Volume I Reconnaissance study Smibelg Hydro Power Plant

Acknowledgment

Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACHRONYMES

A	Catchment area
asl	Above sea level
B	Net benefit
B/C	Benefit – Cost Ratio
D	Pipe diameter
DI	Ductile iron
E	Energy production
F	Specific runoff
FIRR	Financial internal rate of return
g	Acceleration due to gravity
GWh	Giga watt hour
GWh/yr	Giga watt hours per year
Hg	Gross head
Hn	Net head
i	Discount rate
iRR	Internal rate of return
K	Capital cost
km	Kilometres
Km^2	Square Kilometres
kW	Kilowatt
l/s	Litre per second
m	Meter
m^3/s	Cubic meters per second
Mill	Million
MW	Megawatt
NOK	Norwegian Kroner
NPV	Net Present Value
npv	Net present value
NVE	National Directorate of Water and Environment
PE	Polyethylene
PW	Present worth
Δt	Time period
q	Flow rate per second
Q	Annual flow rate
s	Second
W	Watt
yr	Year

Structure of the Pre-feasibility Report

Volume I Reconnaissance Report

Volume I is the Reconnaissance Report, a stand-alone volume that details a complete picture of the project alternatives and the main results including the conclusion for the recommended project for detailed pre-feasibility study in Volume II.

Details including the studies and analysis with in the various fields [geology, hydrology, sediments, hydraulic analysis, economic analysis, etc.] are given in separate sections and annexes.

Volume II Main Report

Volume II is the main Report, a stand-alone volume that describes a complete detail picture of the recommended project and the main results of the analysis to a pre-feasibility level of study.

Details including the studies and analysis with in the various fields [geology, hydrology, sediments, hydraulic analysis, economic analysis, etc.] are given in separate sections and annexes.

Volume III Project Drawings

Volume III documents various project drawings in the form of drawing sheets for the recommended project.

Volume IV Various Analysis

Volume IV documents various project analysis results in the form of annex for each analysis section.

1 EXECUTIVE REPORT

1.1 Introduction

1.2 Key Results of the Study

1.2.1 Power production and cost

1.2.2 Base case Economic Analysis

1.2.3 Environmental Impacts

1.3 Brief Description of Recommended Project

1.3.1 Civil structures

1.3.2 Electromechanical Equipment

1.3.3 Key Project Characteristics

Volume I Reconnaissance Screening of Project Alternatives

1 INTRODUCTION

The first volume of this thesis report will detail the reconnaissance investigation for hydro power potential assessment of kystfelt, Sørfjordelva and Kjerringåga river basins located in Rødøy Municipality, Nordland Norway. The catchment includes all rivers discharging to Gjervalen and Aldersundet from the mountain top of Nubben, Fjellet and Strandtinden. The report will give details on methodology, assumptions and results undertaken during the reconnaissance report.

1.1 Previous Studies

SKS Produksjon undertook the project site identification and study for concession permit for ministry of water and energy for licencing in 2005 and has got permission for development in March 2012.

SKS concession plan is taken as a single alternative in the reconnaissance assessment during power potential investigation of the catchment and its feasibility is evaluated with the other ten identified interdependent potential development projects.

1.2 Objective of the present study

This thesis will envisage the identification and assessment of the potential alternatives in the project site through a stepwise comprehensive planning and economic analysis to evaluate the feasibility of potential schemes with respect to technical, economic, environmental and socio economic aspects; hence, the report will state the preliminary proposed plans for alternative development options and finally prepare a refined prefeasibility level report for the recommended project.

The study will analyse and document all important aspects for formal approval by Department of Hydraulic and Environmental Engineering, NTNU.

The main objectives of this screening report are:

- Provide comprehensive power potential assessment of the project catchment
- Identify suitable power projects that meet the planning criteria detailed below
- Assess the identified alternatives to the level required for reconnaissance study the level of study is defined as that in Book no 5, planning and Implementation of hydro power projects, Hydro power development series (Raven, 1992)

- Perform preliminary economic assessment of the alternatives in order to compare the identified projects in terms of cost per Kwh of generation. Cost base have been defined as per NVE cost curves , (NVE, 2014)
- Recommend the best alternative for prefeasibility study in volume II

1.3 Project location

The Smibelg hydropower project is located in the municipality of Rødøy, Nordland, Norway. The project site is located approximately 105 km west of Mo i Rana and 540 km north of Trondheim. The relative location of the catchment is 66^{0}24’5”:13^{0}10’55” latitude and longitude respectively and shown in Figure 1 below;

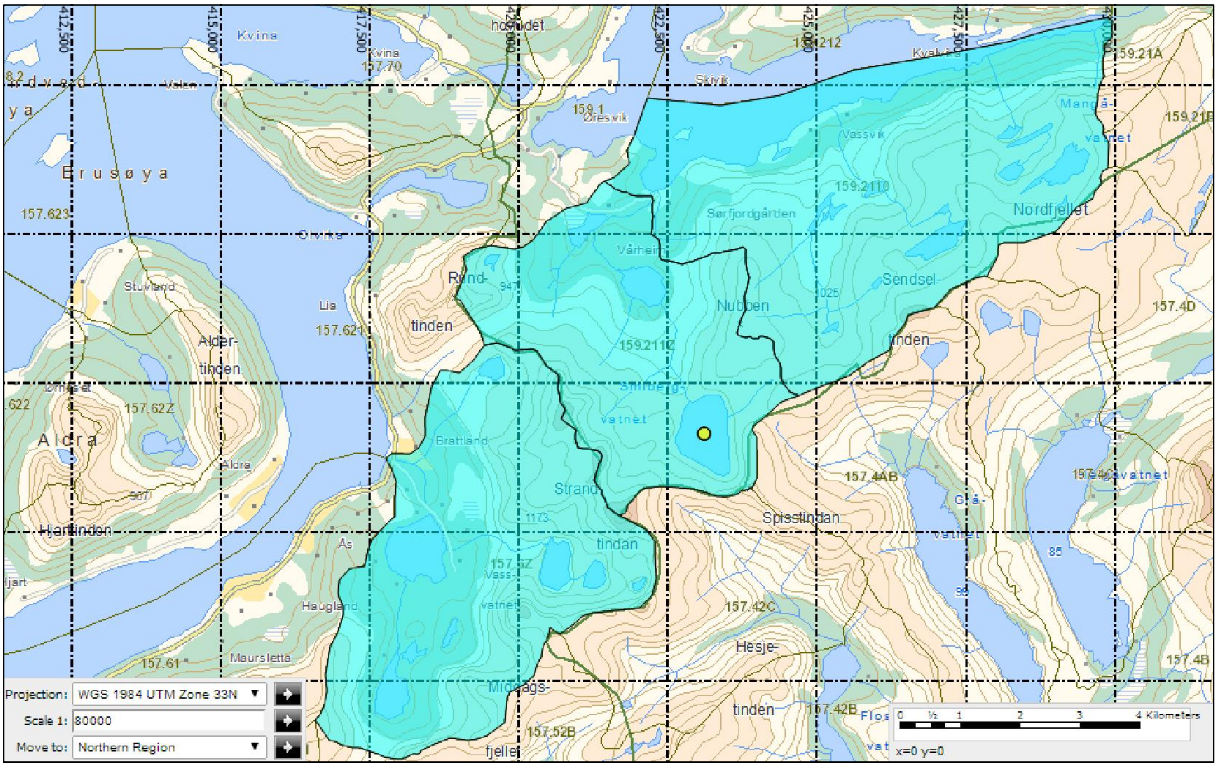

Figure 1 Project Catchment Location Map (NVEAtlas, 2014)

The project forms by using the water invasive approach of collecting water from effluent streams, lakes and the glacier deposit of the Nubben, Fjellet and Strandtinden mountain tops. The identified schemes will utilize the water from the existing mountainous rivers basins of kystfelt, Sørfjordelva and Kjerringåga, where the average annual precipitation rate is around 3000 mm/year.

