THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER RESOURCES

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The Federal Democratic Republic of Ethiopia
Ministry of Water Resources

GENALE GD-6 HYDROPOWER PROJECT FEASIBILITY STUDY

Final Report

Volume 1
Main Report

May 2009

NORPLAN

in association with

Norconsult

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SHEBELLE CONSULT PLC Development, Planning & Engineering Consultants

Structure of the Feasibility Report

Volume 1	**Main Report** Volume 1 is the Main Report, a stand-alone volume that gives the reader a complete picture of the recommended project and the main results of the study. Volume 1 starts with an Executive Summary. Details and data sheets of studies and analyses within the various fields (geology, hydrology, sediments, simulations, hydraulic analysis, economic analyses, etc.) are given in separate volumes/annexes.

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Series B: Civil project structures
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LIST OF ABBREVIATIONS AND ACRONYMS

A	Unit of electric current (Ampere)
A	Area (of tunnels)
a.c	Alternating Current
ACCRD	Asphaltic Concrete Core Rock Fill Dam
ARF	Area Reduction Factor
B/C ratio	Benefit/Cost ratio
ºC	Degree Celsius (centigrade)
CCGT	Combined Cycle Gas Turbine
CDM	Clean Development Mechanism
CER	Carbon Emission Reduction unit
CFRD	Concrete Faced Rock fill Dam
cm	centimetre
CN	Curve Number
CO_2	Carbon Dioxide
CV	Coefficient of Variation
D	Diameter
d.c	Direct Current
DS	Downstream
DSM	Demand Side Management
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EEPCo	Ethiopian Electric Power Corporation
EFAP	Ethiopian Forestry Action Program
EFY	Ethiopian Fiscal (or Financial) Year
EMA	Ethiopian Mapping Authority
ETB	Ethiopian Birr (national currency unit)
ETC	Ethiopian Telecommunications Corporation
EV1	Extreme Value Type 1
EVDSA	Ethiopian Valley Development Studies Authority
FIRR	Financial Internal Rate of Return
FSL	Full Storage Level
FWL	Flood Water Level
GDMP	Genale-Dawa Master Plan
GPS	Global Positioning System
GWh	Gigawatt-hour (1000 MWh)
ha	Hectare (unit of area)
HD	Hydrology Department
HEC	Hydrology simulation model
HH	Household
HPP	Hydro Power Project
HRWL	Highest Regulated Water Level (also FSL)
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
Hz	Unit of frequency (Hertz)

List of Abbreviations, continued

ICB	International Competitive Bidding
ICOLD	International Committee on Large Dams
ICS	Inter Connection System
IDC	Interest During Construction
IEA	Initial Environmental Assessment
IPB	Isolated Phase Bus
ISRM	International Society for Rock Mechanics
ITCZ	Inter-Tropical Convergence Zone
k	coefficient of permeability
km	kilometre
kV	kilovolt (1000 volts)
kVA	kilovolt-ampere (1000 VA)
kWh	kilowatt-hour (1000 Wh)
kW	kilowatt (1000 Watt)
LCGEP	Least Cost Generation Expansion Plan
LCU	Local Control Unit
LF	Ratio of average load to peak load (Load factor)
LLF	Ratio of peak loss to average loss (Loss load factor)
LFO	Light Fuel Oil
LS	Lump sum
LV	Low Voltage
LWRL	Lowest Regulated Water Level (also used MOL)
m	metre
MDE	Maximum Design Earthquake
mm	millimetre
m/s	metres per second
m^3/s	cubic metres per second (unit of flow)
MAF	Mean Annual Flood
MAP	Mean Annual Precipitation
masl	metres above sea level
MCC	Motor Control Centres
MOL	Minimum Operating Level
MoWR	Ministry of Water Resources
MPa	10^6 Pa (Mega-Pascal, unit of pressure (stress))
MPP	Multipurpose project
MUSD	Million United States Dollars
MVA	(Megavolt-ampere) 1000 kVA
MVAr	Megavolt Ampere reactive rating
MV	Medium Voltage
MW	Megawatt (1000 kW)
MWh	Megawatt-hour (1000 kWh)
N	Newton (= 1 kg x acceleration of gravity) (unit of force)
NA	Not Applicable
NMSA	National Meteorological Services Agency
NPV	Net Present Value
O&M	Operation and Maintenance

List of Abbreviations, continued

OPGW	Optical Fibre Ground Wire
Pa	Pascal (= 1 N/m²) (unit of pressure)
PF	Ratio of active power on apparent power (Power factor)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PLC	Power Line Carrier
PSS	Power System Stabiliser
PV	Present Value
R	Resistance (electric)
RCC	Roller Compacted Concrete
RFP	Request for Proposal
ROW	Right Of Way
rpm	revolutions per minute
RQD	Rock Quality Designation
s (sec)	second
SC	Series Compensation (transmission)
SCF	Standard Conversion Factor
SCS	Self Contained System
SIL	Surge Impedance Load
SPT	Standard Penetration Test
STD	Sexually Transmitted Disease
SV	Static Voltage controller
SVC	Static Var Compensator
TBM	Tunnel Boring Machine
TCSC	Thyristor Controlled Series Compensator
TOR	Terms of Reference
TWh	Terawatt-hour (1000 GWh)
UCB	Unit Control Board
UCS	Uniaxial Compressive Strength
UAB	Unit Auxiliary Board
UG	Underground
UH	Unit Hydrograph
US	Upstream
USc	United States Cent
USD	United States Dollar
USSCS	United States Soil Conservation Service
UTM	Universal Transverse Mercator grid (maps)
V	Unit of voltage (Volt)
VA	Unit of apparent power (Volt-ampere)
VAr	Unit of reactive power (Volt-ampere reactive)
W	Unit of active power (Watt)
WES	Standard ogee crest spillway profile
Wh	Unit of energy (Watt-hour)
WAPCOS	Water And Power Consultancy Services,India
WMO	World Meteorological Organisation

1 EXECUTIVE SUMMARY

1.1 Introduction

The Genale GD-6 Hydropower Project was studied to pre-feasibility level in 2004 - 2006 by Lahmeyer International in association with Yeshi-Ber Consult. That study concluded that the GD-6 project is a *"very economic project under a wide variety of conditions always assuming that the project would benefit from the regulation by the upstream GD-3"*.

A basic condition is that there is a market both for firm and for non-firm energy from the projects at acceptable prices. It is presumed that the market will be partly domestic for consumption in Ethiopia and partly for export to Kenya.

The present Feasibility Study is based on the condition that GD-3 will be implemented, and that the reservoir will be in operation before GD-6 is commissioned. However, the feasibility presumes that both projects may be constructed simultaneously as the diversion structures are designed for full flood without regulation by GD-3 reservoir. It is furthermore based on the condition that there is a market either domestic, in Kenya or both.

1.2 Key results of study

1.2.1 Power production and Cost

The Base Case consists of the development of the Genale GD-6 power plant in combined operation with the upstream Genale GD-3 power plant designed by Lahmeyer/Yeshi-Ber to feasibility level in 2007. The Consultant has further discussed the consequences for the Genale GD-5 power plant, when implementing GD-6.

Hydrology

The Genale River inflow data series are derived from analysis of data from the Chenemasa gauging station for the period 1973-2007. However, due to the uncertain quality of Chenemasa stream flows for the period 1973-1983, the 1984-2007 series were used as basis for derivation of inflow series to reservoirs at the GD-3 and GD-6 dam sites.

Table 1-1: Catchment key characteristics

	Chenemasa (m^3/s)	GD-3 (m^3/s)	GD-6 (m^3/s)
Basin area (km^2)	9 190	10 445	13 356
Average flow (m^3/s)	92.2	95.8	102.3
Annual flow (mill m^3)	2 908	3 024	3 223

The average inflow to GD-3 for the period 1984-2007 is higher than the one used by Lahmeyer in the feasibility study. Increasing the turbine discharge of GD-3 from the feasibility study will not add to the firm energy output, but would add slightly to the secondary energy output of the project.

GD-3

The key characteristics of the GD3 power plant are given in the table below.

Table 1-2: Key characteristics of GD-3

Reservoir	FSL MOL Volume	1120 masl 1080 masl 2344 million m^3
Average inflow		95.8 m^3/s
Average turbine outflow		83.9 m^3/s
Maximum turbine discharge		116.0 m^3/s
Turbine number and type		3 x Francis
Installed capacity		254 MW
Average energy [2)]		1640 GWh/year
Firm energy		1600 GWh/year

1) Hydrology series 1984-2004
2) Lahmeyer simulation.

GD-6

The regulated flow from GD-3 results in an almost firm inflow to GD-6. The selected turbine discharge is 120 m^3/s giving an installed capacity of 246 MW, and a powerplant factor of 0.73.

Selection of GD-6 reservoir characteristics are based on simulations of energy output for different full and minimum operation levels. The simulations show that the reservoir requirement at GD-6 is limited and a regulation height of 5 m is selected. The project characteristics of the GD-6 power plant are summarised below.

Table 1-3: Key characteristics of GD-6

Reservoir	FSL MOL Volume	585 masl 580 masl 39.3 million m^3
Average inflow [1)]		102,3 m^3/s
Average turbine outflow		89.0 m^3/s
Maximum turbine discharge		120.0 m^3/s
Turbine number and type		2 x Francis
Installed capacity		246 MW
Average energy [2)]		1 575 GWh/year
Firm energy		1 540 GWh/year
Total cost		469.8 mUSD

For more details, see Section 1.4

Energy

Based on the optimisation analysis, a discharge capacity of 120 m^3/s has been recommended, resulting in plant factor of 0.73. Firm energy is defined to be energy supplied with 95% reliability. The contribution of the two plants GD-3 and GD-6 to firm and total annual energy is shown in Table 9-13.

Table 1-4: Energy output data for GD-3 and GD-6

HEPP	Firm energy [GWh/year]	Average energy [GWh/year]	Average deficit [GWh/year]
GD-3	3140	1725 1)	48.0
GD-6		1575	

1)The power simulations by nMAG 2004 gives higher secondary energy for the GD-3 power plant, than calculated by Lahmeyer.

GD-5

For the purpose of checking the consequences of including GD-5 in optimisation of the Genale cascade of power plants, a preliminary reservoir curve and cost estimate were made for GD-5. Expecting a FSL at 690 and a tail water level of 585 (GD-6 FSL) will add about 655 GWh/y firm energy to the cascade. The preliminary cost estimate adds up to be 320 mill USD.

The preliminary optimisation clearly demonstrates that the option will lower the FSL of GD-5 by 10-15 m, and it is strongly recommended to study this further before concluding on the design of GD-6.

Cost

The total cost for the GD-6 power plant is estimated at 469.8 MUSD. The cost for civil, electromechanical and transmission works are derived from prices experienced in other similar projects. The costs are summarised below, and more details are given in Chapter 11.

Table 1-5: Cost summary

Item	**Total cost (mill USD)**
Infrastructure	49 147
Reservoir cost	935
Dam	109 325
Intake	5 434
Waterway	122 947
Power station	20 299
Power station equipment	88 261
Small Hydropower Plant	2 200
Transmission, switchyard, Local supply	26 530
Environmental cost	2 200
Engineering, supervision and Owners administration	42 508
Total cost	**469 780**

1.2.2 *Base Case, Economic and Financial analysis.*

The economic energy cost (unit generation cost) delivered at Sodo Substation, which is assumed to be the connection point to ICS and export to Kenya for the Genale Cascade projects (GD-3, GD-5 and GD-6) is calculated at near at 4.43 UScent/kWh. This includes technical transmission loss and relative cost-sharing of the transmission line to Sodo. It is further based on the estimated costs and implementation schedule over 5 years for the power station and 40 years of operation horizon thereafter, including annual operation and maintenance cost of 0.8% of the investment cost and 0.2 UScent/kWh produced. The economic analysis is based on a real discount rate of 10.23% as recommended by the Ministry of Finance and economic development (MoFED).

In parallel with this feasibility study for the GD-6 project a feasibility study for the Interconnection Project to Kenya has just been finalized. (Study made by the German consultant Fichtner GmbH with EEPCo and the Kenyan Ministry of Energy as clients.). Several options and cases for interconnection and export to Kenya were studied, giving different results of costs and values for export to Kenya. In connection with this feasibility study for GD-6 the Consultant has calculated the average of the results from the Interconnection Study and applied these results as assumptions in the economic and financial analysis of the GD-6 project. On this basis it is assumed an expected average power value for export to Kenya at 5.16 USc/kWh at Sodo substation, giving the GD-6 project an economic margin of 0.77 USc/kWh.

The bulk tariff to Kenya is calculated as an average of the gap between Kenya's willingness to pay for the power referred Sodo (which is higher than the average price), and EEPCo' minimum requirement for export (which is lower than the average price). Thus, this arrangement would give a win-win situation for both countries, making it a realistic option.

EEPCo's minimum requirement tariff for export is assumed to be the marginal value of power in the ICS, thus making the sales price for power from GD-6 sold internally in Ethiopia. This price is estimated to be only 4.21 UScent/kWh, which would not cover the unit generation cost of 4.43 USc/kWh from the Project referred Sodo substation. This is an indication that the project may not be economic feasible for internal power demand coverage only, and that export to Kenya should be the major purpose of the project. However, given this goal, the project is solid towards all the sensitivity analyses done.

It may be argued that covering internal demand has first priority, but EEPCOo has many projects in the pipeline and a large generation surplus is expected from about 2012 when Gilgel Gibe III is planned to be commissioned.

Given the major objective of selling power to Kenya (where power production is thermal based), the project could be a candidate for obtaining CDM certificate (Clean Development Mechanism) and thus collect income from selling avoided CO_2 quota (Carbone Emission Reduction, CERs). The value of this has not been included in the base case above, but has been analysed in one of the sensitivity options.

Of other benefits, the Project would employ some estimated 5,000 man-years of local unskilled and semi-skilled labour during the construction phase. Though not included in the TOR, the Consultant has analysed as an option, a fee of respectively 1.0% and 5.0% of the yearly revenues from the project to be allocated for local development, since the project in itself does not give any benefits for the local community beyond the investment phase. The amount (respectively USD 0.8 and USD 4.0 mill per year) would allow the community to maintain roads, houses, various services and other infrastructure facilities that will be developed during the construction phase, and even develop the area further.

As an export project, it would also give Ethiopia income of foreign currency.

The benefit of local employment by the project has been included in the economic analysis by applying a conversion factor of 0.63 on local costs, as recommended by MoFED. This reflects the economic value (shadow value) of applying local labour.

The main economic results of the Base Case is shown in Table 1-6 where it is assumed that all power is exported to Kenya. This gives a NPV of USD 56 million compared with an investment cost of USD 445 million (469 million before conversion factor),, giving a benefit-cost ratio of 1.2, and an economic internal rate of return of 12.1%. Thus, the project would be on the border feasible with a discount rate of 12%.

Table 1-6: Base Case Economic Analysis. Export to Kenya

Energy cost	**4.43**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**56**	USD mill.	Net Present Value
EIRR	**12.1%**		Economic Internal Rate of Return
Payback	**24**	years	Payback period
B/C	**1.2**		Benefit - Cost ratio

In the *Financial analysis* the base case is taken as on-lending from the Ethiopian Government at a subsidized interest rate of 2%,, based on the assumption that Government can raise international loans at concessional terms (soft loans). A 20% equity is foreseen at full interest rate of 10%, and 80% of the capital required is assumed as loan. It is further assumed soft conditions like a grace period of 10 years after project commissioning, however interest paid during construction, and maturity of 30 years after end of the grace period. The same tariffs as in the economic analysis are used at Sodo substation.

The main results of the Base Case of the Financial analysis are given in Table 1-7, which shows financial NPV of USD 852 million giving a benefit-cost ratio of 2.8 and a financial internal rate of return at 32.7%.

Table 1-7: Base Case Financial Analysis

Energy cost	**2.11** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**852** USD mill.	Net Present Value Disc. rate: 3.6 %
FIRR	**32.7%**	Economic Internal Rate of Return
Payback	**9** years	Payback period
B/C	**2.8**	Benefit - Cost ratio

The better results than in the economic analysis is due to the assumed subsidized financial conditions. The project's financial feasibility will therefore be vulnerable to major changes in the financial terms.
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The *Conclusion* from the analyses carried out is that based on the parameter values used, the Base Case is feasible in both economic and financial context. The Base Case assumes that all power is exported to Kenya. However, the economic analysis show that the project would still be feasible with only 23% of the power exported and 73% sold internally, while in the financial analysis also 100% sold internally is profitable if the demand is there. Several other sensitivity tests carried out still maintain the feasibility of the project. However, presuming 12% discount rate, some of the sensitivity tests in the economic analysis show that the project might not be feasible under those conditions.

1.2.3 Environmental impacts

The project area straddles the Somali and Oromia Regions with the Oromia Zone of Bale (Meda Welabu Werede) on the left bank and the Somali Zone of Liben on the right bank. Road access to site will start at Siru, which is located on the main road between Negele and Filtu.

The Genale River falls into the Somali-Masai biome and is influenced by both the Somali-Masai and Afro Tropical Highland Biomes. In a regional context, the vegetation of the study area falls under White's (1983) Somalia-Masai regional centre of endemism. The length and severity of drought and its effect on the natural vegetation and pastoral populations is different in various parts of this vegetation type. Acacia-Commiphora deciduous bush land is dominant.

The main road between Negele and Filtu is largely settled and wildlife populations are minimal. The river valley, though, is largely unaffected by development and hosts substantial animal diversity though no unique habitats. The project area does not fall into any of the formal protected zones in Ethiopia nor is there informal protection although there is an understanding at the Kebele level that communities are responsible for conservation of wildlife.

There are two Kebeles (of the Liben Werede) that are affected by the project (by flooding of the reservoir and reduced flows in the section between the dam wall and the tailrace outlet), these are

1. Siru (upstream of the dam wall), and
2. Haydimtu (mainly in the area below the dam wall).

In general land use activities of the direct impact zone along the Genale River relate to response to drought conditions in which grazing and water resources in the Dawa River area are depleted. Both Kebeles focus their arable agriculture and pastoralism around the Dawa River to the south.

The amount of potential grazing lost through flooding of the reservoir will be about 818 ha. Although the reservoir will not reduce access to water, it will mean the loss of approximately 19 ha of riparian woodland grazing on the right bank. Livestock do not make much use of the islands within the river due to the presence of crocodile.

There is no commercial fishery on Genale River in the vicinity of the dam site. However, some individuals catch fish for household purposes and for small scale trading at nearby towns.

There is no permanent settlement in the reservoir area or along the transmission line route to the GD-3 sub-station and no resettlement requirements attached to the project. No roads or other public infrastructure is located within the direct impact zone of the project. A few (22) temporary/seasonal pastoralist camps exist in the reservoir area but access to water will not be lost should the project be implemented.

Virtually all major impacts are associated with the influx of labour and the provision of road access to the area during the construction phase. Although there are no communities in the immediate vicinity of the project, any development will cause secondary impacts in the wider area in terms of socio-economic changes during the construction period. Additional pressure on the riverine habitat downstream of the project may be anticipated through improved access also.

Assuming regulation of the Genale River by the upstream GD-3 reservoir then the incremental effects on the flow regime of adding the GD-6 to the cascade are minimal. No especially unique habitats fall within the reservoir area and, apart from the narrow belt of riverine vegetation, biomass is low and the area is used mostly for occasional grazing with very small patches (10ha) of recession type agriculture. Internationally, although the regulation provided by GD-3 and, to a very marginal extent GD-6, is likely to be beneficial to Somalia; it is doubtful that Somalia will have a government that is able to take advantage in the near future.

The limited impact profile of the GD-6 project results in environmental costs not being high. Overall, with effective environmental management planning and an efficient monitoring regime any negative impacts should be capable of being controlled to acceptable levels.

1.3 Genale GD-6 - Brief description of the recommended project

Project drawing B01

1.3.1 Project location

The Genale GD-6 Hydropwer project is located on the Genale River of the Genale Dawa River basin, approximately 80 km east of Negele, in Liben Zone of the Somali National Regional State. The project area is approximately 700 km by road south and east of Addis Ababa. The project forms the downstream power plant in a series of three utilising the large reservoir of the planned hydropower project GD-3 located some 82 km further upstream along the Genale River. Just upstream of the reservoir of GD-6 is a potential Hydropower Project GD-5, which forms the middle hydropower project in the series. The location of the projects are shown in Figure 1-1 below.

The project GD-6 exploits the head over an approximately 31 km stretch of the river with a maximum gross head of 234 m between the elevations 585 masl and 351 masl.

Figure 1-1: Location of the Genale Hydropower Projects GD-3, GD-5 and GD-6

1.3.2 *Civil structures and reservoir*

The dam of Genale GD-6 with a crest length of around 650 m and a maximum height of 60 m above ground is presented as an asphaltic concrete core Rock fill dam (ACCRD). The options of concrete faced Rock fill dam (CFRD) and the roller compacted RCC dam should be further studied in the final/tender design stage.

The selected dam site (FS-2) is the downstream option of two potential dam sites. The upstream option (dam site FS-1) seems to be more favourable from a topographic point of view. However, the ground conditions at the left abutment of a potential dam at this site might require an expensive cut-off structure. Based on the present knowledge of the geotechnical conditions, a dam structure at the FS-1 site could imply a total dam cost significantly higher than the cost of the dam at the selected site FS-2. On the other hand, if the ground condition at the left bank would prove more favourable than the presently available information would indicate, the total dam cost could be less. It is recommended to carry out further geotechnical investigations at FS-1 as basis for the final design. Shifting the dam from site FS-2 to FS-1 would not have any influence on the rest of the project. Intake, waterway, and reservoir water levels would remain the same as designed.

The dam creates a reservoir with a gross volume of 181 mill m^3. The active volume between highest regulated water level 585 and lowest regulated water level 580 is 39.3 mill m^3.

The topography at the dam site is steep, and a side channel spillway with a chute is found to be the optimum solution for diverting floods at the site.

The power intake is located as a separate structure on the right side of the river, some 900 m south of the dam. From here a 4.7 km long circular pressure headrace tunnel of 63.6 m2 cross section (dia=9 m) will convey the water to the powerhouse cavern. Geological conditions are such that the pressure tunnel will be unlined, with the exception of two 40 m long steel lined penstocks.

A 120 m long vertical shaft connects the headrace tunnel to the surge chamber. The surge facilities are located 850 m upstream of the powerhouse.

The powerhouse will be equipped with two vertical Francis units, totalling 250 MW. The powerhouse is located in a ridge on the right river bank, which offers favourable geological conditions for the powerhouse and transformer caverns and all other appurtenant structures.

A major surge chamber is needed on the tailrace, and a 4000 m^2 chamber is established by widening the tailrace tunnel for the first 330 m downstream of the draft tubes. The surge chamber (tunnel) will have a cross section of 380 m^2. From the surge chamber the turbine flow is conveyed through a Ø 9 m TBM drilled, 11,7 km long tunnel to the tailrace outlet.

1.3.3 *Electromechanical equipment*

Mechanical equipment

Based on the design head and turbine flow, vertical Francis turbines represent the only practical solution for Genale GD-6.

Two units are foreseen. In the case of Genale GD6, the flow duration curve does not favour the use of three units relative to two. The increase in generation is calculated to be only 2GWh. This additional generation does not justify for the increased cost of three units.

The level in the intake reservoir will vary between 585 masl at Full Storage Level (FSL) and 580 masl at Minimum Operation Level (MOL). The normal operation level should be close to 585, and with a tail water level at el. 351, the gross design head for the turbines is set to 234 m. Total output for the two turbines will then be 250 MW.

The governors are conventional electro-hydraulic governors, permitting all normal operation modes. The oil pressure system includes nitrogen type accumulators giving necessary safety to shut down the units in an emergency condition.

The powerhouse crane will be a bridge crane with a main hoist, which will serve any requirements for lifting and moving of heavy components during installation, maintenance work and operation. The crane will be provided with an auxiliary hoist travelling under one of the crane girders.

Steel lining will be installed only for the headrace section immediately upstream of the powerhouse. Two steel penstocks are leading to the turbines via spherical valves.

Detailed description and data tables for turbines, valves, gates, trash racks, steel penstock and bulkheads are given in Chapter 3.8

Generators

The 150 MVA generators will be vertical shaft, salient poles, synchronous generators directly coupled to the Francis turbines.

The generator rated output corresponds to the turbine power at design head and a power factor (PF or cos φ) of 0.86, which will give the generators sufficient capacity for reactive power to support the normal requirements of the transmission grid.

Rated generator voltage should be left to the supplier to optimise, but it will most likely be in the range of 12-16 kV.

Transformers

The 150 MVA, 420/Ug (Ug=transformer voltage) transformers will be located in a separate cavern shortly downstream of the main powerhouse cavern.

Detailed description and data for electrical equipment for Genale GD-6 are given in Chapter 3.10.

Switchyard/Transmission

The switchyard will be located outdoors. The cables will be placed in a separate cable tunnel with outlet 200 m west of the switchyard. A single circuit 400 kV AC line, 75 km long, will be constructed from Genale GD-6 to GD-3 substation. The transmission line will pass near the proposed GD-5 power plant location.

Detailed description of the power system and transmission lines is given in Chapter 4.

1.3.4 Small Hydropower Plant

A bypass for release of a minimum flow of 2.5 m^3/s has been arranged in the diversion culvert. The Consultant suggests installing a small hydro unit to generate power from the compensation water release downstream of the dam. The turbine will be a standard compact unit with horizontal shaft, with a load controller to ensure correct water release at all times.

The installed capacity will be 1.35 MW, and as it should be operated 365 days/year, the yearly energy output will be 11.8 GWh. The unit will be connected to the 33 kV transmission line and supply power into the Negele substation.

1.4 Key project characteristics for Genale GD-6

Table 1-8: Key data of the Genale GD-6 Project - Base Case

Power and Energy	Total rated output from 2 units	246	MW
	Mean annual energy generation	1 575	GWh/a
	Firm annual energy	1 475	GWh/a
	Plant factor	0.73	%
	Design discharge, total for 2 units	120	m^3/s
	Maximum gross head	234	m
	Minimum gross head	229	m
	Type of transmission line to GD-3	400 kV AC, single c.	
	Length of transmission line to GD-3	75	km
Hydrologic Data	Genale River catchment area upstream of Genale GD-6 dam	13 356	km2
	Mean river flow at Genale GD-6 dam site	102.3	m³/s
	20-year flood (natural inflow)	950-1150	m³/s
	100-year flood (natural inflow)	1300-1700	m³/s
	1000-year flood (routed inflow)	1 150	m³/s
	PMF (routed inflow)	2 500	m³/s
Reservoir	Full Supply Level (FSL)	585	masl
	Minimum Operation Level (MOL)	580	masl
	Total volume at FSL	181	Mm³
	Active reservoir volume	39.3	Mm³
	Surface at FSL	8	km²
	Extension of reservoir towards upstream at FSL	12	km
Main Dam	Type of dam	Asphalt concrete core Rock fill dam (ACCRD)	
	Dam crest elevation	591.5	masl
	Maximum height of dam above foundation	60	m
	Crest length of dam	650	m
	Dam volume	1.5	Mill m³
Spillway	Type	Concrete gravity with free overfall and chute	
	Elevation of overfall crest	585.0	masl
	Length of spillway crest	100	m
	PMF outflow	2 500	m^3/s
	Reservoir elevation at PMF outflow	590.2	masl
	Spillway capacity at reservoir level 1525 masl	2500	m³/s
Power Intake	Elevation of intake sill	566.0	masl
	Type and number of intake gates	roller gates, 1 nos	
	Intake gate dimensions (w x h)	5.5 x 8.2 m	
	Trash rack dimensions (w x h)	10.0 m x 12.0 m	
Sediment flushing	NA		
Headrace Tunnel	Tunnel dimension D=9 m	63.6	m2
	Tunnel length intake to penstock	4700	m
Penstock	Diameter of penstock	2 x 4.2	m
	Length	45	m
Powerhouse	Type of powerhouse	Underground	
	Powerhouse cavern dimensions (l x w x h)	65x17x39	m
	Elevation of machine hall floor	360.2	masl
	Cross section of access tunnel	50	m2
	Length of access tunnel	1150	m
	Elevation of turbine centre	347.7	masl
Tailrace Tunnel	Tunnel dimension D=9 m	63.6	m2
	Tunnel length from draft tube outlet to river outlet	11 700	m
	Dimensions of draft tube gates (w x h)	4.25 x 7.1	m
	Elevation of tailrace outlet sill	342.5	masl
Turbines/Generators	Type of turbine (2 units)	Vertical Francis	
	Design discharge, per unit	60	m³/s
	Total rated output at design net head, 2 units	125.4	MW
	Maximum output	129.1	MW
	Synchronous speed	300	rpm
	Generator nominal active rating per unit	129	MW
	Generator nominal apparent power per unit (cosφ = 0.86)	150	MVA
	Maximum runaway speed	480	rpm
Transformers	Type and number of transformers	Three-phase, 2 nos	
	Maximum voltage	420/17.5	
	Nominal power per transformer	150	
	Transformer cell dimensions (l x w x h)	11 x 7 x 6.8	

2 STUDY BACKGROUND

2.1 Project location

Project drawings A01, A02, B01, B02,

The Genale GD-6 project is located on the Genale River of the Genale Dawa River basin, approximately 50 km north west of Filtu and approximately 80 km east of Negele, in Liben Zone of the Somali National Regional State. The project area is approximately 700 km by road south and east of Addis Ababa, via Awasa and Kibre Mengist.

The project GD-6 forms the downstream power plant in a series of three plants utilising the large reservoir of the planned upstream hydropower project GD-3 located approximately 82 km further upstream of the Genale River. Just upstream of the reservoir of GD-6 is a potential Hydropower Project denominated GD-5, which forms the middle hydropower project in the series. Figure 2-1.

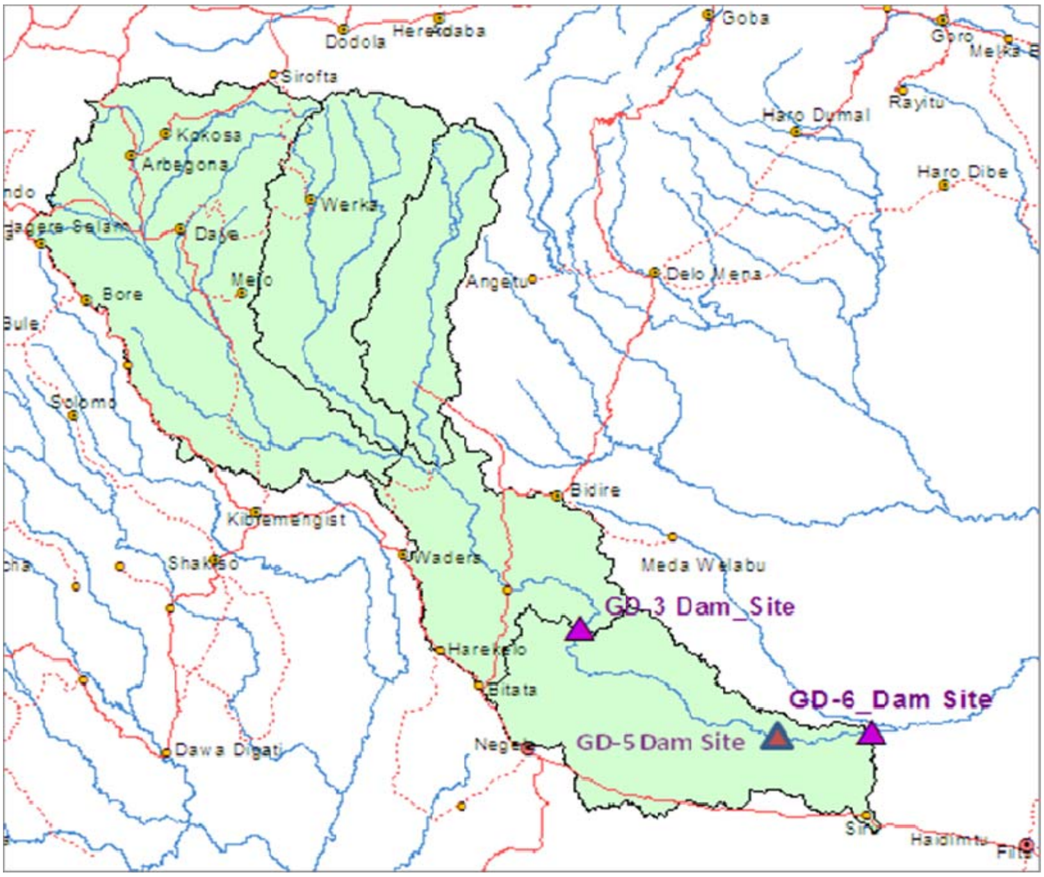

Figure 2-1: Location of the Genale GD-3, GD-5 and GD-6 Hydropower Projects in the catchment area

The project GD-6 exploits the head over an approximately 31 km stretch of the river with a maximum gross head of 234 m between the elevations 585 masl and 351 masl. Figure 2-2 shows the longitudinal section of the Genale River along the reach under consideration.

The project will supply firm energy into the Ethiopian Interconnection System (ICS) and is expected to be connected for export of power to the Kenyan national grid.

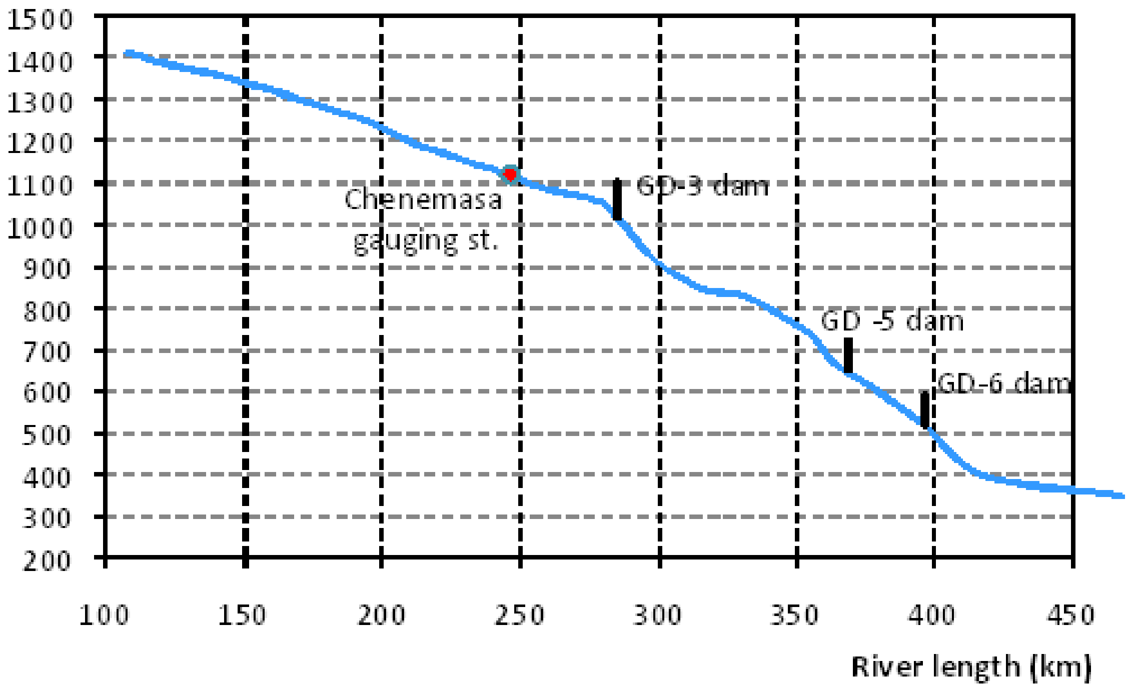

Figure 2-2: Longitudinal section of Genale River showing the power development at Genale GD-3, GD-5 and GD-6.

2.2 Previous studies on Genale GD-6 Hydropower Project,

The Genale GD-6 Hydropower Project was identified by EVDSA/ WAPCOS in 1990, as part of the Preliminary Water Resources Development Master Plan for Ethiopia. The master plan covered all aspects of water resources development. The study identified nine potential hydropower project sites, from GD-1 to GD-9, on the Genale River.

Genale GD-6 is further studied to pre-feasibility level as a separate project by Lahmeyer International in association with Yeshi-Ber Consultant (LI-YB) under the “Genale-Dawa River Basin Integrated Resources Development Master Plan Study Project” (GDMP).

The present Feasibility Study is mainly based on the work and the results of the pre-feasibility study.

2.3 Objective for the present study

Reference is made to the ToR:

The immediate objective of the Feasibility Study is to design the GD-6 Hydropower Project to a bankable Feasibility level, which include all relevant baseline investigations, assessment and plans, drawings *and cost estimates regarding technical, economic/financial, environmental, and socio-economic aspects. The ultimate objective of the study is to increase the energy and power generation capability of the country and to obtain a reliable and adequate supply of electric energy, and sustain economic development.*

The study will analyse and document all important aspects required for the formal approval of the Project by MoWR and other government authorities of Ethiopia.

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3 GENALE GD-6 – PROJECT DESCRIPTION

Project drawing B 01

3.1 Genale GD-6 - Arrangement of project structures

Genale GD-6 is the most downstream one of the potential hydropower schemes on Genale River. The dam of Genale GD-3 creates the head pond and storage reservoir for the cascade with a capacity sufficient for a significantly improved flow regulation.

The Genale-Dawa Master Plan, GD-6 Pre-feasibility study concludes with a feasible site for implementation of a power project at GD-6. The site appears favourable, for the following reasons:

- The GD-3 project regulates the flow in the Genale River and inflow to GD-6 is favourable for firm energy production.
- The site offers good rock conditions
- Several Dam site options with acceptable cross sections are identified
- A head of about 235 m is achieved by a dam, 60 m high and relatively long tunnels, 16.5 km.

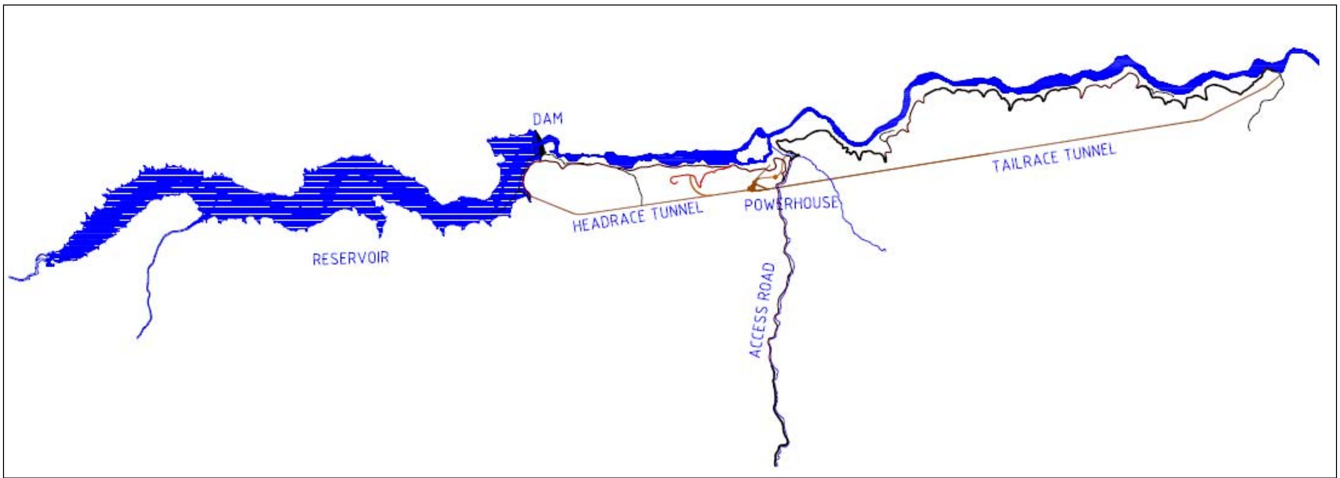

Figure 3-1: Overview of the Genale GD-6 project

An asphaltic concrete core Rock fill dam type (ACCRD) has been selected for feasibility design. It will have a length of 650 m and a maximum height of 60 m above ground.

The 100 m wide side channel spillway is constructed as a free overflow on the right bank of the river. From the side channel a chute takes the flow down to the river.

From the power intake, located 900 m south of the dam, a 4.8 km long pressurised headrace tunnel conveys the water to the powerhouse cavern via a 25 m long lined penstock. A 12 km long tailrace tunnel leads to the Tail water. Both headrace and tailrace need surge facilities.

3.2 Genale GD-6. Layout changes.

The general layout of the Genale GD-6 project is changed from the Pre-feasibility study by Lahmeyer. The major changes are:

- Shifting of the powerhouse from an open air downstream location, to an underground location 12 km upstream, hereby
  - Reducing the length of pressure tunnel from 15 km to 4,8 km.
  - Replacing 12 km headrace tunnel with tailrace tunnel.
  - Avoiding steel lining of an up to 300 m long part of the headrace tunnel.
  - Avoiding 1100 m steel penstock.
  - Needing additional surge chamber on the tailrace
  - Reducing risk for tunnel excavation in the sediment rock.

Dam is shifted downstream, but no principal changes made.

The brief estimate, without trying to calculate cost for rock support, is compared in Table 3-1 below:

Table 3-1: Rough cost comparison between proposed Pre- feasibility design and Feasibility design.

	Pre-feasibility design	Feasibility design
Steel lining, 300 m	12-15 mill	NIL
Steel penstock	38 mill	8 mill
Surge chamber	14 mill	18 mill
Power station, access	NIL	8-10 mill

The estimated prices of the Pre-feasibility study is taken from the Pre-feasibility report. The major difference in cost is related to steel lining and steel penstock. The Pre-feasibility cost is not adjusted for general cost increase since presentation of the report.

An alternative layout with an underground power station located at the downstream end of the tunnel (1-2 km upstream of outlet) would reduce the penstock cost, but the steel lining and surge chamber cost from the Pre-feasibility study will remain unchanged.

In the Consultants opinion the change of project layout has reduced the cost by some 30-40 mill USD based on the cost level used in the Feasibility study.

3.3 Genale GD-6 - Dam and reservoir

Project drawings B03 to B09

3.3.1 Dam axis selection

The maps produced for the present study show that the narrowest valley profile is the one dam site named FS-1. However due to geological conditions the dam site was shifted to FS-2 during the design.

Both dam sites have generally favourable topographic conditions with the hills rising more than 50 m above the considered crest levels.

Several dam sites further downstream were considered, but all options increases the dam volume to an unacceptable level.

The dam axis's is defined by the following co-ordinates:

Table 3-2: Coordinates proposed dam axis

	FS-1	FS-2
Left Bank	North 594 355	North 595 065
	East 646 505	East 647 380
Right Bank	North 594 100	North 594 550
	East 647 130	East 647 475

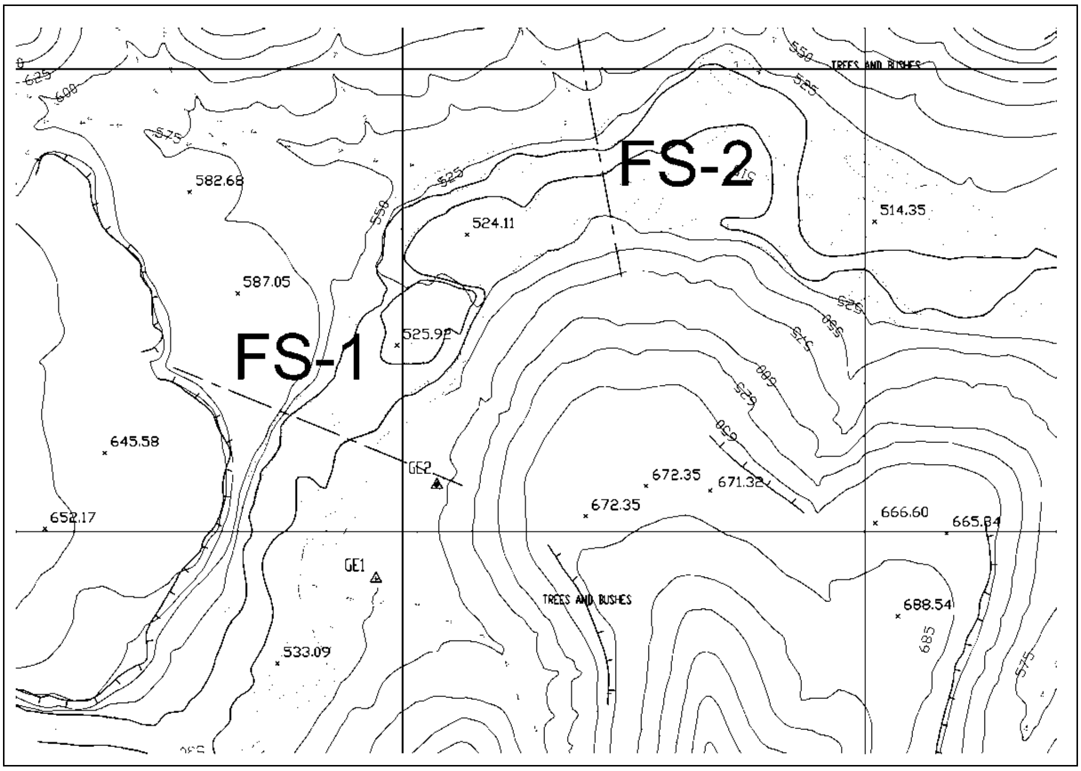

Figure 3-1: Location of Genale GD-6 main dam site options

3.3.2 *Dam height*

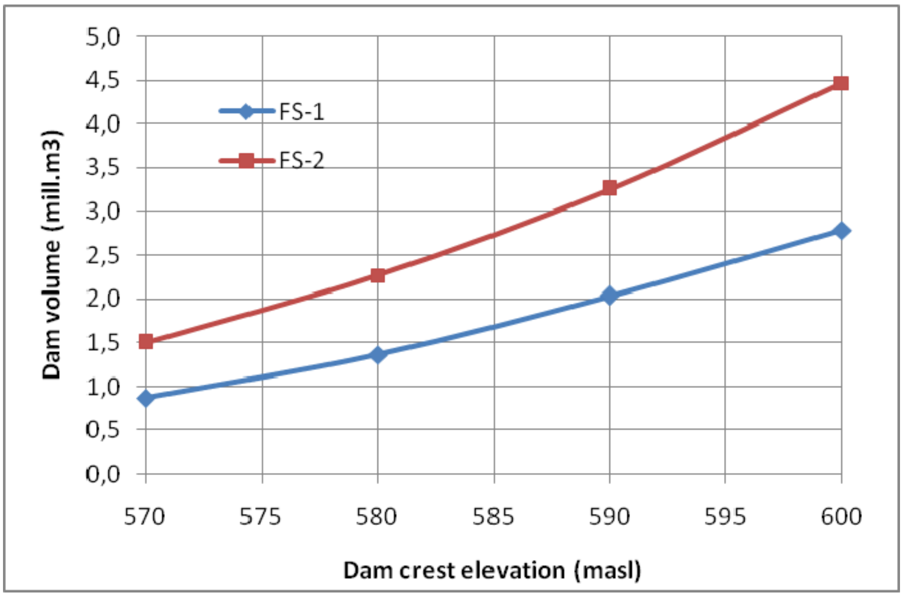

Figure 3-2: Dam volume of studied dam sites.

The analysis leading to the selected dam height is summarised as follows:

- An optimisation analysis has been made (ref. Annex 3 C, Chapter 5), demonstrating that it is beneficial to increase reservoir level above the elevation recommended in this study (585 masl). However, increasing it further reduces the available head and feasibility of the upstream potential HEPP site, GD-5.
- The topographical conditions are favourable above the selected elevation, but rock conditions for the dam foundation are poor above el. 570-575 masl, and hence, increasing the FSL further would imply major cost for dam foundation preparation.
- The reservoir operation studies (see Chapter 9, and Annex 3 C) shows that the Firm energy potential of the cascade development of GD-3, GD-5 and GD-6 will be fully utilised even with a lower dam than selected.
- The reservoir operation studies (see Chapter 9, and Annex 3 A) also shows that the Firm energy potential of the cascade development of either GD-3, GD-5 and GD-6, or GD-3 and GD-6 does not require a major reservoir at GD-6 to utilise the energy potential of the site.
- Excavation of up to 2 m soil, and 2 m rock in the dam foundation has been included in the calculations.
- Increasing the FSL of GD-6 decreases the tunnel lengths of GD-5 HEPP, by an average of 110 m for each 1 m of increase of GD-6 FSL. The value of reduced tunnel length is included in optimisation when considering the option of the cascade GD-3. GD-5 and GD-6.
- The spillway is a free, non-gated side overflow with crest elevation 585 masl, corresponding to FSL. From the spillway a side channel and a chute leads the water down to the river.
- Two calculations for PMF are presented. The worst case scenario gives a PMF of 2665 m^3/s corresponding to a FWL (flood water level) of 590.5.
- Considering the necessary surcharge height for the design flood discharge and sufficient allowance for a freeboard, a crest elevation of 7.0 m above FSL has been selected.

The crest elevation for the structures (main dam and intake) was thus fixed at 585.00 masl.

The 5 m contour digital map shows a minimum ground level of 520-525 masl along the dam axis. With a crest level on 591.5 masl the maximum height of Genale GD-6 dam would thus be 65 m above ground.

3.3.3 Dam type and sealing concept

Project drawings B04

Reference

Reference is made to Chapter 7 and to Volume 4 of the feasibility report, for detailed descriptions of the ground conditions and design considerations regarding the dam and dam site options.

Available materials

Availability of suitable materials is one main criterion for selection of dam type. In the Genale GD-6 project area the rock is of very good quality, easily available close to the dam site at a location that will remain under lowest regulated water levels. The tunnels will also be excavated in rock type well suited for dam construction and for concrete aggregates. Clayey or other types of natural materials suitable for use as low permeability core material are not available in sufficient quantities. The scarce deposits of clayey materials are decomposed from partly gypsiferous materials and are not suited for dam construction because of its swelling and soluble properties. Consequently, an earth fill dam with clay core is out of question for GD-6 dam.

The dam should be constructed using rock materials, either as rock fill dam or as concrete dam.

Three different dam types have been evaluated for GD-6 dam:

- Roller Compacted Concrete Dam (RCCD)
- Concrete Faced Rock Fill Dam (CFRD)
- Asphaltic Concrete Core Rock Fill Dam (ACCRD)

Roller Compacted Concrete Dam (RCCD)

The RCC dam type has several advantages related to layout and to volume of construction materials. The type is furthermore not very sensitive to weather condition during construction.

A major advantage is that the dam crest may be used as spillway. The water diversion structures may be less comprehensive during construction, and the consequences of an accidental overtopping during construction are not as disastrous as for an embankment dam.

The disadvantages are the cost and the need of large quantities of cement and slag for cement replacements, which are not available in the area.

Concrete Faced Rock Fill Dam (CFRD)

Rock fill dams must contain an impervious zone. As no suitable clay materials are available in the area, one option is to construct a concrete slab on the upstream slope of the dam. The concrete face has the advantage that it requires relatively small quantities of materials that need to be transported long distances. The only material not available locally is the cement for the relatively thin front concrete slab. At GD-6 the rock materials are of good quality suitable for dam construction. The cost are favourable.

A disadvantage is the need of spillway structure constructed at the side of the dam, or constructed as a separate concrete structure somewhere within the dam body.

Asphaltic Concrete Core Rock Fill Dam (ACCRD)

An alternative to use a concrete slab as upstream impervious zone in the rock fill dam is to construct an impervious central core of asphaltic concrete. Asphaltic concrete has a special mix of binder in an aggregate mix instead of cement. The core is impervious and flexible, which is of advantage with regard to settlements in the supporting rock fill.

Another advantage is that the construction method is less vulnerable to adverse weather conditions than the other dam types.

Selected dam type

The cost estimates indicates that an asphaltic concrete core would be the most favourable dam type for GD-6. The Consultant has selected ACCRD as basis for the feasibility study. However, unit construction cost as well as cost of materials changes continuously. In connection with final design the cost estimates should be reviewed based on updated unit rates.

3.3.4 Reservoir features

The main reservoir in the Genale River is the GD-3 reservoir, about 100 km upstream of GD-5 dam site. The reservoir is designed as part of the GD-3 feasibility study by Lahmeyer International in association with Yeshi Ber Consult, The following reservoir data has been concluded:

Table 3-3: Genale GD-3 reservoir, elevation-area and elevation-volume relationships

Elevation masl	Area km2	Volume mill m3	
1020	0.0	0	
1030	0.15	1	
1040	0.47	4	
1050	1.4	13	
1060	2.8	34	
1070	9.5	95	
1080	23.0	260	LRWL
1090	39.0	570	
1100	57.0	1040	
1110	76.0	1710	
1120	98.0	2570	HRWL
1130	119.0	3650	
1140	142.0	4950	

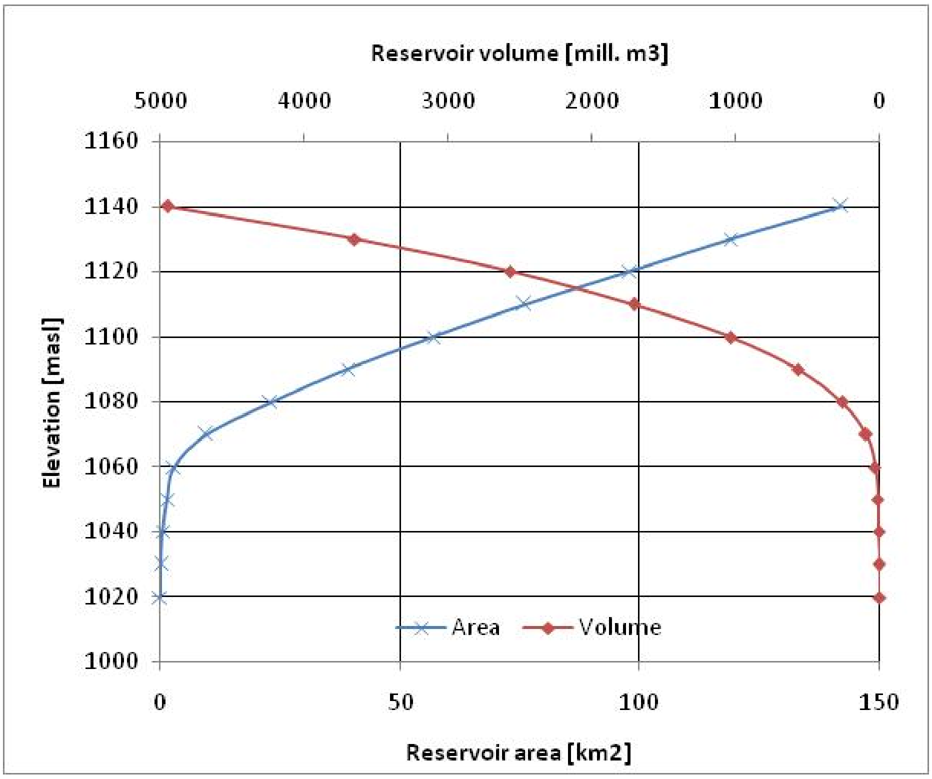

Figure 3-3: Genale GD-3 reservoir, elevation-area and elevation-volume curves.

The optimum regulation limits for the Genale GD-6 dam have been found by the power simulations presented in (Chapter 9). The following features of the reservoir is selected:

- Full Supply Level (FSL): 585 masl
- Minimum Operation Level (MOL): 580 masl
- Live reservoir volume: 39.3 Mm^3
- Total reservoir volume at FSL: 183.6 Mm^3
- Surface area at FSL: 8.15 km2

The reservoir elevation-area-capacity relationships have been established from the digital maps, measuring digitally the areas delineated in the reservoir by the 5 m contour lines. The reservoir capacity was then determined by integrating the elevation-area curve. The results are shown in Table 3-4 and in Figure 3-4

Table 3-4:Genale GD-6 reservoir, elevation-area and elevation-volume relationship

Elevation masl	**Area km2**	**Volume Mill m^3**	
522	0.0		
525	0.1	0.3	
530	0.3	1.2	
535	0.5	3.3	
540	1.0	7.1	
545	1.3	12.8	
550	1.7	20.4	
555	2.4	30.7	
560	3.1	44.3	
565	3.9	61.7	
570	4.9	83.6	
575	5.9	110.5	
580	7.2	143.6	LRWL
585	8.1	183.6	HRWL
590	9.3	227.1	
595	10.2	275.9	
600	11.4	330.0	

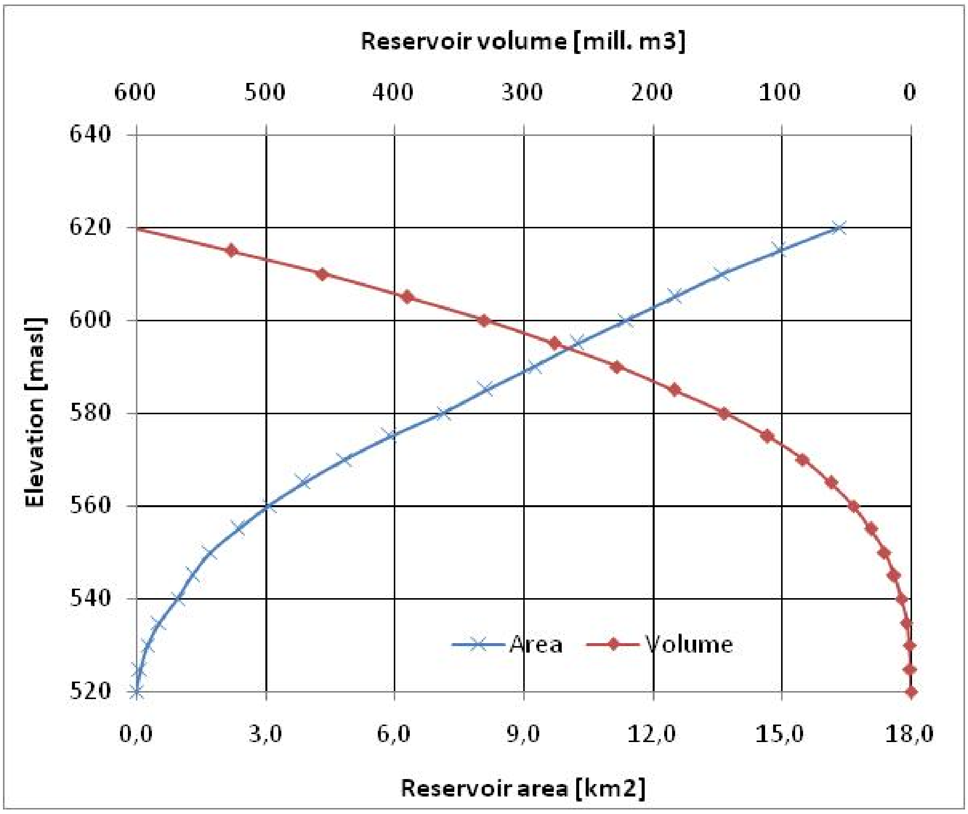

Figure 3-4: Genale GD-6 reservoir, elevation-area and elevation-volume curves

At full supply level 585 masl the headwater of the reservoir extends more than 12 km upstream with a width of the reservoir of some 600 m near the dam site. 650 m will be the average width of the reservoir.

An ungated spillway with crest elevation at FSL, is proposed. Flood levels in the reservoir will then be higher than with gated spillways, but total cost and security for diverting floods makes ungated spill-ways feasible for GD-6. The spillway length is 100 m, and the related flood levels will be (worst case scenario calculation):

- 10-year flood level (850 m^3/s): 587.60 masl (unregulated)
- 100-year flood level (1500 m^3/s): 588.65 masl (unregulated)
- 1000-year flood level (1100 m^3/s) 588.08 masl
- PMF flood level (2590 m^3/s): 589.35 masl

The 10 and 100-year inflow floods will normally be retained by the GD-3 reservoir. The calculated floods are therefore mainly from the local catchment only. The 1000-year and PMF floods are routed through the GD-3 reservoir.

The GD-6 reservoir area is rather small, compared to inflow floods, and the capacity of reducing the larger floods is limited.

3.4 Genale GD-6 - Spillway

Project drawings B09 and B10

3.4.1 Spillway type and dimensions

The spillway is designed to withstand the PMF floods, but with limited freeboard and hence a limited safety.

Type

The GD-6 spillway is planned to be at the right bank of the river. Based on topographical, geological and other factors mainly two types of spillway have been investigated in details as options. The two spillway types are:

- side channel spillway with chute option and
- side channel spillway with stepped spillway option.

For both considered options the following parts of spillway are common:

- Control structure (weir in the form of ogee profile).
- Side channel (trench along the contours).
- Spill channel.
- Control weir at the end of the spill channel.

