Butterfly	Gate	Gate	Gate
Type	2F	21	21	21	3F	21	2R	1R



Type 1
Vertical shaft



Type 2
Horizontal shaft



Type 3
Vertical shaft

The turbine is closed by means of a gate at the intake in the dam or a butterfly valve in the headrace tube, if such one is used. The gate or butterfly valve respectively are fitted with a hydraulic servomotor for opening operations. Closing takes part automatically by a valve being opened in the hydraulic system and the gate (valve) being closed by its own weight (counterweight).

The unit is started by the slow opening of the gate (valve). After the unit has been connected to the network, which takes place automatically, the number of revolutions is controlled by the network. The starting and stopping of the unit take place automatically and are guided by a level indicator in the upper storage in the case of units with fixed runner-blades.In the case ofunits with adjustable blades the automatic operation can be adjusted to both the water level regulation with the level indicator and also to a device ensuring a certain amount of draw-down.

If the voltage of the net disapears, the gate or alternatively the valve is closed automatically. During the closing process the unit attains run away speed. To ensure a quick closure the unit is fitted with two overspeed protections, one solenoid valve and one mechanical hydraulic valve.

If conditions permit intermittent operation of the unit, a turbine with fixed runner blades is recommended. The unit can be given maximum efficiency when fully loaded and thereby the maximum possible production. When the storage has been drained to its lower limit the unit is stopped and it will be started again when the upper limit has been reached.

If regulations of this kind cannot be permitted on account of conditions in the stream, the unit is equipped with automatic regulation of the runner blades. The unit can then be operated with constant upstream water level, i e utilize the available flow or be regulated within the limits prescribed. The average efficiency is somewhat lower for units having runner regulation than for units without such regulation. On the other hand, intermittent operation with utilization of the upstream storage implies a certain loss of head.

For the erection of turbines there are various alternatives depending on local conditions and the head to be utilized.

The following three main types are relevant:

Type 1: Generally for 2 - 3 m head
Propeller turbine with vertical shaft.
Turbine erected in an open turbine chamber in close proximity to the dam. Closure by gate in the intake. (In the lowest range of head the runner must be placed below the lower water level)

Attention has to be paid to the design of the turbine chamber to avoid disturbances in the water flow.

In some cases it may be desirable to place the turbine above the lower water level and it may then be possible to design the headrace as a siphon. An intake gate is not then required. (Figure 2).

Type II: Generally for 5 - 10 m head.
Propeller turbine with horizontal shaft.
Turbine erected in a closed turbine chamber and with a headrace tube from the intake in the dam. Closure by means of a gate in the intake or a butterfly valve in the headrace tube. (Figure 3).

Type III: Generally for 8 - 30 m head.
Propeller turbine with vertical shaft.
Turbine erected in a closed turbine chamber and with a headrace tube from the intake in the dam. Closure by means of a butterfly valve in the headrace tube. (Figure 4).

These three types can be fitted with fixed or alternatively adjustable runner blades. With these six combinations the entire range between 2 and 30 m heads and 100 to 1500 kW can be supplied by suitable units.

The following standardized runner diameters are recommended:
0,5 - 0,7 - 0,9 - 1,15 - 1,5 - 2,0 - 2,3 m.

In the diagram on figure 5 is shown in which ranges the three types will be used.

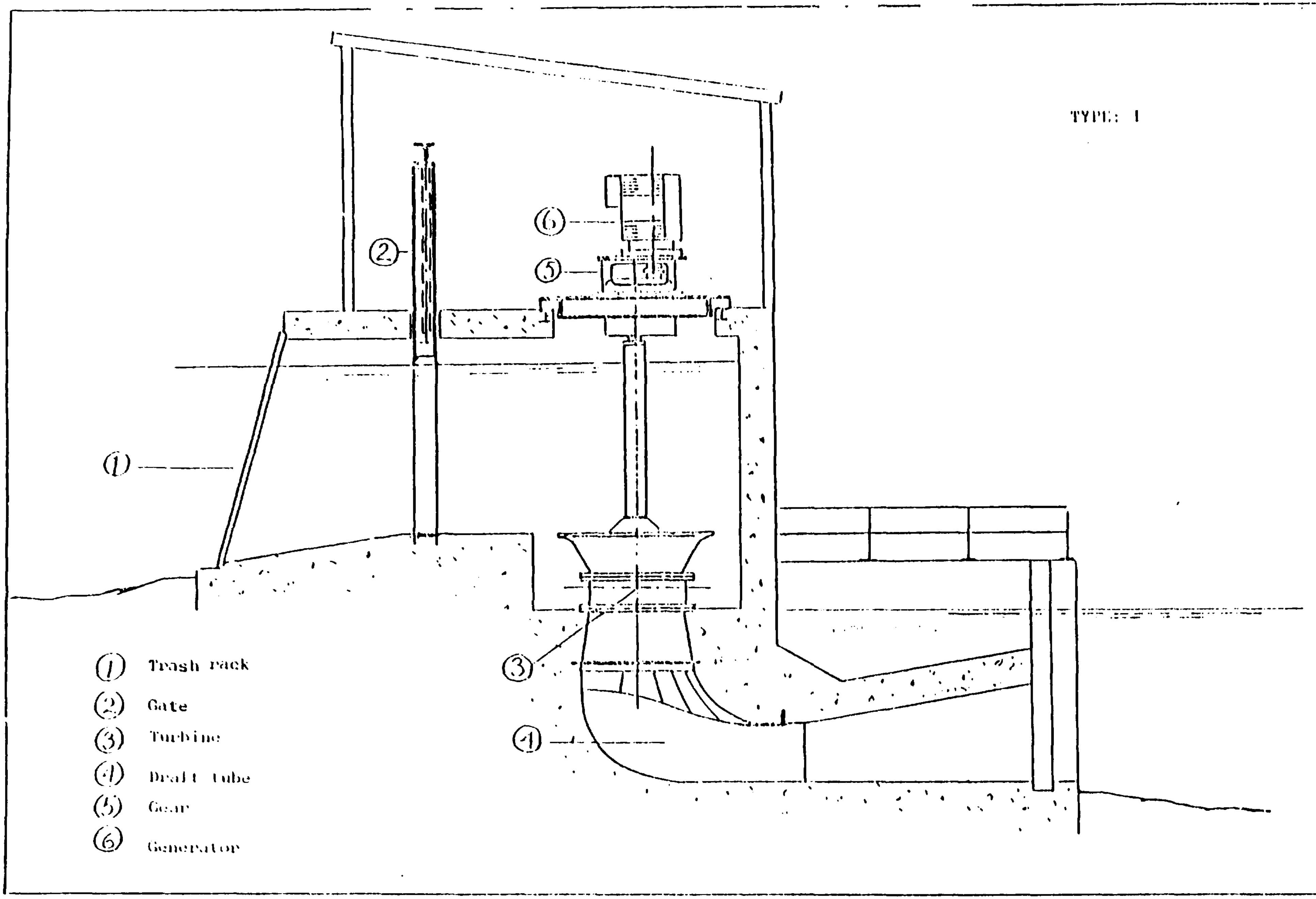
The choise of runner diameter is dependent of many factors as flow rate, head and the position of the turbine in relation to the lower water level. An effort to use any of the recommended diameters will imply a standardization which will be of value as well for the purchaser as for the supplier. In figure 6 the runner diameter as a function of head and flow rate is shown.

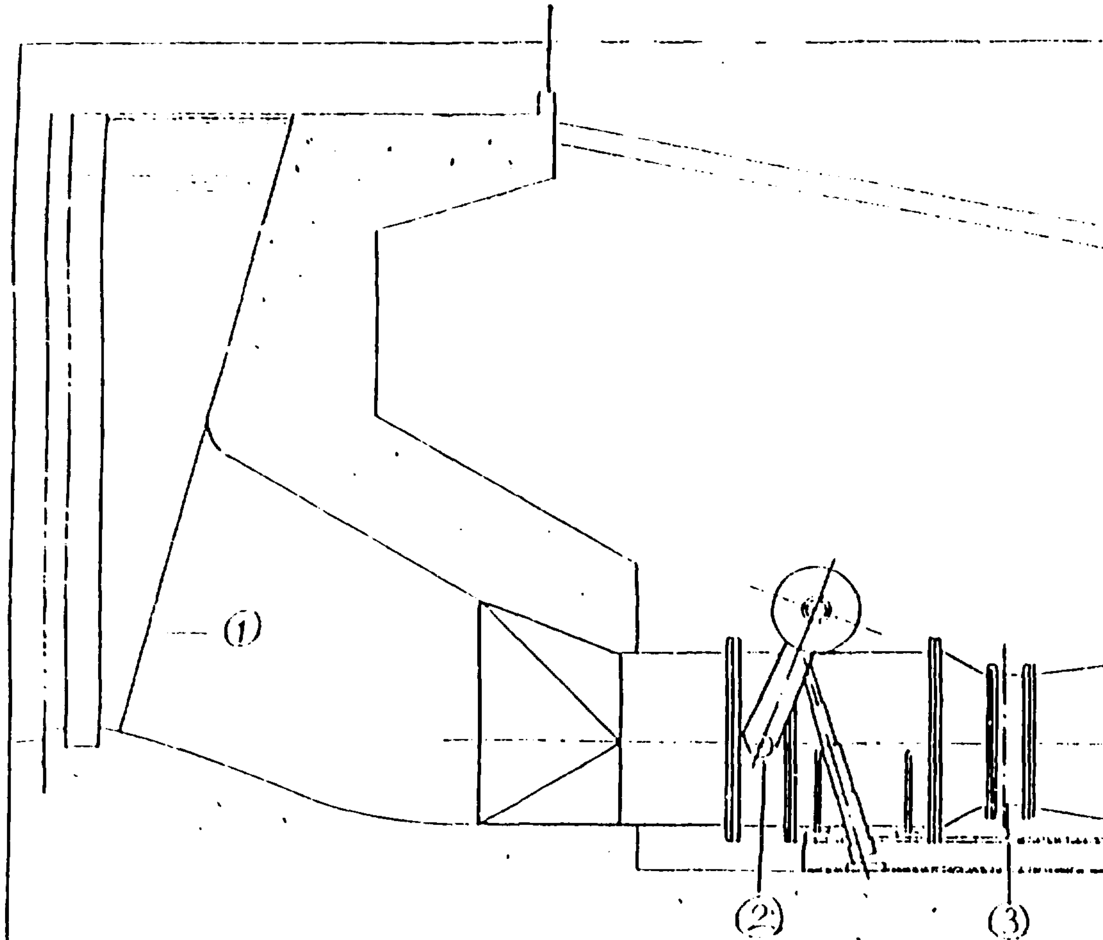
In figure 7 the relation between head, runner diameter and number of revolutions is shown.

