



**Ministry of Energy  
of Georgia**



**Norwegian Water  
Resources and Energy  
Directorate**

**COST BASE  
FOR SMALL HYDROPOWER PLANTS IN GEORGIA  
< 13 MEGAWATT  
(price level 1<sup>st</sup> January 2015)**



2016

## **PREFACE**

In 2013 the Norwegian Water Resources and Energy Directorate (NVE) entered into a cooperation with the Ministry of Energy of Georgia and the National Environmental Agency of Georgia, with the purpose of developing an inventory of all hydropower potential in Georgia, including development and construction costs. The cooperation necessitated a step-wise approach, where the following steps were necessary:

- Preparation and quality control of historical hydrometeorological data
- Land use mapping and preparation of a digital elevation model (DEM)
- Preparation of a national runoff map for Georgia
- Compilation of cost data for hydropower development
- Calculation of the hydropower potential and associated costs

This manual, which has been prepared by Georgian (Gross Energy Group) and Norwegian (Norconsult AS) consultants in cooperation with the Ministry of Energy of Georgia and NVE, contains relevant cost data for hydropower development in Georgia. Hopefully the manual may serve as a useful guide to potential investors in renewable energy in Georgia, as well as a tool for the government for assessment and prioritization of the hydropower development.

# TABLE OF CONTENTS

1	GENERAL CHAPTER .....	1
1.1	GENERAL .....	1
1.1.1	INTRODUCTION .....	1
1.1.2	HISTORY .....	1
1.1.3	CONTENT AND USE OF THE REPORT .....	1
1.1.4	PRICE LEVEL.....	2
1.2	STRATEGY FOR SMALL HYDROPOWER PLANTS .....	2
1.2.1	INVESTMENT ADVANTAGES .....	3
1.2.2	ENERGY POLICY .....	3
1.3	PROCESSES FOR HYDROPOWER DEVELOPMENT IN GEORGIA .....	3
1.3.1	ENVIRONMENTAL IMPACT ASSESSMENT .....	3
1.3.2	LAND TRANSFER.....	3
1.3.3	CONSTRUCTION PERMIT .....	3
1.3.4	GENERATION LICENSE.....	3
1.3.5	INTERCONNECTION AGREEMENT .....	4
2	BUILDING AND ENGINEERING WORK .....	5
2.1	GENERAL .....	5
2.1.1	SCOPE OF DELIVERY .....	5
2.1.2	EVALUATION OF OVERHEADS.....	6
2.1.3	PRICE VARIANCE .....	6
2.1.4	CONSIDERATIONS RELATING TO THE VALUE OF DEVELOPERS' PERSONAL EFFORTS.....	6
2.2	DAMS .....	9
2.2.1	SMALL RIPRAP DAMS .....	9
2.2.2	CONCRETE DAMS .....	9
2.2.3	TIMBER CRIB DAMS .....	11
2.3	INTAKE STRUCTURES.....	17
2.4	POWER STATIONS.....	20
2.4.1	SURFACE POWER STATIONS .....	20
2.4.2	UNDERGROUND POWER STATIONS.....	20
2.5	PENSTOCKS, CHANNELS .....	22
2.5.1	PENSTOCK FOUNDATIONS.....	22
2.5.2	PIPE TRENCHES.....	24
2.5.3	CHANNELS .....	26
2.6	GEOTECHNICAL ENGINEERING .....	29
2.6.1	TUNNEL MINIMUM CROSS-SECTION .....	29
2.6.2	LARGE-HOLE DRILLING .....	29
2.6.3	ROCK DRILLING.....	32
2.7	TRANSPORT FACILITIES.....	32
2.7.1	TEMPORARY ROADS FOR CONSTRUCTION PURPOSES .....	32
3	ELECTROTECHNICAL WORKS .....	34
3.1	GENERAL .....	34
3.1.1	POWER FACTOR ( $\cos\phi$ ) .....	34
3.2	GENERATOR .....	35
3.3	TRANSFORMERS .....	38
3.4	SWITCHGEAR AND CONTROL SYSTEMS .....	40
3.5	POWER LINES .....	43
4	MECHANICAL ENGINEERING .....	44
4.1	GENERAL .....	44
4.1.1	SCOPE OF DELIVERY .....	44
4.1.2	PRICE ESTIMATE.....	44
4.2	TURBINES .....	45
4.2.1	PELTON TURBINES .....	47
4.2.2	FRANCIS TURBINES.....	48
4.2.3	KAPLAN/BULB TURBINES .....	49
4.2.4	OTHER SOLUTIONS AND TURBINES.....	50
4.3	GATES .....	55
4.3.2	ROLLER GATE.....	55
4.3.3	SLIDING GATE.....	56

4.3.4	FLAP GATES.....	56
4.3.5	RUBBER GATES.....	57
4.4	INTAKE SCREENS.....	61
4.5	LIFTING EQUIPMENT.....	63
4.5.1	TRAVELLING CRANE.....	63
4.5.2	ELECTRIC HOIST W/ELECTRIC TRAVELLER.....	63
4.5.3	ALTERNATIVE LIFTING EQUIPMENT.....	63
4.5.4	MOBILE CRANES.....	63
4.6	INTAKE SCREEN RAKES.....	66
4.7	PIPES.....	67
4.7.1	PE PIPES.....	68
4.7.2	GRP PIPES.....	68
4.7.3	SPIRAL WELDED STEEL PIPES.....	69
4.7.4	SEAMLESS STEEL PIPES.....	69
4.7.5	DUCTILE CAST-IRON PIPES.....	69
4.7.6	WOODEN PIPES.....	70
5	COMPLETE ELECTROMECHANICAL DELIVERIES.....	75
5.1	GENERAL.....	75
5.1.1	SCOPE OF DELIVERY.....	75
5.2	COMPLETE SMALL HYDROPOWER PLANT UNIT FROM 500–13,000 KW.....	75
5.2.1	PRICE ESTIMATE.....	75
5.2.2	SMALL HYDROPOWER PLANT GENERATORS.....	76
5.3	MICRO AND MINI POWER UNITS UP TO 500 KW.....	76
5.3.1	PRICE ESTIMATE.....	76
5.3.2	MICRO AND MINI POWER UNITS.....	76
5.3.3	PELTON TURBINES.....	79
5.3.4	FRANCIS TURBINES.....	79
5.3.5	KAPLAN.....	79
5.3.6	OTHER TYPES OF TURBINES.....	79

# 1 GENERAL CHAPTER

## 1.1 GENERAL

### 1.1.1 INTRODUCTION

This manual has been prepared to provide tools for calculating average foreseeable contractor costs (building-related work) and supplier costs (mechanical and electrical equipment) for small hydroelectric power plants with an early phase generating capacity of up to 13,000 kW. These costs will depend on a number of conditions, which may vary from power plant to power plant, and consequently requires the user possesses sound technical knowledge. This applies in particular to the building-related work associated with the hydropower plant. The manual is a supplement to our Cost Base for larger hydropower projects (> 13,000kW).

### 1.1.2 HISTORY

Up to now former Soviet Union standards, as well as the quarterly published manual issued by the Construction evaluation union, has been used in Georgia.

Norconsult AS (Norway) has been assigned the task of preparation the *Cost Base for Small Hydropower Plants* for Georgia (price level 1 January 2015) by the Norwegian Water Resources and Energy Directorate (NVE) as a task in the agreement between NVE and Ministry of Energy (MOE) of Georgia. The final version is a result of joint review and corrections by NVE (also consulting Norconsult) and MOE (assisted by Georgian consultant Gross Energy Group).

Current manual represents a very smart tool for the calculation of hydropower development in Georgia. Maintenance and upgrading of the Cost Base in future will be undertaken when judged necessary.

Power plants with a generating capacity of 0-13 MW are often divided into:

Micro power plants which are power plants with a capacity of up to 100 kW

Mini power plants which are power plants with a capacity of between 100 kW and 1 MW

Small hydropower plants are power plants with a capacity of between 1 MW and 13 MW

### 1.1.3 CONTENT AND USE OF THE REPORT

The report has been divided into three main chapters:

- Construction and civil engineering works
- Electrotechnical engineering works.
- Mechanical engineering works

The report aims to present costs under "normal" conditions, and is intended to be used in the early planning stages to quickly establish the approximate cost of a project and to compare the costs of different hydro projects.

Most prices are presented in the form of graphs with associated text.

#### 1.1.4 PRICE LEVEL

The prices in the report are as of 1 January 2015. All prices are stated in United States Dollars, USD.

### 1.2 STRATEGY FOR SMALL HYDROPOWER PLANTS

Over the past several years, the Georgian Government has undertaken an ambitious program to modernise and liberalise its economy. Institutional reforms have included privatising large state-owned entities, reducing the number of taxes and tax rates, improving tax and fiscal administration, restructuring license requirements, simplifying customs and border formalities, and generally undertaking efforts to make it easier to do business in Georgia.

It can be boldly stated that Georgia is a “Hydro Powered” country. On average 85% of total country generation comes from domestic hydro power plants. Georgia’s natural wealth is comprised principally of water and water resources, and its hydroelectric potential per capita ranks among the world’s greatest. It is a reliable transit country and regional energy hub with significant transit potential for delivering resources from the Caspian region to international markets.

Implementation of potential renewable projects is a top priority for the Ministry and its sources make a major contribution to sustainable development of our country. Growing demand in our and neighbouring countries on electricity strongly encourages potential investors to take full advantage of new approaches and investment opportunities in energy sector of Georgia.

Government's effort to attract foreign direct investments resulted in creating an investor-friendly environment by offering green-field projects based on the Build-Own-Operate (BOO) principal, attractive export markets, free third party access to the grid and efficient legal and regulatory framework.

Liberal tax legislation, Double Taxation Avoidance Treaties with OECD member countries, rapidly expandable export market, simplified procedures, and strong support and commitment aiming at developing of renewable energy sources from the Government of Georgia create favourable business climate for the potential investors.

Georgia's energy independence is an integral component of the country's priorities. Currently, energy mix dependency of Georgia on thermal and external sources is 75%-80% that can only be reduced by development of renewable energy resources, primarily hydro and energy efficiency. Our aim is to increase energy security and support development of green economy. Renewable sector represents the only domestic natural resource addressing Georgia’s domestic needs.

Our goal is to further develop east-west and north-south energy transportation infrastructure in order to increase transit capacity of the country. Additional goals are to improve social and economic condition by attracting new investments in renewable energy projects, improve economic and social condition by creating new jobs and new opportunities for people, further develop modern and reliable infrastructure creating energy independence for the Country and strengthen co-operation with the international organizations in order to accelerate integration of the country into European and Euro-Atlantic organizations.

### 1.2.1 INVESTMENT ADVANTAGES

- Build-Own-Operate (BOO) principle;
- Deregulated Energy Sector;
- Simplified Procedures;
- Diversified & Expanding export markets, including EU;
- No fee for the connection to the transmission grid;
- Carbon Credits Trading;
- New HPPs have priority access to the capacity on the new interconnection to Turkey;
- Generation and Export activities are exempted from VAT
- 15 year PPA for total generation of power plant during September-April period

### 1.2.2 ENERGY POLICY

- Diversification of the energy supply resources, optimal utilization and reserve creation of the Georgian energy resources;
- Exploitation of the Georgia's renewable energy resources;
- Gradual rapprochement of Georgian legislation with EU legislation;
- Georgian energy market development and improvement of the energy trade mechanisms;
- Increasing the role of Georgia as a regional transit country;
- Georgia – clean energy production and regional centre for the energy trade;
- Creation of unified approach on Energy Efficiency and its execution;
- Consideration of the environmental issues during energy projects implementation;
- Improvement of the service level and consumers rights protection.

## 1.3 PROCESSES FOR HYDROPOWER DEVELOPMENT IN GEORGIA

### 1.3.1 ENVIRONMENTAL IMPACT ASSESSMENT

Approved by Ministry of Environment and Natural resources protection in no more than 60 days for public hearing and up to 20 days for approval by the ecology committee.

### 1.3.2 LAND TRANSFER

If the plant site is State-owned, GoG will lease to the investor on the long-term (99-year) basis or transfer the land plot to the investor for a nominal fee (the nominal fee is set by the local municipalities for the purpose of privatization and it is closer to market price) through the direct sale procedure for land privatization.

### 1.3.3 CONSTRUCTION PERMIT

Issued by Ministry of Economic and Sustainable Development of Georgia for HPP of 2 MW or more and by agencies of local self-governance. It takes 30 days for verification of Land ownership, maximum 20 days for approval of technical design (including Environmental Impact Permit), and up to 10 days for issuance of Permit.

### 1.3.4 GENERATION LICENSE

Issued by the Georgian National Energy and Water Supply Regulatory Commission ("NGEWRC"), is the legal basis for power generation activity and should be obtained prior to

the operation of units of 13MW or more. It has a granting period of approximately 30 days, including 5 days to confirm application completeness.

#### 1.3.5 INTERCONNECTION AGREEMENT

Newly constructed plants need to make interconnection agreement with the owner of Transmission line/grid. The connecting is free of charge and transmission rates are set by the GEWRC

## 2 BUILDING AND ENGINEERING WORK

### 2.1 GENERAL

#### 2.1.1 SCOPE OF DELIVERY

The cost base includes costs as stated for each construction and engineering section.

For the last period, there has been tendency of price decrease, though there are some prices that have not changed compared to the prices given in the construction material cost book, which provides information on regulated market prices.

In the *Cost Base for Small Hydropower Plants* general costs such as rigging, overheads, and operational (henceforth referred to as "overheads" or "rigging") expenses are excluded in all building-related cost components and must be added to the total project cost. Generally, the additional rigging cost that should be added is **30% of the total cost of all other works**.

**The following costs have not been included and must be evaluated for each project:**

- Transport and temporary roads for construction purposes.
- Rehabilitation of land and waters (forest clearing, routes, landfills, land adjustment)
- Other general costs: Represent additional costs of 10-15% and usually include the following:
  - Surveying and preparation of engineering basis (maps, profiles, etc.)
  - Stream gauging and hydrologic assessments
  - Environmental surveys
  - Impact assessments
  - Soil surveys
  - Planning and engineering. Depending on conditions by the dam, intake, penstock (incline), power station (depth to rock, etc.).
  - Administration, construction management, quality control
- Taxes and fees (value added tax, investment tax).
- Builder costs (land acquisition, valuation, compensation, financing expenses)
- Unforeseen costs. It is generally recommended to add 15-20% to all cost elements to cover any unforeseen costs.