Floods

In determining the spillway type, the best combination of storage capacity and spillway flood capacity of GD-6 dam and reservoir, all pertinent factors of hydrology, hydraulics design, cost, and damage due to possible dam breach have been considered. Considered spillway type, the maximum spillway discharge (Qmax), required spillway crest length (L) and the maximum reservoir water level (FSL) are as listed bellow:

- ➢ Considered return period for design is PMF.
- ➢ Design flood Qmax= Q(PMF) =2595 m^3/sec.
- ➢ Spillway crest length, L=100 m.
- ➢ Reservoir Full Supply Level, FSL=585 masl.
- ➢ Surcharge, H=5.35m.

Spillway components

The topography of the abutments at the GD-6 dam site is a quite steep hillside. For such topographical condition, the first option of spillway structure is a side channel overflow spillway. The spillway has the following structural components:

a) Ogee profile overflow spillway (weir).
b) Side channel trough.
c) Spill-channel with sub critical slope.
d) Chute or stepped spillway and.
e) Energy dissipation structure (stilling basin).

3.4.2 *Spillway design for flood discharge*

The weir is aligned parallel to the contours at the abutments area.

The basic purpose of the present spillway is to convey large floods through a project without incurring unacceptable damage either upstream or downstream from the GD-6 dam. The capacity of the spillway is largely dependent upon the crest shape, crest length, and the hydraulic head. The hydraulic head is modified by approach conditions, and/or abutment effects, and submergence. In the present GD-6 case hydraulic head is free of influences from upstream side, (except abutments' small effects).

The shape of the GD-6 uncontrolled weir crest profile depends upon the head, the inclination of the upstream face of the overflow section, and the height of the overflow section above the floor of the entrance channel (which influences the velocity of approach to the crest). The complete shape of the lower nappe, which is also the spillway crest surface, is described by separating it into two quadrants upstream and downstream from the high point (apex) of the lower nappe.

The weir crest is at elevation 585.0 masl and will be formed with a WES-type hydraulic designed profile with the formula

$$X^{1.85} = 2.0\, H_d^{\,0.85} \cdot Y$$

where H_d [m] is the design head and X and Y [m] are the horizontal and vertical co-ordinates originating from the weir crest point.

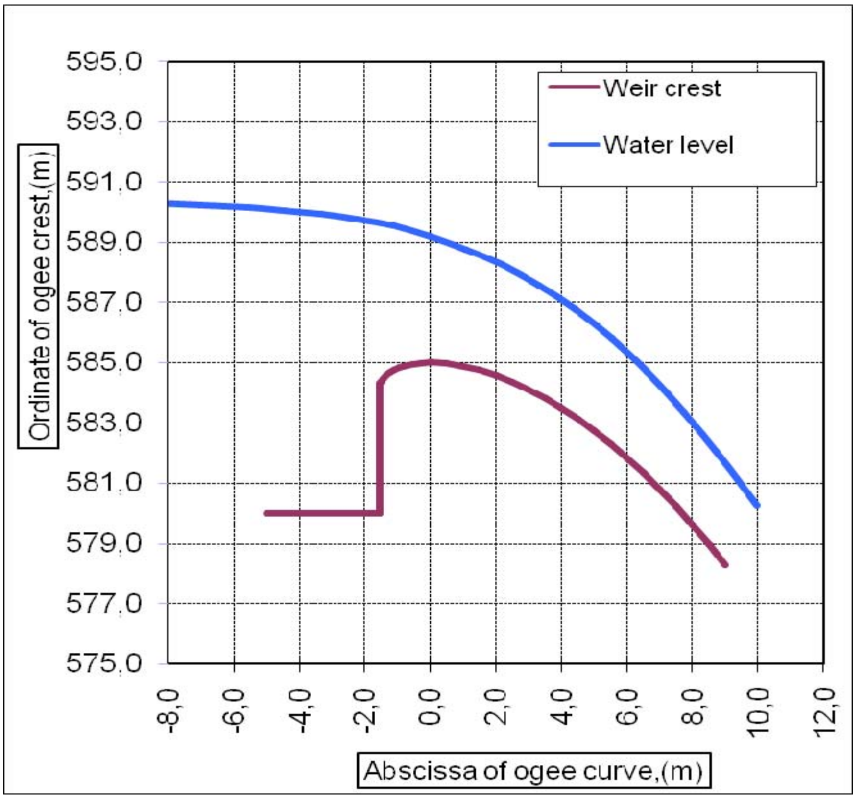

Figure 3-5: Weir Crest Profile and water surface at Probable Maximum Flood (PMF)

Side channel

The side channel spillway control weir is placed alongside and approximately parallel to the upper portion of the spillway discharge channel. Flow over the weir crest falls into a trough opposite the weir, turns approximately 90 degree left, and then continues into the main discharge channel.

In order not to make the channel flow turbulent and producing violent wave action with attendant vibrations and for having good hydraulic performance the flows in the trough is maintained at sub-critical stage. This has been achieved by establishing a control section (broad crested weir) downstream from the spill channel.

Because of turbulence and vibrations inherent in the planned side channel flow, the side channel requires a competent foundation such as rock. In this regard according to preliminary investigations, GD-6 dam site area has rock foundation up to elevations required for such structures, which make the selected type of spillway structurally feasible. The channel sides will be concrete lined and placed on a slope and anchored directly to the rock.

Side channel

Assumed a trapezoidal section side channel trough, with 0.5:1 side slopes and a bottom width of 10.0 m, at start (upstream of the channel) and 30.0 m at the end of the channel.

The side channel design is concerned only with the hydraulic action in the upstream reach of the discharge channel and is more or less independent of the details selected for the other spillway components. Computation of side channel trough has been done by trial-and-error computations.

According to the computations water surface elevation and channel's bottom elevations are 585.0 masl and 575.7 masl respectively.

Spill channel

Through the dam abutment and to the start point up to chute spillway (or stepped spillway) a spill channel structure must be constructed. The spill channel is always operated in sub-critical condition of flow. The following spill channel parameters are adopted:

- Rectangular section with variable widths,
- Bed slop i = 0.003,
- Length L = 165 m,
- Discharge Q = 2665 m3/sec.

Furthermore assumed, that a control section is placed downstream from the spill channel with its bottom 1.0 m above the elevation of the spill channel floor at the downstream end.

According to the design of the spill channel a broad crested weir at the end of the spill channel will have the following parameters:

- Weir crest elevation = 576.7 masl.
- Head over the weir, H = 6.6 m.
- Width of the weir, B = 3.70 m.

- Crest length of the weir, L = 50 m.

Chute

The flood from the spill channel will continue its flow through the chute. The flow condition will be super critical.

From the site topographical and geological conditions, and also from the above spill channel computation, the following chute parameters are determined:

- Trapezoidal section with width at bed = 30-50.
- Bed slop i1 = 0.136, and i2 = 0.320.
- Length L = 232 m.

The chute water surface profile computations gave the following results:

- Velocity at the end of the chute = 34 m/s,
- Water depth at the end of the chute = 2.5 m,
- Froude number Fr is varying from 10 to 40

The maximum velocity along the chute, which is at the end of the chute, 34 m/s is high. Danger of cavitations and hence treatment of the chute channel bottom and sidewalls from possible cavitations may be considered near to the chute end area.

Ski jump

At the end of the chute, a ski jump bucket structure is considered. This option of energy dissipation is the best option for such topography, as the Gd-6 chute terminal area topography.

When a free jet falls vertically into a pool in the Genale riverbed, a plunge pool will be scoured to a depth that is related to the discharge, the height of the fall, the depth of tail water and the bed material. The riverbed will be scoured because of the abrasive action of the water and sediment in the pool. Ultimately, the scour will reach a limiting depth as the energy of the jet is no longer able to remove bed material from the scour hole.

Data used and summary of the computations are presented in the following.

Table 3-5: Ski Jump hydraulic and expected scour sizes computations

Results		
Design discharge, Q	2 500	m^3/sec
Width of ski jump bucket, B	75.0	m
RW level upstream of control broad crested weir	580	masl
Bucket level	518.00	masl
River bed at tail water area	511.00	masl
Velocity at the bucket, V	34	m3/sec
Radius of ski jump bucket curvature, R	2.0	m
Angle, θ	45.0	degree
Length of flight, L,w.surf.	92	m
Expected scour depth below tail water,	33	m
Length of flight, L,deep point.	220	m
Length of scour at bottom	12	m
Length of scour at top	115	m

3.4.3 *Stepped spillway option*

The main function of drop structures is to convey water from a higher to a lower elevation and to dissipate excess energy resulting from this drop.

Baffled apron drops may be used for nearly any decrease in water surface elevation where the horizontal distance to accomplish the drops is relatively short. Velocity at steps should remain constant near to 2 to 3 m/s or somewhat higher.

The main purpose of this stepped spillway design are:

- Determine the number of steps and height of each step,
- Determine height of baffle sill and step horizontal length, which is enough for energy dissipation entirely in the step,
- Compute conditions by which energy dissipation at the end of the stepped spillway to natural river channel will be performed,

According to the computations, the use of a stepped spillway require very wide spillway steps, (about 500 m), which make the option technically not feasible.

3.4.4 *Spillway capacity*

The spillway capacity curve is illustrated in Figure 3-6 below.

The Genale GD-3 reservoir causes significant attenuation of floods. For an estimated PMF peak inflow of 3800 m3/s, the resulting peak outflow will be in the order of 1315 m3/s, resulting in a maximum flood at GD-6 of 2595 m^3/s (PMF worst case scenario with GD-3 reservoir).

The selected PMF is 2500 m^3/s.

A freeboard at PMF-flood of 1.0 m has been chosen for the dam.

The spillway capacity is calculated by the common formula:

$$Q = C * L * h^{1.5}$$

Where:

C= constant, reaching a maximum of 2.1

L= length of ogee crest, 100 m

h= overflow height

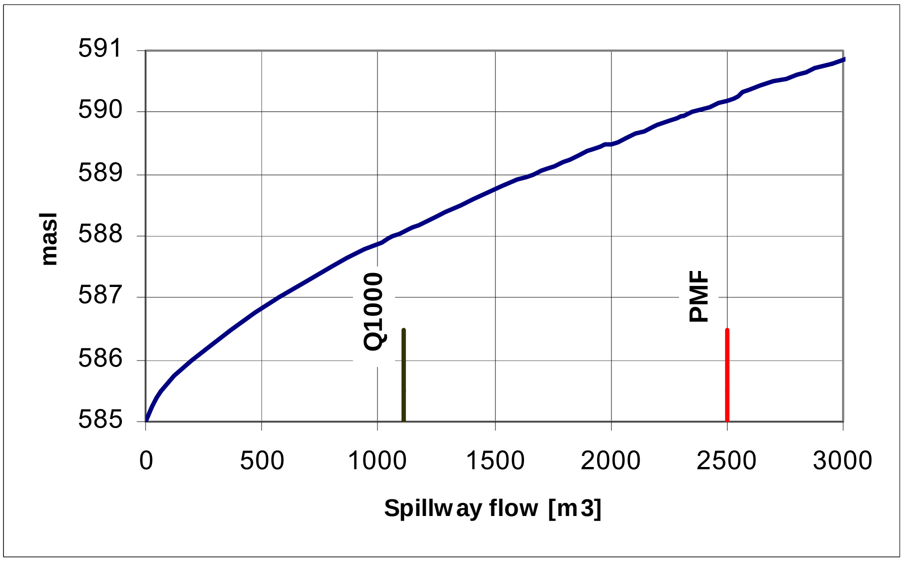

Figure 3-6: Capacity curve of Genale GD-6 spillway

Bypass for minimum release

A bypass for release of a minimum flow of 2.5 m^3/s has been arranged in the diversion culvert. The Consultant suggests installing a small hydro unit to generate power from the compensation water release downstream of the dam. The turbine will be a standard compact unit with horizontal shaft, with a load controller to ensure correct water release at all times.

Parallel to the turbine a redundant bypass system will be arranged to ensure compensation water release even if the generating unit is out of operation.

Project drawings B02 and B08 to B18

3.5 Genale GD-6 - Power waterways, powerhouse and associated structures

Project drawings B10 to B17

3.5.1 General layout

:

The power system of the Genale GD-6 scheme comprises the following main elements:

- power intake as a separate structure including intake roller gate and trash rack. The trash rack can be closed by stop logs.

  The power intake is located at coordinates

  Easting 647 270, North 593 710
- a headrace pressure tunnel with a length of 4 700 m, Circular with diameter 9 m, basically unlined
- a surge system, consisting of a 120 m vertical shaft and a 500 m long surge tunnel

  Located at coordinates: E 651 120, N 593 725
- a construction adit at the downstream end of the headrace tunnel
- two 40 m long penstocks to the turbines
- powerhouse complex including powerhouse cavern with two Francis turbines, draft tubes, draft tube gates, tailrace manifold, 4000 m^2 surge chamber, transformer cavern, access tunnel, cable tunnel, emergency exit tunnel, etc.

  Locate at coordinate: E 651 980, N 593 850 (c unit 2)
- an unlined tailrace pressure tunnel, 11.4 km long, Circular with diameter 9 m, basically unlined

- tailrace outlet with arrangement for installation of stop logs

  Locate at coordinate: E 663 270, N 596 300

The total length of the power waterway from the intake to the tailrace outlet, including the length of the pressure shaft, amounts to 16.1 km. The gross head gained by the diversion of Genale GD-6 amounts to 234 m, of which 60 m are gained by the Genale GD-6 dam.

The configuration of the headrace system is such that it can be emptied via the tailrace tunnel, while the tailrace must be pumped out, when emptying is required.

The major components of the Genale GD-6 power system are described in the following. Reference is made to 3.8 and 3.10 for the description of the mechanical and electrical components.

3.5.2 Power intake and headrace waterway

Project drawings B11 and B17

Intake

The intake with sill on elevation 566 masl is located in a cut on the right side of the river 900 m south of the dam. The intake trash rack (w x h = 10 x 12 m) is designed for partial obstruction. Stop logs can be set in front of the trash rack in the event of maintenance or repair works to be executed on the trash rack or intake gate.

The upstream of the intake cut is excavated deep, to allow for space for sediments to settle.

The trash rack cleaner will be installed on elevation 588.5, and run on rails embedded in a concrete slab.

Intake gates

The top of a vertical intake shaft is located on the platform at elevation 588.5. A roller gate with dimensions w x h = 5.5 x 8.2 m will be installed, with sill on elevation 565 masl. The gate will be designed to close under self-weight. Aeration tubes, filling bypasses and valves will be installed to create balanced water pressure after dewatering before re-opening of the gates.

Flushing device

A sediment flushing system by the intake, is not incorporated. The sediment study shows, that with the upstream GD-3 reservoir the intake will not be affected by sediments during normal lifetime.

The bottom outlet gate could be used for flushing by the dam site, but the necessity of flushing is expected to be limited.

Headrace tunnel

Downstream of the power intake gates, the headrace tunnel continues in slope 1:35.9 down to elevation 435 masl by the surge shaft, where slope is increased to approx 1:10 until it meets the combined construction adit and penstock chamber.

The headrace tunnel will be excavated from the adit by the powerhouse by full profile TBM (tunnel boring machine) dia. 9 m. According to the field investigations, the rock is of sound quality without major joints or fractures, and it is expected that the tunnel can remain basically unlined, apart from occasional shotcrete support. Its standard profile will then be circular with diameter 9 m, corresponding to a cross section of 63.6 m^2.

The velocity under full plant discharge (120 m^3/s) is thus 1.89 m/s.

Surge facility

Hydraulic calculations have shown that the headrace waterway of Genale GD-6 requires a surge facility to control hydraulic transients and pressure changes. The surge facility will include a 50 m^2 vertical shaft of 120 m length and a sloping 50 m^2 tunnel of 700 m total length. The adit portal will be at elevation 602 masl. (The basis for these data is given in the detailed hydraulic analyses in Volume 3, Annex 3 C).

Penstocks

From a chamber at the downstream end of the headrace tunnel, two penstock of 4.2 m diameter, lead to the turbine inlet valves. The length of the penstocks are about 40 m each.

Rock trap

A rock trap is arranged at the end of the headrace tunnel, on top of the penstocks.

Access to the rock trap is provided via an adit tunnel from the main access tunnel, closed by a high pressure bulkhead.

Headrace excavation

The headrace is planned to be drilled from the powerhouse end. The adit from the main access tunnel by the powerhouse is planned with a section suitable for transport of the TBM, and the cavern at the upstream end of the penstock should be large enough for erection of the TBM.

3.5.3 Powerhouse complex

Project drawings B12, to B16

The powerhouse cavern is on the right bank of the river in a ridge some 4.5 km downstream of the dam. The site offers good geological conditions (see Chapter 7).

Powerhouse

The powerhouse is designed to accommodate two turbine-generator sets. The main overall dimensions of the cavern are:

- length: 65 m
- width: 17 m
- height: 39 m (lowest point draft tube to cavern roof).

The turbine centre will be at el. 347.7 masl.

The vertical axis Francis turbines are embedded in reinforced concrete and the generators are supported on an octagonal reinforced concrete plinth and enclosed in a reinforced concrete air-housing.

The turbine inlet valves are located within the cavern on the upstream side of the dismantling joint. They are accessible by the main station crane via hatch openings in the floors above. The hydraulic forces on the closed inlet valves will be transmitted through the bifurcation and penstock to the surrounding concrete and rock. Concrete girders supporting the crane rails are anchored to the cavern wall at an early stage for use during construction. If necessary, the girders will be further supported by concrete columns.

The powerhouse will accommodate all required rooms for safe operation of the power plant. Electrical rooms are located on the generator floor at elevation 355.25. The turbine floor, el. 349.95, accommodates the turbine control cabinets and a mechanical workshop.

The control room, rescue room and wardrobes will be on the main floor, machine hall floor at el. 360.2. While some telecommunication, store room and ventilation will be placed above the control room.

Transformer cavern

The transformers will be installed in a separate underground cavern parallel to the powerhouse cavern 20 m further downstream. Main cavern dimensions will be l x w x h = 25 x 12 x 13 m, in order to accommodate 2 three phase main step-up transformers.

Each transformer will be located in its own pen, which will be designed to prevent fire to spread from one transformer to the other.

Each pen will be equipped with a high pressure water deluge system that would activate automatically in a fire event.

Two tunnels will be provided to take the isolated phase bus (IPB) ducts from the powerhouse to the transformer cavern. Each of these tunnels will serve to take the IPBs from one generator, i.e. 3 bus ducts will pass through each tunnel.

The floor in the transformer cavern will be on elevation 369.5 masl.

A tunnel branching off from the main access tunnel will provide access to the transformer cavern.

Cable tunnel

The high voltage cables from the transformers will be taken to the surface, elevation 490, via a separate tunnel and shaft, totally 560 m. The tunnel will serve as an emergency escape from the powerhouse and will also serve ventilation purposes. The cable tunnel will start from main access tunnel, and the cables are taken in a concrete culvert in the access tunnel to the transformer gallery.

Access tunnel

The access tunnel will be D-shaped, 7.5 x 7.5 m, with cross section about 50 m^2. It will be 1150 m long, and have a slope of approx. 1:10. The tunnel portal will be on elevation 475 masl. The access tunnel will be large enough to permit two-way traffic during construction and allow passage of the largest items of equipment that will be brought into the powerhouse area. The transport of the TBM is expected to be the largest items to be transported in the tunnel.

3.5.4 Tailrace waterway and outlet

Manifold and gates

Two concrete-lined draft tube tunnels convey the water from the draft tube outlets to the tailrace manifold. Each draft tube tunnel is equipped with a roller gate designed to close under self-weight. During normal plant operation each gate is located in its respective gate chamber (combined with transformer gallery) that also contains hoist and associated equipment for operating the gate. The gate slot is normally covered by a watertight lid that has to be removed before setting the gate. The gates make it possible to isolate each draft tube tunnel from the common tailrace tunnel, when access to the turbines is necessary for maintenance and repair, without interrupting the operation of the other unit.

Tailrace surge facility

A major surge chamber is required at the tailrace. The hydraulic analyses (see Volume 3, Annex 3 C) conclude on a surge “shaft” of 4000 m^2. For that purpose the tailrace tunnel will be widened over a distance of 330 m, having the overall dimensions, 12 m wide and 32 m high. This will create a surge facility for safe operation at all Tail water levels.

Tailrace tunnel

The tailrace tunnel will convey the water from the powerhouse back to Genale River. It will have a total length of 11.3 km in addition to the surge tunnel. The tunnel will be excavated by TBM technique similar to the headrace, it is expected that also the tailrace tunnel can be basically unlined, apart from occasional shotcrete support. Its standard profile will be circular with diameter 9 m. Velocity under full plant discharge (120 m^3/s) is 1.89 m/s.

Excavation of the tailrace tunnel is planned to be performed by the same TBM, that first completes the headrace tunnel, and afterwards mobilised to the tailrace by the surge chamber. From here it drills almost horizontal down to the tailrace outlet. In case of unforeseen drilling challenges affecting the overall progress of the construction works, it will be possible to start excavation of the tailrace by drill and blast (D&B) from the tailrace outlet. The tunnel should then be a D-shape tunnel with cross section 90 m^2. The tunnel will then have a cross section sufficient for transporting the TBM out through the tunnel.

Tailrace outlet

The tailrace outlet sill is set on elevation 346.0 masl. On elevation 356.5 masl a platform is provided with road access and a structure that facilitates closure of the tailrace tunnel by Stop logs. The Stop logs can be set and removed under balanced pressure conditions by a mobile crane when dewatering and inspection of the tunnel is necessary. Upstream of the outlet structure, space for demobilising the TBM is planned.

Dewatering the tailrace, when and if required, must be by pumping at the tailrace outlet.

3.6 Genale GD-6 - River diversion during construction

Project drawing B06

General

Design of river diversion structures at GD-6 will depend on the staging of the GD-6 and GD-3 projects. If GD-6 implementation starts after commissioning of the GD-3 project, the river flow is regulated, and design floods for the diversion is drastically reduced. The Consultant has in the design of the diversion structures assumed that construction of the DG-6 dam starts before the completion of GD-3, and hence a design flood of 1300 m^3/s (approx. 25-year) is used.

If GD-6 dam construction starts after GD-3 is commissioned the design flood for the diversion will be in the range of 500 m^3/s, reducing the costs of the diversion by more than 2 mill. USD.

Options

Based on GD-6 dam site area topography and geological conditions, different river diversion alternatives have been investigated. For the different alternatives of rock-fill dam option two alternatives are studied in detail (diversion through tunnel and diversion through concrete conduits under the dam body). If an RCC dam will be the final option, concrete culverts through the dam body will be the selected option.

Tunnels

The tunnels are planned to be at the right bank of the river. This diversion option would include an approach channel, 400 m tunnel(s), upstream cofferdam and downstream cofferdam.

During optimization, attention has been given to different tunnel diameters and to different number of tunnels. Based on this computed required upstream cofferdam height final total costs of all tunnels and cofferdams are computed and the most economical combination of tunnel diameter, tunnel number and cofferdam height selected

According to the detailed optimization results, the minimum total cost is for the following combinations:

- For 1 tunnels with diameter 14.0 m and cofferdam height 15.00 m.
- For 2 tunnels with diameter 10.0 m and cofferdam height 14.40 m.
- For 2 tunnels with diameter 11.0 m and cofferdam height 12.00 m.
- For 3 tunnels with diameter 9.0 m and cofferdam height 11.20 m.

It can be seen that major tunnelling works are required to divert floods during construction. The calculated cost for optimisation purposes is 16-17 mill. USD.

Culverts

The concrete conduits (culverts) are also planned to be at the right bank of the river. This diversion option would include an approach channel, 230 m long concrete conduit(s), phase 1 cofferdam and phase 2 cofferdams. During phase 1 construction will required only one continues cofferdam, at phase 2, two cofferdams are required: one upstream and one downstream.

During optimization, different conduit sizes and different number of openings has been studied. Based on this study, the upstream cofferdam height required for phase 2 has been decided. Finally total costs of all conduits and cofferdams are computed and the most economical combination of single conduit section area, conduit number and cofferdam height has been selected.

According to the detailed optimization, the minimum total cost has been found for the following combinations:

- For 3 openings with cross section area of each 44.25m^2 and phase 2 upstream cofferdam height 14.25m.
- For 3 openings with cross section area of each 38.00 m^2 and phase 2 upstream cofferdam height 16.30 m.
- For 4 openings with cross section area of each 38.00 m^2 and phase 2 upstream cofferdam height 10.70 m.

The total cost is calculated to be in the range of 12-14 mill USD for the options.

Conclusion

The selected diversion concept is 3 concrete conduits of 42.5 m2 (6.5 x 6.5 m). One will be closed after the construction period, the second will be used to divert compensation flow of 2.5 m^3/s, and in the third a bottom outlet gate will be installed.

3.7 Genale GD-6 - Access roads and camps

Project drawings G01 to G12
See also Annex 3D for detailed description of access roads.

3.7.1 *Access roads*

Aims of the road investigation

For the feasibility study of the Genale GD6 hydropower project the access roads have been studied for the purpose of:

- Identifying the most feasible access routes into the various hydropower sites.
- Carrying out the preliminary design plan and profile drawings of all weather access roads and roads required for the construction, operation and maintenance of the hydropower project.
- Producing basic quantities for road construction and drainage for costing purposes.

The preliminary design outputs include drawings, a textural description and quantity calculations.

Project appreciation

From 4 - 7 July, 2007, the site was visited by the project road engineer. The purpose of the visit was to gain first hand information of the site conditions and to note any particular constraints or advantages facing the provision of access roads. The visit was done by 4WD vehicle and on 7 July, aerial reconnaissance was done from helicopter. Much of the alignment along the Genale was also covered on foot.

Hydrological and hydraulic investigations

Selective hydrological investigations have been carried out to assess the run offs at critical points on the proposed road alignments and to estimate what type of drainage structures will be required. The Rational method of estimating run-off has been used for catchments under 0.5 km2 and the HEC-HMS using Clarks Hydrograph system has been used for larger catchments.

Peak discharge 50 year return period was up to 390 m3/s for the Buti valley where it enters Genale River although, predominantly, this area is arid. Our investigations showed that despite being a very arid area with infrequent rainfall, precipitation when it does come is often in the form of intense storms. These storms produce significant quantities of rain and can result in sudden dramatic water flows. The run-off can be substantial, fast flowing and destructive in nature. The design life of the hydro scheme is some 50 years and we can expect the road to be affected by several such floods during it's serviceable life. The Consultant has considered the flooding issue during the preliminary design and have tailored our approach with this in mind especially with regard to the following points:

- Any road crossing of the Koro or Buti valleys will require substantial bridges to accommodate the design flood levels. This will significantly increase the construction costs. The Consultant therefore has positioned the main access road exclusively on the west side of the Buti alley to avoid providing such crossing structures.

- Given the overall low frequency of rainfall, it should be acceptable to build selective drainage structures, which will be allowed to overtop e.g. perforated drifts. This will imply it may not be possible to pass certain points for short periods during intense flooding.

- Roads following water courses should be placed above the estimated flood level

The estimated number and type of drainage structures is presented in the table below:

Table 3-6: Estimate of drainage structures

Pipe culvert Ø=0.9m		**Slab Culverts**		**Bridges**
No	Length(m)	No.	Length(m)	No.
320	2486	67	167	1

<u>Materials investigations</u>

A geotechnical investigation has been conducted along the access route to the Genale GD-6 Hydro-power project area. The investigation was carried out to determine the local soil and rock types and the potential for building materials and ground conditions affecting the access roads. The field work was conducted from 13 November 2008 up to 20 November 2008 and the main conclusions are presented below.

Construction materials potential along the access route can be grouped as rock quarry, borrow, sand and water. Accordingly sufficient quantity of limestone and granitic gneiss for rocks are found along the route corridor. Similarly sufficient quantity of fine to coarse soil for borrow material can be found from low lying flat to undulating topography and Buti stream courses. Sand in patches is found especially along the banks of Genale. Water can be obtained from Genale River. Sub grade soils appeared stable and no occurrence of soft foundation soils was observed.

Design approach and methodology

Roads will be required both for the construction of the Genale GD6 project and later for the operational phase. These roads will be of various standards based on if they are temporary or permanent and if they will be heavily or lightly trafficked. The permanent roads should be built as all weather roads, as such they must be provided either with adequate drainage structures to safely pass all floodwaters or with structures, which will allow overtopping and have restricted access. For economical and environmental reasons, the roads having only light traffic can be built as single lane roads provided passing lay-bys are provided at intervisible intervals. All roads will be built to gravel standard only and maintained during the service life of the hydroelectric plant.

The preliminary design of the access roads aims to provide suitable assess to the various hydropower elements comprising; powerhouse, dam, tailrace, camps, quarries, crushers, site camps, adits etc. Several sources of information have been utilised to define the access routes:

- 1:50,000 topographic maps
- Overlapping aerial photographs from 1991
- The project specific mapping at 1:10,000 with 5m contours
- GPS measurements of the existing tracks and paths

The Consultant has used the Novapoint road design program to design the alignments. This program is based on AutoCAD as a platform and contains comprehensive highway design routines to produce the various outputs. The project drawings: key plan, typical cross section and plan and profile drawings G01 to G12, indicate the roads sections and the type of roads.

Geometric design standards

In the design of the road the Consultant has sought to minimise constructions costs and adverse environmental effects due to terrain intrusion while at the same time providing appropriate geometric standards for the transportation of the relevant project components. The roads are not intended to form a part of the public road network where higher design speed, aesthetics and geometrical standards are of higher priority. The roads have been designed as all weather gravel roads. The Consultant has selected a geometric design standard consistent with other projects of similar nature. These standards are illustrated on the standard cross section drawing G02 and given in the table below:

Table 3-7: Geometric Standards for the project roads.

Parameter	Road Type	
	Permanent	Temporary
Design Speed – km/h	30	25
Minimum Hz Radius - m	25	18
Minumun Hz Radius – m Hairpin bends	15	12.5
Maximum Vertical Gradient - %	10	12
Maximum gradient through hairpins - %	5	5
Standard Crossfall - %	5	5
Maximum Superelevation - %	7	7
Number of Lanes[1]	1 – 2	1 – 2
Lane Width – m	3,5	3,0
Curve Widening - m	3,5	3,0
Widening for provision of guardrail - m	0,5	0,5
Type of Wearing Surface	Gravel	Gravel
Drainage features return flood design period Bridges Slab culverts Pipe culverts	50 25 5	25 10 5

Description of the road sections

The following table summarises all the designed road sections and lengths, they are described in more detail in annex 3D. Note that the access roads to the adits will not be required should the project tunnelling be carried out by TBM.

[1] For single lane roads, intervisible passing lay-bys shall be provided

Table 3-8: Design Road section and Lengths

Road Number	Description	Length	Notes
10,000	Main access road to Powerhouse from public highway	29+458	Permanent road, single lane up to Km 26+600, thereafter double
20,000	Access to upper dam and inlet	7+230	Permanent, double road
21,000	Access to camp	1+966	Permanent, double road
22,000	Access to lower dam, quarries and crushers	2+966	Temporary, double road
23,000	Upper access to dam, quarries and crushers	0+441	Temporary, double road
24,000	Access to adit on head-race tunnel	1+066	Temporary, double road
30,000	Access to tailrace	16+715	Permanent single lane road, restricted access
31,000	Access up Kebyeya Val-ley to camp, workshop and dumps	1+712	Temporary, double road
32,000	Access to tailrace adit 1	0+547	Temporary, double road
33,000	Access to tailrace adit 2	0+783	Temporary, double road
Total		**62+885**	

3.7.2 Camps

An area has been designated for the main camp and appears on road drawing G07. The site is on an elevated plateau some 140 m above the Genale River. The camp will be accessed via road 21,000 and will be built to permanent, double lane standard. The camp will be approximately 6 kilometres by road from both the powerhouse and the dam site. This site can be used both for the temporary camp during the construction period and for the permanent camp during the operational period.

The administrative camp is proposed to be located near the switch-yard and the portal to the power station.

A main construction camp will be required and several temporary camps which can be moved as work progresses.

Separate camps will be required at the different construction sites and for the road construction, which will be located and established by the road contractor.

Basic requirements for housing are shown in Table 3-9: and for administration and various facilities in Table 3-10.

Table 3-9: Housing requirements

Description	Housing			Housing area (m2)	
	No. of families	Families pr. block	No of blocks	One block	All blocks
Management Staff	2	1	2	150	300
High-level staff	15	1	15	100	1 500
Middle-level staff	20	2	10	80	800
Lower-level staff	30	2	15	60	900
Guards	40	2	20	60	1 200
Total	107		63		4 700

Table 3-10: Plant administration and various facilities

Item	List of rooms	Quantity	Area & Remarks
1	Offices	15	230 m^2
2	Meeting Room	1	100 m^2
3	Store & storeman office	1	200 m^2
4	Archives	1	100 m^2
5	Conference Hall of 100 seats	1	180 m^2
6	Library	1	40 m^2
7	Wearing Rooms (for male & female)	2	60 m^2
8	Misc		50 m^2
Total area of the three floors			960 m^2

Reference is made to Annex 3D for more detailed descriptions

Power supply

Construction power will be supplied from the main grid through a double circuit 33 kV transmission line to be constructed from the 66/33 kV substation at Negele.

Waste management

Waste is handled according to its nature and potential negative impacts. Therefore, all waste generated by the camp will be classified in order to be handled correctly. Detailed classification of wastes, methods of treatment and disposal of each type should be studied and arrangements be made during final design work.

Telecommunications and information technology

Good communications are essential for plant of this nature. A reliable telecommunication system is required for proper operation of the plants.

Costing

This work will adopt the standards of Ethiopian Electric Power Corporation (EEPCo) for camp facility requirements. From practical experience on recent hydropower projects, about USD 10 million can be allocated for camp construction for both categories (i.e. for the construction period as well as for operational phases).

3.8 Genale GD-6 - Mechanical equipment

Project drawings B11 to B17

3.8.1 General

The hydro-mechanical equipment will consist of two main packages:

Mechanical Equipment, comprising:

- Turbines with inlet valves and governors
- Compensation water turbine with valves and controls
- Powerhouse cranes
- Cooling and dewatering systems
- Auxiliary equipment
- Ventilation (HVAC)

Hydraulic Steelworks, comprising:

- Intake with necessary gate and equipment
- Dam bottom outlet gate with stop logs
- Adit gates for headrace tunnel
- Penstocks
- Draft tube gates and tailrace stop logs

3.8.2 Turbine selection

Turbine type

Based on the design head and turbine flow, vertical Francis turbines represent the only practical solution.

Number of units

The Consultant has made generation calculations based on the plant's flow duration curve to evaluate the installation of two or three units in Genale GD6 power plant. The costs increase as number of units increase, but at the same time the generation may increase enough to make a larger number of units the optimum cost/benefit solution.

In the case of Genale GD6, the flow duration curve does not favour the use of three units relative to two. The increase in generation is calculated to be only 2GWh. This additional generation does not justify the increased cost of three units.

The reason for this can be seen from the efficiency curves, (see Figure 3-7 below) showing the difference in efficiency at various flows for the two alternatives:

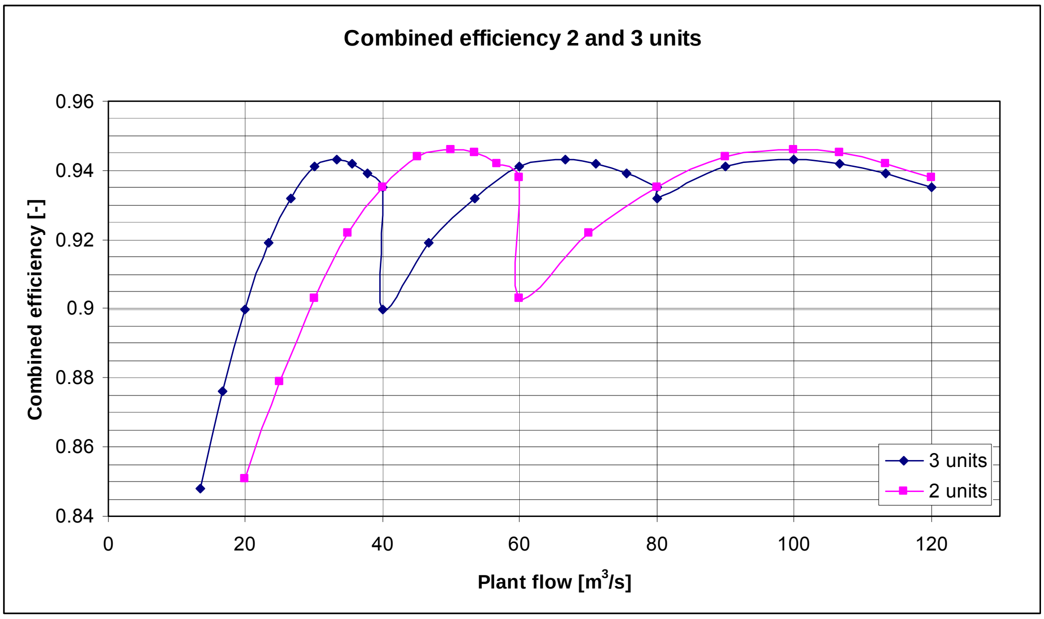

Figure 3-7: Efficiency curves showing the difference in efficiency at various flows for the two alternatives

Flows between 40 and 58 m^3/s favours 2 units and flows from 60 to 80 m^3/s favours 3 units.

A Francis turbine with the considered characteristics will normally have a lower load limit for continuous operation of approximately 40% of its maximum load. This means that the station will be able to operate continuously from around 50 MW (minimum load for one unit) to 250.8 MW (maximum load for two units). The combined efficiency curve for the station will have two maximums, for one and two units in operation, as shown in the figure above. Temporary operation below the "minimum" load will be possible, but should normally be avoided due to the drop in efficiency. The size of the intake reservoir (34 million m^3) combined with the planned release pattern from Genale GD3 implies that the "minimum" load restriction has no practical impact on operation.

Operation pattern

In the long term, the operation of Genale GD-6 must be optimised in relation with the operation of its reservoir, taking also into account the operation of Genale GD-3 station, upstream of Genale GD-6.

Genale GD6 will operate on the water release from Genale GD-3 with some additional inflow. The normal mode of operation will be water level control, but the 5 meter possible drawdown allows for daily peaking operation in periods with low inflow: Up to 160 hours of operation of 1 unit at full load or 80 hours of operation of 2 units at full load.

3.8.3 Main turbine data

Design head

The level in the intake reservoir will vary between 585.0 masl at Full Storage Level (FSL) and 580.0 masl at Minumum Operation Level (MOL). Genale GD6 will operate to supply firm energy most of the time with some peaking operation and full load operation during high flow seasons. The FSL will therefore be the basis for the turbine net design head. This level together with a Tail water of 351 and the Head loss corresponding to two units in operation (6.0 m) are used to define the design head for the turbine:

Net Desing Head = 585 -351 –6 = 228 m

The rating curves for Tail water and headwater shows an increase to +6 and +5 meters respectively when reaching PMF. This will not impact the decision on turbine net design head, as flood situations will occur seldom with GD3 in operation upstream.

Rotational speed

One main choice in determining the turbine data is the rotational speed. A higher speed means smaller dimensions for the turbine and a lower price, but it also requires a larger submergence. Higher speed will also give a more "pointly" efficiency curve, less flexible turbine, and thereby reduce total generation. The generator price will also be reduced with a higher speed. Optimisation calculations carried out have lead to the choice of a rotational speed of 300 rpm, and a moderate submergence. The turbine distributor centreline will be approximately 3.3 m below the minimum water level corresponding to one unit in operation. The discharge for best efficiency will be approximately 80 to 85% of the full-load discharge.

The submergence requirement as well as the position of the point of best efficiency depend on the specific turbine design and will vary slightly between different suppliers.

The main turbine data are summarised in Table 3-11 below.

Table 3-11: Main turbine data - Genale GD-6

Main Data	
Arrangement:	Vertical
Turbine net design head:	228 m
Turbine power at net design head:	125.4 MW
Turbine flow at net design head:	60 m^3/s
Max. head:	232.5 m
Turbine power at max. head	129.1 MW
Turbine flow at max. head	60.6 m^3/s
Turbine speed:	300 rpm
Runaway speed, max. head (approx.):	490 rpm
Turbine runner centre:	el.347.7
Spiral casing centreline submergence:	3.3 m
Approximate Data	
Runner outlet diameter:	2500 mm
Turbine cover diameter:	4400 mm

3.8.4 Turbine design

Sediments

Earlier studies indicate that the sediment load in the Genale River is approximately 1 mill tons annually. Sediment composition and particle distribution 13% sand, 32% silt and 55% clay[2]. The remaining 10% is bed load. The size of the intake reservoir (close to 34 million m^3) and the GD-3 reservoir, makes it reasonable to assume that most abrasive sediments will be deposited in the reservoir, and that sand erosion on the turbine will be a minor problem. The intake is also located high in the reservoir as the useable drawdown is only 5 meters.

Materials

The steel structures of the main turbine parts such as spiral casing, covers, stay ring and draft tube, will be made from fine grained carbon steel according to approved standards. Stainless steel will be used for runner, guide vanes, and waterway surfaces, such as upper and lower cover and also the upper part of the draft tube. Guide vanes and all moving parts of the operating mechanism will have self-lubricating, long life bushings. All non-mating ferrous surfaces will be coated with two-component epoxy paint.

Shaft seal

The turbine shaft seal represents a particularly important aspect of the design. Experience shows that failure of this element can reduce the reliability and the availability of the units. Different type of designs (based on sealing rings or based on a “contact free” solution) can work, but it is essential that the supplier has a good experience record of the specific design. If the design requires a separate sealing water supply of it is very important that a proper filtration system is used.

Runner dismantling

To avoid removing the generator rotor during runner replacement, as well as change or repairs of labyrinth seal rings, the design will allow the turbine runner to be dismantled downwards after having removed the draft tube cone and the lower cover through a recess in the turbine foundation. Runners and other turbine parts to be replaced or repaired can be hoisted to the machine hall floor through hatches in the powerhouse floors.

3.8.5 Main inlet valves

Type of valve

The main inlet valves represent an important element for the reliability of operation of the plant: they are the first means of closure of the waterway, and a failure occurring on a valve may require the waterway to be emptied, which means total loss of generation for a period.

With the given head, two types of valves can be considered:

- Butterfly valves
- Spherical valves

The spherical valves have no obstruction in the waterway (no head loss) and will be given the same diameter as the spiral casing inlet. Its disadvantage is that it is a comparatively heavy and expensive component.

[2] Report # GDMP-P2D.II-E.I March 2006

The closing body (disc) in a butterfly valve represents an obstruction in the waterway causing a head loss. The diameter should be larger than for a spherical valve in order to reduce the loss. In addition, the maximum gross velocity should not exceed 7 m/s as a rule, and sometimes as low as 6 m/s to avoid vibration problems in the closing body. The price for a butterfly valve would still be lower than that of a spherical valve.

Optimisations carried out on a number of projects show that butterfly valves give an altogether better economy for lower heads, and spherical valves for higher heads, the break point being around 200 m head. Genale GD6 has 228 meters net design head, and the optimisation performed favours spherical valves. Another advantage of the spherical valve is that it is easier to arrange revision seal than for a butterfly valve.

Operating system

Counterweight closing, with a hydraulic cylinder for opening gives a very high reliability. Formerly this has been used mostly for small to medium size valves, but its use is extending gradually also to large size valves. Although it may represent an unusual solution for the size of the valves considered here, it presents no technical difficulties. The station layout has to accommodate counterweight arms.

A system based on a double acting hydraulic cylinder for opening / closing together with an accumulator is also a possibility, but its safety of operation will never be able to match that of a counterweight based system, even if redundant systems are used for the accumulator.

The valve will include a by-pass system permitting to operate the valve at equalised pressures during normal operation conditions. The service seal and the revision seal may be either metallic or rubber type.

Weight

The spherical valves will have a diameter around 2 500 mm (exact dimension will be given by the turbine spiral case inlet diameter of the individual manufacturer). Preliminary estimations indicate an erection weight in the range of 160 tons for the spherical valve. The valve can be brought to the station in separate pieces, thus reducing significantly the transport weight.

Main data

The main data for the main inlet valves are summarised in Table 3-12 below:

Table 3-12: Main data for inlet valves - Genale GD-6

Main Data	
Valve type:	Spherical valve
Design head (incl. pressure rise):	30 bar
Approximate diameter:	2 500 mm
Water velocity	10 m/s
Sealing system, main seal:	Rubber / stainless steel
Sealing system, revision seal:	Rubber / stainless steel
Expansion box location:	Downstream
Operating system:	Oil hydr. - counterweight
Erection weight:	Approx. 160 tons

3.8.6 Governors and oil pressure system

The governors are conventional electro-hydraulic governors, permitting all normal operation modes. The oil pressure system includes nitrogen type accumulators giving necessary safety to shut down the units in an emergency condition.

At feasibility level no particular choices have to be considered concerning the governors and oil pressure systems, but we foresee a high pressure hydraulic unit to be utilized, allowing the use of smaller components such as servo valves and servomotors. This will also facilitate the use of industrial standard hydraulic components, and improve spare parts availability

3.8.7 Stability and surges

Design conforms to the transient analyses of waterways described in Volume 3 Annex 3C.

3.8.8 Machine hall crane

The powerhouse crane will be a bridge crane with a main hoist, which will serve any requirements for lifting and moving of heavy components during installation, maintenance work and operation. In addition, the crane will be provided with an auxiliary hoist travelling under one of the crane girders. This will increase the crane operation area and offer quicker operation for smaller components.

The generator rotors will be the heaviest components, and will be dimensioning for the crane. The necessary capacity is estimated to 290 tons.

A solution with two cranes used in tandem with a yoke for the heaviest lift has also been considered. This has the advantage of more flexibility and can permit parallel work on the two units. This solution is often chosen for stations including several units. For only two units, the advantage remains marginal and it is doubtful whether the extra flexibility can compensate for a higher price. A solution with one crane was retained.

The main crane hook will be capable of lifting the tallest component off the transporting vehicle and both main and auxiliary hooks will reach as far down as required to serve the turbine cellar.

The crane will have a radio control allowing operation from any part of the powerhouse.

Table 3-13: Main data for machine hall crane - Genale GD-6

Main Data	
Main hoist capacity, approximate:	290 t
Auxiliary hoist capacity:	20 t
Bridge span, distance between rails (approx):	16.5 m
Crane travel:	62m
Hoisting height (approx):	25 m
Highest hook position above machine hall floor:	9 m

3.8.9 Cooling water system

The solutions used for cooling water systems vary widely, due to the differences in water quality, but also as a result of differences of habits and traditions. The adequacy of the solutions chosen for the cooling water system can have a large influence on operation. Problems with the filtration as well as organic growth in piping and coolers are the main difficulties that may arise in relation to the cooling water system.

The design requirements are numerous and may to a certain point be contradictory:

- Simplicity
- Sufficient redundancy
- Limit the number of elements for which maintenance works will impose to shut down the whole station
- Cooling water requirements during shut-down of the units in case of loss of power

<u>Considered solution</u>

The system considered at this stage is relatively traditional. It includes mainly:

Water supply

Water pumped from the Tail water or supplied from the turbine labyrinth seals, or a combination of both.

The solution of using the turbine labyrinth seal water is attractive as it supplies water “for free”, with an adequate pressure and filtrated through the turbine labyrinth seals. This solution is, however, not offered by all turbine suppliers.

The alternative to labyrinth seal water is to pump the water from the Tail water. For the head considered, taking the water from the pressure shaft is not an economic solution as its pressure exceeds by far what is necessary for cooling purposes. Also, pressure reducing valves are often causing operational problems.

Cooling water tank — All water will be lead to the cooling water tank. The tank has a double function of sedimentation basin and of cooling water reserve for the bearings for stop of the units in case loss of power. The tank includes two parallel compartments permitting removal of sediments in one while continuing operation in the other one.

Filter system — From the tank, the water goes through an automatic filter with mesh size around 1 mm. A manual filter permits to by-pass the automatic filter if required.

Water to consumers — After the filters, water is distributed by gravity to the different consumers, i.e. the generator air coolers, the turbine and generator bearing coolers, the turbine governor cooler, the transformer coolers and the ventilation coolers. Total cooling water quantity is in the range of 76 l/s for each unit and 25 l/s for each transformers and 18 l/s for ventilation, giving a total capacity close to 220 l/s. From the coolers, water is lead back to the Tail water.

Alternative solution

Alternatively, a two stage cooling water system may be considered: a primary system using raw river water for cooling of heat exchangers (water supply as described above), and a closed secondary circuit solution with circulation pumps for circulating the water between the heat exchangers and the different coolers. It is important to choose heat exchangers that are easy to clean, also during operation. The system is, however, expensive due to the additional heat exchangers, and will also increase the amount of cooling water needed due to the reduced temperature differences. The circulating cooling water can be treated to avoid organic growth and calcium deposits.

3.8.10 Drainage and dewatering systems

Separate systems are foreseen for drainage of the different floors of the power station, and for dewatering of the units and of the lower part of the pressure shaft.

Drainage system

Seepage from the rock and other leakages from the different floors of the power station will be lead to the drainage pit located between the draft tubes of the two units. From the drainage pit, three electric submersible pumps, each with a capacity around 20 l/s will be used to pump up the water to the tailrace tunnel, downstream of the draft tube gates.

The drainage system will also include an emergency ejector pump that will operate independent of all electrical systems, being activated by the rising water level in the drainage pit. The capacity foreseen for the ejector is 60 l/s. Alternatively a diesel generated pump may be installed in place of the ejector pump.

Dewatering system

One solution for dewatering the turbines is to empty the water from the draft tubes into the drainage pit, which is then emptied by the normal drainage pumps. Such a procedure represents, however, always a risk of flooding of the station in case of wrong operation.

A separate closed dewatering system taking the water from the draft tubes and discharging it in the tailrace tunnel is therefore considered. The system will also be used for dewatering the last portion of the penstocks during emptying of headrace tunnel. The system will include two pumps with a capacity determined to give a reasonable time for dewatering of the turbines and of the lower part of the pressure shaft. A capacity around 20 l/s per pump should be realistic. From the lowest point of each spiral casing, a small drainage pipe with valve will lead the remaining water to the power station drainage sump.

3.8.11 Ventilation and air conditioning

Reference is made to Section 3.11.

3.8.12 Workshop

The station will include a small workshop with hand tools and small machine tools (as a drilling column). A compressed air system for operation tools and oil treatment equipment will also be included.

3.8.13 Intake equipment

Basic data

The intake equipment including thrash rack, intake gate and related equipment has to be placed such that at a safe submergence of the intake in order to guarantee that no air will be drawn into the headrace tunnel when operating at lowest regulated level (elevation 580).

In addition to the equipment related to the intake itself, a combined bottom outlet and sediment flushing gate is located in one of the bypass conduits under through the dam, used during construction.

Guides for revision stop logs at intake

A set of stop logs are considered in front of the trash rack, with a width and height slightly larger than those of the trash racks. The stop logs would have following main data:

Table 3-14: Data for revision stop logs - Genale GD-6 intake

Main Data	
Number of revision stop logs:*)	1
Sealing system, elements:	Rubber seal
Sill level:	el.567.2
Top level guides:	el. 580
Height of gate	20 000 mm
Width of gate:	10 000 mm
Pressure at sill:	2.2 bar

*) comprises 5 elements H x W = 10 x 4 m

The intake may also be made available in the dry season by opening the bottom outlet gate.

Trash racks

The trash racks have the following main data:

Table 3-15: Data for trashrack - Genale GD-6 intake

Main Data	
Number of trash racks:	1
Free opening between bars:	80 mm
Trash rack inclination:	10^{o}
Sill level:	el.567.8
Height (free opening):	12 000 mm
Width:	10 000 mm
Design net water velocity, approx:	1.0 m/s
Design pressure for clogged rack:	1 bar

The minimum free opening between the bars should correspond to the minimum outlet opening in the turbine runner.

In addition to the top and bottom sill, horizontal supporting beams will support the trash rack panels.

The bar thickness and distance between stiffeners will be given an ample safety factor against vibration damages. The racks will be designed for clogging resulting in 10 mWC differential pressure.. The trash racks will be divided into panels, which can easily be dismantled separately.

Trash rack cleaner

A sturdy trash rack cleaner will be included, permitting to clean the rack with an acceptable efficiency. Main data is given in Table 3-16 below.

Table 3-16: Data for trash rack cleaner - Genale GD-6

Main Data	
Lowest rake position:	el.567.8
Inclination:	10°
Rake "pay load":	3 t
Length of rails:	12 m

Intake roller gate

The intake will be equipped with an intake roller gate. The gate will be self closing by gravity, able to close against the maximum possible flow. Opening will be by a hydraulic cylinder.

The gates have following main data:

Table 3-17: Data for intake gates - Genale GD-6

Main Data	
Number of gates:	1
Type of gate:	Roller gate
Sealing system:	Rubber seals
Gate inclination:	Vertical
Sill level:	el.567.8
Net height:	8.2 mm
Net width:	5.5 mm
Design pressure at sill:	2.3 bar
Type of hoist:	Single acting hydraulic cylinders
Manoeuvre level	589 masl

The hydraulic cylinder, the oil pressure unit and the controls will be located in the gate house at top of the intake shaft.

Diversion Stop logs

The intake dam has an arrangement for diversion during construction, comprising upstream and downstream cofferdams and 3 diversion culverts. The intake of the diversion culverts is equipped with guide for stop logs, to be set when the diversion tunnel is to be permanently closed by a concrete plug.

Table 3-18: Data for diversion stop logs - Genale GD-6

Main data	
Number of stop logs	3
Inclination	vertical
Sill level	523 masl
Stop log height	6 500 mm
Net width	6250 mm

Surface gates

At this stage, no surface flushing gates have been included. Such gates may be included in a later stage if it would appear that floating debris can represent a problem.

3.8.14 Headrace tunnel equipment

Adit bulkhead

An adit bulkhead will be provided in the small stone-trap upstream of the penstock inlet. It will permit access for smaller tractors or more specialised mining equipment into the tunnel. It will be built as a hinged door.

The adit bulkhead will have following main data:

Table 3-19: Data for adit bulkhead -Genale GD-6

Main Data	
Type of adit gate:	Hinged steel door
Sealing system:	Rubber seal
Sill, approx. level:	355 masl
Design pressure (approximate):	270 m
Free adit height:	2.5 m
Free adit width:	2.5 m
Steel lining length (total upstream/downstream):	5 m

Stone rack

To prevent rocks entering the penstock a stone trap will be established immediately upstream of the penstock inlets. The stone trap will be accessible through the adit gate after emptying of the headrace tunnel.

Penstock steel lining

Two parallel penstock steel linings with lengths approximately 50 m will lead the water from the tunnel to each turbine.

A preliminary optimisation of diameter and thickness has been performed. Fine-grained steel with yield strength of 355 MPa has been assumed at this stage. This is a relative conservative steel quality. A general advantage of using low steel grades (that require a larger thickness) is that they can allow more deformation in an extreme situation, thus giving an increased safety compared to a high-grade steel which will be more brittle. Use of a higher grade steel will normally reduce the costs and may be considered as a later stage.

Full external pressure has been assumed in the calculations, which is a conservative assumption. However, with the head and diameters considered, the thickness requirements due to external pressure are practically matching those due to internal pressure, and are not representing a supplementary requirement.

A rate of 5 US cent per kWh has been assumed to value the losses in the diameter optimisation.

The main data of the penstock steel lining and branch pipes are as follows:

Table 3-20: Data for penstock steel lining.

Main Data	
Maximum internal pressure:	288 m
Maximum external pressure:	270 m
Steel lining length:	50 m
Internal diameter:	4.2 m
Lining thickness:	34 mm
Total weight of delivery:	200 ton

The solution with two separate penstocks leading the water from a widening of the headrace tunnel is chosen because of the tunnel layout and because it will generally simplify the works in all aspects, including design, fabrication, transport, erection and control.

3.8.15 *Tailrace tunnel equipment*

Draft tube gates

A complete draft tube gate with electric wire hoist and guides will be installed for each turbine.

An outlet velocity of approximately 2 m/s has been assumed at this stage. The main data for the gates are given in Table 3-21

Table 3-21: Data for draft tube gates - Genale GD-6

Main Data	
Number of gates:	2
Type of gate:	Sliding gate
Sealing system:	Rubber seals
Gate inclination:	Vertical/ 5.7^{o}
Sill level:	el.344
Net height:	7 000 mm
Net width:	5 000 mm
Design pressure at sill:	1.5 bar
Type of hoist:	Fixed wire hoist
Draft tube gate gallery floor level:	369.5 masl

Special design criteria

Each gate will have its own permanent wire hoist. The hoist will be attached to a bracket in the roof of draft tube gate gallery.

The gates will be operated at equalised pressure. A filling valve will be included, either built-in in the gate, or in form of a fixed by-pass system.

To get a better sealing effect during dewatering, the guides will have an inclination of 1 to 10 (5.7^{o}) at the level of the draft tube gates outlets. The guides further up in the gate shaft will be vertical. This change of inclination represents no practical problem for operation.

It is difficult to have an absolute definition of the highest surge, as this depends on the succession of unfavourable operations (loading/unloading of units) considered. The level chosen for the draft tube gate gallery floor is above nearly all predictable situations. Still, there is a theoretical risk for a slightly higher upsurge. For this reason, the gate slots in the floor will be closed by watertight covers. Theses covers will be designed for a pressure of approximately 2 bar. Normal parking position of the gates will be above these covers. Alternatively a nozzle will be established in the draft tube shaft inlet to reduce upsurge.

Outlet stop logs

The outlet is designed with guides for stop logs, allowing the tailrace tunnel to be emptied for inspection.

3.9 Small HPP in the Dam

3.9.1 Compensation Water Turbine Data

The Consultant suggests installing a small hydro unit to generate power from the compensation water release downstream of the dam. The turbine will be a standard compact unit with horizontal shaft, with a load controller to ensure correct water release at all times.

Parallel to the turbine a redundant bypass system will be arranged to ensure compensation water release even if the generating unit is out of operation.

The turbine will utilise the head from the reservoir level to a water level generated by an outlet chamber located in the middle of the three culverts used for construction bypass.

Table 3-22: Key data of the small HPP turbine

Main Data	
Arrangement:	Horisontal
Turbine design head:	62 m
Energy output	12 GWh/y
Turbine power at net design head:	1.3 MW
Turbine flow at net design head:	2.5 m^3/s
Max. head:	64 m
Turbine power at max. head	1.4 MW
Turbine flow at max. head	2.65 m^3/s
Turbine speed:	1000 rpm
Runaway speed, max. head (approx.):	1800 rpm
Turbine runner centre:	~el.521
Turbine centreline submergence:	- 0.95 m
Approximate Data	
Runner outlet diameter:	600 mm
Turbine cover diameter:	850 mm

The turbine is planned to be located in and have an intake from the concrete culvert used as bypass during construction. The unit will have a revision valve, shut-off valve of the butterfly type and a redundant bypass system. The equipment for this unit will be of a standardized compact design.

3.9.2 *Electrical installations*

Generator

The generator will be of standard design, horizontal shaft, two bearings of sleeve or roller type, mounting designation IM 1001. A flywheel is assumed on the ND end. Indirectly cooled by water, by air/water heat exchangers mounted on the stator housing. Excitation will be of brushless type.

Rated data:

Output:	1500 kVA
Voltage	3300 V
Speed	1000 rpm

Transformer

The transformer will be oil insulated designed for outdoor installation and cooled by natural air circulation.

Rated data:

Output	1500 kVA
Voltage ratio	33 ± 2 x 2,5% / 3,3 kV

Generator-transformer connection:
Connection will be by 3,3 kV cable, via a 3,3 kV circuit breaker cubicle. The circuit breaker will be located indoor near the generating unit, and will be used for synchronising as well as all other switching, both for normal operation and for fault clearing.

Connection to the network:
A 33 kV cable will be laid from the transformer terminals up to the end pole of the 33 kV transmission line from the 230 kV switchyard in the power station area. A pole-mounted disconnector with a drop-out fuse will be installed in order to disconnect from the line and provide protection for the transformer.

Station auxiliary power supply:
The plant will be supplied with a.c and d.c power from the dam.

Control and protection: The plant will include a control and protection panel with touch screen for local control. Start and stop will be possible by remote control. Operation and production data will be transmitted to the main power station. The plant will be designed for automatic unattended operation.

3.10 Genale GD-6 - Electrical equipment

Project drawings C01 to C06
and B11 to B17

3.10.1 General description of power station electrical equipment and systems

<u>Main components</u>

The main components of the electrical installations in the Genale GD-6 are the two 150 MVA vertical shaft generators, each connected to a three- phase step-up transformer from which 400 kV cables leads to the outdoor switchyard. The switchyard contains connection to an outgoing single circuit line to the GD-3 switchyard.

The principles are illustrated in single line diagrams on drawings C01-C06.

<u>Design considerations</u>

The proposed design is selected with care to achieve high reliability, low maintenance cost and to meet modern safety standards.

<u>Transport considerations</u>

The transformers are the heaviest (and probably the largest) components to be transported to site. Assuming three-phase transformers, the transport weight would be 130 tonnes. According to available information, the road up to the project site will have sufficient capacity for such transport, taking into consideration that specially designed vehicle will be used. However, even if such vehicles are used the transport will be critical and a road study should be performed in order to establish bottlenecks on the road system and mitigating measures possible.

Auxiliary equipment

Auxiliary supply, control and protection systems in the powerhouse and the switchyard are designed to maintain flexible operation of the entire plant by implementation of redundancy of all essential functions.

Definitions

The term “low voltage” (LV) is used for all voltages below 1 kV. The term “medium voltage” (MV) means distribution voltages between 1 and 36 kV whereas the term “high voltage” (HV) is used for transmission voltages i.e. above 36 kV nominal voltage. However, the term HV may also be used generic for all voltages above 1 kV.

3.10.2 Generators

Generator main data:

The generator data are mainly governed by the turbine design and the stability requirements. Table 3-23 shows the main data proposed for each of the identical units:

Table 3-23: Main data for Genale GD-6 generator units

Parameters	Value
Nominal Active Rating	129 MW
Rated output	150 MVA
Rated power factor (Cos φ)	0.86
Nominal voltage	12 - 16 kV
Rated frequency	50 Hz
Number of poles / Nominal Speed	20 / 300 r.p.m.
Maximum runaway speed	520 r.p.m
Moment of inertia (GR2)	1241 t m^2
Rotor weight	190 tonnes
Generator total weight	525 tonnes

Construction

The generators will be vertical shaft, salient poles, synchronous generators directly coupled to the francis turbines. The generators will be of conventional well proven design and as none of them is extraordinarily slow running an upper combined thrust and guide bearing and a lower guide bearing is assumed. The location of the thrust bearing may, however, be left for the manufacturer to optimise. However, emphasis should be laid on convenient access to the bearing for inspection and maintenance. The thrust bearing will be designed to carry the combined weight of the generator rotor, shaft and turbine runner, as well as the hydraulic thrust during operation.

Output

The generator rated output corresponds to the turbine power at design head and a power factor (PF or cos φ) of 0.86, which should give the generators sufficient capacity for reactive power to support the normal requirements of the transmission lines.

Extreme output

In rare cases, by high headwater level, no spilling, and operation of one turbine only, the tail water level will be low and the turbine can provide more than rated power. By over-opening of the guide vanes the power can be even higher. These extraordinary situations can be accommodated for without overloading of the units by operating at higher power factor and the generators will therefore be dimensioned for continuous operation at up to nominal MVA rating by a power factor of 1.0.

Rated voltage

Rated generator voltage should be left to the supplier to optimise. It will most likely be in the range of 12 - 16 kV.

Moment of inertia

The moment of inertia of rotating parts will be high enough to ensure operational stability and satisfactory turbine regulating conditions.

Stator Frame

The stator frame will be made of steel plate sections welded together in a structure designed to support the weight of the upper spider and the rotating parts as well as to withstand the dynamic mechanical forces during operation. The frame will be provided with structures for supporting and clamping of the stator core.

Stator Core

The stator core will be built up of thin high-grade non-ageing silicon steel segments. Each segment will have a heat resisting insulating varnish to prevent eddy current losses. The segments are stacked and fastened to the frame by dovetail keys. Radial ventilation slots will be provided at intervals by means of steel sheets with spacing strips. The core laminations will be clamped so that vibrations during operation are avoided.

Stator winding

The stator winding will be star connected, consisting of identical single-turn coils with full “Class F” insulation according to IEC Standard 60085. However, the windings should be so dimensioned that the temperature do not rise above class B limits at full load. The windings will be arranged in open slots in the stator core with two coil sides per slot. The ends of the windings, both for phase and neutral will be brought out to separate terminals. The winding ground insulation will be made of several layers of mica flake tapes impregnated with an epoxy based resin according to the Vacuum-Pressure-Impregnation system and cured under pressure to obtain correct dimensions. The slot portion of each coil side will be covered with a conductive varnish to prevent partial discharges between the coil and the iron. Outside the slots, the coil sides will be treated with a semi conductive varnish to provide a uniform voltage stress distribution. The end windings outside the slots will be anchored to a supporting ring designed to withstand mechanical forces during possible fault situations, e.g. short circuits.

Shaft

The shaft will be made of forged steel and machined to specified dimensions. A spider is assumed to be welded to the shaft, or may be an integral part of the shaft itself. The spider supports the rotor ring which may consist of massive rings to be shrunk and keyed to the spider, or will be of the laminated type fastened to the spider by dovetail keys. The shaft must be rated for operation at full rated power by power factor 1.0.

Rotor and field coils

The rotor poles are built up from sheet steel sections, clamped between steel end pieces by means of through bolts. The poles will be fastened to the rotor rim by dovetail keys.

The field coils consist of copper bars brazed together to form a rectangular coil conforming to the shape of the pole core. Each turn is insulated by epoxy based insulation material cured under heat and pressure. The coil will be insulated against the pole core by glass fibre fabric impregnated with polyester or similar.

Each pole will be equipped with a damping winding made of copper rods inserted in semi-closed slots in the periphery of the pole. The rods are brazed together in both ends, and all poles are connected together to form a continuous “cage” winding.

Bearings

The bearings will be self-lubricating hydrodynamic bearings made as complete units to be supported by the upper and lower spider bracket respectively. The upper bearing will be electrically insulated from the bracket in order to avoid circulation of shaft current. An arrangement for condensation of oil vapour escaping from the bearing houses is foreseen.

Slip rings

The slip ring compartment will be located above the machine hall floor. The slip ring assembly will be designed for self-cooling by air drawn from the machine hall. An arrangement for collection of carbon dust from the brushes is foreseen.

Brake and lifting system

A number of brake jacks will be placed on the lower bracket. During braking, the brake jacks will be actuated by air pressure supplied from a compressor unit. Each jack will have a non-asbestos brake lining. A breaking ring is mounted on the underside of the rotor. The brakes will be designed to operate between preset speed limits. The brake jacks will also be used for lifting the rotor during long standstill periods. Locking pins or spacers can lock the jacks in the upper position.

High pressure oil system

The purpose of the high-pressure oil system is to build up a lubricating oil film between the thrust pads and the bearing runner before start-up of the unit as well as during periods of low rotating speed. The high-pressure oil system consists of a separate mounted pump unit with filters, valves and pressure supervision. The oil may be circulated from the bearing or from a separate source.

Cooling system

The generators will be air-cooled and self-ventilated by fan blades mounted on the rotor itself. Cooled air will be drawn from the generator pit at the top and bottom of the generator, and forced through ventilation slots in the stator to air/water heat exchangers arranged around the periphery of the stator housing, thus forming a closed loop ventilation system inside the generator pit.

Fire extinguishing

No fire fighting system is foreseen for the generators. The materials used for winding insulation and for support purposes are flame retardant. Should a fire start inside the generator pit, the fire detection system will trip the generator. A fire outbreak will then not be supported. The relay protection design, comprising two independent sets of relays, will trip the generator automatically should any electrical fault happen.

Transport and erection

The large parts of the generator assembly will be designed and manufactured to transportation weights and dimensions not exceeding the maximum transport limits. Components exceeding these limits will be designed to enable assembly of the component at site.

It is anticipated that the assembly of the stator will take place directly in the generator pit whereas the rotor first will be assembled in the erection bay and then lifted by the crane and lowered into the stator boring.

Excitation system

The excitation system will be of the static type. This system consists of an excitation transformer supplied directly from the generator terminals, a thyristor converter, field flashing circuit, de-excitation circuit, field circuit breaker, over voltage protection and an electronic voltage regulator. The field current will be supplied to the rotor windings by slip rings on the upper part of the generator shaft.

The excitation transformer will be of the dry insulated type. The thyristor converter will be designed with sufficient redundancy to ensure continued operation even if one thyristor branch is out of operation. The thyristor units will be protected by means of quick acting fuses in each branch.

The automatic voltage regulator will be equipped with the additional functionality of a power system stabiliser (PSS).

3.10.3 *Main transformers*

Transformer Main Data

The transformer rating is adapted to the generator power and the vector group to the grid requirements. Table 3-24 shows the main data for one combined three phase group.

Table 3-24: Main data for Genale GD-6 transformers

Parameters	Value
Rated output	150 MVA
Rated voltage	400 ± 5% / U_{gen}
Tap changer	Off-load ± 2 x 2,5 %
Maximum voltage (IEC 60038)	420 / 17.5 kV
Nominal frequency	50 Hz
Short circuit voltage, e_k	13 %
Vector group	YNd11
Cooling	OFWF
Transport weigh w/o oil	130 tonnes
Transport dimensions, L x W x H	6,8 x 2,9 x 4,5 m

Basic design

The choice of transformers depends on the various installations to be supplied. In addition to the main purpose of transforming the produced electric power to the voltage level of the outgoing transmission lines, there is a need for plant auxiliary power and the possibilities to supply the local areas.

The main considerations for the choice of transformer system are:

- Transmission system requirements
- Neutral earthing philosophy
- Investment costs
- Spare parts philosophy
- Transportation limitations
- Station arrangement
- Personnel safety

Generator transformers

The generator transformers are located under ground and should be of the water cooled type (OFWF) and have the same MVA rating as the generators The transformers are located in a separate cavern and individually separated in transformer cells. The low voltage side should be delta connected to balance 3rd harmonic and earthfault currents.

Test voltages

The test voltages for which the transformer must be designed are given in the high voltage section below. Proper altitude correction must be taken into consideration.

Location

The generator step-up transformers should be located as close to the generator terminals as possible in order to avoid long high-current bus bars.

Fire and explosion risk considerations

When placing the transformer underground, due attention should be paid to the risk of an oil fire or explosion. The transformer cells will be practically air tight in order to effectively extinguish a possible oil fire. The cells will also be designed to withstand an overpressure of 0,5 bar in case of an oil explosion.

Connection

The delta-connected winding on the primary side of generator step up transformers will provide a closed circuit for possible third harmonic currents originating from the generator. The high voltage winding is Y-connected with the neutral point brought out on a separate terminal for direct connection to earth. In this way it will be possible to satisfy the requirement of directly earthed neutral in the grid.

Type

The transformers will be of conventional design, core type with tank. Concentric windings will be arranged on a core made of insulated steel laminates. The transformer tank will be designed to withstand an overpressure of one bar as well as to allow near vacuum during drying-out before oil filling.

Oil conservator

The transformer will be equipped with a conservator tank with a capacity of approximately 10% of the total oil volume. A gas relay will be installed in the pipe between the transformer tank and the conservator.

Bushings

The phase and neutral bushings will be arranged on top of the tank. The primary (low voltage) bushings will be designed for connection to encapsulated, air insulated bus bars from the generator. On the secondary (high voltage) side the bushings will be designed for direct connection to SF_6 gas insulated busbars.

Instrumentation

The bushings will have built-in current transformers for measuring and protection. Pressure detectors will be installed in each bushing for detecting overpressure due to a possible internal insulation fault.

Temperature detectors for supervising oil and winding temperatures will be installed in pockets in the tank top cover.

Cooling

Cooling of the transformer oil for underground located transformers will be by means of an external oil/water exchanger. Oil circulation will be by pumps but water will come from the cooling water basin so that the cooling type will be (OFWF). Cooling water will be supplied from the cooling water system through a regulating valve. On the outlet, the water will discharge through a siphon arrangement in order to keep the water pressure lower than the pressure in the oil circuit. Two independent full capacity cooling systems will be installed to allow maintenance work during operation.

Outdoor located transformers will be cooled by external oil/air exchangers. Oil circulation will be with natural flow whereas thermostat controlled fans will increase the air cooling capacity (ONAF)

Transport

In order to reduce transport weight, the transformers will be transported without insulating oil. The tank will be filled with dry air or nitrogen gas under a slight overpressure. Bushings, conservator and other auxiliaries will be transported separately.

3.10.4 400 kV Cables

The connection between the underground step-up generator transformer and the switchyard will be by single-phase PEX cables located in a separate tunnel with multi purpose use as cable, ventilation and emergency evacuation tunnel.

Cable system layout

There will be three single-phase cables for each generating unit. In the switchyard, the cables will be connected via a normal PEX/air bushing. Inside the transformer hall and in the cable shaft, the cables will be installed openly in air securely clamped to and supported by cable ladders. In outdoor areas, covered cable ducts in the ground will be provided.

3.10.5 Transformer-Cable Terminal Equipment

For the transformer, the most straightforward solution would be conventional oil/air bushings. In that case, also the surge arrester and the cable terminal bushing should be conventional types. Normally, bushings for 230 kV and higher must be arranged vertically because they are oil-filled. It would therefore be difficult to arrange these components in a compact manner.

As an alternative to the above, the cable can be terminated directly to the transformer by specially designed oil/SF_6/PEX bushings. This alternative offers the most space saving arrangement. In this case, however, the surge arrester to protect the transformer must be omitted. This can be done, provided that a dynamic surge analysis verify that the surge arrester can be omitted.

Another alternative, which is selected for the purpose of this study, comprises a compact arrangement that also includes the surge arrester. It consists of a SF_6-insulated busbar section, which is connected to the transformer by an oil/SF_6 bushing. At the floor above the busbar is connected to a T-branch with a SF_6-insulated surge arrester and a SF_6/cable bushing.

3.10.6 *400 kV Outdoor Switchgear*

<u>Voltage levels</u>

The voltage level for the transmission systems have been chosen in the system studies to be 400 kV. The basic design data are summarised in the table below:

Table 3-25: Main data High voltage switchgear

Parameters	
System voltage	400 kV
Application	Conection ICS
System	50 Hz, 3 phase
Neutral point earthing	Solid
Highest system voltage as defined by IEC-60038	420 kV
Short circuit and earth fault current, symmetrical r.m.s. value (min breaking current) not less than	31.5 kA
Rated current of busbars and bus coupler if not given in Scope of Works, for each individual substation	2 000 A
Minimum rated current of disconnectors and circuit breakers	800 A
Switching surge withstand voltage according (IEC 60071) (Phase to earth)	1050 kV.
Lightning impulse withstand voltage (1.2/50 m/s kV_{peak}) according (IEC 60071)	1425 kV
Test voltage at power frequency 1 min according (IEC 60071)	N. A.
Minimum nominal creepage distance as defined in IEC 60815, Table II	25 mm/kV

<u>Altitude</u>

The installations for GD-6 are all below 1000 masl. Therefore no corrections for altitude are necessary.

Arrangement

For underground power stations where sufficient space can be allocated in the area outside the cable or access tunnel, the most cost effective design is normally outdoor conventional switchgear. Two alternative configurations have been considered.

a) Double busbar with two circuit breaker system

This system is characterised by connecting each bay to the double bus bar by separate circuit breakers. Disconnectors are installed on both sides of each circuit breaker. The system provides full flexibility of operation with regard to maintenance of circuit breakers. An extra bus-tie breaker is not necessary. This is the most reliable design, especially used for power stations with extremely high demands on availability. The system is mostly used for main power stations, which affect the main grid, or have high production capabilities for longer periods. The increased number of circuit breakers makes this alternative the most expensive.

b) Double bus bar with single circuit breaker

This system is characterised by connecting each bay to the bus bars by one circuit breaker via separate disconnectors. The system provides reasonable flexibility in operation with regard to maintenance of circuit breakers. An additional bus-tie breaker will be installed. This is a reliable design, specially used for important power stations in the main grid that have high production capabilities for longer periods.

c) Single busbar with bypass busbar system

This system consists of two busbars, of which one is normally in operation in single busbar mode. The bypass busbar offers flexibility for maintenance of circuit breakers without interrupting supply.

Cost differences

The increased cost for the different circuit breaker systems must be weighed against the discounted benefits of higher flexibility and availability in operation. In particular, such benefits will occur in case of circuit breaker failure, where the risk of a subsequent complete shut down of one of the units is larger than with more complex circuit breaker system. The risk of a circuit breaker failure is, however, difficult to predict. It depends not only on the statistical failure rate of the breaker itself, but also on the mode of operation of the power station and the quality and intervals of maintenance. Life expectancy for the equipment is in any event very high under rated conditions.

Service interruptions

Possible loss of production during future extension of the switchyard can be negligible or eliminated by making adequate preparations in the initial construction stage, and also by complete spare part storage at the power station.

Conclusions

With the current reliability of circuit breakers and disconnectors single circuit breaker schemes are selected. This is in line with the current practice in Ethiopia and is regarded to be most cost efficient. The basic principles are illustrated in the single line diagram and switchyard layout drawing.

Busbar system

Genale GD-6 will be connected to the grid by a double circuit transmission line. Both circuits connect to the same busbar at the far end, so a double busbar scheme is not mandatory. However, some flexibility for maintenance should be considered. Therefore the selected busbar configuration is single busbar with bypass busbar (item c) above).

Layout

The proposed layouts are principle drawings showing space requirements and could be further elaborated in the detail design phase. The final supplier should also be allowed to adapt the layout to suite his equipment.

Creep distance

IEC 60085/60859 regulations recommend creep distance values ranging from 1.6 cm/kV (r.m.s. phase to earth voltage) to 3.1 cm/kV. In Ethiopia with a dry season, which could cause considerable build-up of dust on the insulators, and with the often sudden and strong start of the rainy season, the creep distance should not be underestimated. A minimum distance of 640 cm is recommended, corresponding to 2.5 cm/kV, which by IEC is characterised as covering conditions in industrial areas with relatively high pollution. Since the dust is probably not very polluted, it will maintain a comparatively loose consistence and will be washed away by the first showers.

Circuit breakers

Single-phase circuit breakers in three-phase groups designed for three-phase breaking and single phase fast reclosing with motor operated spring charging mechanism for performing fast reclosing operation at line fault is foreseen. Disconnectors and earthing switches will be motor operated.

Measuring transformers

Measuring transformers will generally comply with accuracy class 0.5. For metering purposes class 0.2 is foreseen in accordance with normal practice.

Surge arresters

Gapless metal-oxide arresters will be installed. An important design criterion is the magnitude and duration of temporary power frequency over voltages.

3.10.7 *Medium Voltage (MV) System*

Extension

The medium voltage system comprises
- the generator terminal switchgear (12 - 16 kV),
- the 33 kV distribution switchgear for the powerhouse
- the 33 kV distribution switchgear for the 400 kV switchyard service building
- the 33 kV distribution lines to the dam, the intake and the Operators' Camp.

A separate 33 kV line connects the mini-hydro plant in the dam to the rural network.

A double circuit 33 kV line would be constructed at an early stage in order to supply power during the construction stage. This line is assumed to originate at Negele substation and follow existing roads to the construction site. After construction, the line will be connected to the 33 kV switchgear in the switchyard service building.

Generator terminal equipment

The generator terminals will be directly connected to air insulated enclosed high current buses going through a bus-tunnel to the transformer cavern. For such a large generator unit size a generator circuit breaker is considered necessary primarily to reduce the short-circuit duration by faults in the busbars, transformer and cable. By limiting the fault duration, the damages and hazards are considerably reduced in fault situations. A second advantage of such breaker is the ability to supply plant power when the generators are stopped. The generator circuit breaker and disconnector/earthing switch are located adjacent to the generator pit. The excitation transformer is located before the generator breaker. A branch off for supply to the station transformer is located on the downstream side of the corridor.

Generator circuit breakers (GCB)

The GCB will have sufficient capacity to disconnect the generators in the event of a possible short circuit in the bus bar sections.

Maximum short circuit current by a possible short circuit fault in the generator busbar section will be fed from the 400 kV network through the main transformers. The expected short circuit power in the 400 kV network would be maximum 12,500 MVA, corresponding to 31.5 kA short circuit current. Using 13 % as the transformer short circuit voltage, the resulting short circuit power on the generator busbars would be 1056 MVA, corresponding to about 50 kA at 12 kV.

Design considerations

The primary purpose of the medium voltage switchgear is to supply auxiliary power for the power plant. The switchgear will be located in separate rooms in the powerhouse and in outdoor buildings. The auxiliary supply system will be equipped with modern fuse isolator switches or circuit breakers of SF_6 or vacuum type, enclosed in cubicles providing high personnel safety.

Table 3-26: Main data Medium voltage switchgear

Parameters		
System voltage	12 - 16 kV	33 kV
Application	Generator	Rural Electrification
System	50 Hz, 3 phase	
Neutral point earthing	High resistance	Resistance
Highest system voltage as defined by IEC-60038	17,5 kV	36 kV
Maximum short circuit and earth fault current, symmetrical r.m.s. value (breaking current)	36 kA	25 kA
Rated current of busbars and bus coupler if not given in Scope of Works, for each individual substation	N.A.	1 000 A
Minimum rated current of disconnectors and circuit breakers	5500 A	630 A
Insulation level according IEC 60071:	38 kV	70 kV
Switching surge withstand voltage	N.A.	N.A.
Lightning impulse withstand voltage (1.2/50 m/s kV_{peak})	N.A.	170 kV
Test voltage at power frequency 1 min dry and wet. To earth and between phases	38 kV	70 kV
Minimum nominal creepage distance as defined in IEC 60815, Table II	25 mm/kV	

Synchronising

Great care should be taken in order to assure that the 33 kV network is operated as a radial network. No paralleling over the 33 kV system should be allowed.

3.10.8 Station Auxiliary power supply

Due to the size and complexity of the power station a redundant Station Supply System is assumed. The feeder to the station supply will be from:

- the two generators or
- stand by diesel generator unit(s) or
- the 33 kV distribution network

a.c Distribution

The a.c. distribution system will be designed as a 400 V (± 10%), 3 phase four wire plus earth system (TN-S-system).

Provided that at least one generator is in operation, the normal supply will be from the generator terminal busbars, through either AT1 or AT2 to the 33 kV busbar in the powerhouse. From this busbar, the unit 400 V distribution boards are supplied through the station transformers ST1, ST2 and ST3.

The unit distribution boards are interconnected by a ring connection for redundancy. One feeder only will supply the board at the same time, and the contactors installed on the incoming feeders are interconnected by a selection/interlock scheme. A voltage relay will automatically initiate the changeover when no voltage is detected on the bus bar. If no other supply is available, a standby diesel-generating unit, designed for automatic start, will provide power to essential equipment.

The distribution system will supply low voltage power to all station service systems, lighting and battery chargers, local control cabinets with necessary motor starters and sub-distribution panels.

Essential / normal load

The powerhouse systems will be designed with sub-distribution panels that supply essential loads. Essential loads are defined as load necessary for safeguarding operation, start and stop of the units. The same applies for the HV switchyard. If a blackout occurs in the main system, the feeders connected to the essential load panel will be supplied from the standby diesel generators. The essential load distribution system will be continuously energised during normal operation to ensure the system availability.

Station transformers

Station transformers will be installed for supply to the powerhouse, the switchyard, the dam and the intake. In the powerhouse and switchyard, the transformers are located in confined indoor environment, and consequently dry type insulated distribution transformers should be used. For the dam and intake, oil insulated transformers located outdoor may be selected. The kVA rating of transformers depends on the various installations to be supplied. The transformers will comply with the earthing system requirements for the connected grids. The 400 V system will have solidly earthed neutral.

Diesel generators

The diesel generators will be located at the switchyard with cables down to the powerhouse. The diesel unit should be capable of continuous supply of priority loads in the power plant during loss of normal supply and to allow “black start” of the units. The electrical connections are outlined on the single line diagrams for each station.

d.c supply

Equipment that cannot stand a short break in power supply will be supplied from redundant 220 V batteries. The d.c. supply system will consist of the station batteries with battery chargers and distribution cubicles. Two battery banks in the power station will provide full redundancy. In addition, a battery bank will be established at the switchyard site and an interconnection with the power house will be established. The d.c. supply system will provide safe and reliable supply of power and control voltage to all primary functions. The system will be independent from all other power systems, and will ensure reliable execution of the control functions, both for normal operation and during possible failure conditions.

Installation of 24 V or 48 V batteries should be avoided in the main plant. Equipment needing continuous auxiliary voltage should be equipped with d.c/d.c converters.

<u>Switchyard</u>

A single battery system will supply power mainly for the HV switchyard. Priority supply in this area is the relay protection, the control voltage for the hardwired part of the system, and the computer equipment.

<u>Dam and Intake</u>

Normal supply will be from the 33 kV transmission line via the distribution type transformers to the a.c distribution boards.

A stand-by diesel generating unit will be installed at the intake.

A single battery system (24 or 48 V) will provide the power to the intake Local Control System and the control voltage for the hardwired part of this system. Particular functions in the intake area are water level measurement and gate control.

<u>Plant control centre</u>

A single uninterruptible power supply with battery backup will supply a.c. power for the power plant control system.

From the battery banks d.c./a.c power converters will provide uninterrupted power supply to video screens and other equipment/systems designed for 230 V a.c. power supply.

3.10.9 Main earthing system

The earthing systems for the powerhouse and switchyard will be designed according to well established principles and will consist of earthing copper electrodes embedded under concrete foundations in the powerhouse and in the soil foundations for the switchyard with connections (risers) to installed equipment. Earthing rods, approximately 6 m deep will also be provided both in the powerhouses and in the switchyards.

The earthing electrodes will be designed to provide a common equipotential reference for the installed equipment, both in the powerhouses and in the switchyards, and will have sufficient dimensions to reduce voltage transients from possible earth fault at any equipment to an acceptable low level.

3.10.10 Control and SCADA system

Computer based

A computer based, distributed control system is foreseen. Such systems have been utilised for the last three decades in industrial plants, and have dominated in power stations and transmission systems during the last three decades. The computer technology offers a high degree of flexibility and reliability. Transmission of signals is provided by high-speed optical fibre communication systems, which are insensitive to electric stray fields. These systems are also insensitive to electric shocks, which may arise between different parts of the plant during an electric failure. The optical fibre communication systems will also substantially reduce the number of signal cables in the plant.

Control systems that are based on electromagnetic relay technology, will hardly be available in the future. As computerised systems take over, the cost for relay technology will rise and the availability of spare parts will be reduced.

For the Genale GD-6 project, it is foreseen that the central control room will be located in the outdoor Portal Building. From here the operator will be able to control and supervise the entire plant from workstations equipped with video screens (VDU) and keyboard. The workstation is connected to the station computer, which collects data from a number of local control units (LCU) distributed around the plant. LCUs are assumed for each generating unit including step-up transformers, for the Powerhouse auxiliary systems, for the outdoor 400 kV switchyard and for the dam/intake. Each LCU has signal interface to all related measuring transformers and transducers, indicating instruments, metering system, protection relays and a microprocessor based controller with software for all supervisory and automatic functions. The LCUs are connected to a databus for communication to the station control system.

Microprocessors

The LCUs will comprise programmable controllers based on microprocessor technology, and will perform all functions for accessing, analysing and acting on the information from the process and coordinate and perform the operational tasks commanded through the SCS.

Unit LCU

The LCUs for the generating units will be programmed for fully automatic start and stop procedures for the units including synchronisation. The initiated procedure will perform sequentially all command actions. The sequence of operations and the immediate status will be transferred to the SCS.

The operation and functions of the voltage regulators and the turbine governors will not depend on the LCUs.

Auxiliary supply LCU

LCUs will supervise the plant auxiliary power supply system and provide automatic switching to the available power sources according to agreed priority schedules. In addition to the auxiliary power supply, including the medium voltage equipment, these LCUs will supervise the drainage pumps, ventilation system, the cooling water pumps, the chilled water system, fire fighting water pump and lighting and small power etc.

HV switchyard LCU

The LCU and the protection relays will be located in the HV switchyard service building. The LCU will be interconnected with the local control panels for the HV and MV switchgear and the relay protection panels. As an option the use of individual bay computers for each HV bay and each MV bay is considered. Both solutions are viable. Not to exclude some of the potential suppliers it is recommended to let the suppliers offer their best solution.

Intake LCU

The LCU is located in the intake gatehouse. The LCU should cover, the power supply, the transmission of signals from the gate equipment to the powerhouse, the water level controller and the monitoring signals for the dam. Flushing gates will be locally operated only, but signals for «open/closed» will be recorded in the SCS. Trash rack cleaner will be manually operated. Monitoring signals will be transmitted to the station control.

This system provides five levels of control:

Remote Control:

All control functions are performed and supervised from a load dispatch centre (LDC) that can be located at area or country level, depending on the overall operation strategy. The control panel and SCS are controlling the process, i.e. command procedures, automatic control and protection procedures, interlocking routines, etc. The control panel manual control board is disconnected. All control panel indications are active in this mode.

Station Automatic Control:

All control functions are performed and supervised by the operator from the control room in the Portal Building.

The station control rooms will normally be unmanned The SCS system display and concentrates the information from the LCUs before it is conveyed to the LDC. If needed (i.e. by communication failure or in maintenance situations) complete control can be taken over by the SCS as it is equipped with full SCADA functions, video screens and operator’s keyboard. No failure in the SCS should interrupt or block the operation of the power plant.

Local Automatic Control:

All control functions related to one LCU are performed and supervised by an operator on the LCU front panel. In this mode, all commands from the central control room are blocked, but operation can still be monitored at the remote and station control levels.

Local Manual Control:

In this mode, all automatic control functions are disabled. The operator must manually adjust and monitor all functions, e. g. by pushbuttons on the switchgear etc. However, the generator AVR and the turbine governor can still operate in automatic mode.

Start, stop and other control of the generating units will still be possible by manual operation. The monitoring and operation are done by means of the control panels for the automatic voltage control (AVR) and the turbine governor as well as by manual operation of valves, switches etc. for manual operation together with local instruments.

Emergency shut down

An independent emergency shut-down function for the generating units should be installed to be used in the event of a severe fault such as loss of control voltage, LCU internal fault, internal fault in the relay protection, fire or flooding. In addition to automatic activation of the emergency control, emergency buttons will be installed at selected locations.

Modular design

All equipment will be of modular design. Particularly major units of the LCUs such as the microprocessor modules, memory modules, communication modules, I/O-modules, internal power supplies, etc., will all be easily serviceable and replaceable. The cubicles/compartments will be designed so that discharges due to static electricity build-up will not disturb the electronic circuits. All cubicles will be earthed according to the earthing specifications. Throughout the LCUs the signal earth will be kept separated from the cubicle earth, and the two earth systems will be connected at one common point only. No ground loops are allowed.

Data communication

The communication between the SCS and the LCUs will consist of a fibre-optical cable system. The communication layout can either be a bus system, a loop system or a star system.

Protocols

In order to allow free replacement of systems, the use of open defined protocols for data communication should be enforced on the suppliers. IEC 60870 or newer IEC protocols should be preferred particularly between stations. Full benefit should be taken from the new IEC protocols for communication between relay protection and control systems.

Software

The software functions will be finally decided during the detailed design phase. However the Control System Software should include all normal (SCADA) - and Human Machine Interface (HMI) software functions such as:

- Data acquisition from all, including status signals, alarms, analogous measurements, etc.
- Transferring command and control outputs.
- Alarm handling and event recording.
- Dynamic colouring.
- Dynamic presentation of the start/stop sequence for each generator set.
- Database functions for periodical reports.
- Status reports, measurement reports and production reports, etc.
- Production planning, Production optimisation, MVAr control, Genale GD-6
- Historical trends.
- Energy recording and reporting.
- Time synchronisation and time tagging system

- Blocking and acknowledging of information
- Data security and consistency
- Personnel system admission security
- On-line trends, change of data and change of pictures
- Software for production planning, optimisation etc.
- Well supported spread sheet with on-line link to the SCADA system
- Self diagnosis and virus protection
- Full graphic picture building
- Software for system configuration and maintenance
- Software for communication to the national dispatch centre

Power supply

The SCS will be supplied by 400 V a.c. via two d.c/a.c. converters in "hot" stand-by mode. Each LCU unit is foreseen for a d.c. power supply from two independent sources in no-break mode.

Decentralised layout

In order to increase the reliability and reduce the amount of control cables, intelligent control units should be decentralised so that each unit can operate independently in emergency cases.

The plant and station control systems will be installed in air-conditioned rooms. However, the equipment should operate normally even if the air-conditioning system is out of order. These control room will be equipped with elevated floors for cable distribution.

All power supply to the control system hardware will be galvanic isolated from the rest of the plant supply system and will be equipped with separate over voltage protection devices.

3.10.11 Relay Protection

Selectivity

All control and protection will act in such a way as not to close down larger parts of the plant than needed to isolate problems and establish safe conditions.

Relay protection

Separate relay protection cubicles comprising multifunction microprocessor based relays are assumed. The relays will preferably be of the same make (manufacture) to build a uniform modular system. The function of the protection relays will not depend on the control system. The relays are organised in two groups, so that one group provides back-up protection for the other.

Protection relays

Redundant protection relays with redundant power supply from the station supply batteries only should cover short-circuits and earthfault in a selective way through the system. Maximum fault clearing time for such relays should be less than 100 ms. Other faults may be covered by combined relays or protection functions in the control system.

Generally, short circuit and earth fault relay should be duplicated.

Typical selection of relays is listed below. The final selection of relays will be made during the detail design phase.

Line protection

Transmission lines are normally protected by three-phase minimum impedance relay. The introduction of fibre optical communication has opened for use of differential relays also on the lines. As this gives quicker and more selective disconnection of all major line faults, such means should be considered in the final design. The line differential relays are normally able to switch over to minimum impedance principle if the communication channel fails.

Generator protection

- Generator differential relay
- Over-/under voltage relay.
- Over/Under frequency relay.
- Over current/short circuit relay.
- Reverse power relay.
- Negative sequence current relay.
- Loss of excitation relay (Minimum reactance relay).
- Shaft current relay.
- Rotor (field winding) earth fault relay.
- Excitation transformer over-current relay
- Stator earth fault relay.
- Rotational speed relay.
- Vibration and shaft movement supervision relay
- Stator and winding thermal relay
- Minimum impedance relay
- Circuit breaker failure relay (Generator CB)

Main transformer protection:

- Three phase over current relay.
- Three phase unit block differential current relay.
- Restricted earth fault relay
- Fault relay for the circuit breaker

Transmission line protection:

- Differential relays or three-phase minimum impedance relay with fault location facility.
- Three phase over current relay.
- Earth fault relay.
- Three-phase fast reclosing relay.
- Synch-check relay.
- Fault relay for the circuit breaker

Bus bar protection:

- Bus bar earth fault relay.
- Bus bar differential relay

Fault recorders

The fault recorder functions must provide records for fault analysis in the “Standard Common Format for Transient Data Exchange (IEEE-COMTRADE)” Necessary signals from the transformers will be included.

3.10.12 *Telecommunications*

Communication to dispatch centre

Communication to the regional and national load dispatch centres (LDC) will follow the HV transmission lines. The communication system will be designed for speech signals, telecontrol signals and protection signals. Provisions for a future remote control of the power plant via the telecontrol communication channels are foreseen. A communication systems based on Optical Fibre in the Ground Wire (OPGW) is recommended. With OPGW on all HV line there should be no need for power line carrier connection on the lines.

Communication to Intake

The main purposes of communication between the powerhouse and the intake are to provide status information from the dam and the intake (e.g. water level and gate positions) to the Station Control System and to provide speech channels for the telephone system.

For the communication a fibre optical link is recommended

The communication between the intake and the station control system is not considered vital for the operation of the plant. Therefore no redundant communication system is foreseen.

Telephone equipment

A state-of-the-art telephone network will be established to provide telephone connection to the entire plant as well as residential camps, workshops, stores, switchyard and intake. The network will have capacity and provisions for connection to the public telephone network and to other parts of the country along the transmission grid.

Contact should be made to a mobile telephone operator to use some of the fibre optic capacity to establish a commercial mobile access point at least covering the residential camps and administration centre but they should also be encouraged to provide wider coverage.

Local radio communication

Both for the construction period and for later operation there will be need for local speech communication. A VHF or UHF radio system based on semi-duplex operation is recommended. During the construction and commissioning phases separate speech channels will be allocated for the various contractors.

Satellite communication

A broadband satellite telecommunications system may be installed during the construction phase in order to provide internet and e-mail access for employer and contractors. In the operational phase, it would serve as redundant communication for operation and control if the OF communication is out of service. Satellite earth station and transmission system must support symmetric duplex link capacity ranging from 64 Kbps to 2 Mbps, using C-band.

3.10.13 *Domestic and Auxiliary Installations*

Lighting and small power

Adequate indoor and outdoor lighting has been assumed, with illumination levels in accordance with recognised standards. Inside the powerhouse, an emergency lighting system powered from the station battery should be installed. The system should operate instantly when the normal power supply fails. Under normal conditions both the emergency and normal lighting will be in operation. These two systems will have totally separated circuits with power supply as follows:

- Normal lighting will be supplied from the station supply system
- Emergency lighting will be supplied from the batteries via redundant d.c / a.c converters
- Back-up power will be delivered from the diesel unit

Both systems will principally have common distributed "on/off" switches. Emergency lighting will consequently not come on automatically in vacant rooms where lights are switched off. However, special consideration should be paid to areas containing escape routes. a.c lighting and small power socket outlets, for 230 V, will be single-phase, connected between phase and neutral of the 400 V system. In order to reduce the number of equipment types and sizes to be stocked as spares, it should be endeavoured to standardise both lamps and fittings. Fluorescent lighting fittings will be preferred everywhere indoor where feasible. For outdoor lighting sodium floodlights with built-in gear for high-pressure sodium lamps are used.

Normal lighting

The normal lighting system will be designed according to the following design criteria:

Outdoor:

Areas with common staff traffic	25 - 50 lux
Other areas such as the dam, intake areas	20 lux

Indoor:

Offices, control rooms, switchgear rooms	400 lux
Storage rooms, corridors, etc	100 lux
Tunnels with common staff traffic	25 - 50 lux
Other tunnels	5 lux
Equipment rooms	200 lux
Machine hall, etc	200 lux

Emergency lighting

The illumination requirements for the emergency lighting will be at least 1 lux all over the related areas. One fixture as a minimum should be installed in each room.

Exit lights

Exit lights should be installed above doors, staircases, etc. During blackouts these will be powered from their internal batteries for minimum 30 minutes.

Security systems

Admission Control

An admission control system is recommended as part of the power plant security system. As a minimum requirement the entire power plant area will be restricted and guarded by attendants. All visitors to the power plant should be recorded. All regular employees of the power plant should carry an identification card, clipped to the shirt pocket. Power plant attendants should accompany all visitors during their stay in the area.

Video surveillance cameras

Cameras for surveillance of selected areas would be installed. In addition to surveillance of entrance areas, cameras can also be used to monitor operation of vital functions such as gates at the intake and position of disconnectors and earthing switches in the 400 kV switchyard. Screens for monitoring would be installed at the station control room as well as in the LDC.

3.10.14 Mini-hydro plant in the Dam

The required minimum discharge of water to the river will be sufficient to run a mini-hydro power plant with a rated output power of 1500 kVA. The output from the plant is transformed to 33 kV level and transmitted by an overhead line to the switchyard service building at the power station area, where it is interconnected to the rural 33 kV distribution network.

3.10.15 Fire safety

The main purpose of the fire safety measures is to minimise the risk of a fire outbreak. Should a fire situation occur, the fire safety measures should minimise the risk of injury to personnel, limit the material damage from any fire and limit the production loss.

Fire safety will be respected in all stages of design and detail engineering and in the choice of materials, type of cables, paintings, etc. The plant willl be divided into appropriate fire cells to stop smoke from spreading and to limit the damage caused by fire. Emphasis will be made to escape possibilities for personnel. Control cables and preferential power cables will be particularly protected against fire. State of the art escape marking and light equipment should be adopted.

Fire alarm system

A central and addressable fire alarm system, based on analogue detection and serial transmission, should cover the entire power plant. The main control and annunciating panel should be located in the power plant control room and a secondary panel and annunciator panel mounted at the entrance of the power house access tunnel. Optical smoke detectors should principally be used in all areas. In areas where occasional smoke and gas may be expected, heat or flame detectors should be considered to avoid false alarms. Alarm bells and flashing lights will be provided. The fire alarm system will be connected to fire doors, fire dampers, control system, etc.

Each generator and step-up will be separately equipped with a set of fire detectors addressed to the main fire alarm panel. Fire alarm from the generator/transformer will automatically stop the actual generator.

Fire fighting

Firewater should be supplied from a tapping of the penstock or from a water reservoir by using pumps. Fire water pipes should be installed in the powerhouse. Hydrants and hoses should be distributed covering all areas.

The powerhouse will in addition be equipped with portable fire protection equipment such as wheel mounted and fixed mounted removable CO_2 extinguishers.

The main transformers should be equipped with high flow water fire fighting systems, deluge type, with a capacity of 15 l/m^2 pr min and must cover the two transformer cells individually. The system will use untreated water from the river.

The deluge central will be placed in the access tunnel, near the transformer hall. The main sprinkler pipe will be designed for the release of all sprinkler circuits simultaneously. Special design of the civil constructions of the transformer hall should be considered (e.g. the civil structures should be designed to withstand an over pressure of 0.5 bar from an explosion in the transformer).

Use of other extinguishing principles, CO_2, foam equipment and others, have been evaluated but are not recommended. Separate state-of-the-art detection consisting of advanced smoke detectors in combination with heat detectors and pressure transmitters should be provided. Transformer room fire dampers should be controlled automatically.

Rescue room

A rescue room will be provided, with medical equipment, first aid kits oxygen containers and masks, escape equipment etc. The rescue room will be ventilated via a separate ventilation duct in the access tunnel.

Battery room

A separate EX proof ventilation fan and a separate ventilation duct will evacuate the air in the battery rooms. The ventilation duct will have a length of minimum 50 m into the cable shaft tunnels.

3.11 Genale GD-6

3.11.1 General

International standards (Norwegian) have been assumed for the technical specification of the HVAC systems.

3.11.2 Ventilation system

The main objectives of the ventilation system are:

- to ensure the cooling of the main power cables in the cable corridor
- to supply the power station with fresh outside air at normal operation
- to remove smoke and gases and ensure the supply of fresh air in case of fire
- to keep the power station relative humidity within reasonable limits

Cable tunnel

Two fans (F1 and F2) situated at the outside entrance of the cable corridor draw air from the cable corridor to cool the power cables. One fan acts as back-up for the other.

Power station - ventilation room

All rooms in the power station should be ventilated. In Genale GD-6 the ventilation room is situated at level 366.2 with ceiling approximately 5 m higher. The room will have a double door to get in the equipment. The ductwork goes through the ventilation shaft located on the downstream side of the staircase and will be distributed to each floor through the corridor between the rock and the outer wall of the powerhouse.

The system in the ventilation room consists of:

- Fan (F3)
- Damper
- Filter
- Cooling coil (to dehumidify and cool the air)
- Heating coil

Fan F3 draws air from the access tunnel. The air is filtered, dehumidified and eventually reheated before it is distributed in the power station.

Air supplied to the power station is transported by means of overpressure through concrete openings equipped with fire dampers. The air is then pressed through the bus duct gallery to the transformer gallery where it is evacuated to the cable corridor.

Ducts

All ductwork will be complete with balancing dampers, fire dampers, silencers, grilles and diffusers. Electrically operated fire dampers will be installed at all ventilation openings both upstream and downstream of fire-resistant zones.

3.11.3 *Sanitation system*

The main objectives of the sanitation system are:

- to drain water from toilets, showers and sinks
- to drain water from fan-coils
- water supply

Drainage from showers, sinks and fan-coils will be transported to the tail water. Drainage from toilets goes to a closed septic tank.

Water supply will be taken from the cooling water reservoir, and should be filtered and disinfected before distribution.

3.11.4 *Cooling system*

Heat emitting components include transformers, switch cabinets, excitation equipment, lightning, etc.

The cooling water room for Genale GD-6 is situated at el. 366.2. The room contains cooling coils, pumps and manifolds.

The cooling coils are supplied with chilled water from the water-coolers. The main objective of the cooling system is to deliver water to a cooling and dehumidifying coil in the ventilation system and to fan-coils at various locations in the power station.

The chilled water circulating system is a closed circuit between the evaporators of the coolers and fan-coils. Water filters will be installed in the closed circuit to avoid growth in pipes and fan-coils

Heat is released to the condensers. The condensers will be cooled by river water drawn from the tail water system of the power plant. The heated cooling water will exit from the water coolers to the tailrace system.

3.11.5 *Piping system*

The functions of the piping system are:

- to supply and drain off river water to the coolers
- to transport cooled water from the coolers to the cooling-coil in the ventilation equipment and to the fan-coils spread out in the power station
- to supply water to the fire extinguishing system in the transformer cells.

The pipes should be in acid-proof stainless steel and isolated.

3.11.6 Sprinkler system for transformers

The sprinkler system for the transformers should be of the deluge-type with a capacity of minimum 10 l/m^2 pr min and must cover transformer cells individually. The system will use untreated water from the river.

The sprinkler central will be placed in the access tunnel, near the transformer hall. The main sprinkler pipe will be designed for the release of all sprinkler circuits simultaneously.

3.11.7 Fire detection system

The fire detection system will be installed to detect and alarm any outbreak of fire or smoke development in the underground power station. The system will identify the location of the fire and will give signals to the Fire-damper Control System.

If a fire is detected in a particular fire zone, the fire dampers will close to seal the ventilation system. The generators will stop after some time.

The continuous inward flow of fresh air in the access tunnel will make this tunnel the safest escape in case of fire. In case of fire in the access tunnel, the fans in operation at the outside entrance of the cable corridor will be reversed.

3.11.8 Automatic control system for air handling equipment

The automatic control system for the air handling equipment will be integrated with the control system for the water coolers and the fan-coil units to form a complete system.

The system will control and survey the air-handling system. Communication with the system will be by means of display and buttons on the sub-station, and from a personal computer (PC) in the control room. Alarms and status reports should be printed out automatically.

The system should comprise the following functions:

- Regulation and surveillance of the fan capacities to maintain constant static pressure in the air-distribution system.
- Regulation of temperature and humidity of supply air
- Control and surveillance of all local fan-coils.
- Control and surveillance of all fire dampers.
- Control and surveillance the pressure drop over the filters.

The control system should survey the values given in Table 3-27 and give alarm when the measured quantity is out of normal range.

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3.11.9 Ventilation and cooling capacity

Table 3-27: Genale GD-6- Ventilation and cooling capacity

Item	GENALE GD-6
Air flow cable tunnel, fan F1 and F2 (m^3/h)	35 000
Supplied air in Power Station, fan F3 (m^3/h)	20 000
Total cooling capacity (kW)	300

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4 POWER SYSTEM

Project drawings D01

Reference is made to Annex 3 E - " Power System and Transmission Lines" in Volume 3 for details, analyses and supplementary back-ground information.

4.1 Introduction

The electricity supply system in Ethiopia consists of two systems; the Inter Connection System (ICS) and the small Self Contained System (SCS). The ICS consists primarily of large hydropower generating facilities supplying the main grid, while the SCS consists of several small isolated distribution systems located far from the ICS. The electricity in the ICS is generated mainly in small diesel stations, but also in a few hydropower plants. In this study, grid extensions associated with the development of Genale GD-6 HPP will be investigated. Although the project is intended for power export to Kenya, connection of Genale GD-6 HPP to the ICS will also be established. In the following a description of the generation and transmission systems in Ethiopia will be given. The purpose is to present a background for the studies on required grid reinforcements associated with the implementation of the Genale GD-6 HPP.

Brief descriptions of the system in Kenya is given in Annex 3 E in Volume 3.

4.2 Description of the Inter Connection System (ICS) in Ethiopia

4.2.1 Existing generation system

The total installed capacity of the ICS is 755 MW. It consists of 668 MW hydro power and about 87 MW thermal power. The thermal power plants are stand-by diesel stations at Kaliti, Awash Town and Dire Dawa. The geo-thermal station Aluto-Langano is presently non-operational due to low pressure of thermal fuels from the fields. The power stations with installed and dependable capacities are shown in Table 4-1 and the map[3] if the Ethiopian grid, see Figure 4-1 at the end of this chapter.

[3] The map is worked out by EEPCo, but is not fully updated.

Table 4-1: Existing power plants

Power Plant	Installed Capacity (MW)	Dependable Capacity (MW)	Average Energy Production (GWh/year)	Commissioned Year
Melka Wakana	153	153	543	1988
Koka (Awash 1)	43	38	110	1960
Awash 2	32	32	165	1966
Awash 3	32	32	165	1971
Finchaa	134	128	640	1973, 2003
Tis Abay 1	11	11	85	1964
Tis Abay 2	73	68	282	2001
Gilgel Gibe 1	192	184	847	2004
Aluto - Langano *) (geo-thermal)	7	7		1999, 2006
Kaliti (diesel)	10	9		2003
Awash 7 kilo (diesel)	30	22		2003
Dire Dawa (diesel)	40	38		2004
Total	755	723	3316	

*) Rehabilitated

In addition to the existing power plants, the three hydro power plants shown in Table 4-2 are under construction and are supposed to be in service in 2009.

Table 4-2: Hydro power plants under construction

Power Plant	Installed Capacity (MW)	Number of Units	Dependable Capacity (MW)
Tekwze	300	4	300
Gilgel Gibe II	420	4	420
Beles	468	4	468

4.2.2 The existing transmission system

The existing transmission system voltages in the Ethiopian ICS are 230 kV and 132 kV. In addition, there are some 400 kV transmission lines under construction. These are scheduled to come in operation in 2009. There are also some sub-transmission lines designed and operated at 66 kV and 45 kV. The 45 kV systems are being phased out in favour of 66 kV systems.

<u>The 400 kV System</u>

Today there are no 400 kV lines in operation in Ethiopia.

However the Beles hydro power project will be commissioned in 2009. This plant is located north-west of the Bahar Dar city and will be connected to the ICS system through a 400 kV double circuit to Bahari Dar III substation. In addition a 400 kV single circuit is constructed from Bari Dar III to Debra Markos.

Gilbel Gebe II will also be commissioned in 2009. This plant will be connected to the ICS system through one 400 kV single circuit line to Sebata substation in Addis Ababa and another 400 kV single circuit line to Gilgel Gebe I.

The 230 kV System

The 230 kV transmission lines are today the back-bone of the system connecting the power plants at Finchaa, Melka Wakena and Gilgel Gibe-1 to the major load centers in Addis Ababa at Gefersa, Kaliti and Sebeta substations, respectively.

Two 230 kV single circuit lines stretch northwards from Addis Ababa (Gefersa sub-station) via Gedo to Finchaa, and continues from Finchaa as one single circuit line via Debre Markos, Bahri Dar to Alamata. Another 230 kV single circuit line goes from Kality substation in Addis Ababa via Cotobe, Combelcha to Alamata. From Alamata there are two 230 kV single circuit lines to Mekele and one double circuit line from Mekele to Tekese HPP.

A 230 kV double circuit line goes from Addis Ababa (Kaliti) to Koka and further to Melka Wakana HPP. From Koka the 230 kV system continues as a single circuit line towards Dire Dawa. Within Addis Ababa (between Gefersa and Kaliti) there is a 230 kV line from Gefersa through Sebeta to Kaliti. This line is part of a meshed transmission system, consisting of 230 kV lines as well as 132 kV lines, around Addis Ababa.

There is also a 230 kV link from Sebeta to Gilgel Gibe and Ghedo

The Southern 132 kV System

From Gilgel Gibe a 132 kV radial goes to Jimma and continues via Agaro, Bedele to Nekemte. From Jimma a 132 kV line goes to Bonga and further to Mizan.

Another 132 kV radial goes from Gilgel Gibe to Hosaina via Alaba and Wolayta Sodo to Arba Minch. From Alaba the 132 kV network continues to Shashemene from where one radial goes via Awasa and Yirgalem to Shakiso. From Shasemene the 132 kV network continues in two directions, one to Melka Wakana with transformation to 230 kV and one via Adamitulu and Assella to Awash. Between Awash II and Koka there is a double circuit 132 kV line, one of which supplies Wonji Pulp & Paper Factory. Koka is then connected by a double circuit line back to Kaliti, one via Debre Zeit, and one via Ilala Geda.

Today the southern 132 kV network is supplied from Melka Wakana, Awash and Gilgel Gibe, and this 132 kV system forms a ring in parallel with the 230 kV system.

The Eastern 132 kV System

From Koka the 132 kV network continues eastwards via Metehara and Awash Town to Dire Dawa. Between Awash Town and Dire Dawa the 132 kV system is not operated in parallel with the 230 kV network due to lack of protection equipment. In Koka there is no transformation between 230 kV and 132 kV.

The 132 kV network in Addis Ababa

In Addis Ababa there are three main 230 kV transformer substations, Gefersa (west), Kaliti (east) and Sebeta in between. One 132 kV line goes directly from Gefersa to Kaliti while another goes from Gefersa via Sebeta to Kaliti.

From Gefersa there is a radial to Addis North and another one to Mugar.

Kaliti is divided in two substations Kaliti II and I. Kaliti II is supplied by one radial from Kaliti I. From Kaliti I two 132 kV lines supplies Cotobie, one via Kaliti North and one via Weregenu. From Cotobie a 132 kV radial continues via Debre Birhan and Robit to Kombolcha. Kaliti I also supplies Addis Centre at 132 kV.

The existing transmission lines

Conductors

The conductor types currently used in the Ethiopian transmission system on 230 kV and 132 kV are given in Table 4-3 below. All transmission lines in Ethiopia are designed for a maximum conductor temperature of 65 °C. The low design temperature in combination with high line route elevations reduce the thermal ratings of transmission lines substantially compared to countries that practice a design temperature of 80 °C and that seldom build lines above 500 - 1000 masl. Due to large variations in altitudes and ambient temperature, the thermal rating of different lines will vary substantially even if the voltage level and conductor configuration are the same.

Table 4-3: Conductor types in use in the ICS

Conductor Configuration	Type	Al or Al-alloy Cross-section *) (mm^2)	Diameter (mm)	Thermal rating **) (MVA)	Thermal rating **) (A)
230 kV					
2 x Zebra	ACSR	428	28.62	488	1225
2 x Ash	AAAC	180	17.40	258	676
Yew	AAAC	480	28.42	222	582
Mallard	ACSR	403	28.96	218	571
Redwing	ACSR	362	27.43	205	539
132 kV					
Ostrich	ACSR	152	17.28	76	331
Tiger	ACSR	131	16.52	70	306
Cochin	ACSR	107	16.85	63	277

*) per conductor **) Referred to max. conductor temperature of 65 ^{o}C

The main reason for all the different cross-sections at the same voltage level is assumed to be the considerable number of different consultants engaged in Ethiopia; using their own (separate) standards.

Present operating conditions

Based on information from EEPCo the present operating conditions of the system is quite satisfactory. The main problem in the operation is too high voltages caused by the long, fairly light loaded lines. The system has a lot of reactors, but they are all controlled manually and some are only switchable by means of disconnectors.

The system is quite reliable with few outages. There are, however, some problems with theft of steel members from towers.

EEPCo has no up-to-date grid control centre, but the system is equipped with an under-frequency load shedding scheme operating as follows:

- at 48.6 Hz 40 MW load in Addis Ababa is disconnected
- at 48.0 Hz additional 30 MW load is disconnected.

This scheme reduces the probability of system collapse during severe contingencies.

4.3 Load forecast for the Inter Connection System (ICS)

The load forecasts (peak demand target cenario from EPSEMPU 2006, and the consultants revised forecast base case) for the ICS system are shown in Table 4-4. As can be seen from the table, the latest figures worked out by the consultant deviate dramatically from the EPSEMPU 2006 forecast.

Table 4-4: Capacity demand (MW) in ICS

EFY	Target Demand Forecast (EP-SEMPY 2006)	Revised Forecast
2005	520	
2006	625	
2007	744	
2008	900	692
2009	1 079	768
2010	1 286	852
2011	1 485	946
2012	1 705	1 040
2013	1 949	1 144
2014	2 229	1 259
2015	2 544	1 385
2016	2 894	1 509
2017	3 270	1 645
2018	3 674	1 793
2019	4 116	1 955
2020	4 602	2 131
2025	8 021	3 189
2030	14 330	4 522

4.4 Power development program in Ethiopia

4.4.1 Planned generation expansion

EEPCo's power generation expansion plan dated June 2006 is shown in Table 4-5 below.

Considering the EEPCo expansion program, the total generation capacity comprising existing plants and planned projects will be about 3700 MW in year 2015. This is about 1150 MW higher than the Target Demand Forecast from EPSEMPY 2006, and about 2300 MW higher than revised forecast. Therefore, if developed for the domestic market only, the above expansion plan might be postponed by many years.

Table 4-5: Generation expansion plan, EEPCo (June 2006)

Power Plant	**No x Unit Size (MW)**	**Capacity * (MW)**	**EEPCo 2005**
Yayu Coal Fired Thermal Plant	2 x 50	100	2010
Gilgel Gibe III Phase 1	4 x 226	1 004	2011
Gilgel Gibe III Phase 2	4 x 226	1 004	2012
Hallele Worabessa	2 x 48.5 4 x 81.5	97 326	2014 2014
Chemoga Yeda	2 x 81 2 x 59	162 118	2015 2015
Total		2 811	

** Total installed capacity*

In addition to the above referred projects there are other generation candidates for future implementation. Examples are Geba, Baro and Guder hydropower projects.

4.4.2 Planned transmission extensions

Based on the above generation expansion program and plans for connecting new areas to the grid, EEPCo has worked out the following transmission line projects for implementation:

Table 4-6: 400 kV transmission lines

Item No	From	To	No of Circuits and kV	length (km)	Status	In Service year
	Gilgel Gibe-III	Wolayta Sodo	2 x 400	80	Planned	2011
	Wolayta Sodo	Kaliti I	2 x 400	270	Planned	2011
	Gilgel Gibe-III	Gilgel Gibe-I	1 x 400	150	Planned	2011
		Total		**500**		

Table 4-7: 230 kV transmission lines

Item No	From	To	No of Circuits and kV	length (km)	Status	In Service year
	Tekeze	Endeselassie	1 x 230	249	Design	2009
	Endeselassie	Humera	1 x 230	285	Planned-	2009
	Melka Wakena	Ramo	1 x 230	288	Planned	2009
	Ramo	Gode	1 x 230	325	Planned	2009
	Sululta	Cotebe	2 x 230	30	Design	2009
	Dire Dawe	Dj. Border	1 x 230	201	Planned	2009
	Addis North Tap	Addis North	1 x 230	5	Planned	2009
	Bedele	Yayu Coal	1 x 230	48	Planned	2010
	Yayu	Metu	1 x 230	42	Planned	2010
	Bedele	Metu	1 x 230	90	Planned	2010
	Mety	Gambela	1 x 230	150	Planned	2010
	Halele	Werabessa	1 x 230	30	Planned	2014
	Werabessa	Werabessa Tap	2 x 230	5	Planned	2014
	Werabessa	Ghedo	1 x 230	79	Planned	2014
	Chemoga Yeda 1	Debre Markos	2 x 230	36	Planned	2015
	Chemoga Yeda 2	Chemoga Yeda 1	1 x 230	9	Planned	2015
		Total		**1872**		

Table 4-8: 132 kV transmission lines

Item No	From	To	No of Circuits and kV	length (km)	Status	In Service year
	Melka Wakena	Yadot	1 x 132	100	Planned	2009
	Ramo	Fik	1 x 132	250	Planned	2009
	Hagere Mariam	Mega	1 x 132	170	Planned	2009
	Nekempte	Gutin	1 x 132	67	Planned	2009
	Sawla	Key Afer	1 x 132	120	Planned	2009
	Aksta	Alem Ketema	1 x 132	100	Planned	2009
	Kaliti I	Addis Center	1 x 132	14	Planned	2010
	Cotebel	Cotebel I	1 x 132	10	Planned	2010
	Kaliti I	Kaliti North	1 x 132	3	Planned	2011
	Kaliti I	Bole Weregenu	1 x 132	19	Planned	2011
	Yirgalem	Wolayta Sodo	1 x 132	60	Planned	2015
	G. Gibe old	Jimma	1 x 132	71	Planned	2015
	Mesobo	Mekele	1 x 132	25	Planned	2015
	Kality I	D. Zeit	1 x 132	30	Planned	2015
		Total		**1039**		

4.4.3 *Power market assumptions and study objectives*

Genale has a large hydropower potential. The annual growth in electricity demand in Ethiopia is too small to justify implementation of the project on near to medium term. Therefore, if developed early, the project will need to supply power demands in neighbouring countries in addition to the domestic market. The present study investigates the generation potential of the project for export to a large power market outside the country, presumably to Kenya. If economically viable, Genale might theoretically replace thermal power generation projects in Kenya.