In figure 8 the turbine efficiencies which should be demanded is shown.

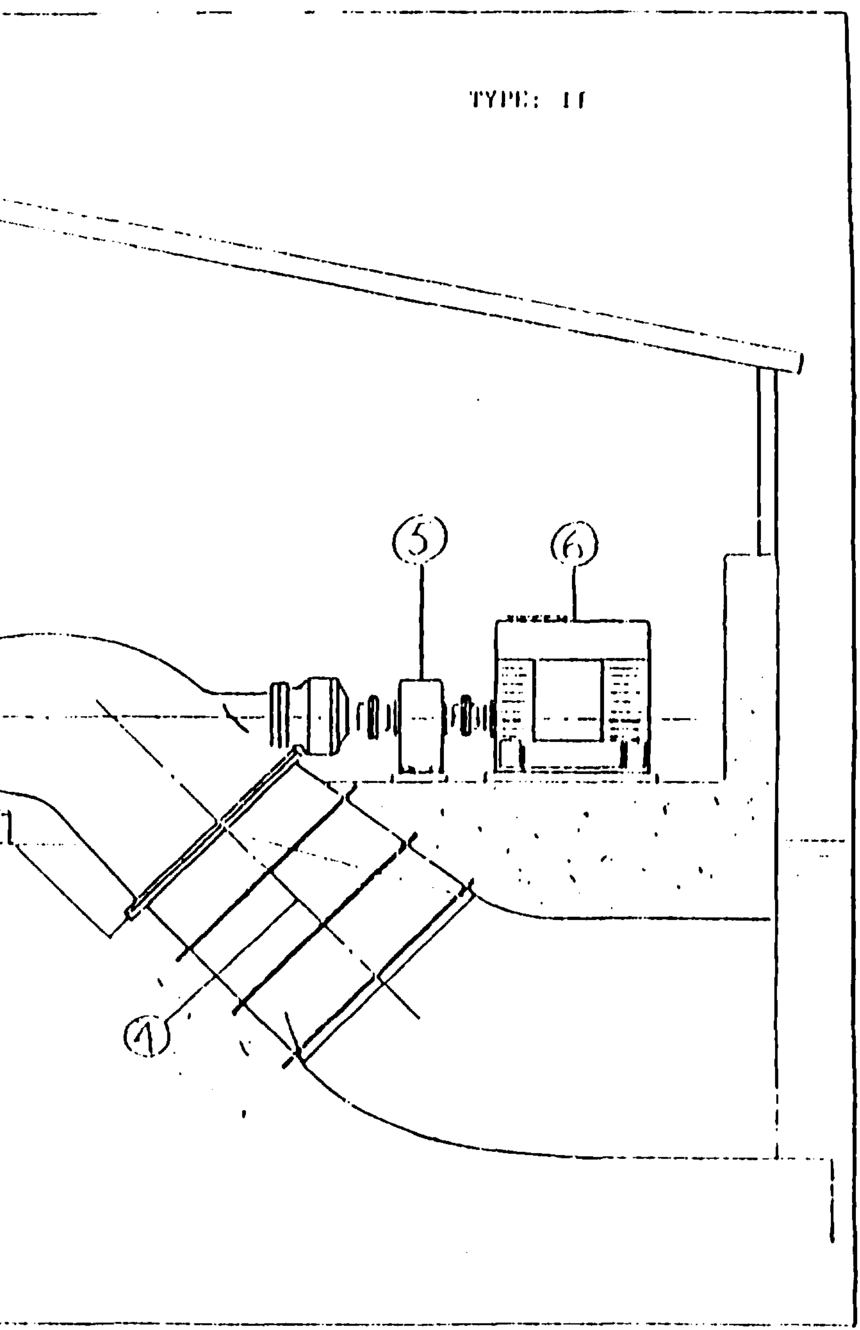
It is generally recommended that the dam will be equipped with a spillway considering the risk of disturbances on gates during wintertime.

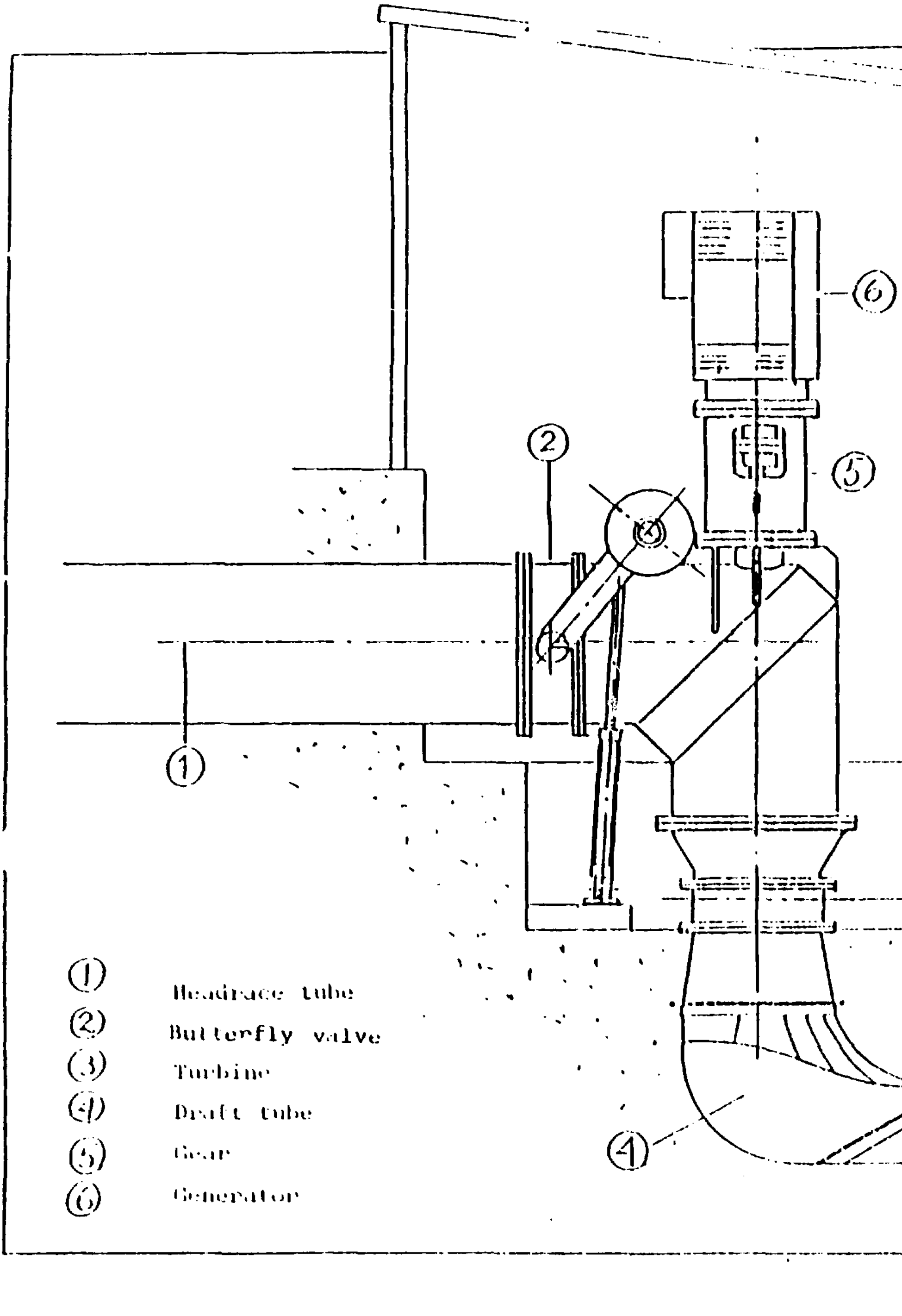
The intake have to be equipped with trash racks with intervals between bars of 50 mm, thereby eliminating risk to fish passing through the turbine.


TYPE: I
(1)
(2)
(3)
(4)
(5)
(6)
(1) Trash rack
(2) Gate
(3) Turbine
(4) Draft tube
(5) Gear
(6) Generator