### 2.1.2 EVALUATION OF OVERHEADS

It is imperative to note that overheads may vary considerably. Costs for small hydropower plants are usually in the region of 10-60%, and in special cases even higher. This must be evaluated on a project to project basis, and depends on the location and available infrastructure. A greater distance to villages/towns results in higher overheads due to increased transport, travel and accommodation costs. The choice of contract and contractor will also affect the overhead costs, as larger contractors tends towards low unit costs at the expense of more overheads, and vice versa for smaller contractors. The total price is usually similar, however. Furthermore, the nature of the work is an important factor. Mainly a single type of work, a long tunnel for instance, leads to lower overheads than complicated work requiring more coordination.

### 2.1.3 PRICE VARIANCE

The presented unit prices for individual construction parts are weighted averages based on collated prices from tendering documents and published index values. Consequently, each unit is assumed to be of "normal" accessibility and difficulty (unless where stated otherwise). In practice a range of factors influence actual unit prices, and price variations are to be expected, between projects and for different construction parts of the same project.

This is accounted for by the provided uncertainty ranges. Simply put, work under very favourable conditions may result in 20% lower unit prices, whereas work in adverse conditions may increase unit prices by 30%, for instance.

### 2.1.4 CONSIDERATIONS RELATING TO THE VALUE OF DEVELOPERS' PERSONAL EFFORTS

#### General

"Personal efforts" are the opportunities a developer has to make a personal contribution, performing parts of the project work and reducing the need for hired assistance, thus reducing overall costs. There are many types of viable personal efforts, usually relating to preparatory and building-related work. Turbines and other similar equipment must usually be supplied by one or several professional suppliers, however.

In many cases it will not be allowed with personal efforts in public power plant projects. Nor will large private power plants be particularly suitable for personal efforts as implementation requires substantial capacity and well organised efforts over a period of time. It would difficult to coordinate the developer's personal efforts with the work of the contractor. However, private landowners and other stakeholders may participate in the project in the normal commercial manner, such as contractor activities.

There are greater opportunities for personal efforts in smaller, private projects (mini and micro power plants). Such projects are often owned by one or a few landowners, and the power plant is often constructed with a great deal of idealism. Personal efforts in smaller projects can significantly reduce external costs, and may be necessary to implement the project at an acceptable price.

### Concept phase

Landowners and owners of waterfall rights are often of the opinion that it should be possible to build a power plant at the site, and they want to develop the idea and assess the feasibility. The first step is often to obtain written information about the procedure from the authorities and then to contact a neutral and experienced consultant on water resource management. It may also be a good idea to hire a consultant for a few hours for a professional evaluation of the project, particularly with regard to the potential size of the project and whether there are any special restrictions (e.g. environmental protection). The personal effort may in this respect consist of procuring the relevant information, studying the procedures, and learning a little bit about others projects. Before proceeding, the rights for the entire development should be established.

### Project Development

The landowner can do a fair bit of preparatory work; obtain maps, specify ownership, inform neighbours about the prospective project, register their thoughts and opinions, inform the municipal authorities about the concept and register the local authorities' viewpoints. If there are several landowners, it may be necessary to organise landowner. It may be important to agree in advance to investigate the development, even if issues of ownership, etc. have not been fully resolved. These are time-consuming activities which the landowner(s) can do himself/themselves (and which they often do best). In this phase, it is often natural to contact external consultants, such as professional developers. This will often result in an independent evaluation of the project, and can result in inspections and meetings where the landowners participate and contribute. If the project is viable, the next phase will be to develop more specific plans and outline the project's main features.

### Obtaining a basic design

This is a phase in which the landowner can do some work, possibly in cooperation with a consultant. He can conduct surveys, establish and estimate ground conditions at the location of the potential dam, penstocks and power station, and indicate the locations on a map. The landowner can obtain permits from the authorities and dig test pits or ditches to determine ground conditions.

Furthermore, the landowner can photograph the river system at the assumed location of the dam and power station during different water flows; preferably from drought to major flood conditions. The photographs should be taken at different seasons and specify the date when they were taken. The photos should be digital and be taken from the same angle, preferably quite far away, at a distance of a few hundred metres, depending on the size of the project/river. It is important to take photos that provide an overview of the site.

### Hydrological surveys, technical pre-engineering, environmental surveys, licence applications

Professional consultants will usually conduct these activities. The landowner may prepare a draft of most of the work relating to very small mini- and micro power plants, in accordance with official guidelines. If necessary assistance may be acquired from a hired consultant for inspection and supplementation.

Preparation of inquiries and budget prices of turbines and equipment is often at the top of a developer's to-do-list. However, the above-mentioned activities should be carried out before it is possible to obtain realistic data for actual quotes for the installation.

#### When a licence or an exception from the obligation to acquire a licence has been granted

When a licence has been granted, implementation of the actual project will start. Detailed solutions for various parts of the installation are then prepared on the basis of the terms and conditions in the licence, surveys, etc., and tenders for equipment and building-related work are prepared. After this, a plan for the environment and landscape is prepared and a detailed safety plan is drawn up. The content of the detailed plans is to a large extent dictated by the licence. Moreover, the plans must be prepared in accordance with official guidelines. It is recommended that this work is conducted by a consultant with expertise in the fields of environmental technology and hydroelectricity. There are many engineers offering such consulting services. Choosing a consultant with expertise in and experience from many different installations will provide optimal solutions and predictable and safe implementation of the project both technically and financially.

#### Funding

The developer or the landowner must provide the necessary funding.

#### Implementation and construction

For mini or small hydropower plants, the landowner will be able to assist with preparatory work, ensuring accessibility for contractors and equipment by clearing the forest, constructing access roads, trenches, suitable sites for temporary accommodation modules and workshop containers, etc.

It will be necessary to ensure that the required permits are obtained, as well as follow-up of administrative issues vis-à-vis public authorities, connection to the public power grid, etc.

#### Operations

During the operating period, it is often natural that the landowner should be responsible for daily supervision. This will primarily involve ensuring that the intake is clean, and possibly regulating the upstream dams to adjust the flow of water to the power plant in question.

#### Power sales

Power sales to the grid must be formalised through agreements and the amount of energy must be measured automatically. In some cases, some of the energy may be used for personal consumption, and energy may be supplied by the grid during shutdown periods. Agreements for- and organisation of such conditions may be individual and may be contingent on the ownership and the size of the power plant.

## 2.2 DAMS

### 2.2.1 SMALL RIPRAP DAMS

The price curves represent the price per consecutive metre of dam.

The given height of the dam is measured from the centre of the dam to the top. It has been assumed that the impervious core of the dam will be constructed using morainic material up to 1 metre below the top dam. Outside the impervious core, it is assumed that there is a Geotextile cloth and an armour layer of blasted rock which is minimum 1 m. thick. The upstream inclination of the dam is 1:2.5 and the downstream inclination 1:2.

Varying depths have been given for the upstream seal trench,  $D = 1, 2$  or  $3.5$  m with a bottom width of  $0.5(H+D)$ , min. 3 m, where  $H$  = height of the impervious core in the centre dam. It is also assumed that there is an injection screen with a depth of  $0.5(H + D)$ .

Downstream it is assumed that there is a depth  $D$  drainage trench with a bottom width of 2 m.

The width of the top of the dam has been stipulated to 5 m, including kerbstone and gravelling intended for driving.

The design flood water level should be set at least 2 m below the top dam.

The following main unit prices have been applied:

Seal trench of local morainic material	3.7 USD/m <sup>3</sup>
Drainage trench	2.1 USD/m <sup>3</sup>
Armour layer / slope protection	3.4 USD/m <sup>3</sup>
Geotextile cloth	0.5 USD/m <sup>2</sup>
Kerbstone and gravel road on top of the dam	6.3 USD/m
Sealing surface preparation	5.7 USD/m <sup>2</sup>

Injection costs may also be added to the total cost. The total cost of injection varies a lot with the local conditions. This is also applies for concrete dams.

### 2.2.2 CONCRETE DAMS

For small concrete dams the following three types of dams have been described:

Gravity dam, slab concrete dam and arch dam. All three types of dams have been designed for overtopping of water up to 0.8 m.

#### Concrete gravity dam

The cost curve shows the price per consecutive metre with a dam height of up to 6 m, concreted in sections of 6.1 m. It is assumed that the rock at the toe of the dam has been injected to a depth of  $0.5 \times H$ , where  $H$  equals the water depth at the highest regulated water level (TWL). The inclination of the dam on the airside is 1:1. It is has been assumed that 1 m of uncompacted material is removed from the dam route.

The following main unit prices have been applied:

Digging, removal of uncompacted material	1.1 USD/m <sup>3</sup>
Foundation preparation (fine scaling)	2.6 USD/m <sup>2</sup>
Formwork	10.4 USD/m <sup>2</sup>
Reinforcement	0.6 USD/kg
Concrete	48.0 USD/m <sup>3</sup>

#### Slab concrete dam with inclined slab

A slab concrete dam may be more economical than a gravity dam above a certain height. A slab concrete dam will be particularly advantageous in areas where it is expensive to have concrete delivered.

For the slab concrete dam, the cost curve shows the price per consecutive metre of dam, concreted in sections of 5 m. The injection screen goes down to a depth of 0.5 x H, where H represents the water depth at the highest regulated water level (TWL). The inclination of the front slab is between 1:0.80-0.95, and the inclination of the supporting slab 1:0.25-1.0. The steepest inclinations are for the tallest dams. The slab concrete dam has not been insulated on the air side. It is assumed that uncompacted material is removed at 2 m width in the dam route, and depth to rock is 0-1m.

The following unit prices have been applied:

Digging, stripping of uncompacted material	1.1 USD/m <sup>3</sup>
Foundation on rock front slab (incl. scaling and sealing)	110.0 USD/m <sup>2</sup>
Formwork	10.4 USD/m <sup>2</sup>
Reinforcement	0.6 USD/kg
Concrete	48.0 USD/m <sup>3</sup>

#### Concrete arch dam

An arch dam might be the best solution for narrow locations. A concrete arch dam is characterised by a low mass volume compared to its height. Arch dams are therefore very practical at suitable dam locations.

In the cost curve, the minimum thickness of an arch dam has been set at 0.6 m. The dam is uninsulated and functions as a flood route. Other associated costs have not been included, such as for discharge gates, pedestrian paths, larger abutments, etc. Rock that has been removed from the toe of the dam is replaced by concrete.

The following unit prices have been applied as a basis:

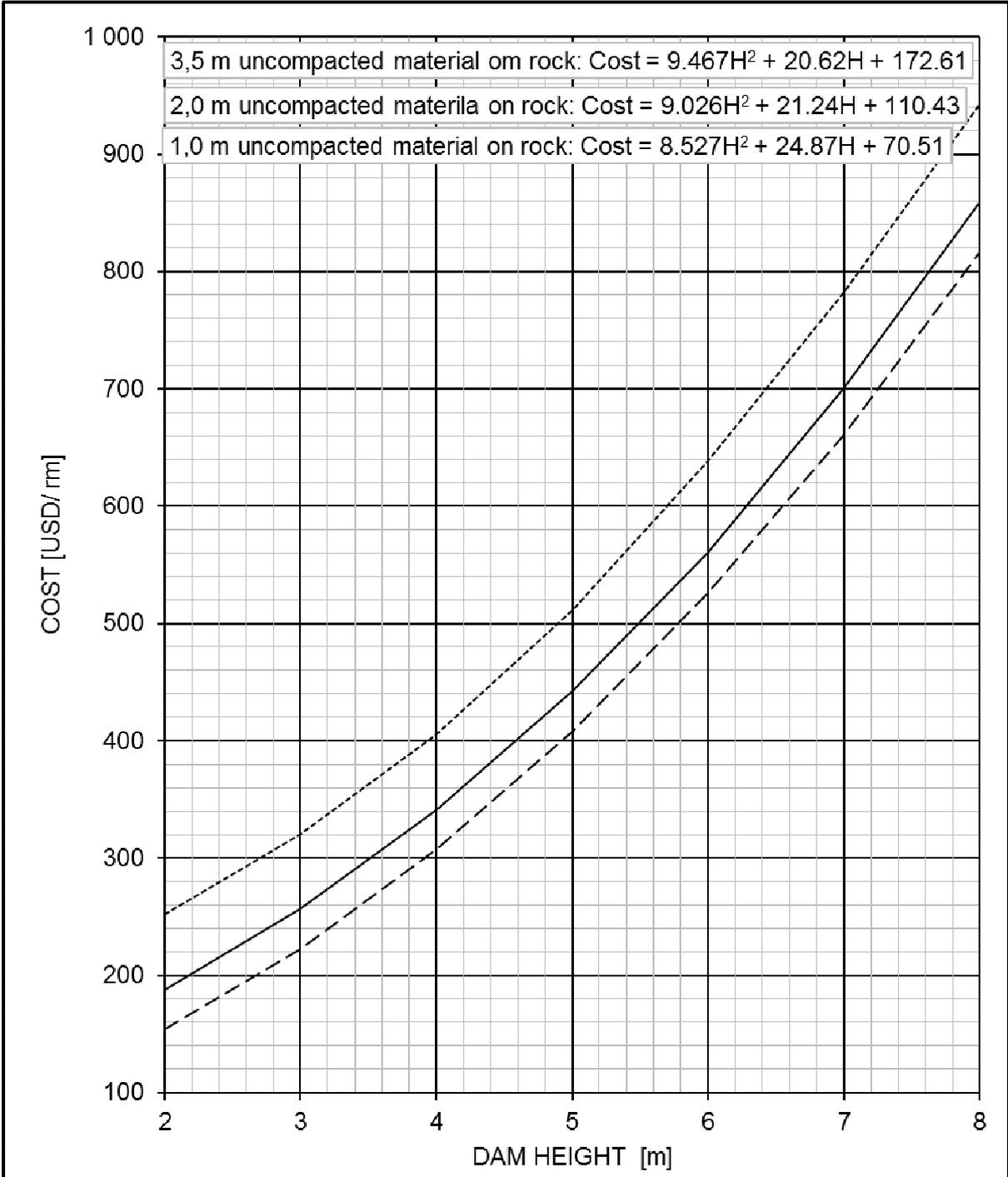
Foundation preparation (scaling and concrete)	80.0 USD/m <sup>2</sup>
Formwork	10.4 USD/m <sup>2</sup>
Reinforcement	0.6 USD/kg
Concrete	48.0 USD/m <sup>3</sup>

### 2.2.3 TIMBER CRIB DAMS

At sites with easy access to rocks, timber and qualified manpower, timber crib dams are sometimes more economical than concrete dams and traditional riprap dams. Moreover, timber crib dams can be constructed with an overflow without major changes to the construction. This is an advantage compared to more traditional riprap dams. However, timber is a living building material with a relatively short lifespan.