The transmission study has investigated how to connect Genale to the domestic grid. It is a precondition for the transmission studies that the export capacity will be sufficient to export all power from Genale. Supply to the domestic market will more or less be limited to reserve supply during severe contingencies in the Ethiopian system.

As part of the optimization studies for the transmission lines, costs were estimated for some different conductor size at 230 kV and 400 kV voltage level as presented in Annex 3 E.

4.4.4 *Connection of Genale GD-3 to the grid*

According to the Feasibility study for GD-3, this plant was supposed to be connected to the grid through a 290 km long 230 kV double circuit line to Mega substation close to the border to Kenya. From this substation it was assumed a 400 kV double circuit line to the Wolayta Sodo substation and the HVDC interconnector to Kenya.

However, the Feasibility Study of the "Ethiopia - Kenya Power Systems Interconnection Project" preformed by Fitchner has now been completed. This study concludes that the HVDC interconnection Ethiopia - Kenya shall start from Wolayta Sodo instead of Mega. Therefore, there is no need for the 400 kV line from Wolayta Sodo to Mega. Hence it is assumed that GD-3 will be connected to Wolayta Sodo.

Two different electrical design alternatives for connection GD-3 to the grid have been evaluated:

- 230 kV design and connection to Wolayta Sodo
- 400 kV design and connection to Wolayta Sodo

A cost comparison of the two alternatives is presented in Annex 3 E, showing that the total annual cost for the 230 kV alternative, including Investment, O&M and value of losses, is approximately USD 15 million higher than for the 400 kV alternative.

It is therefore assumed that GD-3 will be connected to Wolayta Sodo through a 400 kV double circuit line.

4.4.5 Connection of GD-6 to GD-3

Assuming that GD-3 is connected to the Grid at 400 kV level, two different electrical alternatives for connecting of GD-6 have been evaluated:

- 230 kV design and connection to GD-3
- 400 kV design and connection to GD-3

A cost comparison of the two alternatives is presented in Annex 3 E, showing that the total annual cost for the 230 kV alternative, including Investment, O&M and value of losses, is approximately USD 2.5 million higher than for the 400 kV alternative.

It is therefore recommended to connect GD-6 to GD-3 through a 400 kV single circuit line with 2 x Moose conductor.

4.4.6 Transmission system planning criteria and design aspects

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Reference is made to Annex 3 E for fairly detailed considerations regarding selection of planning and design criteria.

4.4.7 Transmission cost estimates

Annex 3E contains cost considerations and estimates in connection with optimization studies and in connection with choice between 230 kV and 400 kV alternatives.

For cost estimate of the recommended transmission system with substations, reference is made to Chapter 11.

4.4.8 Power system analyses

Annex 3E contains power system analyses of GD-3 and GD-6 connected to the grid. Stability analyses are performed in order to investigate transient stability of the two proposed solutions with 230 kV and 400 kV connection of GD-3 and GD-6. The results show that two double circuit 230 kV lines are needed from GD-3 to Wolayta Sodo in order for GD-3 and GD-6 to remain synchronism for a dimensioning disturbance. GD-6 can be connected to GD-3 through one double circuit 230 kV line.

With connection at 400 kV, one double circuit line from GD-3 to Wolayta Sodo is sufficient in order to maintain synchronism at GD-3 and GD-6 for a dimensioning disturbance. GD-6 can be connected to GD-3 with one single circuit 400 kV line, assumed that the dimensioning fault in the system is larger that 240 MW.

Due to loading below SIL, shunt reactors are needed in Wolayta Sodo and GD-3 in order to keep the voltages within the limits defined in the grid code.

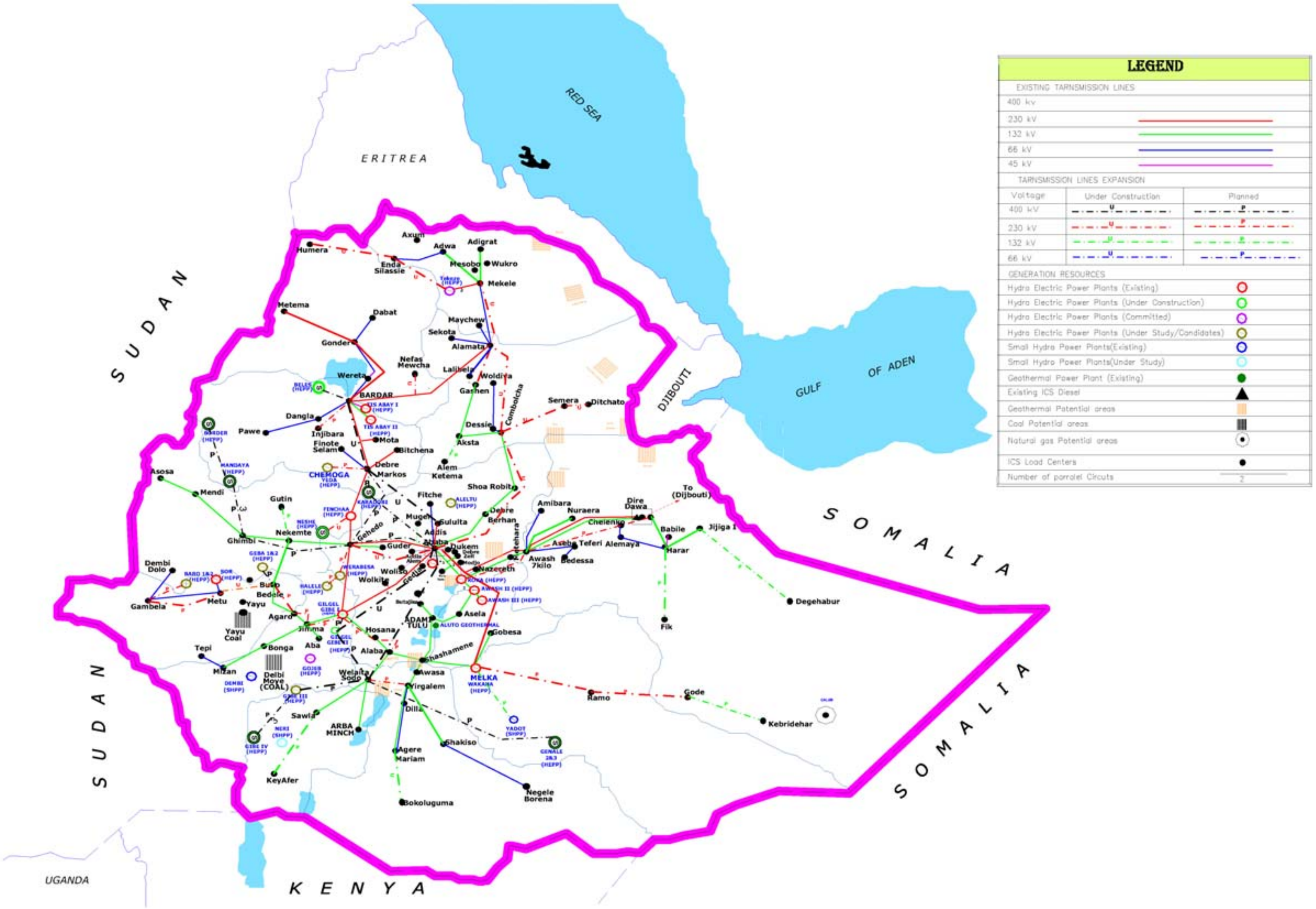

Figure 4-1: Map of Ethiopian Interconnection System (ICS)

5 TRANSMISSION LINES

Project drawings D01 to D05.

5.1 Introduction

This chapter provides technical and economic considerations regarding the design of the 400 kV overhead transmission line between the proposed GD-6 and GD-3 hydro power plants (HPP) including basic design assumptions for the further 400 kV connection from GD-3 to the Ethiopian main grid.

The study has been performed in close co-operation with the power system and environmental impact assessment studies. The main objective of the study has been to ensure that the GD-6 HPP is connected to the Ethiopian grid in a safe, cost effective and reliable manner. In doing this, the studies address various technical, economical and environmental aspects regarding the line route selection as well as design assumptions for the transmission lines.

As accounted for in the power system study a single circuit 400 kV line with twin “Moose” conductors is recommended for the connection between GD-6 and GD-3 while a double circuit 400 kV line with 2 x moose connectors conductors is recommended for the further from GD-3 to be connected with the Ethiopian grid at Wolayto Sodo substation. Typical 400 kV single and double circuit line configurations are shown in Figure 5-1 below.

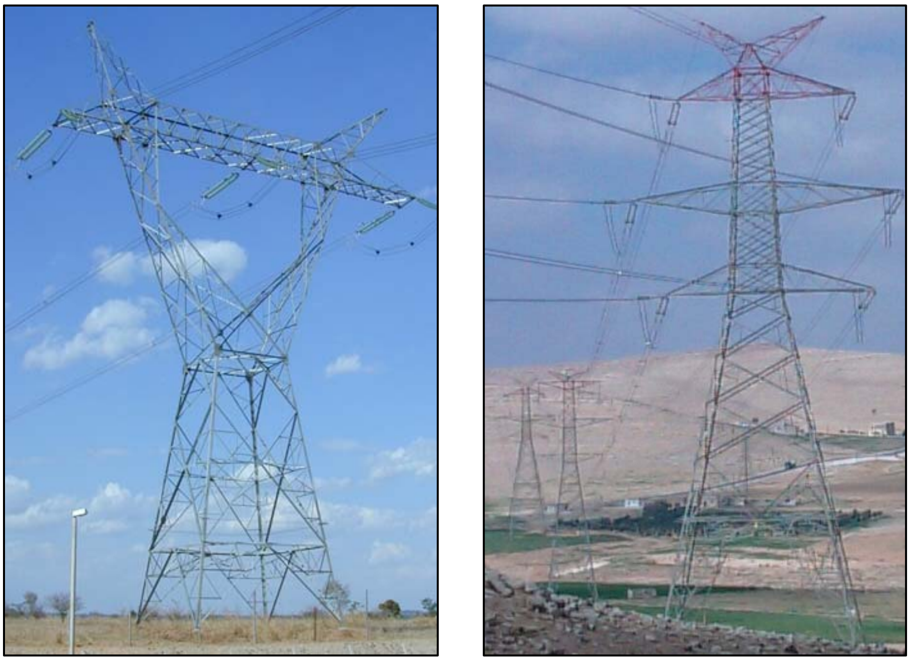

Figure 5-1: Typical 400 kV single and double circuit configurations

5.2 Transmission Line Routes

5.2.1 Connections to GD-3 HPP

In the Feasibility Study for the Genale (GD-3) Multipurpose Hydropower Project (Final Report, August 2007) a system voltage of 230 kV was assumed for the transmission connections to GD-3 comprising two 230 kV single circuit lines from GD-5 and GD-6 and one outgoing 230 kV double circuit line to be connected to the Ethiopian main grid at Mega located approximately 295 km south-west of GD-3

However, as accounted for in the power system analysis the conclusion of the recently finalized Feasibility Study for the “Ethiopia - Kenya Power Systems Interconnection Project” to locate the HVDC converter station at Wolayta Sodo instead of Mega has resulted in that GD-3 also is recommended connected to Wolayta Sodo through a 400 kV double circuit line. In consequence, also the lines from GD-5 and GD-6 to GD-3 are recommended designed for a 400 kV system voltage.

The system voltage upgrade requires the switchyard plan as presented in the GD-3 feasibility report to be expanded due to increased insulation requirements. Further it would be recommended to have the switchyard layout rearranged with the two bays for the outgoing double circuit line to Wolayta Sodo moved to the opposite side of the switchyard (west side) in order to avoid the line to be rerouted through several angle structures in a limited area before continuing straight westwards. The arrangement is indicated on the line route map drawing number D01-4 where both the new alignment for the 400 kV line to Wolayo Sodo and the original alignment for the 230 kV line to Mega is plotted.

5.2.2 GD-5 and GD-6 Reservoirs

The reservoirs for the planned GD-5 and GD-6 hydro power plants influence on the proposed alignment for the 400 kV transmission line from GD-6 to GD-3 recommended to follow the Genale valley on the south side of the river. In order to verify sufficient clearance the reservoirs have conservatively been plotted on the line route maps, drawing number T01-1, -2, -3 and -4 based on a water level (HRWL) of 690 metre for GD-5 and 585 metre for GD-6. Where the line run alongside the reservoirs a minimum height clearance from the HRWL to the line RoW (Right of Way) of 20 metre has been applied.

5.2.3 Line route GD-6 to GD-3

The recommended line route as identified for the 400 kV single circuit line from GD-6 to GD-3 has been plotted on topographical maps in scale 1:50,000 as presented on the line route drawings no T01-1, -2, -3 and -4 assuming a RoW width of 40-50 metres depending on the insulator string applications applied.

The line emerges from the GD-6 switchyard located on the hill above the entrance tunnel to the GD-6 underground power station and is lead westwards on the upper side of the planned access road and 33 kV line to the dam site to reach the GD-6 reservoir after app. 5.5 km.

As the line reach the GD-6 dam site the line enters the technically most challenging sections over a distance of app. 20 km where the line is “pushed” uphill due to the GD-6 and GD-5 reservoirs. On this section some alternative alignments have been identified due to the irregularity of the hill formations and local escarpments close to the reservoirs. Although the more straight line sections identified is technically feasible the final line route is recommended subject to a more thorough investigation during the detail design stage in order to verify the mechanical conductor, tower and span capacities to be within acceptable limits.

Having passed the GD-5 reservoir the valley starts to open up resulting in, with a few exemptions, an easier alignment and from km 58 the line runs straight to reach the GD-3 switchyard at km 76.

Permanent access roads to the RoW is limited to the first and last few kilometres of the line route plus an existing road to a pumping station at Genale river, the road crossing the line at km 35 some 5 km west of the GD-5 reservoir.

Temporary roads during implementation of the project are assumed constructed along the line route. Due to the irregularity in the terrain it is considered not possible to maintain this road within the defined RoW and measures are recommended to be taken in order to limit the environmental impacts in this respect.

The total length of the line has been measured to 76-77 km. However, for cost estimates possible deviations and adjustments during the detail design has been taken into consideration and a total line length of 80 km has been applied accordingly.

5.3 400 kV Single Circuit GD-6 - GD-3 Transmission Line Design

5.3.1 Design standards

It is assumed that the 400 kV transmission line is constructed using International Competitive Bidding (ICB) and that the Contract will be a turn key contract where the detailed design will be the responsibility of the Contractor based on the Employer’s specifications, conceptual drawings and estimated bill of quantities.

It is recommended to use the principles of the International Electrotechnical Commission (IEC) 60826 “Loading and strength of overhead transmission lines” as well as European Standard EN 50341-1 “Overhead electrical lines exceeding AC 45 kV”. Reliability level 2 according to these standards, i.e. loadings with 150 year return period.

5.3.2 Electrical characteristics

<u>Altitude</u>

Although the altitude on sections of the line route reaches close to 1,000 metre above sea level, standard insulation levels are assumed. However, as for the continuing 400 kV double circuit line from GD-3 to Sodo altitudes above 1,000 metre are reached and influence on both the thermal rating and the insulation coordination due to change in air density. Accordingly, a correction factor has to be used for the impulse and withstand voltages as well as air clearances for elevations above 1000 metre.

Pollution

The area is considered only light polluted corresponding to level 2 of IEC 815 with a creepage distance of 19 mm/kV.

Lightening

Isokeraunic values are not available but the number of thunderstorm days per year is estimated to between 40 and 60.

Ground resistance

The ground resistance should be aimed to 25 Ohm except for the first and last three km where the resistance is recommended aimed at 10 Ohm.

Electrical Characteristics

The electrical characteristics for the transmission line are assumed as follows (for altitudes up to 1,000 metre)

Item	Parametre 400 kV	
Nominal voltage	400	kV
Highest system voltage	420	kV
Lightning impulse withstand voltage	1550	kV
Switching impulse withstand voltage	1000	kV
Rated frequency	50	Hz
Minimum insulator creepage distance	19	mm/kV
Maximum shielding angle between shield wire and phase conductor	30°	
Air clearance with no wind	2.80	m
Air clearance with 50 year wind	1.68	m
Conductors maximum operating temperature	75-80	°C
Maximum air temperature (at Roseires)	45	°C
Minimum air temperature	5	°C

Conductor Clearances

The minimum vertical conductor clearances that should be maintained at maximum conductor temperature:

Item	Distance 400 kV
Roads, parking areas etc	9.3 m
Normal land	8.3 m
Other transmission and distribution lines	4.2 m

Phase Conductors

The following physical properties apply for the selected conductor configuration.

Item	400 kV GB-6 – GB-3
Conductors for each phase	2 x ACSR Moose
Cross-section pr. phase	1194.4 mm²
Cross-section pr. conductor	597.2 mm²
Conductor diameter	31.77 mm
Stranding Aluminium	54x3.53
Stranding Steel	7x3.53
Nominal breaking load	161.1 kN
Weight without grease	1.999 kg/m
Rated d.c resistance at 20 °C	0.05468 Ω/km

Shield Wires

The 400 kV transmission line should be designed with two overhead shield wires of which one is assumed to be an optical ground wire (OPGW) with at least 12 single modus fibres for communication purposes. The OPGW should also be designed to withstand the maximum short circuit current approximately 10 kA with maximum temperature 200 °C. Finished fibre attenuation should be less than 0.40 dB/km at 1310 nm and less than 0.23 at 1550 nm.

The second shield wire is assumed to be a galvanized steel wire or an ACS wire with sufficient nominal breaking load and short circuit capacity.

Vibration Dampers

The phase conductors should be equipped with spacer dampers while normal Stockbridge dampers are assumed for the overhead shield wires.

Insulator Strings

Glass or porcelain insulators according to IEC standards should apply. Double string insulators are recommended for all tension strings while various applications should be evaluated during the detailed design stage for suspension strings where the following configurations should be considered:

1. Suspension I-strings on all three phases
2. Suspension I-strings on outer phases and V-string on centre phase

3. Suspension V-strings on all three phases

The optimisation of tower designs and the corresponding insulator string applications is twofold as the RoW width requirement increase from app. 40 metre with V-strings to app. 50 metre with I-strings. For the specific line it is assumed that land compensation is minimal and further that due to the topography the number of tension towers will be high above normal which would favour I-string applications.

Wind pressure

Relevant meteorological data is not available for the actual area. However, for corresponding projects in the region a maximum wind speed of 34 m/s has been applied and is considered reasonable. The detail design has to evaluate if further investigations are required but insignificant deviations are assumed.

The applied wind speed would result in the following wind loads subject to factored loads according to IEC 60826;

- Wind pressure on structures: 86 kg/m^2
- Wind load on conductors: 52 kg/m^2
- Wind load on insulators: 60 kg/m^2

Tower loadings

Tower loading should be calculated according to IEC 60826 and EN 50341-1. The following loadings should be taken into consideration:

- Wind load at 0 ^{0}C applied normal and 45^o to structures with a maximum working tension of conductors and shield wires not to exceed 40% of UTS.
- Construction and maintenance loads.
- Security loads, broken conductor conditions
- Maximum sag at 75 ^{0}C in still air

All towers and their related components are assumed to be capable of resisting any combination of the design basic loads multiplied by a factor of safety of 2.0 in normal conditions and 1.25 in broken wire conditions.

Tower Foundations

Conventional steel reinforced concrete foundations are assumed and steel grillage foundations are accordingly not recommended for this type of line. The detail design is assumed subject to soil investigations to be carried out at each tower location by the selected Contractor. The stability of tower foundations shall be designed for the uplift and compression forces in each tower footing as used in the tower design multiplied by an additional safety factor of 1.1.

The connection between tower and foundation shall be by means of stub angles with bolted-on cleats designed to transfer 100% of the leg loads into the main concrete block comprising the foundation. Accordingly adhesion between the stubs and the foundation concrete shall not be considered as transmitting loads to the foundations.

Grounding

All towers should be permanently grounded in order to avoid dangerous step and touch voltages near towers. The design should be according to IEEE 80 with the earth wires continuously installed. Specific ground resistance has to be measured before construction work starts, and the individual resistance has to be measured as completed, to verify the calculations. The individual tower footing resistance is assumed aimed to be less than 20 Ohm.

Over the first 1.5 km out of any substation or switchyard, all towers, including the terminal towers, should be connected together by continuous counterpoise cable, which also should be connected to the substation / switchyard earthing grid.

5.4 Environmental Mitigation Measures

5.4.1 General

Access and reliability considerations have been primary factors in selection of the transmission line route. For environmental reasons the line route is sought to follow as close as possible to roads and tracks as found technically and economically advisable. Within these limitations internationally recognised environmental recommendations have been applied when selecting the alignment of the line. It should be noted that the final right-of-way to be established during the detailed line survey might deviate from the line route as plotted on the line route map depending on the findings of the detail line survey and soil investigations.

The environmental considerations evaluated when establishing the recommended line route comprise land acquisition, land use, visual impact, electric and magnetic fields impact and impact of construction and maintenance. The extent of these considerations is restricted to issues, which could influence on the technical, economic and environmental feasibility of the transmission line.

5.4.2 Regulatory Controls, Land Acquisition and Land Use

Regulatory Controls

No areas subjected to regulatory controls have been identified being in conflict with the proposed line route.

Land Acquisition and Land Use

The extent of land acquisition is limited to the tower sites where the line passes through cultivated land and farmland. The fact that farming is based on hand planting and harvesting result in the actual area lost for production is small. Although the total tower base area may be up to 10 x 10 meter the unusable area is limited to the four leg concrete columns totalling only 5 m^2 per tower.

The populated areas along the line is scattered and no households have been identified to be reallocated.

Forest loss due to the clearance of the right-of-way is unavoidable. However no forest of commercial value has been identified.

The line clearance is limited to the 40-50 meter wide right-of-way. However, the undergrowth in the right-of-way should be allowed while only leaving a narrow strip to be completely cleared to allow stringing of the line conductors.

Temporary roads during implementation of the project are assumed constructed along the line route. Due to the irregularity in the terrain it is considered not possible to maintain this road within the defined RoW and measures are recommended to be taken in order to limit the environmental impacts in this respect, emphasising erosion problems.

A typical RoW clearing diagram for the proposed 400 kV double circuit line configuration with suspension insulator V-strings is shown in Table 4-2 below.

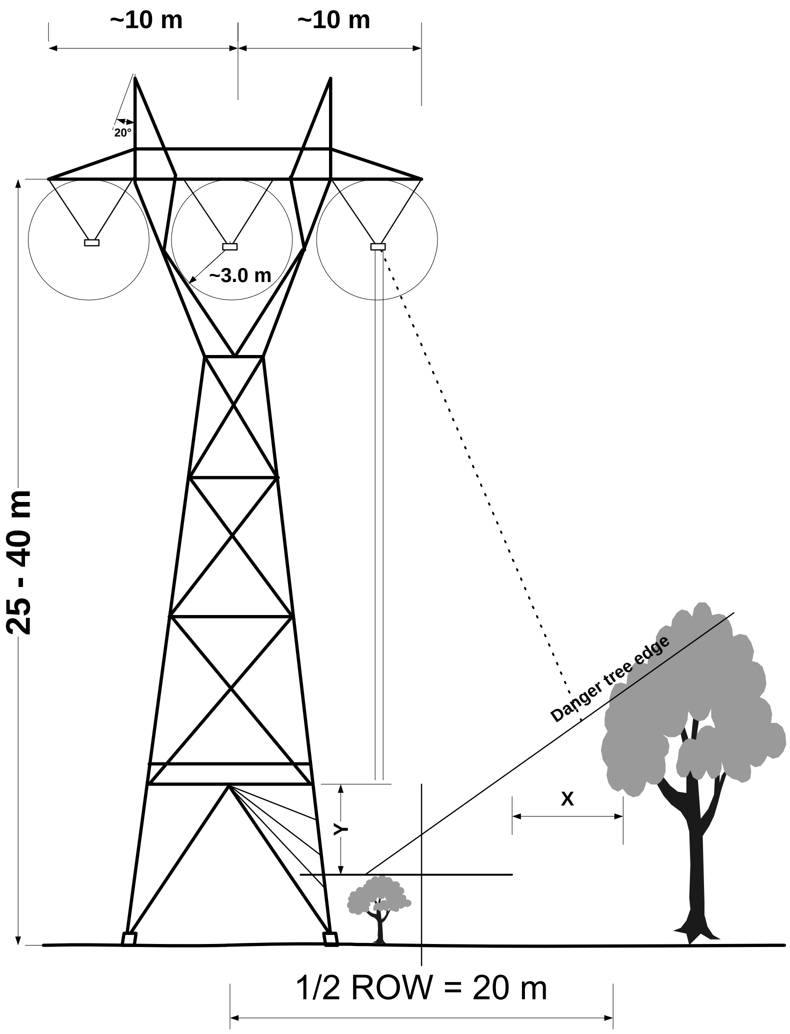

Figure 5-2: Typical 400 kV single circuit RoW clearing diagram

5.5 Substations

5.5.1 Genale GD-6

Genale GD-6 switchyard is described in section 3.10. In summary, it contains two bays for cable generator connections and one bay for the outgoing transmission line. Genale GD-6 is assumed to be connected to the Genale GD-3 switchyard by a dedicated circuit breaker bay.

6 HYDROLOGY, FLOODS AND SEDIMENTS

The detailed description on hydrology and sediments is contained in Annex 3 B in Volume 3. The present chapter summarises the main findings. The key hydrological parameters for the GD-6 site are given in Table 6-1.

Table 6-1: GD-6 Hydropower project. Physical and hydro meteorological parameters

Characteristic	Parameter	Unit	Value
Catchment	Area	km^2	13356
	Elevation site	m a.s.l.	545
	Elevation maximum (peak)	m a.s.l.	3790
	Elevation headwaters	m a.s.l.	3400
	Main river length [(1)]	km	398
	Main river slope [(1)]	m/km	7.2
Rainfall	Catchment [(1)]	mm/a	1045
	Site	mm/a	440
Evaporation	Reservoir (gross)	mm/a	2100
	Reservoir (net)	mm/a	1625
Inflow	Mean (1984-2007)	m^3/s	102.2
	Mean runoff	mm/a	242
Design floods frequency (daily peak)	20-year [(2)]	m^3/s	950-1150
	100-year[(2)]	m^3/s	1300-1700
	1,000 year [(2)]	m^3/s	2000-2500
PMF	PMF (natural/routed)	m^3/s	3900/2550
Sediment transport	Specific yield at	$Ton/km^2/year$	214
	Annual inflow, including 20% bed load	MT/year	2.36

(1) Parameters estimated in the course of PFS(2006)
(2) Natural conditions (without GD-3)

6.1 Introduction

The main objective of the Hydrological Study was to reassess climatological and hydrological characteristics of the study region and to produce a set of hydrological design parameters for the Genale GD-6 hydropower project on the Genale River. The scope and methodology of the hydrological studies has been adapted to the requirements of the feasibility level. This study has been conducted during the period May 2007–September 2008. The work was completed with the valuable support of the personnel of Hydrology Department (HD) of Ministry of Water Resources (MoWR).

The area covered by the hydrological study included the Genale river basin, as defined by the following sub-basins and river reach sections.

- Genale basin down to Genale GD-3 dam site.
- Incremental basin and main river reach between Genale-3 and Genale GD-6.

This study was carried out based on the assumption that the upstream GD-3 project with principal reservoir storage shall be constructed in advance or parallel to the GD-6, making the reservoir of GD-3 available from the first year of operation.

6.2 Scope of hydrological investigations

The GD-6 Pre-Feasibility Study derived regional climatologic and hydrologic characteristics of the Genale basin appears reliable. Hence, the main emphasis of the current study was dedicated to:

- Extension up to date of hydrological data sets
- Quality assessment and compilation of primary hydrologic data i.e. water level records and discharge measurements of the key Genale River gauging station at Chenemasa
- Design and execution of a flow and sediment measurement programme at the Chenemasa gauging station
- Re-evaluation of ratings of the Chenemasa hydrometric station
- Refinement of GD-6 inflow series
- Reassessment of design flood estimates

6.3 Genale river basin

The Genale River has a basin area of some 57,500 km^2. It constitutes the largest sub-basin within the Genale-Dawa river system. The system discharges to the Indian Ocean. The Genale River originates from the southern slopes of the Bale Mountains massif in the north-east and from the Sidamo Mountains in the north-west. The GD-6 sub-basin encompasses a relatively small area of some 13,350 km^2 of the upper and mid-sections of the Genale basin. The basin has an elongated shape. Its straight line length down to GD-6 site is around 250 km. The width of the basin varies from some 100 km in the upper part to less than 20 km in the vicinity of GD-6 project.

6.4 Hydrological data base

The Hydrology Department of MoWR is responsible for the operation of discharge gauging stations and the collection of river flow data in Ethiopia. There are 11 discharge gauging stations within the Genale basin, see Table 6-2.

Table 6-2: Hydrometric stations in Genale basin

Code	River	Station Name	Lat.N		Lon.E		Area (km^2)	Elevation (m)
2023	Morodo	Nr. Bona Kike	6	31	38	41	85.9	2140
2022	Ererte	Nr. Bona Kike	6	31	38	41	99.3	2130
2021	Gelana	Nr. Bona Kike	6	31	38	44	376	1960
2010	Logita	Nr. Bensa Daye	6	30	38	45	729	1900
2014	Bonora	Nr. Bensa Daye	6	31	38	48	343	1840
2024	Konkona	Nr. Bensa Daye	6	31	38	49	52.3	1880
2025	Gambetu	Nr. Aroressa	6	22	38	52	270	1510
2026	U.Genale	Nr. Girja	6	12	38	57	3177	1360
2002	Genale	At Chenemasa	5	42	39	32	9190	1120
2011	Genale	Nr. Kole Bridge	4	26	41	50	56135	198
2001	Genale	At Helwei	4	22	41	53	56583	195

The proposed GD-3 and GD-6 projects with respective basin areas of some 10440 km^2 and 13350 km^2 are located in the mid section of Genale basin. Data collected at the Helwei and the Kole Bridge stations have only limited value for description of hydrology of the project sites. These stations are located some 300 km downstream, and they gauge outflow from a basin more than five times larger than the Genale basin delimited at the GD-6 site.

Of the remaining nine gauging stations, seven are located in the upper mountainous part of the basin on major tributaries that form the Genale River. These stations are situated more than 200 km upstream from the GD-3 site. Records of tributaries streamflow are of great value for the description of Genale River flow formation but should only be used as supplementary information for estimation of hydrological parameters of the planned projects.

Only two stations are located on the Genale main river. The upper Genale station near Girja has a basin area of some 3170 km^2. Unfortunately, this station has not yet been rated. In practise, the only station in the Genale basin, which supplies data that can be used directly for estimation of hydrology of the proposed hydropower projects, is the Chenemasa gauging station.

6.5 Flow series

In the course of the present study the Genale daily flow series were updated up to 2007. Initially the revised rating equations were used to re-generate daily flow series at base station. This allowed compiling the series of observed flows at Chenemasa for the period from 1973 to 2007. However due to the dubious quality of Chenemasa streamflows for period 1973-1983, as the basis for derivation of inflow series to reservoirs at the GD-3 and GD-6 dam sites, the 1984-2007 series were used. The salient statistics of the series derived in the course of this study and the prefeasibility series are given in Table 6-3. Monthly discharge values of the established series are given in Annex 3B.

Table 6-3: Statistical parameters of mean annual series of discharge at Chenemasa discharge station

	NORPLAN (1973-2007)	NORPLAN (1984-2007)	Lahmeyer (1973-2004)
Mean annual flow (m^3/s)	89.0	92.2	89.2
Mean annual flow (mm)	305	316.0	306.0
Min. annual flow (m^3/s)	54.9	54.9	57.0
Max. annual flow (m^3/s)	128.2	128.2	134.4
Coefficient of variation (CV)	0.209	0.217	0.219

Transposition of the Chenemasa flow series to the project sites was carried out with help of runoff-elevation relationships derived for the Genale mainstream basin. The resulting monthly mean flow values of the derived series for the GD-3 and GD-6 sites are given in Table 6-4. The tabulated inflow series, including monthly mean and annual statistics, for the project sites are presented in attachments to the hydrology report.

Table 6-4: Monthly mean inflow (m^3/s), Genale-3 and Genale-6 project sites (1984-2007)

	Chenemasa (m^3/s)	GD-3 (m^3/s)	GD-6 (m^3/s)
Basin area (km^2)	**9190**	**10445**	**13356**
Jan	30.2	31.4	33.5
Feb	23.0	23.9	25.6
Mar	22.5	23.4	25.0
Apr	55.2	57.4	61.2
May	105.0	109.2	116.5
Jun	97.3	101.2	108.0
Jul	113.9	118.5	126.5
Aug	154.2	160.3	171.1
Sep	158.1	164.5	175.5
Oct	193.7	201.5	215.0
Nov	104.2	108.4	115.7
Dec	44.4	46.2	49.3
Year	**92.2**	**95.8**	**102.3**
Annual runoff (mm)	**316**	**289**	**242**

6.6 Flood Study

In the Genale basin, the application of the classical approach to flood frequency analysis is to some degree hampered by insufficient amount of required data. Flood frequency analysis has therefore been carried by a Station-year approach. The area-transposition factors were applied to convert the Chenemasa peak flood values to equivalent peak flood values at the Genale. Due to uncertainty of the flood frequency estimates and possible bias, the design floods for particular projects are described in terms of a range of expected peak flood values rather than as a single value.

*Table 6-5: Daily flood peak values for different return periods at the selected projects sites (**natural** floods)*

Project site	**Return period T (years)**				
	10	20	50	100	1000
GD-3 dam	750-850	850-1050	1050-1250	1200-1500	1800-2200
GD-6 dam	850-950	950-1150	1200-1400	1300-1700	2000-2500

Design flood hydrographs at the project sites were simulated with help of the HEC-HMS model. The Probable Maximum Flood is usually defined as a flood that may be expected from the the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study. Hereby, the team ran the HEC simulation for three different scenarios:

1. A stand-alone scenario; considering the PMF at GD-6 site as an independent event from the upstream reservoir storage.
2. A cascade scenario; when the PMF at GD-6 site would be affected in normal operating circumstances by the operation of the GD-3 reservoir. This reservoir would offer a substantial degree of flood retention, attenuation and delay.
3. A cascade scenario-“worst case”. For this scenario, we used the same model setup as in the case 2, but due to the large size of the basin, it was assumed that the PMP event is not concomitant over the entire basin. Particularly the flood hydrograph in the GD-6 incremental basin was generated from the PMF event starting three days after the beginning of the event used in the remaining four sub-basins.

Table 6-6 presents peak flow values at sub-basins control points and the resulting PMF peak discharge at GD-6 site for all three modelling scenarios. The generated PMF hydrographs at the Genale project sites, including also the GD-3 reservoir and GD-3 to GD-6 channel routing procedure, are shown in Figure 6-1.

Table 6-6: Probable Maximum Flood. Outcome of HEC-HMS simulation procedure

Gd-6 basin element	Flow control	Peak (m^3/s)	Time (h)	Peak (m^3/s)	Time (h)	Peak (m^3/s)	Time (h)
		Scenario					
		1		2		3	
Upper Genale	outflow	1710	84	"	"	"	"
Geberticha	outflow	1380	75	"	"	"	"
Geberticha -Iya reach	Inflow	2860	78	"	"	"	"
Geberticha -Iya reach	outflow (routing)	2835	81	"	"	"	"
Iya	Outflow	1055	72	"	"	"	"
Iya - GD-3 site reach	Inflow	3600	78	"	"	"	"
Iya - GD-3 site reach	outflow (routing)	3020	90	"	"	"	"
Incremental GD-3	Outflow	1175	75	"	"	"	"
GD-3 reservoir	Inflow	3740	87	"	"	"	"
GD-3 reservoir	Outflow	3740	87	1345	135	"	"
GD-3 to GD-6 river reach	Inflow	3740	87	1345	135	"	"
GD-3 to GD-6 river reach	outflow (routing)	3190	99	1315	153	"	"
Incremental GD-6	outflow	1450	78	1450	78	1450	126
GD-6 reservoir	Inflow	**3900**	96	**1590**	144	**2590**	126

Inspection of Table 6-6 shows that depending on the modelling scenario the calculated values of PMF at GD-6 reservoir site vary from 3900 m^3/s for natural PMF to 1590 m^3/s for the scenario with operational GD-3 reservoir and simultaneous PMP event over the entire GD-6 basin. The third scenario with the PMP peak rainfall over the GD-6 incremental basin delayed by three days yielded the PMF of 2590 m^3/s.

No single method of PMF analysis is without limitations. The relatively large size of the GD-6 basin (more than 13,000 km^2) and limited amount of rainfall and flow data makes the PMF estimation somehow difficult and subjective. So many parameters define the basin characteristics and hydraulics of runoff that the hydrologic engineer will always need to rely on experience and good judgment. It is the consultant opinion that for the design purpose of GD-6 outflow structures a conservative PMF value of 2500 m^3/s should be used.

The flood analysis was completed by applying the HEC-HMS model to generate design flood hydrographs with return period of 1000 years. The 1000-years maximum daily rainfall frequency values from Hagere Salem and Negele were used for analysis. The same conceptual setup and parameterization of HEC-HMS model was used as in the case PMF derivation. Information about simulated 1000-years peak values at the GD-6 site is given in Table 6-7 The hydrographs are tabulated in Attachment 3.

Table 6-7: 1000-years design flood peak discharges (m^3/s)

Scenario 1	Scenario 2	Scenario 3
1880	850	1110

The hydrograph flood peak generated from1000-year design storm (scenario 1) is some 10% smaller than the lower limit of the 1000-year frequency range of 2000 m^3/s-2500 m^3/s (see Table 6-5). In order to maintain consistency with the frequency values hydrograph ordinates could be scaled by peak ratio of both estimates.

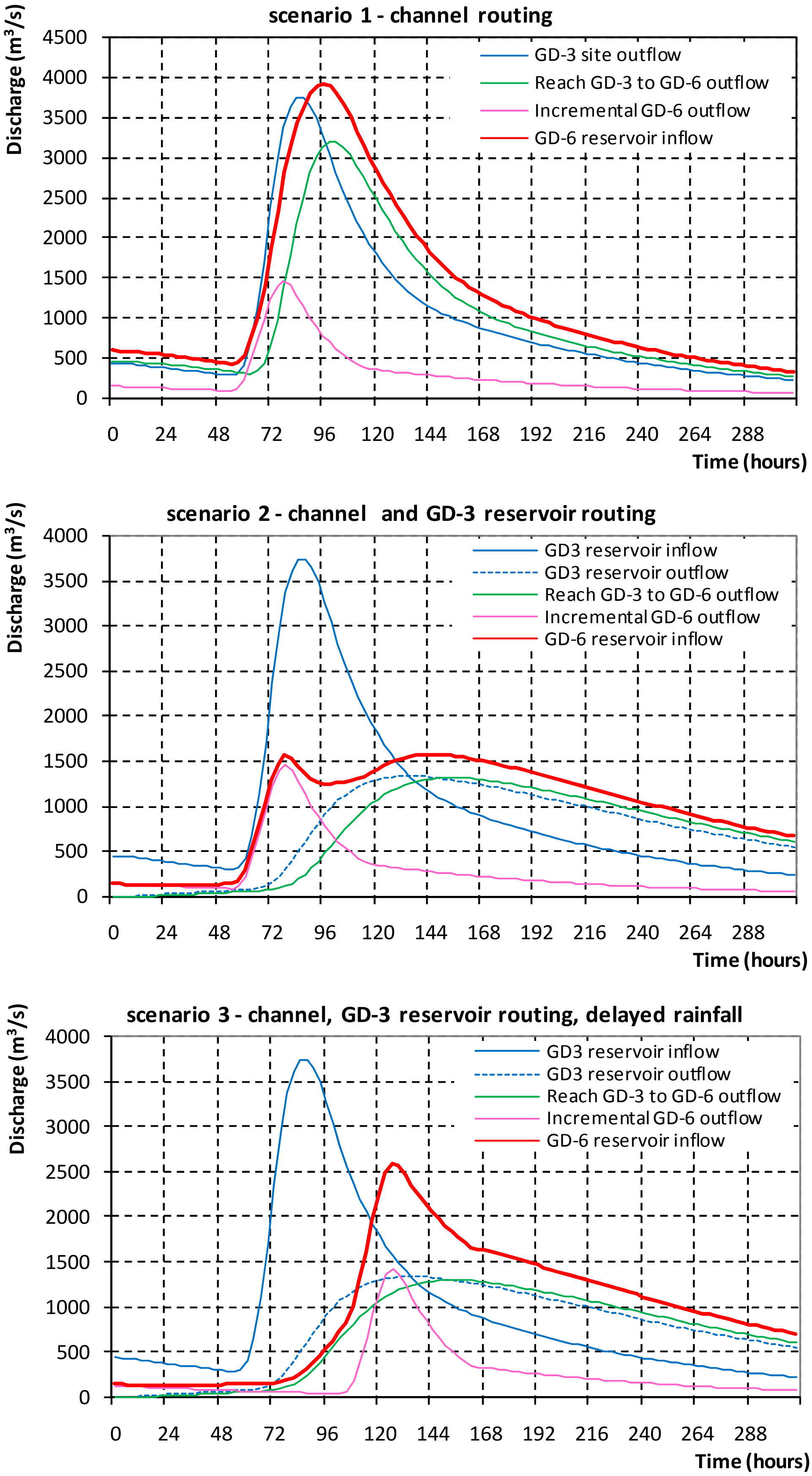

Figure 6-1: GD-6 reservoir; PMF design flood hydrograph

6.7 Sediment transport and reservoir sedimentation

S

The deposited sediment volume and the volume of planned reservoirs left after 50 of operation have been calculated for two modelling scenarios:

- Scenario of stand-alone independent reservoirs which treats the GD-3 and the GD-6 reservoirs independently of each other. It assumes that sedimentation in a particular reservoir is not affected by sedimentation in the other reservoir
- Cascade scenario when sedimentation in the GD-3 reservoir affects the deposition in the GD-6 reservoir.

The principal results of calculations for the stand-alone scenario on assumption of bed load as 20% of the total suspended sediment load are summarized in table below.

Table 6-8: Sedimentation parameters for stand-alone scenario

Hydropower Project		GD-3	GD-6
Suspended load	MT/year	1.61	1.96
Bed load (20% of suspended)	MT/year	0.32	0.39
Total sediment	MT/year	1.94	2.36
Suspended load	Mm^3/year	1.34	1.64
Bed load (20%)	Mm^3 /year	0.22	0.26
Total sediment	Mm^3 /year	1.56	1.90
Trap efficiency	%	96.4	71.5
Sediment deposition	Mm^3 /year	1.51	1.36
Sediment deposition-50years	Mm^3	75.3	68.0
Total Reservoir storage	Mm^3	2621.3	158.8
Reservoir active storage	Mm^3	2344.6	35.1
Dead storage	Mm^3	276.7	123.7
Volume left after 50 year	%	97.1	57.2

The reservoir cascade scenario take into consideration the influence of upstream reservoirs on sedimentation in reservoirs located downstream in the system. For the Genale River the planned GD-3 reservoir has been regarded as a stand-alone, independent reservoir. The planned GD-6 reservoir is located downstream from the GD-3 and its sediment inflow includes two parts: sediment discharged from the GD-3 reservoir and lateral sediment flow from the incremental basin between the GD-3 and the GD-6 reservoirs. The calculation results for the Genale cascade scenario are summarized in Table 6-9.

Table 6-9: Sedimentation parameters for cascade scenario

Hydropower Project		GD-6
Outflow of suspended load from GD-3	MT/year	0.068
Inflow of sediment from incremental basin	MT/year	0.351
Total suspended sediment	MT/year	0.419
Bed load (20% of suspended)	MT/year	0.084
Total inflow of sediment	MT/year	0.503
Total suspended load	Mm^3/year	0.349
Bed load (20%)	Mm^3 /year	0.056
Total sediment inflow	Mm^3 /year	0.405
Trap efficiency	%	71.4
Sediment deposition	Mm^3 /year	0.289
Sediment deposition-50years	Mm^3	14.459
Total Reservoir storage	Mm^3	158.8
Reservoir active storage	Mm^3	35.1
Dead storage	Mm^3	123.7
Volume left after 50 year	%	90.9%

7 GEOLOGY, GROUND CONDITIONS AND CONSTRUCTION MATERIALS

Project drawings E01 to E06 and E-14
Volume 4 with Annexes 4 A – 4 F

7.1 Project geology

Following information is based on geological mapping conducted for the Feasibility study, with support in the publication *Memoir 11, Ethiopian Institute of Geological Surveys - GEOLOGY OF THE NEGELE AREA,* with *Geological map Negele*, 1:250.000, *1998.*

In the area of concern, Precambrian biotite gneiss of the Alghe Group is exposed along the Genale river and overlain by Jurassic-Cretaceous sedimentary formations.

The Precambrian rocks vary in lithology. In some areas these rocks are without the banding or pronounced foliation which is typical for gneiss. Intrusive rocks of mafic composition also occur, especially in the area of the Tailrace tunnel. Degree of weathering in Precambrian rocks is assumed variable, also the degree of fracturing and faulting. In some areas, especially in the area of the headrace tunnel, the rock may be more or less without fractures. The general impression is that degree of fracturing is low, but in some areas pronounced fracturing and faulting was observed. Faults have been identified both in the field and on aerial photographs, apparently with a concentration in the area of the Tailrace tunnel.

The Jurassic-Cretaceous formations Jerder Limestones and Melmel limestones are deposited on top of the Precambrian basement rocks. *Jerder Limestones* comprise mudstones, fossil reef limestones to wackstones, black shales, dolomitic wackstones, pelletal grainstones and sandstones. Map Negele shows presence of gypsum in the Jerder Limestones. Sites of extensive fossil reef limestones (biohermes) are found within the project area. The fossile reef limestones are impressive structureless masses of unevenly textured, moundlike porous rocks, built exclusively of biohermes and highly dolomitized. They belong to the sequence of Jerder Limestones.

Melmel Limestones are informed to comprise pelletal oolitic limestones, mudstones, alternating beds of wackstones, packstones, and packstones to grainstones, conglomerates and chalky limestones.

The width of the exposed gneiss belt along the Genale River shown on Geological map Negele decreases from in the order of 5km at about 75km upstream of the proposed power house site, to in the order of 0.5km at the power house site. This indicates that the gradient of the boundary along the river is somewhat higher than the terrain gradient. Along the about 16 km distance in E-W direction, from intake to outlet, the boundary declines about 200 m, see Figure 7-1. With the suggested project layout, both water ways and powerhouse are situated in the Precambrian basement rocks, well below the boundary.

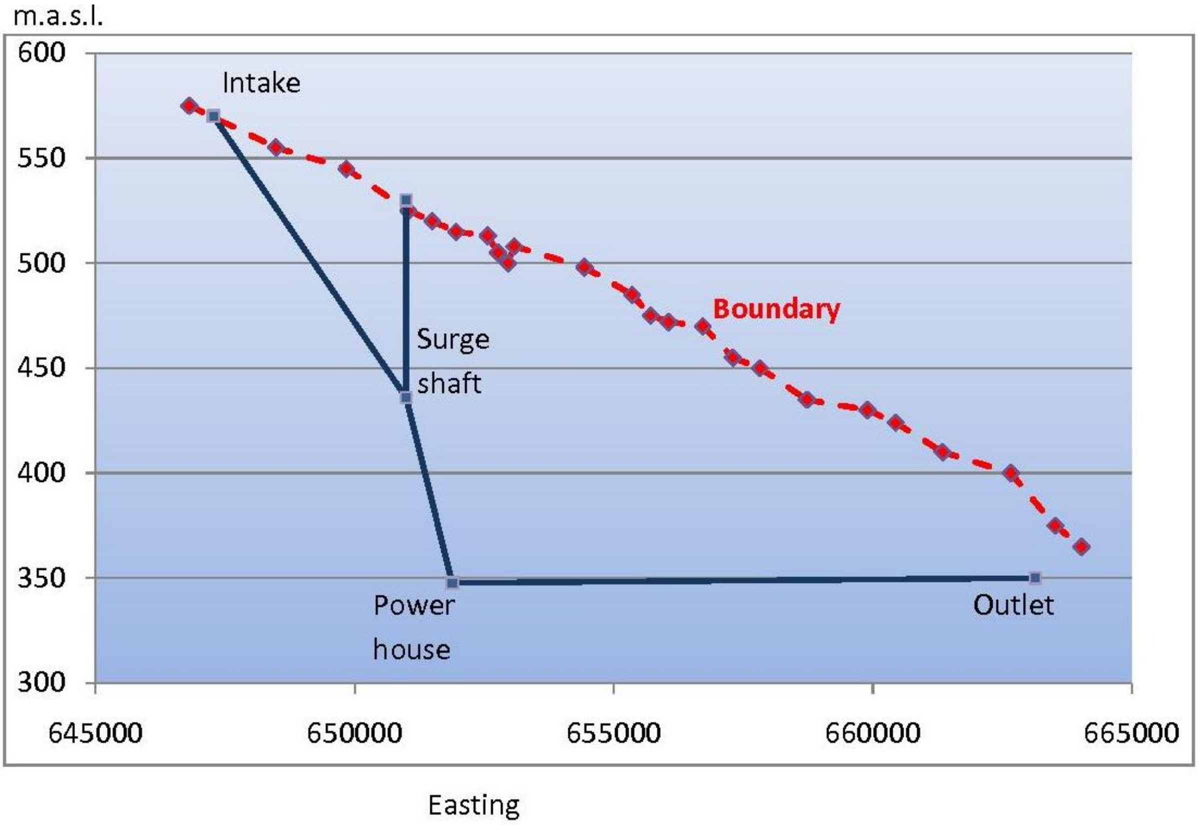

Figure 7-1: East – west section with projection of boundary between the Precambrian basement rock and overlying Jurassic-Cretaceous sedimentary rocks, and of tunnel system.

For detailed description of the project geology is referred to Feasibility Report Volume 4

7.2 Site study and investigations

7.2.1 Aim and strategy for site investigations

The general idea has been to address important geotechnical issues necessary to demonstrate, to a Feasibility study level, the technical and economic feasibility of developing the scheme, with sufficient level of investigations. Initially all relevant information from previous studies of the project area was reviewed and analysed. A critical analysis of sufficiency and quality of information was done, related to the actual construction works, where ground conditions may be critical for the design.

Based on the available, existing information, a “ground conditions expectation model” was developed, see Volume 4, considering how the various construction parts are affected by the character of the ground. In this process, key problems were defined, also potential lack of information in relation to Feasibility evaluations and design of the project. A “ground conditions expectation model” is a prediction obtained by evaluating and analysing the available geological information and placing them in relationship to the project conditions and demands specified in the formulation of the ground conditions issues. An expectation model is "problem oriented" and available information is structured so that the most important physical conditions (of technical or economic significance for the project) are analysed.

In regard to dam foundations, conditions of importance are the thickness and character of soil overburden, topography and character of bedrock, as well as occurrence of potential leakage channels, like high-permeability weakness zones. One consideration is to conclude on necessary excavation depth for the foundation. Another consideration is to define the effect of leakage zones, and to conclude on potential remedial measures. Of importance is also the availability of construction materials.

For tunnels, considerations are suitable location of tunnel portals, sufficient rock cover along the tunnel, tunnelling properties, stability conditions and permeability conditions. These aspects are of importance for the layout / design and for the cost, and if ground conditions are found unsatisfactory for the tentative layout, modifications are needed.

Information on ground conditions has been obtained by various methods, including aerial photo interpretation, geological mapping, and exploratory rotary core drilling. In situ permeability tests were conducted in core drilled boreholes. A number of laboratory tests were conducted on selected rock samples.

7.2.2 Geological mapping

A main concern in the Feasibility study geological mapping has been to properly map the boundary between the Precambrian basement rock and the overlying Jurassic-Cretaceous sedimentary rocks. Accessible locations where the boundary could be observed were identified by use of GPS waypoints. Results from this mapping are presented in Feasibility Report Volume 4 and Annex 4A in Volume 4

7.2.3 Exploratory core drillings

The final program for geotechnical investigations had to be significantly reduced because of budget reasons. The access to the project area and especially the site for drillings is difficult. Most of the drill sites required helicopter to position the drilling rig and transport all necessary equipment. The final budget for the investigations allowed for drilling of 5 bore holes only. The position of boreholes were carefully selected in order to get best possible cost-benefit out the available budget.

Site investigations included 5 core drilled boreholes with a total length of about 245m, including permeability assessment by falling head testing and packer testing. 4 of the boreholes were drilled for investigation of dam sites (FS-1 and FS-2), while a 70 m deep hole was drilled in a depression downstream of the planned powerhouse location.

Rock core samples were selected for laboratory testing and petrographic analyses. For description of rock conditions encountered in the boreholes and the results of the laboratory testing is referred to Feasibility Report Volume 4 and Annex 4A in Volume 4

7.2.4 Exploratory rotary core drilling

The main objective of core drillings at the dam sites was to collect core samples of the materials for assessment of lithological variation and rock mass quality and variation in permeability conditions. Information on variation in rock strength was obtained by laboratory testing of selected rock samples and information on variation in permeability conditions by packer testing in the bore holes.

Exploratory core drillings are listed in Table 7-1. Their locations are shown in location Figure 7-2 and Figure 7-3.

Table 7-1: Rotary core drillings.

BORE HOLE	COORDINATES (GPS)		ELEVATION, m asl (by GPS)	Plunge / azimuth, °	DEPTH DRILLED m
	EAST	NORTH			
BH-1	646511	594442	595	90 / -	54.00
BH-2	646638	594231	590	90 / -	58.55
BH-3	647174	594110	600	90 / -	31.55
BH-4	647391	595114	591	90 / -	30.02
BH-6	652633	593999	520	65 / 252	70.35
Total					244.5

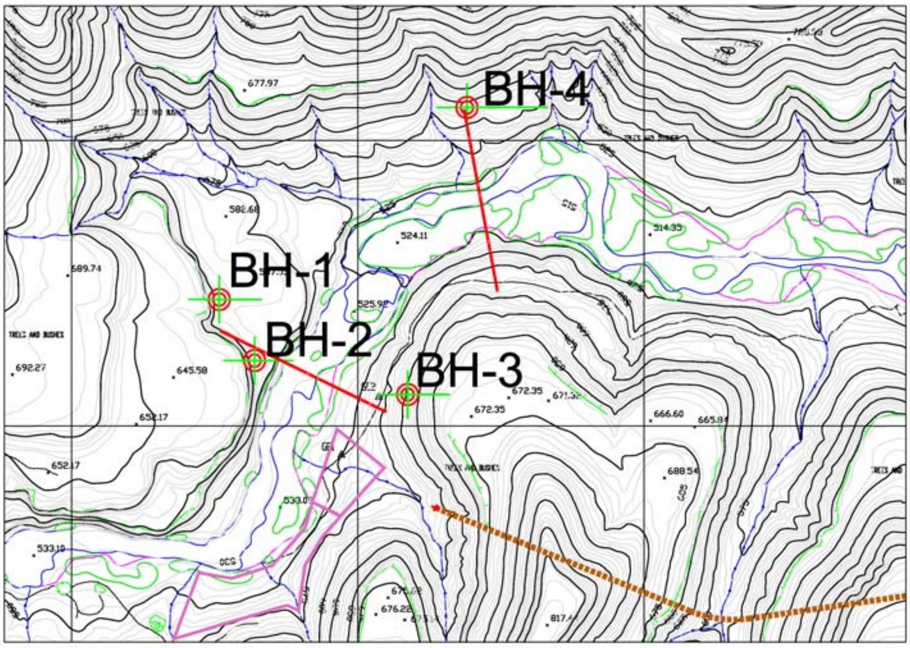

Figure 7-2: Location of bore holes at the potential dam sites FS-1 and FS-2

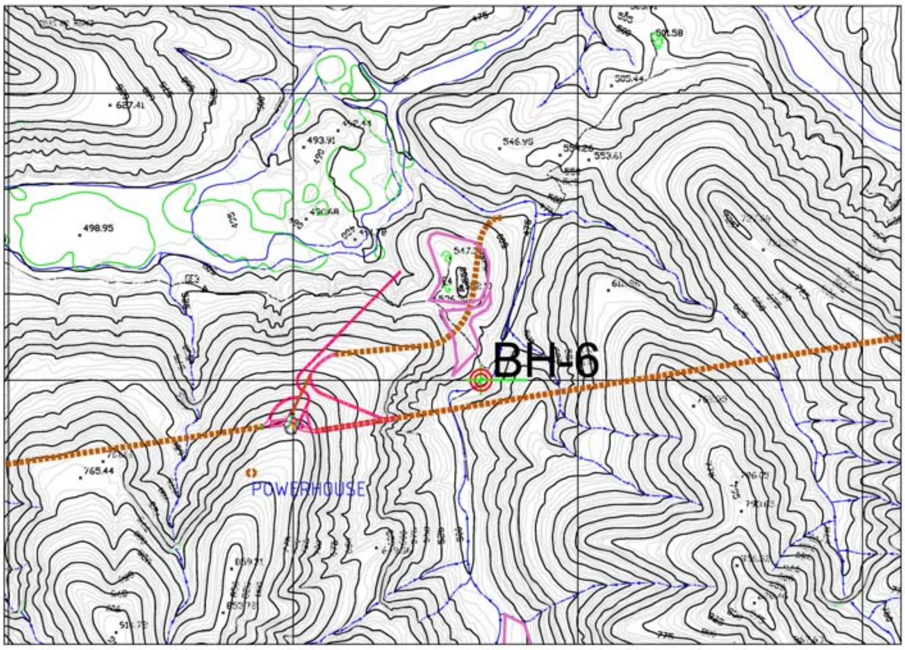

Figure 7-3: Location of bore hole BH-6 in the power house and tunnel area.

Information on thickness of soil overburden, length drilled in sedimentary rocks and in basement rocks, as well as maximum depth measured to ground water table is shown in Table 7-2. For detailed information is referred to the core logs, Annex 4 B.

Table 7-2: Summary of information from exploratory boreholes.

Borehole no. / Length, m	Thickness soil overburden, m	Length in sedimentary rocks, m	Length in basement rocks (gneiss), m	Maximum depth to ground water table, m
BH-1 / 54.00	8,9	41.1	4.0	40.5
BH-2 / 58.55	12	43	3.6	52.0
BH-3 / 31.55	8.0	21.3	2.25	21.5
BH-4 / 30.02	2.5	24.0	3.5	21.1
BH-6 / 70.35	4.0	-	66.35	6.0

7.2.5 *In-situ permeability tests*

Water Pressure testing was carried out using packers, and water injected into a defined section of the borehole in 5 steps applying pressure ranging from 0.5 bar to 5.0 bar. In addition, the falling head testing method was applied.

Detailed results of the test are reported in Annex 4 D in Volume 4 of the report. Summary of the test results are presented in Table 7-3.

The test results show significant variations in the bioherm formation at the dam site FS-1 as well as some variations in the sedimentary rock formation and in the transition to underlying formations. Tests in the 70 m deep borehole in gneiss in the power hose area show practically no permeability at all.

Table 7-3: Summary of field permeability tests in the boreholes

SUMMARY of field permeability test reults.

			Luegon Values				Coeff. of permeability k [m/s]				Comments;
Bore hole no.	Test Section [m]	Material	High	Low	Average	Recomm-ended	High	Low	Average	Recomm-ended	
BH1-1	8.5 - 12.4	Bioherm, weak and friable							5,2E-07		Falling Head Test
BH1-2	19.0-24.75	Bioherm	20	15	16	15	3,2E-06	1,7E-06	2,4E-06	2,4E-06	
BH1-3	40.0-44.65	Basal Conglomerate	2,2	0,3	1,5	2,0	3,3E-07	4,3E-07	2,3E-07	3,0E-07	
BH1-4	40.0-54.0	Fresh feldspatic gneiss and Conglomerate	2,8	1,4	2,2	2,2	6,6E-07	3,2E-07	4,8E-07	5,0E-07	
BH2-1	10.3-15.0	Fractured Bioherm							2,1E-07	2,0E-07	Falling Head Test
BH2-2	20.0-25.1	Bioherm, porous	22	18	20	20	4,2E-06	3,0E-06	3,6E-06	3,6E-06	
BH2-3	33.0-37.55	Strong Bioherm, low porosity	28	24	26	26	1,9E-06	1,0E-06	1,4E-06	1,4E-06	
BH2-4	44.1-48.95	Basal Limestone Conglomerate	28	23	26	26	4,7E-06	3,6E-06	4,2E-06	4,2E-06	
BH3-1	10.4-13.0	Fine grained weak Marl							4,4E-07	4,4E-07	Falling Head Test
BH3-2	22.0-33.55	Clay Limestone	1,4	0,6	1,1	0,9	1,2E-07	3,9E-08	8,7E-08	8,0E-08	
BH4-1	8.8-10.5	Weak Marl							5,7E-07	5,7E-07	Falling Head Test
BH4-2	12.0-16.5	Marl upper part, Sandston lower part	19	12	16	15	3,6E-06	2,0E-06	2,6E-06	2,6E-06	
BH6-1	40.0-46,37	Massive feldspatic gneiss	0,1	0,0	0,0	0,0	1,4E-08	0,0E+00	2,9E-09	0,0E+00	
BH6-2	46.0-70.35	Massive feldspatic gneiss	0,0	0,0	0,0	0,0	0,0E+00	0,0E+00	0,0E+00	0,0E+00	

7.2.6 *Laboratory testing*

Uniaxial compressive strength testing and / or point load strength testing have been conducted on 18 rock core samples the purpose of classification and assessment of engineering properties of importance for design considerations. In addition to this, tests have been done on specific gravity, unit weight, porosity, water absorption, modulus of elasticity, abrasion and swelling of rocks. Detailed results of all tests are presented in Volume 4.