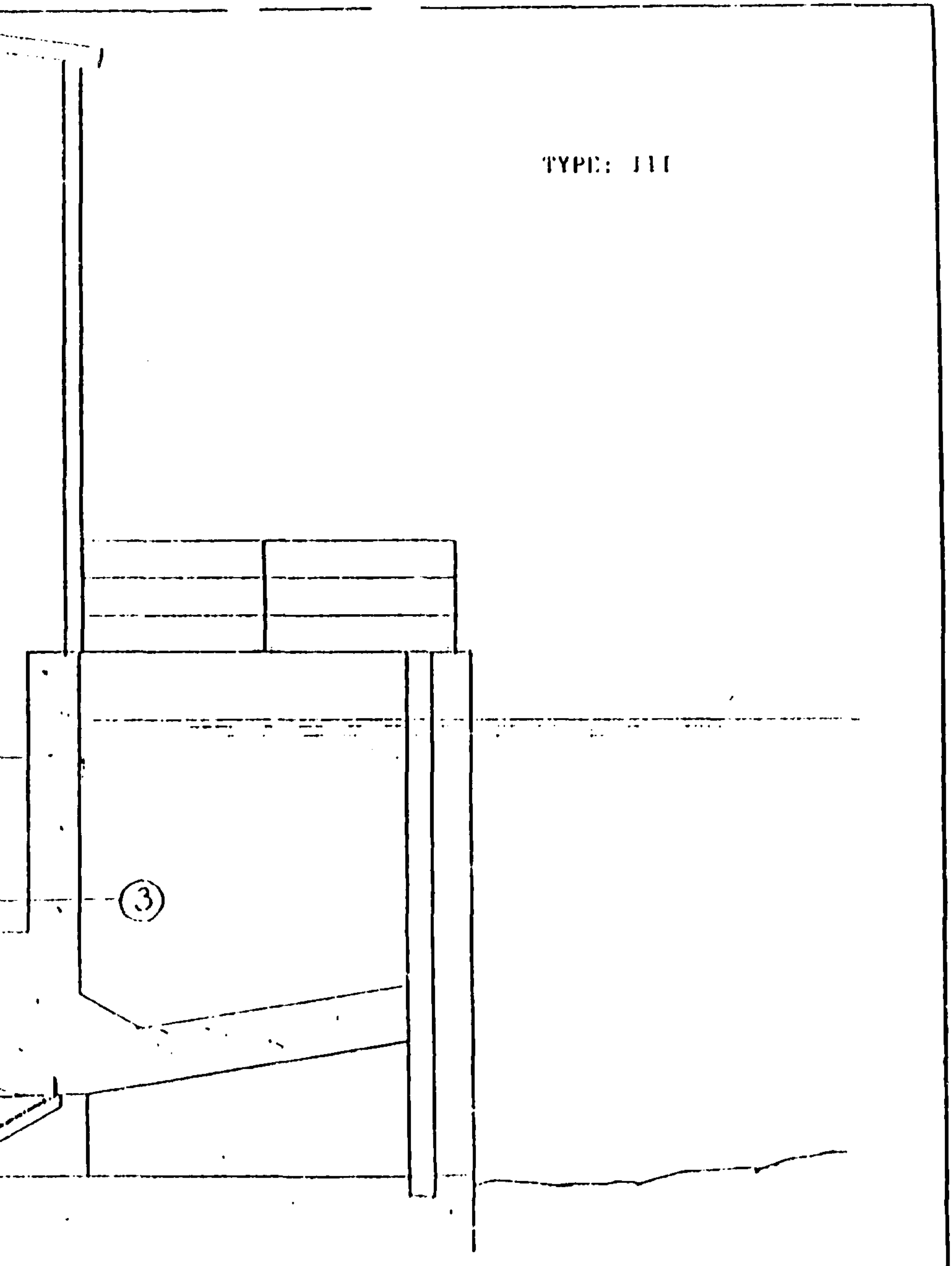


(1) Trash rack
(2) Butterfly valve
(3) Turbine
(4) Draft tube
(5) Gear
(6) Generator


TYPE: II
(5)
(6)
(4)

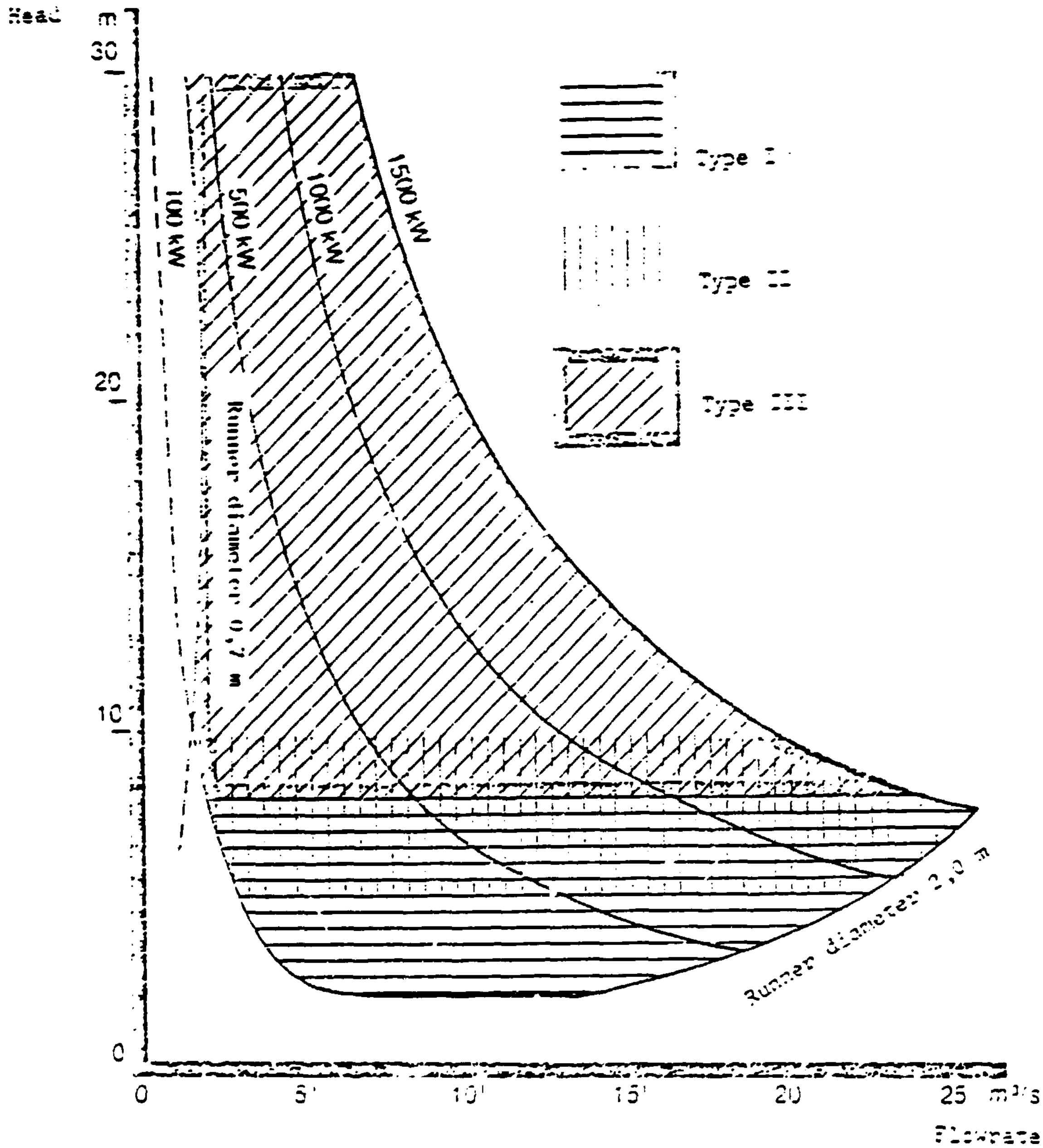


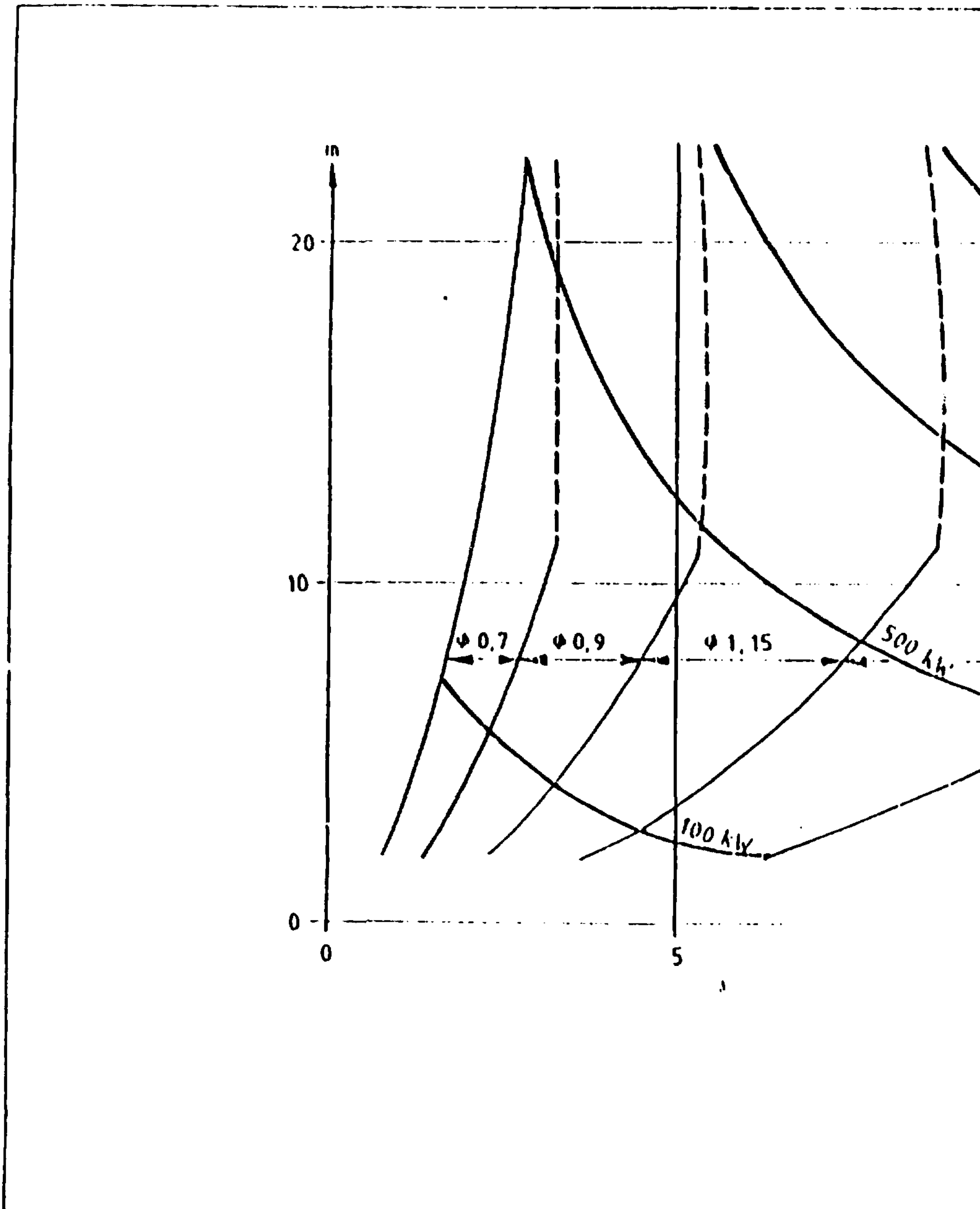
(1) Headrace tube
(2) Butterfly valve
(3) Turbine
(4) Draft tube
(5) Gear
(6) Generator