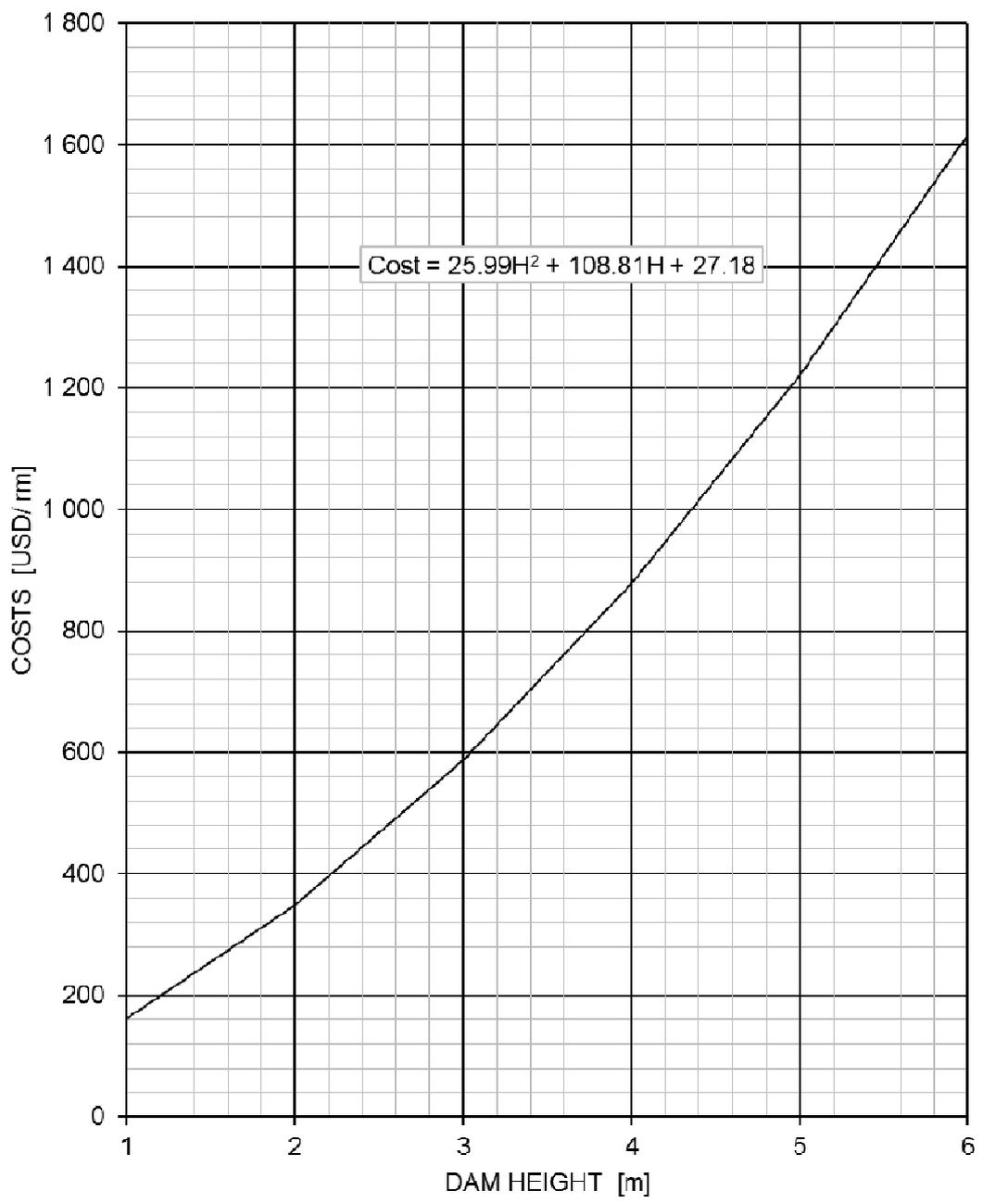
For the timber crib dam the cost curve shows the price per consecutive metre of dam. The dam includes a seal trench and timber plank sealing on the water side.

The price of the timber crib dam does not include overflow. However, the cost developments with timber plank overflow will be relatively similar. The curve is based on empirical figures with normal unit prices for the various building and engineering works. The costs will largely be determined by local conditions.



--- 1 m uncompact material on rock  
 — 2 m uncompact material on rock  
 ..... 3,5 m uncompact material on rock

<b>Small rockfill dams</b>	Price level January 2015	
Apply to rockfill dams with an impervious core of moraine Including road at top	 Norwegian Water Resources and Energy Directorate NVE	Fig 2.2.1



**Concrete-gravity dams**

Price level January 2015

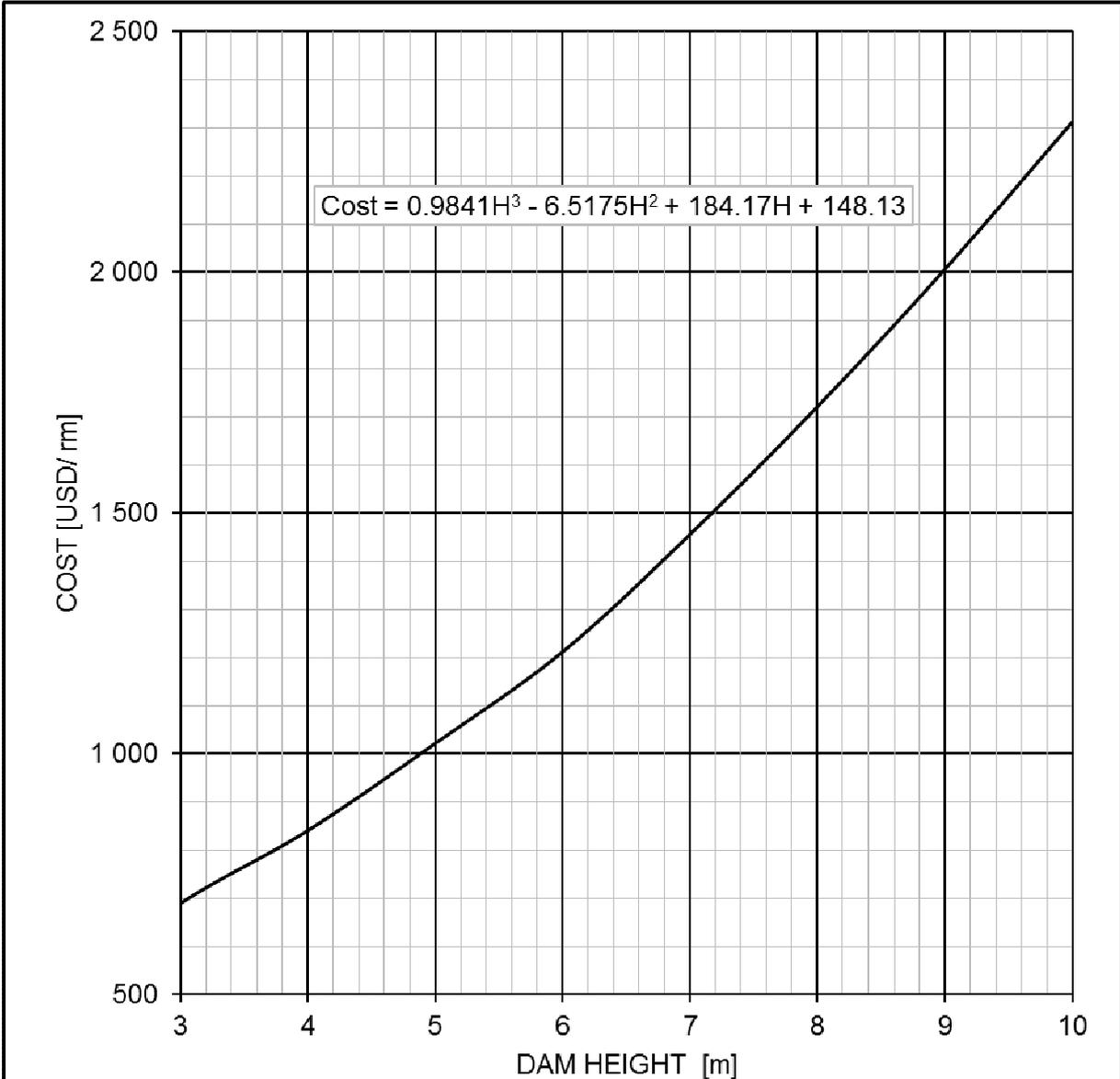
Calculated as an overflow dam with up to 0.8 m overtopping

- Price concrete: 48 USD/m<sup>3</sup>
- Price formwork: 10.4 USD/m<sup>2</sup>
- Price reinforcement: 0.6 USD/kg

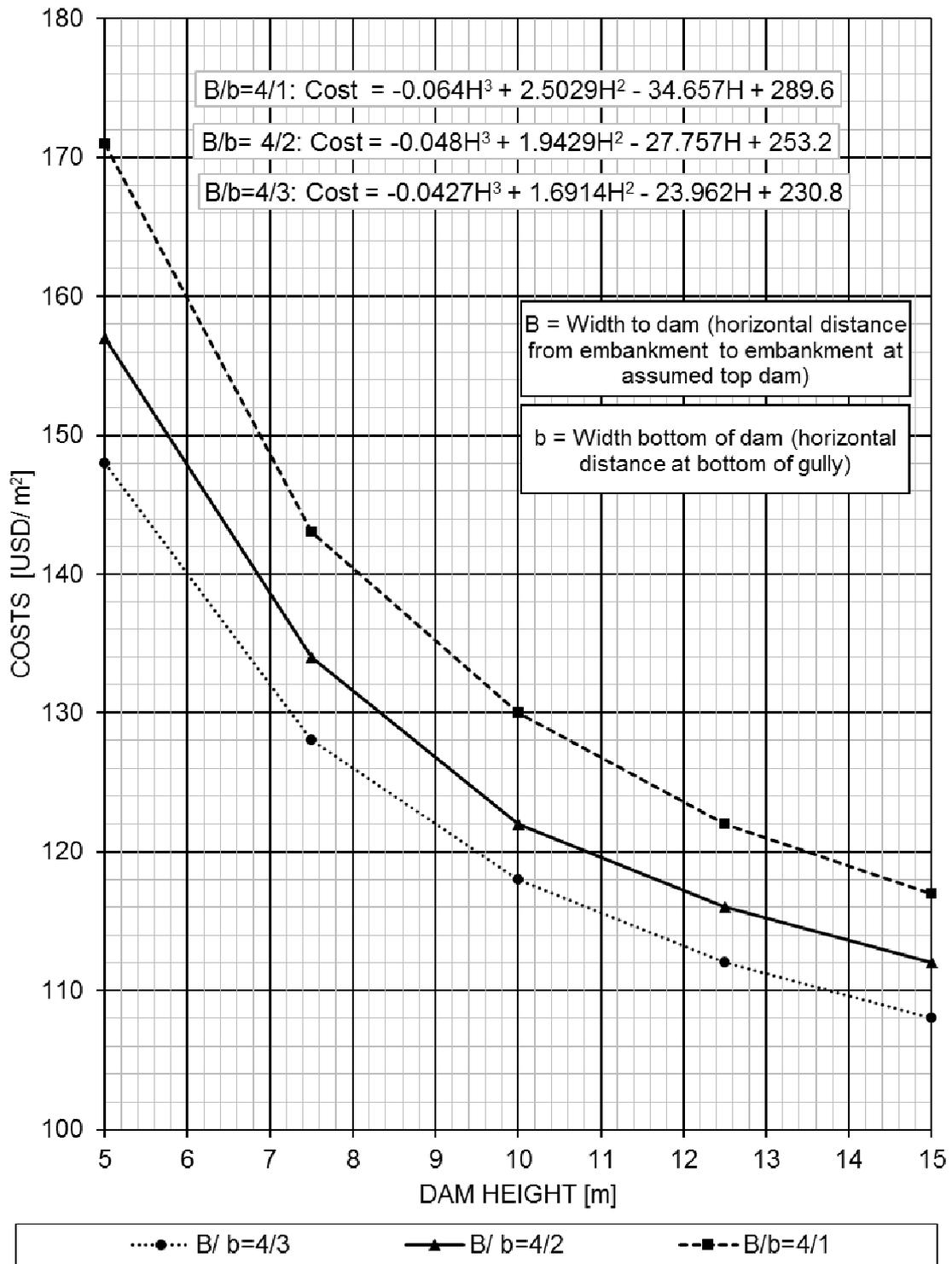


Norwegian Water Resources and Energy Directorate

Fig 2.2.2



<b>Flat slab deck dams</b>	Price level January 2015	
Price concrete: 48 USD/m <sup>3</sup> Price formwork: 10.4 USD/m <sup>2</sup> Price reinforcement: 0.6 USD/kg	 Norwegian Water Resources and Energy Directorate N V E	Fig 2.2.3