1.3.1 Project Catchment Features

The project catchment has approximately an area of 65.36 km^2. The catchment has a length of approximately 6 km from the far end discharging point.

The catchment is characterized by four small river valleys directly discharging water forming their own drainage path down to the Norwegian Gjerval Sea. Steep mountain terrain is aligned on each side of the river valley making the catchment divide. The project will utilize the available flow by using a water collection system through tunnels and pipes to the desired intake location for optimum power production.

The elevation hypsography of the catchment varies from a minimum value of 0 to 1152masl and its distribution with in the catchment is shown below in Table 1. A small portion of the catchment (30%) is occupied with elevation less than 300masl; hence it will create a favourable ground for maximum power production.

Table 1 Elevation Hypsography of project Catchments Source: (Lavvann, 2014)

Kjerringåga	kystfelt	Sørfjordelva	
Elevation masl	Elevation masl	Elevation masl	% Comm. Area
0 - 148	0 - 413	0 -168	10 %
148 - 197	413 - 493	188 - 235	20 %
197 - 249	493 - 575	235 - 350	30 %
249 - 360	575 - 630	350 - 450	40 %
360 - 480	630 - 674	450 - 506	50 %
480 - 531	674 - 714	506 - 564	60 %
531 - 613	714 - 750	564 - 627	70 %
613 - 707	750 - 786	627 - 687	80 %
707 - 827	786 - 864	687 - 748	90 %
827 - 1160	964 - 1023	748 - 1152	100 %

1.3.2 Environment

The land use composition in the catchment comprises glacial mountain, marsh, forest and sea. The summary for areal coverage with in the catchment was taken from the available 1: 50,000 scale NVE web based map output, generally the project catchment is covered with glacier mountain tops and forest on down falling steep valleys in addition to that it includes scattered farm lands and five to six households located downstream of the main river Vassvikelva. The land use distribution for the project catchment is shown below in

Table 2.

Table 2 land use pattern Source: (Lavvann, 2014)

Land use	Catchment		
	Sørfjordelva	kystfelt	Kjerringåga
Cultivated land	0.1 %	0.0 %	0.7 %
Marsh	0.6 %	0.0 %	0.7 %
Sea	8.9 %	5.0 %	8.4 %
Forest	16.5 %	1.4 %	28.5 %
Mountain	69.9 %	92.2 %	58.2 %
Urban	0.0 %	0.0 %	0.0 %

There are no severe environmental disturbances however environmental as well social impacts of the alternative schemes are left for consideration for the next level of study to recommend the need as well as extent of social and environmental investigation required at least with the following core study points.

- Need for resettlement
- Minimum flow requirement
- Restricted regions
- Cultural and historical values
- Recreational value and fisheries

1.4 Planning criteria

The planning criteria for this level of study are directed solely based on the overall power demand of Norway; hence, the planning criteria taken in to the planning process lies in the identification of power plants which will support base load power demand to the existing nationwide grid. Under the firm power potential assessment the following list of economic criteria's are considered:

- Unit cost of generation should not exceed generation cost of 0.6 Nok/Kwh
- Assessment should avoid already developed projects
- Incorporation of protected regions with in the catchment shall be minimized
- Environmental impact of the new development shall be assessed

- Integration in to the existing Norwegian national grid should be documented

1.5 Power Market and Energy price

Power production has been increasing over the year and increased transmission capacity to fill the energy demand as a result a dynamic market has evolved where power can be bought and sold across regions and country easily.

In Norway the power market is deregulated in to a free market system which calls for variable power price that needs to be determined based on supply and demand just like other commodities.

1.6 Site visit and data collection

The thesis work is planned to incorporate two field visits to the site one right after the reconnaissance assessment the other right after the design of the main component structures for confirmation on the location as well as geology of the identified site.

1.6.1 Data

Topographic map: The Norwegian online web based platform covering the whole country is used from Norwegian mapping authority (StatnsKraftvek, 2014). A map scale of 1: 50,000 and below using Norgeskart and Gis link are used for topographic analysis of the catchment. Data gathered from the platforms for this level of study are geographical location, distance measurement and profiling of the selected section.

Runoff map: The Norwegian web based platform for water resource development maintained by (NVE, 2014) from NVE atlas and Lavvann with varying scale are used to examine the water resource potential of the project catchment. For this reconnaissance report they have been utilized to gather existing plants, location gauging stations and specific runoff at selected intake points respectively.

Geological map: The Norwegian Web based platform from the Norwegian geological society (NGU, 2014) is used for examining the bed rock geology and soil cover of the project catchment.

2 REGIONAL GEOLOGY

Geological mapping and systematic investigation of the bed rock geology and soil cover of the project area is the key towards overall project cost and consequently to the feasibility of each alternative scheme. A preliminary geological investigation has been carried out for this level of study to foresee the existing geological units and soil cover of the project area and as such its influence in the hydro power development is stated.

2.1 Geological units

The Scandinavian Peninsula is characterised by the "Baltic Precambrian Shield" (Hveding, 1992). Norway bedrock is comprised of approximately 2/3 Precambrian and 1/3 Palaeozoic (often referred to as Caledonian) units. These units are more than 230 million years old and are the basis for the hard rock environment of Norway. The geological units within the region are composed mainly of calc-alkaline intermediate volcanic rocks and intruded by granodioritic to granitic rocks (Skår, 2002).

The geological units within Norway, from a rock engineering point of view, are classified as being of high quality (Nilsen, 1993). Stability problems relating to weakness zones, faults, rock stresses, and unfavourable jointing are possible, and these need to be considered on a case by case basis at the specific project locations during the next phase of investigation.

2.1.1 Bed rock Geology

The general bed rock geology in the project catchment is mainly dominated with øyegneis, granite and foliated granite. The details of bed rock geology as observed from the (NGU, 2014) are shown in the Figure 2 below. Granite is a good rock from engineering point of view as such its intact rock quality may influence the tunnel, cavern and trench excavation in the proposed alternatives; therefore detailed geological observation shall be done in the next level of investigation.

2.1.2 Soil cover

There is no soil cover in the top mountain rather the topography of the area is exposed rock with undulating slopes and forest cover in the steep heel downfall as sited from aerial photo of the region. Generally the variation in depth and type of soil will have prominent influence in the final cost of the project. The soil cover distribution with in the catchment is shown in the Figure 3 below; the corresponding costing of the schemes in bare rock excavation is incorporated in section 6 COST ESTIMATION.