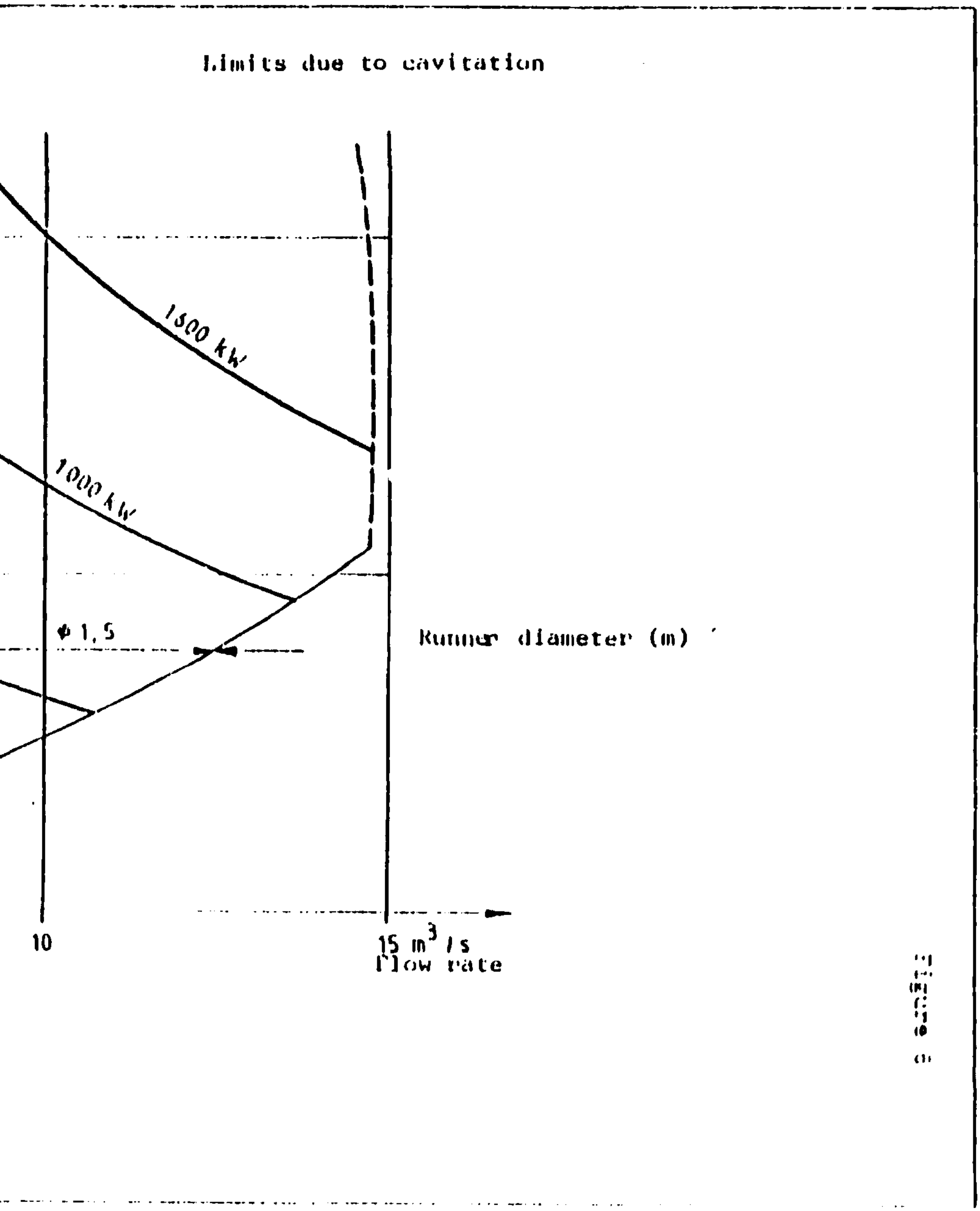
TYPE: III
3

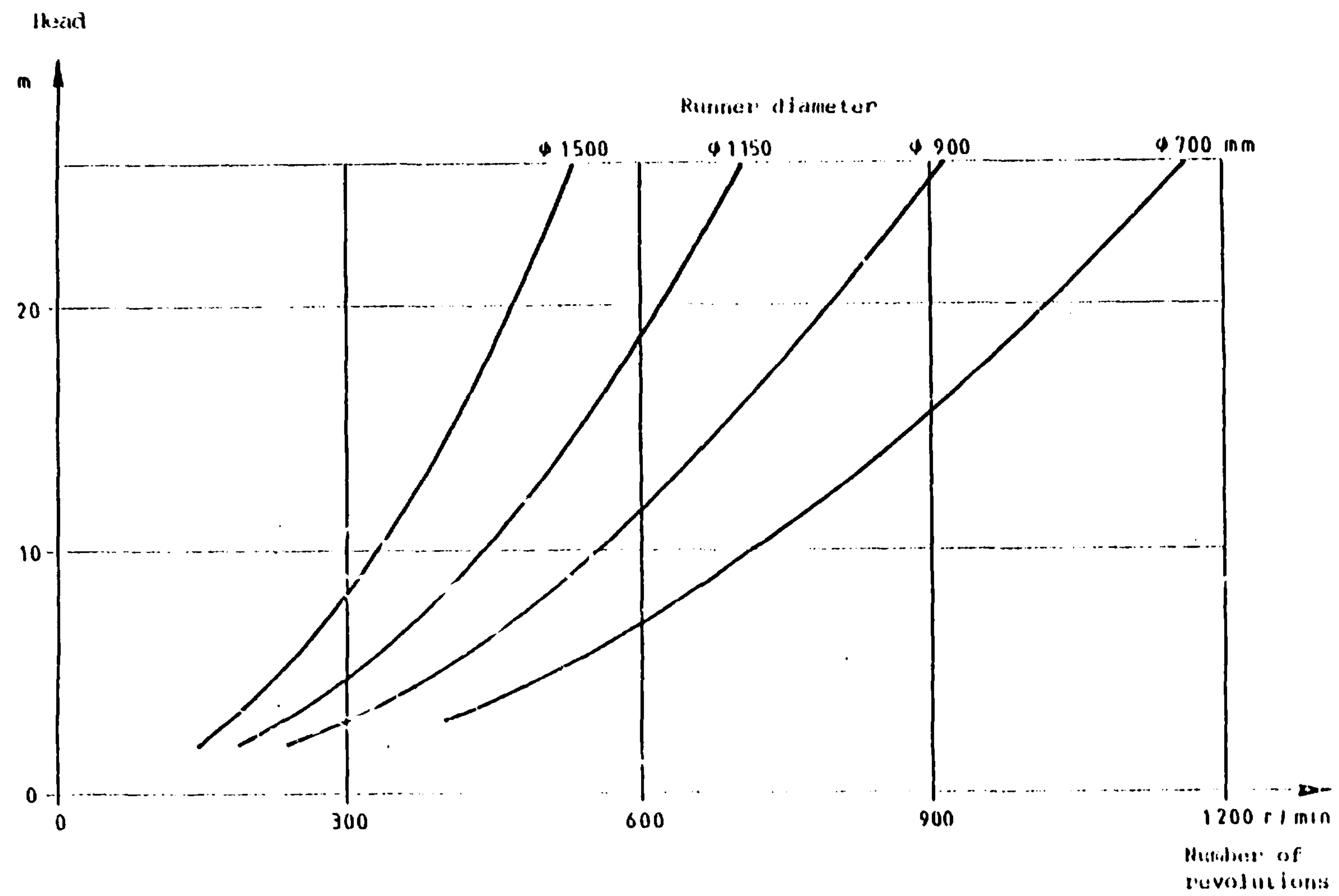
Recommendation for
choice of type I, II or III