**Concrete-arch dams**

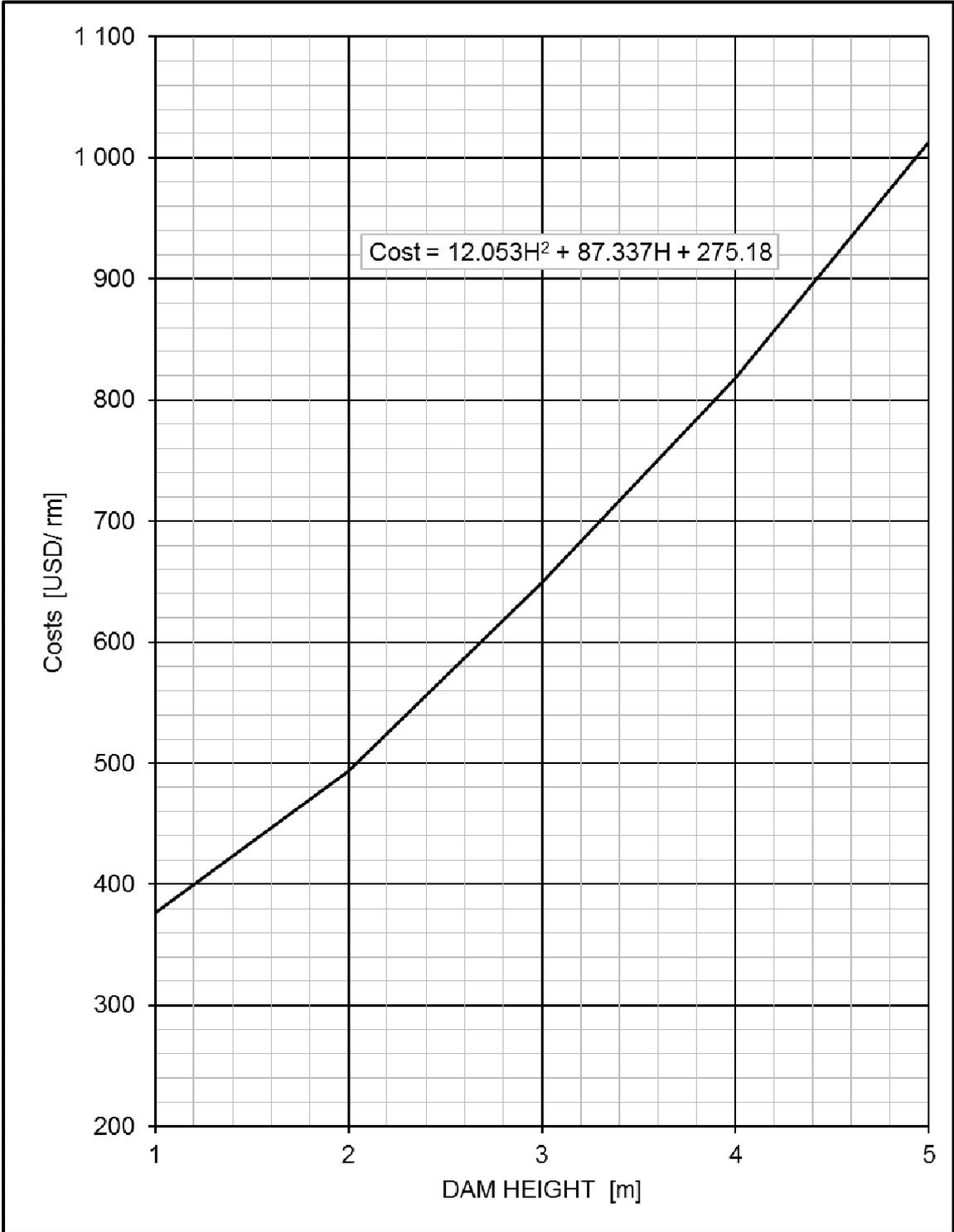
Price level January 2015

Price concrete: 48 USD/m<sup>3</sup>  
 Price formwork: 10.4 USD/m<sup>2</sup>  
 Price reinforcement: 0.6 USD/kg



Norwegian Water Resources and Energy Directorate

Fig 2.2.4



<b>Timber crib dams</b>	Price level January 2015	
Apply to civil work costs Assumed relatively easy access to materials	 <p>Norwegian Water Resources and Energy Directorate</p> <p>NVE</p>	Fig 2.2.5

## 2.3 INTAKE STRUCTURES

For small plants, and in particular mini/micro power plants, it is important to reduce development costs as much as possible. It may therefore be appropriate to build intake structures that are significantly simpler and cheaper than for larger hydropower plants. In general, the choice and design of intake structures vary significantly and are highly dependent on local conditions.

An intake includes an intake reservoir, an intake screen/strainer, and a closing device. The reservoir/ intake structure should be designed to minimise problems relating to ice freeze-up/frazil ice, debris floating on the water surface and sediment transportation. This may also be diverted away from the intake whilst trying to maintain optimal inflow conditions. Typically, the top intake should be at least 2 m below the water level (lower for large diameters). A small reservoir can be constructed by digging out/blasting out masses in order to lower the bottom or by constructing a dam which dams up the water. For larger dams see Chapter 2.2. Generally speaking, an intake will increase in scope with the rate of flow to be handled and with better operational reliability in the structure. Dam costs are calculated separately.

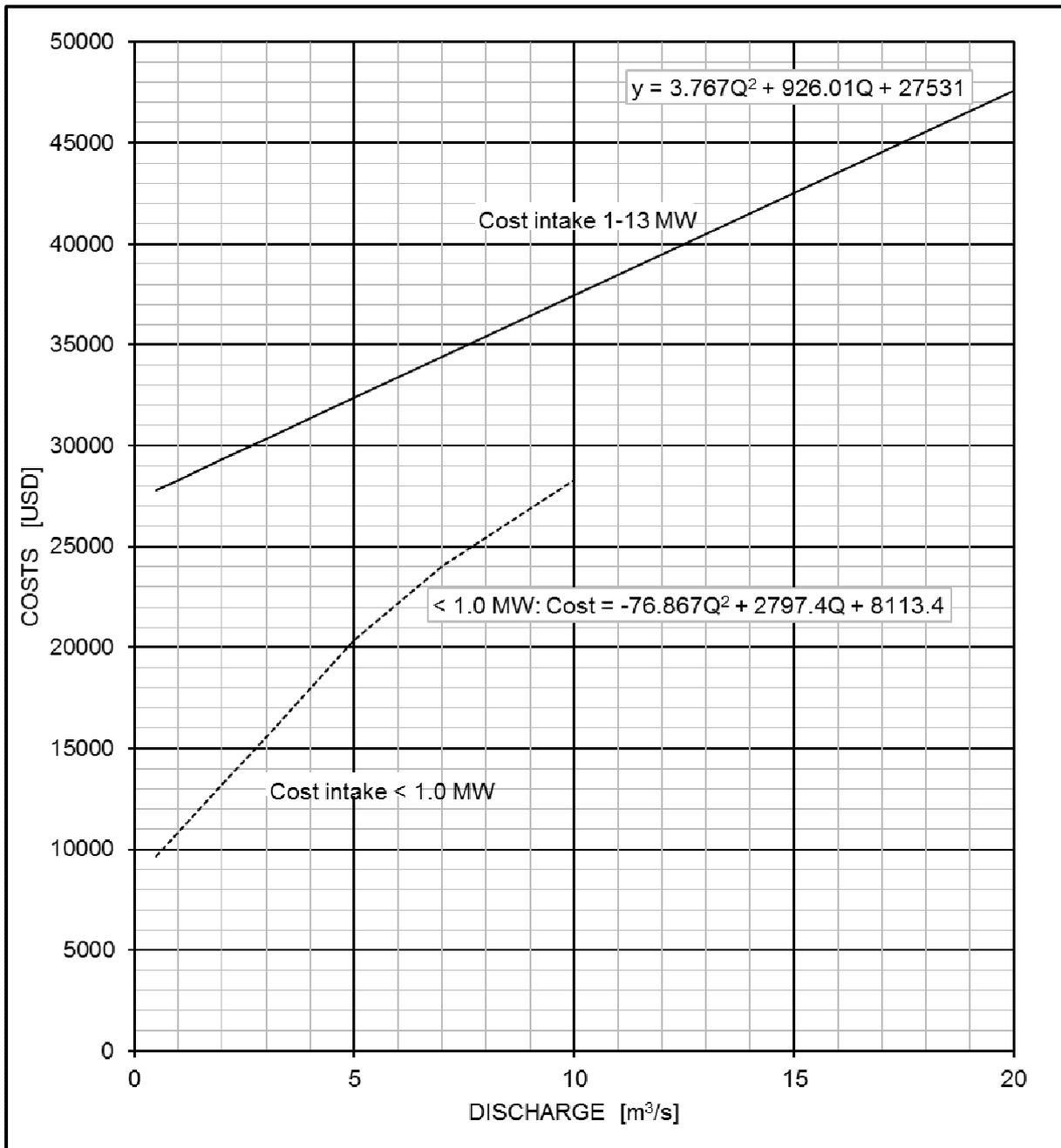
For plants of up to 1 MW it is a fundamental question whether to construct an intake which will function for a long time without monitoring (proper submersion but well above the river bed, and the system must be self-cleaning), or whether to construct an intake which requires more frequent maintenance during operation (manual leaf/ice removal, etc.) The first alternative often gives an intake structure with a minimum height of 3.5-4 m. The latter gives a lower intake dam and thus much lower costs.

Intake structures are often integrated into the intake dam. For very simple intakes the structures are low and may be more prone to ruptures. The builder may find it economical to conduct major repairs/maintenance of the dam/ intake reservoir after each flooding, as long as the water masses do not cause damage downstream of the intake. A very simple intake dam may be constructed using local filling materials and a sealing cloth, for instance for a log dam or a concrete overflow sill, or by making use of a natural sill out of a scouring/pond. Some types of dams cannot be overtopped. Alternative flood diversion measures must then be implemented. Mini- and small hydropower plants will need more robust and larger intakes to secure safe operation, and traditional dams as described in Chapter 2.2 will often form a part of the structure.

The simplest forms of intake might in some cases consist only of a strainer, whereas for larger plants with higher absorption capacity, it will be more appropriate to build a concrete intake. Such an intake will often have an intake screen and the possibility of installing a stop log/control gate, an intake cone, and a gate/valve to shut off the waterway. A gatehouse is often necessary to protect the gate system. It may also be necessary to provide a screen rake and install a pipe break valve where stipulated in the regulations, instrumentation/a monitor, etc.

The cost curve for intake structures is related to the rate of flow, and applies to building and engineering work. It has been assumed that the regulating elevation is minimal/low as the elevation will greatly affect costs.

Costs relating to screens, gates, screen rakes etc. are not included in the building-related costs. These have been included in Chapter 4, Mechanical Engineering. However, costs for the intake cone and a simple superstructure are included. The cost curve is based on empirical figures with normal unit prices for the various building and engineering work.



<b>Intake structures</b>	Price level January 2015	
<p>Apply to civil works          Assumed minimum regulating height          Includes single gatehouse for intake &gt; 1 MW          For intake to power plant &lt; 1 MW:          negligible submersion requirement,          no conus and prepared for stop logs only (no gate)</p>	 <p>Norwegian Water Resources and Energy Directorate</p>	Fig 2.3.1

## 2.4 POWER STATIONS

Building and engineering costs for power stations are presented in a cost curve for surface power stations.

### 2.4.1 SURFACE POWER STATIONS

The costs of surface power stations are given as a function of discharge; in fig 2.4.1

There are, however, great variations in the empirical figures. This is because the power stations are very different in terms of location, size and general standard of the plant. The costs also vary according to the choice made between crane rails/removable roof, vertical/horizontal-axis unit, the number of units, and foundation on rock/uncompacted material. In general, it is the choice of turbine type/elevation head, which is the most important and determines the design of the power station. Consequently, the costs have been presented as a function of the elevation head and absorption capacity.

For plants around 1 MW it is a fundamental question whether to construct a power station which will function without daily monitoring (typical power company) or, for instance, a power station where the owner lives close by and is able to monitor the station on a daily basis. The prices in the enclosed curves are for stations with a generator capacity of > 1MW.

### 2.4.2 UNDERGROUND POWER STATIONS

Mini, micro and small power plants with a capacity below 2-3 MW are not suitable for construction underground/inside mountains. For small hydropower plants with a higher output, the costs are determined on the basis of volume calculations from the cost base of larger power plants. Despite the substantial variations in volume, it was attempted to express the space requirements in a simple formula with the net height of fall (head), total maximum water flow for the station and number of generators as parameters.

An indication of the blasted volume for underground power stations can be obtained by applying the following formula:

$$\text{Blast volume } V = 78 \times H^{0.5} \times Q^{0.7} \times n^{0.1}$$

V = blasted volume, m<sup>3</sup>

H = net head, m.