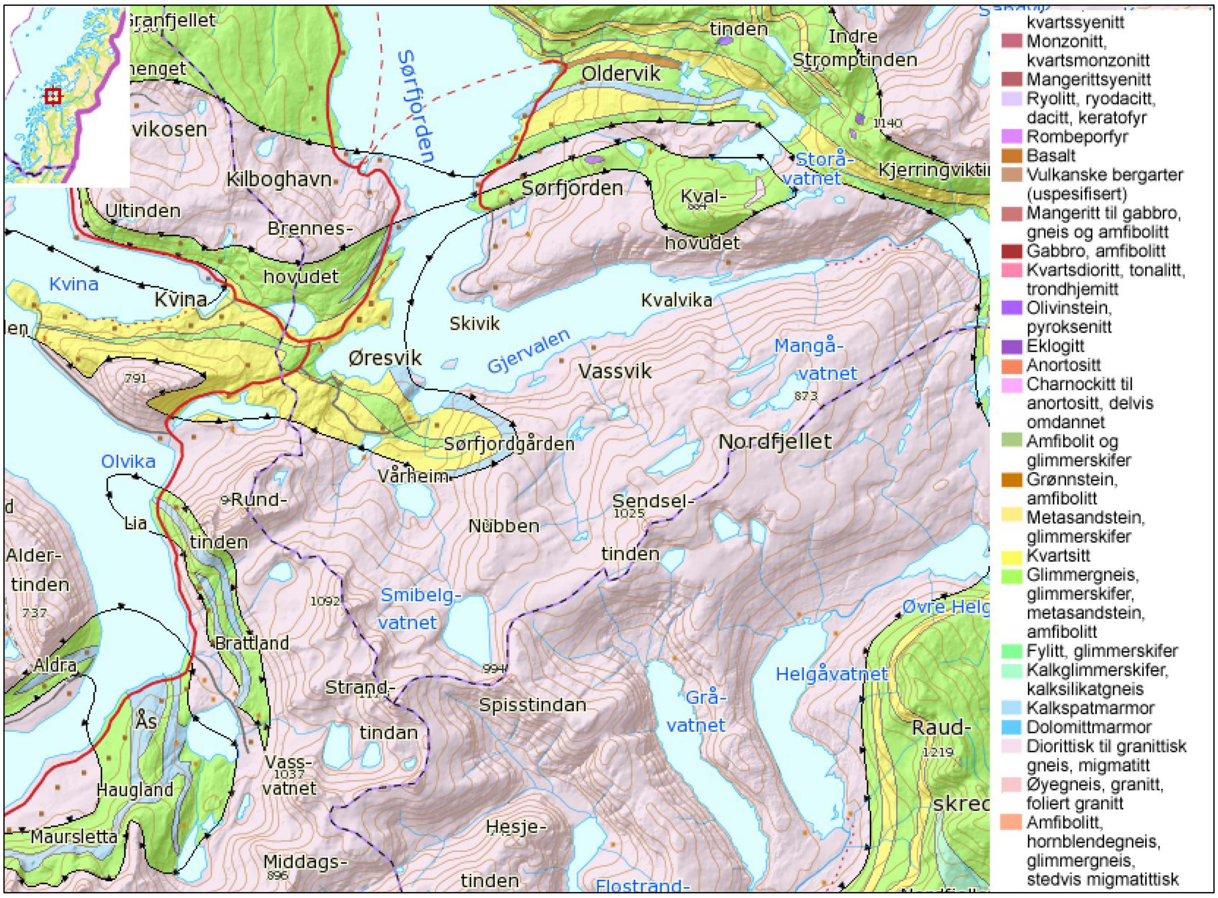

Figure 2 Bed rock geology of project Catchment, Nordland (NGU, 2014)

2.2 Seismic Hazard

The seismic effect in the design of the alternative schemes are left for study for the next detailed prefeasibility study; however the seismic nature of the Rana region is known both from the fact that this was the location of the largest known earthquake in northern Scandinavia in recent times, M_s 5.6-6.5 earthquake of August 13, 1819 and relatively from its high and constant activity in 20th century (Erik C. Hicksa, 2000).

2.3 Limitations

The variation in the bed rock geology and rock quality at key project component locations in the surface will influence the feasibility of each alternative scheme identified in section 4 SCHEME IDENTIFICATION of this report; therefore a detailed geological investigation shall be conducted in order to evaluate the merits of the development options and endeavour possible rock quality issues.

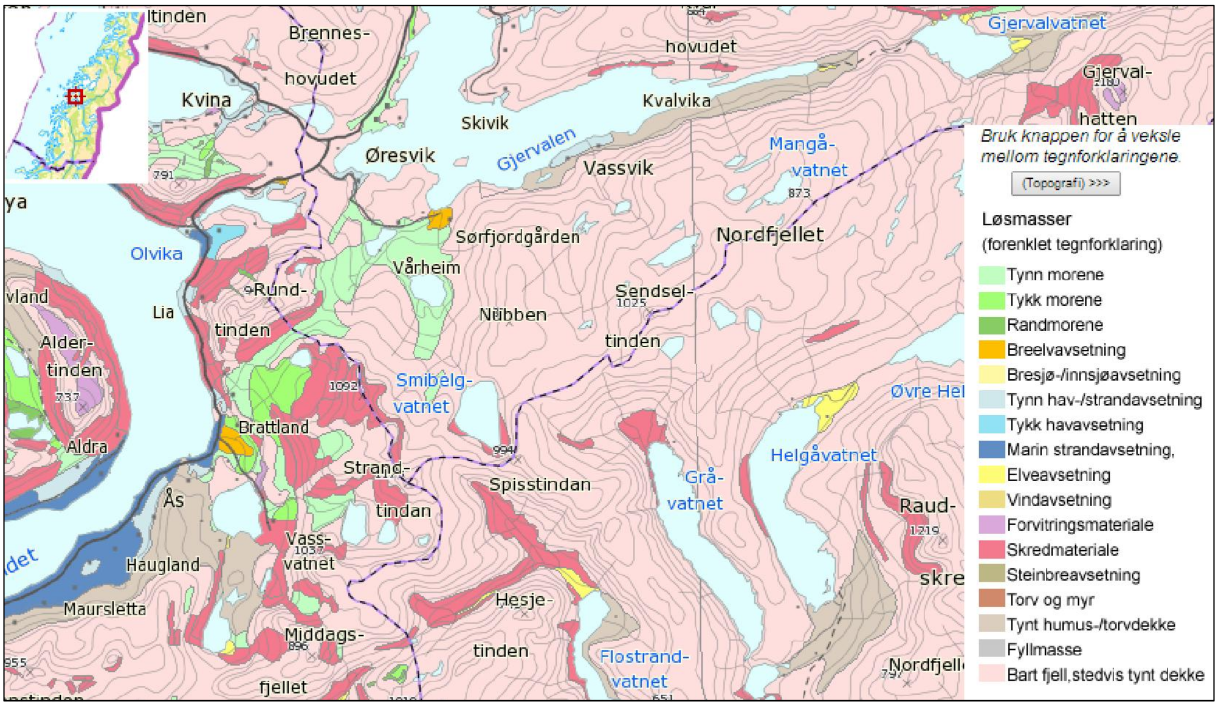

Figure 3 Soil cover of project Catchment (NGU, 2014)

3 HYDROLOGICAL ANALYSIS

3.1 Hydrological data and analysis

The inflow in to the system, from its contributing catchments and variation of the inflow over the year are the key to wards estimating the overall potential output. “Water is the basic source (or “fuel”) for hydro power generation and knowledge about the availability and its distribution is vital for both planning and operation of a hydropower system” (Killingtvet & Sælthun, 1995). The hydrological analysis has been undertaken and the results from the analysis are feed in to energy analysis described in section5 HYDRAULIC AND ENERGY ANALYSIS. The following step outlines the key steps undertaken for hydrological analysis.