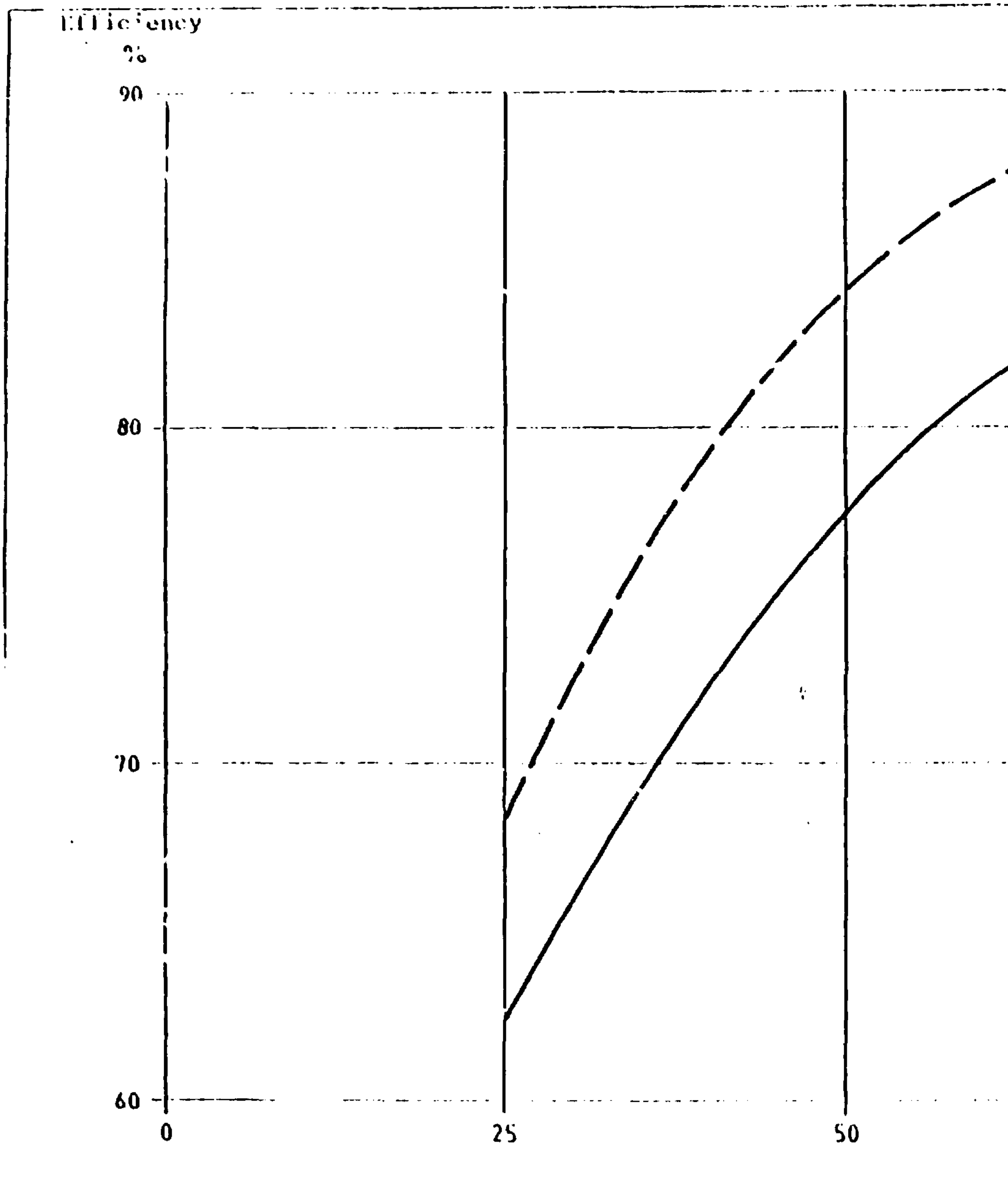


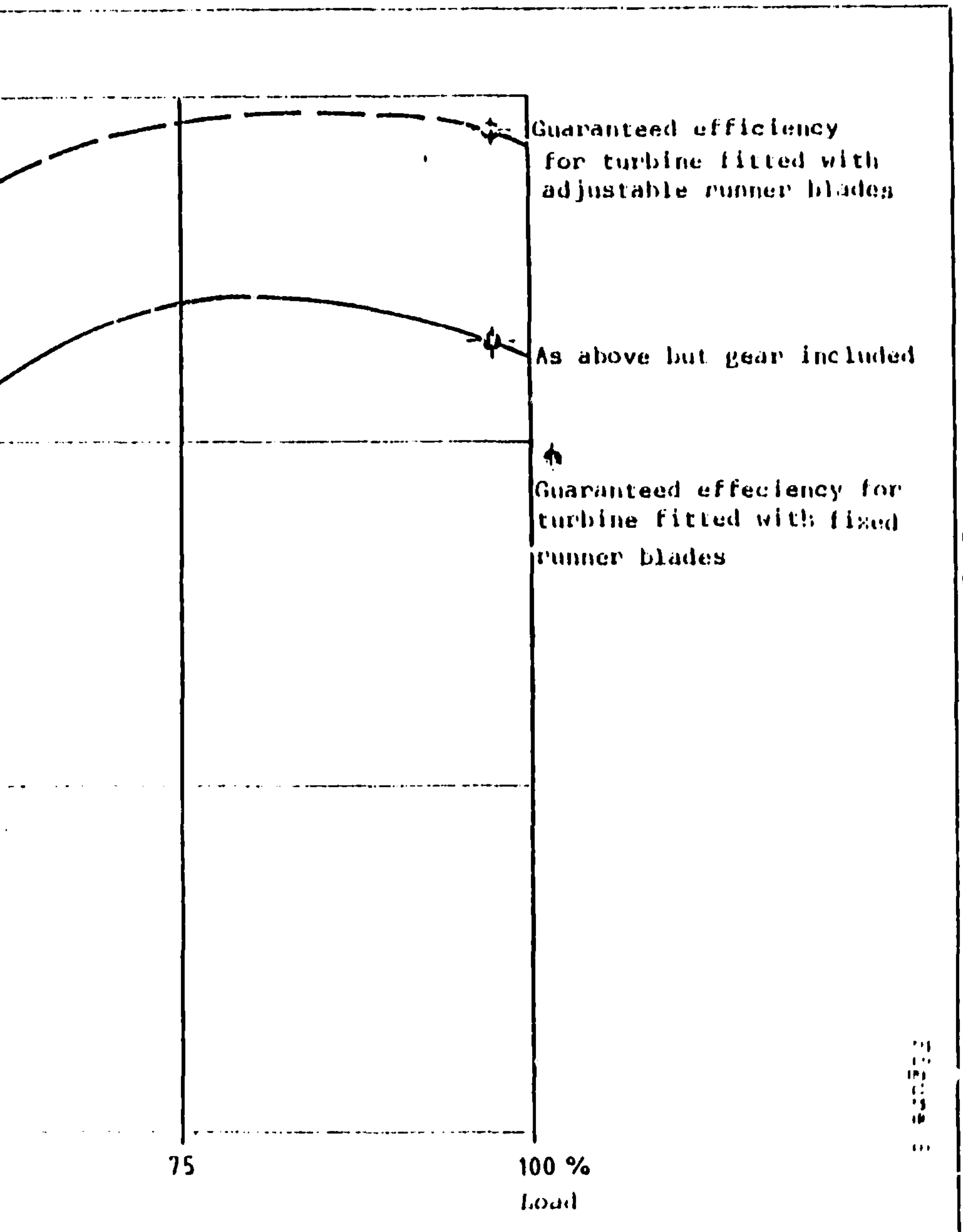
m
20
10
0
0
5
φ 0,7
φ 0,9
φ 1,15
500 kW
100 kW

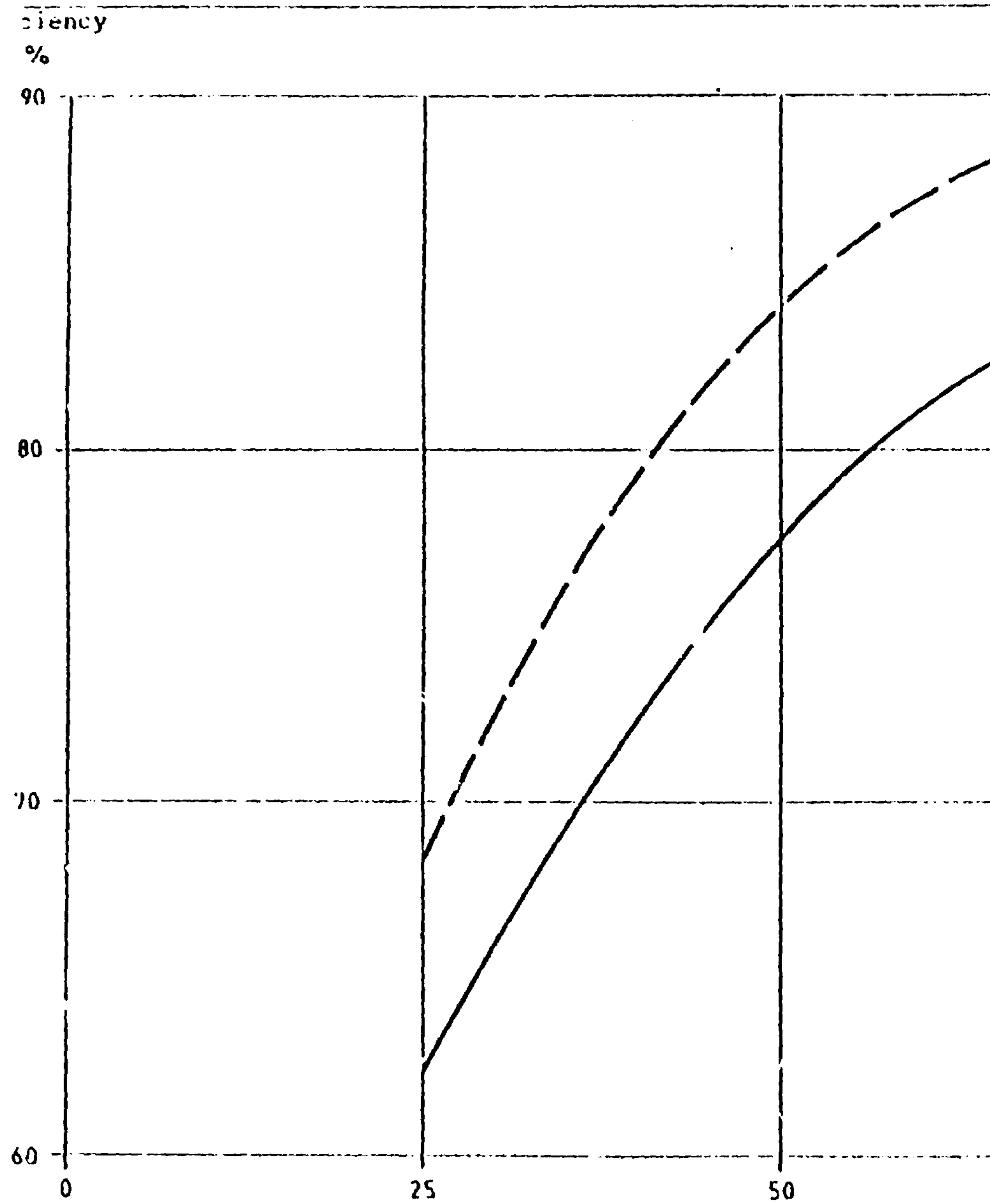

Limits due to cavitation
1600 kW
1000 kW
Φ 1,5
Runner diameter (m)
10
15 m³/s
Flow rate