Q = total maximum water flow, m<sup>3</sup>/s

n = number of power units

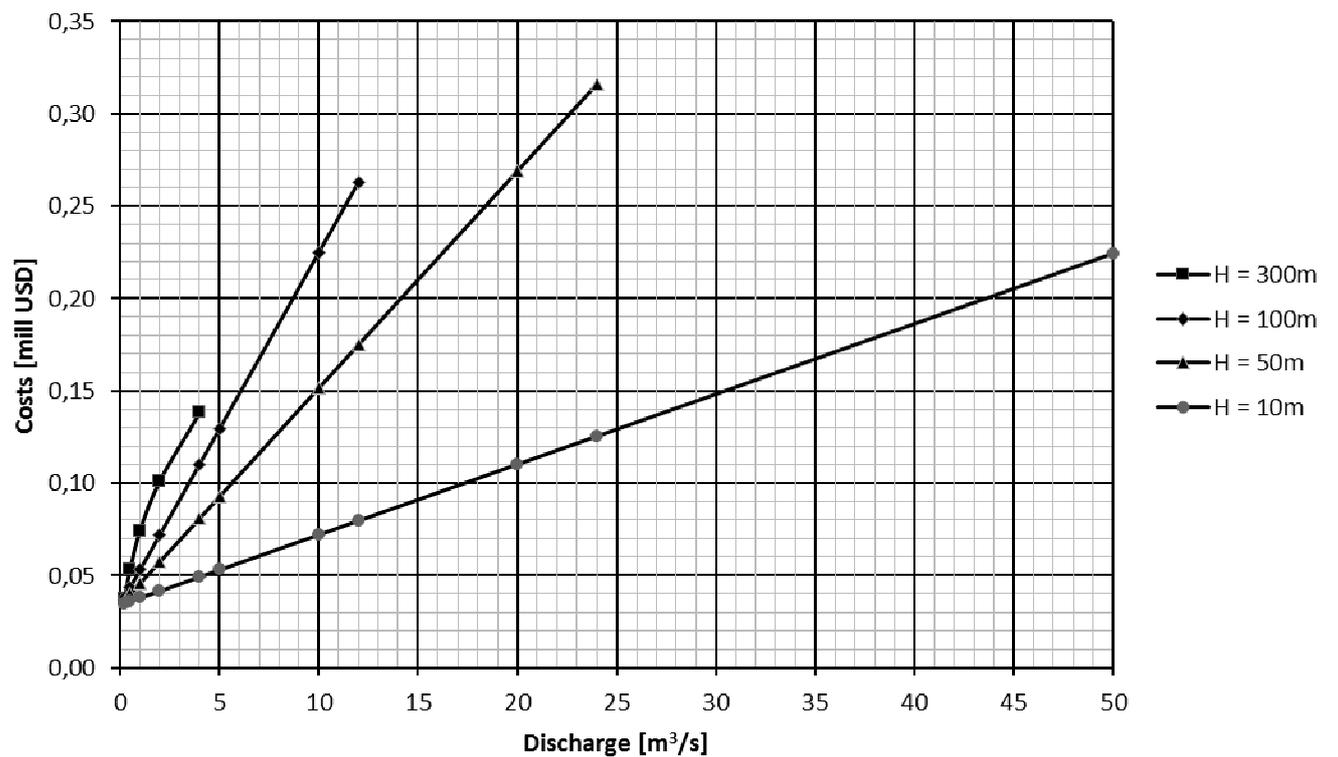
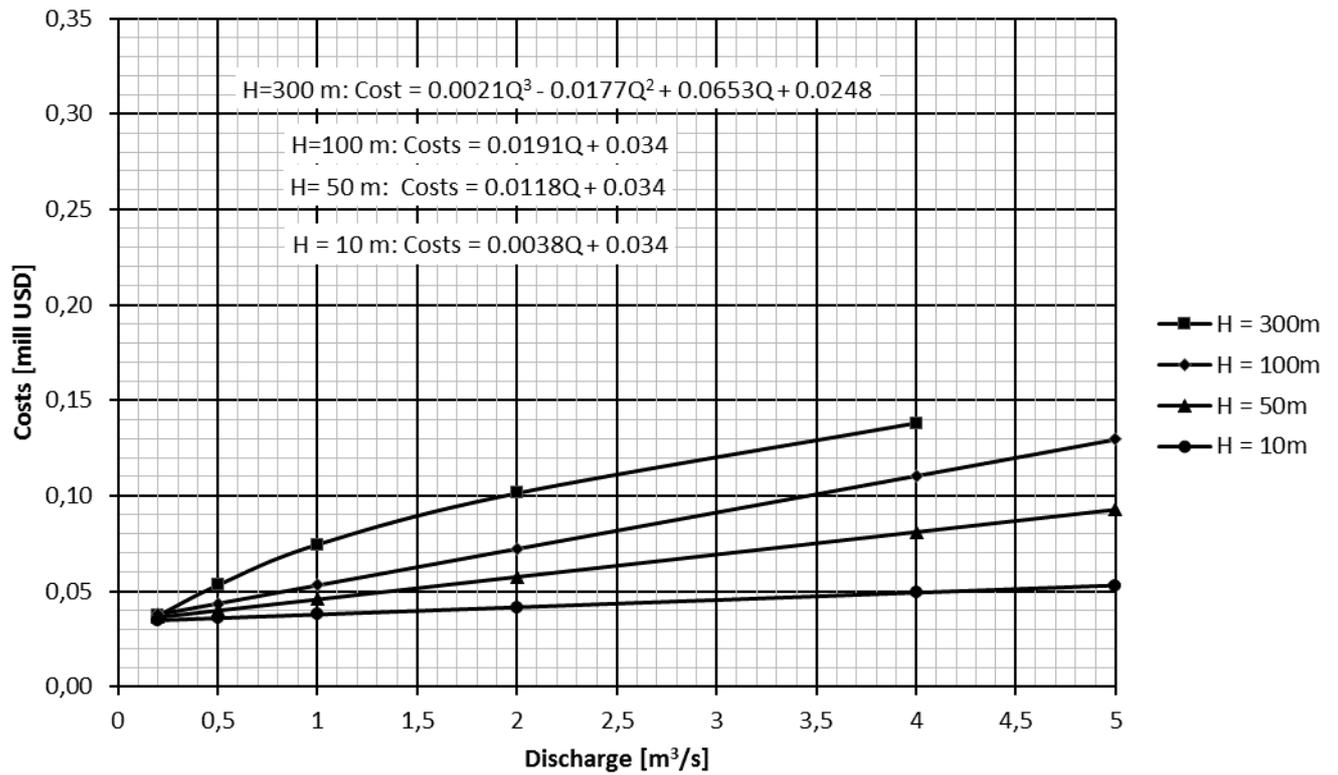
Estimations obtained by applying this formula will only be approximate. It is therefore recommended that an outline is drawn up for each installation and that this is used as a basis for calculating the blasted volume.

The total building-related engineering costs for underground power stations can be obtained by multiplying the estimated mountain volume by a unit price comprising the costs of blasting and construction of the power plant. Thus the unit price includes blasting, formwork,

reinforcement, concreting, preventive measures, masonry, plastering, painting, etc. An evaluation of this, compared with empirical figures for construction of power stations in the open has concluded that the unit price as of January 2015 can be set at 50 USD/m<sup>3</sup> blasted volume.

Unforeseen costs have not been included, and it is important to be aware that power station prices vary significantly.

For underground power stations additional costs must be expected in connection with an access tunnel with cable culvert, separate exit tunnel if required, escape room, etc. *These costs must be calculated separately, cf. Cost Base for Large Hydropower Plants, NVE.*



**Surface power station/power house**

Price level January 2015

Apply to civil work  
 Discharge is maximum discharge in the station with one power unit.  
 Supplement for to power units: 10%  
 Supplement for foundation on uncompacted material: 10%



Fig 2.4.1

## 2.5 PENSTOCKS, CHANNELS

Pipes and shutting devices are classified according to their damage potential in the event of a rupture. The design requirements will reflect the damage potential. Consult official guidelines.

Relevant types of pipes comprise spirally welded steel pipes, glass-fibre reinforced pipes of unsaturated polyester (GRP), polyethylene pipes (PE) and ductile cast-iron pipes, and of which GRP and cast-iron pipes are the most common.

In principle, the pipe foundations can either be buried or laid on foundation blocks. The various pipe types have different foundation requirements, due to e.g. the type of material, jointing method and how the impact forces are transferred. The most common combinations are listed in the table below.

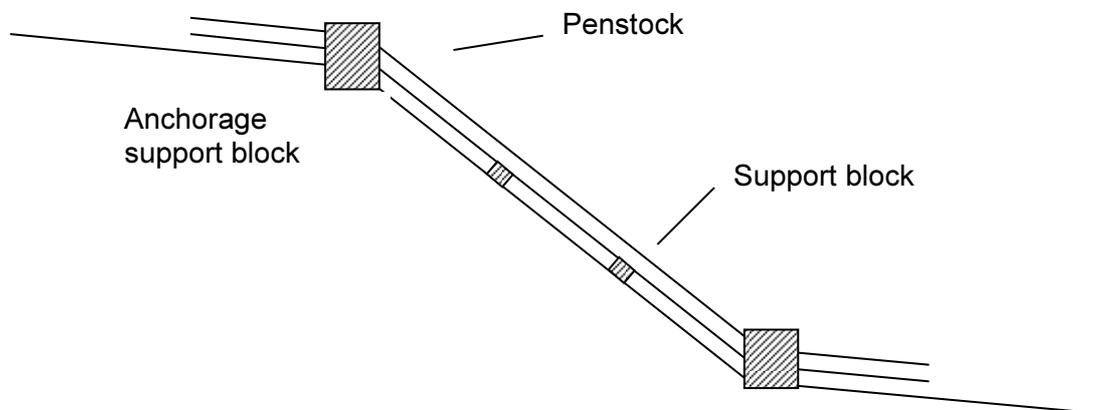
Type of pipe	Buried	On foundation
Steel pipes		X
GRP pipes	X	X
PE pipes	(X)	
Ductile cast-iron pipes	(x)	(x)

For mini and micro plants it may be appropriate to lay the pipe on the ground and clip it to the mountain. This is a simple construction method primarily used for small pipe diameter PE pipes and steel pipes.

### 2.5.1 PENSTOCK FOUNDATIONS

Penstocks are buried or laid on foundations in the open.

Concrete foundations have different designs according to the forces they have to sustain, the type of pipes, whether there is a support bar or whether they absorb impact forces in an angular deflection in the penstock.



Costs for the different pipe types are presented in corresponding Chapter, Mechanical Engineering.

The design of pipe foundations will vary between the different types of pipes. In the following the mean cost has been calculated. The foundation design is available from the supplier's installation instructions. Experienced consultants/contractors will also be able to provide assistance.

In the following, the estimated building and engineering costs of the penstocks include foundations for an open penstock with the following assumptions:

Clearing the route, incl. rock removal/scaling	1.1 USD/m <sup>2</sup>
Digging, including loading and transport	1.8 USD/m <sup>3</sup>
Blasting	4.4 USD/m <sup>3</sup>
Foundation bolts	24.0 USD/each
Formwork (one-sided)	10.4 USD/m <sup>2</sup>
Reinforcement	0.6 USD/kg
Concrete (minor concreting)	70.0 USD/m <sup>3</sup>

In addition the following assumptions have been made:

Spacing between foundations:	9 m (steel) / 6 m (GRP)
Spacing between anchor logs:	60 m
Average foundation height from the ground to the lower edge of the pipes:	1 m

The cost curves have been prepared for moderate slopes and good ground conditions.

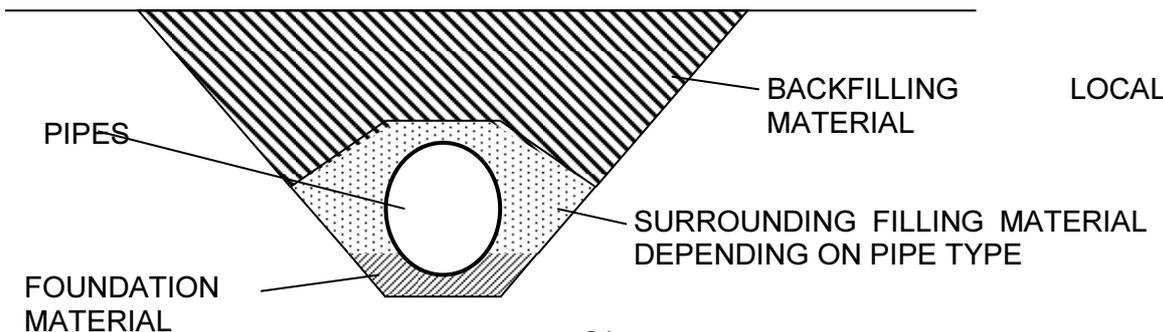
The costs of penstock foundations depend to a large extent on the size of the anchor logs, which must be dimensioned for water pressure, change of directions and pipe diameter. Laying the anchor log at a horizontal bend in the rock cut/mountain trench will significantly reduce the volume of concrete.

2.5.2 PIPE TRENCHES

Cost tables have been prepared for earth trenches and combined earth/rock trenches for use in cost assessments of embedded pipes. The tables apply to trenches in a relatively easy terrain.

GRP and cast iron pipes are most suitable for embedding. PE pipes may also be buried, but then at low pressures and in easy terrain.

The drawing below shows a typical trench section for buried pipes:



The inclination of trench slopes has been set at 1:1 for earth trenches and 5:1 for rock trenches. The bottom width of the trench is set as equal to the pipe diameter plus 1.0 m.

The costs in the tables include all contractor costs relating to digging, blasting and backfilling from 300 mm above the pipes. Costs for reinforcement of trenches have not been included.

Refilling around the pipes is included in the prices. The prices are contingent on the use of local material. If local material is not available, approximately 3.0 USD/m<sup>3</sup> must be added for delivery of the refilling material.

The price does not include construction of a temporary road to enable the digging of trenches and installation of pipes. This must be calculated separately. The road construction costs may be substantial, particularly if the terrain is steeper than 1:5.

The costs of rock trenches are set as equal to the cost of combined earth/rock trenches.

A terrain profile is required in order to be able to calculate the costs of pipe trenches, as well as a thorough assessment of the local conditions. Uneven and/or steep terrain and difficult access will have a great impact on the total costs.

Uncertainty in the cost estimations for relatively easy terrains is ± 30%.

The following unit prices have been used:

- Clearing of vegetation                    1.1 USD/ m<sup>2</sup>
- Digging                                        1.1 USD/m<sup>3</sup>
- Rock removal/scaling                    2.0 USD/m<sup>2</sup>
- Blasting                                      12.0 USD/m<sup>3</sup>
- Refilling material                        3.6 USD/m<sup>3</sup>  
    (handling of local material)
- Backfilling                                 2.8 USD/m<sup>3</sup>

*Trench costs (USD/m). Trench width equals 1.5 m at the bottom.*

Total trench depth:	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench	30	40	70	110
Rock trench or combined earth/rock trenches	40	55	85	120

*Trench costs (USD/m). Trench width equals 2.5 m at the bottom*

Total trench depth:	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench	35	50	85	130
Rock trench or combined earth/rock trenches	60	80	120	170

### 2.5.3 CHANNELS

Where conditions allow, channels can be a good alternative to for example pipes. Curves are prepared for uncompacted material and rock. It has been assumed that the material/masses are impervious and that a lining/armour layer is unnecessary.