3.1.1 Specific Runoff

It is deemed advantageous to use Specific runoff maps from NVE Lavvann (NVE, 2014) for reconnaissance investigation and have been used for this level of study, the online platform uses flows from 1961-2014 to determine the average specific runoff values for the project catchment in agreement with the GIS platform to include the variation in the topography of the region.

3.1.2 Mean Flow

The average flow at predefined intake points have been calculated by multiplying the specific runoff with catchment area for each sub catchment. The sum of each sub catchment mean flow included in each scheme is taken as the total available main flow for each scheme identified below in section 4 SCHEME IDENTIFICATION.

3.1.3 Design Flow

The design flow for this level of study is considered as two times the total average flow available in each scheme for dimensioning of project component structures. However detailed optimization analysis is required to determine the magnitude of the design flow and such analysis is mandatory in the pre-feasibility level study.

3.1.4 Utilization Factor

Utilization factor indicates the percentage of the flow which a hydropower scheme is able to utilize for generation, flow duration curves are used as main tool in order to determine the utilization factor for the computed optimum design flow; basically two major factors influence the value for utilization factor:

- The proportion of time and the magnitude of events which exceed the maximum capacity of the hydropower scheme (Floods).
- The proportion of time and magnitude of events which are less than the minimum capacity of the hydropower scheme (Droughts, winter freezing of the river, environmental flows and minimum turbine flow).

As such to account for the above factors a generally accepted practical norm in the Norwegian hydropower Industry is used to determine the utilization factor of 68.5% to modify the design flow stated in section 3.1.3 above. The results of these assumptions are used in section 5 HYDRAULIC AND ENERGY ANALYSIS to compute the required hydraulic and energy analysis for this level of study.

4 SCHEME IDENTIFICATION

The purpose of reconnaissance study was to identify as many schemes as possible satisfying the planning criteria stated above in section 1.4 Planning criteria. This section of the report states the comprehensive rigorous assessment methodologies undertaken to identify the potential schemes for the project catchment. The summary of the identified schemes is detailed in section 4.5 Scheme Summary.

4.1 Methodology

For this level of planning study, systematic identification of intake location, scheme alignment, storage possibilities, intra basin transfers, selection of required component structures etc. has been undertaken using comprehensive topographic and catchment analysis using the NVEs web based online platform. Details of the topographic and catchment identification are shown in separate section below.

Specific steps has been followed to maximize the key project qualities of a hydro power project, these are head and flow from the project catchment. The following preliminary steps have been followed to arrive at a suitable scheme.

- Catchment identification
- Major river identification
- Topographic analysis
- Scheme identification
- Selection of key project component location
- Review and enhancement

4.1.1 Catchment Identification

The extent of the project catchments was delineated by the online web based platform NVE atlas (NVE, 2014) and shown in Figure 1 Project Catchment Location Map above through the highlighted section. The catchment divide enables to identify the cross catchment possibilities of tapping water from one catchment to the other to maximize the flow for increased generation capacity.

4.1.2 Topographic Analysis

Detailed but preliminary topographic analysis has been undertaken to formulate the alternative schemes identified in the following section of the report focusing to maximize utilization of head and water available in the catchment. Long section of the river has been prepared for the four main rivers to foresee the extent of head concentration per meter length of the river using the GIS platform from Norgeskart (Norway, 2014) in addition to that relative cross-catchment possibilities are analysed and are detailed in annex A.

Intake locations are identified and catchment delineation followed by computation of average specific runoff were undertaken and summarized in the

Table 3 below. Combination of sub-catchments through intra basin transfer using the advantage of existing natural topography was used to come up with unique schemes described below in section 4.2 Scheme Identification.

Table 3 Project Sub - Catchment at selected Intake points, Lavvann output.

Sno	Description	Elevation masl	Area Km2	Specific Runoff l/s/km2	Q_{av} m3/s
1	Nedre storåvatenet	380	3.7	126	0.466
2	Vakkersjordvatna	400	6.2	119.5	0.741
3	Mangåga	571	4.2	121	0.508
4	Smibelgvatnet	506	4.4	133.6	0.588
5	Storåga	497	4.2	152.4	0.640
6	Smibelg-1	499	0.6	153	0.092
7	Smibelg-2	506	0.7	152	0.106
8	Smibelg-3	498	0.1	119.6	0.012
9	Østre vakker	490	3.5	127.5	0.446
10	Østre storåvatnet	751	1.8	139.2	0.251
11	Svartvatnet	184	11.7	122.3	1.431
12	Vassvatnet	107	16.4	122.8	2.014
13	Heimstadelva	115	1.8	123.6	0.222
14	Dalåga	102	1.6	137.20	0.220

4.2 Scheme Identification

The topographic analysis has been undertaken in two phases, these are:

- Identification of interdependent schemes to identify the effect of adding a sub-catchment at the expense of increased capacity and cost of the plant
- Rationalizing the identified interdependent schemes into independent schemes based on their economic merit and maximized power output.

Interdependent schemes were identified in the initial analysis to foresee the effect of adding a sub-catchment at the expense of the cost that the additional project structure might demand to add to the existing scheme. A total of eleven interdependent schemes are identified and summarized below in section 4.5 Scheme Summary.

Preliminary project costing and economic analysis described in section 7 ECONOMIC AND FINANCIAL ANALYSIS has been conducted and resulted confirmation of feasibility for all schemes satisfying the planning criteria set above in section 1.4 Planning criteria .

A total of five Independent schemes are selected upon feasibility of all alternative schemes towards maximized production output even if there were options with a smaller capacity that will give a smaller unit cost of development. The selected schemes are described as proposed alternatives in the following section and are highlighted in annex B.

4.3 Layout of Proposed Alternatives

Alternative 1 describes Scheme 8 in scheme summary and it is the one proposed by SKS Produksjon for concession permit to NVE. The layout details are presented in map layout Drawing D1-A3. Alternative 2 to 5 are schemes proposed for this thesis work.

Alternative 2 describes modified Scheme 7 in scheme summary; the layout comprises a system of tunnels and pipes to tap all available flows with underground power house arrangement located under Loften Mountain north of river Vassvikelva. The layout details are presented in map layout Drawing D2-A3.

Alternative 3 describes Modified Scheme 6 in scheme summary; the layout comprises a system of pipes and tunnels collecting water from all sub-catchments for an increased potential output though in this scheme there will be a greater construction difficulty due to steep gradient from selected intake points to penstock start location. The layout details are presented in map layout Drawing D3-A3.