7.2.7 *Rock mass quality*

<u>Rock strength</u>

According to laboratory testing of uniaxial compressive strengths, the Precambrian gneiss is classified as high to medium in strength, while bioherm is classified as low to medium (see

Table 7-4)

Table 7-4: Uniaxial compressive strength testing of gneiss and of bio-herm

Type of rock	UCS, MPa	ISRM Classification
Gneiss	21.2	Medium
	48.5	Medium
	32.6	Medium
	56.6	High
	55.9	High
	55.9	High
	57.0	High
	63.7	High
	30.2	Medium
Bioherm	21.5	Medium
	7.2	Low
	11.0	Low
	9.1	Low
	4.9	Low
	22.7	Medium

Rock mass classification

For assessment of rock support needs in a tunnel project, a normal procedure is to define the variation in quality of the rock mass. Such classification of rock mass quality is then related to the stability conditions in regard to tunnelling. One commonly used classification system is the NGI-Q system. In this, the physical properties of the rock mass, the ground water behaviour and the rock stress situation are input parameters used for establishing the rock mass quality. Realistic conclusions in regard to rock support prediction are depending on reliable input parameters for the rock-mass classification. Reliable input parameters are again depending on observations or test results of sufficient quantity and quality.

The Genale tunnels are expected to be entirely located within the Precambrian basement rock, see Figure 7-1. Even with the limited information from core drillings within the basement formation, there is reason to expect in general fair to good stability conditions for the tunnels. A tentative rock mass classification has been done, see chapter 7.2.7. On basis of information from rock exposures along the Genale river and from exploratory drillings, some ideas about variation in rock quality are obtained. and have been used as basis for a highly tentative assessment of rock support needs, see Table 7-5. This distribution is comparable, or with slightly better than the quality distribution suggested In the Pre-feasibility report (35% good, 55% fair and 10% poor, see Table 7-5.

Table 7-5: Tentative rock mass classification for Genale tunnels

Rock quality class	NGI Q value	Headrace tunnel	Tailrace tunnel	Access tunnel	Power house / transformer cavern
		Percentage			
Q1 - Very good to extremely good	≥40	30	20	30	30
Q2 - Good	10-40	40	40	40	40
Q3 – Poor to fair	1-10	25	22	25	25
Q4 – Very poor	0.1-1	5	10	5	5
Q5 – Extremely to exception-ally poor	0.001-0.1	-	3	-	-

The general impression from the geological mapping is that the rock mass quality may be somewhat better in the area of the headrace tunnel than in the area of the tailrace tunnel. This is reflected in the suggested distribution in Table 7-5 .

This understanding of rock mass quality is reflected in the rock technical evaluations and cost evaluations done in the present study. The presented expected rock mass distribution is highly uncertain, and more detailed considerations are needed for the Detailed design, based on additional investigations.

7.3 Geotechnical risk

One main risk in the GD-6 project relates to the dam site. The proposed dam site FS-1 (HYGEN 11 in the pre-feasibility study), is topographically the best-suited dam site. However, along the left bank is a huge formation of bioherm, which is a reef limestone (comparable to a coral reef.). Reef limestone is formed by corals or other organic lime materials, and is generally inhomogeneous. Cavities and voids may often have high permeability, be weathered and also be filled with silty, sandy materials. Major questions are i) the extent of leakages through this material if left under or at the side of the dam, and ii) how to prevent leakages or critical seepage under or passed the dam. The extent of the bioherm as well as its engineering properties are of vital importance for the suitability of the dam site and the performance of the dam foundation and consequently also for the cost of the dam. Geotechnical investigation of the bioherm is therefore essential for the selection of the dam site.

Another main risk in the project described in the Pre-feasibility study seemed to be related to the location of boundary between the Basement Complex and the overlying Jurassic-Cretaceous sedimentary rocks, with the tunnel located close to this boundary. As described above, detailed mapping has been done for locating the boundary.

The design has also been modified in order to place the tunnel at a safe depth below the sedimentary rocks, see Figure 7-1. With the present alignment, the tunnels and powerhouse cavern is safely placed within the Precambrian basement.

With reference to the geotechnical categorisation shown in Table 7-6, the underground constructions are concluded to be of Geotecnical category 2, both in regard to construction and in regard to operation. The tunnel of the Pre-feasibility study was considered to be of Geo-technical category 3.

Table 7-6: Geotechnical categorisation, in agreement with European Standard 1997 - Eurocode 7 – Geotechnical Design

Geotechnical category	Structure	Ground conditions
1	Small, simple, straight-forward	Uniform. Adequate character-istics
2	Conventional	Varied
3	Large, unusual. Abnormal risks	Complex, problematic. Poor characteristics

7.4 Design considerations

7.4.1 General layout

In the Pre-feasibility design, the powerhouse was chosen as a sur-face solution. The Inception report suggested that according to avail-able geological information, an underground powerhouse should be a feasible option. Further, the Inception report suggested to consider shifting the powerhouse to an upstream location, in order to shorten the pressurized part of the waterway, and hence reduce the danger of major leakage from the headrace, and accordingly the requirement for leakage preventive measures.

The location of the powerhouse cavern suggested in the Inception report has been maintained in the Feasibility study. With this location of powerhouse, the headrace tunnel constitutes about 30% of the wa-ter way.

One consideration in regard to the optimal location of an underground powerhouse is in regard to rock stability. The location concluded in this study is result of optimization in regard to rock conditions. With this location, the caverns for powerhouse and transformers are placed in the basement rock, at safe depth below the sedimentary formations.

7.4.2 *Dam*

The prefeasibility study concluded the dam site HYGEN 11, (for this study renamed to FS-1), as the most favourable. From a topographic point of view this dam site seems to be the most favourable among all the other potential dam sites. A dam on this site would give the least volume of the dam body, and consequently the lowest dam cost.

The left abutment of a dam at this site FS-1 would, however, be constructed against a bioherm formation. Characteristic for this highly inhomogeneous biologically formed material is the possibility of high porosity and cavities and appurtenant high permeability. Cavities and continuous open canals might contain weak or loose silty sandy materials formed by weathering, which could become hydraulically unstable when exposed to high concentrated local hydraulic gradients. This could cause hydraulic failure and underground erosion with serious consequences. Conventional grouting would not be sufficiently reliable to prevent this risk because the grout would not replace the possible erodible in situ material. Other measures to reduce the risk are expensive. The extent of the bioherm formation at the left abutment has significant impact on total dam cost.

Because of the risk of high cost for treatment of the bioherm, dam sites FS-2 and FS-3 further downstream of FS-1 were studied. Cost estimates showed that the extra cost of constructing a cut-off wall in the bioherm might significantly exceed the increased cost for constructing FS-2 with its larger volume. The Consultant therefore selected to base the Feasibility Study on FS-2 dam site to be on the safe side regarding cost.

The Consultant recommends, however, that the dam site FS-1 should be more closely investigated in connection with the detailed design to get more reliable bases for estimating the extent and the cost of the necessary cut-off structure.

7.4.3 *Headrace tunnel*

The Genale headrace tunnel has a length of about 4,375m. Main idea for excavation is by use of TBM. With a diameter of 9.0 m, the cross-sectional area is 63.6m^2. With a tentative elevation of the intake of 561 masl and of lower end of 350 m masl, the tunnel has a slope of about 4.5°. With alternative excavation method by use of Drill & Blast method, necessary cross-sectional area is 90 m^2.

The headrace tunnel is expected to be located in rock mass consisting of Precambrian gneiss in its full length. Observations in rock exposures and exploratory core drilled boreholes indicate in general moderate to good rock mass quality.

Headrace tunnel is planned to be unlined. Such design gives considerable cost saving, but is conditional of satisfactory rock stresses. Requirement for a stable situation is a minimum principal stress higher than the water pressure in the tunnel. Due to the concluded sufficient rock cover for the pressurized headrace tunnel, a satisfactory condition is achieved in regard to risk for hydraulic breach.

7.4.4 *Power station complex*

Chosen location of the Genale power station cavern is at approximately N593 850, E652 000, with a depth below top of Precambrian basement in the order of 170 m and a depth below terrain in the order of 400-450 m. Dimensions of the powerhouse cavern are L*W*H = 40*17*65 m.

Cavern orientation

The rock stability, and thereby the rock support needs, is affected by orientation of an underground excavation in regard to orientation of weaknesses in the rock mass. Optimal orientation of a cavern is with the walls oriented at an angle with geological weakness planes, i.e avoiding orientation along a major weakness orientation. Potential weaknesses are foliation planes and joints and faults. Based on available information about orientation of geological weaknesses, an orientation of N25°E is considered optimal.

Design of concrete plug, distance from power station

The chosen design is based on the philosophy that the concrete plug with grout curtains shall act as a seal between the unlined headrace tunnel and the drained tunnel system downstream.

The location of the plug as well as the design of plug and grout curtains have to be chosen so that the amount of water passing this seal is below an acceptable limit. Water passing this seal and leaking into the dry tunnels is to be taken care of by suitable drainage systems.

In the design of the concrete plugs, the following has been considered:

- The concrete plugs at the transitions between the unlined pressure tunnel and the steel-lined penstocks should be long enough to keep the hydraulic gradient sufficiently low. Practice in Norway is to let the length of the plug be at least 4% of the head (a hydraulic gradient of maximum 25). With HRWL of 585 masl. and elevation concrete plugs of 350 masl., the water head here is about 235m. A length of 15m is suggested for the concrete plugs at upper end of penstock and at upper end of access tunnel branch to headrace tunnel.

- The next question is the distance from the transition to power station. This distance should be sufficient to give an acceptable low hydraulic gradient along possible leakage routes from the unlined headrace tunnel and into the power station cavern, and will have to reflect local geological conditions. With the chosen design, the distance 50 m from transition to power house wall is about 20% of the head, which is considered conservative. In the detailed design could be considered an optimisation by moderate reduction of this distance.

7.4.5 *Tailrace tunnel*

The tailrace tunnel, with a length of about 11.300 m, is planned to be submerged. Optimal excavation is concluded to be by use of TBM, with drilling starting from the surge chamber in the upper end of the tailrace tunnel. The inclination of tunnel is very minor, with elevation of bottom of tunnel increasing from el. 340 masl. at upstream end to 341 at outlet, i.e. close to horizontal. With a diameter of 9.0 m, the cross-sectional area is 63.6m^2.

Tail water level is planned to be about 350-351 masl.

7.4.6 Reservoir

The reservoir will for the greater part be in the gneiss formation. The gneiss has very low permeability. Generally, the gneiss is dense without with limited number of joints faults.

The soil in the area is dominated of alluvial sand in the riverbed and along the river, or weathering products from the sedimentary formations overlying the gneiss washed down from the sides of the valley.

The weathering products from the sedimentary rock ar partly fin grained silt and sand, with some clay. This soil will have a good sealing effect of joints, which may be open for seepage.

The reservoir's ability to hold water is considered to be excellent.

The soil cover along the sides of the reservoir is relatively shallow. There are no risk of major stability problems along the reservoir. However, minor local land slides without severe consequences may take place by sudden draw down of the water level.

7.5 Methods for tunnel excavation

From a rock technical point of view, it is concluded that tunnel excavation in the Precambrian rock mass can be done either by the traditional Drill & Blast method or mechanically by full-face boring (TBM). Tunnelling method was discussed in the Pre-feasibility Study. It was concluded that TBM method was advantageous due to the length of the headrace tunnel and the homogeneity of the rock mass.

A new analysis of optimal excavation method has been done for the present study, with comparison between TBM and Drill & Blast methodology. It is concluded that for the Tailrace tunnel, excavation by the TBM method seems most favourable. Optimal excavation method for the Headrace tunnel by TBM is less clear. In this study, TBM is presented as the most likely method for excavation of the Headrace tunnel, but Drill & Blast method is considered as a possible option. For other tunnels, like access tunnels, cable tunnel and transport adits, the Drill & Blast method is the concluded optimal excavation method.

The German Tunnelling Committee (Deutscher Ausschuß für Unterirdisches Bauen - DAUB), recommend selection of TBM concept depending on rock mass characteristics as shown in Table 7-7. When combining the available ground information from Genale with the actual types of TBM, the recommendation is to go with an open hard rock type machine.

Table 7-7: Recommendations for selecting and evaluating tunnel boring machines (DAUB)

	Open TBM		**Shielded TBM**	
	Recommended	*Possible*	*Recommended*	*Possible*
Compressive strength (MPa)	300 – 50	50 – 5	50 – 5	300 – 50
Tensile strength (MPa)	25 – 5	5 – 0.5	5 - .05	25 – 5
RQD (%)	100 – 50	50 – 10	50 – 10	100 – 50
Fissure spacing, m	>2.0 – 0.6	0.6 – 0.06	0.6 – 0.06	>2.0 – 0.6

Optimal shaft excavation methodology depends on factors as cross-sectional area and length, but also on the contractor's preference.

For shaft excavation the alternatives are:

- raise climber (ALIMAK)
- reaming from a pilot hole (RBM)
- shaft sinking by Drill & Blast.

For this project, reaming from a pilot hole by use of a Raise Boring Machine (RBM) is proposed for the surge shaft and cable shaft, and emergency shaft, if such will be deemed necessary.

Each of the proposed methods listed have advantages and disadvantages as discussed in Volume 4 of this report.

7.6 Tunnels - rock engineering and rock support philosophy.

7.6.1 Tunnelling properties

Tunnelling properties encompass the mechanical and geological parameters of the rock mass that are relevant for the excavation. These are:

- strength and strength anisotropy of the rock
- content and form of abrasive materials
- frequency, orientation and character of discontinuities
- stress situation

Information on these conditions, based on exploratory core drillings and laboratory testing, is presented in Volume 4.

7.6.2 *Stability conditions / design considerations*

Stability conditions define the need for rock support, and thereby tunnel costs as well as tunnelling progress. The stability conditions may also affect choice of tunnel alignment and tunnel shape. Stability of rock excavations depends mainly on:

- Rock mass quality
- Rock stresses
- Ground water
- Size, geometry and orientation of the excavation

The Precambrian basement rocks are considered suitable for tunnel construction. The rock mass is of sufficient quality and strength for being self-supporting in tunnels and other underground openings. Weakness zones will affect the rock stability and rock support needs and presence of such zones have been considered for Feasibility study optimisation of layout and design.

Joint frequency is expected in general moderate to low outside the fault zones, creating block stability problems where conditions are unfavourable. Unfavourable conditions are characterized by a joint set oriented sub-parallel to the tunnel, and a dip direction into the tunnel. In general, potential failures in the Genale tunnels and caverns are expected to be block failures, where rock blocks in roof and walls may loosen and fall out if not supported. Normally, stable conditions are achieved by use of rock bolting, as spot bolting or as systematic bolting, in combination with sprayed concrete, discontinuous or continuous.

The rock mass in a fault zone may not be fully self-supporting. Depending on fault characteristics as strength, stress situation, occurrence of water and of course width and orientation with respect to the tunnel, various types of rock support is foreseen. This can be either heavy, reinforced sprayed concrete, if necessary in combination with spiling bolts and reinforcement arches, or it can be cast concrete lining. Minor faults with inactive, fine materials may be supported by fibre-reinforced sprayed concrete in combination with grouted rock bolts. Small faults of this type may in some cases be self-supporting in dry tunnels, but may need sprayed concrete as erosion protection in a water-tunnel. In fault zones and zones containing materials with swelling properties, rock support with higher support capacity will have to be used. In cases of fault zones with altered, clayey material, this material may be so weak that it is prone to squeezing. In such cases a structural rock support may be needed, e.g. steel-reinforced sprayed concrete ribs or cast-in-place concrete lining.

7.6.3 *Rock support philosophy*

Rock support is provided to improve the stability in an underground opening. A main principle is to design the rock support in accordance with the actual ground conditions encountered in the tunnel. This requires flexible support methods, which can be quickly adjusted to meet the continuously changing quality of the rock masses. Such flexibility is achieved by the use of rock bolts, sprayed concrete, and cast-in-place concrete lining, either alone or as integral elements of the support.

Rock supporting works are normally carried out in two main stages:

- *Initial support,* which is installed to secure safe working conditions for the tunnelling crew. The types and methods of support to be used are decided in agreement between the engineer and the contractor. The contractor is responsible for the initial support: in practice the working crew decides the amount of rock support necessary for their own safety. The initial support should be designed to constitute a part of the permanent rock support.

- *Additional, or final support,* is installed to meet the requirements for a satisfactory function of the project during its life. The owner determines the additional rock support. Usually, he and his consultant decide both the methods and amounts of support after excavation.

Water tunnels

For water tunnels, special concerns may influence the rock support design. One consideration is the size (cross-sectional area) of the tunnel in relation to the design discharge and consequences of reduction in size of tunnel opening due to block falls. Normally, a certain amount of block falls can be accepted. Another consideration is the risk for unacceptable failures in water tunnels where future access and repair works are complicated. In such cases, the concluded rock support should be on the conservative side.

Shafts

During excavation of a shaft, even small rock falls are a severe risk for the shaft crew, and unacceptable. Sprayed concrete lining in the full length of the shaft, installed continuously with the excavation, will counteract this risk.

Access / cable tunnels

In access tunnels and other underground areas where people stay and work during the operation of the plant, rock falls are unacceptable due to risk for injuries. In cable tunnels rock falls are unacceptable due to the risk for damage on cables / installations. This risk is counteracted by lining the roof of such tunnels in their full length with sprayed concrete.

Power station cavern

Any rock fall in power station caverns and in transformer caverns is unacceptable, due to risk for personal injuries and for technical damage. Normally both the cavern roof and the walls above the machine hall floor is supported by a combination of sprayed concrete and systematic rock bolting. A special concern in large caverns is that excavation is done in stages and that rock support in the walls in one stage has to be done before excavation of the stage below. This is important in view of access possibilities. Another aspect is that the amount of rock support installed has to be sufficient to take care of any potential change in stability condition encountered in the bench below. A conclusion of this is that rock support quantities in the roof and walls in the power station caverns normally should be conservative.

7.7 Construction materials

7.7.1 Concrete aggregate

The gneiss material present and available within the entire project area is considered suitable as aggregates for concrete production. As very little natural fluvial materials, such as sand and gravel of satisfactory quality are available, most of the materials will have to be manufactured by cruising and sorting.

The tunnel spoil from the TBM is basically well suited as concrete aggregates. However, because of the shape of the grains from the driller heads, also this materials needs crushing.

Alkali-Silica reactivity tests have been conducted in the laboratory. The results show that there is no alkali silica reactivity of the gneiss formation used as aggregates with normal Portland cement.

7.7.2 Dam materials.

Materials for the dam and coffer dams will partly come from the tunnel excavation, and partly be quarried in a rock quarry between the intake structure and the dam. Most of the materials will be from the solid gneiss formation.

Materials for filters and transition zones of the dam will be tunnel spoil from the TBM

Aggregates for the asphaltic concrete core in the dam will similarly be manufactured form the gneiss either from tunnel excavation and from the rock quarry.

7.7.3 Spoil from the TBM

It is expected that at least 90 % of the material form the TBM tunnel excavation may be reused as concrete aggregates and dam construction materials.

7.8 Seismic hazard

The Geophysical Observatory of the Addis Ababa University specifically assessed the seismic hazard for a dam site at Genale River (GD-2 and GD-3) in connection with the Pre-feasibility study carried out by NORPLAN in association with Norconsult in 1997-1999. The assessment was carried out according to the methods recommended in the Global Seismic Hazard Assessment Program (GSHAP 1993). The report "Seismic hazard assessment for a dam site on Genale River" issued by the Geophysical Observatory Addis Abeba University; Nov.1998 is enclosed as Annex 4 F.

The Consultant considers that the report is still valid for feasibility level design of GD-6. It recommended that the report should be updated for the final design.

The results of the study are summarised in Table 7-8 showing the Peak Ground Acceleration for horizontal component as fraction of g (gravitational acceleration).

Table 7-8: Peak Ground Acceleration Genale dam sites, rock site.

Return period	**Peak ground acceleration**
100 Years	0,048 g
200 Years	0,058 g
500 Years	0,067 g
1000 Years	0,077 g
5000 Years	0,105 g

According to ICOLD Recommendations (Bull. 72), the site is rated to Hazard Class I, this represents "Low Hazard". Most dams in this hazard class will not experience damage under the MDE (Maximum Design Earthquake). Design Earthquake should be selected at a return period of 200 years, which corresponds to a Design Peak Ground acceleration of 0,058 g, i.e. 0,57 m/s^2 for structures founded on rock. The consequences for the design will be either only slightly stronger concrete or a slightly thicker concrete cross-section. For earth fill or rock fill dams it would mean slightly flatter slopes.

All structures at Genale will be founded on hard rock. No significant deposit of fine sand or silt, which would be susceptible for liquefaction, has been identified close to the anticipated engineering structures.

The stability of the Genale GD-6 dam has been cheeked according to the recommendations in the report.

8 SURVEYING AND MAPPING

8.1 Introduction

For the Genale GD-6 feasibility study, surveying and mapping has taken place at three different levels:

1. Use of existing maps from Ethiopian Mapping Authority (EMA)
2. 1:10,000 scale maps made specifically for the project based on aerial photography
3. Conventional ground surveying for profiling of specific hydropower component sites

In this chapter the various mapping and surveys carried out are described. There is a supporting document, Annex 3F "Surveying and Mapping", in Volume 3 containing various data, reports and results.

8.2 Maps from Ethiopian Mapping Authority

Maps from EMA at two different scales were used on the project:

- 1:250 000 maps - these cover the whole country and were used for investigation of roads and transmission line alignments.
- 1:50 000 maps - these maps cover most of the country and show contours at 20 m intervals. The 1:50 000 scale map; KEFENEY 0540-C2, prepared by EMA based on aerial photography from 1991, cover the whole layout of the power scheme. Other similar 1:50 000 scale maps have been among the main planning tools for the study/design team while dealing with the Genale GD-6 reservoir catchments areas, access roads, other infrastructure related to the project and transmission line routes.

8.3 Project mapping from aerial photography

For the major planning activities, maps at 1:10,000 scale with 5m contours were produces specifically for the project and covered 297 km2. The ground control, aerial triangulation, and cartographic production were carried out by Photomap Ltd. of Kenya. The mapping was based on the EMA aerial photographs at approximately 1:56,000 scale taken in November and December 1991.

The photo control and ground survey were carried out using static GPS observations. In addition to the 20 photo control points, six permanent beacons were established as intervisible pairs as a base for further surveys; two at the proposed dam site, two near the proposed power house and two near the proposed outlet. A survey mark description sheet has been filled out for each of these marks and is contained in the Annex 3F.

The raw data measurements were supplied in World Geodetic System WGS 84 and then transformed to the local UTM system for Zone 37. The following references were used:

Ellipsoid:	Clarke 1880 (modified)
Datum:	Adindan (30^{th} Arc)
Map projection:	Local UTM, Zone 37
Level datum:	Medomena 0540-S3 H=1381.78

The map production took place in Photomap's office in Nairobi. The data capture and photogrammetric compilation was done by Wild, digital plotters which sends the data to the Kork Digital Mapping System graphic software. Final editing was done using AutoCAD and ArcView GIS. All features appearing on the maps are presented in separate layers e.g. roads, buildings, contours, rivers, text etc. The topographic features are 3-dimensional and possess X, Y and Z coordinate values and are suitable for direct input to the consultant's terrain modelling programs. The maps were delivered to the consultant in both paper and digital form as 3-dimensional AutoCAD files.

A survey report and aerial photography film report and map production report from Photomap is contained in the Volume 3, Annex 3 F, "Surveying and Mapping"

8.4 Ground Surveys

Additional topographic surveys have been carried out covering the proposed dam sites in detail. These surveys have been done using total stations and are based on the control points provided during the photogrammetric control. By adopting this technique the Consultant has ensured that the entire mapping program is based on a common grid and datum. The additional surveys have supplemented the digital terrain model such that accurate contours of 1m can be generated for the surveyed area.

Details of the additional topographic survey at the dam sites are described in Annex 3 F in Volume 3 of the report.

9 RESERVOIR OPERATION AND POWER PRODUCTION

Reference is made to Annex 3 A in Volume 3 for the various attachments referred to in the text. The attachments contain data and detailed simulation results. The results given in Attachment 15-17 are for optimisation purposes, and do not include final selection of turbine equipment, and the capacity and energy output is slightly lower than the final.

9.1 Objectives

The objective of the reservoir operation studies was to evaluate reservoir regulation and power plant output for a number of alternative dam heights (full supply levels) and turbine discharges of the GD-6 project.

The configuration of the Genale River hydroelectric schemes is defined by the GD-3 storage reservoir and power plant, from which the downstream power plants, GD-5 and GD-6, without appreciable storage, is driven by pre-regulated flow from GD-3.

The following chapters of this report present a description of the applied methodology, data preparation and results obtained.

9.2 Methodology

9.2.1 Introduction

The Consultant used the Norwegian software model, nMAG2004 for simulation purposes. An introductory description of the model is attached in Annex 3A.

The nMAG 2004 simulation model can be applied to simulate the water balance and flow routing through a system of inter-connected water courses or bodies, comprising river reaches, natural lakes, regulation reservoirs and hydroelectric plants.

The input matrix includes the following main parameters, to be selected by user:

- Reservoir data, volume-area curve, evaporation etc. as described above
- Turbine discharge (m^3/s)
- Nominal gross head, (m)
- Head loss coefficient (s^2/m^5)
- Control point, if minimum flow releases for downstream requirement
- Restriction data, compensation flow etc.
- Operational strategy
    - Annual average turbine discharge
    - Daily and yearly demand curves
    - Daily and yearly energy market prices

9.2.2 *GD-3*

The upstream located Genale GD-3 power plant is designed to Feasibility level by Lahmeyer/Yeshi Ber, 2007. The study concludes with the following key features:

Table 9-1: Summary of project characteristics GD-3

Reservoir	FSL	1120 masl
	MOL	1080 masl
	Volume	2344 million m^3
Average inflow [1)]		$95.8 m^3/s$
Average turbine outflow		$83.9\ m^3/s$
Maximum turbine discharge		$116.0\ m^3/s$
Turbine number and type		3 x Francis
Installed capacity		254 MW
Average energy [2)]		1640 GWh/year
Firm energy		1600 GWh/year

1)Hydrology series 1984-2004
2)Lahmeyer simulation.

In order to evaluate the combined performance of 2 or 3-component schemes in the Genale River Cascade, the GD-3 has to be included in the simulation model to allow for variation in reservoir releases depending on incremental inflows downstream. The simulated regulated inflow to GD-6 is shown in Figure 9-1below.

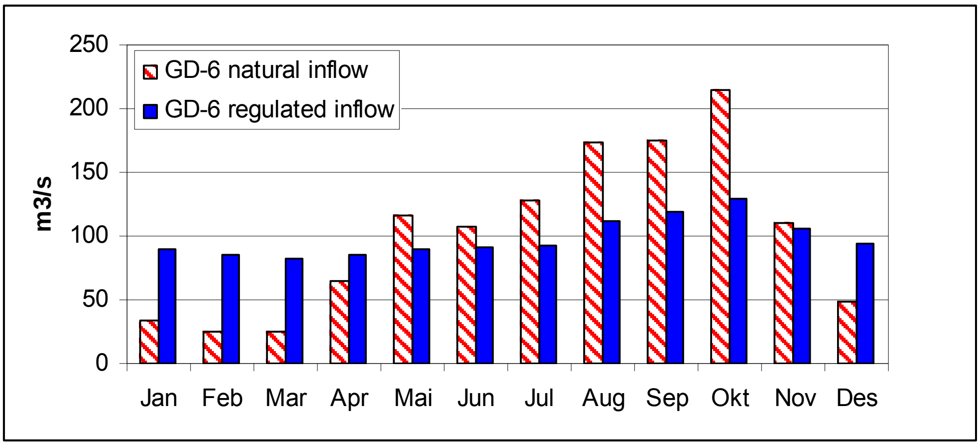

Figure 9-1: Natural and regulated monthly inflow to GD-6

Figure 9-1 shows clearly the regulation capacity of the GD-3 reservoir. The inflow to GD-6 will be well regulated, giving an almost firm inflow to GD-6 simulation model of 84 m^3/s.

9.2.3 *Reservoir operation*

For the present evaluation purpose, the principal aim of the model is to maximise the power and energy generation of GD-3 and GD-6 in combined operation, considering annual and seasonal hydrological variations contained in the inflow series, reservoir characteristics and operation rules, evaporation losses and downstream water requirements.

The reservoir operation is simulated for daily time intervals applying:

- Daily inflow data (m^3/s), with scaling factor from Chenemasa.
- Turbine flow (m^3/s)
- Evaporation, calculated daily, based on monthly average figure.

The relation between reservoir level, volume and surface area is defined according to the reservoir topography as given in Figure 9-2. The regulation of the GD-3 reservoir is set as fixed with:

HRWL 1120 masl, and

LRWL 1080 masl

Reservoir volume 2344 mill m^3

The simulation model optimises the energy output for a given reservoir alternative, by an iterative process. Firm energy is defined on the basis of the continuously generated power, equalled or exceeded for a given percentage of time, 95% (demand coverage of about 98.8% in the model).

The output of the model can be determined by the user, to present results of the simulation comprising tabulations and statistics of the time series of:

1. Inflows for each module, m^3/s
2. Outflow for each module, m^3/s
3. Spill and bypass, m^3/s
4. Reservoir levels and volume, masl and mill m^3
5. Power and energy output, MW and GWh
6. Value of energy, mill USD

All results can be individually selected and stored in data files to facilitate post processing and analysis.

9.2.4 *Power plant*

Daily values of the power output are calculated for each combination of H/Q with the power formula:

$$P = 9.81\, \eta_t\, \eta_g\, Q\, H_n$$

where:

P	generation capacity, MW
η_t	turbine efficiency (function of Q and H)
η_g	generator efficiency (constant or variable with output)
Q	turbine discharge. m^3/s
H_n	net head, m

9.3 Data preparation

9.3.1 Reservoir

The basic reservoir topography is defined by Elevation-Area-Capacity relationships, which for GD-6 were derived from detailed map (5 m contours) of the reservoir area which is described in Chapter 0. GD-3 reservoir curve is taken from the feasibility study.

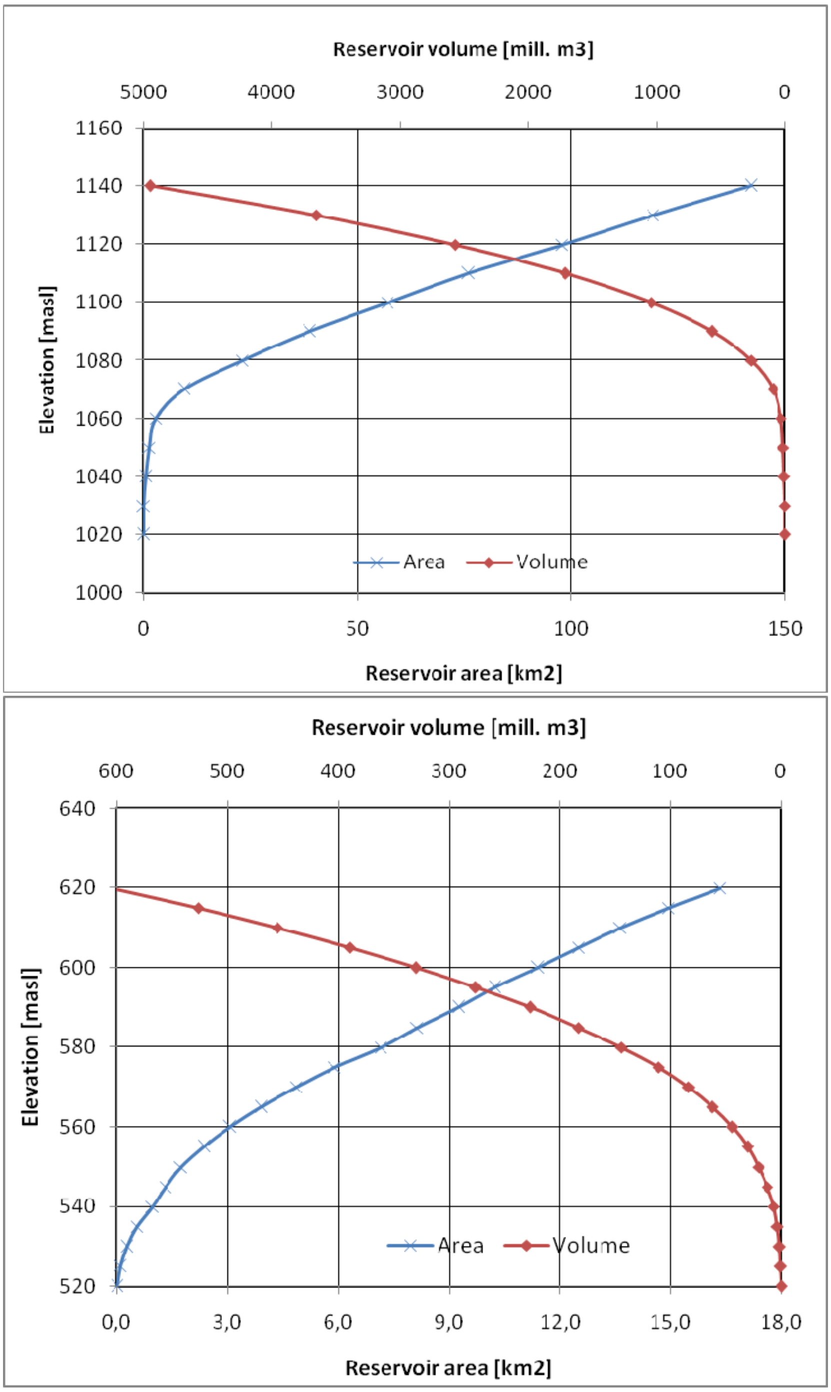

Figure 9-2: Reservoir curve GD-3 (up) and GD-6 (down)

For the GD-6,reservoir, a number of alternative operating limits for:

- Full supply level (FSL)
- Minimum operating level (MOL)

defines the active storages available for the-simulation.

9.3.2 *Operating rules*

The operation of GD-6 is depending of the water release from GD-3, set to be 83.9 m^3/s as annual average, with a maximum turbine discharge of 116 m^3/s. The incremental yearly average inflow between GD-3 and GD-6 is 6.5 m^3/s. The turbine discharge of GD-6 should hence be higher, in the range of 118 to 124 m^3/s.

As used for the calculation of firm power at GD-3, a 95% coverage (time exceedence basis) was applied. A 95% reliability level implies the acceptance of 5% failures over time, or up to 13 monthly deficits within the 24-year simulation period. This equals 98.5-98.8% demand coverage in the nMAG model.

In the event of a deficit, the reservoir reaches minimum operating level and water release is restricted to inflow in that period. The occurrence, magnitude and duration of the deficits are, however, unrestricted in ordinary Firm Energy definition, while in the nMAG the magnitude of the deficit affects the Demand Coverage.

9.3.3 *Hydrological inputs*

All hydrological inputs were determined in the hydrological investigations reported in Chapter 6, and Volume 3, Annex 3 B.

<u>Inflow series</u>

In the course of the present study the Genale daily flow series were updated up to 2007. This allowed compiling the series of observed flows at Chenemasa for the period from 1973 to 2007. However due to the dubious quality of Chenemasa streamflows for period 1973-1983, as the basis for derivation of inflow series to reservoirs at the GD-3 and GD-6 dam sites, the 1984-2007 series were used. The actual flow characteristics are given in Table 9-2 and monthly flows at the respective project sites are shown in Table 9-3.

Table 9-2: Flow characteristics of Genale River downstream of Chenemasa.

Incremental Basin	Chenemasa - GD-3	GD-3 - GD-6
Area (km^2)	1255	2911
Mean elevation (m a.s.l)	1430	1280
Mean annual runoff (mm)	89.6	70.5
Mean annual flow (m^3/s)	3.6	6.5
Mean annual flow at Chenemasa (m^3/s)	92.2	92.2
mean annual flow at site (m^3/s)	95.8	102.3

Table 9-3: Monthly mean inflow at project sites

	Chenemasa (m^3/s)	GD-3 (m^3/s)	GD-6 (m^3/s)
Basin area (km^2)	**9190**	**10445**	**13356**
Jan	30.2	31.4	33.5
Feb	23.0	23.9	25.6
Mar	22.5	23.4	25.0
Apr	55.2	57.4	61.2
May	105.0	109.2	116.5
Jun	97.3	101.2	108.0
Jul	113.9	118.5	126.5
Aug	154.2	160.3	171.1
Sep	158.1	164.5	175.5
Oct	193.7	201.5	215.0
Nov	104.2	108.4	115.7
Dec	44.4	46.2	49.3
Year	**92.2**	**95.8**	**102.3**

The resulting reservoir inflow/outflow series tabulations, including monthly and annual statistics, are presented in Volume 3, Annex 3 A, as Attachment 1-10.

Net evaporation

Net evaporation (loss) from the reservoir surfaces was calculated taking into account total lake evaporation and rainfall incident on the reservoir surface. The derived mean monthly profile for GD-3 and GD-6 is included in Table 9-4.

Table 9-4: Average monthly evaporation loss at the GD-3 and GD-6 dam sites

Month	E_0 (mm)	P(mm)	Net (mm)	Month	E_0 (mm)	P(mm)	Net (mm)
GD-3 dam site				**GD-6 dam site**			
Jan	185	9	**177**	Jan	190	6	**184**
Feb	183	18	**165**	Feb	181	5	**175**
Mar	190	79	**111**	Mar	198	37	**161**
Apr	146	206	**-60**	Apr	161	146	**15**
May	145	143	**2**	May	163	98	**65**
Jun	130	9	**121**	Jun	167	7	**160**
Jul	132	8	**124**	Jul	170	1	**169**
Aug	149	4	**145**	Aug	192	0	**191**
Sep	157	34	**123**	Sep	188	17	**171**
Oct	139	142	**-3**	Oct	163	84	**80**
Nov	150	52	**98**	Nov	149	53	**96**
Dec	170	13	**157**	Dec	175	17	**157**
Year	**1877**	**717**	**1160**	**Year**	**2097**	**472**	**1625**

Downstream water demands

The lower Genale Irrigation Scheme will require an average monthly minimum flow as given in the Genale Dawa Master Plan, see Table 9-5. The water requirement is entered in the model as a minimum release from GD-6. .

Table 9-5: Monthly average water requirement for Lower Genale Irrigation plant

	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Des
Q m^3/s	13.2	7.2	10.6	21.2	22.2	13.8	9.8	15.0	24.7	28.6	26	20.4

9.3.4 *Power plant parameters*

Efficiencies

A standard efficiency curve for Francis turbine was applied. The head range at GD-6 is limited and will not affect the efficiency. Maximum efficiency at the optimal operation point corresponds to 94 %.

A combined efficiency of the electrical equipment was set to a constant value of 97.5 %.

As GD-3 has major change in head, slightly lower efficiency is used for that power plant in the model.

Head loss

The Head loss of the optimised TBM tunnel cross section is calculated to be around 6,0 m. The Head loss shall be entered in the model as a Head loss coefficient in s^2/m^5 correcting the Head loss according to actual turbine discharge.

Tail water rating

The Tail water level fluctuation is included in the calculations as part of the Head loss coefficient. Calculation of a reliable Tail water level curve has been difficult since surveying of the river profile at the tailrace was not possible during the surveying campaigns.

At the turbine discharge of 120 m^3/s, the Tail water level at the outlet reaches 351 masl, increasing to about el. 357 during flood.

Compensation flow

The compensation flow release at GD-6 Dam site is set to 2.5 m^3/s throughout the year.

Firm energy output

The firm energy level is selected as an input to the model by the user. The model then simulates the demand coverage based on the selected level of firm energy. The firm energy is then adjusted by the user, until the demand coverage is 98.8% (95% firm energy).

9.4 Reservoir operation simulation

Given the task of evaluating and comparing a number of alternative project configurations in terms of dam height/full supply level, minimum operating level and installed capacity in GD-6, in-depth analysis is required through repeated simulation for numerous combinations of these parameters.

9.4.1 Alternative full supply level

Power simulation analysis was carried out systematically for four alternative reservoirs full supply levels (FSL) varying between el. 570 – 600 masl. MOL was considered to be 5 – 10 m lower.

Installed capacity variants

The installed capacity of GD-6 fully depends on the outflow from GD-3, 116 m^3/s, and the GD-6 turbine discharge was then varied between 116 – 124 m^3/s in steps of 2 m^3/s.

The turbine discharge varies only from of 1.15 – 1.21 x mean flow.

The result of the simulations is given in detail in a table in Volume 3, Annex 3A, Attachment 15, and a brief summary in Table 9-6, below

Table 9-6: Energy potential of GD-3 GD-6 cascade

Turb. disch		118 m^3/s		120 m^3/s	
FSL [masl]	MOL [masl]	Firm energy [GWh/y]	Average energy [GWh/y]	Firm energy [GWh/y]	Average energy [GWh/y]
570	565	3040	3176		
575	570	3080	3210		
580	575	3100	3244	3100	3246
585	580	3140	3279	3140	3281
585	583	3140	3293		
590	585	3170	3314	3170	3316
595	590	3200	3348	3200	3350
600	593	3230	3383	3230	3385

9.4.2 Comparing minimum operation level

In order to evaluate firm power and energy generation of the cascade development GD-3 and GD-6, simulations were carried out for different MOL reservoir levels. The summary in Table 9-7 below refers to turbine discharge 118 m^3/s and shows that the MOL could be increased from initial estimates.

Table 9-7: Energy output for different MOL's

FSL [masl]	MOL [masl]	Firm energy [GWh/y]	Average energy [GWh/y]
585	575	3100	3257
585	580	3140	3279
585	583	3160	3293
585	584	3160	3297

The table illustrates clearly that the reservoir of GD-6 should be operated at an elevation above el. 583, and being lowered down to proposed MOL just before rainy season only.

9.4.3 Alternative simulation, including GD-5

The Genale River cascade should include 3 projects, GD-3, GD-5 and GD-6. The GD-5 project is studied in the Master Plan, and brief estimates is made as part of this study. The Master Plan concluded on a FSL at el. 690 and the Tail water level at FSL GD-6. This chapter combines GD-5 and GD-6 in a preliminary simulation and optimisation to find the consequences for the FSL for GD-6.

Table 9-8: Key characteristics of GD-5 main option

Reservoir FSL MOL Volume	690masl 685masl 35.3 million m^3
Average inflow	104.0 m^3/s
Tail water level	FSL GD-6
Average turbine outflow	85.0 m^3/s
Maximum turbine discharge	117.0 m^3/s
Turbine number and type	2 x Francis
Installed capacity	100-120 MW
Average energy (GD-5+GD-6)	2210 GWh/year
Firm energy (GD-5+GD-6)	2170 GWh/year
Total cost [1)]	320 mUSD

1)Witht FSL GD-6, el. 585

The volume of the GD-5 reservoir is estimated from 1:50 000 scale maps, and the regulation was set to 5 m, between FSL 690 and MOL 685 as the main option. Detailed simulations of GD-5 shows that a reservoir regulation of 5 m is on the high side, and the potential would increase somewhat, by reducing the regulation height.

The variable data/cost included in the simulation model are:

1. FSL 680-700, dam cost
2. Power station equipment (cost/MW)
3. Tailrace tunnel length, varying with FSL of GD-5

The detailed result of the simulations is presented in Volume 3, Annex 3A, Attachment 16, with a brief summary of the energy output in Table 9-9 for turbine discharge 118 m^3/s. An example of the nMAG result is enclosed in Annex 3A, Attachment 18.

Table 9-9: Energy potential of cascade GD-5 and GD-6

FSL GD-5 (masl)	MOL GD-5 [masl]	TWL GD-5 FSL-GD6	MOL GD-6 (masl)	Firm energy (GWh/y]	Average energy [GWh/y]
680	665	570	565	2110	2143
680	675	580	575	2110	2145
680	675	590	585	2110	2147
690	685	570	565	2170	2209
690	685	580	575	2170	2211
690	685	590	585	2170	2212
700	695	570	565	2230	2275
700	695	580	575	2230	2276
700	695	590	585	2230	2278

1) The simulation was made with demand coverage of 98.5%, and the total Firm energy of the cascade referred in the tables, is on the high side.

The average energy from GD-5 is about 600 GWh/year with GD-6 FSL 585.

9.5 Result of optimisation

9.5.1 GD-3 and GD-6

The result of the optimisation of the cascade GD-3 and GD-6 is summarised in Table 9-10 and Table 9-11 based on an energy value of 6 and 10 USc/kWh respectively.

In the Consultants opinion 6 USc/kWh is on the low side for optimisation of projects with a lifetime of more than 50 years. Considering hydropower projects that should replace thermal plants, some fired with diesel, an energy value of 8-10 USc/kWh is expected to be more relevant in the near future.

Table 9-10: Optimisation of GD-6 reservoir (6 USc/kWh)

Turb. disch		118 m^3/s			120 m^3/s		
FSL [masl]	MOL [masl]	Firm energy [GWh/y]	Average energy [GWh/y]	NPV (mill USD)	Firm energy [GWh/y]	Average energy [GWh/y]	NPV (mill USD)
570	565	3040	3176	724			
575	570	3080	3210	737			
580	575	3100	3244	744	3100	3246	743
585	580	3140	3279	752	3140	3281	751
585	583	3140	3293	760			
590	585	3170	3314	757	3170	3316	757
595	590	3200	3348	753	3200	3350	753
600	593	3230	3383	752	3230	3385	752

Table 9-11: Optimisation of GD-6 reservoir (10 USc/kWh)

Turb. disch		118 m^3/s			120 m^3/s		
FSL [masl]	MOL [masl]	Firm energy [GWh/y]	Average energy [GWh/y]	NPV (mill USD)	Firm energy [GWh/y]	Average energy [GWh/y]	NPV (mill USD)
570	565	3040	3176	1264			
575	570	3080	3210	1290			
580	575	3100	3244	1308	3100	3246	1308
585	580	3140	3279	1330	3140	3281	1330
585	583	3140	3293	1345			
590	585	3170	3314	1349	3170	3316	1348
595	590	3200	3348	1356	3200	3350	1355
600	595	3230	3383	1371	3230	3385	1370

Attachment 15 and 16 in Annex 3A, shows the detailed result of the simulations for optimisation as referred also in chapter 9.4.1 to 3. The attachments also show the preliminary optimisation figures, Net Present Value, for comparing the different alternatives, includes the NPV NPV value of energy, minus the NPV of the variable implementation costs, as:

- Dam and spillway
- Electro- mechanical equipment
- Minor items as gates etc.

Tunnel cost GD-6 is fixed, as only minor change in turbine discharge is considered.

The alternatives including GD-3 and GD-6 show that increasing FSL increases the calculated value of the project. However, the dam cost is more unreliable as FSL increases above el. 580, due to more challenging rock conditions.

9.5.2 *GD-3, GD-5 and GD-6*

The results of the optimisation of the cascade GD-3, GD-5 and GD-6 is summarised in Table 9-12.

Table 9-12: Optimisation of cascade GD-5 and GD-6

FSL GD-5 (masl)	MOL GD-5 [masl]	TWL GD-5 FSL-GD6	MOL GD-6 (masl)	Firm energy (GWh/y] 1)	Average energy [GWh/y]	NPV (mill USD)
680	665	570	565	2110	2143	1904
680	675	580	575	2110	2145	1896
680	675	590	585	2110	2147	1881
690	685	570	565	2170	2209	1949
690	685	580	575	2170	2211	1941
690	685	590	585	2170	2212	1926
700	695	570	565	2230	2275	1990
700	695	580	575	2230	2276	1981
700	695	590	585	2230	2278	1966

1) The simulation was made with demand coverage of 98.5%, and the total Firm energy of the cascade referred in the tables, is on the high side.

The figures show that the highest NPV relates to a GD-5 FSL of 700 combined with GD-6 FSL at el. 570.

9.6 Conclusions

Based on the simulations results of the GD-3 and GD-6 alternative, the FSL of GD-6 should be at minimum el. 585, while including the GD-5 project in the optimisation it could be lowered down to around el. 570.

The Consultant recommends that the cascade development GD-5 and GD-6 should be further studied before a decision to construct GD-6 is taken. The following preliminary conclusion can be drawn for the design of GD-6:

1. Without GD-5
    a. FSL 585 masl
    b. Turbine discharge 120 m^3/s
2. With GD-5
    a. FSL GD-6, el. 570
    b. FSL GD-5, to be further investigated

If there is doubt about the feasibility of GD-5, the alternative 1 should be selected. The FSL of 585, still allows for a future implementation of the GD-5 project at higher expected energy value than what is commonly used today.

9.6.1 Operation strategy

During normal operation of the GD-6 reservoir, the reservoir level should be kept above el. 583 except for periods when rainstorms are expected in the incremental catchment area, or as a reserve in case of draught in the Lower Genale area to supply required water for irrigation.

9.7 Discussion of results

9.7.1 Production statistics

The simulations clearly illustrate the high level of firm energy capacity of the Genale River cascade.

Selection of 120 m^3/s turbine discharge will not increase the firm energy of the project, but allows for peaking operation in the same scale as finally designed at GD-3, see also chapter 9.9.

The firm power output of the GD-3 and GD-6 cascade is 3140 GWh/year, and the result are summarised in Table 9-13.

Table 9-13: Energy output data for GD-3 and GD-6

HEPP	Firm energy [GWh/year]	Average energy [GWh/year]	Average deficit [GWh/year]
GD-3	3 140	1735	48
GD-6		1575	

The monthly average energy output of GD-3 and GD-6 HEPP's are tabulated in Table 9-14 and graphically shown on Figure 9-3.

Table 9-14: Monthly average energy output (GWh)

	GD-6	GD-3
Jan	126.8	147.2
Feb	109.9	129.8
Mar	118.9	137.4
Apr	119.0	132.0
Mai	130.1	141.3
Jun	128.0	137.4
Jul	134.7	143.3
Aug	144.2	151.4
Sep	143.8	150.4
Oct	151.5	156.8
Nov	137.0	148.8
Des	131.6	149.7
Total	**1 575**	**1735**

The firm energy output adding GD-5 to the cascade increases by 755 GWh/year, totalling 3 830 GWh/year, and the results are summarised in Table 9-15.

Table 9-15: Energy output data for GD-3, GD-5 and GD-6

HEPP	Firm energy [GWh/year]	Average energy [GWh/year]	Average deficit [GWh/year]
GD-3	3 830	1 735	56
GD-5		2 275	
GD-6			

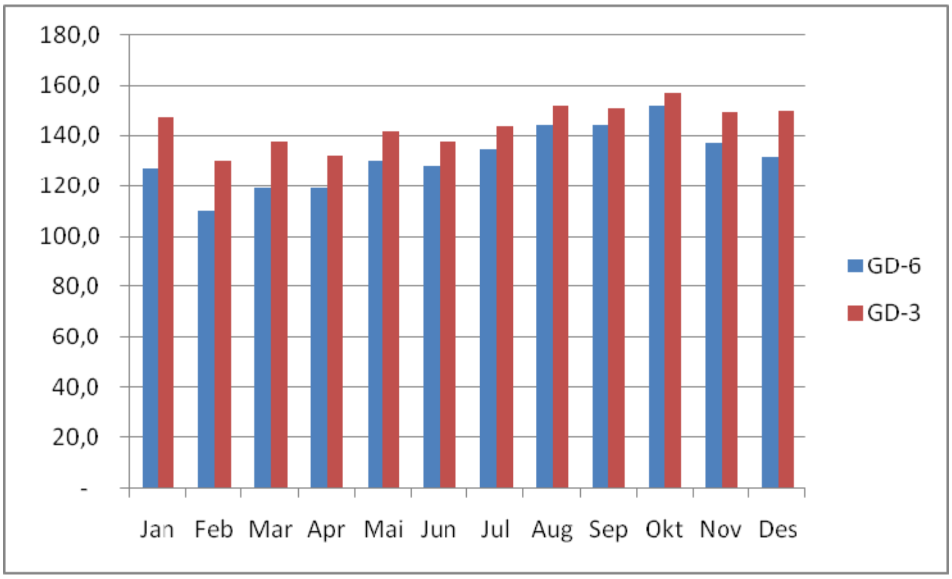

Figure 9-3: Average monthly energy output GD-6 (GWh).

It can be seen that the months with potential deficit energy is during February to April.

Figure 9-4 shows the yearly energy output of GD-3, showing that year 2004 is a year where the reservoir of GD-3 is emptied, and major deficit will occur. The detailed energy output figures, monthly and yearly is given in Annex 3A, Attachment 14 and Table 9-16. Details of the GD-3 output is also referred in detail in Annex 3A.

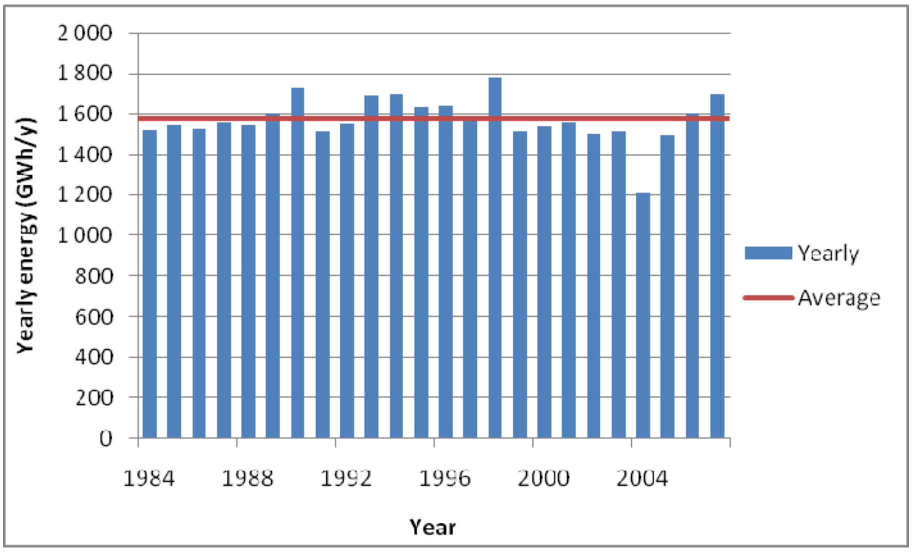

Figure 9-4: Yearly energy output from GD-3 (GWh)

Table 9-16: Detailed energy data for GD-6.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean	Max	Min	Total
1984	128.1	110.5	122.1	118.7	125.2	125.6	129.3	134.6	139.7	136.0	127.3	124.7	126.8	139.7	110.5	1 521.8
1985	122.4	110.3	122.1	122.8	137.4	130.5	137.0	139.3	131.9	136.9	127.4	126.0	128.7	139.3	110.3	1 544.2
1986	122.4	110.5	122.1	121.6	130.3	129.7	133.8	133.7	138.9	136.6	127.3	124.5	127.6	138.9	110.5	1 531.5
1987	122.5	110.5	123.8	125.8	138.3	136.9	135.6	133.7	129.0	141.9	130.3	127.4	129.7	141.9	110.5	1 555.8
1988	123.1	110.6	122.3	120.3	127.8	124.3	133.7	145.2	133.5	151.1	128.0	125.3	128.8	151.1	110.6	1 545.1
1989	122.6	110.5	122.5	124.6	131.6	127.0	132.3	136.6	144.2	151.6	135.1	168.5	133.9	168.5	110.5	1 607.2
1990	138.9	116.1	131.1	128.7	143.7	156.7	152.2	176.0	170.3	164.5	127.3	125.0	144.2	176.0	116.1	1 730.4
1991	122.2	110.1	123.5	123.0	127.8	122.4	130.3	137.7	132.8	131.9	127.3	128.2	126.4	137.7	110.1	1 517.1
1992	126.5	113.7	125.1	120.3	123.5	122.2	131.3	134.7	136.2	157.5	132.3	131.7	129.6	157.5	113.7	1 555.0
1993	131.5	118.9	132.3	127.4	145.6	135.1	131.6	151.0	157.9	176.1	157.4	130.6	141.3	176.1	118.9	1 695.3
1994	124.6	111.9	124.3	122.6	132.7	132.9	143.3	169.4	170.4	176.1	163.7	131.6	142.0	176.1	111.9	1 703.6
1995	126.7	112.6	126.5	128.5	133.4	127.3	131.4	136.4	164.4	176.2	147.9	126.8	136.5	176.2	112.6	1 638.1
1996	123.7	111.3	122.7	123.3	131.8	145.0	138.0	158.1	170.7	164.8	125.9	123.7	136.6	170.7	111.3	1 638.9
1997	123.0	110.5	122.0	122.6	126.7	121.9	131.4	131.7	127.3	145.0	156.6	175.8	132.9	175.8	110.5	1 594.6
1998	166.4	143.9	133.2	123.3	133.2	127.4	139.9	176.0	170.5	176.6	156.7	128.7	148.0	176.6	123.3	1 775.7
1999	123.2	110.5	123.2	119.8	125.7	121.8	130.9	132.3	129.5	147.5	128.7	126.5	126.6	147.5	110.5	1 519.6
2000	122.4	110.1	121.7	118.6	131.1	124.5	128.2	132.3	132.7	149.0	136.8	131.1	128.2	149.0	110.1	1 538.4
2001	123.3	111.0	123.6	122.7	131.3	131.8	135.4	141.2	135.1	139.9	129.4	130.9	129.6	141.2	111.0	1 555.6
2002	123.7	110.5	123.5	121.8	127.9	122.4	129.5	131.4	127.3	131.8	126.9	126.6	125.3	131.8	110.5	1 503.4
2003	125.4	110.6	122.2	122.4	131.5	126.6	130.8	131.2	128.1	134.5	127.1	127.6	126.5	134.5	110.6	1 517.9
2004	125.2	39.4	12.3	92.3	76.9	82.7	121.9	136.9	135.2	137.1	127.5	127.5	101.2	137.1	12.3	1 214.9
2005	123.3	110.7	105.4	56.4	148.4	128.6	135.2	139.9	142.1	146.2	134.5	131.3	125.2	148.4	56.4	1 501.9
2006	123.0	110.8	123.5	126.9	131.6	128.5	137.2	146.4	133.5	150.7	160.8	131.6	133.7	160.8	110.8	1 604.4
2007	129.0	111.5	123.2	121.7	128.9	140.9	152.2	176.2	170.5	176.4	145.1	127.6	141.9	176.4	111.5	1 703.2
Average	**126.8**	**109.9**	**118.9**	**119.0**	**130.1**	**128.0**	**134.7**	**144.2**	**143.8**	**151.5**	**137.0**	**131.6**	**131.3**	**155.4**	**105.6**	**1575.6**

9.7.2 *Operation profiles*

<u>Regulated flows</u>

Figure 9-5 shows the regulation effect of the GD-3 reservoir in which an almost firm flow of 84 m^3/s is maintained throughout the dry season. This represents an augmentation of more than 60 m^3/s above average low-flow rates which occur between February and March.

In the normal high-flow season between August and October, average flow rates are reduced by about 40%.

The flow duration curve before and after GD-3 reservoir is shown in Figure 9-6.

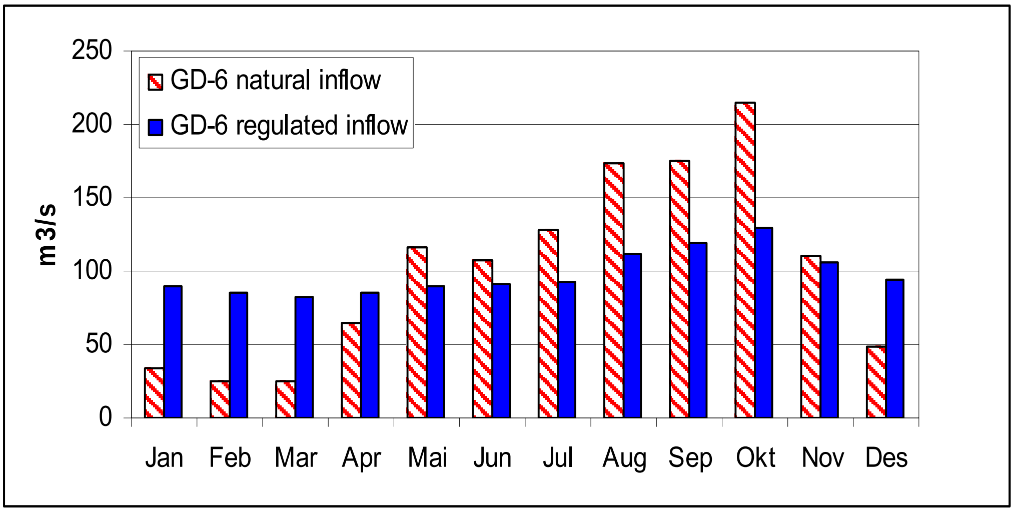

Figure 9-5: GD-6 monthly flow characteristics with and without GD-3 reservoir.

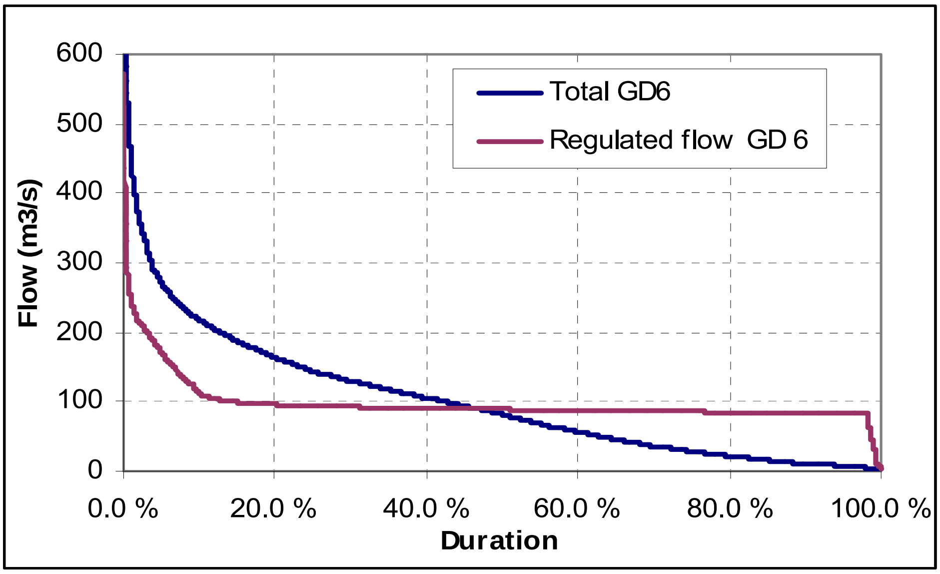

Figure 9-6: Flow duration curve before and after GD-3

<u>Reservoir operation</u>

The following reservoir curves are shown in the next pages

- Figure 9-7: Reservoir level GD-3
  Figure 9-8: Reservoir volume GD-3
- Figure 9-9: Reservoir level duration curve, GD-3.
- Figure 9-10: Monthly mean, max and mIn reservoir level
- Figure 9-11: Change in reservoir volume by year
- Figure 9-12: Reservoir level GD-6

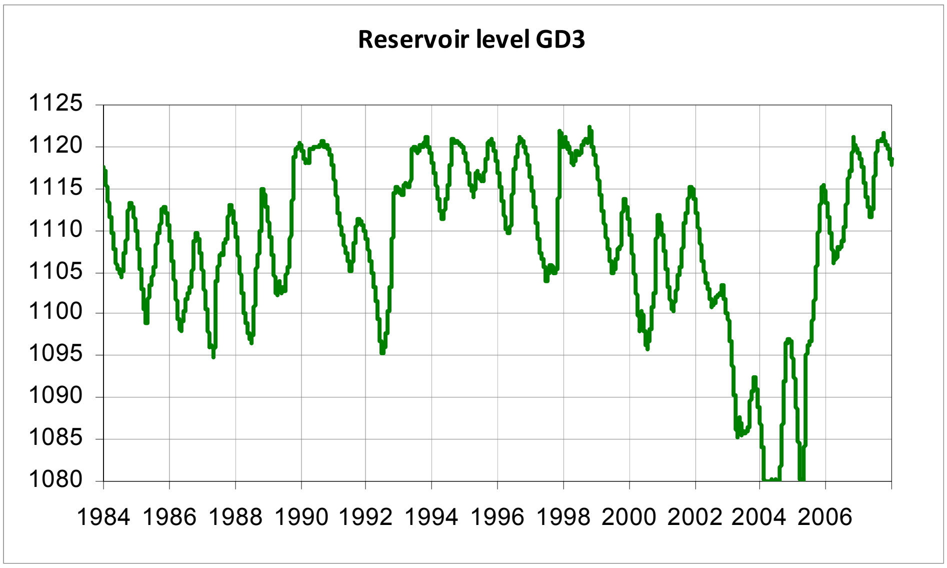

Figure 9-7: Reservoir level GD-3

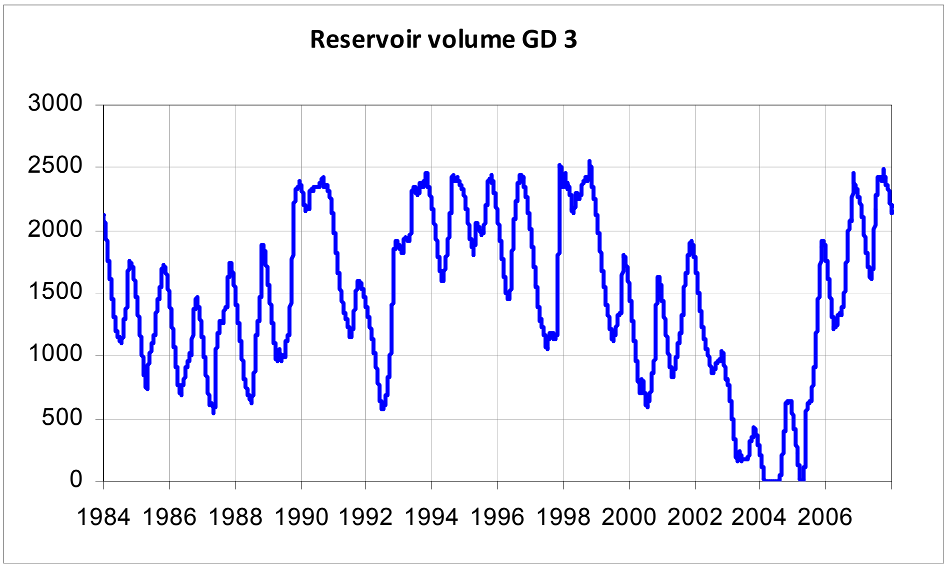

Figure 9-8: Reservoir volume GD-3

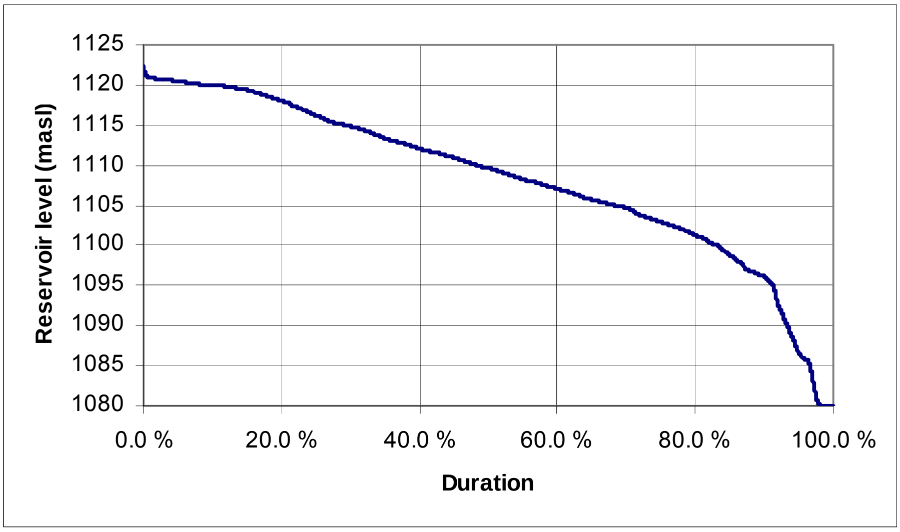

Figure 9-9: Reservoir level duration curve, GD-3.

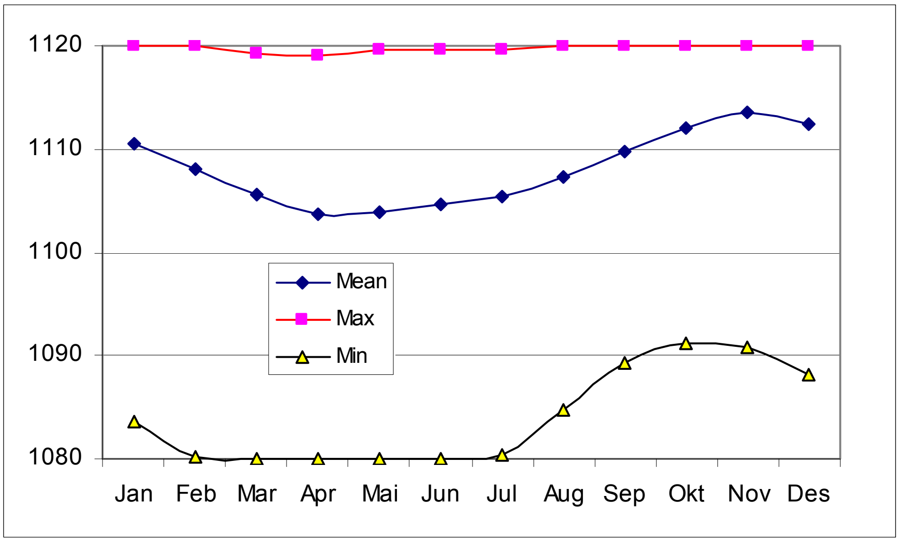

Figure 9-10: Monthly mean, max and mIn reservoir level, GD-3

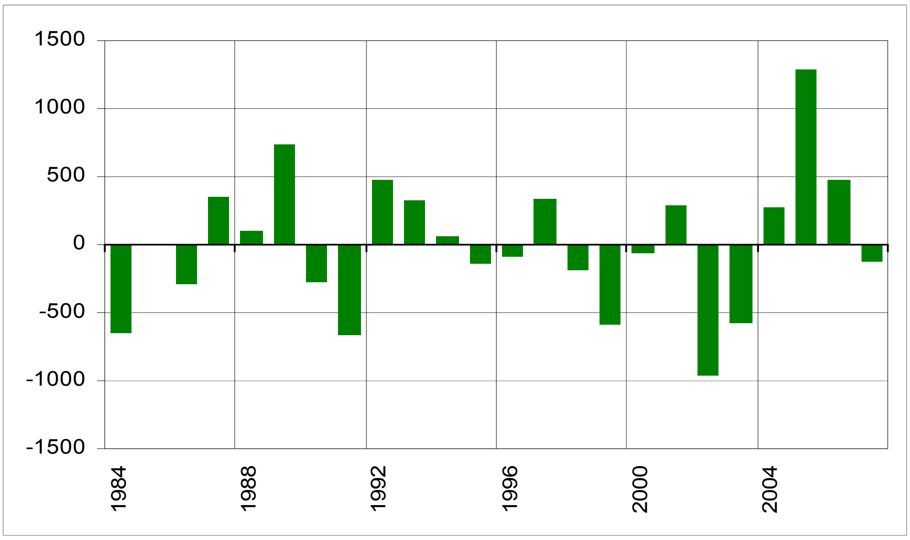

Figure 9-11: Change in reservoir volume by year, GD-3

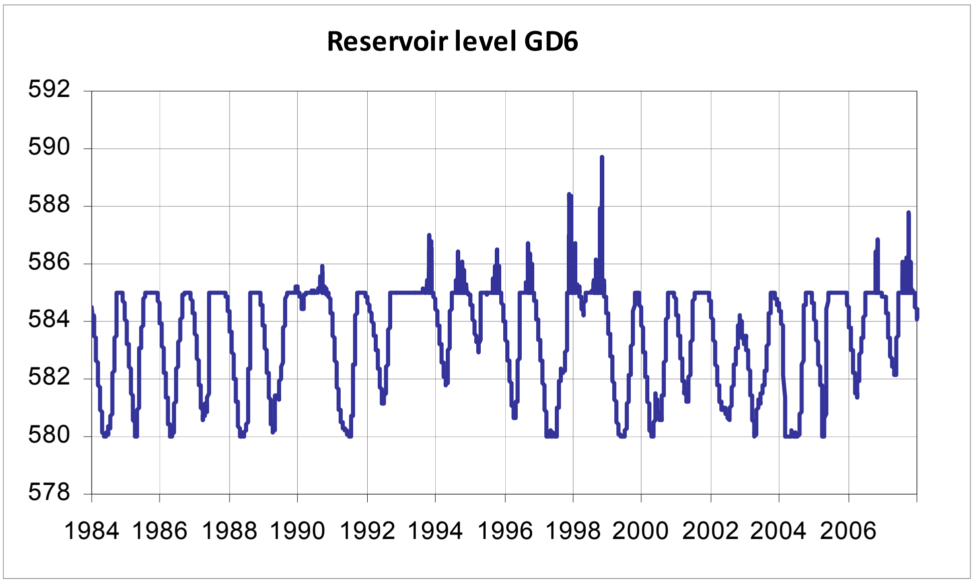

Figure 9-12: Reservoir level GD-6 (peak floodwater levels is incorrect)

The GD-3 reservoir curves, , shows the annual cycle of water level variation defined by a gradual drawdown-period between November and April filling in the high flow season from August to November. The GD-6 reservoir, Figure 9-12, reaches, full reservoir conditions in most years.

Only under the most critical conditions, as experienced in 2004 and 2005, the reservoirs are drawn down to minimum operating level during February and March. 2005 is a wet year, see GD-3 reservoir curve Figure 9-8.

As indicated in the GD-3 reservoir level duration curve , Figure 9-9, for the whole period of generation, near full reservoir conditions are attained for about 10 % of time and less than 10 % of the time the reservoir is below 30% volume. For maximum power generation, reservoir levels should be kept as high as possible in order to utilise the best combination of flow, head and turbine efficiency.

Annual time series

The annual series plot of energy output, GD-6, illustrates the Genale River cascades ability of producing firm power. It is only the year 2004 that there is a deficit on yearly basis.

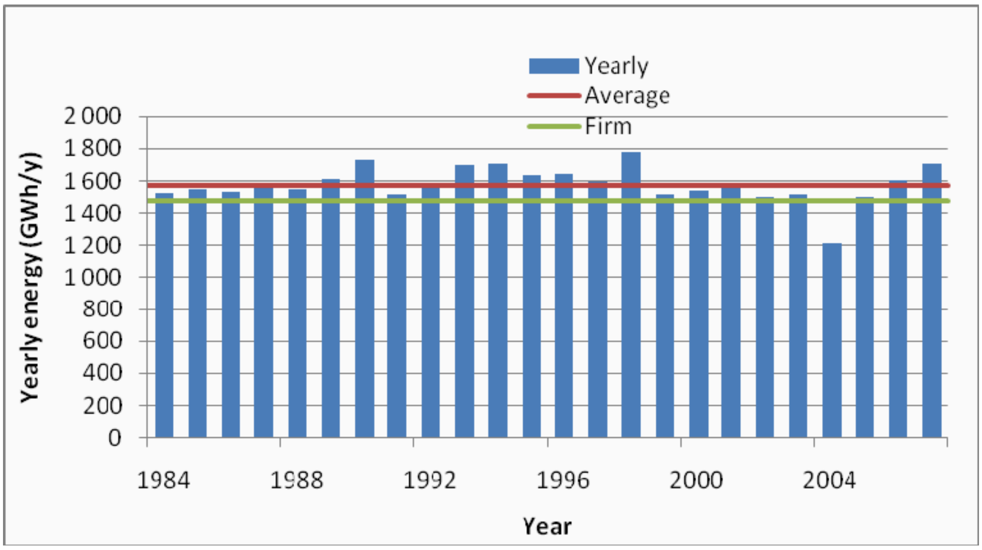

Figure 9-13: Annual time series of generated energy

9.8 Small Hydropower Plant

An environmental water release of 2.5 m^3/s is planned at the Dam site.

The Consultant suggests to install a small hydropower unit to generate power from the compensation water release The turbine will be a standard compact Francis unit with horizontal shaft, with a load controller to ensure correct water release at all times.

Compensation flow will be released 365 days/year and the turbine will supply firm energy to the 33 kV grid connected to Negele substation.

The average capacity of the unit will be 1.35 MW and the yearly energy output 11.8 GWh.

9.9 Daily operation profiles

The Genale River projects are designed as base load projects, with a plant factor of about 0.73. The annual average turbine output for GD-6 is 180 MW, with a firm capacity of 165 MW. Based on a typical ICS daily load curve, as presented for a weekday in 2007 in Figure 9-14, the GD-6 project could supply a peak output of 250 MW, and cover its relative part of load during the rest of the day.

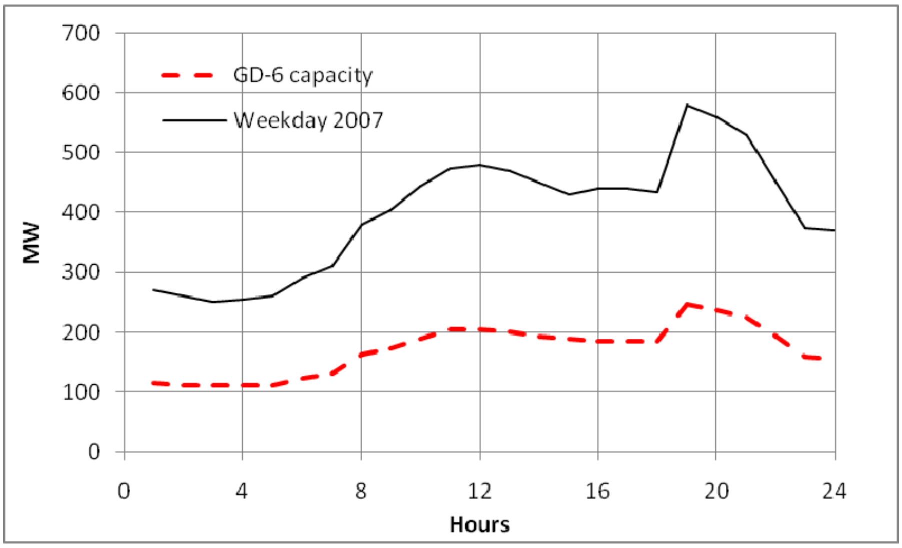

Figure 9-14: Typical daily load curve

10 THE EIA STUDY

10.1 Introduction - Extent of the EIA

The construction and operation of a dam and hydropower scheme on the Genale River will result in impacts in both the upstream and the downstream. Some of these impacts will be significant from an ecological or socio-economic perspective, and some will not be. The delimitation of impact zones encompassing the project area and the study area is explained following.

10.1.1 Direct Impact Zone (DIZ)

Inundation of the valley behind the dams and the associated works would create a direct impact zone with the following elements:

- a core area always under water;
- the drawdown zone, around the permanently flooded area;
- A short altered river section between dam and tailrace outlet;
- the shore and periphery of the reservoir; and
- sites of ancillary works, access roads and transmission lines.

10.1.2 Secondary Impact Zone

Secondary Impact Zone (SIZ) encompasses the areas adjacent to the DIZ/reservoir, along access routes and power transmission corridor, which will be effected by the project and people immediately downstream of the development. This zone includes communities which, although not physically displaced, come into direct contact with the development activities and staff. These communities may rely on resources within the DIZ.

10.1.3 Tertiary Impact Zone

Tertiary Impact Zone (TIZ), which encompasses possible issues upstream and downstream due to the changes in river flow regime and dam wall barrier effects.

Given the extensive study area significant use of satellite imagery and GIS was made in the EIA, to both describe existing baseline conditions and to analyse potential change.

The Figure following shows the project location and indicative impact zones. The red box denotes the terrestrial tertiary impact zone, the blue the secondary and the black the direct impact zone.

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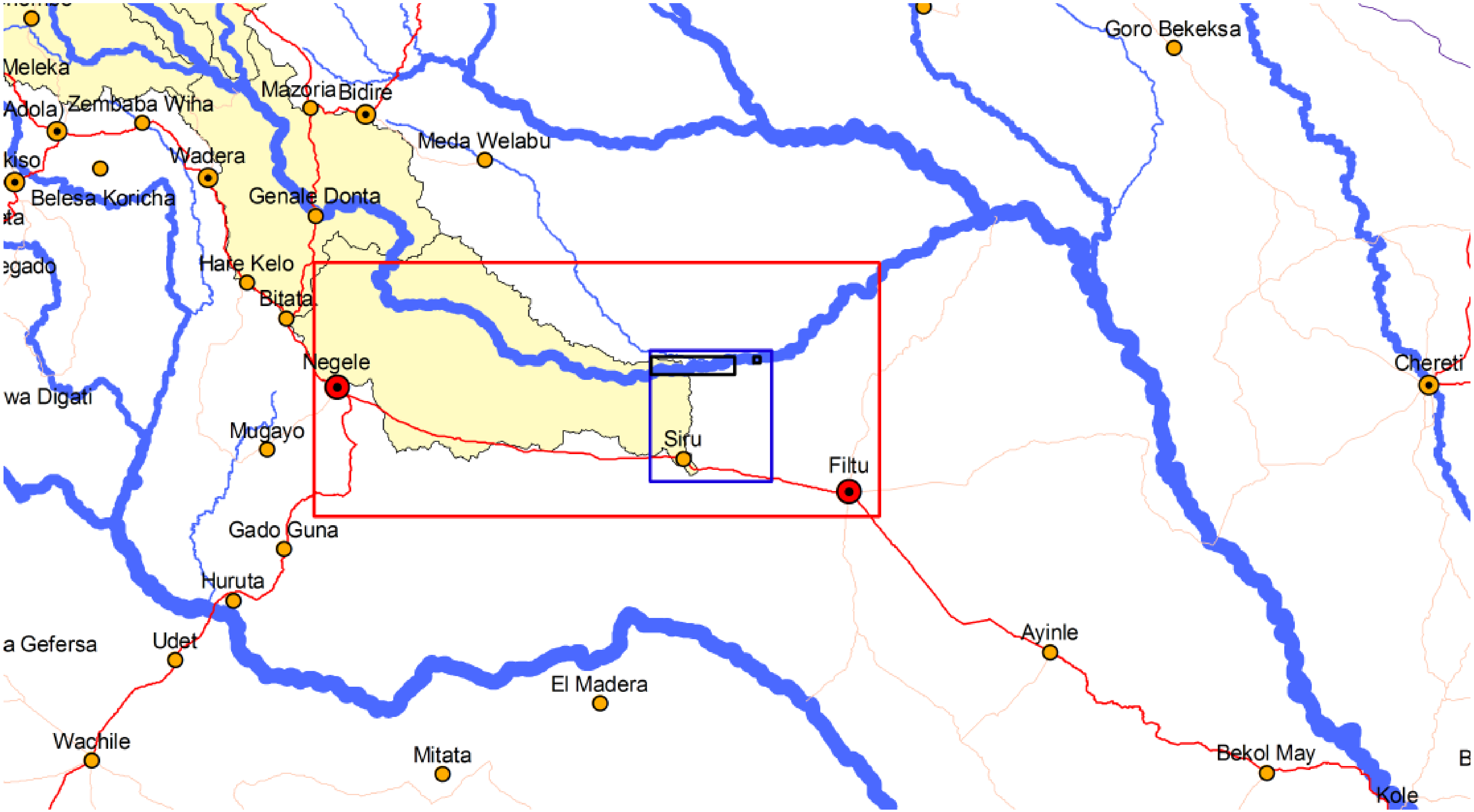

Figure 10-1: Project Location and Impact Zones

10.2 Project Context and Focus

From the perspective of the EIA, critical issues are the landtake for the dam, reservoir and access routes and the changes to the downstream river flow regime that will occur in the reservoir filling and operational phase.

The project area straddles the Somali and Oromia Regions with the Oromia Zone of Bale (Meda Welabu Werede) on the left bank and the Somali Zone of Liben (Liben Werede) on the right bank. Upstream much of the Genale catchment between GD-3 and GD-6 falls within the Oromia Zone of Bore (Liben Werede). The two Zone Capitals are Negele in Bore Zone and Filtu in the Liben Zone. Road access to site will start at Siru which is located on the main road between Negele and Filtu.

The Genale River falls into the Somali-Masai biome and is influenced by both the Somali-Masai and Afro Tropical Highland Biomes. In a regional context, the vegetation of the study area falls under White's (1983) Somalia-Masai regional centre of endemism. The length and severity of drought and its effect on the natural vegetation and pastoral populations is different in various parts of this vegetation type. Acacia – Commiphora deciduous bushland is dominant.

The main road between Negele and Filtu is largely settled and wildlife populations are minimal. The river, though, is largely unaffected by development and hosts substantial animal diversity. The project area does not fall into any of the formal protected zones in Ethiopia nor is there informal protection although there is an understanding at the Kebele level that communities are responsible for conservation of wildlife.

The GD-6 Genale River basin is approximately 2,920 km2. The land use varies considerably form intense arable agriculture to open livestock production systems An assessment of the present land use in the basin indicates that approximately 62.5% of the basin is used for open livestock production a further 19.7% has a mixture of arable and livestock with emphasis on livestock and 17.8 is intense arable agriculture. Due to the low and erratic rainfall the primary form of farming is pastoralism (cattle, sheep, goats, camels) with smaller areas of arable agriculture. The most common crops are; maize, wheat, lowland teff, haricot-beans and sorghum.

There are two kebeles (of the Liben Werede) that are affected by the project (by flooding of the reservoir and reduced flows in the section between the dam wall and the tailrce outlet), these are:

1. Siru (upstream of the dam wall), and
2. Haydimtu (mainly in the area below the dam wall)

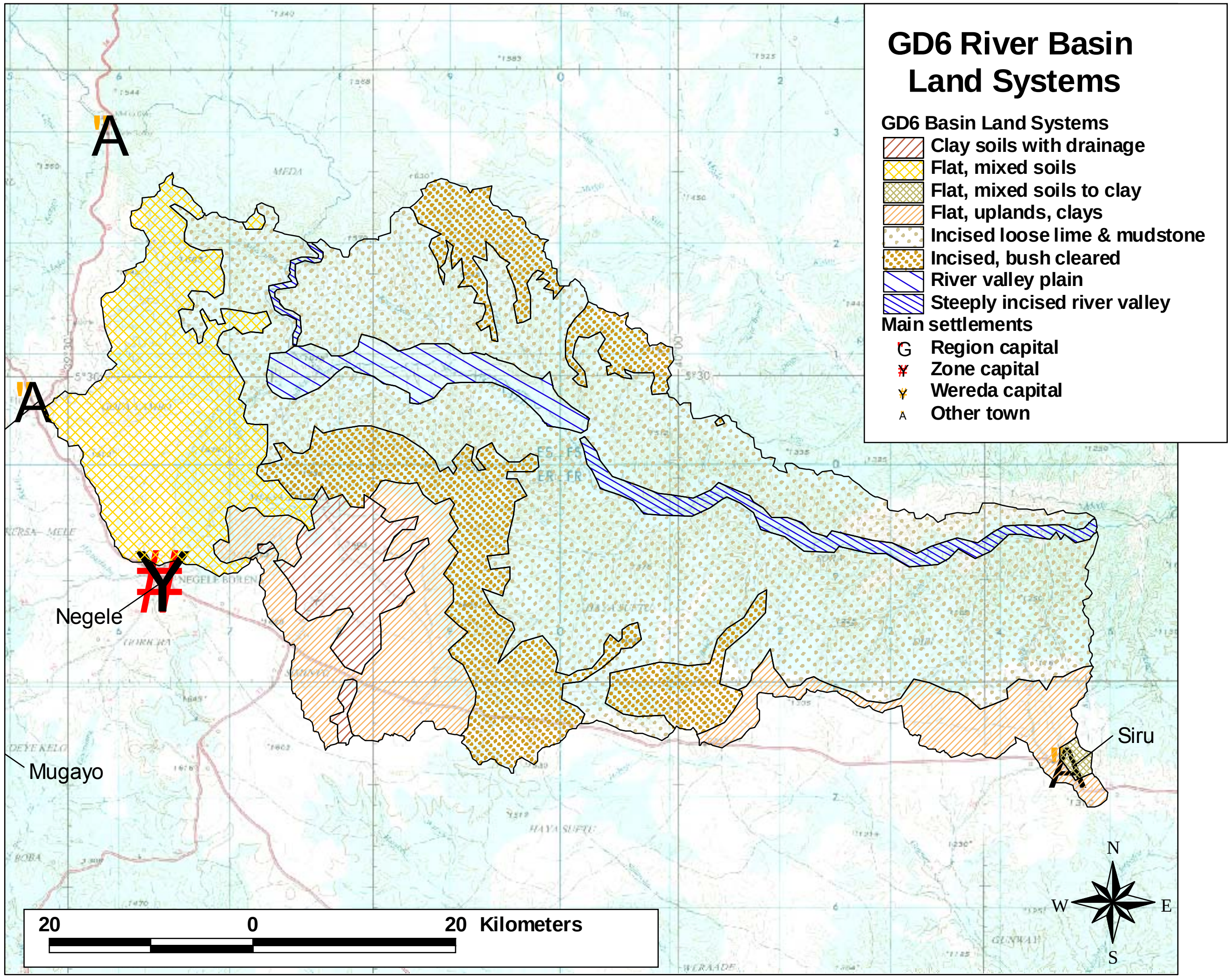

Figure 10-2: Land systems of the GD6 Genale River catchment

In general land use activities of the project area along the Genale River relate to response to drought conditions in which grazing and water resources in the Dawa river area are depleted. Both kebeles focus their arable agriculture and pastoralism around the Dawa River to the south.

10.2.1 Somali Liben Zone Socio-economic Characteristics

The main socio-economic linkages relevant to the GD-6 project are with the Somali National Regional State (SNRS) and its administrative units on the right bank (taken as looking downstream) of the Genale River, focussing on the reservoir area. On the left bank in Oromia there is an absence of settlement in and around the project area and land use appears to be limited and as an extension of activities originating from the right bank.

Somalis are mainly pastoralists and agro-pastoralists. The nomadic or transhumance way of life of pastoralists responds to highly unstable natural environment and to a future-oriented perception of time and space. However, although with arid and semi-arid rangelands pastoralism may be thought of as the only sustainable economic system in the Somali region, pastoral households are recently becoming more and more attached to semi-permanent settlements in the vicinity of watering points. This may be due to different factors, such as intensive water development, constraints to mobility, commercialization and migration of labour.

Digodi is the domination clan in the area and is strongly linked by lineage to the clans of Hawiya, the Hawazle of Hiran, and the Rahawein of Baay, Minor ethnic groups such as the Gerri from Hudet and Moyale, and the Maherran from Chisimaio populate the surroundings of Filtu. Clan uniformity and homogeneity are evident signs of a rigid and impermeable social structure, with strict forms of allegiance and intra/inter-group solidarity. In times of crisis, wealth redistribution, sharing of food resources, and assets concession are all coping mechanisms involving relatives and neighbours.

Patriarchal rules govern social and gender relations, according to a hierarchical power structure. Among the Digodi, land is usually administered by the elders of the village, who formulate rules about resource use and distribution according to the Koranic law. Enclosure is however expanding, and many farmers cultivate their own land, family-inherited plot of land irrespective of the possessions of their clan.

Generally speaking, land tenure rules and access to and control over resources vary from clan to clan, but land is usually a possession of the head of the household, commonly a man. Social and gender division of labour is also defined in relation to the economic needs of the family and its practices, whether pastoralist or agro-pastoralist.

10.3 The Project Site

10.3.1 Habitats

The area of the Genale River valley proposed for GD-6 is a moderately to sharply incised valley cutting through Jurassic sediments of mudstones, limestone and sandstone down to a hard gneiss along which the river runs. The steepness of the river valley and the presence of a hard rock base results in limited soil development and narrow riparian woodlands.

In general the uplands and valley sides contain a dry open bush dominated by Acacia and Commiphora with sparse grazing resources (about 818 ha of this habitat that will be flooded). This bush abruptly meets with the riparian woodland which is between 5 and 40 m wide along the river bank. The riparian woodland occurs on the rocky islands in the river (the river varies in width from a minimum of 120m to about 500 metres. The total area of riparian woodland within the area of the reservoir is about 185 ha. The areas of habitats within the development zone are indicated in Figure 10-3.

Table 10-1: Area of habitats falling within the reservoir

Habitat	Area (ha)
Open Water	134
Riparian woodlands	185
Acacia-Commiphora bush	818
Total Reservoir at maximum flood level	1137

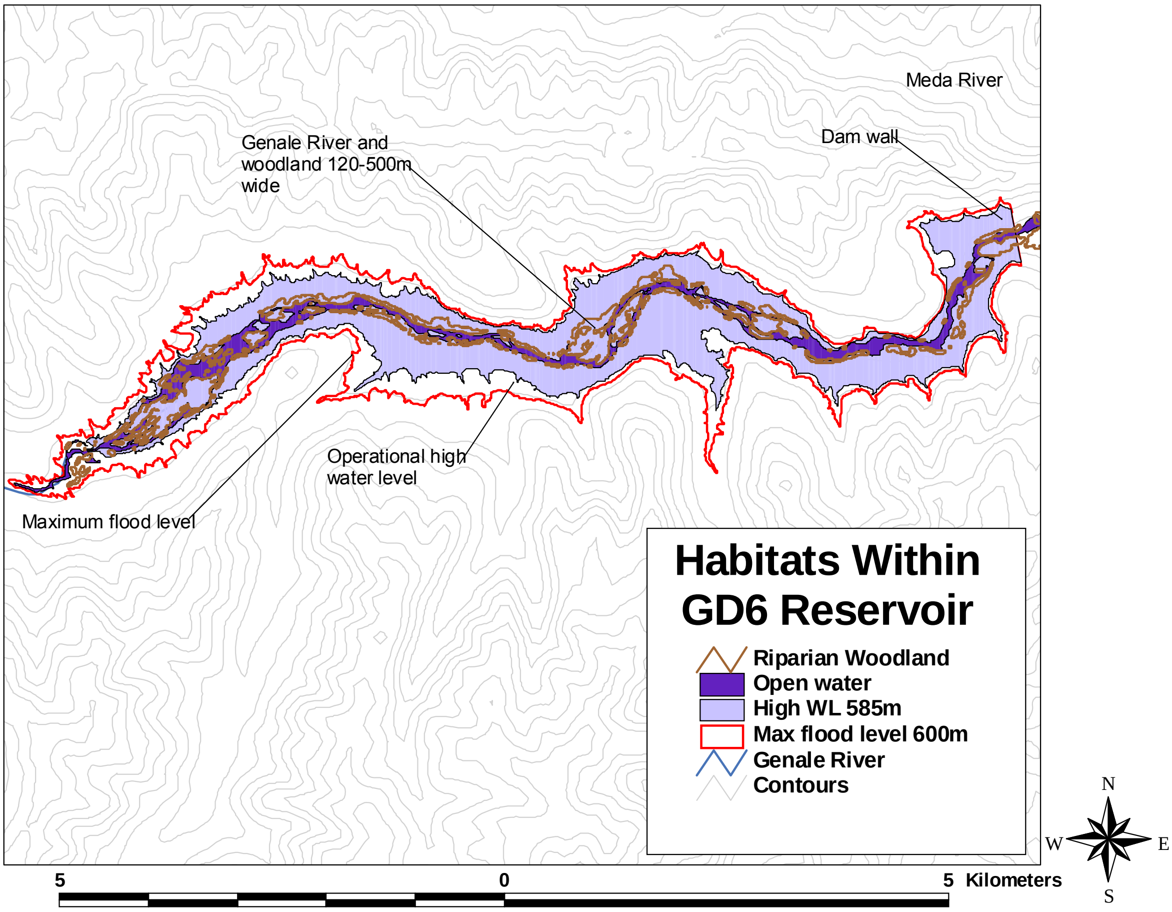

Figure 10-3: Major habitats within GD-6 reservoir

Table 10-2: Area of habitats between theGD-6 dam wall and the Meda River and between the Meda river and the tailrace outlet

Habitat	Area (ha)
Open Water (Dam wall to Meda River)	82
Open Water (Meda River to tailrace)	175
Riparian woodlands (Dam wall to Meda River)	66
Riparian woodlands (Meda River to tailrace)	80

10.3.2 Settlement

No permanent settlement was found within the proposed reservoir area or immediately downstream. This does not mean that the area is not used on a seasonal or occasional basis. Use of the area is partially in response to drought conditions there are temporary camps for pastoralists. The maximum number of temporary sites (past and present) utilised by pastoralists within the reservoir area is 22, with a further 13 between the dam wall and the outlet from the tailrace that will not be inundated.

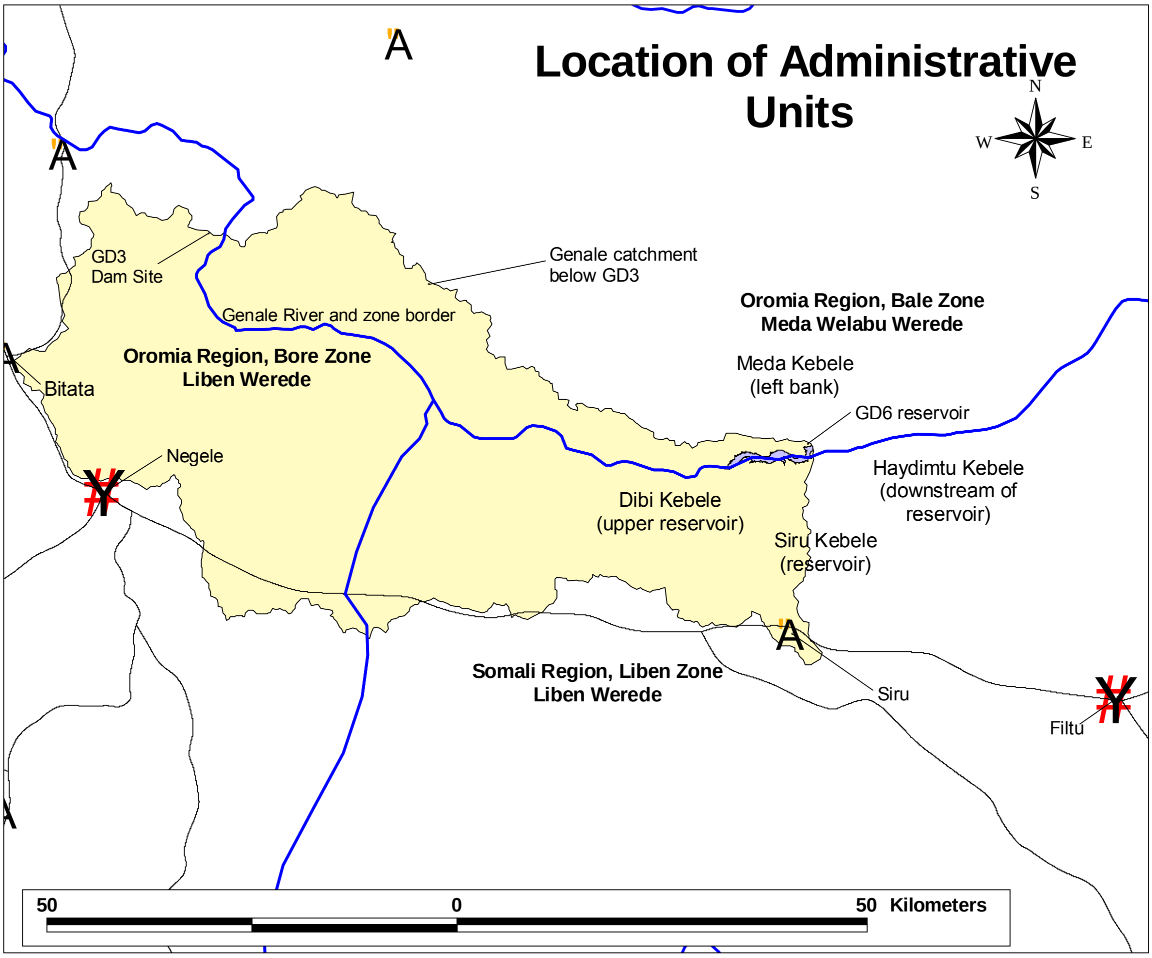

Figure 10-4: Location of administrative units affected by GD-6

10.3.3 Arable Agriculture

The survey of the DIZ located three areas of arable agriculture, one of which is irrigated. These are indicated in Figure 10-5.

The irrigated agriculture covers an area of 0.9 ha and lies approximately 2.2 km downstream of the proposed dam wall. The owner (Mr Gemale) stays in Haydimtu Kebele which is about 50km away and three people work on the lands area during the crop production season. Water is pumped via a diesel water pump into a furrow to flood irrigate the arable lands area. The key crops produced are maize, sorghum, onions, tomato, pawpaw, melon and beans (soy and haricot).

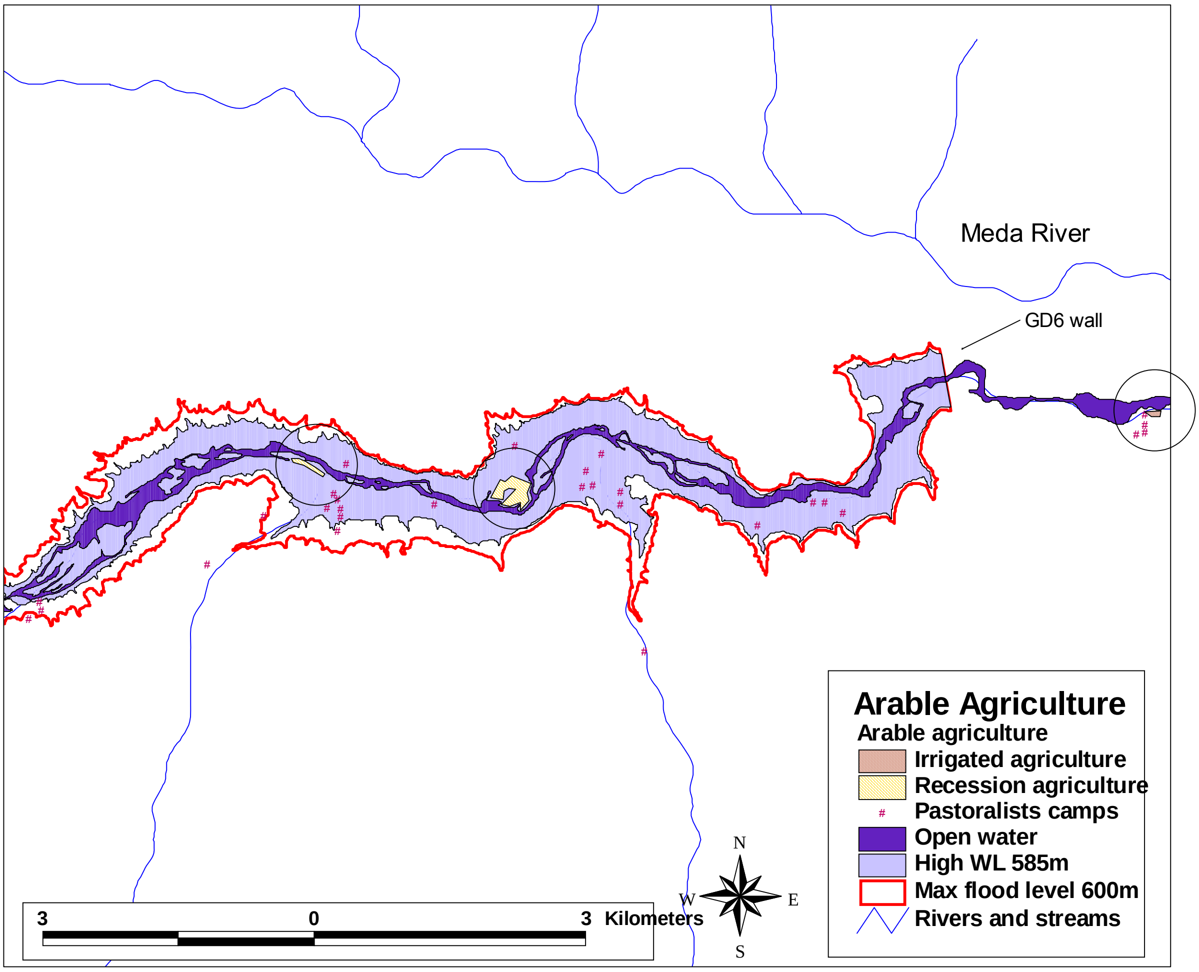

Figure 10-5: Areas of arable agriculture within the site

There are other arable areas based on recession agriculture called Jerdere which is farmed by two families from Sifu kebele located within the reservoir area. The main crops grown are; maize and onion. The field survey identified an area of riverbank of approximately 1.6 ha which appears to have been cleared in 2008 for arable agriculture as a thorn fence protects the area from livestock.

In general there are few areas of suitable alluvial soils for agriculture to take place in the Genale river valley and the proposed project reservoir will only affect two recession agricultural areas of about 10.6 ha.

10.3.4 *Livestock Production*

Livestock production in the Genale river valley is constrained by low rainfall and the presence of Tsetse Fly which transmit a fatal livestock disease to domestic stock.

During drought years, when water resources in the Dawa River and other traditional watering points dry up, pastoralists move to the Genale River in search of water and grazing. As indicated in the settlement section, a maximum of 22 temporary livestock sites have been identified within the reservoir area on the right bank and 13 in the area between the dam wall and the tailrace (also predominantly on the right bank).

The main types of livestock are sheep and goats that are brought into the area on a seasonal basis (which tend to rely on the riparian woodland). Cattle and camels are also brought into the area but in low numbers due to the presence of Tsetse Fly. The cattle and camels are not kept near the river and tend to graze on the highlands, simply entering the area for water. Camels use browse that is cut from the riparian woodlands.

Major livestock diseases near the river are Anthrax, tick borne diseases, abagorba, (Ngana) and livestock intestinal diseases.

The amount of grazing lost through flooding of the reservoir will be about 818 ha. Although the reservoir will not reduce access to water, it will mean the loss of riparian woodland grazing on the right bank. Stock and people do not make much use of the islands within the river due to the presence of crocodile. Average tropical livestock units (TLU) for Liben zone is 52/km^2 (GDMP, 2006).

10.3.5 *Other Land Uses and Natural Resources*

During the social surveys, people who have used the river valley during the recent past were asked to outline their use of river and riverine resources.

During the field survey it was observed that the greatest impacts to riparian vegetation came from clearing and fire for arable lands and collecting of materials for stock bomas. Livestock grazing into the riparian was also opening up the narrow woodland.

10.4 Potential Environmental and Social Impacts

GD-6 will operate largely as a run-of-river plant with the regulated flow from GD-3 being diverted through the power house. Thus, during normal operation periods the stretch of river between the dam wall and the inflow of the Meda River (5.1km) will only have much reduced flows except when GD-3 and subsequently GD-6 spills and a flood occurs. There is no commercial fishery on Genale River in the vicinity of the dam site. However, some individuals catch fish for household purposes and for small scale trading at nearby towns.

Assuming regulation of the Genale River by the upstream GD-3 reservoir then the incremental effects on the flow regime of adding the GD-6 to the cascade are minimal. No especially unique habitats fall within the reservoir area and apart from the narrow belt of riverine vegetation biomass is low and the area is used mostly for occasional grazing with very small patches (10ha) of recession type agriculture.

There is no permanent settlement in the reservoir area and no resettlement requirements attached to the project. No roads or other public infrastructure is located within the direct impact zone of the project. A few (22) temporary/seasonal pastoralist camps exist in the area and mitigation will need to be considered for temporary grazing areas inundated.

Virtually all major impacts are associated with the influx of labour and the provision of road access to the area during the construction phase. Although there are no communities in the immediate vicinity of the project, any development will cause secondary impacts in the wider area in terms of social and health changes and opportunities for economic and commercial livelihood. Additional pressure on the riverine habitat downstream of the project may be anticipated through improved access also.

Overall, however, with effective environmental management planning and an efficient monitoring regime any negative impacts should be capable of being controlled to acceptable levels. The limited impact profile of the GD-6 project results in environmental costs not being high.

10.5 Irrigation and Downstream Issues

10.5.1 Irrigation in GD-6 Basin

At the reservoir site the Genale is deeply incised and the tributary streams fall steeply to the Genale. Around the reservoir there are no areas of land with deep soils and moderate gradients which would be suitable for irrigation.

The Genale Dawa Master Plan Study carried out an assessment of all the potential irrigation projects that have been identified in the Genale Dawa Basin. The original long list of 93 projects with a total area of 1,074,720ha was reduced to a short list of 10 projects with a total area of 59,000ha. None of these 10 short listed projects is in the GD-

6 catchment. This makes it extremely unlikely that there will be irrigation development on any scale between GD-6 and GD-3.

The Oromiya Irrigation Development Agency (OIDA) is developing small scale irrigation in the Oromo Regional State which forms the northwest portion of the Genale Dawa Basin. Only one of the schemes that have been listed by OIDA as developed or with potential for development is in the GD-6 catchment. This is the Genale Donta scheme, a pump irrigation scheme of 40ha adjacent to where the Delo Mena to Negele road crosses the Genale River. This scheme was completed in 2005 with financing from Norwegian Church Aid. The design flow taken from the Genale by this scheme is 122 l/sec at peak irrigation, requirement which is not significant in the context of GD-6.

Although it was reported in 2005 by the Irrigation Development Department of the Somali Regional State that there was 2,000ha of pumped irrigation in the Lower Genale area, this was not borne out by the site visits to the area; around six irrigation cooperatives had been formed by the Italian NGO COOPI and had been supplied with pumps, fuel, technical assistance and inputs. Recent site visits indicate that the cooperatives have not survived well after the withdrawal of assistance in December 2005. In any case the areas served are small (about 10ha per cooperative) and, even if any of the cooperatives have survived, the changes in the flow regime of the Genale will not adversely affect them and the reduced risk of flooding on their farm land adjacent to the Genale should affect them positively.

There are areas of traditional recession irrigation along the banks of the Genale. The crop is sown into the soil of the river bank as the flood recedes and grows on the soil moisture, see Figure 10-6.

Figure 10-6: Recession Irrigated Maize by Lower Genale

The regulation of the flow in the Genale by GD-3 will reduce the variation in water level between high flow and low flow and will, therefore, reduce the potential for this type of cultivation.

The total area of recession irrigation is likely to be small, there are not a great number of localities that are suitable, however recession irrigation may be important to individual families but the regulation of water here is not controlled by GD-6.

10.5.2 Irrigation Potential Downstream of GD-6

The only area in Ethiopia downstream of GD-6, which has potential for irrigation development, is the Lower Genale Irrigation Project (LGIP), which is located between Dolo Odo, on the border to Somalia, and the town of Kole.

A pre-feasibility study for this project was carried out in 2005 which gave an EIRR for the project of 2%. A feasibility study, the draft of which was completed in November 2008, used less conservative assumptions than the pre-feasibility study and gave an EIRR of 7.3%. These low EIRRs do not make it likely that this project will attract international finance.

In any case the LGIP pre-feasibility study found that the impact of the regulation of the GD-3 hydropower project was not very significant; the timing and duration of two annual crops can be arranged to coincide with the double peaked annual hydrograph of the unregulated river.

The increased dry season flows resulting from regulation of the Genale by the GD-3 hydropower project would allow a slightly larger area of perennial crops to be grown on the project.

The GD-6 dam will provide minimal additional regulation of the Genale at the site of the LGIP diversion dam; the only perennial tributaries of the Genale downstream of GD-3, the Welmel River and the Wabe Mena, have their confluences with the Genale downstream of GD-6. The additional catchment of GD-6 over GD-3 lies in the Middle Basin and the tributaries are ephemeral; flowing during rainfall events but drying up shortly after the conclusion of the rainfall event.

10.5.3 Transboundary Issues

The Genale River is an “International Waterway”; it has its origin in one country, Ethiopia, and flows to another country, Somalia. The World Bank Operational Policy OP 6.50; “Projects on International Waterways”, is therefore triggered by projects on the Genale River.

OP 6.50 requires that, before any before any project can be implemented on an International Waterway, an agreement should be entered into by the riparian countries.

At the start of the rainy season, when storms in the Lower and Middle Basin may be expected to give high salinity runoff at a time when there is little natural flow from the Upper Basin, the regulated flow of low salinity water from the reservoirs will serve to reduce the salinity of the cross border river flow.

During the rainy season the dams on the Genale will increase the salinity of the cross-border flow; in the rainy season the reservoirs will retain part of the low salinity water from the Upper Basin whilst the saline water from the Lower Basin will runoff to the rivers. The reduction of the salinity of the river water at the start of the rainy season, when the salinity is too high, would be beneficial to downstream users whereas the increase in salinity during the remainder of the flood season may be beneficial in reducing the risk of infiltration problems.

Somalia has long sought to regulate the flow of the Juba River to provide flood mitigation, irrigation development and hydropower. The planned Baardhere dam, just upstream of the town of the same name, was originally designed to irrigate up to 170,000ha, but the size of the planned dam was reduced, under pressure from potential financiers, to a size with sufficient storage to irrigate 50,000ha, to take account of the necessity of sharing of the water of the Genale/Juba with Ethiopia.

The construction of the GD-3 dam would provide some of the regulation required by Somalia and may obviate or substantially reduce the need for the Baardhere Dam; however the incremental effect of adding the GD-6 project would be minimal.

The regulation of the Genale/Juba River will reduce flooding. In Ethiopia there are few reports of serious flooding but in the Lower Juba Valley in Somalia there has been very serious flooding leading to loss of life, livestock and livelihood. The regulation by GD-3 may help to reduce the severity of this flooding but there is little effect expected from GD-6.

10.5.4 Key Assumptions Made in the EIA

After the scoping phase to identify main issues associated with development of the GD-6 project the EIA study made a number of key assumptions for the study, namely:

1) GD-3 HPP upstream will regulate the river flow leaving GD-6 as a run-of-river project; i.e. any impacts associated with changes to the hydrological regime are captured by the GD-3 project

2) There are no permanent settlements at the GD-6 dam site or in the proposed reservoir area; i.e. no resettlement requirement for the project and no settled communities directly affected

3) The GD-3 dam will act as a silt trap for the upstream catchment and hence catchment erosion, sedimentation and land use issues are relevant only for the stretch between the GD-6 and the GD-3 dams

4) The EIA is a feasibility level document and the format chosen for the report is modelled on World Bank Group guidelines cross-referencing to ensure the main issues required by Ethiopian guidelines are covered

5) Guiding Principle - the level of baseline study, impact analysis and mitigation recommendations should be commensurate with the degree of impact anticipated

The preceding discussion and assessment of impacts as well as the reporting has been done with reference to these key assumptions.

11 COST ESTIMATE - SUMMARY

11.1 General

Detailed cost estimates have been prepared for the power plant. The details are presented in Volume 3, Annex 3A.

The cost estimate has been broken down in 11 main sections as follows:

1. Infrastructure, roads and camps
2. Reservoir costs
3. Dam
4. Intake
5. Waterway
6. Power station
7. Power station equipment
8. Small Hydropower Plant
9. Power transmission and switchyard
10. Environmental mitigation measures
11. Engineering, supervision and Owners administration

All prices and cost data are quoted in US Dollars (USD) and refer to the price level of ultimo 2008. No taxes, import duties or IDC (interest during construction) are included in the cost estimate.

Table 11-1: Summary of project cost

Item	**Total cost (mill USD)**
Infrastructure	*49 147*
Reservoir cost	*935*
Dam	*109 325*
Intake	*5 434*
Waterway	*122 947*
Power station	*20 299*
Power station equipment	*88 261*
Small Hydropower Plant	*2 200*
Transmission, switchyard, Local supply	*26 530*
Environmental cost	*2 200*
Engineering, supervision and Owners administration	*42 508*
Total cost	**469 780**

Detailed cost disbursement schedules for the selected project is given in Annex 3 G, and the summary below in Figure 11-1.

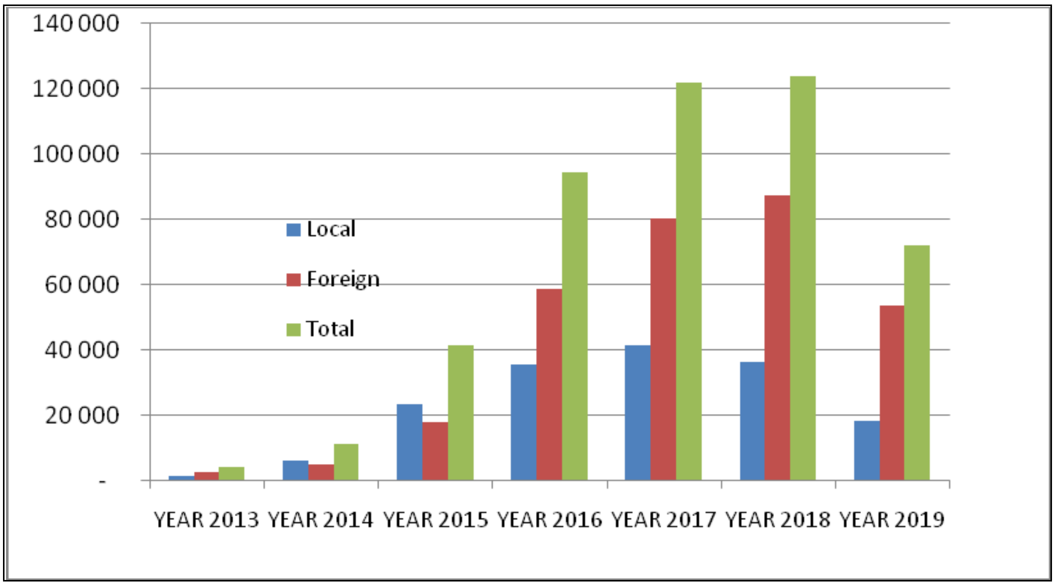

Figure 11-1: Cost distribution

11.2 Contract packages

It is assumed that most of the project will be implemented through international competitive bidding, and that the project will be split in a number of lots. On this basis the following major contract packages are assumed:

- 33 kV transmission line
- Camp construction
- Civil works, dam, power station, waterways and roads
- Electro-mechanical works.
- 400 kV transmission lines and sub-station

The mobilisation for the main contractor is scheduled to start with minor upgrading of the existing track, and with major transport requirement before the main access is completed, it is advised to have the road contract as part of the main contract.

11.3 Labour and construction equipment

The cost estimate and the construction schedule have been prepared based upon the assumption that the civil works construction will be carried out by modern construction techniques, using heavy construction plant.

Cost of all equipment and labour are included in the unit prices.

11.4 Infrastructure

Access roads and bridges

The following table summarises the main quantity items derived from preliminary calculations based on actual road lengths and pavement composition. The costs in Table 11-2 are based on other recent projects of similar nature.

Table 11-2: Basic Quantities and Cost Estimate for Access Roads

Cost estimate for Genale GD6 access roads (USD) Total km 62+885					
	Item	**Unit**	**Quantity**	**Unit price $**	**Cost $**
Pavement	Gravel wearing course 150 mm	m3	50 876	22	1 119 283
	Subbase 350 mm	m3	142 923	25	3 573 064
Earthworks	Common excavation	m3	424 218	5	2 121 089
	Fill	m3	227 150	10	2 271 495
	Rock excavation	m3	24 029	18	432 521
	Clearing	ha	95	980	93 100
Drainage	Pipe culverts Ø0.9m	Lm	2 487	180	447 595
	Slab culverts	Lm	167	3 200	534 400
	Bridges	Lm	20	11 500	230 000
Erosion Protection	Stone pitching	m2	4 697	27	126 822
Guardrail	Guardrail	Lm	23 960	70	1 677 200
Incidentals	Incidentals	km	63	1 500	94 328
Environmental	Provisional sum	PS	63	9 600	603 696
General	Camps, vehicles, lab etc.	PS			2 140 000
				Sub total	15 464 592
				16% contingencies	2 474 335
				Total	**17 938 926**
				Kilometres	63
				Cost per km	**285 266**

Operators Camp

The cost of construction of a site camp for the use of the owner and the contractor's expatriate personnel is based upon assumptions of a certain number of houses and unit cost per m^2.

The total cost of the Camp has been estimated to approx. 20 mill USD exclusive of access roads, power supply and contingencies.

11.5 Cost of power plant civil works

11.5.1 General

The cost estimates for civil works are based upon quantities for the major project items and the unit rates for these items.

A list of the main unit rates adopted for costing of the project is given in Table 11-5 below.

In order to establish the list of unit rates of civil works, the Consultant has used cost from other projects in Africa and internationally as a basis. These unit prices have been adjusted in accordance with information obtained on international contractors' prices given under competition for the Gilgil-Gibe and Tekeze hydropower plants in Ethiopia. The unit rates in the unit rate table include all direct costs including purchase costs of construction plant, the operation and maintenance cost and the relevant portions of site installations. The contractor's preliminaries and general costs amounting to 15-25% of direct cost for the dam and the power plant work are added in the summary. The contractor's preliminaries and general costs includes the contractor's mobilisation, operation of camp and offices, insurances and bonds, international transports and air freight, site administration, travel cost for expatriates, profit and parts of the site installations not included in the direct costs for the various items.

One of the major costs in the project is the tunnel boring machine (TBM) and operation of the TBM. The general cost related to TBM is normally higher than the 25 % used in the summary, but the major part of the TBM depreciation and procurement cost is included in the unit rates, as described below in 11.5.3.

It is further assumed that most of the other heavy construction plant tunnelling equipment and the heavy concrete batching, mixing and transportation plant have to be brought into the country.

11.5.2 Surface excavation works

Outdoor rock and soil excavation has been split into two rates, smaller confined excavations where care has to be taken due to subsequent concrete works or other treatment works, and larger soil or rock excavations as necessary for the intake area, dam foundation areas etc.

11.5.3 Cost estimate-TBM

The cost estimates are established as functions of many parameters, as TBM diameter, machine specifications, machine prices and depreciation, boring lengths, rock mass drilling properties and assumed rock support and grouting quantities.

The estimates are based on prices and information supplied from machine suppliers (price of new machines, rest value, drilling and cutter costs, etc.), from contractors (running and staffing costs, repair costs), and experience from several projects. All figures in Mill. USD as per 01.01.2009.

Table 11-3: Cost estimate - TBM

Cost element	Tailrace tunnel, 11.20 km	Headrace tunnel, 4.74 km *	Headrace+tailrace tunnel, 15,94 km
Transport to site, according to Robbins	1 700 000	1 700 000	1 700 000
TBM, back up and conveyor	26 160 000	23 300 000	29 600 000
Labour force, local and expatriate	5 330 000	2 420 000	7 540 000
Cutter, spare parts, acc. to Robbins	12 820 000	5 430 000	18 250 000
Other materials (cable, vent, light etc.)	730 000	300 000	970 000
Invert filling	520 000	220 000	690 000
Other machinery in tunnels	1 570 000	700 000	2 210 000
Shifting of TBM from headrace to tailrace			1 000 000
Total net cost	48 830 000	34 070 000	61 960 000
Net tunnel cost per m USD	**4 360**	**7 188**	**3 887**
Site installations, general costs, site overhead administration and profit, 25%	12 207 500	8 517 500	15 490 000
Total cost estimate, see assumptions below	61 037 500	42 587 500	77 450 000
Cost per tunnel meter, USD	**5 450**	**8 985**	**4 858**

**Cost if drilled with TBM no. 2.*

The following cost elements are included in the cost estimates:

- Transport of all necessary equipment to and from site
- Mobilisation necessary for excavating and supporting the tunnel
- Assembly and disassembly of TBM, back up and other equipment
- All costs related to personnel for performing the tunnel boring, rock support, groundwater treatment, etc
- Cost for machines and equipment, for the different alternatives, updated according to Robbins Company
- Depreciation rate, anticipated to
  - o 70% for short sections (<7000 m)
  - o 80% for long sections (7000-14000 m)
  - o 90% for long sections (>14000 m)
- All consumable spare parts
- Ventilation, dewatering, electrical cables and light in the tunnels
- Invert segments or in situ invert concrete where rubber tyre vehicles are adopted
- Transport of the excavated material to deposit outside the tunnel portals, with a distance of 500 m
- Some handling and transport of the excavated material on the deposit and to final destination
- Contractor general costs, site overhead, administration and profit are included with 25%

Elements not included are:

- Rock support and lining
- Access roads and preparation of site mobilisation area
- Excavation of access tunnels and launching chambers

- Transport of spoils in excess of some 500 m from the tunnel entrance
- Treatment plant for tunnel discharge water (if necessary)
- Contingencies
- All client related costs, including right of land, financing, design and supervision

As indicated in the table above, the tunnel costs are highly dependant on the investment cost and depreciation of the TBM. New TBM machine and high depreciation amount are included in the estimate presented above.

The GD-6 tunnel excavation could be drilled by one TBM, and the unit price used is rounded up to:

- *3900 USD/m*

Used and refurbished machines could be applied at the projects, if available at tender stage, and could result in lower prices for TBM excavated tunnels.

11.5.4 Cost estimates – Drill & Blast Waterway

The excavation cost for a tunnel is normally given by the formula:

$P = C + K * A$ USD/m

C and K are constants, and A is the theoretically excavated area. K is the marginal excavation rate and is set to 21 USD/m^3. The described cost formula normally applies to all cross-sections above 30 m^2 and has been used in order to arrive at the basic tunnel costs for different tunnel diameters.

Rock support cost of the tunnels has been estimated separately depending upon the use of the tunnel, the size of the tunnel and the rock mass quality along the tunnel route. The temporary support work will generally comprise grouted rock bolts and fibre reinforced shotcrete.

The final evaluation has been made based on average international production rates and prices according to in-house data and informal discussions with contractors. All cost data has been collected and analyzed in the USD currency.

Table 11-4: Cost estimate – Drill & Blast

Cost element	Cost range, USD/m
Excavation, 90 m2	3 500 - 5 000
General costs, 30-35%	1 300 - 2 100
Total tunnel cost	**4 800 - 7 200**

The lower unit rates indicated in the table represent current Scandinavian price level, the upper range rates are observed at recent international project(s) (2008), thus indicating a higher price level for this type of underground projects.

Costs of tunnel excavation include transport of the spoils to a distance of approx. 500 m from the end of the tunnel.

11.5.5 Underground excavation. General.

The rate for excavation of large caverns such as underground power stations and surge chambers has been taken to be 35-40 USD/m^3. Cost of support and strengthening of the excavated faces in the caverns have been calculated based on the estimated number of rock bolts and quantities of shotcrete to be used at the different faces of the caverns.

11.5.6 Foundation treatment of dams

Three different rates have been applied, one for cleaning and preparation for concreting, one rate for drilling and grouting and one rate for drilling of drainage holes. The grouting rate has been calculated from previous bills for drilling, water leakage tests and assumptions regarding cement consumption.

11.5.7 Concrete works

Cement

The concrete rates have been estimated, based upon the assumption that all cement will be locally produced at Muger.

Conventional concrete

A variety of concrete types will apply for the construction, each having different requirements regarding cement content, sizes of aggregates, requirements to cooling and difficulties regarding placing and compaction. The concrete rates have therefore been split in different categories, varying from 180-220 USD/m^3, according to cement content, location and method of placing and compaction and several different rates have been adopted.

Formwork

The amount of formwork per m^3 of concrete will vary for different structures and sections of work and has been calculated separately.

Four different formwork rates have been adopted to reflect the difficulty of the formwork, outdoor crane handled formwork, under ground formwork in the powerhouse, lining formwork in tunnels and lining formwork in the shafts.

Reinforcement

For reinforcement one rate has been applied to all sections of work.

11.5.8 Unit rates

The main unit rates used for cost estimates of the civil works are given in Table ¨Table 11-5 below. Other rates are given in the detailed cost estimate in Annex K.

Table 11-5 Unit rates Civil Works

	INFRASTRUCTURE WORKS		**UNIT**	**Local**	**Foreign**
code	***Road works***		**Rate USD**	**cost**	**cost**
A08	Road maintenance	lm / year	12	80 %	20 %
A09	Asphalt surfacing	m2	20	60 %	40 %
A10	Cement bonded road surface treatment	m2	15	70 %	30 %
A20	Clearing	ha	980	80 %	20 %
A21	Common excavation	m3	5	80 %	20 %
A22	Fill	m3	10	80 %	20 %
A23	Rock excavation	m3	18	80 %	20 %
A24	Gravel wearing course 150 mm	m3	22	80 %	20 %
A25	Subbase 350 mm	m3	25	80 %	20 %
A26	Erosion protection	m2	27	80 %	20 %
A27	Guard rail	lm	70	70 %	30 %
	CONCRETE WORKS				
	Outdoor				
C01	Plain vertical formwork	m2	60	70 %	30 %
C02	Plain sloping formwork	m2	80	70 %	30 %
C03	Plain horizontal formwork	m2	80	70 %	30 %
C04	Curved formwork	m2	100	70 %	30 %
C06	Mass concrete	m3	120	70 %	30 %
C10	Structural concrete C35 outdoor	m3	180	70 %	30 %
C14	Reinforcement steel	ton	2 000	70 %	30 %
	Underground				
C21	Formwork to tunnel lining	m2	80	70 %	30 %
C22	Formwork to shaft lining	m2	110	70 %	30 %
C24	Plain vertical formwork UG	m2	70	70 %	30 %
C25	Plain horizontal formwork UG	m2	90	70 %	30 %
C26	Plain curved formwork UG	m2	110	70 %	30 %
C27	Sliding/climbing formwork UG	m2	50	70 %	30 %
C28	Mass Concrete UG	m3	140	70 %	30 %
C29	Concrete in tunnel lining C35	m3	220	70 %	30 %
C30	Concrete in shaft lining C35	m3	220	70 %	30 %
C31	Concrete in tunnel slab C35	m3	150	70 %	30 %
C32	Structural concrete C35 UG	m3	200	70 %	30 %
C34	Reinforcement steel	ton	2 050	50 %	50 %
	DAM WORKS				
	Foundation preparation for dams				
D02	Foundation preparation for dams	m2	8	40 %	60 %
D03	Drilling and grouting	lm	150	25 %	75 %
D06	Grout curtain	m2	100	20 %	80 %
	Earth and Rock fill dam				
D10	Asphalt core	m3	380	20 %	80 %
D12	Filter fill, crushed rock, (D=0-60 mm, T= 1.5m)	m3	23	40 %	60 %
D13	Filter fill, crushed rock, (D=0-20 mm, T= 0,2m)	m3	23	40 %	60 %
D14	Transition fill (D=0-150 mm, T=1.0 m)	m3	15	40 %	60 %
D15	Transition fill (D=0-200 mm, T=4.0 m)	m3	15	40 %	60 %
D16	Rock fill (D=0-0.3m)	m3	13	40 %	60 %
D17	Rock fill drainage layer(D=0.03-0.2m)	m3	15	40 %	60 %
D18	Rock fill,D=0-0.6m	m3	12	40 %	60 %

D19	Rock fill, D=0-1.0 m	m3	10	40 %	60 %
D20	Rock fill from excavations	m3	8	40 %	60 %
D21	Rip-Rap slope protection	m3	15	40 %	60 %
D23	Transport / haulage	m3-km	1.0	70 %	30 %
D24	Rip-Rap toe protection	m3	25	40 %	60 %
D26	Instrumentation	%	1	10 %	90 %
	Spillway				
D30	Formwork, plain	m2	45	0 %	100 %
D31	Formwork, sloping	m2	50	0 %	100 %
D32	Formwork, curved	m2	60	0 %	100 %
D37	Concrete in Spillway	m3	180	0 %	100 %
	EXCAVATION WORKS				
	Open air				
E04	Clearing and grubbing	m2	2	30 %	70 %
E05	Stripping of topsoil	m2	4	30 %	70 %
E06	Soft excavation (easy)	m2	4	50 %	50 %
E07	Soft excavation (normal)	m3	6	50 %	50 %
E08	Soft excavation (difficult)	m3	8	50 %	50 %
E09	Soft excavation (under water)	m3	15	50 %	50 %
E10	Rock excavation (easy/bulk)	m3	8	50 %	50 %
E11	Rock excavation (normal)	m3	15	50 %	50 %
E12	Rock excavation (structural)	m3	17	50 %	50 %
E13	Rock excavation (under water)	m3	40	50 %	50 %
E14	Rock excavtion dam foundation	m3	27	50 %	50 %
E15	Rock excavation, contour requirment	m3	27	50 %	50 %
E16	Contour drilling	lm	5	50 %	50 %
E17	Rock quarrying	m3	3	40 %	60 %
E18	Stabilising rock slopes	m2	40	50 %	50 %
E19	Stabilising earth slopes	m2	10	50 %	50 %
E20	Back fill and compact, excav. material	m2	3	50 %	50 %
E21	Back fill and compact, selec. material	m3	5	50 %	50 %
E22	Cofferdam fill	m3	10	50 %	50 %
E24	Rip-Rap protection river bed and slopes	m3	22	70 %	30 %
	Rock support				
E30	Rockbolts grouted, L=3m	No	75	40 %	60 %
E31	Rockbolts grouted, L=4 m	No	150	40 %	60 %
E32	Rockbolts grouted, L=6 m	No	300	40 %	60 %
E33	Rock achors, L= 10 m	No	320	40 %	60 %
E34	Shotcrete	m3	400	35 %	65 %
E35	Shotcrete with fiber	m3	500	35 %	65 %
E36	Cement grouting	ton	1400	60 %	40 %
E37	Polyurethane grouting	kg	15	20 %	80 %
E38	Wire mesh	ton	2500	30 %	70 %
	UNDERGROUND EXCAVATION				
E40	Excavation of cavern. General	m3	35	35 %	65 %
E41	Excavation of cavern. Top stoll	m3	40	35 %	65 %
E42	Smooth blasting	m2	15	35 %	65 %
E43	Excavation of shaft A=5m2,	lm	1 400	35 %	65 %
E44	Excavation of shaft A=10 m2,	lm	2 200	35 %	65 %
E45	Excavation of shaft A=20 m2,	lm	3 200	35 %	65 %
E46	Excavation of shaft A=30 m2,	lm	4 200	35 %	65 %
E49	Widening of shaft (additional m2)	m3	110	35 %	65 %
E51	Excavation of tunnel A=16m2,	lm	1 900	35 %	65 %
E52	Excavation of tunnel A=20 m2,	lm	2 050	35 %	65 %
E53	Excavation of tunnel A=25m2,	lm	2 200	35 %	65 %
E57	Excavation of tunnel A=50 m2,	lm	2 860	35 %	65 %
E61	Excavation of tunnel A=90 m2,	lm	3 700	35 %	65 %
E63	Marginal tunnel excavation	m3	21	35 %	65 %
E64	Cleaning tunnel invert	m2	10	35 %	65 %
E65	Pressure grouting of tunnel	m	1 000	35 %	65 %
	Rock support underground				
E70	Shotcrete with fiber, at face	m3	500	30 %	70 %
E71	Shotcrete with fibers	m3	450	30 %	70 %
E73	Shotcrete with fiber in shafts	m3	700	30 %	70 %
E75	Rockbolts grouted, L=3m	No	80	25 %	75 %
E77	Rockbolts grouted, L=4 m	No	90	25 %	75 %
E78	Rockbolts grouted, L=6 m	No	100	25 %	75 %
E79	Spiling rockbolt, L=6m grouted	No	160	25 %	75 %
E80	Rockbolts in shaft, grouted, L=3m	No	120	25 %	75 %
E81	Steel arch sets	ton	4 000	20 %	80 %
E84	Grouting of plug	LS	80000	50 %	50 %
E98	Excavation of TBM tunnel D=8 m	lm	4 180	20 %	80 %

E99	Excavation of TBM tunnel D=8.5 m	lm	4 390	20 %	80 %
E100	Excavation of TBM tunnel D=9 m	lm	4 600	20 %	80 %

11.6 Quantities of civil works

The basis for calculation of the quantities is the project drawings in Volume 2. Topographic digital maps having 5 m contours have been prepared from aerial photos and have been scaled to the appropriate scales for profiles etc.

At the dam sites, the terrain has been surveyed along cleared profiles and maps with 2 m contours have been prepared. Some difficulties in surveying of the river bed were experienced, and the map in the river bed is edited from the Photomap map and a limited number of surveyed points.

Based upon core drillings at the Dam sites the thickness of the soil above the rock, have been estimated by the geotechnical engineers. Minor soil cover is registered in the project area.

Item

Each section is split into a number of items, typically such as rock excavation, concrete works, rock bolts etc. comprising the main specialised works to be constructed for a given section.

Quantities

Quantity estimates have been prepared for each individual item. Minor items, auxiliaries and finishing works, special site installations as well as mechanical and electrical installations were considered either by inclusion of these activities in the detailed cost estimate, or as an percentage. Miscellaneous cost items are added to the above, depending on their volume and relative cost.

The tunnels are designed as unlined tunnels, and the quantities of rock support are based upon the geological reports estimates of rock quality and required support.

The major quantities of the construction works are summarised in Table 11-6 below.

Table 11-6: Summary of main Civil Works quantities GD-6

Description	Unit	Quantity
Excavation dam, spillway and intake	m^3	548 000
Embankment fill in dam	m^3	2 640 000
Tunnel excavation	m^3	1 130 000
Cavern excavation	m^3	149 000
Mass concrete outdoor	m3	374 000
Concrete outdoor	m^3	54 000
Concrete powerhouse & transformer hall	m^3	5 500
Shotcrete	m^3	16 000
Grouted rock bolts	no	21 500

11.7 Hydraulic steelwork and electro-mechanical costs

11.7.1 General

It is assumed that all electrical and mechanical equipments will be procured after international competitive bidding on a limited number of plant packages on turnkey basis, covering detailed design, supply, transports, erection and commissioning.

The cost estimates of hydraulic steelwork, electrical and mechanical equipment in the power plant are based upon the consultant's database and experience from other power plants. Special allowances for sea and overland transport as well as cost for erection, testing and commissioning have been included. The cost of electro-mechanical equipment for power plants is not stable, and major variations is experienced during tendering of international projects.

It has been assumed that supervision of erection, testing and commissioning of the equipment is carried out by expatriate personnel from the manufactures and by the consultant in co-operation with the client.

All electrical and mechanical equipment and hydraulic steelworks have to be imported and is considered to have a major portion foreign cost.

The following detailed cost is calculated.

11.7.2 Mechanical works

The cost of the mechanical works are summarised in Table 11-7, powerhouse equipment and in Table 11-8, Hydraulic steelworks.

Table 11-7: Mechanical equipment cost

Itemm	Name	Description	Number	Cost
	Main Powerhouse			**1000 USD**
1	Vertical Shaft Francis Turbines	129 MW Vertical Shaft Francis Turbines at 300 rpm under a net head of 228 mWC	2	23,000
2	Spherical Shut-off Valves	Diameter 2500 mm valves with revision seal and dead weight closing	2	
3	Governors	Electronic-hydraulic PID Governors with frequency, water level, and load control	2	
4	Cooling Water and Drainage System	Pumping of water from tailrace with gravity feed to consumers from cooling water reservoir at gallery, Drainage from drainage sump, devatering directly	2	1,714
5	Machine Hall Crane	290 ton Bridge Crane with auxiliary hoist	1	1,886

Table 11-8: Hydraulic steelworks

	Hydraulic steelworks			
1	Intake Gate	Roller gate B x H = 5.50 x 8.20 meter	1	1,059
2	Intake Gate Stop Logs	Stop logs to reach elevation 585, 10 x 14, Pressure 20 mWC	1	529
3	Trash Racks	B x H = 10 x 12 m. Designed for full clogging	1	483
4	Trash Rack Cleaner	Manually operated from elevation 890.5	1	371
5	Bottom Outlet Gate	Radial gate designed to lower res-ervoir during dry season, 2.5 * 4 meter to fit in culvert, design head 60 meter	1	594
6	Penstock	Diameter 4200 mm. Designed for internal pressure including water-hammer and external pressure of 270 mWC, length: 50 meter	2	5,302
7	Adit Gate	2.5 x 2.5 m gate for access to stone trap tunnel, Design pressure 275 mWC	1	223
8	Draft Tube Gate	B x H = 5 x 7 m. Design pressure 15 m. Operation by wire hoist from transformer hall	2	706
9	Tailrace Stop Logs	Stop logs at tailrace exit, assumed low, and divided in several sections	1	143
10	Bypass Stop Logs	B x H = 6.5 x 6.5 meters, pressure 69 mWC	1	571
11	Trash rack	To be positioned near Stop logs, dimensioned for 1 bar differential pressure	1	149

11.7.3 *Electrical equipment*

A computer model has been used to estimate the weight, dimensions and cost of the generator. These prices have been compared and calibrated with the Consultant's cost database for similar and recent international projects. Special allowances for sea and overland transport as well as cost for erection, testing and commissioning have been included.

The estimated cost of electrical equipment and HVAC inclusive of contingency for Genale GD-6.

Table 11-9 Cost of Electrical equipment

Description		Q'ty		Amount Mill. USD
Generators	Sn = 150 MVA PF = 0.96 n = 300 rpm	2	Unit	19.230
Main transformers Three-phase	Sn = 150 MVA Ug / 400 kV ek = 13 %	2	Unit	6.900
400 kV Cables PEX insulated	L = 1100 m	1	Set	6.400
400 kV Switchgear	Conventional Outdoor	1	L.S.	2.470
Transformer/cable connec-tion	400 kV SF6	1	L.S.	1.170
33 kV switchgear Cubicle mounted	Powerhouse and switchyard	1	L.S.	3.220
Station Supply equipment	400 V a.c. 220 V d.c.	1	L.S.	6.700
Control, protection & tele-com				3.730
Aux. cables & Earthing				3.640
Domestic installations				1.200
33 kV lines to Intake & Camp				1.100
Spare Parts				3.020

11.7.4 *Small hydropower unit*

A minimum water release flow of 2.5 m^3/s is proposed from the Dam site. The available head at the Dam site is about 60 m, and it is proposed to install a small turbine to utilise the energy in the outlet. The cost of the complete small turbine unit is given in Table 11-10.

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Table 11-10: Small turbine unit cost

Item	Description	Q'ty	Unit	Amount 1000 USD
Compensation water Turbine	1.3 MW horisontal Shaft Unit with contoller and butterfly valve	1	Each	557,000
Butterfly Shut Off Valve	Diameter 800 butterfly valve	1	Each	93,000
Auxilliary Equiment	Parallel bypass in case of power-plant failure.	1	L.S.	107,000
Crane	10 ton electrical hoist.	1	Each	9,000
SUM, MECHANICAL EQUIPMENT				**766,000**
Generator	1500 kVA, 1000 rpm Brushless exciter & AVR	1	Each	314,000
Transformer	1500 kVA, 33/3,3 kV Oil insulated	1	Each	114,000
3,3 kV cable termination	With circuit breaker	1	L.S.	95,000
3,3 kV cable	PEX insulated	200	m	46,000
33 kV line termination	Pole mounted	1	L.S.	15,000
Control & auxiliary equipment		1	L.S.	300,000
SUM, ELECTRICAL EQUIPMENT				**884,000**
SUM, MECHANICAL & ELECTRICAL EQUIPMENT				**1 650,000**

11.8 Transmission system

The cost for transmission system is calculated based on tendered prices received from a number of projects in Africa and adjusted according to the price level in Ethiopia. A summary of the costs for the transmission system are given in Table 11-11.

The distance to GD-3 is 80 km and to Negele substation about 70 km.

Table 11-11: Cost of Transmission System

400 kV Transmission line to GD-3	187 600 USD/m
33 kV double circuit *Construction by local contractor*	14 000 USD/m

11.9 Environmental cost estimate

The environmental costs provide for the compensation and mitigation of direct impacts not managed under the main design concept.

The guiding principle is that people or communities directly affected by the construction of the GD-6 HEPP should be no worse off (and preferably better off) after project implementation. What must be avoided is a situation whereby people in the direct impact zone “subsidise” the project through a reduction in their standard of living or income generation opportunities.

Table 11-12: Environmental cost

No.	Item	Cost and Units	Capital cost	Annual Recurrent Cost Construction Phase
1	Reservoir clearing (costed as civil works)	800/ha	654,400	
2	Technical environmental optimisation	provisional	200,000	
3	Compensation for cultivated land	6.000/ha	60,000	
4	Outreach, awareness and capacity building	150.000	150,000	175,000
5	Rehabilitation of works areas	9.000/ha	135,000	
6	Monitoring of construction work	125.000/year	15,000	125,000
7	Post construction environmental audit	70.000	70,000	
	Sub-Totals		560,000	300,000
	Contingency at 10%		56,000	30,000
	Totals (USD)		**616,000**	**330,000**
	Total for Construction Phase (assumed at 5 years)	2,266,000		

11.10 Engineering, administration and physical contingencies

To arrive at the total cost for the project, the costs of engineering, supervision, Owners administration and contingencies have to be added to the construction costs.

Final design, preparation of bid documents, bid evaluation and participation in contract negotiations, preparation of work drawings and supervision of construction have been taken as 8% of the total construction cost and contingencies.

The owner’s administration costs have been taken as 3 % of the total costs.

To cover unforeseen costs, contingencies have been added to the construction costs with 5% for electrical and mechanical work, 10% for environmental mitigations, infrastructure works and transmission works and 10% for other civil works.

11.11 Summary of costs

Table 11-13: Cost summary - Genale GD-6

Item no	Item		1000 USD Total Cost	1000 USD Local Cost	1000 USD Foreign. Cost
1	***INFRASTRUCTURE***				
1.1	ROADWORKS		13 408	10 520	2 888
1.2	HOUSING		18 006	14 405	3 601
1.3	OFFICES etc.		6 450	5 156	1 294
1.4	GENERAL COST	18 %	6 815	5 414	1 401
1.5	CONTINGENCIES	10 %	4 468	3 549	918
	TOTAL INFRASTRUCTURE		***49 147***	***39 044***	***10 103***
2	***RESERVOIR***				
2.1	COMPENSATION		60	60	0
2.2	SITE CLEARING		660	594	66
2.3	GENERAL COST	18 %	130	118	12
2.4	CONTINGENCIES	10 %	85	77	8
	TOTAL RESERVOIR		***935***	***849***	***86***
3	***DAM***				
3.1	EXCAVATION DAM SITE		3 817	1 844	1 973
3.2	DIVERSION		10 677	5 663	5 014
3.3	COFFERDAMS		5 031	1 932	3 099
3.4	DAM		46 582	17 260	29 322
3.5	SPILLWAY		14 442	8 442	6 000
3.6	GENERAL COST	25 %	19 183	8 324	10 859
3.7	CONTINGENCIES	10 %	9 592	4 162	5 429
	TOTAL DAM		***109 325***	***47 627***	***61 698***
4	***INTAKE***				
4.1	EXCAVATION		560	276	284
4.2	CONCRETE WORKS		868	518	349
4.3	STEEL STRUCTURES		2 524	529	1 996
4.4	GENERAL COST	25 %	988	331	657
4.5	CONTINGENCIES	10 %	494	165	329
	TOTAL INTAKE		***5 434***	***1 819***	***3 615***
5	***WATERWAY***				
5.1	HEADRACE TUNNEL		21 247	4 671	16 575
5.2	SURGE CHAMBER HEADRACE		6 839	2 759	4 080
5.3	PENSTOCK TUNNELS		6 041	1 059	4 982
5.4	DRAFT TUBES		1 414	447	967
5.5	SURGE CHAMBER TAILRACE		6 887	2 346	4 542
5.6	TAILRACE TUNNEL		52 880	11 281	41 599
5.7	TAILRACE OUTLET		1 768	892	876
5.8	GENERAL COST	25 %	17 248	4 006	13 242
5.9	CONTINGENCIES	10 %	8 624	2 003	6 621
	TOTAL WATERWAY		***122 947***	***29 464***	***93 483***
6	***POWER STATION***				
6.1	MAIN ACCESS TUNNEL		4 638	1 661	2 976
6.2	ADITS TUNNELS		5 594	1 976	3 618
6.3	POWER STATION AND TRANSFORMER CAVERN		1 698	589	1 108
6.4	CONCRETE WORKS		3 726	2 305	1 422
6.5	PORTAL		432	243	189
6.6	CABLE TUNNEL and CULVERT		1 466	591	875
6.7	GENERAL COST	25 %	1 830	932	898
6.8	CONTINGENCIES	10 %	915	466	449
	TOTAL POWER STATION		***20 299***	***8 763***	***11 535***
7	**POWER STATION EQUIPMENT**				
7.1	MECHANICAL		27 132	5 426	21 706
7.2	ELECTRICAL		48 000	3 389	44 611
7.3	HVAC		1 284	257	1 028
7.4	GENERAL COST	10 %	7 642	907	6 734
7.5	CONTINGENCIES	5 %	4 203	499	3 704

	TOTAL POWER STATION EQUIPMENT		***88 261***	***10 479***	***77 782***
8	**SMALL HYDROPOWER PLANT**				
8.1	CIVIL WORKS		245	71	174
8.2	EL&MECH		1 660	132	1 528
8.3	GENERAL COST	10 %	190	20	170
8.4	CONTINGENCIES	5 %	105	11	94
	TOTAL SMALL HYDROPOWER PLANT		***2 200***	***234***	***1 965***
9	**TRANSMISSION, SWITCHYARD, LOCAL SUPPLY**				
9.1	SWITCHYARD		3 491	1 252	2 239
9.2	400 kV TRANSMISSIOON LINES		16 069	4 897	11 172
9.3	POWER SUPPLY		2 410	964	1 446
9.4	GENERAL COST	15 %	3 296	1 067	2 229
9.5	CONTINGENCIES	5 %	1 263	409	854
	TOTAL TRANSMISSION, SWITCHYARD, LOCAL SUPPLY		**26 530**	**8 589**	**17 940**
10	**ENVIRONMENTAL COST**		**2 200**	**1 980**	**220**
11	**ENGINEERING,SUPERVISION AND AD-MINISTRATION**	**10 %**	**42 508**	**14 861**	**27 646**
	TOTAL PROJECT COST		**469 780**	**163 710**	**306 070**

12 CONSTRUCTION PLANNING

12.1 Introduction

The construction schedule described in this chapter shows that the Genale GD-6 can be commissioned after about 5 years of construction work, following a preparatory period of about 2 years for preparation of design, bidding documents and concluding the contract negotiations. The following conditions prevail:

- Mobilisation for tunnelling works and road construction should start in the month of October.
- The existing track to the Genale River will immediately be upgraded to allow mobilisation for tunnel excavation of the main access tunnel.
- Mobilisation of TBM (tunnel boring machine) at site shall be in month 16.
- Supply of electric power is available at the sites ahead of start of main construction works.

More details are given below regarding construction techniques and approach.

12.2 Construction areas

12.2.1 Construction camps

The main construction camp will be located near the Genale River, on the hill, next to the switchyard area and main access tunnel.

Satellite camps will mainly be at the Dam site, at the intake site and borrow area near the intake. A small camp will also be required at the tailrace for a short period.

12.2.2 Residence facilities

In the initial phase (1 year) temporary housing will be established at the main construction camp, while the construction of the permanent camp is going on. The permanent camp will be used for the Owners and Contractors personnel for the rest of the construction period.

The owner's permanent camp is proposed located on the south side of the river, on a plateau some 2 km upstream of the main constructions camp.

For labour accommodation, it is assumed that the contractor will arrange a separate camp in accordance with the government regulations.

Temporary water supply to the camp areas will be supplied from the river. Water treatment plants and wastewater treatment plants will be provided at the sites.

12.2.3 *Power supply*

Power supply during construction will be through a new double circuit 33 kV power line to be constructed from the Negele substation. The line should preferably be ready for use as soon as tunnel excavations works start in month 2, but temporary power supply be diesel generators must be expected.

12.2.4 *Spoil deposits*

Excavation of the dam foundation, intake cut, the tunnels and the powerhouse will result in large quantities of material (approx. 2 mill m^3).

Rock spoils from drilling of tunnel and from powerhouse excavation will be processed and used as concrete aggregates and as fill materials for the GD-6 dam.

All spoil from the Power station area is expected to be transported to the dam site.

If part of the tunnel excavation will be done from the tailrace outlet, suitable spoil deposit area is identified in the Kebeya valley.

12.2.5 *Borrow area*

A borrow area for the purpose of excavating materials for the dam construction, is located on the right side of the river, next to the excavated cut for the intake.

12.2.6 *Concrete aggregate production plant*

The GD-6 construction areas are located within at distance of 7 km upstream (intake) and 17 km downstream (tailrace outlet) of the powerhouse area and main construction camp. It is expected that one aggregate production plants, which will comprise plants for crushing, screening, sand milling and washing will be located in the main construction camp.

The tunnels and the caverns are all located in basement rock and the quality is considered to be good enough for crushing to concrete aggregates.

A few possible borrow sites for sandy material are located, but they may not be suitable for concrete production, due to long hauling distance and limited quantity.

12.2.7 *Concrete batching and mixing plants*

One concrete batching and mixing plants are foreseen to be located at the main camp.

The concrete mixing plant will provide the concrete for the dams and spillways, the power intakes and the powerhouses and for rock support in the tunnels.

Shotcrete for tunnel support works and conventional concrete (CVC) for the tunnel portal structures will be required from the start of the construction works. The batching and mixing plants with cement storage silos and aggregate silos therefore have to be erected at the start of the construction works.

The concrete plant should have sufficient capacity to provide the necessary shotcrete for rock support works and for supply of concrete to the dams, to the powerhouse and to the waterway tunnel linings etc. The plant should have an expected capacity of 80-100 m^3/h.

The largest concrete works to be executed is the powerhouse area with about 20 000 m^3, and the dam/spillway works with some 40 000 m^3.

12.2.8 Storage of fuel and explosives

Safe transport and storage constitute an important logistics and security challenge. The question of supply and storage of explosives will have to be taken up with the potential suppliers and the relevant authorities in the final/tender design phase.

12.3 Project construction GD-6

The drilling of 16 km waterway of GD-6 by one tunnel boring machine (TBM) Ø=9.0 m, is expected to last 170 weeks plus required time for demobilising the TBM at the intake and mobilise it in the tailrace surge chamber (totally about 4 years).

It will be of great importance to mobilise and start drilling of the waterway as soon as possible. It is therefore planned to use the existing track down to Genale to start mobilising for the D&B tunnel excavation by the powerhouse, for immediate start of the Main Access tunnel.

12.3.1 Main Access Tunnel

Mobilisation for tunnel excavation is expected to start 6 weeks after road construction starts.

Excavation of the access tunnel and the adit to the headrace should be start immediately after mobilisation at the main camp. The time required for excavation of the 1 300 m long access and adit tunnels are 33 weeks, and 5 weeks for excavation of the penstock chamber.

The mobilisation of TBM should be within 16 months from signing of the construction contract. Ordering of the TBM is expected to take place immediately after signing, and 16 months would be the expected time required for manufacturing and transporting a TBM to Ethiopia.

12.3.2 Diversion works

Construction of the road from the main camp to the Dam site is expected to take 25 weeks.

After mobilisation of camps/workshops and construction of internal roads, excavation for the diversion culverts and the spillway with chute canal, is started. Some of the excavated material will be used to establish the Phase 1 cofferdam around the area of the 3 concrete diversion culverts of 44 m^2 each.

The diversion culverts will be located at the right river bank, and an area of about 30 m width and 250 m length shall be excavated and prepared for construction of the 3 culverts. The required cofferdam will have an overall length of 350 m along the right side of the river, but will be relatively low, around 5-6 m.

The completion of the diversion works is expected to be after 45 weeks.

12.3.3 Construction of asphaltic concrete core dam

Succeeding the construction of the diversion culverts construction of the Phase 2 cofferdams could start. With the construction of the up-stream cofferdam to el. 538, crossing of the river is easy, and clearing, grubbing and excavation of soft material in the upper parts of the left dam abutment can also start.

When the construction of the downstream cofferdam is also completed to el. 528, excavation of the dam foundation in the river bed can start.

After completing the excavation, the foundation preparation works are done. The preparation work comprise minor blasting, blanket grouting, concreting of the foundation plinth for the asphaltic concrete core, and curtain grouting underneath the plinth.

When the foundation preparations are completed in the lower part of the dam, the embankment placing is started. The embankment comprises zones of quarried rock fill, drainage layer, transition layers from tunnel spoil and a filter of crushed rock between the transition layer and the core. The different zones are placed and compacted as specified in the description of the dam. The embankment fill is assumed placed at an average rate of 70 000 m^3/week, and is estimated to be completed in 45 weeks.

The plugs and the gate in the diversion culverts/bottom outlet are installed during a low flow period February-March after completion of the dam and the spillway.

12.3.4 Construction of spillway

Construction of the spillway can be started as soon as mobilisation at the Dam site is completed. Excavation of more than 200 000 m^3 is expected. The rock masses should preferably be taken directly into the dam embankment. The concrete works will start in the side channel, weir and chute.

12.3.5 *Construction of intake*

The intake is located some 900 m south of the dam. An intake cut must be excavated to el. 365 before concrete construction works can start. Major rock excavation works is planned at the site, as the excavated material will be used for fill material of the dam.

After the TBM has completed the headrace, are demobilised and moved to the tailrace, the intake channel will be lowered by min. 5 m to create a volume for settlement of sediments in front of the intake.

The borrow area for dam material is shown on the drawing just in front of the intake channel.

12.3.6 *Construction of tailrace outlet*

The tailrace outlet is designed with an outlet construction including stop logs and a tailrace channel of 200 m length back to the Genale River.

The main objective of the design additional to safe closing of the outlet, is that the TBM shall be demobilised in the open after completing the tailrace tunnel. This requires a bay of some 50 m length, which is located between the rock cut and the stop log structure.

Construction of the tailrace structures will be after the major concrete works are completed.

12.3.7 *Construction of tunnels*

<u>Waterway</u>

Tunnel construction will be done by the TBM method, and the following construction equipment will be required:

- One single gripper TBM, Ø=9m, with ordinary back-up rig. The TBM is electrically driven, requiring 3.5 MW capacity, and has the following standard back-up equipment:
    - Roof bolting equipment
    - Probe drilling equipment
    - Ring beam manipulator
    - Shotcrete manipulator
    - Back-up belt conveyor

The headrace tunnel, 4.7 km, will be excavated from the Power station and upstream to the intake. The high pressure tunnel, 800 m, has a slope of 1:10 while the remaining upstream will have a slope 1:29. Drainage of the tunnel will then be easy by gravity, down to the Power station, where pumping will be required.

After completion of the headrace the TBM will be shifted to the tailrace surge chamber where it will be mobilised to drill the 11.3 km long tailrace tunnel. The tunnel is almost horizontal, starting at el. 338.5 and ending at el. 340.

TBM capacity

The assessment of rock quality applied for the conventional alternatives is also relevant for the TBM concept. For rock mass of high quality, the rock support may be performed without interrupting the boring operation. In rock mass of poor quality, support work will delay the boring process and give additional construction time. The capacities of the support are set as a combination of partly done support work while boring and partly stopping the tunnel boring for such work. Additional time is added for handling ground water problems.

The total time for excavating each tunnel is thus the sum of the time for boring, rock support and handling of water problems. The results are presented in Table 12-1. Starting date is the date for order to proceed.

Table 12-1: Time estimate - TBM

Activity	
Manufacturing	12 month
Transport to site	3 month
Assembly and starting up activities	3 month
Boring	29 month
Additional time for rock support and grouting	1 month
Disassembly and removal	2 month
Total time, from order to proceed	50 month

Other tunnelling works

Tunnel construction, outside major waterway sections, will be done by the drill and blast method, and the following construction equipment will be required:

- Electrically powered drilling jumbos on rubber tyre chassis with hydraulically operated booms and drilling hammers. The chassis to be diesel powered for driving in and out of the tunnels. One unit should be suitable for tunnelsections around, or less than 20 m^2.
- Diesel or electrically powered shotcrete robots on rubber tyre chassis and with hydraulically operated booms carrying hoses and nozzles for spraying the ready mixed shotcrete.
- Front end wheel loaders or electrically powered front-loading excavators for mucking out.
- Dump trucks for transport of muck.
- Diesel or electrically powered shotcrete robots on rubber tyre chassis and with hydraulically operated booms carrying hoses and nozzles for spraying the ready mixed shotcrete.
- Trucks for charging dynamite and for bolting and grouting with hydraulically operated booms and working platform.

- Mobile, electrically powered ventilation fan units, service containers and miscellaneous accessories.
- Backhoe-mounted hydraulic hammers for scaling.
- Hydraulically operated articulated forms for concreting of roof and walls in the tunnels. The form to be mounted on rubber tyres for convenient transport.

The sequences of excavation are drilling, charging, blasting, ventilating, loading and mucking out. After each round temporary rock support will be applied as required. Normally this will be by rock bolting and shotcrete. When adverse conditions are met, thick shotcrete layers combined with reinforced shotcrete ribs might be required.

The headrace surge tunnel is assumed excavated descending from outside, el. 605, towards the vertical shaft to the headrace tunnel. The shaft will be, 120 m long, and excavated by first drilling a, i.e., dia. 2 m shaft. Enlargement to 50 m^2 will be by drilling and blasting from above, using the pilot shaft as chute for the spoil.

After the excavation of the main access tunnel, followed by excavation of the headrace adit is completed, the the top headings of the powerhouse and the transformer hall, the adit to the tailrace surge tunnel and the draft tube tunnels will be started. After these tunnels are excavated the tailrace surge chamber and tailrace tunnel is ready for excavation.

Excavation of the cable tunnel will be done from the transformer hall to the switchyard. The upper part of the tunnel will be a drilled shaft, dia. 4m, about 80 m long.

12.3.8 Construction of the powerhouse and the transformer cavern

Excavation works

The upper 6-7 m high top heading of the powerhouse cavern will be excavated from the access through the transformer gallery.

The permanent rock support of the cavern roof consisting of ~0.10 m fibre reinforced shotcrete and grouted rock bolts will be installed before further excavation of the powerhouse cavern.

Excavation from the top heading down to the machine hall floor will take place by benching and the access tunnel will be used for transportation of the excavated rock masses.

After further benching down to the generator floor level, the bus-bar tunnels to the transformer cavern will be excavated. The bottom part of the cavern below the generator floor will be excavated partly from above through the main access tunnel and partly from the tailrace tunnel/draft tubes.

Permanent rock support to the walls, mainly by systematic rock bolting and layers of shotcrete will be performed as an integrated part of the excavation activities. This will allow for safe, working conditions immediately after excavation of the cavern has been completed.

Concrete works in the powerhouse

After excavation of the upper part of the cavern above machine hall floor level, concrete works for the overhead crane beams will follow. The crane beams and parts of the supporting columns are fixed to the walls by grouted rock anchors. The permanent support of the crane beams will be established after excavation is completed by extension of the columns down into the powerhouse sub-structure.

After excavation of the powerhouse cavern the concrete works for the 15 m long off-loading and erection bay in the outer end of the power-house is started, and completed as fast as possible. As soon as this section of the powerhouse has reached the machine hall floor level, the overhead travelling crane is installed. Thereafter the draft tube steel linings are erected and embedded, followed by erection and embedding of penstock steel linings and turbine spiral-casings. Finally the concrete works on the generator floor and the machine hall floor is done.

Installation and erection of electro-mechanical equipment

Prior to installation and erection of any permanent mechanical and electrical equipment, except for the travelling crane, all major civil works in the powerhouse has to be completed in order to reduce the extent of spoil, dust etc. in the installation period. This will include a thorough cleaning up of the machine hall cavern.

No separate erection bay has been constructed in the powerhouse. It is therefore assumed that erection of Unit 2 is started when erection of Unit 1 is almost completed.

Erection and installation of auxiliary electrical and mechanical equipment will be done in parallel with the installation of the generating units after completion of the civil works in the powerhouse and the transformer hall.

12.4 Implementation schedules GENALE GD-6

Drawing F01.

Implementation schedules based upon dependent activities has been prepared for the Genale GD-6.

12.4.1 Construction times for tunnels

The construction time for each tunnel has been estimated based upon basic excavation rates for tunnelling and equivalent time rates for applying rock-support works such as shotcrete, rock bolts and concrete lining.

The basic tunnel excavation capacity in favourable rock masses, is estimated to 24 m^3/hour for a D7 m tunnel.

For calculating advance rates, the following time consumption has been assumed for tunnel rock support works:

Excavation of D7 m tunnel in sound rock:

- Rock bolting in tunnels: 8 bolts/hour
- Fibre reinforced shotcrete: 6 m^3/hour
- Rigging for rock bolting: 0.2 m/hour
- Rigging for shotcrete: 0.5 hour

The TBM will normally have a capacity of up to and above 90-100 m/week under conditions expected to be found at GD-6.

The average progress rate has been estimated to 35 - 40 m/week for tunnels where the whole cross section is excavated in one operation. Based upon the above assumptions the following average construction rates have been applied (from Table 12-1):

- Headrace and tailrace tunnel: 95-100 m/week
- Access tunnel and other tunnels: 35-40 m/week
- Shafts: 12 m /week

The construction time for the waterway is expected to be 175 weeks, plus 12 weeks for remobilisation, and is expected to be on the critical path for commissioning of the first unit.

12.4.2 *Genale GD-6 Underground powerhouse*

Excavation of rock and providing shotcrete and grouted rock bolts and concreting of the crane girders is estimated to 24 weeks.

Installation of the draft tubes and the spiral casing and concreting of 5 100 m^3 of concrete is estimated to require 70 weeks. The main electro-mechanical installations can commence 70 weeks after start of the installation of the draft tubes.

Construction of the access tunnel, the powerhouse and installation of the electromechanical equipment and filling of the reservoir is on the critical path. It is estimated that testing of unit 1 may start 220 weeks after start of construction.

12.4.3 *Implementation schedule Genale GD-6*

With the assumptions given above regarding excavation rates, powerhouse concrete works rates, time for erection of the generating units, construction rate for the dam and the filling rate of the reservoir the commissioning time for the power plant has been estimated based upon dependency between the different activities.

The critical path for commissioning of the Genale GD-6 power plant appears to be construction of the waterway, if drilled by one TBM only. All generating units will be installed and waiting for the reservoir to be filled up to MOL .

13 ECONOMIC AND FINANCIAL ANALYSIS

13.1 Power Markets and Supply Alternatives

13.1.1 Market Overview

The optimal generating characteristics and the timing of the construction of the GD-6 will depend on the markets into which its electricity will be sold. Given the location of the project relative to the largest concentrations of consumers in the region, the two most obvious potential markets, as is the case for the recently studied Genale-3 (GD-3) scheme, are the Addis Ababa area via the Ethiopian Interconnected System (ICS) and the Kenyan national grid via a link to a proposed new HV transmission line.[4]

In reality, the future markets for Ethiopian electricity in general are likely to expand far beyond the borders of Ethiopia, into the Sudan, westwards to Uganda and northwards to Egypt. The financing of a transmission interconnection with the Sudanese grid was approved in December 2007 and there are firm plans to create a cross-border trading grid within the Nile Basin countries. These developments will greatly increase the export market for competitively priced electrical energy and Ethiopia is ideally placed to exploit vast new markets.

With regard to the local market in Ethiopia, the main consumer centre is Addis Ababa located some 430 air-km (and 750 road-km) from the GD-6 project. This market could be supplied by reinforcing the existing 230 kV network or through the planned 400 kV network. The closest node in the 230 kV interconnected grid is at the Melka Wakena HPP some 200 air-km from GD-6. However, the generation from the GD-6 project will be connected to the substation at the proposed GD-3 project, about 80 km upstream of the Genale River.

As for the Kenyan market, Kenya Electricity Generating Company Ltd. (KenGen), Kenya Power & Lighting Company Ltd.(KPLC), and EEPCo agreed in March 2006 on a concept of interconnecting the two power systems. A Memorandum of Understanding was signed in Nairobi in May 2006, and a study has recently (February 2009) been finalised to feasibility level paving the way for the financing of the project. The study, *Ethiopia-Kenya Power Systems Interconnection Project,* a co-operation between EEPCo and Kenyan Ministry of Energy (MOE), has been carried out by the German consulting company Fichtner Gmbh, and it will hereafter be referred to as the *Interconnection Study*.

[4] A third potential market is certain regions in Somalia. However, in the present assessment of potential markets, Somalia has not been considered as it is currently very small (with a potential reportedly of 50 to 100MW and, particularly, the political environment is very unstable. However, this may well change at some time in the future.

Figure 13-1 shows the suggested routing for the proposed interconnection line. The Interconnection Study suggests a 500 kV DC line from the substation Wolayta/Sodo on the Ethiopian side in connection with the Gilgel Gibe III project, to Longonat substation outside Nairobi. The length of the main line is 1066 km. In addition are there 400 kV connection lines to the two substations of which 55 km are in Ethiopia and 80 km in Kenya respectively, which make the total length of the line about 1200 km.

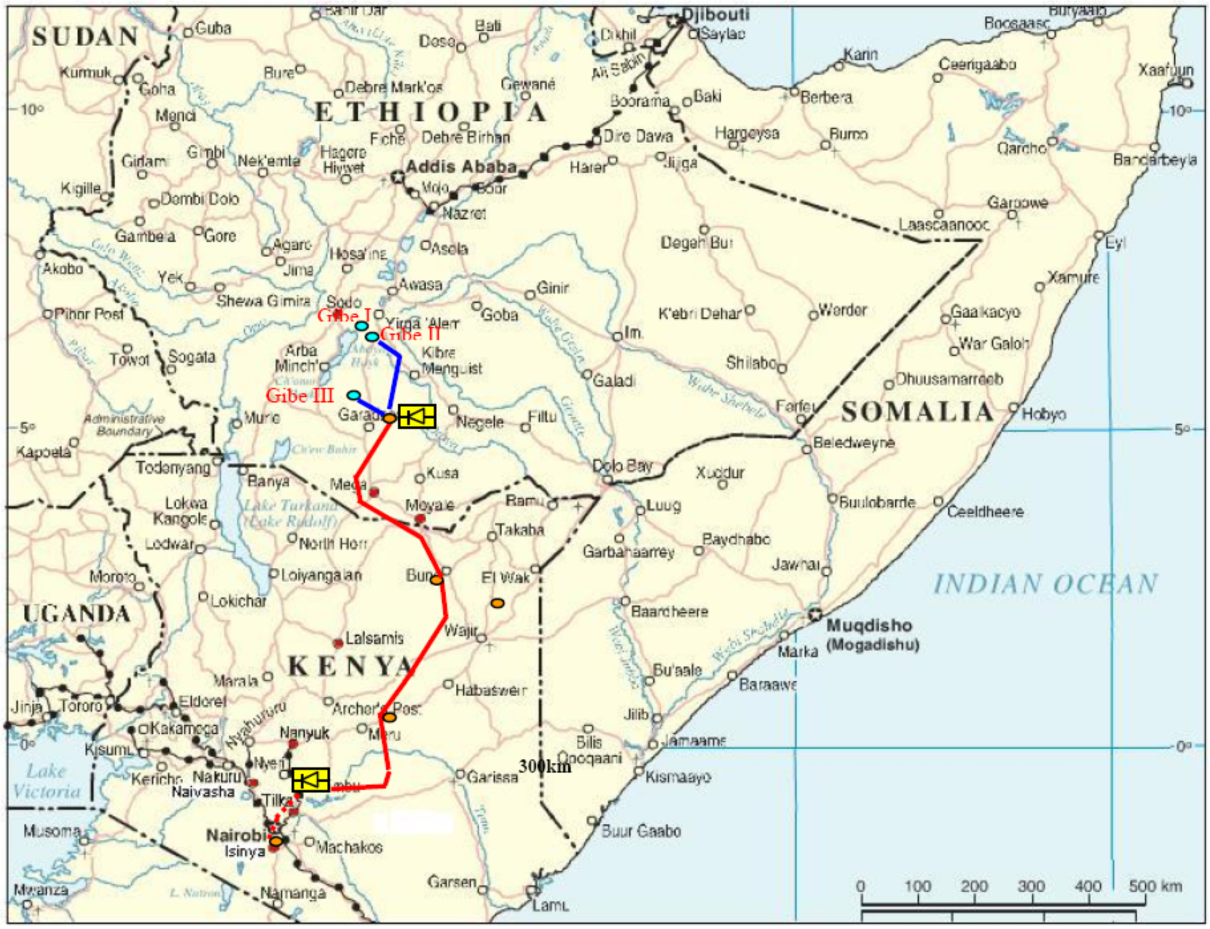

Figure 13-1: Proposed Interconnection Line Ethiopia – Kenya

(Source: Ethiopia-Kenya Power Systems Interconnection Project)

The present chapter assesses the above mentioned two markets in terms of forecast electricity supply and demand and in terms of candidate electricity generating projects with which GD-6 would compete.

13.1.2 *Ethiopia: Power Sector*

At the end of FY 2007, Ethiopia's interconnected system ICS consisted of eight hydropower plants in four river basins across the country, three larger diesel plants, a number of small diesel plants, and a geothermal plant, with a total installed system capacity of 782 MW;

whereas dependable capacity is estimated at 758 MW. The average energy output of the ICS plants is 3,316 GWh

Small hydro and diesel power plants in the SCS have a combined capacity of 32 MW.

Table 13-1: Existing Generation Capacity at End of FY 2007

Plant Name	***Hydro***	***Diesel***	***Geo-thermal***	***Total***	***Total***	***Average Energy***	***Year of Com-miss.***
	Installed Capacity (MW)				**Depend-able Cap. (MW)**	**(GWh)**	
Koka	43.2	-	-	43.2	38	110	1960
Awash II	32.0	-	-	32.0	32	165	1966
Awash III	32.0	-	-	32.0	32	165	1971
Finchaa	134.0	-	-	134.0	128	640	1973/200
Melka Wakena	153.0	-	-	153.0	153	543	1988
Tis Abay I	11.4	-	-	11.4	11	85	1964
Tis Abay II	73.0	-	-	73.0	68	282	2001
Gilgel Gibe	184.0	-	-	184.0	184	847	2004
Aluto Langano	-	-	7.3	7.3	0	0	1999
Awash 7 Kilo	-	35.0	-	35.0	35	478	2004
Kaliti	-	14.0	-	14.0	14		2004
Dire Dawa	-	38.0	-	38.0	38		2004
Small Diesel	-	25.2	-	25.2	25	-	1958/200
Total ICS	**662.6**	**112.2**	**7.3**	**782.1**	**758**	**3316**	
Total SCS	**6.2**	**25.6**	**-**	**31.7**	**31**	**-**	1967/200

Source: EEPCo, Facts in Brief 2006

Energy production by system and source for the years FY 2002-2006 is shown in . The figures confirm the dominance of the ICS and hydropower.

Table 13-2: Energy Production by System and Source (GWh)

System /Source / FY	2002	2003	2004	2005	2006
ICS					
Hydro	1975.2	2007.1	2262.5	2521.0	2832.0
Diesel	0.1	21.1	15.8	18.4	12.0
Geothermal	1.0	0.0	0.0	0.0	0.0
Total	**1976.3**	**2028.2**	**2278.3**	**2539.6**	**2844.0**
SCS[5]					
Hydro	16.6	16.5	16.6	17.9	19.0
Diesel	16.5	19.0	21.5	31.1	32.0
Total	**33.1**	**35.5**	**38.1**	**49.0**	**51.0**
ICS + SCS					
Hydro	1991.8	2023.6	2297.1	2539.1	2851.0
Diesel	16.6	40.1	37.3	49.5	44.0
Geothermal	1.0	0.0	0.0	0.0	0.0
Total	**2009.4**	**2063.7**	**2316.4**	**2588.6**	**2895.0**

Source: EEPCo, Facts in Brief 2006

The ICS faced supply deficits in the past, which led to power rationing. In order to alleviate this problem, EEPCo introduced 87 MW of diesel fired power plants in 2004 in selected parts of the grid (in addition commissioning the Gilgel Gibe hydroelectric project). For a few years thereafter, Ethiopia has been in a comfortable position as far as its supply and demand balance is concerned. However, with rapid growth, particularly in generation requirements in the last couple of years, the energy balance is now being strained, as shown in Table 13-3. To cope with this situation, and also acknowledging the vagaries of rainfall and the fact that demand is increasing significantly, GoE is developing an ambitious generation and transmission program, in ad-

[5] Some discrepancies are noted for the SCS in relation to figures in Table 2.1.

dition to looking at possible energy efficiency interventions to relieve pressure on power system expansion.

Table 13-3: Supply and Demand Balance for ICS FY 2007

ICS	Aver. Energy GWh	Power MW
Demand referred at power station (Generation)	3269	623
Supply capability, of which:	3316	758
- Hydropower	2838	646
- Thermal	478	112
Balance	47	135
System load factor	60% (55-58%)	
Losses	22% (17-20%)	

Note: As some 2007 figures differ from typical ranges in previous years, the latter are shown in parenthesis.

EEPCO remains committed to increasing its hydro-power plant capacity which it views as an environmentally friendly “lower-cost” option (in particular in a high and volatile oil price environment). EEPCO is building two additional large plants: Tekeze, with an installed capacity of 300MW and 980 GWh of firm energy, and Gilgel Gibe II, with an installed capacity of 420MW and 1,500 GWh of firm energy. These two projects are scheduled for commissioning in 2008.

GoE plans to add more generation capacity to the system over the next 5-10 years. Additional projects include Tana Beles, with a capacity of 460MW and 1,830 GWh in terms of energy, Gilgel Gibe III, with a capacity of 1,800MW and 6,300 GWh (an export oriented project), and Halale Werabessa, with a capacity of 420MW and 2,030 GWh of energy.

13.1.3 Ethiopia: Demand Forecast and Generation Expansion Plan

Ethiopia's most recent power system master plan is presented in EEPCO's "Power System Expansion Master Plan Update" (EPSEMPU) of June 2006. This document updates EEPCO's master plan of April 2004. EEPCO's load forecast covers both the ICS and the SCS. In relation to the GD-6 project and supply to the grid plus possible export to Kenya, only the development of the ICS is relevant which is therefore the focus in the following..

Since 2004, EEPCO prepares only two forecast scenarios: a Target Forecast and a Moderate Forecast. Earlier forecasts comprised three scenarios (reference, high, low). Generation and transmission system expansion planning is based on the Target Forecast.

The Target Load Forecast assumes an economic growth of 12% and 150,000 new connections annually over the entire planning horizon, reflecting the Government's commitment to economic development and poverty eradication. The Target Forecast results in net generation requirements of 71,570 GWh and a peak demand of 14,330 MW in FY 2030, yielding an average annual demand growth rate of 14.3%. The Moderate Forecast for FY 2030 is about 50% lower (34,030 GWh and 6,814 MW, giving an average growth rate of 10.9%). Both forecasts, shown in Table 13-4 are considerably higher than EEPCo's forecasts in 2004[6].

EEPCo's generation expansion plan, based on the Target Forecast is shown in Table 13-4 The expansion plan for the Moderate Demand Scenario (only prepared up to 2016) is similar to that for the Target Scenario except for a delay of Halele Werabesa HEPP until 2016.

The plan involves massive capacity additions, increasing the capacity of 726 MW in 2006 to 4,476 MW of dependable capacity in the ICS in 2015, and 14,823 MW in 2030.

The capacity additions are, with the exception of the initial years, sufficient to meet the national peak demand including reserve requirements. After the commissioning of Gilgel Gibe III HEPP, the reserve margin exceeds 50%. There is considerable surplus capacity not only for the assumed export to Sudan (200 MW) and Djibouti (100 MW), but also for further power exports. However, this surplus decreases drastically after 2023, so that it cannot be used for firm exports. Since the preparation of the Master Plan Update in 2006, it is understood that some changes have been made to mid-term planning.

In EEPCO's plan, projects in the Genale Dawa basin with a total capacity of 605MW will be added in 2018 which, according to EEPCO, includes GD-6. However, in the Feasibility Study Update (2006) for the Ethiopia-Sudan Power Systems Interconnection Project, GD-3 is scheduled for 2015 and GD-6 for 2024.

[6] EEPCo's 2004 forecast showed an average growth rate of 9.1% p.a. for the Moderate Forecast, and 9.7% p.a. for the Target Forecast.

Table 13-4: EEPCo Generation Expansion Plan Summary

Year FY	Con-fig.	Power ant	Cost MUSD Gen.	Cost MUSD Trans	Type	Added Capacity MW	Total Capacity MW	System Peak MW	Reserve Margin MW	Reserve Margin %
Mid-Term Plan										
		Existing					726			
2007	1 x 7	Aluto			Geo	7	733	744	- 11	-2%
2008	4 x 75 4 x 105	Tekeze Gilgel Gibe II	451.3	51.0	Hydro Hydro	300 420	1,033 1,453	900 900	133 553	13% 38%
2009	4 x 105	Beles*	468.7	117.0	Hydro	420	1,873	1,079	794	42%
2010	2 x 50	Yayu Coal	175.3	26.0	Coal	100	1,973	1,286	687	35%
2011	5 x 180	Gilgel Gibe III-1	957.3	143.6	Hydro	900	2,873	1,485	1,388	48%
2012	5 x 180	Gilgel Gibe III-2	410.3	-	Hydro	900	3,773	1,705	2,068	55%
2013							3,773	1,949	1,824	48%
2014	2 x 48 4 x 82	Halele Werabesa	474	24.5	Hydro Hydro	96 326	3,869 4,195	2,229 2,229	1,640 1,966	42% 47%
2015	2 x 81 2 x 59	Chemoga Yeda I Chemoga Yeda II	391.2	8.45	Hydro Hydro	162 118	4,357 4,475	2,544 2,544	1,813 1,931	42% 43%
Long-Term Investment Plan							4,819	2,894	1,925	40%
2017					Hydro		4,819	3,270	1,549	32%
2018		Genale Dawa			Hydro	605	5,424	3,674	1,750	32%
2019		Baro			Hydro	645	6,069	4,116	1,953	32%
2020		Calub			Gas	600	6,669	4,602	2,067	31%
2021		Gilgel Gibe IV			Hydro	2,000	8,669	5,135	3,534	41%
2022							8,669	5,733	2,936	34%
2023		Caradobi			Hydro	1,800	10,469	6,407	4,062	39%
2024							10,469	7,165	3,304	32%
2025							10,469	8,021	2,448	23%
2026							10,469	8,988	1,481	14%
2027		Gojeb Aleltu Mandaya Border Tendaho			Hydro Hydro Hydro Hydro Hydro	150 454 1,734 1,836 180	10,619 11,073 12,807 14,643 14,823	10,082 10,082 10,082 10,082 10,082	537 991 2,725 4,561 4,741	5% 9% 21% 31% 32%
2028							14,823	11,322	3,501	24%
2029							14,823	12,730	2,093	14%
2030							14,823	14,330	493	3%

Source: EEPCO: EPSEMPU 2006 Executive Summary

13.1.4 GD-6 Revised Forecast

As mentioned earlier, EEPCo's Target Forecast and Moderate Forecast imply average annual growth rates of 14.3% and 10.9%, respectively, for the period up to 2030. In comparison, the average actual growth rate for the period FY 2000-2007 was 9-10% p.a. (see Table 13-5). GoE and EEPCo have, however, as discussed earlier, intensified efforts both with respect to generation expansion, electrification of new towns and villages, and customer connections. An illustration of this are the actual growth rates achieved for the period 2005-2007 in Table 13-5.

Nevertheless, as Table 13-5 also shows, EEPCo's generation and peak demand projections already in 2007 exceed actual figures considerably, by 7-14% in terms of energy and by 13-19% in terms of peak demand, for the two scenarios. Although EEPCo's growth assumptions gradually decline over the forecast period, one may question the high averages referred to above for a period of 25 years. Concern has earlier been expressed about overoptimistic demand growth driven by generation targets (supply driven) rather than what can realistically be financed and implemented. This reflects inter alia international experience that the cost per connection grows exponentially in more distant frontier areas, in addition to the time needed to reach and connect the population in such areas. Very few countries can show to double digit growth rates over an extended period of time. The Target Forecast shows a development that one associates with rapid industrialisation as one saw in South-east Asia in the 1980s and early 1990s.

More specific factors in the case of Ethiopia that speak for prudence in forecasting future demand are the following: (i) the massive sector expansion plans have to be financed and implemented. Although significant international support has been secured, the country's financial and physical resources are stretched, and there are concerns regarding EEPCo's financial sustainability in operating an ever-expanding power system; (ii) related to this is the fact that present tariffs are significantly below costs of supply. The considerable tariff increases that are required will have a dampening impact on demand, provided - furthermore - that low-income consumers in remote areas can afford the cost of connection in the first place; (iii) finally, specific rural loads are low and develop only gradually, whereas past trends in consumption reflect a relatively large urban element.

For the present study, therefore, it is proposed to use EEPCo's Moderate Scenario as a High Forecast. The Consultant has, in addition, prepared two simplified forecasts, one proposed as a Base Case Forecast and a second as a Low Forecast. The two latter assume average annual growth rates of 9% and 7%, respectively, with a starting point in FY 2008, based on actual figures for FY 2007. The revised forecasts appear in Table 13-5.

Table 13-5: GD-6 Revised Forecast

	High Forecast		Base Case		Low Forecast	
Year FY	Net Generation Requirement (GWh)	Peak Demand (MW)	Net Generation Requirement (GWh)	Peak Demand (MW)	Net Generation Requirement (GWh)	Peak Demand (MW)
2005	2 535	520	2 540	521	2 540	521
2006	3 025	606	2 844	587	2 844	587
2007	3 501	701	3 269	623	3 269	623
2008	4 128	826	3 629	692	3 596	685
2009	4 828	967	4 028	768	3 955	754
2010	5 620	1 125	4 471	852	4 351	829
2011	6 325	1 266	4 963	946	4 786	912
2012	7 082	1 418	5 459	1 040	5 217	994
2013	7 897	1 581	6 005	1 144	5 686	1 084
2014	8 816	1 765	6 605	1 259	6 141	1 170
2015	9 823	1 967	7 266	1 385	6 633	1 264
2016	10 917	2 186	7 920	1 509	7 163	1 365
2017	12 038	2 410	8 632	1 645	7 665	1 461
2018	13 182	2 639	9 409	1 793	8 201	1 563
2019	14 374	2 878	10 256	1 955	8 775	1 672
2020	15 610	3 126	11 179	2 131	9 302	1 773
2021	16 888	3 381	12 185	2 322	9 860	1 879
2022	18 265	3 657	13 282	2 531	10 452	1 992
2023	19 750	3 954	14 345	2 734	10 974	2 091
2024	21 351	4 275	15 492	2 952	11 523	2 196
2025	23 079	4 621	16 731	3 189	12 099	2 306
2026	24 944	4 994	18 070	3 444	12 704	2 421
2027	26 958	5 398	19 516	3 719	13 339	2 542
2028	29 134	5 833	20 882	3 980	14 006	2 669
2029	31 486	6 304	22 343	4 258	14 706	2 803
2030	34 030	6 814	23 726	4 522	15 497	2 953
2005-30	10,9 %	10,8 %				
2007-30			9,0 %	9,0 %	7,0 %	7,0 %

Source: Consultant, and EEPCo for "new" High Forecast

Note: Figures above the lines in 2005 and 2007 represent reported actual figures at respe ctive points in time.

The Base Case Forecast projects a peak demand of some 4,500 MW in 2030, which is seven times the level in 2007. In comparison, the High Forecast shows a demand of some 6,800 MW, and the Low Forecast close to 3,000 MW. In terms of energy requirement, the Base Case Forecast projects approximately 24,000 GWh for 2030, compared to 3,300 GWh in 2007.

In relation to Ethiopia's own requirements, GD-6, with an installed capacity of 246 MW, would be taken up in about 1.5 - 1 year's time (Base Case), dependent on whether it is commissioned in 2018 or in 2024. In terms of energy, the firm energy of GD-6 of approximately 1,500 GWh is about double of the ICS need for additional energy of around 800 GWh in 2018, and 25% over the need for 1,200 GWh in 2024. The commissioning of GD-3, with some higher output of power and energy than GD-6, and which is a condition for the construction of GD-6, could make the optimal in-phasing of GD-6 into the ICS moved further into the future, dependent on what the actual growth rate of the demand in the ICS will be.

With an interconnection to Kenya, however, the combined domestic requirements and export potential would represent a market more than large enough to fully absorb the project's output from day one. This is elaborated in the following sub-chapter below.

13.2 Kenya: Demand Forecast and Generation Expansion Plan

13.2.1 Kenya: Demand Forecast

Kenya's most recent power system master plan is presented in the *"Update of Kenya's Least Cost Power Development Plan 2008-2028"*, prepared in February 2007 by the Kenya Power & Lighting Company (KPLC) in collaboration with the Ministry of Energy (MOE) and Kenya Electricity Generating Company (KenGen). The study updates the Least Cost Power Development Plan (LCPDP) of May 2005 which covered the years 2006-2026. While Kenya's sales forecast presents both the integrated system and the isolated system, the load forecast covers only the integrated system.

Kenya has prepared three forecast scenarios: a reference forecast, a high and a low forecast. The Reference Forecast of 2007 assumes an economic growth of 6.5% p.a. from 2008 onwards, which is in line with short term World Bank and IMF projections[7], and additional 120,000 connections for the next four years.

The forecast results in net generation requirements of 31,000 GWh and a peak demand of 5,282 MW in FY 2030, which represents an average annual growth rate of 7.2% (see Table 13-6). The results of the Low Forecast in 2030 are about 10% lower, and the results of the High Forecast are about 25% higher. Up to FY 2025, the Reference Forecast remains below the projection of the Power Development Plan Update of 2005.

[7] IMF World Energy Outlook, October 2007; World Bank Country Brief September 2007

The present Kenyan power market is considerably larger than that of Ethiopia (almost 90% and 60% larger in terms of energy requirement and peak load, respectively), for a population that is approximately half the size. This indicates a more widespread use of electricity and a more mature power sector in Kenya compared to Ethiopia. With a lower electricity starting point, one would expect higher growth projections for Ethiopia than for Kenya, which is also borne out by the countries' respective load forecasts (other things assumed reasonably equal).

Kenya's load forecast appears to provide a sound basis for estimating the potential for export from GD-6 which, as seen in the next section, is also reflected in the country's plans for meeting future demand through imports from, amongst others, Ethiopia. The capacity of GD-6 corresponds to approximately 1.5 year's growth in peak demand in Kenya at a time when commissioning of the plant is likely.

And, as said in the previous sub-chapter, the combined domestic requirements (ICS) and export potential would represent a market more than large enough to fully absorb the GD-6 project's output from day one.

Table 13-6: Kenya Power Demand Forecast

Year FY	Actual Net Generation Requirement (GWh)	Actual Peak Demand (MW)	High Forecast Net Generation Requirement (GWh)	High Forecast Peak Demand (MW)	Base Case Net Generation Requirement (GWh)	Base Case Peak Demand (MW)	Low Forecast Net Generation Requirement (GWh)	Low Forecast Peak Demand (MW)
2001	4 081	724						
2002	4 563	760						
2003	4 750	786						
2004	5 035	830						
2005	5 347	884						
2006	5 697	916						
2007	6 169	979	6 246	1 057	6 203	1 082	6 161	1 043
2008			6 672	1 130	6 607	1 153	6 534	1 106
2009			7 209	1 221	7 119	1 206	7 011	1 187
2010			7 790	1 320	7 638	1 294	7 493	1 269
2011			8 498	1 441	8 251	1 398	8 061	1 366
2012			9 251	1 569	8 895	1 508	8 656	1 467
2013			10 060	1 707	9 580	1 625	9 285	1 574
2014			10 929	1 855	10 398	1 749	9 952	1 688
2015			11 862	2 014	11 082	1 881	10 657	1 808
2016			12 865	2 186	11 905	2 021	11 403	1 935
2017			13 943	2 370	12 781	2 171	12 194	2 070
2018			15 102	2 567	13 713	2 330	13 032	2 213
2019			16 349	2 780	14 705	2 499	13 921	2 364
2020			17 690	3 009	15 762	2 679	14 862	2 525
2021			19 133	3 256	16 887	2 871	15 861	2 696
2022			20 687	3 522	18 085	3 076	16 920	2 876
2023			22 359	3 807	19 362	3 294	18 044	3 068
2024			24 160	4 115	20 723	3 527	19 236	3 272
2025			26 099	4 447	22 174	3 774	20 502	3 488
2026			28 188	4 804	23 720	4 038	21 845	3 717
2027			30 438	5 188	25 368	4 320	23 720	3 961
2028			32 862	5 603	27 126	4 620	24 784	4 219
2029			35 473	6 049	29 000	4 941	26 391	4 494
2030			38 287	6 531	30 999	5 282	28 098	4 785
2001-07	7,1 %	5,2 %						
2007-30			8,2 %	8,2 %	7,2 %	7,1 %	6,8 %	6,8 %

13.2.2 *Kenya: Generation Expansion Plan*

The generation expansion based on the Reference Load Forecast covers the period FY 2008-2028. The plan includes additions of geothermal, coal, diesel, gas turbine, combined cycle and some hydro capacity. Imports constitute a considerable part of envisaged supply options, accounting for 900 MW in FY 2026. The initial 300 MW of imports in 2013 and 2014 are attributed to Ethiopia, Uganda and Tanzania.

While hydro power plants represent about 70% of existing generation capacity, the capacity mix in 2028 will be dominated by coal plants and imports (around 20% each), followed by combined cycle, diesel and geothermal plants (around 10% each). The balance is provided by hydropower, gas turbines and cogeneration. The capacity additions result in a total integrated system capacity of 2,027 MW in FY

2015, and 4,871 MW in FY 2028, as shown in Table 13-7, compared to 1,045 MW installed capacity in 2007.

Table 13-7: Kenya Generation Expansion Plan

Year	Configuration			Station	Cost mUS$	Type	Added Capacity MW	Total Capacity MW	System Peak MW	Reserve Margin MW	%
2007								1,045	1,082	-37	-4%
2008	2	x	30	Sondu Miriu		HYDRO	60				
2008	1	x	80	Gas Turbine		GT	80	1,185	1,153	32	3%
2009	6	x	15	Medium Speed Diesel		MSD	90				
2009				Olkaria III		GEO	35				
2009	-1	x	10	Fiat GT Retirement		GT	-10				
2009				Kiambere Optimiz.		HYDRO	20				
2009				Mumias Cogeneration		COGEN	25				
2009	1	x	35	Olkaria II 3rd Unit		GEO	35				
2009				Kipevu Combined C.		CC	30	1,410	1,206	204	14%
2010				Raising Masinga Dam		HYDRO					
2010				Tana Rehabilitation		HYDRO	6.6				
2010	2	x	330kV	Mombasa -Nbi TL	209.9	Line					
2010	1	x	20	Kindaruma 3rd Unit		HYDRO	20				
2010	2	x	10.3	Sangoro		HYDRO	20.6	1,457	1,294	163	11%
2011	6	x	20	Medium Speed Diesel	139	MSD	120	1,577	1,398	179	11%
2012	1	x	70	Geothermal	171.3	GEO	70	1,647	1,508	139	8%
2013	1	x	100	Import		IMPORT	100	1,747	1,625	122	7%
2014	2	x	100	Import		IMPORT	200	1,947	1,749	198	10%
2015	-3	x	15	Olkaria I Retirement		GEO	-45				
2015	1	x	25	Olkaria I Replacement		GEO	25				
2015	1	x	100	Coal	195.6	COAL	100	2,027	1,881	146	7%
2016	1	x	70	Geothermal	171.3	GEO	70				
2016	5	x	20	Medium Speed Diesel	119	MSD	100				
2016	2	x	220kV	Olkaria-Nairobi TL	34	Line		2,197	2,021	176	8%
2017	4	x	20	Medium Speed Diesel	92.4	MSD	80				
2017	1	x	90	Gas Turbine		GT	90	2,367	2,171	196	8%
2018	1	x	100	Import		IMPORT	100	2,467	2,330	137	6%
2019	-6	x	12.5	Kipevu I Retirement		MSD	-75				
2019	4	x	20	Medium Speed Diesel	92.4	MSD	80				
2019	1	x	100	Coal	195.6	COAL	100				
2019	1	x	90	Gas Turbine		GT	90				
2019	2	x	330kV	Mombasa -Nbi TL	209.9	Line		2,662	2,499	163	6%
2020	-10	x	5.66	Iberafrica Diesel Ret.		MSD	-56.6				
2020	4	x	20	Medium Speed Diesel	92.4	MSD	80				
2020	1	x	70	Geothermal	171.3	GEO	70				
2020	1	x	100	Import		IMPORT	100	2,856	2,679	176	6%
2021	2	x	100	Coal	391.2	COAL	200	3,056	2,871	184	6%
2022	-7	x	10.57	Tsavo Diesel		MSD	-75				
2022	-1	x	90	Gas Turbine		GT	-90				
2022	3	x	90	Combined Cycle	156.7	CC	270				
2022	1	x	100	Import		IMPORT	100	3,261	3,076	185	6%
2023	2	x	100	Coal	391.2	COAL	200				
2023	2	x	330kV	Mombasa -Nbi TL	209.9	Line		3,461	3,294	167	5%
2024	1	x	70	Geothermal	171.3	GEO	70				
2024	4	x	20	Medium Speed Diesel	92.4	MSD	80				
2024	1	x	100	Import		IMPORT	100	3,711	3,527	184	5%
2025	2	x	100	Coal	391.2	COAL	200				
2025	1	x	90	Gas Turbine	49	GT	90				
2025	2	x	330kV	Mombasa -Nbi TL	209.9	Line		4,001	3,774	227	6%
2026	1	x	70	Geothermal	171.3	GEO	70				
2026	2	x	100	Import		IMPORT	200	4,271	4,038	233	5%
2027	-1	x	90	Gas Turbine		GT	-90				
2027	3	x	90	Combined Cycle	156.7	CC	270				
2027	4	x	20	Medium Speed Diesel	92.4	MSD	80	4,531	4,320	211	5%
2028	2	x	100	Coal	391.2	COAL	200				
2028	2	x	70	Geothermal	342.6	GEO	140	4,871	4,620	251	5%

Source: Update of Kenya's Least Cost Power Development Plan 2008-2028

13.3 Costs of Supply Alternatives [8]

At the present time, most attention is being focused on new, and as yet uncommitted, hydropower projects on the following river basins:

- The Gibe River and its tributaries with the Gilgel Gibe (Stages III and IV) and Halele-Werabesa (Stages I and II) hydropower projects;

- The Abay River (Blue Nile) and its tributaries with the Chemoga-Yeda (Stages I and 11) and the main Abay River hydropower projects (Karadobi, Mendaia and Border);

- Baro-Akobo River with the Baro (Stages I, II and Genji Diversion) hydropower project

- Genale-Dawa River Basin with, inter alia, Genale GD-3 and GD-6.

Hydropower projects on other rivers are also being promoted, but the above river basins are currently yielding hydropower projects with attractively low unit generation costs and projects along the first three rivers listed above will compete with GD-3 and GD-6 for implementation. Of the above schemes, those that have been studied to a level sufficient to define the principal cost and performance parameters are as shown in Table 13-8.

[8] In addition to the Pre-feasibility Studies GD-6 Hydropower Project, Lahmeyer, 2006, this section draws on the Feasibility Studies Genale (GD-3) Multipurpose Hydropower Project, Lahmeyer International, 2007.

Table 13-8: Principal Cost and Performance Parameters of Selected Hydropower Candidates

Project Name	**Installed Capacity MW**	**Energy Generation GWh**	**Project Cost MUSD**	**Unit Generation Cost [3] USc/kWh**	**Cost Estimate Year**
Gilgel Gibe III	1,800	6,000	n/a	3.4	2006
Gilgel Gibe IV	2,000	7,500	n/a	n/a	2006
Halele-Werabesa (I and II)	422	2,030	474	3.0	2005
Chemoga-Yeda (I and II)	280	1,348	391	3.5	2005
Karadobi[1]	1,600	12,314[2]	2,232	3.8	2006
Baro (Stages I, II and Genji)[1]	896	4,636	1,315	4.5	2006
Geba (Stages I and II)	259	1,734	n/a	2.3	2004
Genale GD-3	353	1,238	338	2.8	2006

[1] Scheme recommended by Norplan/Norconsult/Lahmeyer

[2] Including the additional energy generated at downstream schemes (in the Sudan) without additional investment

[3] Discount rate is 10%

Source: Feasibility Study Genale GD-3 Hydropower Multipurpose Project, Lahmeyer International, 2007

13.3.1 Candidate Electricity Generation Options in Kenya

As discussed above in relation to Kenya's generation expansion plan, additional capacity in the 2020 decade will predominantly be provided by coal fired plants, combined cycle plants and imports. Thus, the GD-6 scheme will compete with both fossil fuel fired generating plants in Kenya and imports from other grids (e.g. Uganda). There is insufficient information available to assess the likely cost of imports from other grids, but unit costs for thermal plants in Kenya may be estimated. Given that Kenya has a well established port at Mombasa, the country is able to import both refined oil and coal.

Two fuel price scenarios have been adopted, for a refined product mix based on a crude oil price of USD 50 and one for USD 100 per bbl. For a mix of 90% HFO and 10% LDO the total costs of purchasing and transporting the fuel from the Middle East and delivered in Mombasa are presented in Table 5.5 For imported coal, two prices cif Mombasa have been applied, USD 40 and USD 60 per ton.

Table 13-9: Fuel Prices for Kenya

Crude Oil Price	**USD 50/bbl**	**USD 100/bbl**	**Calorific Value**
Price of Mix of HFO (90%) and LDO (10%) Delivered	USD 290/ton	USD 535/ton	38.4 mmBtu/ton
Price of Imported Coal (cif)	USD 40/ton	USD 60/ton	23.0 mmBtu/ton

Source: Adapted from Feasibility Study Genale GD-3 Hydropower Project, Lahmeyer Internat., 2007

Key performance and operating data for a 300MW combined cycle plant running on a 90%/10% mixture of HFO/LDO and for a 200MW coal fired plant are given in Table 13-10. These plant sizes correspond to those found in Kenya's generation expansion plan.

Table 13-10: Performance and Operating Data for Candidate Thermal Plants – Kenya

Plant Type	Installed Capacity MW	Capital Cost USD/kW	Fixed O&M USD/kW/a	Variable O&M USc/kWh	Scheduled Outage Weeks/a	Forced Outage % of time	Heat Rate Btu/kWh
CCGT	3x100	820	6.5	0.26	3	4	7,260
Coal Plant	200	1,820	35.0	0.66	5	6	11,300

Source: Consultant

The resulting unit generation costs for these two plant types are given in Table 13-11 for a 60% load factor, and for a "low" and a "high" crude oil price and coal price.[9]

Table 13-11: Unit Generation Cost for Oil Fired CCGT and Coal Plant @ 60% Plant Factor (USc/kWh) - Kenya

Plant Type	**Crude Oil Price USD/bbl**	
	50	**100**
CCGT	8.1	12.9
	Coal Price (USD/ton)	
	40	**60**
Coal Fired Plant	8.5	9.6

Source: Consultant

[9] No technically determined relationship is implied by the same directional movement in low and high oil and coal prices; however market forces tend to create a link, although the extent is difficult to establish. The term" high" and "low" are relative and imprecise terms.

Variations in unit cost as a function of plant factor for the two oil and coal prices are shown in Figures 5.3 and 5.4.

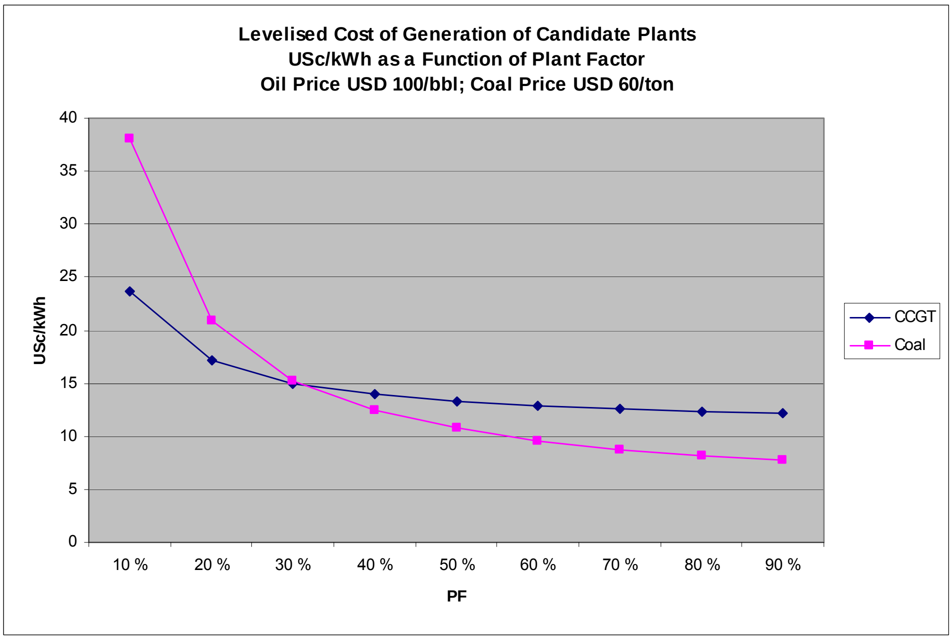

Figure 13-2 Thermal Unit Costs as a Function of Plant Factor; "High" Oil and Coal Prices

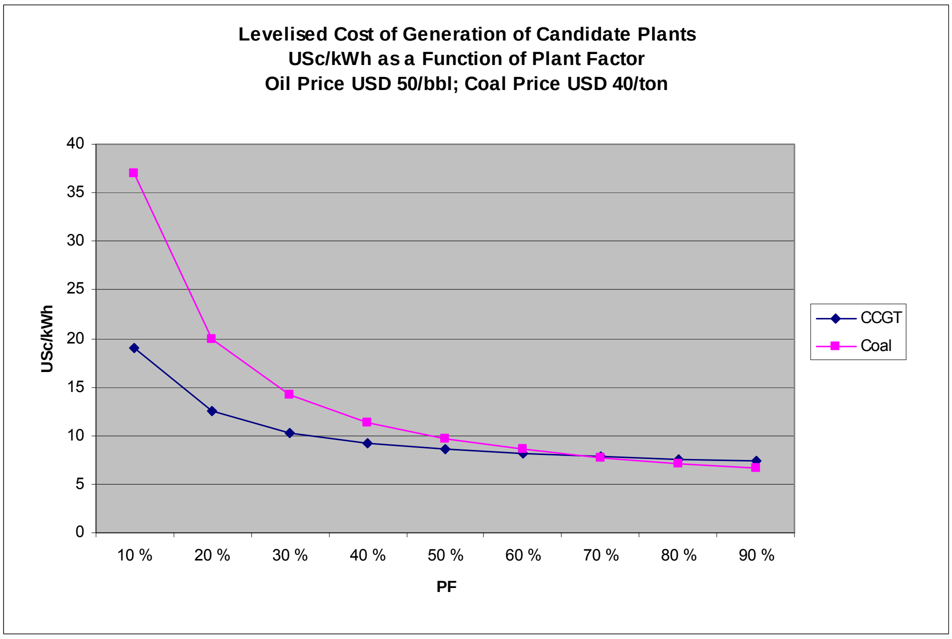

Figure 13-3 Thermal Unit Costs as a Function of Plant Factor; "Low" Oil and Coal Prices

As is the case for Ethiopia, in terms of a comparison of generating costs hydropower can compete successfully with thermal power options in Kenya based on imported fuel. However, a direct comparison of the figures cannot be made for Kenya as two further factors need to be taken into consideration[10]:

- Kenya as a buyer would expect a discount in relation to its avoided thermal costs, to account for the greater risk associated with dependence on imports and to allow both parties to gain from power trade[11];

- Likely higher cost of transmission associated with imports than for domestic generation, which would affect the cost comparisons. (In the next chapter the cost of the Ethiopian-Kenyan Transmission Line as to the *Interconnection Study* will be referred.)

13.3.2 *Conclusion*

In Ethiopia, the viable alternatives, or competitors to GD-6 are fossil fuel fired power plants and other domestic hydropower schemes. The viable fossil fuel fired plants would generate electricity at about between USc 9.0 and 14.5 per kWh at a plant factor of 60%, depending on crude oil prices. The planned hydropower schemes would generate electricity at between USc 2.5 and 4.5 per kWh.

In Kenya, the hydropower resources are largely exhausted and according to the current expansion plan, electricity will have to be imported and new thermal plant commissioned. The viable alternatives (or competitors) to GD-6 in Kenya are fossil fuel fired power plants. The most attractive fossil fuel fired plants would generate electricity at around between USc 8.0 and 13.0 per kWh at a plant factor of 60%, depending on fuel prices.

From the above it is clear that GD-6 could supply the electricity markets in both Ethiopia and in Kenya. Although the generation expansion targets set in Ethiopia will require massive investments in new generating capacity, there are several very attractive hydropower schemes in the planning pipeline; in other words competition should be stronger in Ethiopia than in Kenya. In Kenya, hydropower resources have been largely exhausted and competitors of GD-6 will be expensive fossil fuel fired plant.[12]

13.4 Cost of Transmission to Kenya

Cost of transmission to Kenya has recently been studied to feasibilityy level in the report "*The Ethiopia-Kenya Power Systems Intercon-*

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[10] As far as transmission costs, this applies also to Ethiopia, although distances and the difference between these for the different generating options would be smaller than for exports to Kenya.

[11] On the other hand, imported hydropower from Ethiopia could imply greater price stability, and thereby lesser risk, than for domestic options based on imported oil or coal.

[12] Plus possibly geothermal energy at costs that are not readily available.

nection Project". This was referred to in Chapter 13.1 above as the *Interconnection Study* (Fichtner, 2009). The report suggests a 500 kV DC line from the substation Wolayta/Sodo on the Ethiopian side in connection with the Gilgel Gibe III project, to Longonat substation outside Nairobi. The length of the main line is 1066 km. In addition are there 400 kV connection lines to the two substations of which 55 km are in Ethiopia and 80 km in Kenya respectively, which make the total length of the line about 1200 km.

It is suggested being developed in two stages, Phase 1 for 1000 MW transfer capacity in 2012 in connection with the commissioning of Gilgel Gibe III, which will result in a considerably power surplus in Ethiopia from that year, and another 1000 MW in Phase 2 from 2020.

The cost of the line is estimated at EUR 595 mill in Phase 1 and EUR 202 mill in Phase 2, a total of EUR 797 mill. Ca 41.2 % of the costs in Phase 1 originates in Ethiopia, 48.0 % in Phase 2, and in total 42.9 % (EUR 342 mill) falls on the Ethiopian part. In Table 13-12 the correspondent costs of the line in USD is indicated.

Table 13-12: Cost of Interconnection Line HVDC Ethiopia-Kenya (from Wolayta to Longonot). Costs indicated in MUSD

	Ethiopia	**Kenya**	**Total**
Phase 1	318.5	455.0	773.5
Phase 2	126.1	136.5	262.6
Total	444.6	591.5	1036.1

Source: Fichtner 2009. Converted to USD at an exchange rate of 1.3 USD per EUR (as per 17th of March 2009) by the Consultant.

The studies are made under various assumptions of combined export to other countries as follows:

- Sudan, scaled up from 100 MW (788 GWh) in 2009 to 1200 MW (9800 GWh) in 2020
- Djibouti 100 MW (788 GWh from 2010)
- Egypt 700 MW (5200 GWh) from 2020.

These options result in different availabilities for export to Kenya. It is also assumed options with export to other countries via Kenya.

In Phase 1, over the years 2012 – 2019, it is assumed that the export to Kenya increases from 2503 GWh to 5729 GWh (less small fractions, max 34 GWh, of opposite energy flow).

In Phase 2, over the period 2020 – 2027 there are studied two options,

a) 1200 MW to Sudan, the export to Kenya increases from 7657 GWh to 10541 GWh (less small fractions of opposite flow)

b) 1200 MW to Sudan and 700 MW to Egypt, the export to Kenya increases from 5436 GWh to 8002 (less small fractions of opposite flow)

By different combinations of these export options the Interconnection Study has estimated the economic and financial results of three scenarios for export to Kenya:

<u>Scenarios:</u>

- Case 1: Export to Kenya only, in line with Kenya's growing demand for import over the project horizon
- Case 2: Export to other countries also via Kenya
- Case 3: The Interconnection line is "fully" utilized continuously with 6,000 hours a year from the commissioning date.

The economic and financial results of the interconnection line were not made fully available to the Consultant from EEPCO's side at the time of writing (since EEPCo had just received the report themselves), but were indicated as follows:

- EIRR: 23.5 – 25.0 % at a discount rate of 12 %
- B/C ratio: 1.43 – 1.57
- For EEPCO: FIRR 20.8 – 22.0 %, and payback 8-9 years
- For KPLC: FIRR ca. 17.2 – 17.8 %, and payback 11–13 years
- The levelized cost of interconnection 1.37 – 1.87 USc/kWh (the annualized and discounted cost per kWh)
- Equalized Bulk Tariff: 5.70 – 5.9 USc/kWh. (The market clearing price between Kenya (KPLC)'s maximum willingness to pay for supply options less costs of interconnection, and Ethiopia (EEPCo)' minimum sales price requirements (the value if the energy is sold to ICS) plus costs of interconnection, The gap between KPLC's maximum price and EEPCo's minimum price is about 1.8 – 2.1 USc/kWh in three different cases.

Of these results, the last two; the "Levelized cost of interconnection" and the "Equalized bulk tariff", have been assumed as input data in the Economic and Financial analyses of GD-6 by the averages of the three scenarios, with the respective values of 1.6 USc/kWh and 5.85 USc/kWh. These makes up the (sales) value of the power from GD-6 referred at Sodo substation to be *5.16 USc/kWh for Export and 4.21 USc/kWh for power produced for the internal market*. The calculation is shown in Table 13-13 below.

Table 13-13: Power values at Sodo Substation

Power values, ref. Ethiopia-Kenya Interconnection Study, USc/kWh		Case 1	Case 2	Case 3	Average
Equalized Bulk Tariff for Export		5,92	5,92	5,70	5,85
Cost of Interconn., Total		1,87	1,56	1,37	1,60
Ethiopian Part Interc.	42,9 %	0,80	0,67	0,59	0,69
Power value at ICS/Sodo for Export:		5,12	5,25	5,11	5,16
Ethiopia Minimum Price Export		5,00	4,90	4,80	4,90
Less part of cost Interconn		0,80	0,67	0,59	0,69
Power value at ICS/Sodo for Non-export:		4,20	4,23	4,21	4,21

13.5 Economic Analysis of the GD-6 project

13.5.1 Study Assumptions

The main priority of all power projects in Ethiopia is to cover the rapidly increasing demand internally. However, according to our own market reviews in Chapter 1, and also confirmed by the Ethiopia-Kenya Interconnection Project (Fichtner) referred to in Chapter 2, there will be a significant surplus of generation from about 2012, when Gilgel Gibe III-2 is supposed to be commissioned, which will be available for export. As other planned projects also will be commissioned during the next decade, the generation surplus - and thus the availability for export, will continue to increase over the decade. Thus, in 2018, when the GD-6 project is due to be commissioned, a large surplus of generation capacity is expected and the only market for the power will be the export market.

It is therefore assumed in *the Base Case* that all the power produced at GD-6 will be exported to Kenya over the interconnection line studied. The power from the project will physically be delivered to the ICS at the new substation that will be built in connection with the GD-3 project. It is further assumed that there will be constructed a 400 kV AC line from GD-3 substation to the connection point for the interconnection line to Kenya at Sodo substation, and GD-6 will share the costs of this line with its relative part of the production in the Genale River Cascade (GD-3, GD-5, and GD-6.).

Reference point

The reference point for the economic and financial analysis is therefore assumed at Sodo substation. Also for the scenario where the project output be absorbed in the internal marked in Ethiopia, the reference point is assumed to be Sodo. There is calculated a technical loss of 43 GWh over the connection line from GD-6 via GD-3 substation to Sodo substation.

Power values

The basic sales price is assumed at 5.85 USc/kWh at generation as shown in Table 13-14 and elaborated in the text above. This is a weighted and discounted average sales price between Kenya's assumed maximum willingness to pay and Ethiopia's minimum price requirement, thus giving a net benefit and financial profit for both parties.

In the Interconnection Study it has been assumed that firm power delivered to Kenya has the value of avoided costs of coal power, while secondary power (non-firm) has the value of avoided operation and fuel costs of diesel generation.

A similar approach has been adopted in this analysis:

The GD-3 and GD-6 projects together will deliver about 3075 GWh firm energy out of a total average of 3301 GWh. The more projects the ICS engage in, the more reliable and less vulnerable the system will be for deficits in the precipitation. By the time that GD-6 will be commissioned, the generation into the ICS will come from many projects spread over long distances over Ethiopia, and the commissioning of GD-6 will add also a system benefit in form of increased reliability of the ICS. In addition, connection to the much larger thermal system in Kenya will make the system even more reliable, as long as the transmission lines have sufficient capacity.

Non-firm

It is therefore reasonable to assume that a portion of the secondary power could have the value of firm power. However, the secondary power is, as shown, a relatively small portion, and as it may be assumed to have the high value of avoided costs of operating diesel generation (the Interconnection Study), it is assumed the same value as firm power in the economic and financial analyses.

Peak

The GD-3 and GD-6 are designed with as high plant factor as about 0.75. Thus, they may be characterised as “base load” power plants. Considering peak values specifically is less important for this kind of power plants. Nevertheless, in the sensitivity analysis scenarios with higher and increasing power values have been made, and these could represent increasing value of peak power in Kenya over time.

SMHP

For the small hydropower scheme that will deliver electricity to the local 33 kV network, a generation price of 5.0 UScents has been assumed. (It should be noted that in addition it will add a benefit to the local network as its inclusion will reduce the power losses in it.)

13.5.2 Methodology of Economic Analysis

Project period

Economic and financial analyses have been calculated from year 1 and onwards, and all present values (PV) are referred to beginning of year 1. In *EEPCo’s Generation Expansion Plan* (Table 13-4) the Genale projects are *assumed commissioned in 2018*. In order to assume commissioning around 2018 with a construction period estimated to be 7 years, it is assumed *project start-up at beginning of 2013* (Gregorian Calendar) with planning throughout most of the year and construction start-up in October. This is then year 1 in the calculation model. The first turbine will start its production mid-year 2019, and full production is assumed from beginning of 2020. The small hydro for local deliveries is assumed start up production primo year 2019.

The economic analysis has been calculated over a project horizon of 48 years, whereas about the last 40 years cover the project in operation.

Discount rate	The primary discount rate applied in the economic analysis, 10.23% real, is in accordance with recommendations for general investment analysis given by the Ministry of Finance and Economic Development in its guidelines *National Economic Parameters and Conversion Factors for Ethiopia* of June 2008 (MoFED 2008). The rate of 10 % was applied in the Feasibility Study for GD-3.
Conversion Factors	Economic analysis differs from Financial analysis in that use of resources should be valued at economic prices (sometimes called "shadow prices"), which of many reasons may differ from the market prices. In (MoFED 2008) there is therefore indicated a list of conversion factors (CF) for different kind of industries, use of domestic resources, and at different aggregated sector levels. These guidelines should be used in valuation of domestic resources when studying economic analyses of projects in order to reflect the real value of the project for the society. With reference to (MOFED 2008) the following conversion factors were chosen to be relevant for this analysis: CF for *local labour* is assumed at 0.63 (assumed 70% skilled labour) as a weighted average of the CFs under the World Price Numeraire (MoFED 2008) It is reasoned by that not all local labour have high opportunity costs. For *other local costs* the CF has been assumed at 0.9 in accordance with the CF for Domestic Resources under the World Price Numeraire. It is reasoned by that domestic resources in total have only 90 % opportunity costs. *Foreign exchange* is a scarce resource in Ethiopia. In the sensitivity analysis it has therefore been run a scenario with a CF of 1.11 for foreign exchange in accordance with the CF for foreign exchange under the Domestic Price Numeraire. Since the project is assumed to export power to Kenya and thus generate foreign exchange, the power value has been added this conversion factor in this scenario. The tariff increased from 5.16 to 5.73 USc/kWh. A correspondent CF was added on the costs side, i.e. interests to be paid on the international credits. (The foreign exchange needed for the purchase of the international costs of investments is assumed being covered by concessional credits. The flow of foreign exchange in this connection is therefore a nil-sum.)
Costs	The investment cost of the project is basically estimated at nearly USD 470 mill, whereas the local part has a value of USD 164 mill. Adjusted for the conversion factor for local labour, local and total costs declined with USD 24 mill. The total cost applied in the economic analysis is therefore USD 445.4 mill, whereas local costs make up USD 139.3 mill. Costs of operation and maintenance (O&M) are assumed to be 0.8 % of the investments plus 0.2 UScent/kWh produced.
Price levels	All costs and prices throughout the economic analysis are calculated with real price level of ultimo 2008. VAT, import tax and duties are not

included either in the economic or in the financial analyses. The main reason for this is an assumption that international donors and credit institutions most likely will make the major financing of the project, and that the capital expenditures thus will be exempted from taxes and duties.

CO_2 / CDM

Since the project will substitute thermal power in Kenya it could be a candidate for CDM (Clean Development Mechanism), and it is assumed a carbon emission reduction (CER) value of 25 USD per avoided ton of CO_2. This price level is about the double of current value. Assuming future value is merely guesswork, but the chosen price reflects a likely increase in value over the project horizon. It is assumed that the project will substitute planned new thermal power plants as to the *Kenya's Expansion Generation Plan* (Table 13-4), mainly coal fired power plants (50%) and combined cycle gas turbine (CCGT) plants (30%). The avoided emission is assumed at factor 0.4 tonCO_2/$MWh_{el\text{-}output}$.

13.5.3 Local benefits

The Genale Dawa river flow will be mainly regulated in the reservoir above the GD-3 project, and most of the multipurpose benefits will therefore be credited this projects. There are so small multipurpose benefits directly resulting from the GD-6 project that this has been ignored in the calculation.

Development fee

Though not included in the TOR, the Consultant has analysed, as an option, a fee of respectively 1.0% and 5.0% of the yearly revenues from the project to be allocated for local development since the project in itself does not give any benefits for the local community beyond the investment phase. This amount would allow the community to maintain roads, houses, diverse services and other the infrastructure facilities that will be developed during the construction phase. (This is only affecting the Financial analysis, but is mentioned here as listing of auxiliary project benefits for the local society.)

13.6 Results of the Economic Analysis

All results of the Economic Analysis below are referred at Sodo Substation.

13.6.1 Basic results

The main results of the Economic analysis for the Base Case are shown in Table 13-14. This assumes that all power is exported to Kenya. There is no value of reduced CO_2, since it is not verified that the project actually will qualify for it. (This can only be verified through an application process for CDM-certificate.)

The Base Case gives a NPV return of USD 56 million on an investment of USD 445 million. This gives an EIRR of 12.1%, Benefit/Cost ratio (B/C) of 1.2, and pay-back period of 24 years based on the discounted benefits and costs. The unit cost of generation referred Sodo substation is 4.43 USc/kWh.

It should be noted that since the EIRR is just over 12.0%, a discount rate of 12.0% would also give a slightly positive NPV.

Table 13-14: Economic Main Results of Base Case. 100% Export to Kenya

Energy cost	**4.43** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**56** USD mill.	Net Present Value
EIRR	**12.1%**	Economic Internal Rate of Return
Payback	**24** years	Payback period
B/C	**1.2**	Benefit - Cost ratio

13.6.2 Sensitivity Analyses

Sensitivity analyses were run on the Base Case only. The following 6 analyses have been done, one at a time:

1. Export with CO_2 value (adding 1.0 UScent to the bulk tariff), which also corresponds to about Kenya's maximum willingness to pay without a CO_2 value (+0.95 UScent)
2. 2% yearly growth in Kenya's costs for variable O&M in their thermal power plants (fuel, variable O&M and CO_2-values), which results in corresponding increase in WTP and bulk tariff for Ethiopian power.
3. Conversion Factor of 1.11 for foreign exchange in the power value
4. Pro rata increase of 10% on all project costs
5. 5 % less production (less water availability)
6. All power applied in the ICS for covering internal demand

The results of the Base Case and Sensitivity analyses are shown in the tables above and below and the calculations behind in the Annex 3H, Appendix pages 1 – 9.

Table 13-15: Sensitivity analysis 1: Export to Kenya, CO_2-value included

Energy cost	**4.43** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**132** USD mill.	Net Present Value
EIRR	**14.4%**	Economic Internal Rate of Return
Payback	**17** years	Payback period
B/C	**1.4**	Benefit - Cost ratio

Sensitivity analysis 1 - Export to Kenya and CO_2-value included gives a NPV return of USD 132 million on an investment of USD 445 million. This gives an EIRR of 14.4%, Benefit/Cost ratio (B/C) of 1.4, and pay-back period of 17 years based on the discounted benefits and costs.

Table 13-16: Sensitivity analysis 2: Bulk tariff growth rate correspondent to 2% growth rate in variable O&M costs of thermal power plants in Kenya, alternatively increasing values of peak energy.

Energy cost	**4.43** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**219** USD mill.	Net Present Value
EIRR	**15.9%**	Economic Internal Rate of Return
Payback	**16** years	Payback period
B/C	**1.6**	Benefit - Cost ratio

Under this assumption where the tariff slowly increases from 5.16 USc/kWh in year 1, via passing 8.0 cent after 22 years, and ending at 12.6 cent after 45 years, which is the last year of the study, the EIRR obtained is 15.9%. This gives a NPV of USD 219 million, Benefit/Cost ratio (B/C) of 1.6, and pay-back period of 16 years based on the discounted benefits and costs.

Table 13-17: Sensitivity analysis 3: Conversion Factor 1.11 on foreign exchange

Energy cost	**4.43** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**99** USD mill.	Net Present Value
EIRR	**13.4%**	Economic Internal Rate of Return
Payback	**19** years	Payback period
B/C	**1.3**	Benefit - Cost ratio

By a conversion factor of 1.11 on foreign exchange the project achieves an EIRR of 13.4%, NPV USD 99 mill, Benefit/Cost ratio (B/C) of 1.3, and pay-back period of 19 years.

Table 13-18: Sensitivity analysis 4: Costs +10%

Energy cost	**4.81** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**27** USD mill.	Net Present Value
EIRR	**11.0%**	Economic Internal Rate of Return
Payback	**30** years	Payback period
B/C	**1.1**	Benefit - Cost ratio

With increase of 10% pro rata in all costs, the EIRR achieved is 11.0%, thus still economic feasible at a discount rate of 10.23%. However, it would not be feasible with discount rate 12%. The NPV achieved would be USD 27 million. The unit energy costs would increase to 4.8 UScent/kWh.

Table 13-19: Sensitivity analysis 5: 5 % less inflow to the GD-3 and GD-6 reservoirs than in the Base Case.

Energy cost	**4.66**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**37**	USD mill.	Net Present Value
EIRR	**11.5%**		Economic Internal Rate of Return
Payback	**27**	years	Payback period
B/C	**1.1**		Benefit - Cost ratio

Under this assumption where there are 5 % less inflow to the GD-3 and GD-6 reservoirs the unit energy cost increases to over 4.6 USc/kWh. The project is still feasible with an EIRR of 11.5%, NPV at USD 37 million, Benefit/Cost ratio (B/C) of 1.1, and pay-back period of 27 years based on the discounted benefits and costs. The project would not be feasible with a discount rate of 12%.

Table 13-20: Sensitivity analysis 6: ICS internally Ethiopia (no export)

Energy cost	**4.43**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**-16**	USD mill.	Net Present Value
EIRR	**9.7%**		Economic Internal Rate of Return
Payback	**n. a.**	years	Payback period
B/C	**1.0**		Benefit - Cost ratio

For coverage of internal demand only the project results are not feasible giving slightly negative NPV and EIRR below the discount rate.

<u>The Minimum Export to Kenya that makes the project feasible</u>

By 23% of the generation referred at Sodo for export to Kenya, the results are break even and on the border feasible with NPV = 0, EIRR 10.23% and B/C = 1.0.

<u>Reduction in bulk tariff to Kenya</u>

The assumed export bulk tariff at Sodo substation in the Base Case is 5.16 USc/kWh, while the energy cost of generation is 4.43 USc/kWh. This margin of 0.73 cents is 16.4% of the unit cost of generation, and 14.1% of the assumed tariff. This means that the project can bear a tariff reduction of up to ca. 14% before break even is reached, and export becomes economically unfeasible.

13.6.3 Conclusion of the Economic Analysis

The Base Case project is economically feasible with a discount rate of 10.23%. Since the resulting EIRR is 12.1% the project would be on the border feasible with a discount rate of 12%. On the other side, with a discount rate of 12%, negative sensitivity assumptions will then make the project unfeasible.

The project has proven solid results towards the sensitivity analyses. It can bear relatively large cost increases and less inflow of water to the reservoirs. Finally, it can bear tariff reductions for Kenyan export of up to 14% before break even is reached.

The only negative result of the sensitivity analysis is in the case where all generation is applied for covering internal demand in Ethiopia. However, with not more than 23% of the generation sold to Kenya the project reaches break-even with an EIRR at 10.23%. From this it may be concluded that the project is not feasible without the Interconnection line to Kenya, but if this be constructed, large parts of the generation might as well be sold internally in Ethiopia.

The main reasons that the project is feasible for export to Kenya and less feasible for internal coverage in Ethiopia may be summarised as follows:

- The value of (firm) energy is regarded higher in Kenya than in Ethiopia because Kenya's internal generation development will have to be by thermal generation projects. These will have higher costs than Ethiopian hydropower options, particularly if there will be a value on the country's CO_2 emissions. If the unit generation costs of the interconnection line is lower than the difference in unit generation costs between Kenya and Ethiopia, the export is feasible.

- The unit generation cost of GD-6 is higher than EEPCo's assumed minimum price for export. The unit generation cost of GD-6 is higher than EEPCo's assumed minimum price for export. There will therefore exist other hydropower projects in Ethiopia with lower unit generation costs (referred connection point to ICS) than GD-6.

13.7 Financial Analysis of the GD-6 project

13.7.1 Introduction and assumptions

Financial Analysis has been made for the Export alternative only, and the relevant assumptions of the Base Case in the Economic Analysis form the Base Case of the Financial Analysis as well. It is for example assumed that the sales price of the power is based on the same bulk tariffs as elaborated in the economic analysis. The project's share of the cost of transmission from the power plant to Sodo substation is covered by the investor.

It is assumed an On-lending model with interest during construction (IDR). The basic financing is a combination of Concessional Credit (international soft loan), and equity on market conditions.

Equity — It is assumed that the investor of the project will have to raise 20% of the investments in equity. For the remaining 80% capital needs the investor will achieve concessional credits.

Terms of financing — The interest rate on equity is assumed 10% real. On the concessional credit, a soft loan model with 2% real interest rate is assumed. Terms from donors can be even lower, but it is assumed a small on-lending fee from the government to the project included. It is further assumed 10 years grace period and maturity (repayment) period of 30 years. The concessional part can also include a grant part of the investment.

For discounting future values in the PV calculations, the weighted average of the interest rate on equity and on the loan is applied..

Financers — The project could be an entirely Ethiopian Public owned project operated by EEPCo, or a limited company with several share holders including EEPCo and international organisations and investors. Foreign organisations or investors could contribute with subsidised financing (soft loans or other means) and in return for these subsidies, require special outputs or terms for the project. There are many options for this, and this study cannot foresee such negotiations. Therefore, only one common on-lending model has been assumed.

It may be assumed that Kenya contributes to the financing by a Power-Purchase-Agreement (PPA) that guarantees their purchase of the power at certain terms. The PPA would be the base for seeking funding of either of the two models above.

Financial versus economic model

While economic analysis is based on the use and income of real resources, and values on parameters and variables should refer to the society’s valuation of these, the Financial analysis, on the other hand, shows the financial (money) flow of disbursements and income for the project.

Instead of discount rate, interest rate is used for discounting values, and in the financial analysis interests during construction (IDR) is relevant and has been included.

Different kind of taxes could also be relevant for the financial analysis, but they will mostly be exempted in such projects according to the Ministry of Finance and Economic development (MoFED)

Apart from the above issues, there are no main differences between the economic and financial analyses in the study.

13.8 Results of the Financial Analysis

The Base Case model assumes 20% of the investment as concessional grants, 60% as concessional credit with 2.0% interest rate, and 20% of the investment as equity. This model gives a unit generation cost at only 2.19 USc/kWh, and when the net bulk tariff is assumed at 5.16 UScent, the margin is “formidable” with an FIRR of 32.7% on the investments, based on the “cash flow” of the project.

The NPV of USD 852 million is a return of 182% of the investment, therefore a benefit/cost ratio of 2.8 is reached, and the payback period on the investments is 9 years after project start up (2 years after commissioning), based on discounted cash flow.

Table 13-21: Main financial results of the Concessional Credit model with 20% grants of the investment

Energy cost	**2.11**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation	
NPV	**852**	USD mill.	Net Present Value Disc. rate:	3.6 %
FIRR	**32.7%**		Economic Internal Rate of Return	
Payback	**9**	years	Payback period	
B/C	**2.8**		Benefit - Cost ratio	

The calculation of the Financial analysis model result are shown in Annex 3H, Appendix Pages 10 - 17.

13.8.1 Sensitivity Analyses

With the basically good results based on the assumed financing and financial terms, the sensitivity assumptions shall be large negatively before the investments give low return.

Even with no grants, the results were only slightly lower than in the base case with FIRR still over 30%, since the interest rate on the loan part is low anyway:

Table 13-22: Financial sensitivity analysis of Base Case: Financial results of the Concessional Credit model with no grants.

Energy cost	**2.41**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation	
NPV	**794**	USD mill.	Net Present Value Disc. rate:	3.6 %
FIRR	**31.1%**		Economic Internal Rate of Return	
Payback	**9**	years	Payback period	
B/C	**2.5**		Benefit - Cost ratio	

Increasing the investment costs with 10% the unit generation cost increased with 0.14 USc/kWh, resulting in reduced FIRR from 32.7% to 30.3%. The payback period increased with one year. Considering that this is a real rate of return, the project is still very good.

Table 13-23: Financial sensitivity analysis of Base Case: Costs +10%

Energy cost	**2.25** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation	
NPV	**821** USD mill.	Net Present Value	Disc. rate: 3.6 %
FIRR	**30.3%**	Economic Internal Rate of Return	
Payback	**10** years	Payback period	
B/C	**2.6**	Benefit - Cost ratio	

The next sensitivity shows how 5 % less production (reason could be less inflow to the reservoirs, less demand or less production availability of technical reasons) affects the financial results. The energy cost increases from 2.11 to 2.21 USc/kWh, but with a net bulk tariff at 5.16 USc/kWh the project is still "formidable" with a NPV of USD 788 mill. and FIRR at 31.3 %.

Table 13-24: Financial sensitivity analysis of Base Case: Results of 5 % reduced energy production

Energy cost	**2.21** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation	
NPV	**788** USD mill.	Net Present Value	Disc. rate: 3.6 %
FIRR	**31.3%**	Economic Internal Rate of Return	
Payback	**9** years	Payback period	
B/C	**2.6**	Benefit - Cost ratio	

By sales to internal demand in Ethiopia only, the net tariff /sales price is reduced from 5.16 UScent/kWh to 4.21 UScent/kWh compared with export price to Kenya. This gives reduction of NPV from USD 852 million to 609 million, FIRR from 32.7% to 27.0%, and B/C from 2.7 to 2.3 compared with the results of the Basic model. The payback period increased from 9 to 10 years. It is assumed that all generation can be sold to the internal market at ICS.

Table 13-25: Results of sales to ICS internally in Ethiopia only

Energy cost	**2.11** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation	
NPV	**609** USD mill.	Net Present Value	Disc. rate: 3.6 %
FIRR	**27.0%**	Economic Internal Rate of Return	
Payback	**10** years	Payback period	
B/C	**2.3**	Benefit - Cost ratio	

In the next sensitivity analysis it is assumed that the investments to be done in year 7 is stretched over the years 7 and year 8. The first unit will be delayed by 1.5 years in commissioning, and the second unit by 1 year. Full production from year 9.

This gives reduction of FIRR from 32.7% to 25.9%, and in NPV from USD 852 mill to USD 790 mill. The payback period increased from 9 to 11 years.

Table 13-26: Results of Delay in Implementation (1-1.5 years)

Energy cost	**2.17** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**790** USD mill.	Net Present Value Disc. rate: 3.6 %
FIRR	**25.9%**	Economic Internal Rate of Return
Payback	**11** years	Payback period
B/C	**2.7**	Benefit - Cost ratio

13.8.2 Development Fee

Though not included in the TOR, the Consultant has included, as an option, a local/regional fee of the yearly revenues from the project to be allocated for local development, since the project in itself does not give any benefits for the local community beyond the investment phase. This amount would allow the community to maintain roads, houses, diverse services and other the infrastructure facilities that will be developed during the construction phase.

By a fee of 1% of the revenues as an example, the contribution to local development would be USD 0.8 million per year. By a fee of 2% of the revenues, the contribution would also double to USD 1.6 million per year, and so on. By a fee of 5% the contribution would be USD 4.0 million. The financial result for the project investor by a fee of 1% and 5% of the revenues would be as follows:

A fee of 1% would give reduction of NPV from USD 852 million to 839 million, FIRR from 32.7% to 32.4%, and B/C remains around 2.7 compared with the results of the Basic model. The payback period also remains at 9 years.

Table 13-27: Results of Development fee of 1% of revenues

Energy cost	**2.11** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**839** USD mill.	Net Present Value Disc. rate: 3.6 %
FIRR	**32.4%**	Economic Internal Rate of Return
Payback	**9** years	Payback period
B/C	**2.7**	Benefit - Cost ratio

A fee of 5% of the sales revenues would give reduction of NPV from USD 852 million to 786 million, FIRR from 32.7% to 31.2%, and B/C reduced from 2.7 to 2.6 compared with the results of the Basic model. The payback period remained at 9 years.

Table 13-28: Results of Development fee of 5% of revenues

Energy cost	**2.11** US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation		
NPV	**786** USD mill.	Net Present Value	Disc. rate:	3.6 %
FIRR	**31.2%**	Economic Internal Rate of Return		
Payback	**9** years	Payback period		
B/C	**2.6**	Benefit - Cost ratio		

13.8.3 Conclusion of the Financial analysis

The presented results show that the project is financially sound. FIRR is as high as over 32 % in the Basic concessional model with grants, giving a NPV that is over 1.8 times the investments, thus a B/C ratio of 2.8.

The results of the Sensitivity analysis are also positive with FIRR varying between 25–32%. The project is vulnerable mostly to changes in the financing terms.

Finally it is analyzed the consequence of introducing a Development Fee of 1% and 5% for the benefit of the local community in the project area. This would give the communities respectively USD 0.8 million and 4.0 million per year during the operation phase. The FIRR for the project would be reduced from 32.7% to 32.4% and 31.2% in the two respective options.

The project gives better financial results than economic results. This is because the financial terms are assumed subsidized to a high degree according to present concessional terms by the most relevant financing institutions and donors compared to the terms in the economic model, which is based on the general opportunity cost of capital, assumed to be 10.23% real. The interest rate on equity is assumed the same, since a private investor in principle will invest according to the general market conditions, and the assumed opportunity cost of capital in principle shall represent a general, normal return on capital.

The reason for subsidizing the project to the extent as assumed must be a political will, internationally or internally, to give the project priority as a catalyst for development and cooperation of the Nile basin area where both Ethiopia and Kenya belong. However, it can be questioned whether the whole project (apart from the 20 % equity capital assumed in the model) will be given soft loans on such beneficiary terms, even grants, particularly if assumed to be developed by a private investor, and the financial results are above “normal profitability”, even when considering the political, technical and economic risks involved in developing the project.

13.9 Inclusion of Genale GD-5

It has also been studied the inclusion of GD-5 constructed through the years 2018-2021 and full production from 2022. GD-6 is assumed as in the Base Case. (ref 9.4.3 and 9.5.2)

The economic analysis for the combined implementation of GD-5 and GD-6 alternative with GD-5 FSL 690 and GD-6 FSL 585, gave the following result for the two projects seen in total:

Table 13-29: Economic Analysis of GD-6 and GD-5 in total. Basic assumptions.

Energy cost	**5.06**	US cent/kWh	Annualized cost per kWh at ICS/Sodo Substation
NPV	**11**	USD mill.	Net Present Value
EIRR	**10.5%**		Economic Internal Rate of Return
Payback	**39**	years	Payback period
B/C	**1.0**		Benefit - Cost ratio

The two projects together is feasible with an EIRR at 10.5% and NPV of USD 11 mill, just above the requirement of 10.23% for the FIRR.

GD-5 is however not studied to feasibility level.

With reference to chapter 9.5.2 the preliminary optimisation of the cascade shows that the best option for implementation should have a reduced GD-6 reservoir FSL in the case of an alternative combined implementation.

Financial analysis has not been made for this case.