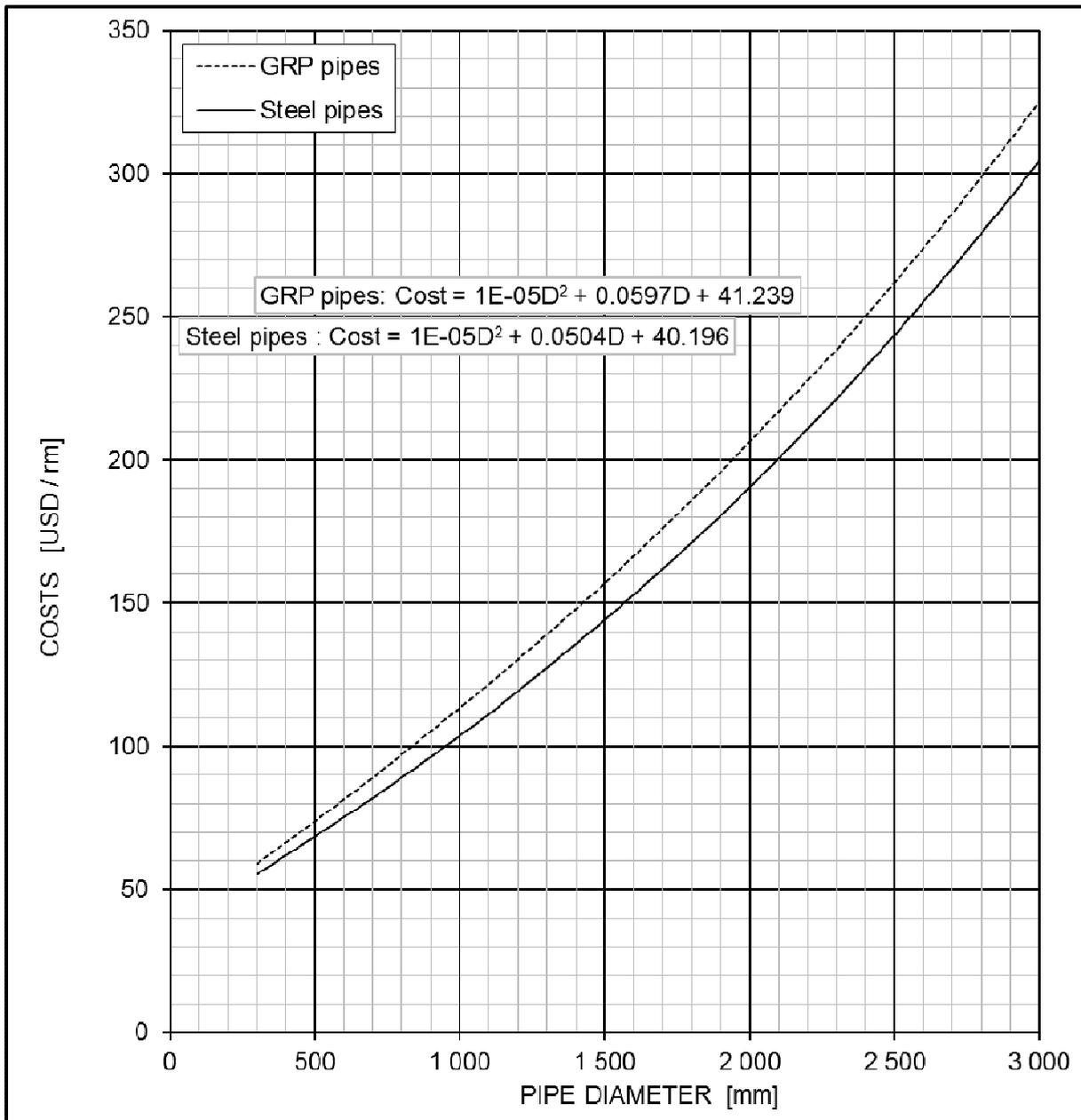
The estimated cost curves are based on work in an easy/ moderate terrain with the following unit prices.

Clearing	1.1 USD/m <sup>2</sup>
Digging	1.1 USD/m <sup>3</sup>
Blasting	4.4 USD/m <sup>3</sup>

Bottom width: 1-2 m

Pitching/tightening is not included.

Unforeseen costs are not included.



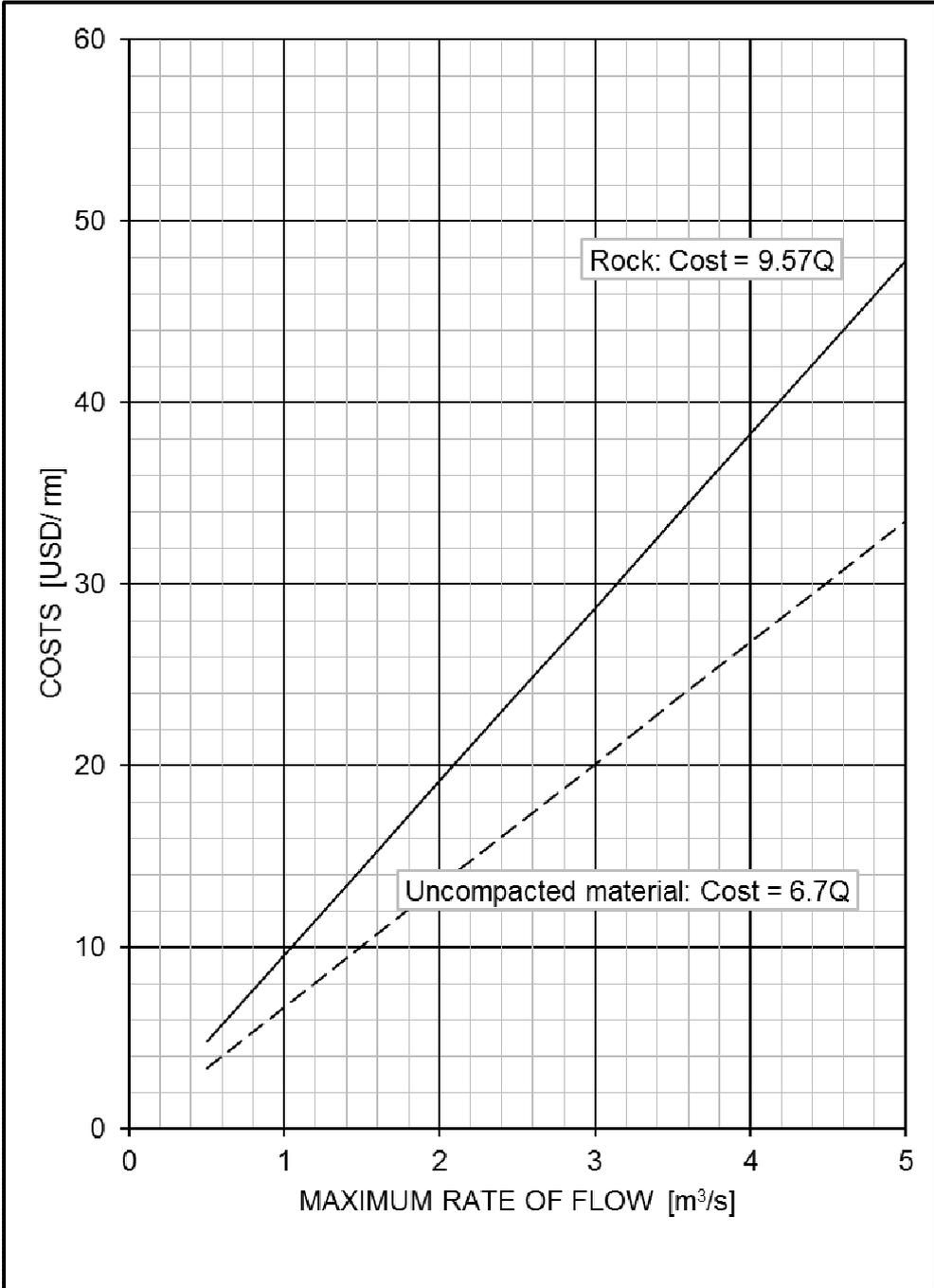
**Foundation for surface penstock**

Price level January 2015

Distance between foundations:  
 Steel 9 m and GRP 6 m.  
 Distance between anchor blocks: 60 m.  
 Average foundation height bottom of pipe: 1 m  
 The calculated costs apply to moderate heads and favourable ground conditions.



Fig 2.5.1



<b>Channels</b>	Price level January 2015	
Assumed max. water speed in uncompacted material channel: 0.5 m/s Assumed max. water speed in blasted channel: 0.7 m/s For other assumptions, see Chapter 2.5.3 Channels	 Norwegian Water Resources and Energy Directorate NVE	Fig 2.5.2

## 2.6 GEOTECHNICAL ENGINEERING

Rock work is sometimes necessary for small hydropower plants. Consequently, costs have been estimated for the so-called "minimum cross-section", i.e. the least expensive tunnel cross-section in relation to tunnel length.

Costs relating to large-hole drilling have also been estimated.

The cost of rock work depends to a large extent on the quality of the rock and the geological conditions, which may vary considerably within a small area. Compared with easy rock conditions, the cost of rock work can easily triple or quadruple if rock conditions are difficult, and might in some places be even higher. Rock conditions can be variable and should be considered carefully. Faults and cracks appearing as recessions in the terrain are often of a poorer quality and one should avoid constructing tunnels or bore holes that run in the same direction as these.

### 2.6.1 TUNNEL MINIMUM CROSS-SECTION

Tunnel costs for small hydropower plants are generally lower than for large projects. The reason for this is that there are a number of minor players on the market for small hydropower plants. Costs are estimated for cross-sections from 10-22 m<sup>2</sup>, run as conventional tunnel operations.

A 40% rock protection supplement is included in the tunnel costs. This is normal for good rock conditions. For small hydropower plants poor rock quality may exclude the tunnel option as an alternative.

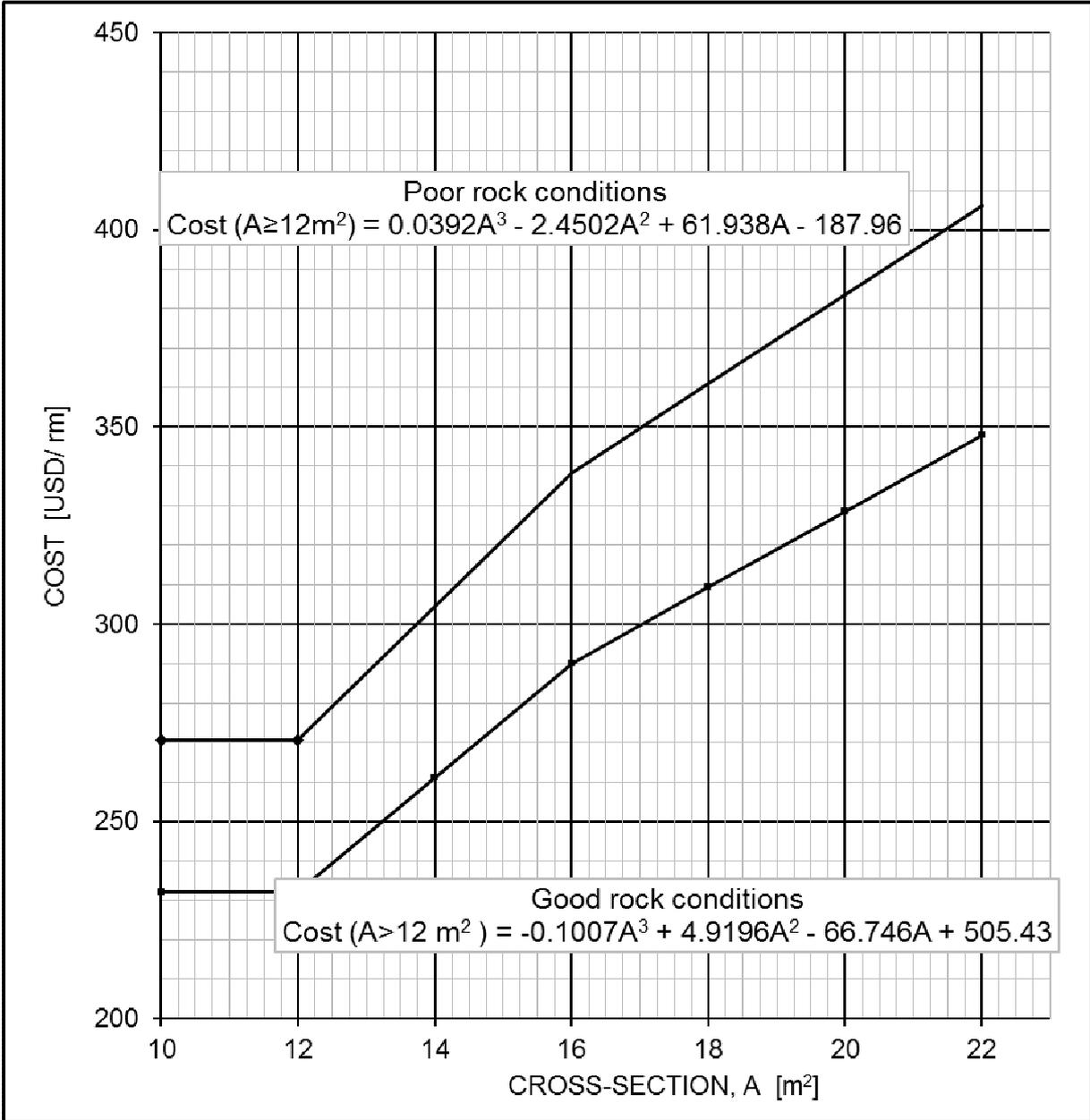
### 2.6.2 LARGE-HOLE DRILLING

There are three cost curves for large-hole drilling, showing good, medium and poor drillability. The costs apply to drilling of pilot holes which are expanded (reamed) when the drill bit is retracted.

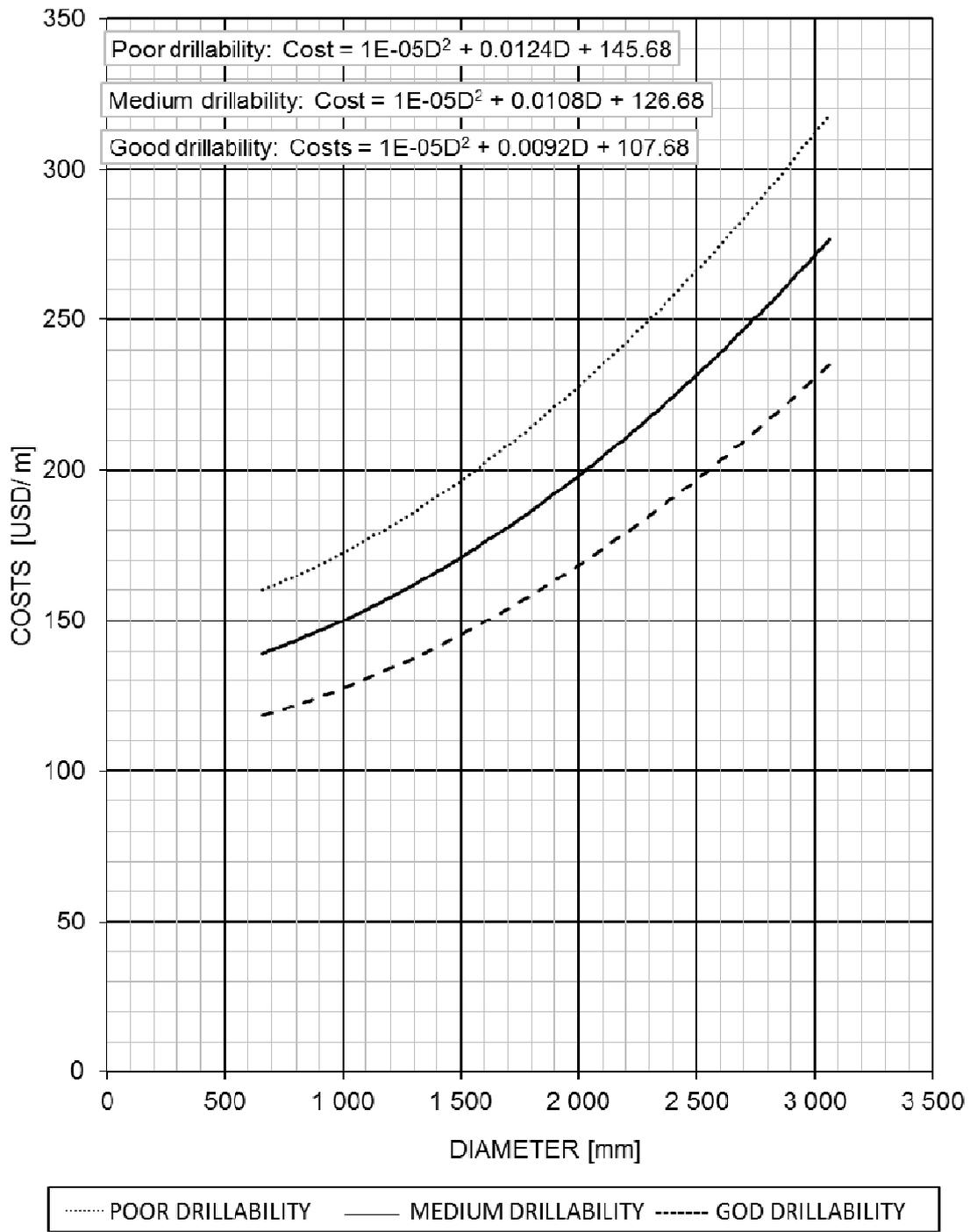
Rock protection costs have not been included in the cost curves. Rock protection is not normally conducted where rock conditions are good. However, this should be considered in each case.