Alternative 4 describes scheme 10 the layout comprises a tunnel from Smibelg to Storåga and a penstock pipe taking the water from Storåga to Vassvatnet where the power house is located. The layout details are presented in map layout Drawing D4-A3.

Alternative 5 describes scheme 11 where the water flowing from the alternative four power plant scheme is taken along with other sub catchments and drops to a power house at Ågneset.

The layout details are presented in map layout Drawing D5-A3.

4.4 Scheme Components

The identified alternative schemes has been evaluated with respect to scheme components required to finalize a complete picture of each alternative and the following section describes the assumptions and procedure's undertaken for each scheme component under consideration.

4.4.1 Diversion and Intake Structures

A small concrete gravity dam has been proposed for all scheme alternatives at this level of study since the topography of the project catchment favours runoff the river schemes except at Lake Smibelgvatnet which allows storage of water with significant amount of storage as compared to the surrounding small lakes.

Reference has been made to NVE cost curve design standards for small dams having the following construction features, construction of dams in section of 6.1 m and foundation rock injection depth of 0.5 x H, where H the water depth at the highest regulated water level HRWL.

Brook and frontal intake types which includes intake pond, trash rack and a closing gate has been proposed to find the cheapest solution allowing optimum flow condition, whilst avoiding problems related with freezing of water and rock boulders entering into the intake.

4.4.2 Water ways

Most but not all of the identified schemes are fitted with tunnels and pipes to transport water from one sub-catchment to the other. Here in this section of the report the theoretical basis behind the selection, optimization and design of tunnels and pipes are described.

Tunnels are proposed from Storåga to Smibelg, Smibelg to Østre Vakker and from Manåga to Nedre Storåvatnet to transfer the water from each catchment based on the topography, bed rock geology, economics and probable construction difficulties.

The alignment of the tunnels are aligned in such a way that they satisfy the minimum rock cover requirement, matches with the topography without losing head, technically easier for excavation methodology selection and economically attractive. Summary of proposed tunnels from all of the alternatives are described below in Table 4.

Table 4 Summary of Proposed Tunnels

Description	Tunnel			Remark
	length m	A m2	Excavation Method	
Storåga to Smibelg	2444	16.00	Drill and blast	Free gravity flow
Smibelg to Østre Vakker	2530	16.00	Drill and blast	Free gravity flow
Manaåga to Storåvatnet	2100	16.00	Drill and blast	Free gravity flow
Penstock tunnel	565	varies but <10	Directional drill	pressurized flow
Tail race tunnel	300	16.00	Drill and blast	Free gravity flow
Access tunnel	600	30.00	Drill and blast	Transport and accesses

Design procedure

To assure the required stability requirement for tunnels summarized above the Norwegian rule of thumb principle is used to quantify the results. The minimum rock covers required against rock stress, squeezing and rock fall are calculated.

Preliminary tunnel diameter optimization has been undertaken using simplified formula shown below; (Gunnes, 2000)

$$A = 1.27\, x\, Q^{0.82}$$

Where: A= area in m^2 and Q = design discharge in m^3/s

However, among other factors the cross-sectional areas of proposed tunnels are determined by the minimum area required for drill and blast by Norwegian tunnel contractors.

Buried Pipes are normally preferred as compared to tunnels in cases where the topography allows for pipe alternative; hence, DCI, PE and GRP pipes are compared in terms of the pressure and cost required per meter length of a pipe to be installed and all of identified projects are fitted with buried GRP pipes as the best alternative. The summary of the installations for the realization of the schemes are shown in the following

4.4.3 Surge Chambers

Preliminary surge analysis of the schemes shows surge shaft is not required to alleviate water hammer problem. For the analysis the time required for the generator to reach from zero to full load normal speed (Ta) is recommended to be in the range of 5 to 8 sec. generally to have a stable governing system which can adjust the power demand with water requirement at the turbine, the dynamic properties of the conduit system should satisfy the following rules.

$$\frac{Ta}{Tw} > 6$$

Where: Ta = Time required for the generator to attain full load at normal speed

Tw = Penstock time constant, time that the penstock requires to reach from zero to maximum discharge under the influence of the available gross head.

$$T_w = \frac{Q}{gH} x \sum \frac{L}{A}$$

Where: Q = maximum design discharge

H = Gross head

L = Length of tunnel plus penstock

A = Cross sectional area

L/A = from the nearest water surface upstream to the nearest water surface downstream

The computed penstock time constant will satisfy the governing rules hence surge shaft is not required, however detailed analysis on pressure in front of the turbine and governor stability are required and posted for the next level

Table 5 Summary of Pipes to be installed

Description	pipe			Remark
	length m	Diameter mm	Type	
Nedre Vakker to nedre storåvatnet	465	Varies	GRP	Buried
Østre vakker to østre storåvatnet	3000	2800	GRP	Buried
Nedre storåvatnet to penstock	1200	Varies	GRP	Buried
Manåga to penstock	1700	1650	GRP	Buried
Surface Penstock				
Scheme 1,3,5	565	1850,2100,2100	GRP	Buried
Scheme 2 & 4	1432	1850,2100	GRP	Buried
Scheme 9	1050.00	1950	GRP	Buried
Scheme 10	1565	2000.00	GRP	Buried
Scheme 11	700.00	2750.00	GRP	Buried
underground penstock				
Scheme 6	565	2700	DCI	concrete Lined
Scheme 7	565	2700	DCI	concrete Lined
Scheme 8	600	2550	DCI	concrete Lined

4.4.4 Power station

The topography as well as capacity of the plant has a major influence for selection of power house type, hence for identified schemes of capacity less than 10 Mw a surface power house has been proposed and the capacity and dimensions are fixed using head and design flow of each scheme.

For schemes greater than 10 Mw underground power house is proposed and is located in the Loften region having sufficient rock cover, good rock quality of granodiorite and short access tunnel. The capacity of the underground excavation is fixed using the blasted volume required using the following formula obtained from NVE cost curve (SWECO Norge AS, 2012). However the arrangement and details of the power house outline are left for pre-feasibility study.

$$V = 78\, x\, H^{0.5} x\, Q^{0.7}\, x\, n^{0.1}$$

Where: V = Blast Volume, m^3

H = Net head, m

Q = Total maximum water flow, m^3/s

n = Number of units

4.4.5 Mechanical and Electro technical works

Turbines

Turbines are the main engines in any hydropower development and are used to convert potential energy of water in to rotational mechanical energy of turbine shaft which is coupled with the generator shaft, turbine type alternatives has been sought for the identified schemes taking the head and speed number as criteria from the following turbine selection design curve and two equal capacity Pelton turbine units are proposed except for Scheme 11 which is fitted with single Francis turbine at the expense of higher flow and low head.

At this level the possibility of using two turbines as compared to one is observed to fetch the extra advantage of using two units as compared to one unit. Hence, they will decrease the probability of power shutdown in case of sudden turbine breakdown and using two units of equal capacity will allow utilization of one spare part to maintain both units which will minimize the overall maintenance speed and cost; hence two units of equal capacity are provided for each scheme that has a capacity greater than 5 Mw and one unit for the rest.