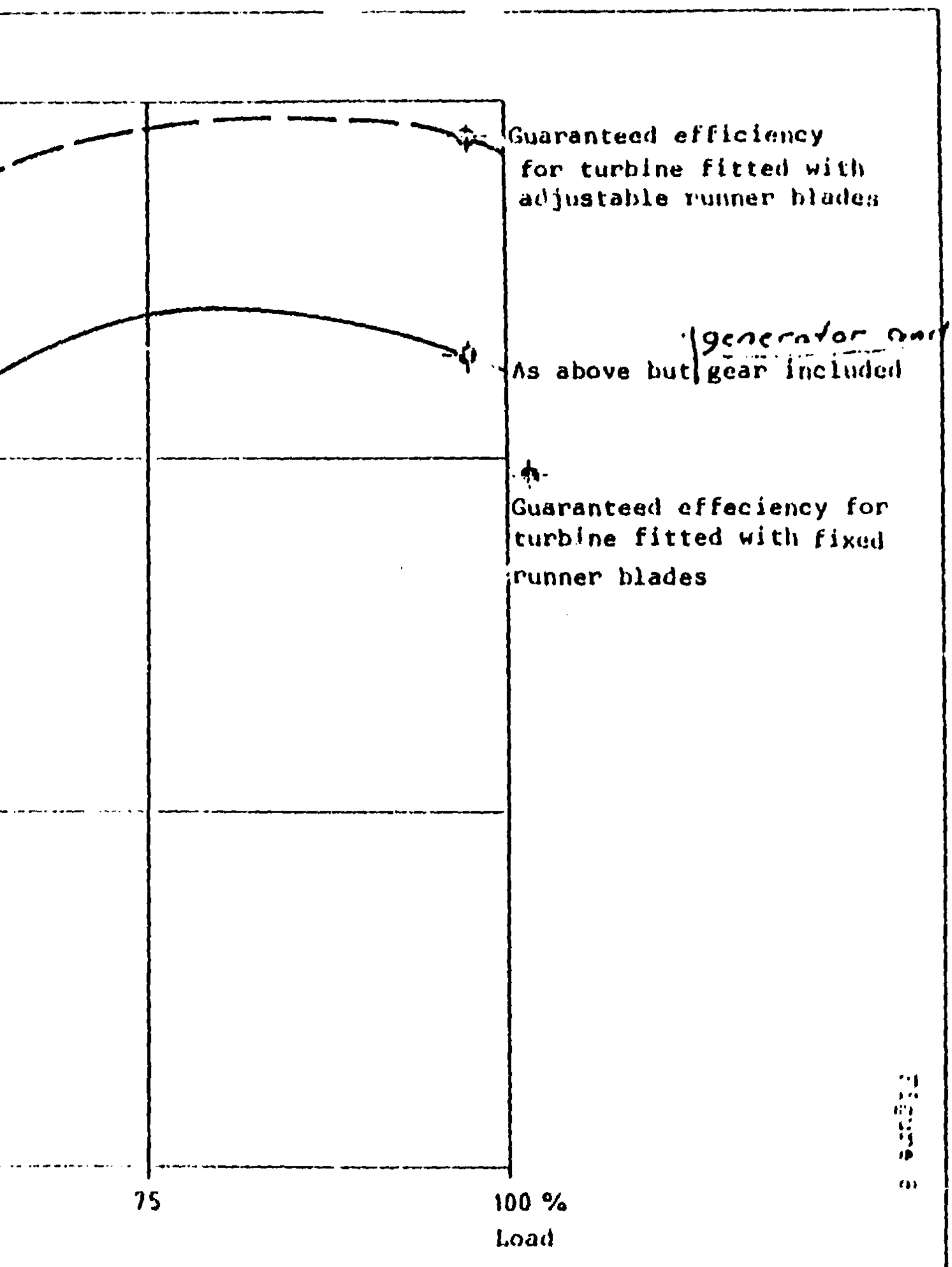


Head
m
Runner diameter
φ 1500
φ 1150
φ 900
φ 700 mm
20
10
0
0
300
600
900
1200 r/min
Number of
revolutions


Efficiency
%
90
80
70
60
0
25
50


Guaranteed efficiency for turbine fitted with adjustable runner blades
As above but gear included
Guaranteed effeciency for turbine fitted with fixed runner blades
75
100 %
Load


iency
%
90
80
70
60
0
25
50



Guaranteed efficiency for turbine fitted with adjustable runner blades
(generator only)
As above but gear included
Guaranteed effeciency for turbine fitted with fixed runner blades
75
100 %
Load

Headrace tubes for units of type II and III must be dimensioned economically with respect to prevailing conditions. Alternative types of tubes are wood, steel and fibre reinforced plastic. From the point of view of laying as well as that of maintinance, it appears that plastic tubes have advantages to be taken into consideration when making comparisons.

Bearing in mind the unit's manner of operation with relatively slow closure, the rise in pressure in the headrace tube is relatively low, thereby eleminating the need for a surge chamber for units of type III.

8. Dimensioning of the capacity of the plants

Determining for the capacity of a unit is partly the utilized head, partly the inflow of water and its regulation possibilities and partly the marginal costs and value of the capacity.

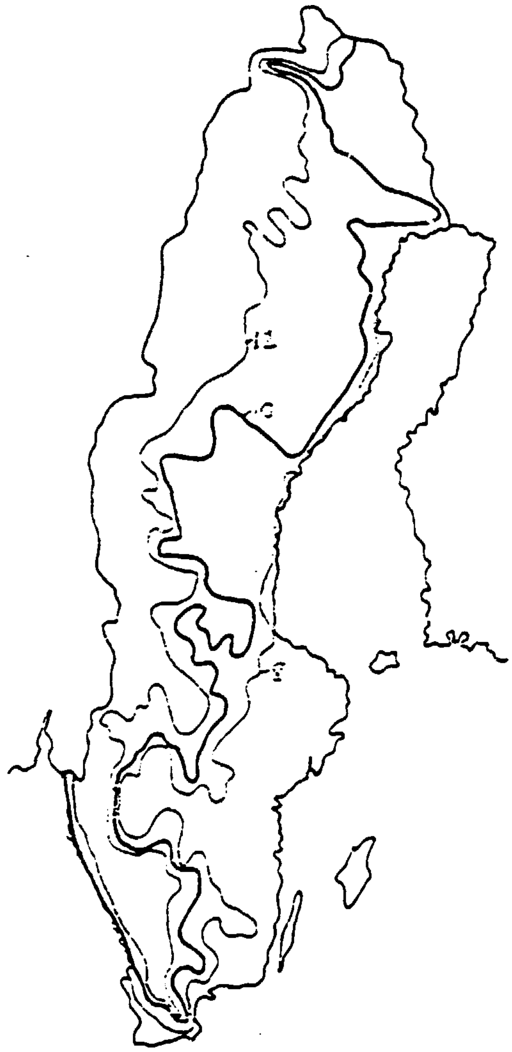
For those areas in Sweden where mini-power plants are of current interest, the specific outflow of water is between 5 and 25 l/s km^2 as shown on the map in figure 9. As an average value a specific outflow of 10 l/s and km^2 can be assumed. Decisive for choise of capacity will at last be the cost of the installed capacity and the value of the energy production. With the help of the diagram in figure 10 the capacity can be determined for various catchment areas and heads. The diagram is valid for a specific outflow of 15 l/s and km^2.

It should be observed that fast changes of the water level at the intakes of the plants may cause troubles due to ice floes, this is specially the case where there are narrow intake channels Therefore it may be motivated in these cases to choose a relatively small capacity and thus limit the changes of the water level.

9. Invitation to tender

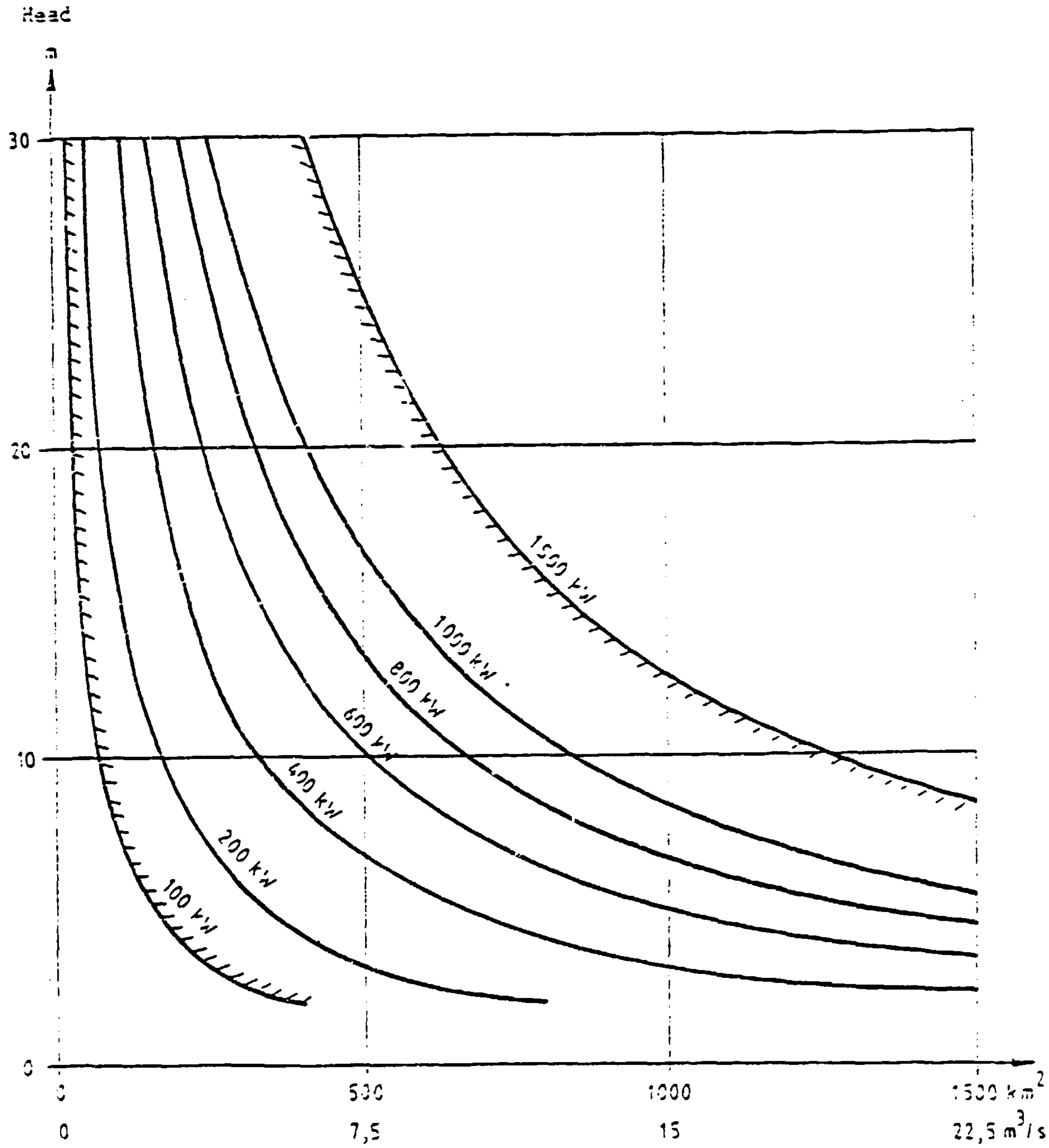
In order to facilitate uniform purchasing of mechanical and electrical equipment, recommendations are made for inviting tenders. It is deemed imperative that all of the mechanical and electrical equipment be purchased from one and the same supplier, who shall have sole responsibility for complete delivery of the equipment.
The invitation does not specify dimensions or the material for different parts of the delivery. Instead it is assumed that the tenderer who is liable for complete delivery will specify the details in the tender - in some cases with alternative choies of material. The runner chamber and the runner blades have to be made of material which is resistent to corrosion. In the tender the quality is to be described. The tenderer must append to the tender an erection drawing for the plant from which the purchaser can determine the extent of the civil engineering work which must be taken into consideration in evaluating the tender with reference to the total cost.

Figure 3



Average outflow 1931-1960 in liter per second and km^2

Figure 10



Output at various heads, catchment areas and corresponding design discharge (at specific outflow 15 l/s and km²).

The following shall be observed in connection with tendering:

- a suitable level of the turbine in relation to the lower water level shall be recommended by the tenderer with regards to efficiency and the risk of cavitation.

- in cases where runner with fixed blades are offered, they shall nevertheless be manually adjustable to permit turbine output to be adjusted. The tender shall specify a cylindrical or a half-spherical runnerchamber.

- the turbine shall normally be equipped with dual over-speed protections - one with a solenoid valve and one with a mechanical-hydraulic mechanism.

- the unit shall be designed to withstand at least 2 hours of run-away-speed.

- the output of the generator shall be overdimensioned in relation to the turbine output in order to obtain more favourable temperature conditions and thereby prolong the life of the generator.

- necessary measures shall be taken to facilitate inspection and repair of the unit.

It is to be observed that the tender need not to be connected with the standard unit for the propeller turbine proposed by the Swedish Power Association. The tenderer has the possibility to make his own alternative proposals with sufficient technical basis for evaluation.

In appendices 2-5 the basic data for the tender are given.

10. Matters to be submitted to the Water Court

For the restoration of old plants for which permission granted earlier have not been utilized a water court decision is required. The same is valid for suplementing units to plants still in operation in order to increase the energy production.

To the application to the water court a summary technical description of the project shall be attached containing information of the capacity of the new unit, the value of the energy production and the annual and capital costs to be met by the project. Interests involved shall be stated. The application shall indicate the relationship between the net value of the plant and the value of the damage. In the cases of restoration or extension of old plants the economic legality are generally undeniable. In the cases of new plants, however, testing of the economic legality may be decisive with regard to the right to carry out the project. For such plants the fishing interests may be crucial.

To facilitate legal aspects of renovation of old plants special recommendations have been made.

11. Economic aspects

The costs in Skr/kW for the mechanical and electrical equipment concerning units with fixed runner blades are shown in the diagram in figure 11. Units fitted with adjustable runner blades will cost 250 000 - 300 000 Skr kr more per unit. The costs have been verified in connection with purchasing of six units with fixed runner blades and five units with adjustable runner blades. The costs of the construction work for these eleven plants are in average 60 % of the total costs. The costs are valid for the year 1979. The average cost per kWh has been calculated to 13,5 öre/kWh. (Interest 8 %, period 25 years, cost of operation and maintenance 1 % of the cost of installation). In figure 12 the average costs are accounted.

The Swedish Association of Electricity Supply Undertakings has drawn up recommendations concerning the payment for energy from small power plants. The payment is different in winter and summer and during daytime and nighttime. For the eleven plants analysed here, the payment has been 10 to 12 öre/kWh i e less than the average cost.

12. Government subsidies

In order to promote utilization of closed down small hydro plants, the government has since 1978 - 07 - 01 given subsidies to such plants. The subsidy is upward limited to 35 % of the total cost of the restoration. Subsidies are only given to such restorations which can be proved profitable from the national economic point of view. On the other hand subsidies are not given when the cost of restoration is less than the revenues. The current forms of subsidies are valid until 1981-07-01. Up to March 1980 42 million Swedish kronor have been granted for 48 projects with an energy production of more than 100 GWh/year.

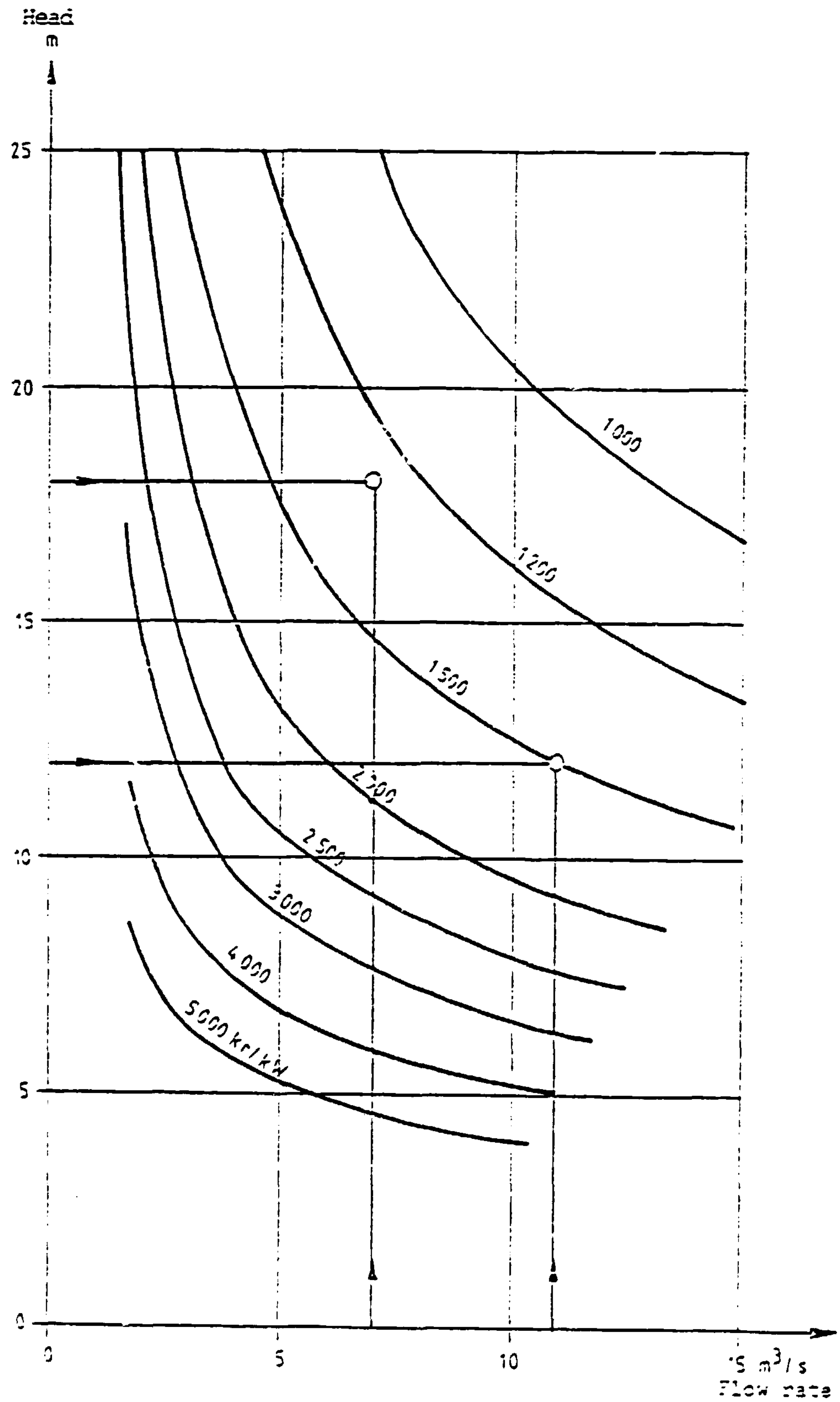
Figures of the projects are shown below:

	Number	Capacity	Energy Production	Subsidies
		kW	GWh/year	M Skr
Prototype units	8	5000	21,5	6,15
Other units	40	19300	83,0	35,74

13. Future promotion of small hydro

The government subsidies certainly have had a positive effect on the restoration of small hydro plants in Sweden. It has, however, been difficult for many of the owners of small hydro to finance the remaining part of the cost (65 %) by ordinary bank loans. A combination of reduced subsidies and governmental loans would probably be of great importance for the further development of small hydro. Subsidies would primarily be used to pay the costs of the first investigations and the costs at the Water Court. Such a promotive system is under consideration.

Figure 11



Costs in Skr/kW for the mechanical and electrical equipment for units with fixed runner blades as function of flow rate and head.

Average costs

	Capacity kW	Energy-production GWh/year
1. Average costs for six plants with fixed runner blades	700	3,3
2. Average costs for five plants with adjustable runner blades	530	2,8
3. Average costs for all eleven plants	620	3,0

Cost for mechanical and electrical equipment		Other cost		Total cost	
M Skr	Skr/kW	M Skr	Skr/kW	M Skr	Skr/kW
1,50	2 150	2,50	3 550	4,00	5 700
1,75	3 300	2,35	4 400	4,10	7 700
1,6	2 600	2,4	3 900	4,05	6 600

Figure 12

It has been judged necessary to make general surveys concerning the most suitable restoration of small plants in every watercourse where small hydro is of current interest. Such general surveys also will help the owners of small hydro to cooperate in the dimensioning and design of the plants in the same river. These general surveys are administrated by the provincial governments.

MINI-POWER STATIONS

Prototype installations - experience gained

The eight prototype installations have been object of follow-up studies and records have been kept of the experience gained. This experience has been made use of in forming the standardized purchasing programme. The operational experienced has also been documented in operational reports and inspection reports.

This is only a summary of the points which are of particular importance when designing the machines and electrical equipment for mini-power stations.

The disposition of the unit

The installation elevation of the unit should be studied with regard to cavitation and runaway conditions for each installation. Even for a relatively small head there may be certain advantages with a unit with a vertical shaft, for example to reduce the size of the building required and to reduce the vibrations during runaway.

Because of the automation of the installation, there are stringent requirements for the shut-off of the water-path if the connection to the power net-work is interrupted. If the butterfly valve or gate, whichever is fitted, fails to operate, runaway is obtained with the unit rotating at approximately twice its normal speed and the draft tube is subjected to a very great strain. This tube should be designed to withstand the vibrations which occur and for the same reason it should be cast into concrete.

The design of the intake

The intake should be provided with some type of extra shut-off (stop-logs) to make it possible to close the water-path if the butterfly valve cannot be closed, even though this condition must be regarded as very exceptional.

The design of the trash rack

In order to reduce the necessity of cleaning the trash rack it may be desirable to increase the spacing between the bars from the normal 20 mm to 50 to 60 mm. This may be possible if the turbine is a propeller-type turbine with fixed blades which reduces the risk of injury to fish passing through the turbine. Particular attention should be paid to this point.

Trash rack

Rationalized automatic trash rack cleaners are now on the market and in some cases installation of such equipment may be justified. Cleaners can also be installed after experience has been gained with the watercourse in question. The necessity for cleaning varies considerably.

Head-race tubes

A very considerable number of the proposed mini-power stations are fitted with head-race tubes. When these are renewed the choice of materials and dimensions is reconsidered. The standardized mini-power stations have a relatively long shut-down period and a negligible pressure rise after shut-off. It is probable that the use of higher flow-velocities than previously is justified and this also results in cheap head-race tubes. However, particular attention should be paid to the shaping of the tubes at the inlet and at the connection to the turbine butterfly valve in order to obtain favourable flow with the lowest possible losses. The details of the design and of the foundations for the tube must be decided for each installation individually. The choice of material for the tube must also be made from case to case using a tendering procedure. Nowadays, fibreglass reinforced plastic tubes can often compete with wooden or steel tubes.

Butterfly valves

The butterfly valves used in four of the prototype installations have functioned well. In future installations they should also be fitted with a hand-pump. Stops should be provided to prevent them being turned beyond the end position. Similarly, they should be provided with secure locking devices for use when work is being carried out in the turbine casing.

Shut-off gates

In two of the prototype installations gates were chosen instead of butterfly valves. The primary reason was economy - lower installation cost and smaller losses in the water-path. From the operational point of view, however, a butterfly valve has certain advantages, particularly in the winter. As was pointed out above, it is desirable that future installations with butterfly valves are also provided with simple shut-off gates which can be operated manually if the valve does not function.

The turbine

Special attention should be paid to facilities for inspection of the runner in future and for this reason the runner should be made accessible via man-hole covers.

The cooling-water supply and the question of filtration should be given careful consideration.

The question as to whether the cooling-water pump for the supporting bearing should be driven by direct current, so that it can continue to operate when the power station is without power, should be considered.

Facilities for (manual) adjustment of the blades in future should be provided at all installations. The question as to whether the runner hub should be cylindrical or spherical must be decided in each individual case weighing loss of efficiency against costs.

The prototypes units are guaranteed to withstand runaway operation for 2 hours. Due to the vibrations which arise, runaway testing has only been carried out for short periods. In the case of normal shut-down the valve closes and no runaway occurs. When the connection to the power network is interrupted, the turbine speed increases to about twice the normal speed and runaway occurs for about 1 minute before the valve has time to close.

Runaway protection devices must be duplicated and in addition to an electro-magnetic valve there must be a mechanical-hydraulic runaway protection device.

The vibrations during the synchronizing operation and during runaway when the unit drops out must be counteracted as explained above.

When the turbine casing is provided with a vent pipe this must have its opening above the upper water-level. Otherwise there is a risk that the station will be flooded if the non-return valve fails to operate.

The gearing

Lifting facilities (an eye-bolt) should be provided over the gearing for future dismantling during repair work.

The noise-level of the gearing is lower than was expected.

The generator

Care should be taken to ensure that the generator is not designed for too low capacity. The value of the losses in the generator is sufficient to justify over-dimensioning of the generator. The generator should be cooled by means of a thermostat-controlled suction fan.

In the case of large generators the windings should be provided with resistive elements in order to allow the temperature of the windings to be determined in a simple manner.

The method to be used for cooling should be decided at an early stage so that both the generator and the building can be designed accordingly.

Complete tests should be carried out at the workshops of the generator maufacture in the case of future deliveries.

Automatic control equipment

The water-level detection equipment should be designed for the greatest possible operational reliability and if it is necessary for the prevention of flooding of the power station dam it should be duplicated.

Fault indication and signalling systems must be chosen for each case. The standard design of the prototype units is such that if it is wished to run the machines with a fault which is not considered serious it is necessary to disconnect the signalling system. For future mini-power stations a more sophisticated signalling system might be considered to be justified in some cases.

The automatic control system for starting and stopping has functioned satisfactorily for all the prototype installations.

Voltage variation on the connected network

During the designing of the mini-power stations the question of voltage variations during synchronizing was given much attention and apprehension was expressed in case the variations should be of such a magnitude as to be troublesome.

The results of measurements at one of the installations which was considered to be critical showed that the magnitude of the voltage variation is in agreement with that found by theory but that the duration of the disturbance is very short and that it is without significance in practice.

Other points

The problem presented by ice in the inlet channel should be taken into account during the design. During short-term regulation the ice-cover can be broken and ice-floes may float downstream and cover the trash rack with interrupted operation as a result. This can be counteracted by dimensioning the channel so that the velocity of the water is kept low (<1 m/s) and by limiting the 24-hour variation in the dam water-level to within 5 - 10 cm by means of automatic intermittent operation.

However, turbines with fixed runner blades are not recommended on sites where ice-problems are expected.

Appendix 2

Mini-power station
Data for invitation to tender

Power plant: Waterway:

Municipality: County:

Owner: Contact person: address:
tel.

Restoration (_) Renovation (_) Addition (_) New Facility (_)

		Fixed runner blades (F)	Adjustable runner blades (A)
Turbine type: propeller turbine			
Type I:	Open turbine pit, vert. (I)	(_)	(_)
	Intake gate (_)		
Type II:	Closed turbine pit, hor. (II)	(_)	(_)
	Intake gate (_)		
	Butterfly valve (_)		
Type III:	Closed turbine pit, vert. (III)	(_)	(_)
	Butterfly valve (_)		

Head race tube: Length: .... m Diameter .... m

Water level, upstream: max.: +..... downstream: max.: +....
normal: +..... normal: +....
min.: +..... min.: +....

Head (geod) max.: ..... m
normal: ..... m
min.: ..... m

Flow max.: ..... m^3/s
ave.: ..... m^3/s
min.: ..... m^3/s

Draft head during operation measured from centre of runner	max.:	m
Turbine output:	.....	kW
Generator output	nom.:	kW
	max.:	kW

Speed: turbine		normal	rev/min
"		runaway speed	rev/min
generator		normal	rev/min
"		runaway speed	rev/min

Delivery weight: .... ton

Erecting weight: max. .... ton

Notes:...

....

....

Date for tender:..

Appendix 3

Mini-power station
Data for submitted tender

Power plant: Waterway:

Municipality: County:

Owner: Contact person: address:
tel.

Restoration ( ) Renovation ( ) Addition ( ) New facility ( )

		Fixed runner blades (F)	Adjustable runner blades (A)
Turbine type: propeller turbine			
Type I:	Open turbine, pit, vert. (I)	( )	( )
	Intake gate ( )		
Type II:	Closed turbine pit, hor. (II)	( )	( )
	Intake gate ( )		
	Butterfly valve ( )		
Type III:	Closed turbine pit, vert. (III)	( )	( )
	Butterfly valve ( )		

Head race tube: Length: .... m Diameter: .... m

Water level, upstream: max.: +..... downstream: max.: +....
normal: +..... normal: +....
min.: +..... min.: +....

Head (geod) max.: ..... m
normal: ..... m
min.: ..... m

Design discharge: ..... m^3/s

Runner diameter ..... m

Elevation of centre of runner +.....

Short-term regulation	volume:	.....	Mm^3
	amplitude:	.....	m
Design discharge:		.....	m^3/s
Generator output	nominal:	.....	kW
	maximum:	.....	kW

Notes:..

....

....

Date for tender:..

Appendix 4

<u>Mini-power station</u>
<u>Mechanical and electrical equipment</u>
<u>Scope of tender</u>

Power plant:

Owner:

The tender shall quote mechanical and electrical equipment for a mini-power station of type VAST.
The components and works covered by the invitation to tender are specified below.

As confirmation, the tenderer shall indicate below what is included in the tender by marking the appropriate boxes with an x.

Component	Invitation to tender includes	Remarks
Intake gate with hydr. servomotor	( )	
complete equipment for regulation	( )	
Butterfly valve with hydr. servomotor	( )	
complete equipment for regulation	( )	
Overspeed protections:		
solenoid valve	( )	
mechanic-hydraulic valve	( )	
Intake unit of steel plate (dimensional) data indicated in the drawing)	( )	
Turbine casing with necessary racks and manholes	( )	
Fixed guide ring and bearing housing for journal bearing (rubber bearing)	( )	
Runner with hub and hub cone plus four runner blades	( )	
Servomotor for regulation of runner blades built into runner hub and complete equipment for regulation	( )	

Runner shaft (tubular)	( )
Combined thrust and guide bearing	( )
Runner chamber, split	( )
Draft tube (dimensional data)	( )
Discharge lines between turbine casing and draft tube	( )
Coupling between turbine and generator shafts	( )
or	
coupling between gear shaft and generator shaft	( )
Base beams and foundation bolts	( )
Safety devices	( )
Oil for initial filling of servomotors, gear and bearings	( )
Gear, cylindrical single-storey gear	( )
Asynchronous generator, type ...	( )
Electrical and control equipment	
Capacitor bank	( )
Control and relay board	( )
400 V switchgear	( )
Diverse electrical auxiliary equipment e.g. for level regulation	( )
Transformer, standard 0.4/10 kV or 3.3/10 kV	( )
Plus the following works:	
All transports	( )
Erection	( )
Supply labour	( )
Auxiliary devices for erection	( )
Mobile crane	( )
Electrical power and compressed air for erection	( )

Trial operation, three days ( )

Painting ( )

Remarks:..

Date for tender:..

Mini-power station
Contents of tender

1. Guarantees

a) Efficiency guarantee

A hydraulic efficiency guarantee shall be provided, based on tests on model wheels. The efficiency guarantee shall relate to 25, 50, 75 and 100% load at H= m.

b) Output

A guarantee shall be provided that the maximum output stated in the tender at H= m can be achieved.

c) Cavitation guarantee

Provided that the draft head during operation does not exceed the value specified in appendix A2, a guarantee shall be provided that the turbine can be operated continuously with the stated output without risk of harmful cavitation as described in standard SEN 25 80 10.

d) General delivery guarantee

The complete delivery is guaranteed for a period of 2 years or 10 000 hours of operation, whichever comes first.

A guarantee is provided that overspeed for no more than 2 hours shall not lead to permanent damage.

2. Insurances

The supplier shall be responsible for all transport and erection insurances for the delivery.

3. Delivery time

Within 2 months following order placement, final erection drawings shall be submitted to the purchaser. The specified partial delivery deadlines shall then be met in order that the construction work can proceed according to schedule.

4. Penalty clauses

a) Efficiency guarantee

If it can be proved that the efficiency guarantee cannot be met, the agreed-upon price shall be reduced by 1% for each percent by which the average cannot be reached.

b) <u>Output guarantee</u>

If the guaranteed output ...kW cannot be achieved at the specified head H= ...m, fines shall be payable in the form of a reduction of the agreed-upon price by the same percent as the output loss represents of the guaranteed output.

c) <u>Delivery delay</u>

If commissioning of the power plant is delayed through the fault of the supplier and the purchaser thereby suffers a loss, fines for delivery insurance shall be payable. The fines shall be 0,5% per each whole week of delivery delay, provided that the delivery delay is the cause of the delay in commissioning.

5. <u>Tender price</u>

The price for complete delivery, not including "Moms" (value added tax, VAT) shall be specified in the tender. In view of the fact that the delivery times are generally less than 1 year, the price shall apply without any index adjustment clause.

6. <u>Terms of payment</u>

Payment shall be made in 3 equal partial remittances in accordance with NLM71.

7. <u>General conditions</u>

General Conditions NL70, NLM71 and TP71S shall apply to the delivery, unless otherwise specified when ordering.