The drilling costs per metre are higher for a long hole than for a short one. Consequently, the costs should be corrected by a factor linearly increasing from 1.0 to 1.25 for drilling lengths starting at approximately 200 m up to 500 m.

Due to the uncertainty relating to the direction of the pilot hole, it is uncommon to drill more than 500 m using this method. The maximum drilling length is currently up to 3,500 m. However, much progress is being made in this field and such lengths require directional steering of the drill bit, ref. Item. 1.1.3.



<b>Tunnel - minimum cross-section</b>	Price level January 2015	
Load and carry: 12-16 m <sup>2</sup> , max up. gradient 1:5, 0-1 km Niche loading: 18-22 m <sup>2</sup> , max up. gradient 1:6,5, 1-3 km The tunnel costs include 20% rock protection measures.	 Norwegian Water Resources and Energy Directorate	Fig 2.6.1



**Large-hole drilling**

Price level January 2015

Rock protection costs not included  
 Shaft length min. 150 m  
 Shaft incline: 45-90 degrees



Fig 2.6.2

### 2.6.3 ROCK DRILLING

Fully electric-operated equipment and non-rotating drill string are two fundamental ideas behind the development of a new technology for directional full profile drilling in hard rock.

Penstocks for hydropower plants can be drilled efficiently by remote controlled equipment without adversely affecting the surrounding landscape. The technology is based on drilling from the lowest end of the tunnel and up to the intake point at the highest point. Integrated equipment for navigation and direction control makes it possible to drill in curve, and to reach a predetermined location with high level of accuracy.

Equipment currently in operation can drill tunnels with diameters in the range of 0.7 m to 1.5 m over distances up to approximately 1.5 km, and over elevation differences up to approximately 1 km.

Current drilling equipment is so far adapted for drilling over slopes of approximately 4 or more degrees upwards. It is also possible to adapt the equipment for horizontal drilling. The equipment is designed modularly in order to ensure flexible and efficient transportation and rigging. Moreover it enables drilling operations without access roads.

Assignments are usually carried out at fixed costs depending on local conditions. For planning purposes, the budget costs for complete drilling solutions with diameter 700 mm can be assumed to be in the range of 1,400 USD to 1,600 USD per metre. For assignments with diameters in the range of 1,200 mm to 1,500 mm the correspondingly cost is in the range of 2,100 USD to 2,700 USD per metre.

It is often necessary to fully or partially line penstock tunnels. Specialist equipment is available for lining work, and this is conducted from the lower end of the tunnel.

## 2.7 TRANSPORT FACILITIES

### 2.7.1 TEMPORARY ROADS FOR CONSTRUCTION PURPOSES

Empirical figures from various hydropower plants have been used as a basis for calculating construction costs of temporary roads.

The costs will vary significantly with the topography and accessibility of the material, as well as the standard of the temporary roads.

It was assumed that the temporary roads maintain a standard corresponding to (a Georgian) forest road category 3.

The costs comprise a fully prepared road including planning, staking out, digging, blasting, culverts, placing of base courses and gravelling. The scope of each operation such as blasting and transport of material will have a significant impact on the price.

Costs for a fully prepared temporary road:

- Temporary road in easy terrain: 20 USD/running metre
- Temporary road in moderate terrain: 30 USD/running metre
- Temporary road in difficult terrain: 60 USD/running metre

Maintenance of temporary roads in the construction period is assumed to constitute approximately 10% of the temporary road costs.

For small and simple bridge constructions, costs are estimated at approximately 500 USD/m<sup>2</sup> roadway (decking).

## 3 ELECTROTECHNICAL WORKS

### 3.1 GENERAL

This chapter provides a basis for calculating the average foreseeable costs for electro-technical installations in small scale hydro plants. The attached price curves represent electrotechnical equipment for generators larger than 500 kW. Generators below 500 kW are often part of the “scope of work” for the turbine delivery and are therefore included in the price curves for turbines.

For small scale hydropower plants it is important to keep the electrotechnical equipment as standardised as possible, provided it still delivers a certain level functionality and reliability. The price basis for this chapter assumes the control systems are based on the normally closed contact principle and asynchronous generator for generators smaller than 1,000 kVA. It is also assumed that the power station is to be connected to the distribution grid.

The price basis upon which the curves are built is collected from mostly Georgian small scale power plants which has been tendered, contracted or built during the last five years, with an emphasis on the last year or two. In some instances budget prices for certain parts have been collected from different contractors. Some prices are highly variable; this may be explained by the fact that some contractors account for the possibility of additions to the scope of the work. As such, some contractors may suggest an overly expensive solution, whereas others may suggest a solution which differs somewhat from the design specifications in order to be perceived as cheaper than their competitors. Some budget prices may be misleading as they often lack design-, installation- and commissioning costs.

Machine costs are highly controlled by the material costs on the international market, but even more so are the electrotechnical components. The price of general electrotechnical components appear to have increased moderately since 2010.

The price increase of small scale generators is in the order of 0-10%, while power transformers have dropped in price by about 0-20%.

In earlier versions of the Cost base for small-scale hydropower plants the costs of switchgear and control has been shown in two chapters with two corresponding graphs. These two main component groups are usually delivered in a combined package from the contractor. These costs have therefore been combined as one cost in the Cost base for small-scale hydropower plants 2015. Earlier costs of these components have been a bit high, and these have also been adjusted to fit the price level of 2015.

The following main components are presented in this chapter:

- Generator
- Power transformer
- Control systems, including auxiliary power supply
- Medium voltage switchgear
- Power lines and grid connection

#### 3.1.1 POWER FACTOR (COS $\Phi$ )

The output of electrotechnical components such as generators, power transformers and switchgear are given in kVA or MVA. In the Civil and Structural and Mechanical Chapters kW is often used as reference of output. In order to establish a context between the chapters in the Cost Base, the following electrotechnical components will be presented in kW as well. It is assumed a power factor of 0.85 for components above 2 MVA and 0.9 for components below 2 MVA. As an example the resulting kVA performance is 18 and 11 percent higher than the one given in kW for components above- and below 2 MVA respectively.

## 3.2 GENERATOR

### Scope

The price in this chapter is based on air cooled generators with output from 500-2,000 kVA and water cooled generators within the 2,000-13,000 kVA range. Generators with lower output than 500 kVA are usually sold as a complete package together with the turbine etc.

Most generators of this magnitude employ horizontal axis machines. In the price basis it has been assumed a support which can carry the turbine on a free shaft and with a natural flywheel mass and no flywheel. The prices are mainly based on generators with 375-1,000 rpm (synchronous). Slowly rotating generators are not standardised and are therefore more expensive. In figure 3.2.1a and 3.2.1b the prices are based on generators with rpm between 500 and 750 rpm. If the chosen generator has a higher rpm rating than 750 the price will be in the "higher price level". If the generator rpm rating is below 500 rpm then the price will be in the "lower price level".

Aggregates with 375 rpm or less are not included in the Cost Base. In these cases it will usually be cost saving to use gears between the turbine and generator in order to increase the rpm.

### Ventilation

The power plants ventilation system needs to be designed in order to disperse the excess heat from the generator. This heat typically amounts to 2-3% of the nominal effect for an air cooled generator. During winter, some of this heat can be utilised to heat the machine room. Ventilation shafts for intake air should be designed with an appropriate air filter.

### Price Level

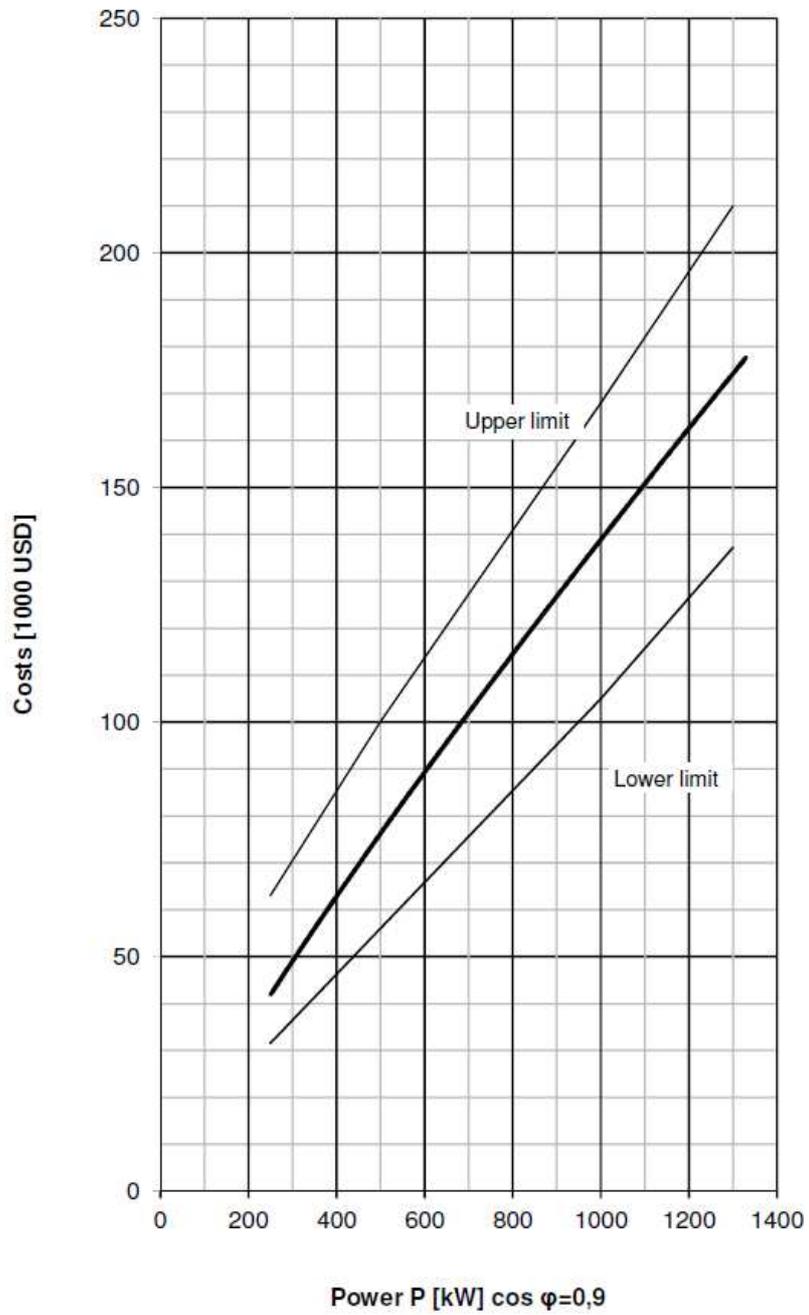
The utilised prices in this chapter are collected from Norwegian small scale power plants which has been tendered, contracted or built the last five years, and with an emphasis on the last two years.

In the following paragraphs, some foreseeable price discrepancies for various changes / additions which are beyond the scope of this report have been outlined:

- Vertical alignment                      +10%
  - Asynchronous generator              -5%
- (Not relevant for generators larger than approximately 1,000 kVA)

Generator voltage for machines with output lower than 1,500 kVA is usually 400 V. Machines with higher output than 2,500 kVA are usually high voltage machines, while the intermediate machines usually have 690 V.

Voltage regulators are delivered as a standard component together with the generator.