Pelton turbines have a larger operational range and are able to be run with flows as low as 10 % of the maximum turbine discharge. This compares to Francis turbines which should not be run below approximately 40 % of the maximum turbine discharge. Minimum turbine flows are not incorporated into the hydrological analysis for this level and will have no effect on this study. This should be considered in further stages of investigation.

The rest of Electro mechanical components are considered in detail during energy analysis and cost estimation sections of the following report.

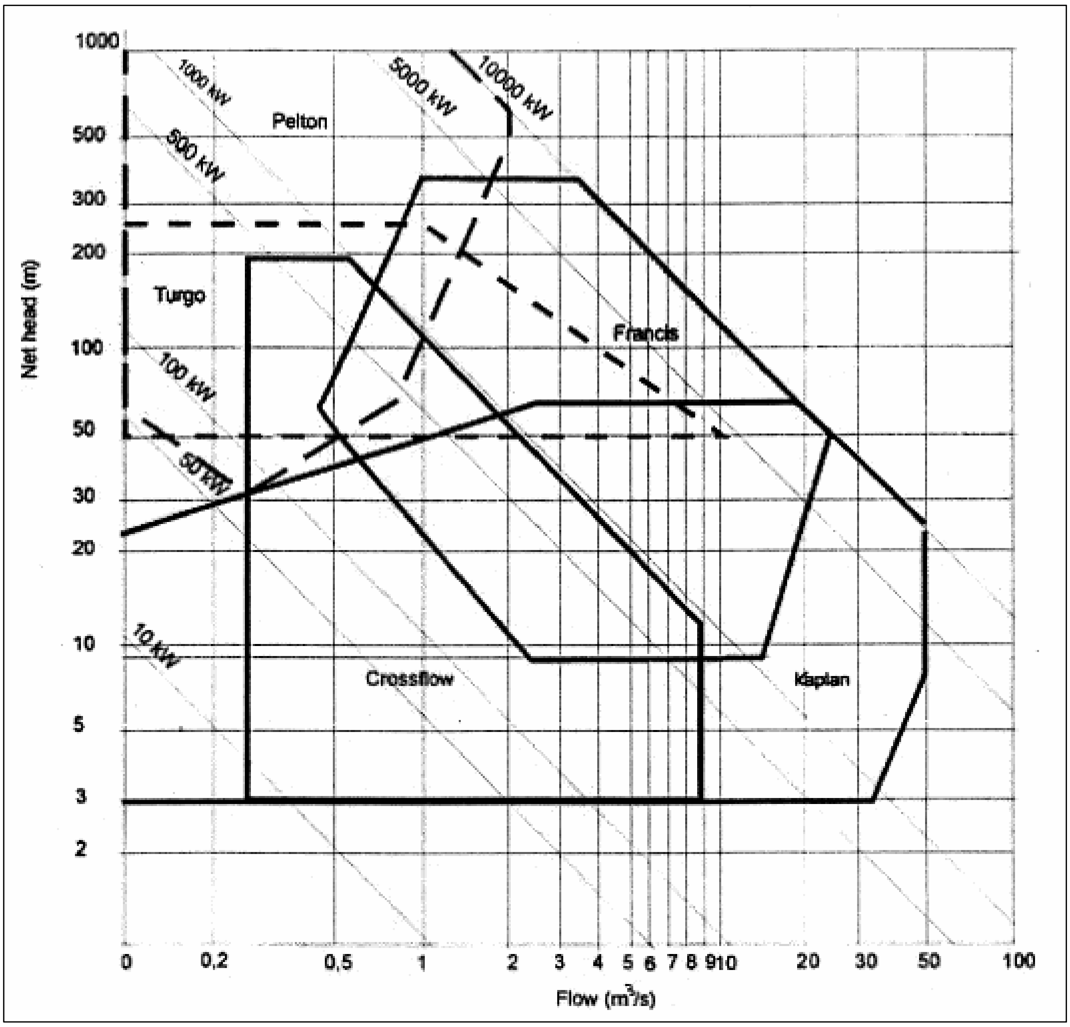

Figure 4 Guide Curve for Turbine Type Selection

4.4.6 Out fall

The out fall for releasing the water back to the river are considered and the location of the power house nearby to river or lake is considered to ascertain the shortest possible distance and reduced cost.

The preliminary level for surface as well as underground arrangements is set at 10 masl, however for the next level explicit detailed analysis of river flood level as well as submergence requirement has to be cheeked to set the outlet level as per international design standard codes.

4.4.7 Review and Enhancement

The full optimization is left for the next pre-feasibility study; hence it will put a challenge on the screening assessment of this study to the extent of feasibility of the recommended scheme. However the results are documented as reference for future assessment study.

4.5 Scheme Summary

This screening assessment has identified 11 schemes passing the planning criteria set above and are summarized with a key parameters in Table 6.

The layouts of each scheme are fitted with the topographic map and are presented along with the cost estimation and economic analysis in annex C.

Tabular summary of the independent schemes identified are presented in table xx with the basic technical and economic parameters.

There is no existing developed hydro power plant in the catchment considered and as such no detail is presented.

A study for transmission and connection to the existing grid is not considered and therefore are posted for the next prefeasibility study, although there are potential transmission lines in the catchment understudy.

Table 6 summary of Schemes with key planning parameters

Sno.	Description	Intake level	Outlet level	Mean flow m3/s	Tunnel m	Pipe Trans m	Penstock Length m
Scheme 1	Storåvatnet	382.00	10.00	1.21	x	1665.00	565.00
Scheme 2	Vakkersjordvatna	379.68	10.00	1.21	x	465.00	1432.00
Scheme 3	Storåvatnet	383.00	10.00	1.72	2100.00	1665.00	565.00
Scheme 4	Vakkersjordvatna	379.68	10.00	1.72	2100.00	465.00	1432.00
Scheme 5	Loften	383.00	10.00	1.72		3365.00	565.00
Scheme 6	Loften	383.00	10.00	2.30	7594.00	465.00	565.00
Scheme 7	Loften	383.00	10.00	2.94	7074.00	465.00	565.00
Scheme 8	Loften	484.25	10.00	2.64	7680.00	3450.00	1100.00
Scheme 9	Svartvatnet	187.00	10.00	1.43	x	x	1050.00
Scheme 10	Hundåga	498.00	110.00	1.44	2444.00	x	1565.00
Scheme 11	Brattland	102.00	10.00	3.25	2444.00	1175.00	700.00

Note: In the table above X should be understood as not provided/included.

Table 7 summary of Independent Scheme Alternatives

Sno.	Description	Intake level	Outlet level	Mean flow m3/s	Installed capacity	Turbine Type	Power House type
Scheme 6	Loften	383	10	3.15338	20685.45	2 x pelton	Underground
Scheme 7	Loften	383	10	3.15338	20671.25	2 x pelton	Underground
Scheme 8	Loften	484.25	10	2.64309	22051.44	2 x pelton	Underground
Scheme 10	hundåga	502	110	1.43808	9914.56	2 x pelton	surface PH
Scheme 11	Brattland	104	10	3.25392	5333.51	1 x Francis	surface PH

5 HYDRAULIC AND ENERGY ANALYSIS

The assumption and details of hydraulic and energy calculation are stated in separate section below,

5.1 Hydraulic calculations

To determine the available head for generation the probable hydraulic losses has to be deducted from the gross head.

Hydraulic losses with in hydropower development can be classified in to three:

- Major loss from tunnels and pipes
- Minor loss at contractions, joints, bends, entrances etc.
- Turbine and generator losses

For this level of study the minor losses are not considered rather they are included in the general simple hand rule of 1 m/km as a total loss in the conduit system. The losses in the turbine and generator are accounted using efficiency value of 90 % for the power calculation.

For transfers pipe and low pressure tunnels free flow with a velocity range of 0.7 to 1.5 m/s are considered and the manning roughness coefficient for pipes and tunnels are taken as 80 and 35 respectively. For penstock pipes flow velocity of 4 m/s and roughness value of 80 is considered in the analysis.

5.2 Energy computations

To determine the energy potential of each identified scheme energy computation formula with some adjustment factors are stated below,

$$E = (\rho * g * n * q * H) * \Delta t * U$$

Where: E = Energy potential, GWh

ρ = Density of water, Kg/m^3

g = Gravitational acceleration, m/s^2

q = Design flow, m^3/s

Δt = Time, hrs

U = utilization factor, 68.5%

The result of the energy analysis has been feed in to economic analysis to compute the overall probable benefit from each individual scheme. However storage possibilities for schemes that include Smibelg and Storåga will increase in secondary power and are considered as 10% of the total energy as added value in the economic analysis section of the report and the details of the optimization are posted for the next pre-feasibility study.

6 COST ESTIMATION

6.1 General Cost Estimation Basis

Cost base manual from NVE has been used to calculate the average foreseeable cost for contractors (Civil works) and supplier costs (mechanical and electro technical Equipment's) for capacity less than 10 Mw and greater than 10 Mw generating capacity (SWECO Norge AS, 2012).

The prices in the report are as of 1 January 2010. The prices and costs are recorded in Norwegian kroners. No taxes, import duties and interest during construction are included in the cost estimate. The following section describes the assumptions and steps taken to estimate the cost of each project component and the summary cost estimate of each scheme are documented in annex D

6.2 Estimate Civil works

This section provides a basis for calculating the average foreseeable contractors cost for civil work. Average foreseeable means there is a 50% risk of costs getting higher and a 50% risk they will be lower (SWECO Norge AS, 2012). With regard to uncertainty margins there is a 90% probability for real costs to be in the computed costs.

6.2.1 Dam and Intake

For typical dam design reference is made to NVE cost base manual that are designed according to the regulations governing water course structures- dam safety regulations and guidelines for construction and maintenance of small dams (NVE, 2014).

The height of the dams are computed using the simple hand rule 3Ø and topography as a limiting factor, accordingly the costs of each proposed dam are calculated by multiplying the cost at maximum dam height by the river cross-sectional width at the damming point which is profiled using Norgeskart (StatnsKraftvek, 2014).

The proposed costs of intakes are calculated as a lump sum value using the maximum design discharge and capacity of the power plant for each alternative scheme.

6.2.2 Water ways

6.2.2.1 Tunnels

Tunnel costs for small hydro power are generally lower than for large hydro power. The costs of tunnels are computed based on the cross-sectional area of each scheme multiplied with the length of the tunnel. 20% for rock support and 20% for preparing and running are included in the cost estimate.

6.2.2.2 Pipes

Materials examined during the cost analysis includes polyethylene (PE), glass reinforced polyester (GRP) and ductile cast iron (DCI). Technically based on the flow magnitude and pressure requirement of each scheme GRP pipes are found to be the cheapest pipe after comparing on NVE cost curves.

6.2.2.3 Penstock

Glass reinforced polyester (GRP) and ductile cast iron (DCI) pipes are the commonly used pipe materials for penstocks and in principle their foundation can be buried or laid on foundation blocks. Buried GRP pipes are proposed for surface power house schemes and DCI are proposed for underground schemes laying aside the unlined tunnel option at this level of study.

6.2.3 Power House

Both surface as well as underground power house are proposed for the respective schemes, the cost is computed as lump sum value for surface power house using maximum discharge and gross head as limiting criteria to read from NVE cost curve. For the underground alternatives the following three steps have been followed to compute the cost of power house, these are:

- Calculate the station installation as N = 8.5 x Q x H in Kw and choose the number of units and type.
- Use the approximate estimate formula above in section 4.4.4 to compute the required blasted Volume
- Use the total building related contractors cost for blasting as 2250 Nok/m^3.

6.2.4 Accesses Road

The minimum road standard criteria for Norwegian road category 3 is adopted as a means for access road construction and the cost figures are taken using moderate to difficult terrain arrangement since the project comprises both of the above transport terrain features.

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.

6.3 Estimate Mechanical and electro technical Equipment's

Generally the cost of the total mechanical and electro technical equipment's reaches up to 50% for hydro power developments. Estimation of the major component like turbine, generators, transformers, auxiliary system, pumps, control system and switching gear costs have been done and to account the unaccounted costs a 10% added cost of the calculated cost have been done to arrive at total cost.

6.3.1 Mechanical Equipment's

Turbines

The cost is derived from the cost curves based on the head and flow of each of the schemes.

Generally Pelton turbines are proposed for high head and low flow schemes whereas Francis turbines has proposed schemes with larger flows and lower heads. Both of the NVE manuals are used for cost computation with their corresponding generating capacity.

6.3.2 Electro Technical Equipment's

Generators

Generally hydropower generators can be either air cooled for smaller capacities or water cooled for larger capacities; hence both options are recognized and selected based on the individual scheme capacity. Generator total cost is computed as a lump sum using capacity as the criteria for the cost curves.

The total cost for transformers, auxiliary system, switching gear and control system electro-technical equipment's are computed based on schemes generating capacity and are computed as a lump sum value from cost curves of both manuals.

7 ECONOMIC AND FINANCIAL ANALYSIS

7.1 Economic and financial analysis

To determine the viability of the identified schemes a financial analysis is required. By evaluating the anticipated lifetime costs and benefits of the schemes a degree of clarity can be provided on the overall return on the investment and the sequencing of cash flows. Commonly used discounting techniques are used to compute and compare the ranking of the identified schemes. The details of the methodologies are summarized below,

For reconnaissance level of study the following economic tools have been evaluated to rank the identified projects.

- Net present value(NPV):
  Calculates the net present value of the alternatives with preference being given to the alternative with the largest present worth

$$\mathrm{PW} = -\mathrm{K} + \mathrm{B}(\frac{\mathrm{P}}{\mathrm{W}}, \mathrm{i\%}, \mathrm{T})$$

- Benefit cost ratio(B/C)
  Calculates the net present value of the scheme benefits divided by net present value of the scheme costs.

$$\mathrm{B/C} = \mathrm{PW}_{\mathrm{b}} / \mathrm{PW}_{\mathrm{C}} = \frac{\sum_{t=1}^{40}\left(\frac{P}{F}, i\%, T\right)Bt}{\sum_{T=1}^{40}\left(\frac{P}{F}, i\%, T\right)Ct}$$

- Annual cost method

Converting all costs and benefits into equal annual figures allows the profit or loss over the lifetime of a project be expressed on an annual basis. Here the levelised unit cost is used for comparisons of the alternatives.

$$\text{Levelised unit cost} = \frac{\text{total annual cost}}{\text{total annaul energy}}$$

- Internal rate of return (IRR)
  The internal rate of return is a measure of the return on the investment. The required IRR will vary between Clients based on the cost of financing that they can obtain and the IRR of alternative projects which they may have under consideration. The IRR of a scheme is calculated by setting the net present value equal to zero and determining the corresponding value of the IRR:

$$\mathrm{PW} = -\mathrm{K} + \mathrm{B}\left(\frac{\mathrm{P}}{\mathrm{W}}, \mathrm{i\%}, \mathrm{T}\right) = 0$$

- Development rate
  Development rate is a measure of the annual costs required during project lifetime at the expense of constant annual generation without outage of the power plant.

$$\text{Development rate} = \frac{\text{annual generation}}{\text{Annual cost}}$$

Summary of the financial analysis for independent schemes are shown in the table below,

Table 8 Financial analysis and ranking summary

Sno	Description	Unit	Scheme 6	Scheme 7	Scheme 8	Scheme 10	Scheme 11
1	Total investment cost	M kr	206.3	204.0	230.2	63.4	55.1
2	Net present value	M kr	140.8	142.9	139.8	114.6	47.4
3	Internal rate of return	%	12 %	12 %	11 %	19 %	14 %
4	Benefit cost ratio		1.68	1.70	1.61	1.26	1.86
5	Levelized Unit cost	Kr/Kwh	0.37	0.37	0.39	0.22	0.34
6	Development Rate	Kr/kwh/year	2.9	2.9	2.7	4.7	3.0
	Rank	unit cost	4	3	5	1	2
		DR	4	3	5	1	2
		b/c	3	4	2	1	5
		IRR	4	3	5	1	2
		NPV	2	1	3	4	5

7.2 Comparison of the financial analysis methods

Each of the above techniques has advantages and disadvantages with regard to the presentation and understanding of the results of the study. The ranking of schemes varies between the NPV and the other three analysis methods, and as such the definition of the optimum project relates directly to the investment profile, alternative opportunities, and needs of the client.

8 CONCLUSION AND RECOMMENDATION

Rank 1:

- Scheme 10 with unit cost of generation of 0.22 Nok/Kwh takes the first place with installed capacity of 9.9 Mw and economic return rate of 19%.
- From Economic point of view regardless of the capacity Scheme 10 is more promising than the rest of the identified schemes.
- Extra costs like pumping, underwater piercing etc. will not be available in the scheme.
- Optimum utilization of the storage potential from both smibelg and Storåga lakes can be used efficiently with the extra advantage of the topography.
- There is existing accesses road near to vassvatnet and project configuration is simple with no complex transfer systems.
- Surface power house will have some security issues than underground alternatives

Rank 2:

- Scheme 11 with a unit cost of 0.34 nok/kwh takes the second place with installed capacity of 5.33 Mw and a return of 14%.
- Extra costs like pumping, underwater piercing etc. will not be available in the scheme.
- Optimum utilization of the storage potential from smibelg, storåga and vassvatnet lakes can be used efficiently with the extra advantage of the topography
- Easy accesses for transportation and maintenance for the power house components
- Hydrological measured data series are available for the river storåga at vassvatnet
- Surface power house will have some security issues than underground alternatives

Total generation capacity from scheme 10 and Scheme 11 gives 15.248 Mw with total investment cost of 118.49 M nok.

Rank 3:

- Scheme 8 with unit cost of 0.39 Nok/kwh takes the third place with a return rate of 11%.
- Extra costs like pumping, underwater piercing etc. will be available in the scheme
- Difficulty in construction along the terrain starting from ditch excavation in bare rock to multiple intake dam and power house excavations shall be expected.
- Arrangement of the scheme dictates underground power house and as such it will increase for the safety of the power plant
- Complex project layout configuration with tunnels pipes and caverns.

Total investment required for construction will double the cost of the two plants with a value of 229.48 M nok for installed capacity of 22.051 Mw.

Choice for decisions are left for you as a client/advisor to decide, generally either of the two development alternatives can be taken forward for detailed study upon confirmation of go ahead for study. Results of unit cost variation for each alternative are shown in the following Figure 5.

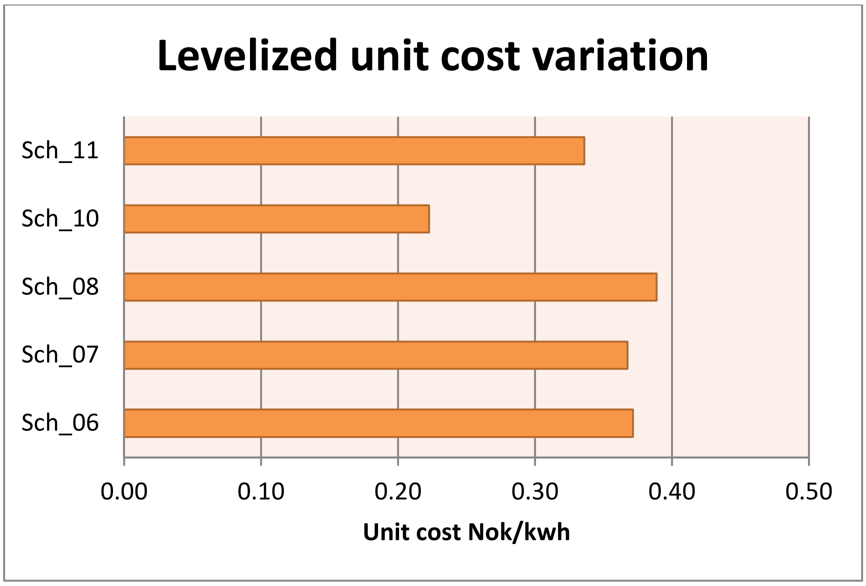

Figure 5 Variation for unit cost of Generation

Volume II Pre-feasibility Study for Recommended Project

1 INTRODUCTION

1.1 Back Ground

1.2 Scope of The study

1.3 Methodology

1.4 Available Data

2 PROJECT DESCRIPTION

2.1 Dam and Intake

2.2 Water way

2.3 Power house

2.4 Connection to Grid

2.5 Access Road

3 GEOLOGY, GROUND CONDITION AND CONSTRUCTION MATERIAL

3.1 Introduction

3.2 Regional Geology

3.3 Soil Cover

3.4 Seismicity

3.5 Limitations

4 HYDROLOGY, FLOODS AND SEDIMENTS

4.1 Introduction

4.2 Scope of Hydrological Investigation

4.3 Flow Pattern and Hydrological Analysis

4.4 Flow Duration Analysis

4.5 Flood Analysis

5 RESERVOIR OPERATION AND POWER PRODUCTION

5.1 Introduction

5.2 Need for Regulation

5.3 Operation Planning

6 POWER SYSTEM

6.1 General

6.2 Need for new transmission line

6.3 Assessment of Existing plans

6.4 Transmission system planning and design aspects

6.5 Preliminary Power system analysis ….

7 EIA STUDY

7.1 Preliminary EIA

7.2 Preliminary SIA

8 COST ESTIMATE

8.1 General

8.2 Estimation Base