**Costs generator < 1300 kW**

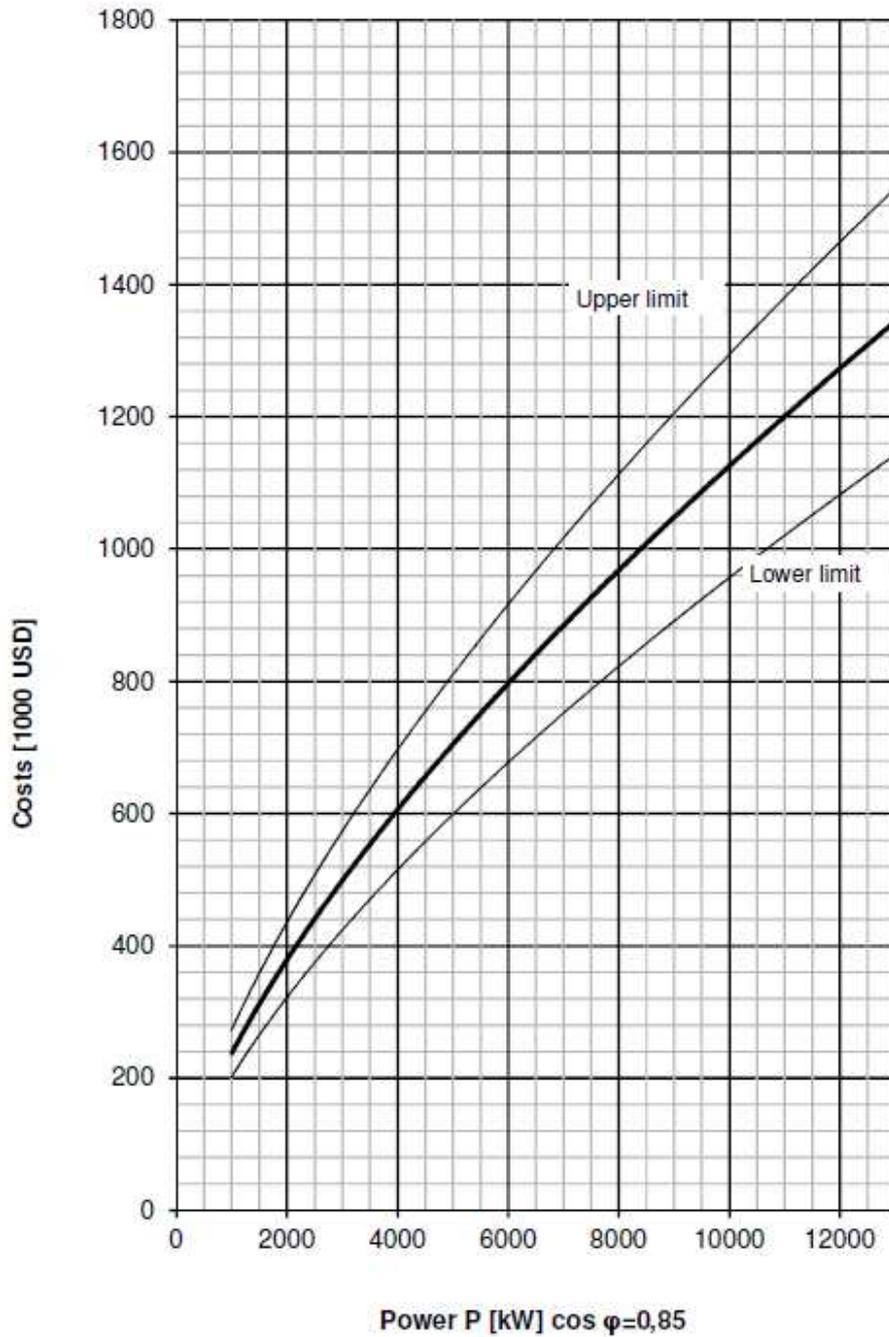
Price level Jan. 2015

Typical generator voltage of output class  
 Bearings: Turbine on free axis  
 Balance mass: Normal, without flywheel  
 Unit position: Horizontal



Norwegian  
 Water Resources and  
 Energy Directorate

**FIG 3.2.1a**



**Costs generator 1300 kW - 13000 kW**

Price level Jan. 2015

Typical generator voltage of output class  
 Bearings: Turbine on free axis  
 Balance mass: Normal, without flywheel  
 Unit position: Horizontal



Norwegian  
 Water Resources and  
 Energy Directorate

**FIG 3.2.1b**

### 3.3 TRANSFORMERS

#### Power transformers

This price basis includes transformers for grid connection to the distribution grid.

Transformers below 1,600 kVA are usually standard oil filled distribution transformers. It is currently common to employ dry isolated transformers, even though these transformers are approximately 0-5% more expensive than standard oil filled distribution transformers. Larger transformers are not standardised to the same degree, and are therefore more costly.

Transformers can usually be adjusted within five steps using a step coupler. Load-break switches which can adjust the voltage during operation are highly expensive and not appropriate for this type of power plant.

#### Cooling

Most transformers for power plants of this size can be placed outdoors or in properly ventilated rooms which are naturally air cooled.

#### Prices

The transformer prices are based on Georgian experience on electro-technical works for small scale power plants during the last years.

There is no demand for complicated control systems for transformers on small-scale hydropower plant. It is usually enough to implement temperature guard for protection against overload. For the largest transformers it may be necessary to implement gas guard protection.

<b>Basic Costs of the Electric-technical works</b>		
#	Name	Cost in USD
1	3	4
<b>Average prices for the installation of electrical equipment for small hydro</b>		
<b>I. Transformers:</b>		
1	Transformer 200kV. 250/10 kVA	9,130
2	Transformer 400kV. 400/10 kVA	13,050
3	Transformer 600kV 630/10 kVA	15,500
4	Transformer 800kV 1000/10 kVA	24,000
5	Transformer 1200kV. 1250/10 kVA	26,400
6	Transformer 1600kV. 1600/10 kVA	32,600

7	Transformer 2000kV. 2500/10 kVA	34,500
8	Transformer 4000kV. 4000/10 kVA	55,700
9	Transformer 6000kV. 6300/10 kVA	75,600
10	Transformer 8000kV. 10000/10 kVA	82,000
11	Transformer 10000kV. 10000/10 kVA	82,000
12	Transformer 12000kV. 2X6300/10 kVA	98,700

### 3.4 SWITCHGEAR AND CONTROL SYSTEMS

The price basis is based on switchgear and control systems delivered in relation with small scale power plants which has been tendered, contracted or built the last five years, and with an emphasis on the last two years, as well as switchgear and control systems for 10-35 kV distribution grid. The prices is estimated to have risen by approximately 10% since the 2010 levels.

In the following price curves an overview of the price level for switchgear and control system with one generator are shown. In the graph, two price levels are shown. The lower curve represents the price of switchgear and control for hydropower plants 10-35 MW, and the upper curve represents the price level of 10-35 MW. The price level between these is due to the major difference in complexity for larger hydropower plants.

Prices for plants with two or more generators are not accounted for, but one can assume that two generators would approximately double the price.

Auxiliary systems such as medium and lower voltage auxiliary power supply, auxiliary transformer, cable systems, diesel generator, battery system with DC-supply, earthing, fire detection systems, marking as well as communication systems, are included in the price.

#### High Voltage Switchgear

Switchgear for power plants below 13,000 kVA is usually fairly simple.

For the price basis it is assumed that the scope of work ends at the power plant wall, meaning that the switchgear is delivered without connection to a high voltage cable system or power lines.

The grid TSO can in some cases demand that the power plant employs a capacitor in order to do phase compensation in power plants with asynchronous machines. In many situations this will reduce some of the benefits of choosing an asynchronous machine compared to a synchronous machine.

#### Control System

A control system normally consists of:

- Power Control
- Generator Protection
- Additional protection for switchgear and possibly for power transformers
- Controls for switchgear
- Water level regulation
- Remote Control (SCADA)
- Battery with rectifier

The smallest and medium-sized plants are usually not intended to supply on its own local power. It is therefore common to use power control. The local TSO may require that larger plants should be able to supply the local network, for example in the case of a fault on the overhead line. This implies speed control which is a more expensive solution. Both power control and speed control can be integrated in the unit control, but are often delivered as separate control units for bigger generators.

Generator control includes start and stop functions of the unit and its auxiliary functions. Usually equipment for automatic synchronisation and water level control is integrated in the control system. The operation of the power plant should be as automated as possible. The type of waterway and operating philosophy usually determines the appropriate automation level.

Most small scale hydro power plants, except for the very smallest, will have remote control. This can be delivered as standardised systems which are specialised for smaller hydro power plants. These systems need only a few signals transmitted through the telecommunications or other alternative communication protocols. Most power plants which deliver power to the grid are required to register the delivered energy with a kWh-meter which can communicate with the grid TSO.

The generator relay system contains at a minimum:

- Overcurrent / short-circuit protection
- Return Circuit Protection
- Residual current device

And possibly:

- Over- / under-voltage relay (only for synchronous machines)
- Differential relay (common on machines larger than about 2,000 kVA)
- etc.

Other relay systems may consist of:

- overcurrent / short circuit protection for outgoing lines
- Residual current device for outgoing lines
- etc.

Power plants with generator voltage higher than 400 V needs an auxiliary transformer in order to provide secure power for the auxiliary power plant system. These types of transformers are usually dry isolated and used to power motors for pumps, fans, battery chargers etc. These transformers typically cost between 4,000 – 8,650 USD for outputs between 25 and 50 kVA.

**III. Switchgear and control systems. Costs in USD**

1	10kV for 2000 kW	74,500
2	10kV for 4000 kW	81,000
3	10kV for 6000 kW	88,000
4	10kV for 8000 kW	93,000
5	10kV for 10000 kW	99,000
6	10kV for 12000 kW	106,000
7	35kV for 2000 kW	272,500
8	35kV for 4000 kW	305,000
9	35kV for 6000 kW	340,000
10	35kV for 8000 kW	365,000
11	35kV for 10000 kW	395,000
12	35kV for 12000 kW	430,000

### 3.5 POWER LINES

The first thing that must be examined during the planning phase of a power plant, is how power should be transmitted to the local distribution or regional grid. A promising project may prove to be uneconomic if it requires the construction of a relatively long, new power line or if an existing power line must be upgraded.

Prices of power lines (conducted as both cable system and overhead lines), varies greatly depending on the terrain and climate conditions. It is therefore important to obtain advice and quotation from an overhead line contractor, consultant or the local grid owner at an early stage of feasibility study. Prices for overhead lines have risen significantly more than other electrical system parts since 2010. For more information about power lines, see chapter 3.7 in the Cost base for hydropower plants.

Two types of poles are use, timber or metal, for the grid connection in Georgia. There are differences in transmission line sections; single-circuit or double-circuit lines are common. The table below shows power line costs in USD for a number of alternatives. The cost base for power lines also includes materials and labour costs.

II. Cost of 1 km transmission line construction (single-circuit) in USD		
1	10 kV AC-35 mm <sup>2</sup> on timber pole	22,000
2	10 kV AC-50 mm <sup>2</sup> on metal pole	30,000
3	10 kV AC-70 mm <sup>2</sup> on metal pole	33,000
4	10 kV AC-70 mm <sup>2</sup> on metal pole (double circuit)	52,000
5	35 kV AC-95 mm <sup>2</sup> on metal pole	86,000
6	35 kV AC-150 up to mm <sup>2</sup> on metal pole (double-circuit)	135,000

## **4 MECHANICAL ENGINEERING**

### **4.1 GENERAL**

#### **4.1.1 SCOPE OF DELIVERY**

Delivery of mechanical engineering works generally includes equipment fully installed and ready for operation, if not otherwise specified in the comments to each individual price curve.

However, the delivery does not include:

- Building and construction work
- Ventilation, installation of lighting and heating/cooling in the power plant
- Spare parts
- Value-added tax
- Builder expenses
- Unforeseen costs

#### **4.1.2 PRICE ESTIMATE**

The prices are based on installations purchased in the last five years, and, whenever there is sufficient basis to do so, on installations constructed in the last couple of years. For some components, older prices (index adjusted) are used to obtain a broader basis. The prices have been adjusted for price increase up to 2015 levels. The NOK / USD rate is fixed to 7.5.

Since the last cost base update in 2010 there has been significant variations in the cost increase for the different components. Some component groups have experienced price growth exceeding 50%, while others have similar prices now compared to five years ago.

In general, turbines have experienced a significant cost increase. Turbine components are manufactured in a number of countries, and are therefore influenced by international price development. It can be pointed out that the price of stainless steel has increased by 15-20% the last five years.

Budget prices from suppliers have shown to vary quite significantly. In general, one should be careful using such budget prices in the early phase of projects. Comparison with the price curves in this cost base is recommended.

There will be a discontinuity in the price curves when moving from small hydro to large hydro. There are mainly two factors: differences in construction, and local grid requirements. Smaller units can be built relatively simple, typically as compact units, while somewhat larger units needs more robust and expensive constructions. The grid requirements may differ from country to country, imposing different demands on the governors in the plant, and hence price transition from small to large hydro will shift according to the load limits in each country's regulations.

## 4.2 TURBINES

Turbine prices are given as USD/kW nominal effect, and as a function of maximum flow capacity and net head.

Price curves have been prepared for each of the most common turbine types on the market for turbines with a power range of between 500–13,000 kW. For turbines with a power range of up to 500 kW, see Chapter 5.3, Micro and mini power units.

The rotational speed has been included in the price curves for turbines with a power range of between 500 and 13,000 kW. If the rotational speed is lower than stated in the curves, gears are often used for turbines in the power range below 2–3 MW.

The net head graphs indicated in the price diagrams correspond to a common range for small turbines of the Pelton, Francis and Kaplan type, respectively. The highest graphs do not in any way represent an upper limit for the use of turbines of this type.

The rotational speed graphs are only indicative, corresponding to a specific forced rate (submersion/suction head). If a turbine is chosen with another rotational speed than the one specified in the relevant flow diagram, the head curve can still be used to define the price per. kW.

The rotational speed can be taken into account in the following manner:

If one chooses a turbine with a lower rotational speed than the one shown in the diagram over the given rate of flow and head, the turbine price will generally be somewhat higher than indicated in the diagram based on the value of the rate of flow and the head graph, and vice versa if a higher rotational speed is chosen than the one shown in the diagram. Also, a lower speed will be a safer choice, while a higher speed will be technically more challenging.

The given price level for turbines reflects what can be referred to as a normal price level. There are turbines on the market that are both significantly cheaper and more expensive than indicated in the price curves.

We have prepared price curves for the following turbine types:

- Pelton
- Francis
- Kaplan / bulb turbine

The following has been included in the individual curves:

### Turbines with a capacity of 1–500 kW

See Chapter 5.3 Micro and mini power units.

### Turbines with a capacity of 500–13,000 kW

The given price curve is valid for turbine, turbine controller and inlet valve (except in Kaplan turbines).

For prices of electrical equipment for plants with a capacity above 500 kW, see the price curves in Chapter 3 Electro-technical work.

## General advice on the choice of turbine supplier

In addition to the price, the following should be considered when selecting a turbine supplier:

- References. Contact other developers who have used the same supplier.
- Power plant automation. Important concerning how much work is required for daily operations.
- The turbine's operating range, the maximum and minimum rate of flow for continuous operation. Important for making maximum use of the flow.
- Efficiency. Be critical of turbine efficiencies that are not supported by reliable documentation. If available, ask to be shown measurement results from referenced plants, or model test results.
- Operational reliability can be just as important as high efficiency.
- Is everything included in the delivery (price)? Check whether the quote includes all necessary equipment/work.

Schematic diagram:

