ENTRO

EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

PRE-FEASIBILITY STUDY OF MANDAYA HYDROPOWER PROJECT, ETHIOPIA

FINAL REPORT

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with participation of :

- EPS (Egypt)
- Tropics (Ethiopia)
- YAM (Sudan)

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LIST OF ABBREVIATIONS/ACRONYMS

A	Ampere (Unit of electric current)
AC	Alternating Current
ARF	Area Reduction Factor
B/C ratio	Benefit/Cost ratio
ºC	Degrees Celsius (centigrade)
CCGT	Combined Cycle Gas Turbine
CFRD	Concrete Faced Rockfill Dam
cm	centimetre
CN	Curve Number
CV	Curve of Variation
D	Diameter
DC	Direct Current
DSM	Demand Side Management
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EELPA	Ethiopian Electric Light and Power Authority
EEPCO	Ethiopian Electric Power Corporation
EFY	Ethiopian Fiscal (or Financial) Year
EMA	Ethiopian Mapping Authority
ENCOM	Eastern Nile Council of Ministers
ENSAP	Eastern Nile Subsidiary Action Programme
ETB	Ethiopian Birr (national currency unit)
ETC	Ethiopian Telecommunications Corporation
EV1	Extreme Value type 1
FIRR	Financial Internal Rate of Return
FSL	Full Supply Level
FWL	Flood Water Level
GPS	Global Positioning System
GWh	Gigawatt-hour (equals 1000 MWh)
ha	Hectare (unit of area)
HD	Hydrology Department
HEC1	Hydrology simulation model
HFO	Heavy Fuel Oil
HH	Household
HPP	Hydro Power Project
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
Hz	Unit of frequency (Hertz)
ICB	International Competitive Bidding

ICOLD	International Committee on Large Dams
ICS	Interconnected System
IDC	Interest During Construction
IDEN	Integrated Development of the Eastern Nile
IEA	Initial Environmental Assessment
ITCZ	Inter-Tropical Convergence Zone
km	kilometre
kV	Kilovolt (1000 volts)
kVA	Kilovolt-ampere
kWh	Kilowatt-hour
kW	Kilowatt
LAN	Local Area Network
LCGEP	Least Cost Generation Expansion Plan
LF	Load factor (Ratio of average load to peak load)
LLF	Loss load factor (Ratio of peak loss to average loss)
LFO	Light Fuel Oil
LS	Lump sum
LV	Low Voltage
LWRL	Lowest Regulated Water Level
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 (Ethiopia)
MSHP	Medium Scale Hydropower Plants Study
MPa	Mega-Pascal (Unit of pressure (stress))
MPP	Multipurpose project
MUSD	Million United States Dollars
MVA	Megavolt-ampere
MVAr	Megavolt Ampere reactive rating
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt-hour
N	Newton (= 1 kg x acceleration of gravity) (unit of force)
NA	Not Applicable
NELSAP	Nile Equatorial Lakes Subsidiary Action Programme
NBI	Nile Basin Initiative
NMSA	National Meteorological Services Agency
NPV	Net Present Value

O&M	Operation and Maintenance
OPGW	Optical Fibre Ground Wire
Pa	Pascal (= 1 N/m^2)
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 Stabilizer
PV	Present Value
R	Resistance (electric)
RCC	Roller Compacted Concrete
RFP	Request for Proposal
RHO	Regional Hydrological Office
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
SVS	Static Var Compensator
TCSC	Thyristor Controlled Series Compensator
TOR	Terms of Reference
TWh	Terawatt-hour
UCB	Unit Control Board
UCS	Uniaxial Compressive Strength
UAB	Unit Auxiliary Board
UG	Underground
US	Upstream
USc	United States Cent
USD	United States Dollar
USSCS	United States Soil Conservation Service
UTM	Universal Transverse Mercator grid (maps)
V	Volt
VA	Volt-ampere
VAr	Volt-ampere reactive
W	Watt
Wh	Watt-hour
WMO	World Meteorological Organisation

E1. EXECUTIVE SUMMARY

E1.1 PROJECT AREA

The Mandaya project site is located on the Blue Nile (Abbay River) some 20 km downstream of its confluence with the Didessa river (Figure E1). The catchment area for the Mandaya project comprises some 128,729 km^2 of the Blue Nile river basin. The headwaters of the Blue Nile are in the mountains surrounding Lake Tana. The Didessa river is one of the largest tributaries of the Blue Nile and drains an area to the west of Addis Ababa.

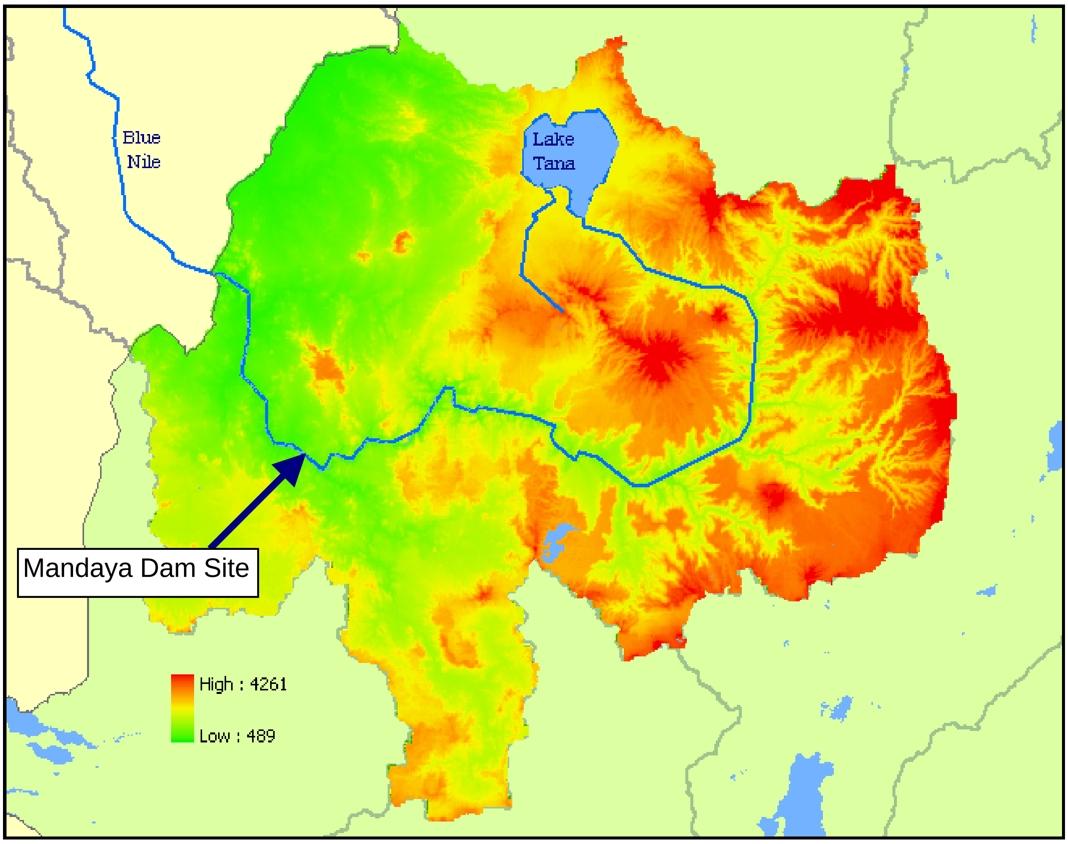


Figure E.1 : Abbay River Basin

Much of the upper part of the basin comprises the highland plateau with elevation generally exceeding 2000 m. The plateau exhibits extensive level areas with intensive agriculture divided by incised valleys. The Blue Nile flows generally within a deeply incised gorge which has a relatively gentle gradient falling some 630 m over some 600 km from an elevation of El.1030 m at Kessie bridge to El. 500 m at the Sudan Border.

E1.2 DEVELOPMENT OPTIONS FOR BLUE NILE (ABBAY) RIVER

The United States Bureau of Reclamation, carried out a major study of the land and water resources of the Blue Nile river basin in Ethiopia over the period 1960-1964. The study identified major hydropower development sites on the main stream of the Blue Nile as follows (in order moving upstream from Sudan Border):

- Border
- Mandaya
- Mabil
- Karadobi

Table E.1 summarises the key features of the Border, Mandaya and Mabil projects as defined by USBR. Information for the Karadobi project presented in Table E.1 has been derived from the Pre-feasibility study report.

Table E.1 : Characteristics of Potential Hydropower Projects on Blue Nile (USBR)

Site	Dam Height (m)	Full Supply Level (m)	Gross Storage ($m^3 \times 10^6$)	Installed Capacity (MW)	Energy Output (GWh/year)
Border	84.5	575	11,074	1400	6200
Mandaya	164	741	15,930	1620	7800
Mabil	171	906	13,600	1200	5314
Karadobi	250	1146	40,200	1600	9708

An initial review of the Mandaya project concluded that the site was suitable for development of a dam up to 260 m in height, with a full supply level of up to El. 860 m. The reconnaissance overflight revealed that the potential reservoir area appeared to be largely unpopulated. No roads, tracks or settlements were observed in the reservoir area. In general, the reservoir area was found to be covered with undisturbed open woodland.

Having ascertained that there was an opportunity to develop a higher reservoir at Mandaya than previously considered in the USBR studies in 1964, two options were considered for the long-term development of this reach of the Abbay river.

- Development of Mandaya to the maximum feasible elevation with full supply level of up to 860m in conjunction with the Karadobi development, developing the hydroelectric power potential of the river with two very large dams and reservoirs, or
- Development of Mandaya dam and reservoir to a lower elevation in conjunction with the Karadobi project and a third dam, which has been tentatively named Beko Abo, which could be developed in conjunction with a Mandaya reservoir full supply level elevation of El. 800 m.

The Beko Abo site lies some 2.5 km upstream of the existing bridge across the Abbay river on the Bure – Nekemte road. The Beko Abo site has various advantages compared to the Mabil site in that it would allow development of Mandaya to a higher elevation thus ensuring that the Mandaya reservoir has sufficient volume for effective regulation of inflows from the Abbay and Didessa rivers and avoids flooding of the Bure – Nekemte road bridge which would otherwise occur with the Mabil dam development,

Table E.2 : Energy Output for Mandaya Project

FSL (m)	Minimum Operating Level (m)	Operating Range (m)	Installed Capacity MW	Gross storage m^3 x 10^6	Live storage m^3 x 10^6	Firm energy %	Generation Flow %	Spillage Flow %
741*	724.8	16.2	1600	16,200	5,600	52%	75.9	24.1
800	760	40	2000	49,200	24,600	92%	94.4	5.6
860	820	40	2400	106,700	41,400	95%	95.5	4.5

A development at Mandaya with a full supply level of El. 800m would capture some 94.4% of flow for energy generation with only 5.6% of flow lost to spillage. Firm energy generation would amount to 92% of total generation as a result of the improved flow regulation with live storage of 154% of MAF. This development is clearly far superior to the lower level option proposed by USBR in terms of energy generation and provision of regulated flow downstream in Sudan.

For this study a full supply level of Mandaya reservoir of El. 800 m has been adopted allowing future development of the Beko Abo site as summarised in Table E.3, below:

Table E.3 : Characteristics of Proposed Hydropower Projects on Abbay

Site	Dam Height (m)	Full Supply Level (m)	Gross Storage (m^3 x 10^6)	Installed Capacity (MW)	Energy Output (GWh/year)
Border	90	580	13,300	1200	6011
Mandaya	200	800	49,200	2000	12,119
Beko Abo	110	906	na	800 - 1000	na
Karadobi	250	1146	40,200	1600	9708

E1.3 HYDROLOGY

The principal flow record for hydrological analysis for the Mandaya project is that for the Abbay River at Kessie (Station No. 2001). Mean annual flow at Mandaya over the 50 year period 1954-2003 has been estimated as 1013.5 m^3/s, taking account of future diversion of 77 m^3/s of flow from Lake Tana to the Beles Multi-purpose development.

Table E.4 : Summary of Adopted Flow Series for Project Sites

Site	Catchment Area (km^2)	Mean Annual Flow (Natural) (m^3/s)	Mean Annual Flow (with Beles Diversion) (m^3/s)
Kessie	65,784	517	440
Karadobi	82,300	649	572
Mandaya	128,729	1091	1014
Border	176,918	1547	1547
El Deim		1547	1547

E1.4 FLOOD STUDIES

Analysis of flood discharges has been carried out for the Abbay river at Kessie, Border and Deim. Based on this analysis, preliminary estimates of flood discharge have been determined for the Mandaya site for purposes of spillway design as shown in Table E.5 below. A flood magnitude of 30,000 m^3/s has been adopted for spillway design.

Table E.5 : Maximum Daily Discharge Estimates for Mandaya Site

Return Period (years)	Estimated Flood Magnitudes for Mandaya Site (m^3/s)
10,000	32,250
1,000	25,831
100	19,400
50	17,455
20	14,856
10	12,852

E1.5 SEDIMENT

Measurements of sediment concentration in the Abbay / Blue Nile river have been carried out at Kessie and Border hydrometric stations in Ethiopia and at Deim in Sudan. Relatively few measurements have been made with some 27 measurements at Kessie over the period 1960 – 2004. Figure E.2 below illustrates the sediment rating relationships for the periods 1960-61, 1985-95 and 2004.

Current sediment discharge at Kessie has been estimated based on measurements carried out in 2004 as shown in Table E.6 and this has been used to derive an estimate for the Mandaya site (Table E.7).

Figure E.2 : Sediment Ratings for Abbay River at Kessie

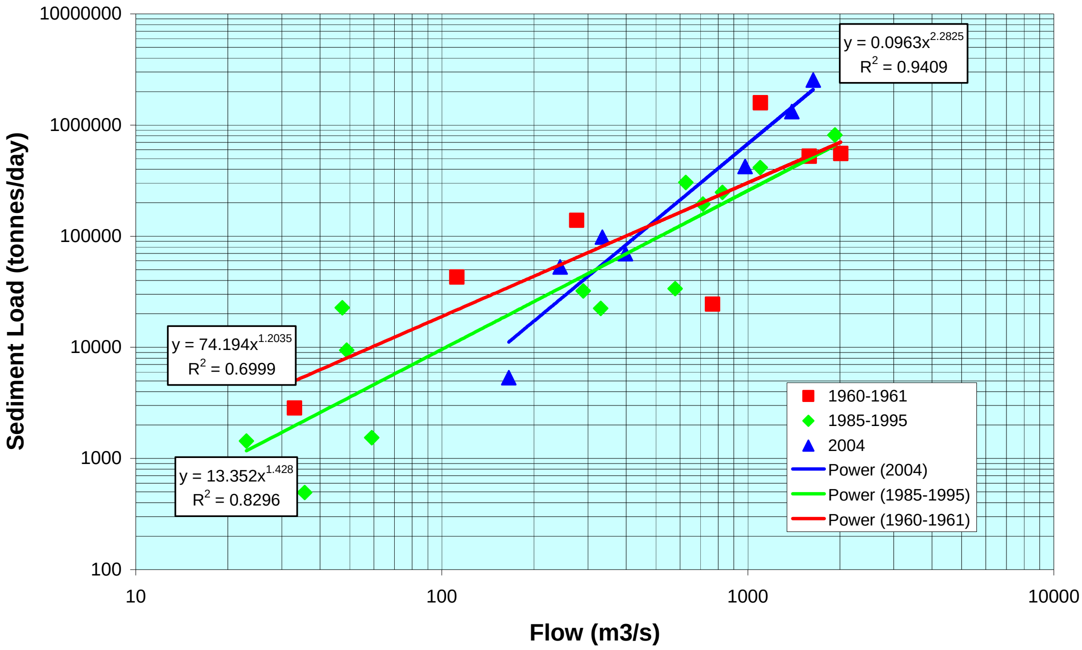


Table E.6 : Estimated Sediment Discharges at Kessie

Item	1960 – 1961 Data		2004 Data	
	Specific Sediment Discharge ($t/km^2/yr$)	Average Sediment Load (million tonnes / yr)	Specific Sediment Discharge ($t/km^2/yr$)	Average Sediment Load (million tonnes / yr)
Suspended sediment	901	59.3	2,791	183
Bedload (20%)		11.9		37
Total sediment discharge		71.2		220

Table E.7 : Estimated Sediment Discharges at Mandaya

Location	Catchment Area (km^2)	Specific Suspended Sediment Discharge (t/km^2/yr)	Average Sediment Load* (million tonnes / yr)
Kessie*	68,074	2,791	220
Incremental catchment area Kessie to Mandaya	60,655	900	65
Mandaya	128,729		285

*based on data for Year 2004 including bedload

E1.6 RESERVOIR AND POWER SIMULATION

Energy outputs of the Mandaya project and other development options on the Abbay / Blue Nile have been determined using RAPSO, a river flow and energy model which simulates the entire Nile river system. Energy output for the recommended Mandaya project development with full supply level of El. 800m is presented in Table E.8, below:

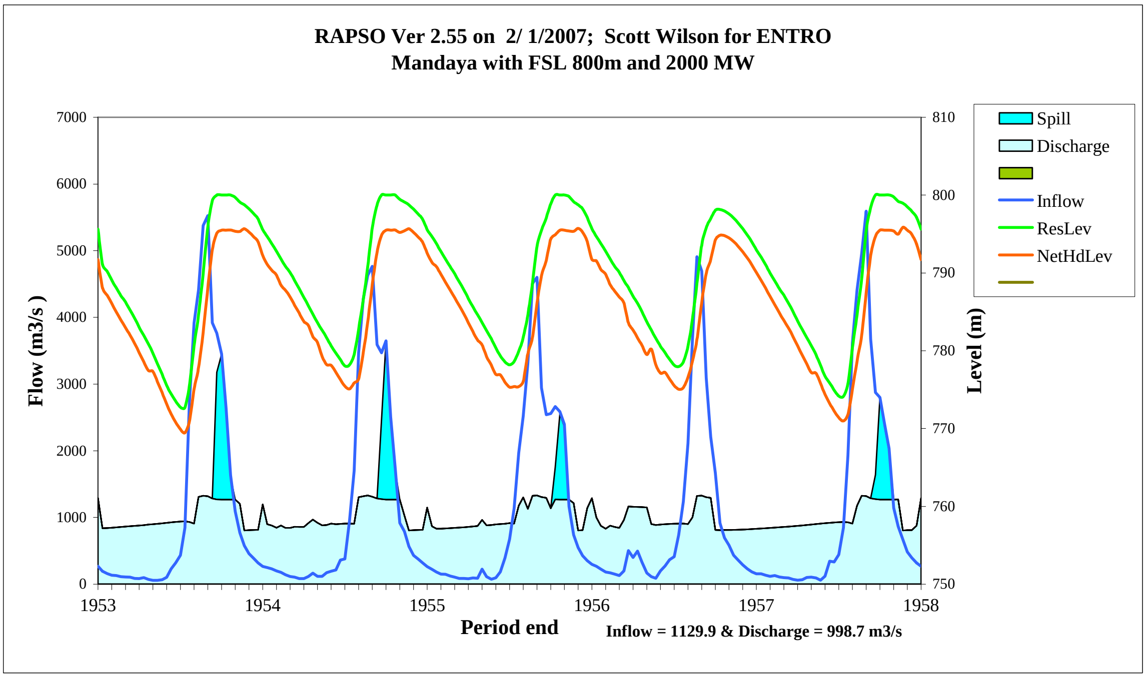
Table E.8 : Energy Output of Mandaya Project

Option	Installed Capacity (MW)	Energy Output (GWh/year)			
		Base		With Mandaya	
		Firm	Average	Firm	Average
Karadobi	1,600	8,276	8,802		
Mandaya FSL 800	2,000	11,194	12,119		
Border	1,200	3,966	6,011	7,429	8,114
Low Dal	340		1,944		2,187
Uplift at Existing Power Stations	0				2,211
Uplift at Existing Power Stations	135*				2,657

* Additional plant at Roseires

A typical period 5-year of operation of the Mandaya project as simulated by RAPSO is illustrated in Figure E.3, below.

Figure E.3 : Typical 5-Year Period Operation of Mandaya



E1.7 EFFECTS OF MANDAYA ON ENERGY GENERATION IN SUDAN

The effects of the Mandaya project on generation at existing hydropower projects in Sudan has been determined using the RAPSO model as illustrated in Table E.9.

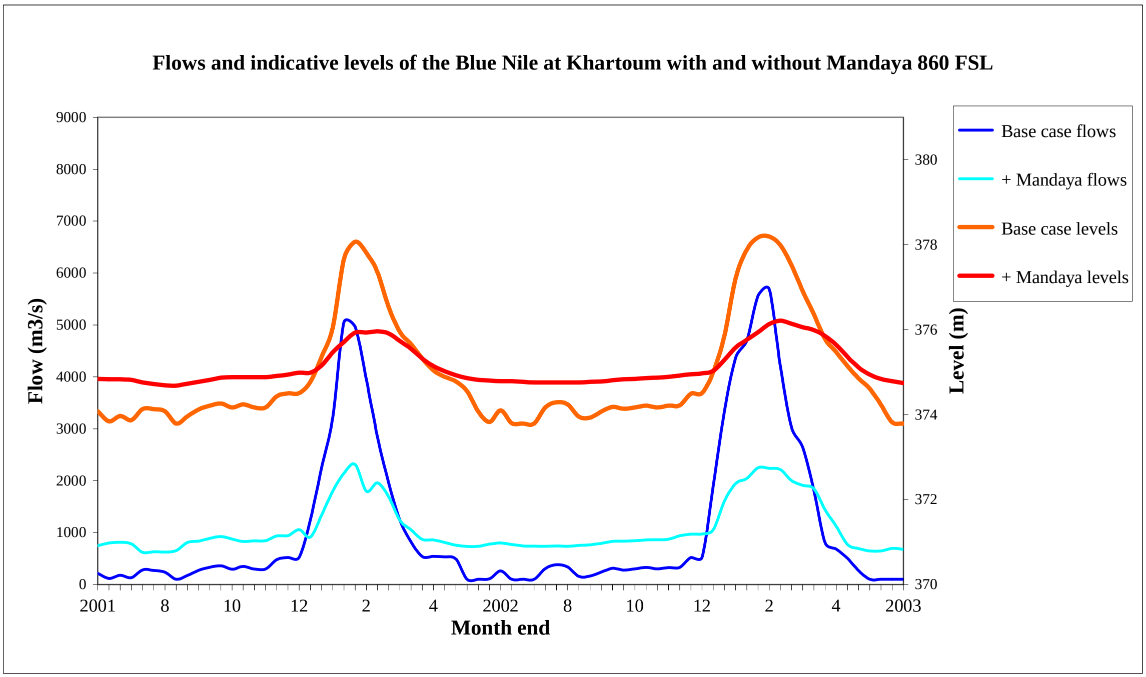
Table E.9 : Uplift in Generation at Sudan Hydropower Projects due to Mandaya

Option	Average Energy Output GWh/year				
	Roseires	Sennar + Ext.	Merowe	Total	Uplift
Base Case, Existing with Roseires flushing operation	1436	302	5903	7640	0
With Mandaya, with Roseires flushing operation	2142	490	6263	8895	1255
With Mandaya, without Roseires flushing operation	2304	521	7026	9851	2211
Roseires MOL raised to El. 471 and 3 x 45 MW extension	2750	521	7026	10297	2657

E1.8 EFFECTS OF MANDAYA ON FLOOD LEVELS IN SUDAN

Operation of the Mandaya project will alleviate flooding in Sudan as a result of the substantial degree of flow regulation. Figure E.4, below illustrates that under a typical flood year water levels in Khartoum would be reduced by some 1.5 to 2 metres.

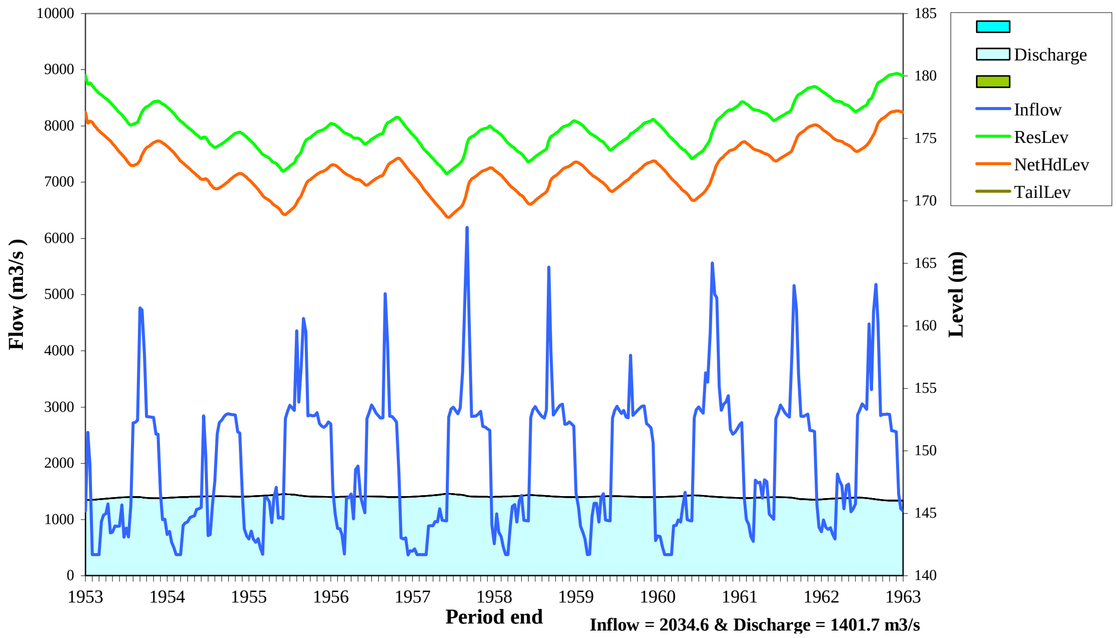
Figure E.4 : Impact of Mandaya on Flood Levels in Khartoum



E1.9 EFFECTS OF MANDAYA ON HIGH ASWAN IN EGYPT

The filling of the Mandaya reservoir will result in a reduction of water level in Lake Nasser / Nubia and consequently reduce the generating head at High Aswan power station. Figure E.5 below illustrates the reduction in water level at High Aswan by some 12 metres that would be expected in the early years as Mandaya reservoir fills. Average reduction in energy generation at High Aswan over the 50-year simulation period due to the reservoir filling and operation of the Mandaya project has been calculated as 202 GWh/year, although the reduction in generation will be greater in the early years.

Figure E.5 : Aswan 10-year Operation with Mandaya Filling from January 1954



E1.10 GEOLOGY OF MANDAYA SITE

Geological mapping at the Mandaya site confirmed the existence of the two major, broad geological formations divisions; namely the Precambrian, Biotite Gneissic Tonalite Formation and the late Tertiary Basalt Formation. The biotite gneissic tonalite is the foundation rock for the entire dam.

The typical rock mass condition, as seen in the scoured river section comprises unweathered to slightly weathered, and hard to very hard with weak foliation, sometimes the foliation is dispersed and the rock is geo-mechanically massive with estimated UCS in the range 150 to 200 MPa., with some degree of strength anisotropy caused by the foliation.

The river section is 400m wide at the centreline. There are many large, scoured outcrops of metatonalite at and nearby to the centreline. These indicate an unweathered very hard rock with incipient foliation and discontinuous vertical joints. The unconfined uniaxial strength of the rock material is high generally above 150 MPa. Such rock is considered uniform through the centreline area. These foundation conditions are considered to be excellent for the purpose of constructing an RCC dam, including all the various peripheral elements, such as diversion works, spillway and power station.

The Mandaya project area appears to be located in a relatively low seismic hazard zone. Mapping of seismic activity in Ethiopia and the neighbouring regions from 1906 until 2003 indicates that Mandaya dam site is 200km away from the nearest epicentre.

E1.11 PROPOSED DESIGN OF MANDAYA DAM AND POWER STATION

Having regard to the site topography and geology at the Mandaya site, together with the substantial flows which must be accommodated both during construction and in the spillway facilities it is considered that an RCC dam is the most appropriate choice of dam type.

The Mandaya dam with full supply level of El. 800 m will have an RCC volume of some 13 million cubic metres. As such it will be one of the largest volume RCC dams in the world. The rate of placing of the RCC will be of critical importance to the overall construction programme. Table E.10, below lists the planned and completed RCC dams that have had an average rate of placement in excess of 100,000 m^3/month. It should be noted that peak placing rates achieved at Longtan in China exceeded 400,000 m^3/month and therefore the proposed placing rate at Mandaya of 250,000 m^3/month appears to be achievable.

Table E.10 : Average Placing Rates of Major RCC Dams

Dam	Height (m)	Volume of RCC (M m^3)	Placement period (months)	Average rate (m^3/month)
Basha Diamer (design stage)	285	10.50	32.3	325,000
Longtan	217	4.95	33.0	150,000
Upper Stillwater	91	1.13	9.0	125,325
Tha Dan	95	4.90	40.0	122,500
Olivenhain	97	1.07	8.8	121,895
Beni Haroun	118	1.69	16.4	102,860

The spillway will comprise 12 radial gates each 16 m wide by 18 m high, with a total discharge capacity of approximately 30,000 m^3/s with the reservoir at full supply level. The spillway gates have been sized to be capable of discharging the 1 in 10,000 year flood. It is recognised that incoming flood peaks will be significantly attenuated as the flood passes through the reservoir, particularly as the reservoir will normally be drawn down by 20 metres or more at the start of the flood season. In practise therefore, the selected discharge capacity of 30,000 m^3/s may be reduced during detailed feasibility level studies.

The power waterway system will comprise a reinforced concrete intake structure located on the main dam incorporating unitised intake gates and associated control equipment for each of the eight turbine-generator units. The intake structure will also be equipped with trash screens and trash raking mechanism, and slots to allow bulkhead gates to be deployed for gate, waterway and unit maintenance. Downstream of the intake eight surface-mounted steel penstocks descend the face of the dam and connect directly to individual turbine units.

The powerhouse will be a surface type structure of reinforced concrete and structural steel, construction, completely detached from the dam structure and located on the right bank. The powerhouse accommodates a loading/service bay, one bay for each of the 8 Francis turbine units, control block and offices.

The tailrace arrangement comprises an open channel that joins with the existing river approximately 350 m downstream of the powerhouse, and an RCC separation wall to limit the interferences between the tailrace channel and the spillway plunge pool.

The switchyard will be located on the right bank, downstream of the dam site, at a distance of approximately 500 m from the powerhouse.

E1.12 MECHANICAL AND ELECTRICAL EQUIPMENT

The turbines will be vertical shaft Francis type with steel spiral casing. Each turbine will be directly connected to a vertical shaft synchronous generator. The water for each turbine will be supplied through a separate intake structure and penstock. Intake gates will be provided for emergency shutdown of the units. At the outlet, draft tube gates will be provided to permit dewatering of the turbine for inspection and maintenance purposes.

The rated output of each turbine will be 250 MW assuming a design net head of 171.9 m. The synchronous speed of the unit has been selected at 176.5 rpm. Each turbine will be equipped with an electronic digital type governor. The runner will have an approximate external diameter of 4.6 m and a height of approximately 1.9 m.

The generators will be of conventional air-cooled, self-ventilating type, with a rated capacity of approximately 288 MVA. Voltage will be in the range11–18 kV. The speed of each generator will be 176.5 rpm which corresponds to a 17 pole pairs generator.

The generators will be connected to single-phase transformers by metal-enclosed, isolated phase bus ducts. A coupling circuit breaker SF6 type (rated voltage 24 kV) would be provided to connect the generator to the grid through the generator transformers.

E1.13 TRANSMISSION SYSTEM

It is envisaged that the transmission system would connect the Mandaya power station to both the Ethiopian and regional electricity network.

The connection to the Ethiopian grid would comprise a 400 kV double circuit transmission line from Mandaya to Debre Markos following a route to the North side of the Mandaya reservoir (Length approximately 300 km), The connection to the Sudan grid would comprise either an AC or DC interconnection, depending on the magnitude of power expeort from Ethiopia tpo Egypt.

The AC option would comprise a 500 kV double circuit transmission line from Mandaya to Meringan (or Rabak, or Hasaheisa) following a route to the West side of the Border reservoir (Length approximately 650 km).

The DC option would comprise a HVDC interconnection from Mandaya to a receiving station in Egypt with a tapping station at Hasaheisa in Sudan.

E1.14 ACCESS ROADS AND BRIDGES

A new access road will be required from the existing Addis Ababa to Asosa road to the Mandaya site. Improvement of the existing road from Addis Ababa to Mendi will be required to accommodate construction traffic and heavy loads.

Downstream of the Mandaya project a major multi-span bridge structure will be required across the Nile to permit construction access to the North bank and future connection to the existing road system North of the project location and Abbay river.

E1.15 COST ESTIMATE

The cost of the Mandaya project has been estimated as USD 2472 million inclusive of environmental mitigation measures. A breakdown of the project cost is given in Table E.11.

Table E.11 : Mandaya Project Cost Estimate

Item	Cost (Million USD)
Environmental Mitigation	22.0
Access Roads and Infrastructure	86.3
Reservoir Clearance	39.7
Civil Works	
Diversion works	60.6
RCC Dam and spillway	1,283.4
Powerhouse and tailrace	116.4
Switchyard and Buildings	5.5
Civil contingencies	219.9
Mechanical and Electrical Plant	334.4
Sub-total	
Engineering and Construction Management	216.8
Owners Administration	86.7
OVERAL TOTAL	2,471.7

E1.16 CONSTRUCTION PROGRAMME

The Mandaya project will take some 8 years to commencement of generation of the first units. Final installation and commissioning of all 8 turbine-generator is anticipated to require 10 years from commencement of construction.

Assuming that feasibility studies are carried out over the period 2008 – 2009, it is considered that the project could be completed by the end of year 2021.

E1.17 ENVIRONMENTAL IMPACT

The Mandaya project will inundate an area of some 574 km^2 consisting mainly of open woodland. The reservoir area is sparsely populated and the displaced population has been estimated at approximately 600 people.

E1.18 CO_2 EMISSION SAVINGS

The Mandaya project will provide carbon emission savings of some 424 million tonnes of CO_2 compared to equivalent thermal generation based on a 50/50 gas-fired CCGT / coal fired thermal generation mix.

E1.19 GENERATION PLANNING AND ECONOMIC APPRAISAL

The Mandaya hydropower project has been selected as part of the least cost development plan within the generation planning analysis for commissioning in approximately 2020 in advance of the Karadobi and Border projects.

The regional power trade development, including the interconnector linking Ethiopia to Sudan and Egypt, has been found to be economically attractive based on fuel cost savings in Sudan and Egypt in a loose pool arrangement with net benefits (10% discount rate) of up to USD 2,590 million as shown in Table E.12, below.

Table E.12 : Net Benefits of Generation Savings – Loose pool (Million USD)

$MUSD_{2008}$	SU : 700 MW, EG : 0 MW	SU : 700 MW, EG : 700 MW	SU : 700 MW, EG : 2000 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Demand median - Fuel median	1 280	1 910	2 010	2 270	2 380
Demand median - Fuel low	840	1 120	1 340	1 520	1 520
Demand ET low - Fuel median	1 170	1 920	2 260	2 540	2 590
Demand ET high - Fuel median	820	1 140		1 550	1 600

The regional power trade development, including the interconnector linking Ethiopia to Sudan and Egypt, has been found to be economically attractive based on fuel and investment cost savings in Sudan and Egypt in a tight pool arrangement with net benefits (10% discount rate) of up to USD 2,590 million as shown in Table E.13, below.

Table E.13 : Net Benefits of Generation Savings – Tight Pool (Million USD)

Present worth of savings (generation) - MUSD$_{2006}$	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium demand for Ethiopia - Fuel medium -Tight pool	2 810	2 960
Low demand for Ethiopia - Fuel high -Tight pool	3 140	4 020
Low demand for Ethiopia - Fuel medium -Tight pool	2 380	2 990

E1.20 KEY PROJECT CHARACTERISTICS

Power and Energy			
	Installed Capacity	2000 MW	
	Annual energy generation	Firm	11,194 GWh/yr
		Average	12,119 GWh/yr
	Plant factor	69%	
Hydrological data			
	Catchment area	128,729 km^2	
	Mean annual flow	1091 m^3/s (natural)	
		1014 m^3/s (with Beles diversion)	
Reservoir data			
	Full supply level	800 m	
	Minimum operating level	760 m	
	Operating range	40 m	
	Gross storage	49.2 x 10^9 m^3	
	Live storage	24.6 x 10^9 m^3	
	Surface area at FSL	736 km^2	
	Length of reservoir at FSL	300 km	
Dam			
	Type	Roller compacted concrete (RCC) gravity	
	Maximum height	200 m	
	Crest elevation	803 m	
	Crest length	1400 m	
	Dam volume	13,000,000 m^3	
Spillway			
	Type	Gated overfall with chute	
	Design capacity	30,000 m^3/s	
	Elevation of spillway crest	782 m	
	No.of gate bays	12	
	Size of gates (W x H)	16 m x 18 m	
Power Intake			
	Sill elevation	743.8 m	
	No. of intakes	8	
	Gate size (W x H)	3 m x 5.4 m, 2 per unit	
Penstocks			
	Number	8	
	Diameter	5.4 m	
	Length	246 m	

Powerhouse		
	Type	Surface
	Overall length	217 m
	Overall width	22 m
	Generator floor level	616.5 m
	Access / loading bay level	631.5 m
Turbines		
	Type	Francis, vertical axis
	No.	8
	Speed	176.5 rpm
	Design net head	171.9 m
	Setting	605.39 m
Generator		
	Type	Vertical synchronous
	Size	288 MVA
Transmission within Ethiopia		
	Route	Mandaya to Debre Markos
	Length	300 km
	Voltage	400 kV ac
	Type	Double circuit
Transmission to Sudan		
	Route	Mandaya to Meringan
	Length	650 km
	Voltage	500 kV ac
	Type	Double circuit

1. INTRODUCTION

1.1 BACKGROUND OF THE NILE BASIN INITIATIVE

The Nile Basin encompasses ten countries: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. In 1997, the Nile riparian countries initiated dialogue on a long term Cooperative Framework and in 1999 the Council of Ministers of Water Affairs of the Nile Basin States (Nile-COM) formally launched the Nile Basin Initiative (NBI)-an interim financing mechanism for development of regional projects. The NBI is represented by its executive arm, the Nile Secretariat (Nile-SEC) based in Entebbe, Uganda.

Nile-COM has approved a basin-wide integrated program to jointly pursue sustainable development and management of the Nile waters for promoting economic growth, eradicating poverty, and reversing environmental degradation. The program is called the Shared Vision Program (SVP) and includes seven projects, namely (1)Trans-boundary Environmental Action (2) Regional Power Trade (3)Efficient Water Use for Agriculture Production (4) Water Resource Planning and Management (5)Confidence Building and Stakeholder Participation (6)Applied Training and (7)Socio-Economic Development and Benefit Sharing.

In parallel, Nile-COM also approved action-oriented sub-basin programs, namely the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) and the Eastern Nile Subsidiary Action Program (ENSAP). NELSAP includes Burundi, Democratic Republic of Congo, Kenya, Rwanda, Egypt, Sudan, Tanzania, and Uganda while ENSAP includes Ethiopia, Egypt, and Sudan (Annex 1). Eritrea is participating in ENSAP as an observer. NELSAP and ENSAP are meant to shift focus from planning to action on the ground through investment in actual development projects. Such projects cover irrigation and drainage development, hydropower development and power transfer networks & trade, watershed management, sustainable development of lakes & wetland systems, river regulation, flood & drought management, etc.

Nile-COM then formed the Nile Equatorial Lakes Council of Ministers (NELCOM) and the Eastern Nile Council of Ministers (ENCOM) to oversee the activities of NELSAP and ENSAP, respectively. NELCOM and ENCOM are assisted in their activities by teams of technical specialists from the respective member countries.

1.2 ORIGIN OF THE STUDY

Following the establishment of ENCOM, Ethiopia, Egypt, and Sudan have jointly adopted a strategy to develop, utilize, and manage water resources of the Eastern Nile basin in an integrated, equitable, and sustainable manner.

In defining the cooperative development paradigm, the countries identified sixty-four potential regional projects. Out of these seven priority projects, known as the Integrated Development of the Eastern Nile (IDEN) were selected. These are:

- Ethiopia-Sudan Interconnection Project,
- Eastern Nile Power Trade Investment Program Study

- Eastern Nile Multi-sector Planning Model,
- Baro-Akobo Multipurpose Hydro Power Project,
- Flood Preparedness and Early Warning,
- Irrigation & Drainage Development, and
- Watershed Management.

In order to prepare, monitor, and supervise the implementation of the IDEN, ENCOM established the Eastern Nile Technical Regional Office (ENTRO) in Addis Ababa.

In January 2002 on behalf of ENCOM, the Minister of Water Resources of the Government of Ethiopia (ENCOM Chairman) requested the African Development Bank to fund the Eastern Nile Power Trade Program Study. The African Development Bank included the funding of the Study in the Lending Program for the year 2003. The Terms of Reference (TOR) have been prepared by the Bank Mission, which visited Ethiopia, Egypt, and Sudan in July 2003. The TOR has been based on deliberations of the consultation workshop attended by donors and the EN country representatives held in Addis Ababa in July 2003 and documents collected from the field.

The Study area encompasses the Eastern Nile region, which includes Egypt, Ethiopia, and Sudan. The countries, along with other riparian states, share the waters of River Nile.

1.3 THE CONSULTANTS

Following an international competitive bidding procedure Electricité de France (EDF), in association with Scott Wilson of United Kingdom (SW) were appointed by ENTRO to carry out the Eastern Nile Power Trade Program Study.

EDF and Scott Wilson are supported and assisted by sub-Consultants in Ethiopia, Egypt and Sudan as follows:

- Tropics Consulting Engineers plc, Ethiopia,
- Electric Power Systems Eng. Co. (EPS), Egypt,
- YAM Consultancy and Development Co. Ltd, Sudan.

The Contract for the Eastern Nile Power Trade Study was signed on 26th June 2006 and the assignment commenced on 20th October 2006.

1.4 SCOPE OF THE SERVICES

The study will be carried out in two parts:

Phase 1: Co-operative Regional Assessment of Power Trade Opportunities

Phase 2: Feasibility Study of the Power Interconnection involving Ethiopia, Egypt and Sudan.

Phase 1 of the study includes the following key activities:

- Development of a Strategy for Power Trade
- Inception and Market Assessment
- Supply and Delivery Option Analysis
- Pre-feasibility Studies of Hydropower Projects
- Investment Planning and Modelling
- Regional Investment Programme

1.5 PRE-FEASIBILITY STUDIES OF HYDROPOWER PROJECTS

In order to widen the list of supply options that will be used in investment planning, the Terms of Reference require that the co-operative regional assessment of power trade opportunities shall include three pre-feasibility studies for hydropower sites that have been studied at reconnaissance level and agreed upon by the three EN countries. The sites are:

- Mandaya, Ethiopia
- Border, Ethiopia (close to the border with Sudan) and
- Dal-1 in Sudan (close to border with Egypt).

The location of each of the three sites is shown on Figure 1.1.

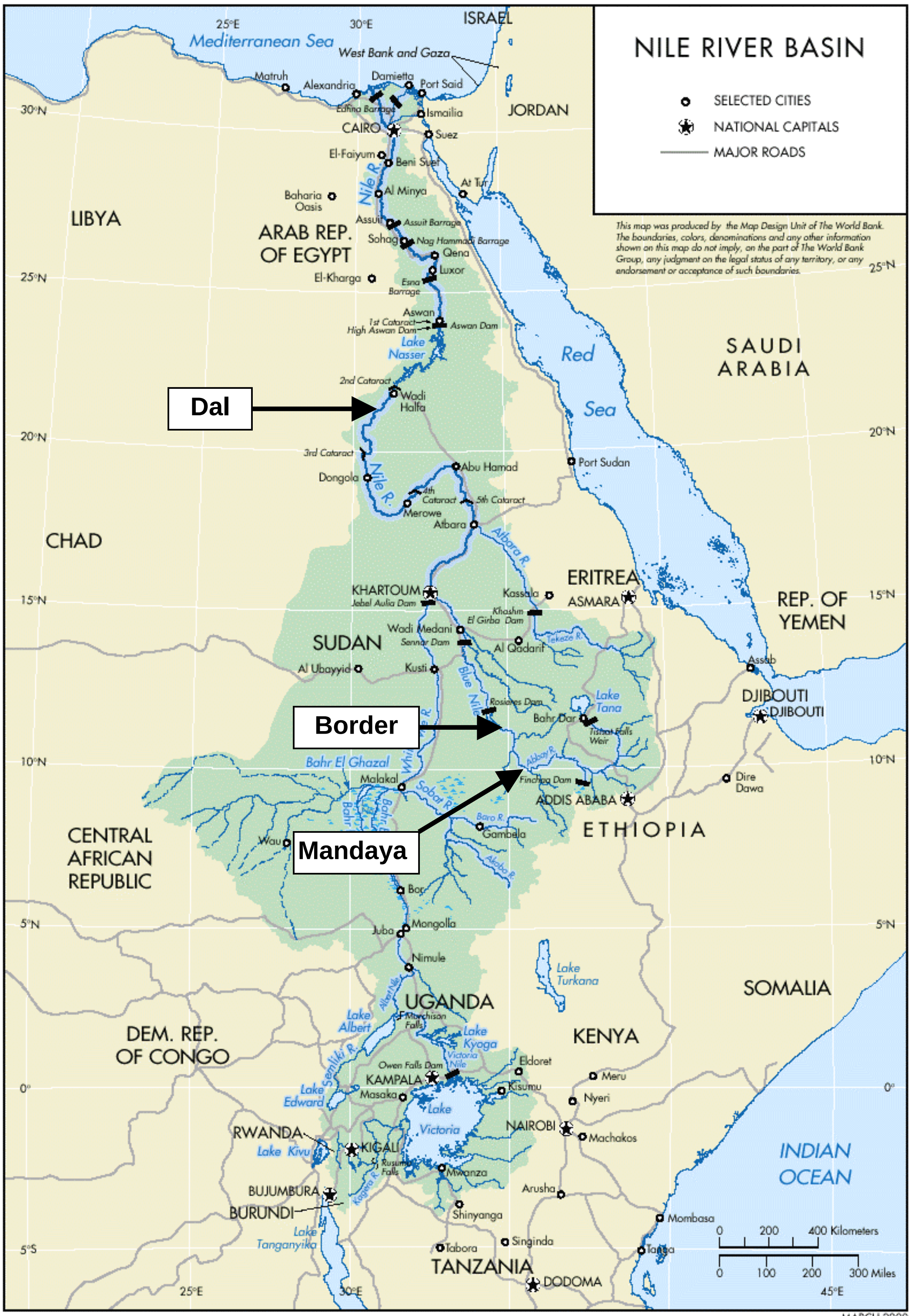
The pre-feasibility studies are required to be completed within 9 months of the commencement of the project, by 20th July 2007.

In the pre-feasibility Studies, multiple uses of the Nile waters (hydropower, irrigation, and flood control) and the associated regional benefits and costs will be considered. In particular, the benefits of potential irrigation, reduction in silt, and flood control in the hydropower sites, agreeable to the EN countries, will be clearly identified. These benefits will serve as useful comparative indicators for the countries in making decisions related to these projects. The Environmental and Social Impact assessment will be carried out in accordance with the Bank guidelines. Further, in accordance with the Bank Group's Involuntary Resettlement Policy (January 2003), resettlement and compensation plan will be prepared for affected population.

This report presents the Pre-feasibility Study of the Mandaya Hydropower Project in Ethiopia. The environmental and social impact assessment of the Mandaya hydropower project is presented in a separate report.

Figure 1.1 : Location of Hydropower Project Sites

IBRD 30785



MARCH 2000

2. BACKGROUND TO THE MANDAYA PROJECT

2.1 PROJECT AREA

The Mandaya project site is located on the Blue Nile some 20 km downstream of its confluence with the Didessa river. The catchment area for the Mandaya project comprises some 128,729 km^2 of the Blue Nile (Abbay) river basin. Drawing M1 presents the project location.

The headwaters of the Blue Nile are in the mountains surrounding Lake Tana, the largest tributary of which is the Gilgel Abbay. Lake Tana, at an elevation of approximately EL. 1785 m provides significant regulation of the natural river flow in the upper reaches of the Blue Nile. The Didessa river is one of the largest tributaries of the Blue Nile and drains an area to the west of Addis Ababa.

Much of the upper part of the basin comprises the highland plateau with elevation generally exceeding 2000 m. The plateau exhibits extensive level areas with intensive agriculture divided by incised valleys. Mountain peaks rise to over 4000 m in the North. The Blue Nile flows generally within a deeply incised gorge which has a relatively gentle gradient falling some 530 m over 600 km from an elevation of El.1030 m at Kessie bridge to El. 500 m at the Sudan Border.

The course of the Blue Nile describes a broad arc exiting Lake Tana to flow in a south-easterly direction before exhibiting a wide turn to flow generally westwards as far as the Didessa confluence and thereafter northwards in the direction of the Sudan border. Thereafter the river flows generally northwards towards the confluence with the White Nile at Khartoum.

2.2 PREVIOUS STUDIES

2.2.1 Land and Water Resources of the Blue Nile River Basin (1964)

The United States Bureau of Reclamation, Department of the Interior, carried out a major study of the land and water resources of the Blue Nile river basin in Ethiopia over the period 1962-1964. The study identified major development sites on the main stream of the Blue Nile as well as on each of the tributary valleys. The study included an extensive programme of survey and mapping including establishing a primary network of trigonometric stations throughout the Nile basin. Levelling was also carried out to establish height control in Ethiopia related to the downstream countries of Sudan and Egypt.

Specific sites identified with significance to the present study included the following potential dam and hydropower sites on the main Nile (in order moving upstream from Sudan Border):

- Border
- Mandaya
- Mabil
- Karadobi

Mapping and geological appraisal was carried out for each of the above sites. Hydrological studies were also undertaken leading to an assessment of the potential energy output for each site. Outline designs and cost estimates were prepared for each site. Table 2.1 summarises the key features of the Border, Mandaya and Mabil projects as defined by USBR. Information for the Karadobi project presented in Table 2.1 has been derived from the Pre-feasibility study report.

Table 2.1 : Principal Characteristics of Hydropower Projects on Blue Nile (USBR)

Site	Dam Height (m)	Full Supply Level (m)	Gross Storage ($m^3 \times 10^6$)	Installed Capacity (MW)	Energy Output (GWh/year)
Border	84.5	575	11,074	1400	6200
Mandaya	164	741	15,930	1620	7800
Mabil	171	906	13,600	1200	5314
Karadobi	250	1146	40,200	1600	9708

2.2.2 Abbay River Basin Integrated Development Master Plan Project (1996/99)

The Abbay River Basin Integrated Development Master Plan was carried out over the period 1996 to 1999. The study included extensive sectoral studies of natural resources, water resources, land resources development, environment, socio-economy and infrastructure. The results of the study are presented in a Main Report and a series of Sectoral Study volumes. The report includes a series of maps presenting basin-wide information in a GIS format including rainfall, runoff, soils, geology, land use, population amongst others.

Within the study updated concept designs and cost estimates were prepared for the various dams and hydropower projects previously identified by USBR although no additional fieldwork was undertaken at the dam sites.

2.2.3 Karadobi Multipurpose Project Pre-Feasibility Study (May 2006)

The Karadobi Multipurpose Prefeasibility study was carried out over the period 2005-2006 by Norplan, Norconsult and Lahmeyer International. The study included extensive technical and environmental studies. Hydrological studies of the Blue Nile carried out as part of the Karadobi project are of particular relevance to the ENTRO Power Trade Program Study since these included detailed review and analysis of the flow records the two key river gauging stations on the Blue Nile at Kessie and Border.

The study presented detailed cost estimates of the proposed Karadobi project including unit rates for construction activities. The cost estimates provide a valuable point of comparison for similar activities at the Mandaya site.

2.2.4 Beles Multi-purpose Project

The Beles project was studied at feasibility level by the LEK Consortium (Lahmeyer, Electrowatt, Knight Piesold Ltd (now Scott Wilson)) over the period 1999 – 2000. When completed the project will divert some 77 m^3/s of water from Lake Tana in the upper reaches of the Abbay river to the Beles catchment for purposes of hydropower generation and irrigation. This will reduce flows in the middle reaches of the Abbay river including at the Karadobi and Mandaya sites. Flows at Border site will be unchanged except to the extent that the diverted flow is used consumptively for irrigation since the Beles river joins the Abbay some 50 km upstream of the Beles site.

2.3 INITIAL REVIEW OF MANDAYA PROJECT

At the outset of the study an initial review of the Mandaya project was undertaken based on information from available mapping at 1:50,000 scale, aerial survey by light aircraft and field reconnaissance. The primary objective of the review was to assess the previous studies and to identify constraints to development of the Mandaya site.

The review concluded that the site was suitable for development of a dam up to 260 – 280 m in height, with a full supply level of up to El. 860 - 880 m. The reconnaissance overflight revealed that the potential reservoir area appeared to be largely unpopulated. No roads, tracks or settlements were observed in the reservoir area. In general, the reservoir area was found to be covered with undisturbed open woodland.

Having ascertained that there was an opportunity to develop a higher reservoir at Mandaya than previously considered in the USBR studies in 1964, two options were considered for the long-term development of this reach of the Abbay river:

- Development of Mandaya to the maximum feasible elevation with full supply level of up to 880m in conjunction with the Karadobi development, effectively developing the hydroelectric power potential of this reach of the river with two very large dams and reservoirs, or
- Development of Mandaya dam and reservoir to a lower elevation in conjunction with the Karadobi project and a third dam at an intermediate site.

The reach of the Abbay river between the Mandaya and Karadobi sites was examined on the available 1:50,000 scale maps. This examination lead to identification of a third site, which has been tentatively named Beko Abo, which could be developed in conjunction with a Mandaya reservoir full supply level elevation of El. 800 m. The Beko Abo site lies some 2.5 km upstream of the existing bridge across the Abbay river on the Bure – Nekemte road. The Beko Abo site has various advantages compared to the Mabil site:

- Allows development of Mandaya to a higher elevation thus ensuring that the Mandaya reservoir has sufficient volume for effective regulation of inflows from the Abbay and Didessa rivers,
- Avoids flooding of the Bure – Nekemte road bridge which would otherwise occur with the Mabil dam development,

- Benefits from the existence of the Bure – Nekemte road and bridge which provides access to the site and across the river from the existing roads resulting in considerable cost savings in road infrastructure compared to the Mabil development.

The revised proposal for the development of the Abbay river, including a higher dam at Mandaya and the Beko Abo development is summarised in Table 2.2, below:

Table 2.2 : Principal Characteristics of Proposed Hydropower Projects on Abbay

Site	Dam Height (m)	Full Supply Level (m)	Gross Storage ($m^3 \times 10^6$)	Installed Capacity (MW)	Energy Output (GWh/year)
Border	90	580	13,300	1400	6011
Mandaya	200	800	49,200	2000	12,119
Beko Abo	110	906	na	800 - 1000	na
Karadobi	250	1146	40,200	1600	9708

Na: not ascertained

2.4 MANDAYA AND BORDER CATCHMENTS

The Abbay river basin within Ethiopia may be divided into sixteen sub-catchments with areas as listed in Table 2.3 below. The approximate catchment areas to the Mandaya and Border dam sites are also shown in the Table.

Table 2.3 : Abbay river Basin – Sub-catchment Areas

Sub-catchment	Area (km^2)
Lake Tana	15,320
North Gojam	14,389
Beshilo	13,242
Welaka	6,415
Jemma	15,782
South Gojam	16,762
Muger	8,188
Guder	7,011
Finchaa	4,089
Didessa	19,630
Angar	7,901
Wonbera	12,957
Dabus	21,032
Beles	14,200
Dinder	14,891
Rahad	8,269
Total at Mandaya	128,729
Total at Border	176,918

2.5 MANDAYA RESERVOIR CHARACTERISTICS

The reservoir characteristics of the Mandaya reservoir have been determined by measurement from existing and newly commissioned mapping and are presented in Table 2.4 and Figs. 2.1 and 2.2.

Table 2.4 : Mandaya Reservoir Elevation – Area – Volume Characteristics

Elevation (m)	Area (km^2)	Volume ($m^3 \times 10^6$)
610	0	0
620	6	30
630	16	140
640	28	358
650	44	716
660	6	1,256
670	87	2,011
680	112	3,006
690	144	4,286
700	175	5,881
710	203	7,771
720	232	9,946
730	276	12,486
740	383	15,781
760	500	24,614
780	611	35,727
800	736	49,201
820	875	65,318
840	1,023	84,303
860	1,219	106,728
880	1,440	133,326

Figure 2.1 : Mandaya Reservoir Elevation Area Relationship

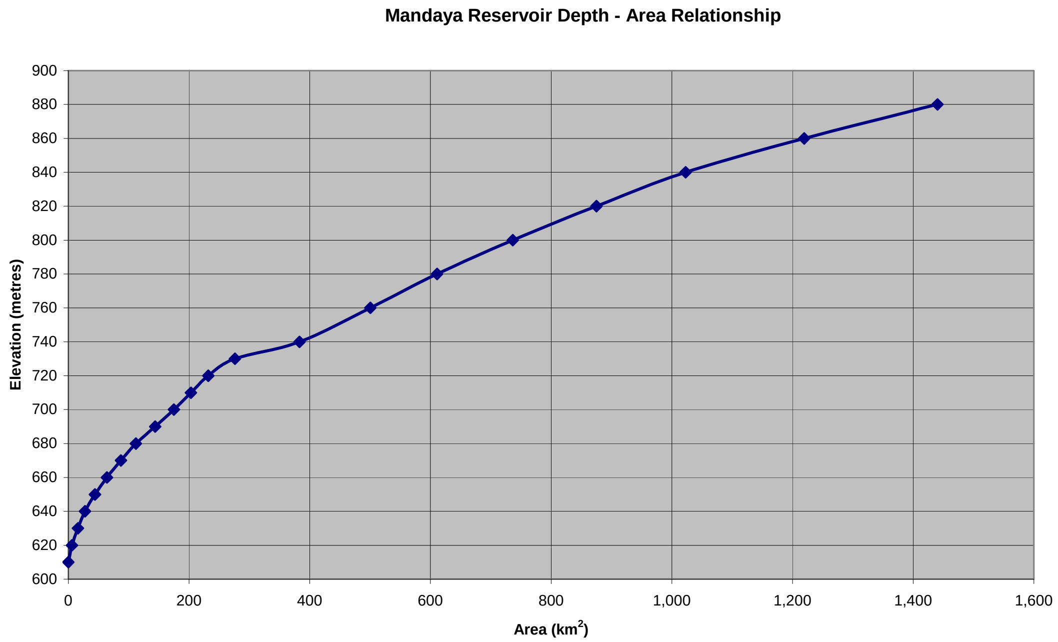
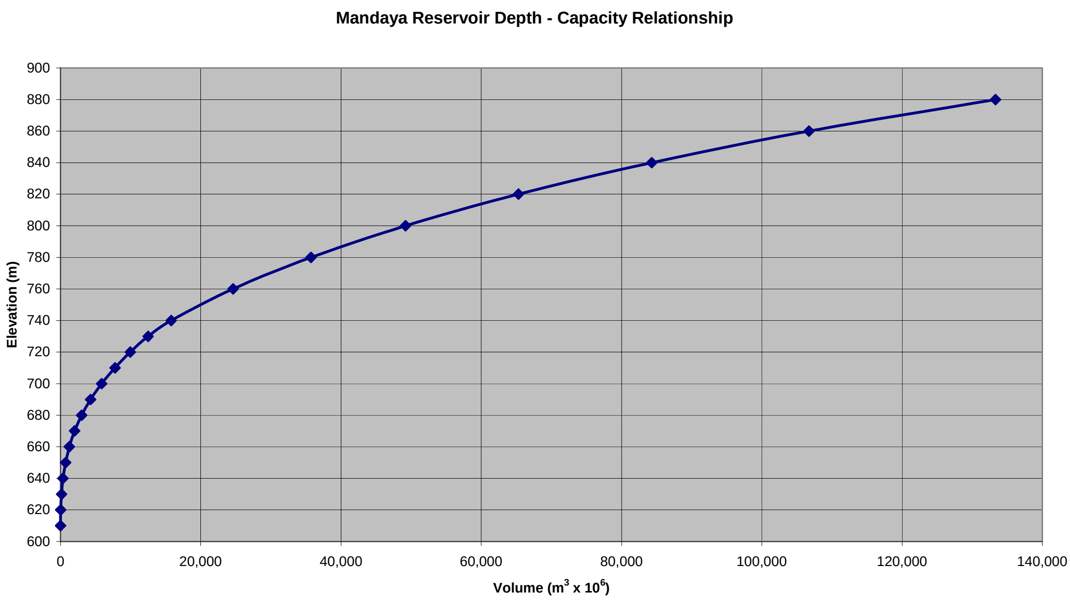


Figure 2.2 : Mandaya Reservoir Elevation - Volume Relationship



2.6 REFERENCES

(1) Land and Water Resources of the Blue Nile River Basin (USBR, 1964).

(2) Abbay River Basin Integrated Development Master Plan Project (BCEOM, 1996/99).

(3) Karadobi Multipurpose Prefeasibility Study (Norplan, Norconsult and Lahmeyer International (2006).

(4) Beles Multi-purpose Project, LEK Consortium (Lahmeyer, Electrowatt, Knight Piésold Ltd, 1999/2000).

3. TOPOGRAPHY AND MAPPING

3.1 EXISTING MAPPING

3.1.1 Topographic Mapping

Mapping in Ethiopia is published by the Ethiopian Mapping Authority (EMA). Available mapping is listed within the Map Catalogue which is published from time to time, the latest edition at the time of writing being that for 2002. EMA is also responsible for aerial photography and remote sensing information.

The national geodetic network was initially established between 1957 and 1961 covering some 30% of the country and straddling the Abay (Blue Nile) watershed. Primary position and height control was established by triangulation and levelling along the Nile valley in collaboration with the United States in conjunction with the Blue Nile River Basin studies. The datum for Ethiopian mapping is Adindan (30th Arc).

Mapping in Ethiopia is on the Transverse Mercator Projection with UTM Zone 37 grid and based on the Clarke 1880 (Modified) spheroid. Specific parameters used for mapping as supplied by EMA are as follows:

```
ASHTECH POINTS FILE
PROGRAM:            PRISM v2.0.00        Jan 08 2007
CREATED FROM:       Fillnet Output File  FILLTOT.FOP
SYSTEM:             UTMN                 Univ. Transverse Merc. (N)
DATUM:              ADINDAN              Adindan
TRANSLATION:                             {  -162.000,  -12.000,  206.000}
ELLIPSOID:          CLK80                Clarke 1880
SEMI-MAJOR AXIS:                         6378249.1
INVERSE FLATTENING:                      293.46500
PROJECTION:         TM83                 Transverse Mercator
ZONE:               ZN36       36        Zone36 - 30 E to 36 E
UNITS:              METER                METER
```

Available mapping comprises sheets covering the majority of Ethiopia at scales as follows:

- 1:1,000,000
- 1:250,000
- 1:50,000 with 20 m contour interval.

Large-scale maps are also published at scales of 1:10,000, 1:5,000 and 1:2,500 but these are generally only available for the main urban centres.

The 1:250,000 scale maps cover the entire country with 73 map sheets and are valuable especially for planning purposes.

The 1:50,000 scale maps are the principal mapping of interest for the pre-feasibility study of the Mandaya project. Over 1570 individual sheets are required to cover the whole of Ethiopia. Up to 2002 some 65% of the country has been mapped at 1:50,000 scale.

The 1:50,000 scale maps cover the entire catchment area of the Abay river upstream of the Mandaya project site as well as the dam site itself. The maps with 20m contour interval have been prepared from air photography, much of which has been carried out by Swedsurvey over the period 1980-1982.

3.1.2 Thematic Mapping

Thematic maps at scales of 1:1,000,000 and 1:2,000,000 are published by EMA, based on data collected from other agencies such as the Ministry of Agriculture and the Ministry of Mines and Minerals. These include:

Ministry of Agriculture

- Geomorphology and Soils
- Land Resources
- Agro-climatology Resources Inventory
- Land Use / Land Cover
- Land Resources Short and Perennial
- Mean Annual Rainfall
- Regional Rainfall Pattern
- Generalised Agro-climatic
- Climax Vegetation
- Natural Regions
- Land Use Potential
- Soils
- Land Suitability

Ministry of Mines and Minerals

- Geology of Ethiopia
- Geology of Local Areas (various sheets)
- Hydro-geology of various areas
- Metalogenic Map of Ethiopia

3.1.3 Mapping of Mandaya Project Area

The Mandaya dam site is located on 1:50,000 scale map sheet 1035-D3 Re-Iti. The Mandaya reservoir area is covered by some 12 map sheets as follows:

- 0935 B1 Abay-Didessa Confluence
- 0935 B2 Dibinchini
- 1035-D3 Re-Iti
- 1035-D4 Sire Benti
- 1036 C2 Albasa
- !036 C3 Abay Dar
- 1036 C4 Kelo
- 1036 D1 Inabara
- 1036 D2 Gomer
- 1037 C1 Kuch

3.2 MAPPING CARRIED OUT AS PART OF THE STUDY

3.2.1 Digital Mapping

Mapping at a scale of 1:10,000 with 10 metre contour interval of the Mandaya site and reservoir area has been commissioned as part of the study. The mapping has been carried out by BKS Ltd of Coleraine, Northern Ireland under a sub-Contract.

The mapping has been carried out using SPOT satellite imagery scenes for over 90 % of the area, supplemented by Landsat and SRTM data (Shuttle Radar Terrain Model). Control for the survey was obtained from the existing topographical mapping.

Digital mapping has been carried out to 1:10,000 scale topographical content and standards together with Digital Terrain Data comprising 10 metre contouring and spot levels. These data have been supplied suitable for use with either AutoCAD or Microstation software.

Hard copy plots from the digital mapping have been supplied, to an agreed sheet layout and presentation, at 1:50,000 scale. Copies of SPOT images have also been supplied.

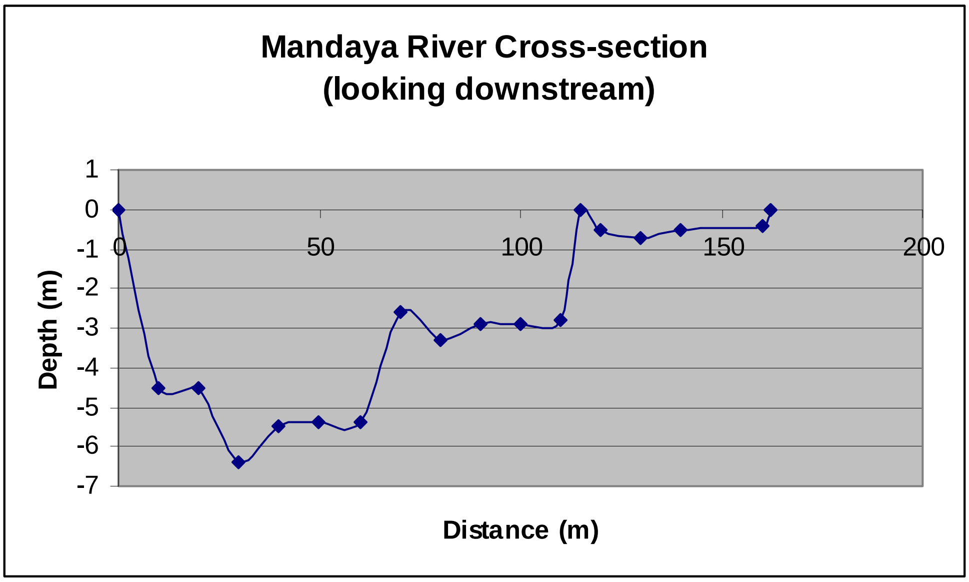
3.2.2 Ground Survey

Ground survey at the Mandaya site has included both survey of the dam centre-line cross-section using electronic “total station” equipment and sounding of the river bed profile from a boat. The surveyed river-bed cross-section is shown on Figure 3.1.

It had been intended to relate the topographic surveys of the dam site to the Ethiopian grid system by reference to the trigonometric station which is shown on the

1:50,000 scale map sheet within 1 km of the dam site. However, the reference station could not be found in the field and the local survey was therefore located with reference to coordinates established by hand held GPS system.

Figure 3.1 : Mandaya River Cross-section



The valley profile and river profile at the Mandaya site are shown in Drawing No. M15.

4. HYDROLOGY

4.1 INTRODUCTION

The Mandaya site is located in the lower part of the Abbay (Blue Nile) catchment in Ethiopia. The upper reaches of the catchment lie upstream of Lake Tana in mountainous areas.

The land around the Mandaya dam site is mountainous, having elevations ranging from 590 metres above sea level (masl) in the river bed at the dam site to the local plateaux on each bank of the river at the dam site at an elevation of some EL. 900 masl. Upstream of the Mandaya dam site, the valley narrows to a steep sided gorge of up to 1500 m depth below the surrounding plateau. Elevations rise to over 2000 masl in hills on the right and left banks upstream.

The Abbay has confluences with one principal and perennial tributary in this potential reservoir area, namely the Didessa river on the left bank. Other tributaries are shorter in length and have smaller catchment areas.

The relief and principal drainage network of the Abbay's upstream catchment area to the Mandaya dam site are presented in Figure 4.1.

4.2 CLIMATE

Climate in the Ethiopian highlands is strongly influenced by the effects of elevation, which gives rise to distinct zones and characteristics. Traditional classifications based on altitude and temperature indicate presence of five zones, of which three are predominant in the Abbay river basin.

Kola -tropical hot and arid type, below 1500 m altitude with mean temperature in the range 20-28ºC.

Woin Dega – sub-tropical warm, between 1500-2500 m altitude with mean temperature in the range 16-20ºC.

Dega – temperate highland climate above 2500 m altitude with mean temperature in the range 6-16ºC.

Contemporary classifications according to Köppen, as adapted by NMSA/Lemma for Ethiopia defines 5 types within the Abbay river basin comprising:

Cwc – Cool highland (at highest elevations)

Cfb – Warm temperate II (Didesa sub basin in the south)

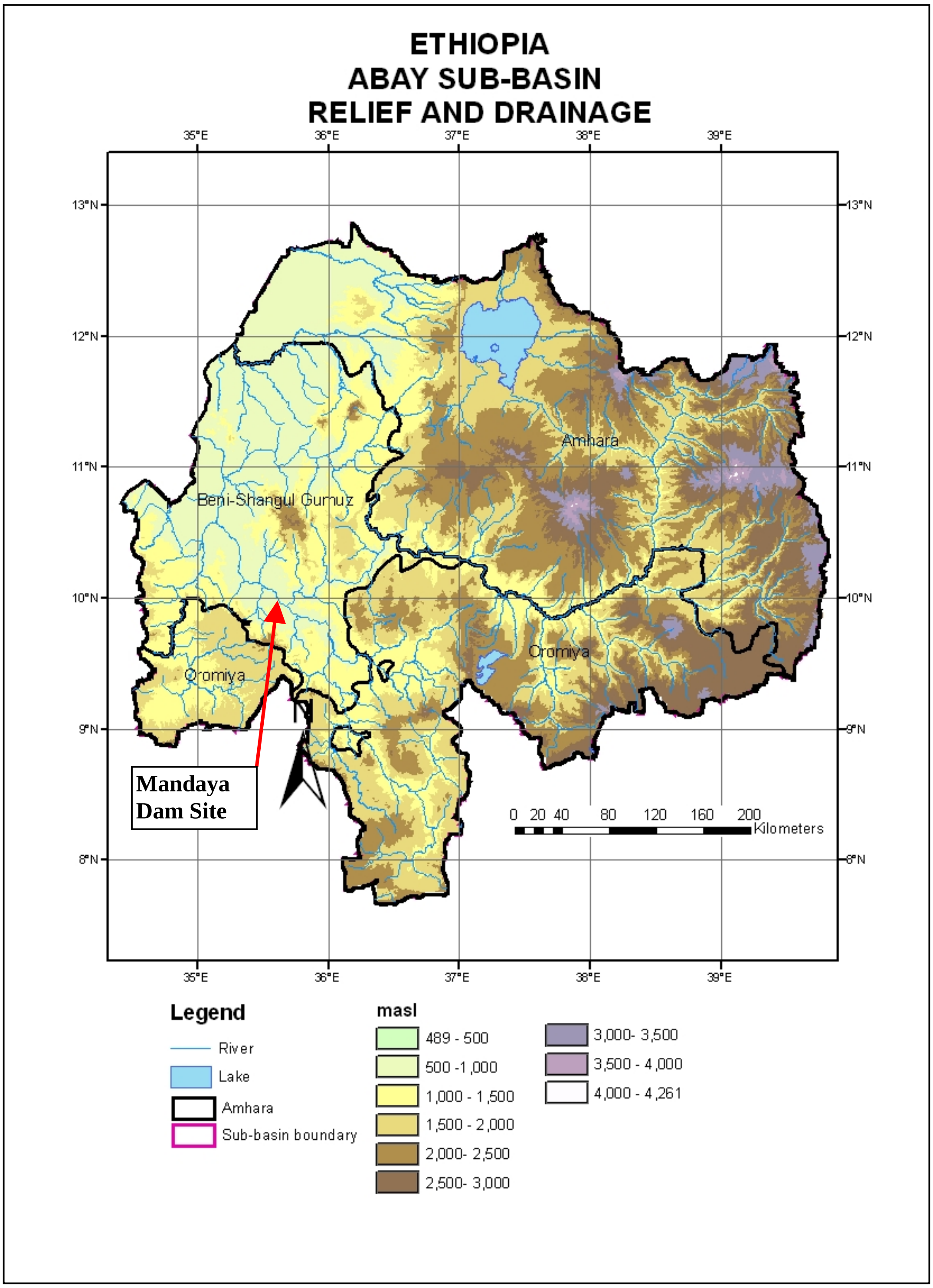
Cwb – Warm temperate I (across the plateau)

Am/Aw – Tropical III/II (in the main river valley and at lower elevations)

There are three principal rainfall-inducing regional climatic mechanisms:

- Summer monsoon (Inter-tropical convergence zone - ITCZ)
- Tropical upper easterlies
- Local convergence in the Red Sea coastal region

Figure 4.1 : Ethiopia – Abbay Sub-basin: Relief and Drainage



Source: Ethiopia Country Paper, Hydrosult *et al*, 2006.

The ITCZ exerts its influence through its northerly migration commencing in March. Around June the ITCZ moves further north and produces the main wet season in most of the central and northern areas. The wet season here generally last until October, until the influence of the ITCZ diminishes as it moves southwards towards the equator. Thereafter, between November and March, generally dry conditions prevail throughout much of the country.

There are no climatological stations in or close to Mandaya dam site and reservoir location. Descriptions of climate are therefore based on regionally mapped data by the former Ethiopian Meteorological Service provided in the National Atlas of Ethiopia. Mandaya lies in the Tropical Climate II type of the nine types of the Koppen classification system occurring in Ethiopia. Areas with Tropical Climate II are mostly found in the west of Ethiopia and are characterized by dry winter months, the mean temperature of the coldest month being greater than 18°C and mean annual rainfall between 680 and 2000 mm.

4.3 RAINFALL

In regard to rainfall regimes and seasons, a standard nomenclature for Ethiopia has been compiled by NMSA. In different parts of the country rainfall regimes are described as Mono-modal, Bi-model and Diffuse. In much of the Abbay river basin the mono-modal pattern predominates, as defined by just two distinct season: wet and dry.

According to mapping of the former Ethiopian Meteorological Service (National Atlas of Ethiopia, 1988) and more recent mapping, mean annual rainfall at the Mandaya reservoir site is expected to be in the order of 1,500 mm (Figure 4.2). The rainfall pattern is almost uni-modal. The “*Belg*”, or short rainy season, which occurs from mid-February to mid-May in the east of the Abbay basin and elsewhere is not distinct in the Mandaya area. Rainfall quantities in the Belg season are low and variable and frequently have no significant impact on tributary rivers of Abbay in the Mandaya area which may remain dry or continue to recede. The “*Kiremt*” or main rainy season lasts from June to September and may extend in the Asosa and Mandaya area into October, as experienced during our surveys October 2006. Normally, there is very little rainfall between October and January.

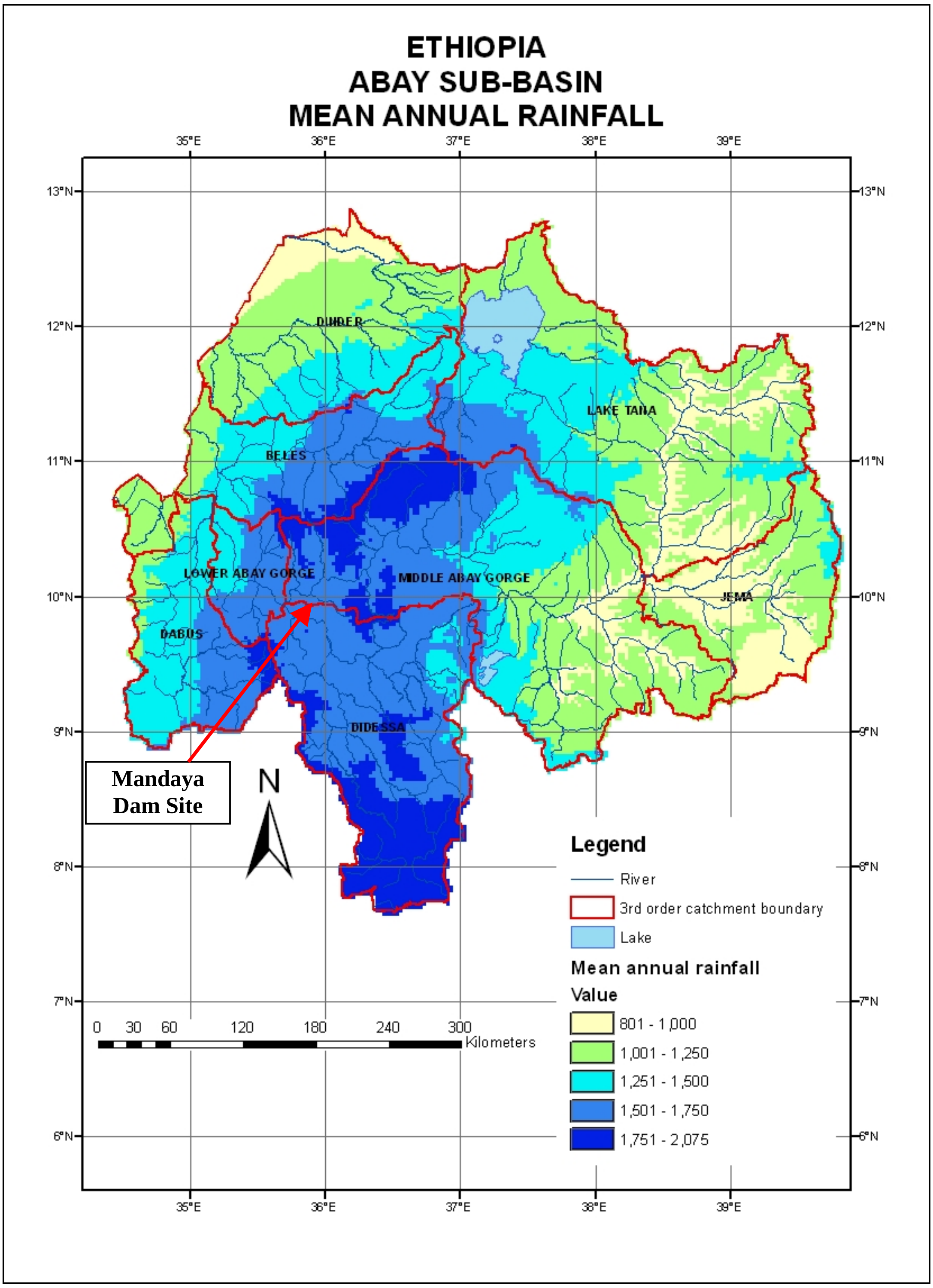
The nearest representative station with climatological records in this region is at Asosa town, located some 110 km West of Mandaya dam site. Climatological statistics for Asosa are published on the National Meteorological Agency’s website. Monthly mean rainfall is shown in Table 4.1.

Table 4.1 : Monthly Mean Rainfall at Asosa

Rainfall	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
mm	<1	4	23	60	134	194	234	237	194	132	21	2	1,235
Season	Dry	Dry	Dry	Wet2	Wet2	Wet2	Wet2	Wet2	Wet2	Dry	Dry	Dry	

Note: Wet 2 is main rainy season (Wet1 is small rainy season and is not designated at Asosa)
Source: National Meteorological Agency’s website.

Figure 4.2 : Mean Annual Rainfall of Abbay Basin



Source: Ethiopia Country Paper, Hydrosult *et al*, 2006.

4.4 TEMPERATURE

According to mapping of the former Ethiopian Meteorological Service (National Atlas of Ethiopia, 1988), mean annual temperature in the Mandaya project area is between 25 and 30°C. Quarterly temperature ranges are indicated as follows:

- January and April, between 25 and 30°C
- July and October, between 20 and 25°C

Recent mapping indicates that Mandaya dam site is located in the hottest part of the Abbay basin, with a mean annual temperature between 25 and 28°C.

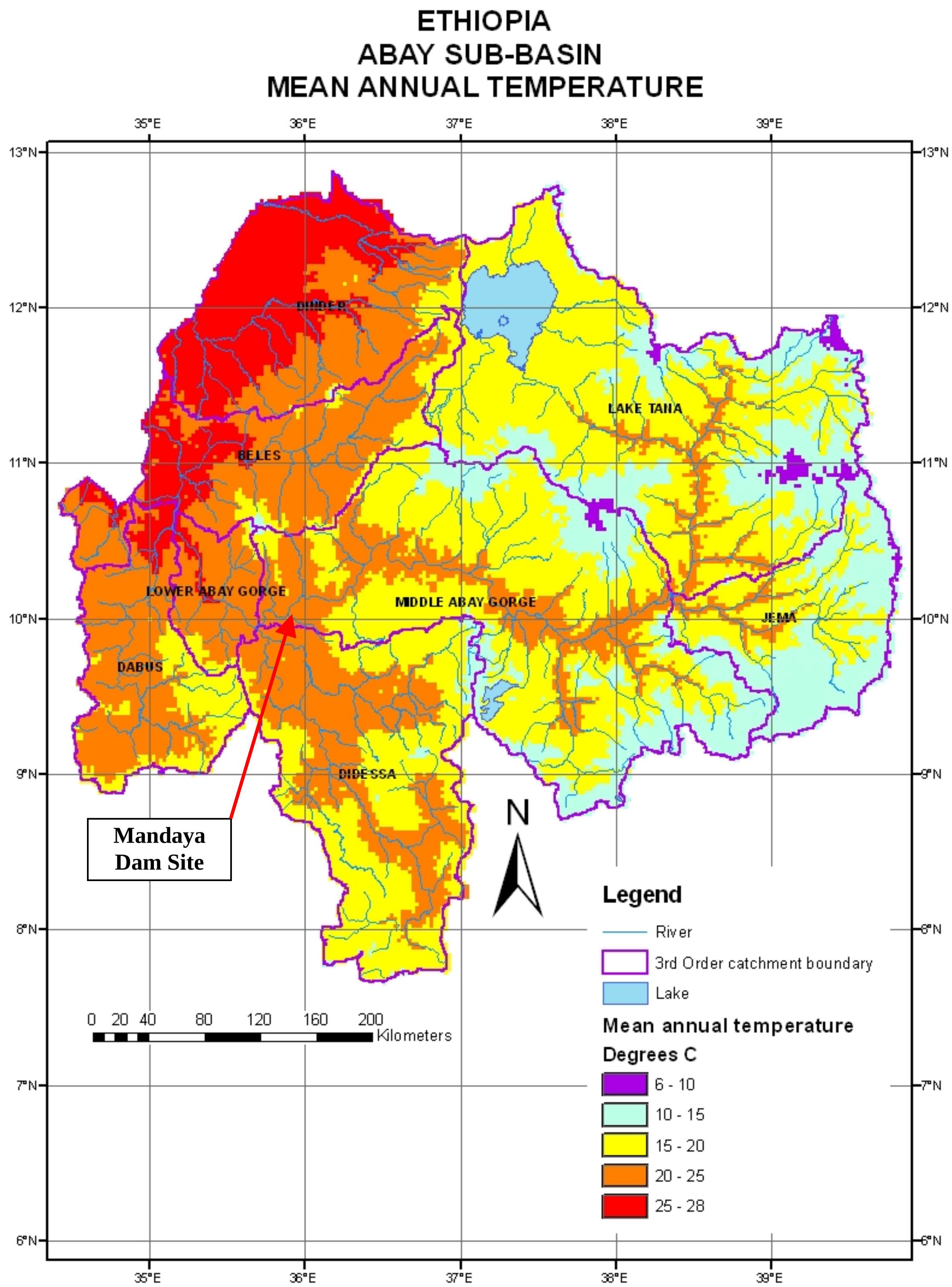
In the days around the spring equinox in March 2007, when field surveys were conducted near Boka, some 30 km downstream of the Mandaya dam site, daytime temperatures were observed at Boka mission and along the Abbay river. They typically ranged between 30 and 40°C in the shade, sometimes greatly exceeding 40°C. This is noteworthy with regard to future field surveys and civil engineering works in the area. Temperature records for Asosa town (Table 4.2), at an elevation of 1,540 masl show that March and April are the hottest months in the region, supporting the high temperatures experienced at Boka in March 2007.

Table 4.2 : Temperatures at Asosa

Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean maximum °C	30.5	31.8	32.5	31.7	28.5	25.4	24.6	24.6	25.5	26.4	28.1	29.1	28.2
Mean minimum °C	14.2	15.5	16.5	16.3	15.8	15.3	14.7	14.6	14.7	14.8	14.9	14.3	15.1
Mean °C	22.3	23.6	24.5	24.0	22.1	20.3	19.6	19.6	20.1	20.6	21.5	21.7	21.6
Extreme maximum °C	37.2	36.6	36.8	38.5	38.0	32.5	30.5	29.4	29.5	35.5	35.6	33.0	38.5
Extreme Minimum °C	8.1	8.2	9.0	5.0	6.0	10.0	9.0	8.0	7.0	7.5	9.0	6.7	5.0

Source: National Meteorological Agency's website.

Figure 4.3 : Mean Annual Temperature in Abbay Basin



Source: Ethiopia Country Paper, Hydrosult *et al*, 2006.

4.5 HYDROLOGICAL DATABASE

Hydrological data were obtained for this analysis from three sources:

- Ministry of Water Resources (MoWR) of Ethiopia,
- Eastern Nile Technical Regional Office (ENTRO),
- Pre-feasibility Report of the Karadobi Multi-purpose Project.

The MoWR dataset contained data for 23 hydrological stations distributed over the Abbay (Blue Nile) river basin and its tributaries supplied as spreadsheet (Excel) files in addition to file listing all available stations.

Each station file contained station identification data (ID, Name, River Name) and the sub-catchment area upstream the station. Tabulated Data comprised monthly total runoff and maximum and minimum mean daily discharges. Annual total runoff was supplied for years with complete data. When available, momentary peak discharge was also included with the date of recording and also the maximum mean daily discharge for the whole year. Units were consistent across all files, discharges in m^3/s and runoff in Mm^3 [MCM]. For station 1001 (Bahir Dar on Lake Tana), levels were given instead of runoff/discharge. Table 4.3 summarizes the attributes of the MoWR stations collected from station files and the list file. Data for station 6005 included more than 77 estimated values (method is not given) and station 3027 has 3 estimated values (i.e. months).

Data for a smaller number of stations were obtained from ENTRO (12 stations) and included only total monthly runoff data and annual totals (for complete years). 7 of these stations were already included in the MoWR set and a quick comparison showed no conflicts between both sets. There were only minor differences for station 2002. The remaining 5 stations have either too short a record to be useful, too intermittent record, or cover very small catchment areas. Therefore it was decided to focus the analysis on the MoWR set of stations.

As a first step in analysing the data, the record completeness is calculated as follows for each observed variable (e.g. total runoff, minimum level):

$$\text{Completeness} = \frac{\text{No. of Months with data}}{\text{No. of Months in the Record}} \times 100\%$$

Then the records were studied further for gaps and the resulting chronographs are shown in Table 4.4 for total runoff (all stations except 1001) and mean water level for station 1001.

Table 4.3 : Inventory of MoWR Supplied Hydrological Stations

Station No.	River / Lake	Site	Lat. (North)	Long. (East)	Installation Date	Area km^2	Avg. Elev.	Record[1]	Completeness		
									TR/Mean	Max[3]	Min[3]
1001	Lake Tana	@ Bahir Dar[2]	11º36'	37º23'	9-3-1959	15319		1959-2003	91%	97%	97%
1002	Gelgel A.	Nr. Marawi	11º22'	37º02'	27-3-1959	1664		1959-2004	97%	97%	97%
1003	Koga	@ Merawi	11º22'	37º03'	27-3-1959	244		1959-2003	92%	92%	92%
1005	Ribb	Nr. Addis Zemen	12º00'	37º43'	19-5-1959	1592		1959-2002	91%	90%	90%
1006	Gumara	Nr. Bahir Dar	11º50'	37º38'	1-6-1959	1394		1959-2004	91%	88%	87%
1007	Megech	Nr. Azezo	12º29'	37º27'	7-10-1959	462		1959-2003	79%	79%	80%
2001	Abbay	Nr. Kessie	11º04'	38º11'	2-3-1956	65784		1953-2004	92%	92%	88%
2002	Mugher	Nr. Chancho	9º18'	38º44'	21-11-1958	489		1970-2004	100%	100%	100%
2003	Abbay	@ Bahir Dar	11º36'	37º24'	9-3-1959	15321		1959-2003	95%	96%	96%
2007	Beressa	Nr. Debre Berhan	9º40'	39º31'	7-12-1960	211		1961-2003	98%	98%	97%
2017	Muga	Nr. Dejen	10º10'	38º09'	26-2-1980	375	2800	1980-2002	90%	90%	90%
3005	Guder	@ Guder	8º57'	37º45'	15-2-1959	524	2518	1959-2004	98%	97%	97%
3008	Chemoga	Nr. Debremarkos	10º18'	37º44'	27-11-1959	364	2760	1960-2002	95%	95%	95%
3023	Dura	Nr. Metekel	10º59'	36º29'	12-1-1961	539		1962-2002	88%	88%	88%
3026	Neshi	Nr. Shambo	9º45'	37º15'	4-3-1963	322		1963-2000	100%	100%	100%
3027	Amerti	Nr. Shambo	9º44'	37º17'	4-3-1963	252		1963-1983	100%	99%	99%
3028	Dondor	Nr. Metekel	10º56'	36º31'	9-5-1975	184		1992-2003	92%	92%	92%
4001	Didessa	Nr. Arjo	8º41'	36º25'	1-4-1959	9981		1960-2004	67%	66%	66%
4005	Dabana	Nr. Abasina	9º02'	36º03'	10-4-1961	2881[4]		1961-1984	89%	89%	89%
5002	Dabus	Nr. Asosa	9º52'	34º54'	10-6-1963	10139		1963-1979	64%	64%	64%
6002	Abbay	@ Sudan Border	11º14'	34º59'	24-5-1959	172254		1961-2004	43%	43%	43%
6004	Gilgel Beles	Nr. Mandura	11º10'	36º22'	4-2-1980	675		1982-2003	94%	91%	91%
6005	Main Beles	@ Bridge	11º15'	36º27'	16-3-1983	3431		1962-2004	90%	73%	73%

[1] All data are Monthly [2] Lake Tana outflow station, level measurements are given [3] Maximum and Minimum discharges [cumecs] except for station 111001 where maximum and minimum levels [m] are given [4] Area in the station file conflicts with that in the station list

Table 4.4 : Hydrological Data Chronograms

Station No.	River / Lake	Site
111001	LAKE TANA	@ BAHIR DAR
111002	GELGEL A.	Nr. MARAWI
111003	KOGA	@ MERAWI
111005	RIBB	Nr. ADDIS ZEMEN
111006	GUMARA	Nr. BAHIR DAR
111007	MEGECH	Nr. AZEZO
112001	ABBAY	Nr. KESSIE
112002	MUGHER	Nr. CHANCHO
112003	ABBAY	@ BAHIR DAR
112007	BERESSA	Nr. DEBRE BERHAN
112017	MUGA	Nr. DEJEN
113005	GUDER	@ GUDER
113008	CHEMOGA	Nr. DEBREMARKOS
113023	DURA	Nr. METEKEL
113026	NESHI	Nr. SHAMBO
113027	Amerti	Nr. Shambo
113028	DONDOR	Nr. METEKEL
114001	DIDESSA	Nr. ARJO
114005	DABANA	Nr. ABASINA
115002	DABUS	Nr. ASOSA
116002	ABBAY	@ SUDAN BORDER
116004	GILGEL BE.	Nr. MANDURA
116005	MAIN BELES	@ BRIDGE

Complete Year

x Completed Year via estimation, x = number of months estimated

x Completed Year via estimation, x = number of months estimated (but not stated in the data file as estimated)

x Incomplete Year, x = No. of missing months

No Data for Whole Year

4.5.1 Quality Control

The data were subjected to a few quality control checks. First visual screening showed a few mistyped numbers with two decimal points or misplaced decimal point. These were corrected and flagged in the data files. Then the data were converted from the tabulated format where each line contains 12 monthly values to a time series format. Sometimes, when data for complete years were missing, the whole year was omitted which needed further attention when converting the data format. For each of the 22 flow stations (apart from station 111001, for which level measurements were available), three time series were created, total runoff [TR, MCM], maximum daily discharge [Q_{max}, m^3/s] and minimum daily discharge [Q_{min}, m^3/s]. A fourth time series of mean monthly discharges [Q_m, m^3/s] was then calculated from the total runoff series considering the number of days in the month. This fourth series was used for quality control checks against the maximum and minimum daily discharges. Whenever $Q_m > Q_{max}$ or $Q_m < Q_{min}$ the record for that month was flagged and further investigated. Sometimes, errors resulted from mistyping one number or misplacing the decimal point and were fixed accordingly. At other times, Q_{min} and Q_{max} were exchanged by mistake. Sometimes, it appeared that Q_{max} and Q_{min} were not recorded so they were assigned the value of Q_m. Most of the errors in Q_m were fixed and TR was calculated accordingly. The spreadsheets now contain an additional worksheet (TS) with time series data.

4.5.2 Analysis and Gap Filling

After quality control checks were done as above, corrected time series data for total runoff were tabulated by year. Hydrographs for each year (for each station) were plotted. In general, hydrographs for all stations peak in August with high percentage of flow (70-95%) occurring during the flood season (July – October). The hydrograph for the Abbay near Bahir Dar, at the outlet of Lake Tana (station 112003) has its peak in September due to the effect of the lake. Some peaks are sharp (August flow is large compared to July and September) while others are flatter (September flow is nearly as high as August). For most stations and years, the position of the peak did not change from a year to the other. However, for some stations, a few hydrographs looked unusual. These years were flagged for further attention. Figures 4.4 and 4.5 show the mean monthly hydrographs for the Abbay at Bahir Dar and the Abbay at Kessie. Hydrographs for 112003 Abbay at Bahir Dar for two periods, pre-1997 and post-1997 show the increase in the dry season (January – June) flows due to regulation of lake Tana which was completed in 1996 as illustrated in Figure 4.6.

For each station, in addition to the mean monthly hydrograph, the standard deviation, coefficient of variation, maximum and minimum monthly runoff were also calculated based on the available records. The mean hydrograph was converted to monthly distribution factors (h_i, i=1, 2… 12) by dividing the ordinates by the total of the monthly means (Note that the number of data years vary for each month). Monthly gaps were filled using those distribution factors using the nearest available data value. If TR(i) is required, TR(i+1) is available, then TR(i) = TR(i+1) * h(i)/h(i+1), if the gap length is one month, values on both sides are used (i.e. TR(i) = (TR(i+1) * h(i)/h(i+1) + TR(i-1) * h(i)/h(i-1))/2). Moving sequentially, one could build the whole record but the reliability of the estimate is reduced as one moves away from the nearest observation. Using this method to estimate the peak can be misleading. The records of all stations except 3027, 3028 (time limitation) were completed in this way. Missing full years were not filled because the results would be too unreliable.

Figure 4.4 : Seasonal Runoff Pattern of Abbay River nr Bahir Dar (1959 – 2003)

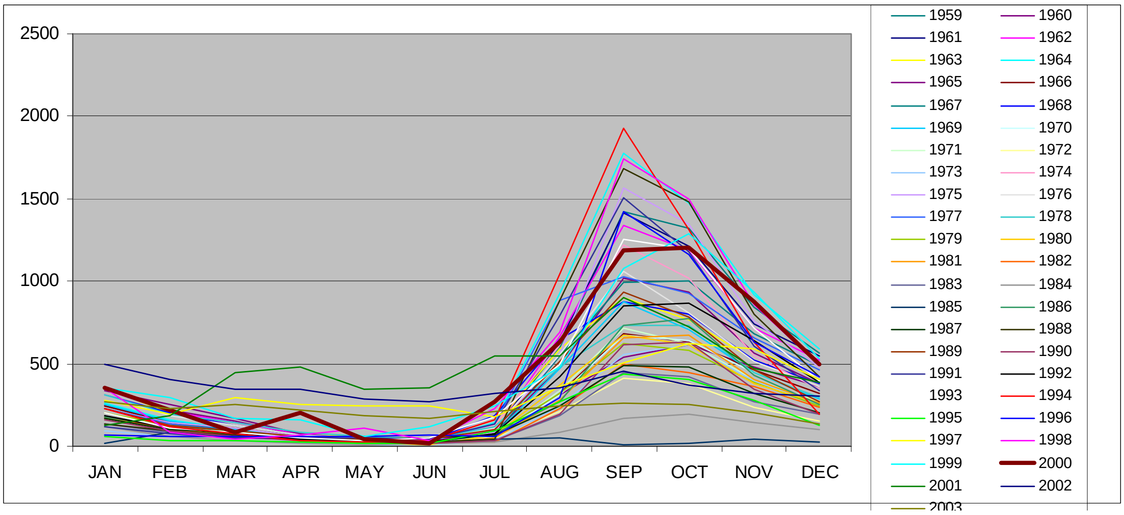


Figure 4.5 : Seasonal Runoff Pattern of Abbay River at Kessie (1981 – 1990)

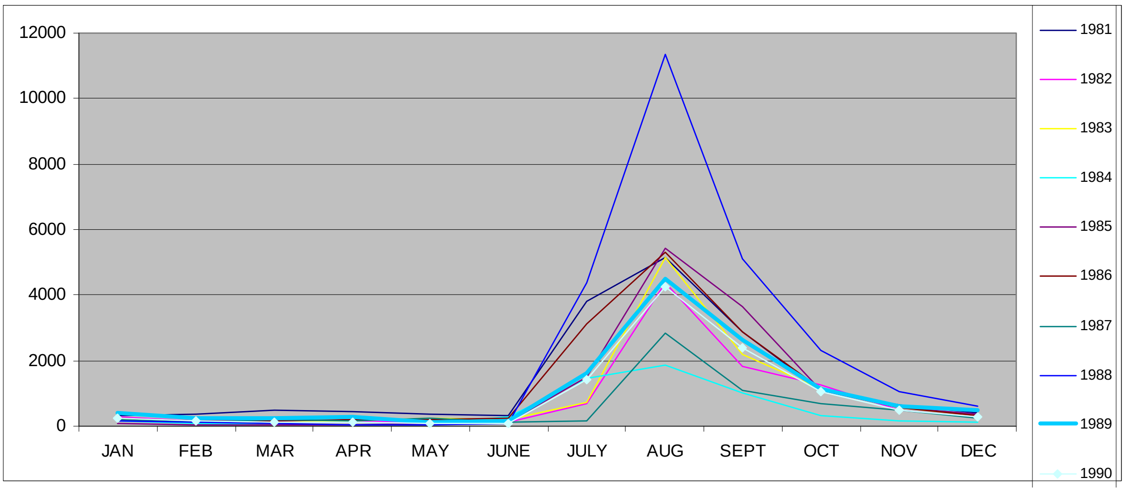
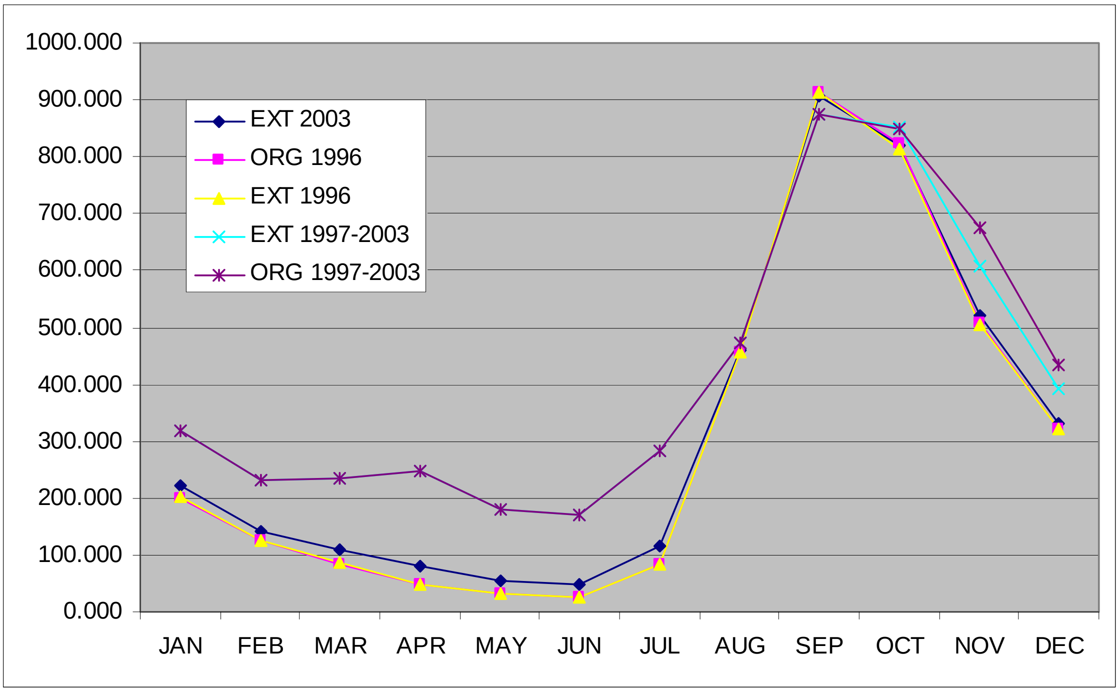


Figure 4.6 : Seasonal Runoff Pattern of Abbay River at Bahir Dar (112003) before and after (1997 – 2003) regulation by Chara Chara Weir



For each station, the mean annual hydrograph after filling was compared to that before filling and the effect of filling was minor in most cases. Deviations increased when the number of filled months was relatively large compared to the total record. Annual hydrographs were also compared as well as the time series to see whether the filling produced compatible data.

It can be seen from the two hydrographs illustrated in Figures 4.4 and 4.5 that the peak flow at Kessie hydrometric site typically occurs in August while that for the Abbay River at Bahir Dar occurs one month later in September. This is due to the attenuation effect of flow from the upper part of the Abbay catchment passing through Lake Tana. The attenuation effect is more marked since the construction of the Chara Chara weir and the associated use of Lake Tana for regulation. As a result of this the upper catchment above Bahir Dar does not contribute very significantly to flood discharges in the Abbay downstream at Kessie and Border hydrometric sites.

4.6 KEY HYDROMETRIC STATIONS

Three key hydrometric stations in Ethiopia have been selected for the present studies of the Mandaya hydropower project as follows:

- 2001 Abbay River (Blue Nile) at Kessie Bridge
- 6001 Abbay River (Blue Nile) at Shogole

- 6002 Abbay River (Blue Nile) at Sudan Border.

In addition, the El Deim gauging station on the Blue Nile in Sudan was also selected as a key station for the hydrological analysis.

Hydrometric stations are also located on the Didessa (Anger), Dabus and Beles rivers which flow into the Blue Nile within Ethiopia. However, because of the length of the data series (complete years) and the small catchment areas of the gauging station sites, these stations were not selected for detailed analysis.

4.6.1 Abbay at Kessie Bridge

The recorded data series for the Abbay at Kessie was examined with particular care owing to its importance as having the longest period of recorded data for the Abbay River in Ethiopia. The gauging station was inspected during the course of the site visit to the Border dam site in October 2006. The gauging station is located at the bridge where the main road from Addis Ababa to Debre Markos crosses the Abbay River .

Staff gauge sections are mounted on the concrete abutment on the left (South) bank. An automatic recorder was installed at one time but it is understood that this was abandoned due to problems of siltation. At the time of the visit the staff gauge was only partially visible due to extensive sediment deposits and a channel had been dug between the river and the gauge plates.

Gauging using a current meter is carried out by means of a cableway some 150 metres upstream of the bridge. A new bridge is at present under construction to replace the existing structure. The new bridge is located very close to the cableway and the temporary works (cofferdams etc) are likely to affect the gauging section and may also influence flow patterns and sediment deposition at the site. However, the historic data series adopted for the study covers the period 1954 – 2003 predates the bridge construction works and the validity of the data used in the present study is therefore unaffected.

The Pre-feasibility Study report for the Karadobi project drew attention to significant disparities between flow measurements and the stage-discharge relationship at the Kessie Bridge gauging station. In particular, the stage-discharge curve parameters for the period since 1984 exhibited an unusually high exponent (2.46) compared to former relationships which typically had an exponent in the range 1.949 to 2.084. This anomaly resulted in the flows for the period since January 1984 apparently having significantly higher flood peaks than appeared to be justified. Detailed analysis of flow measurements since 1984, including new gaugings as part of the Karadobi study led to development of revised stage-discharge relationships as shown in Table 4.5. These relationships have been reviewed and adopted for the present study.

Table 4.5 : Stage-Discharge Rating Curves, Abbay River at Kessie

Curve	Stage	Period of Validity		Curve Parameters $\{Q = a(H-H_0)^b\}$			Range of Validity
ID	**Variant**	**From**	**To**	**H_0**	**a**	**b**	**(Stage H)**
Original Curves (MoWR)							
1	1	01 Jan 60	31 Dec 67	-0.07	68.32	1.986	H < 1.6
1	2			-0.07	67.15	1.997	1.6 < H < 4.72
1	3			-0.07	61.48	2.055	All
2	1	01 Jan 68	31 Dec 70	-0.14	58.80	2.084	H < 4.5
3	1	01 Jan 71	31 Dec 72	0.11	71.04	2.061	H > 4.5
3	2			0.11	84.37	1.949	All
4	1	01 Jan 73	31 Dec 83	0.03	69.80	2.030	All
5	1	01 Jan 84	Present	-0.22	31.80	2.460	All
Revised Curves (Karadobi Study)							
5	1	01 Jan 84	31 Aug 98	0.14	62.18	2.098	All
6	1	01 Sept 98	Present	0.21	44.12	2.183	All

4.6.2 Abbay at Shogole (6001)

Hydrometric measurements commenced in 1959 and continued to 1979. However, within this period only 2 years of data are complete. Accordingly, the data series was considered too unreliable to be of value in the present study.

4.6.3 Abbay at Border (6002)

Hydrometric measurements at the Border station began in 1961 and continue to the present. The gauging station is equipped with a cableway that has been used in the past to carry out flow measurements using a cable-suspended current meter. No current meter measurements are being made at present due to concern amongst users of the strength of the cable across the river which is now over 40 years old.

Although long-term estimates of flow magnitude at the Border site compare reasonably well with data for the El Deim site in Sudan, inspection of the record reveals very substantial differences when monthly values are compared. Accordingly, because of the longer period of data availability and the greater frequency of flow measurements, the data for El Deim has been adopted rather than that recorded at Border (6002).

4.6.4 Blue Nile at El Deim

The gaugings at El Deim started in 1962 and many measurements have been carried out in some years. The site was reported to be *"stable and the rating is reliable and precise".* (Sutcliffe and Parks, 1999). However, it is understood from communications with individuals in Sudan that the cableway is now in poor condition and as a result current meter measurements have not been carried out for some 20 years.

4.7 TIME SERIES FOR FLOWS AT MANDAYA DAM SITE

4.7.1 Mandaya Site

The Mandaya site is located some 300 km downstream of the Kessie gauging station and some 150 km upstream of the Border gauging station. No long-term time series data is available for the majority of the intervening catchments. Accordingly the time series for the Mandaya site has been derived by the "catchment area method" using data for the Abbay at Kessie and Nile at El Deim. The flow series thus derived is presented in Annex A.

4.7.2 Adopted Flow Series

The mean annual flows for the adopted flow series are summarised in Table 4.6 below. Monthly time series data for the Abbay at Kessie, incremental flows from intervening catchments and adopted flow series for Karadobi, Mandaya and Border sites are presented in Annex A. The diversion of flow from Lake Tana into the Beles River has been taken into account in deriving the flow series at Mandaya. It is considered that losses within the Beles river will be negligible. The main usage for the diverted water within the Beles catchment is for power generation and is non-consumptive. Consumptive use for irrigation is likely to be supplementary and is not considered to be significant in the overall water balance.

Table 4.6 : Summary of Adopted Flow Series for Hydrometric Stations and Project Sites

Site	Catchment Area (km^2)	Mean Annual Flow (Natural) (m^3/s)	Mean Annual Flow (with Beles Diversion) (m^3/s)
Kessie	65,784	517	440
Karadobi	82,300	649	572
Mandaya	128,729	1091	1014
Border	176,918	1547	1547
El Deim		1547	1547

4.8 FLOOD STUDY

Flood estimates are required for three main purposes:

- Design of Mandaya spillway for safe passage of flood flows
- Design of river diversion works for Mandaya dam construction period
- Evaluation of impacts downstream.

4.8.1 Data Available

For all stations listed in Table 4.3 except for 1001 (which has level records at the outlet of Lake Tana), monthly maximum mean daily discharges are available for most years that have mean flow records as shown in Table 4.4. For a subset of 6 stations, maximum instantaneous peak discharges are also available for a smaller number of years. In order to derive flood estimates, the following methodology was applied:

- Perform flood frequency analyses for stations on the Abbay (Kessie, Border, and Deim) by fitting extreme value distributions to available data from these stations to estimate the design flood discharges at different return periods

- Develop a regional flood relationship based on catchment area, this required statistical analysis of maximum annual flood data (maximum mean daily) from all available stations. In carrying out this analysis account was taken of the observation that the catchment of the Abbay river upstream of Lake Tana does not contribute significantly to flood magnitudes flows at Kessie and downstream locations due to the attenuation effect and associated delay in time of the flood peak, particularly since completion of the Chara Chara weir.

- Using the regional relationship, estimate the 1 in 10,000 year flood at Mandaya site from the key stations: Kessie, Border, and Deim, once again taking account of the effect of Lake Tana.

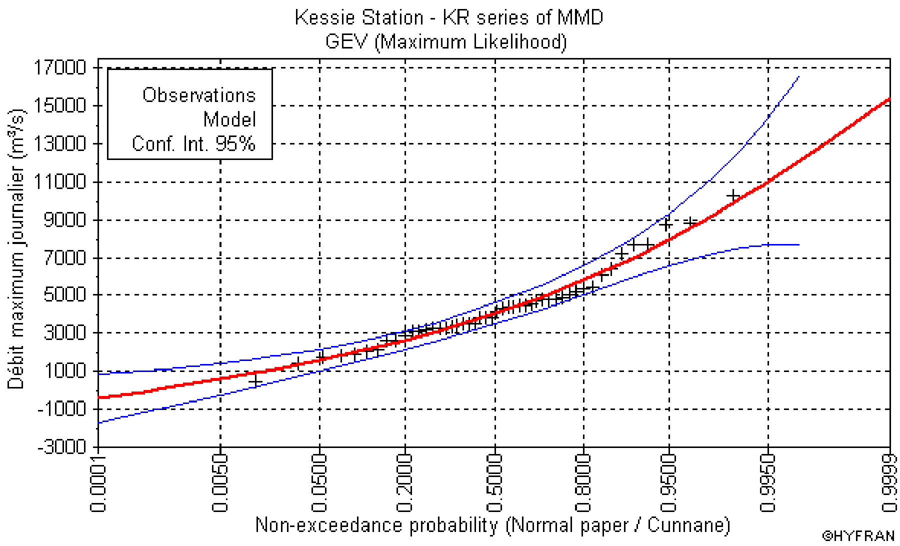
- Analyse momentary peak discharges to relate them to monthly peak discharges and calculate a multiplication factor to convert maximum mean daily to instantaneous peak. Apply these to estimate the design flood discharges at both sites.

4.9 FLOOD FREQUENCY ANALYSIS

4.9.1 Flood Frequency Analysis at Key Stations

For the main stations along the Abbay (Kessie, Border, and Deim), flood frequency analyses were done to estimate the annual maximum mean daily flows at different return periods. Generalized Extreme Value (GEV), Gumbel, Pearson III (P3), Log Pearson III (LP3), and Log Normal II and III (LN2, LN3) distributions were fitted to the annual series of each of the 4 stations using the HYFRAN software. The best fit was achieved by a different distribution in each case although hypothesis testing did not reject any of the other distributions in all cases. A set of criteria including Chi-Squared test, proximity of distribution statistics to those of the data, and visual inspection were applied to select the best distribution in each case. Figures 4.7 to 4.9 show these fits for Kessie, Border and Deim stations.

Figure 4.7 : Frequency Analyses of Maximum Daily Discharge for Abbay at Kessie



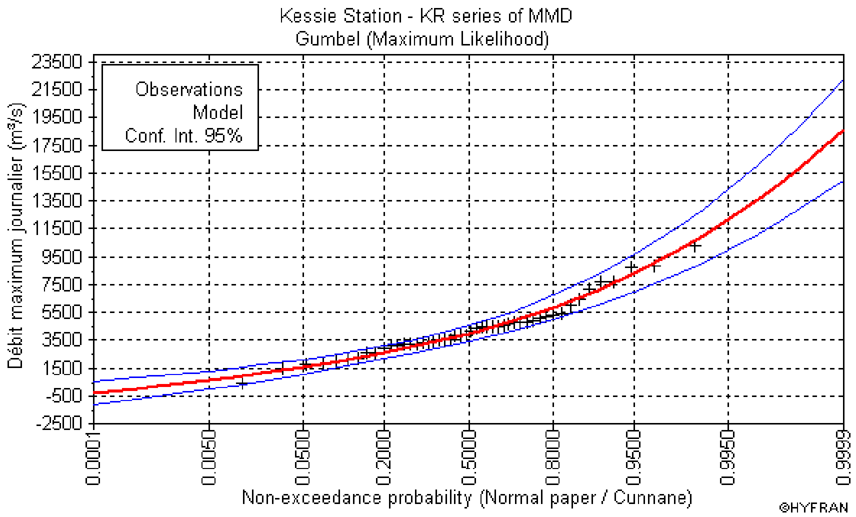


Table 4.7 : Estimated Maximum Daily Discharges (m^3/s) for Abbay at Kessie

Return Period (Years)	Method	
	GEV	Gumbel
10000	15415	18593
1000	12942	14790
500	12137	13644
100	10145	10980
50	9229	9827
20	7953	8288
10	6924	7099
5	5808	5860

Figure 4.8 : Frequency Analysis of Maximum Daily Discharges for Abbay at Border

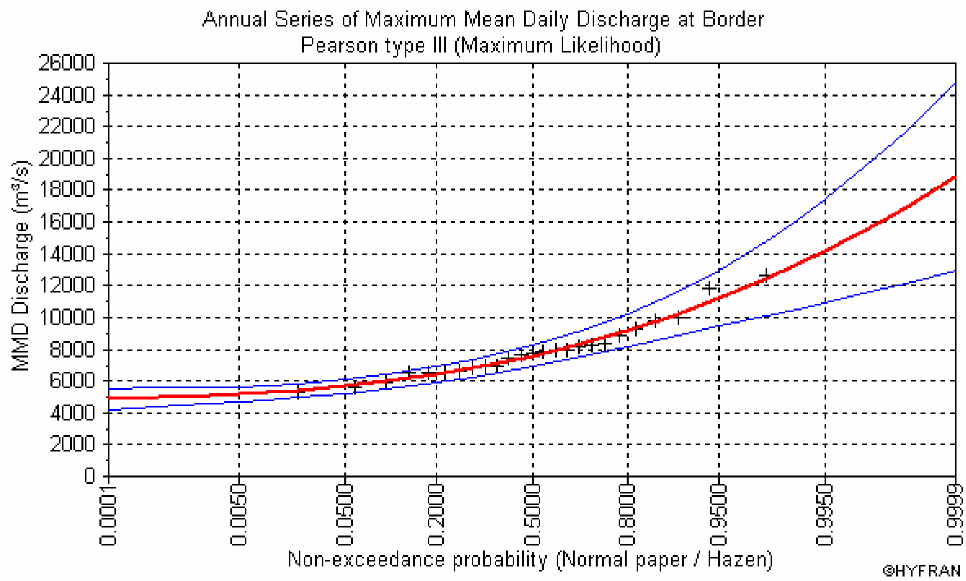
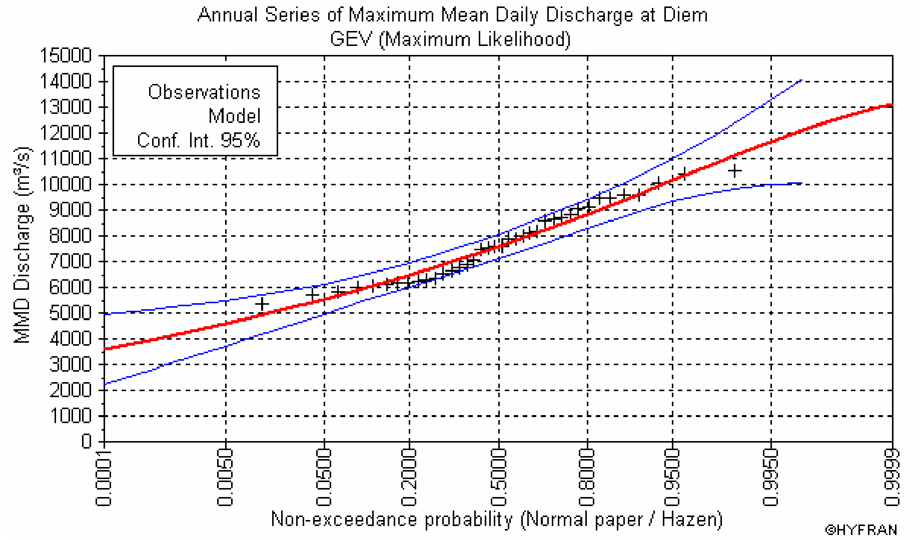


Figure 4.9 : Frequency Analysis of Maximum Daily Discharge for Blue Nile at Deim



Using the best fitted, the annual maximum mean daily discharge was estimated for different return periods as shown in Table 4.8.

Table 4.8 : Estimated Maximum Mean Daily Discharge (m^3/s) for Main Abbay Hydrometric Stations using the Best Fitted Distribution

Return Period (years)	Kessie	Border	Deim
	Gumbel	P3	GEV
10,000	18,593	18,824	13,137
1,000	14,790	16,138	12,387
100	10,980	13,323	11,266
50	9,827	12,434	10,829
20	8,288	11,213	10,156
10	7,099	10,238	9,558

It can be seen that the estimated flood discharges at Border are only marginally greater than at Kessie despite the catchment area at Border being some 2.7 times greater than at Kessie. Flood estimates derived using the flow record for Deim are significantly lower than at Border, which is located only a short distance upstream, or at Kessie. One of the causes of this is likely to be the relatively short period of data available (25-47 years) for such analysis but other factors are also likely to affect the analysis including:

- Accuracy of measurements
- Differing periods of record
- Effects of in-bank storage attenuating flood peaks downstream
- Non-coincidence of flood peaks in downstream sub-catchments.

The implication of these findings is that estimating maximum mean daily flood flow for Mandaya will depend on the station used.

It is recommended that a detailed analysis is undertaken during feasibility studies including deriving flood estimates for differing frequencies for each sub-catchment where possible and integrating the individual sub-catchment flows in a suitable model.

4.9.2 Analysis of Regional Maximum Discharge Data

For each of the 23 river gauges listed in Table 4.3, the annual maximum mean daily discharge (maximum mean daily) time series was determined. As determined from the mean time series, the months of July, August, September, and October correspond to more than 75% of the annual flows on average with October flows constituting a smaller percentage than the rest of the flood season month for most stations and years. Therefore, and in order to increase annual maximum mean daily data availability, the annual maximum mean daily was determined for all years with maximum mean daily records for at least two months of the three flood months (July, August, September). The year was discarded if only one month of these was available unless the momentary peak was recorded in that month. The quality control checks done for the mean flow analysis helped spotting and correcting some errors in maximum discharge records. For most years and stations, the annual maximum mean daily occurred within these three months with a few occurring in October and fewer occurring in June. The highest maximum mean daily value in each year was thus extracted forming annual series for each station and Table 4.8 shows the statistics of these series. It is worth noting that the average and maximum mean daily flows at Deim are less than those at Border because many of the missing years at Border are in the dry period of the 1980s. As expected, the relative variability (expressed as the coefficient of variation: CV) is higher for stations with smaller catchments.

4.9.3 Regional Flood Relationship

In order to be able to obtain flood discharges at Mandaya site (where no flow records are available) and to make use of the longer Kessie and Deim records at Border, a regional flood relationship was developed between the mean annual maximum mean daily and the catchment area.

A similar relationship was also developed for momentary peak flow but with only 6 data points, the credibility of such relationship may be debatable. The Maximum Mean Daily Flow-Area exponential relationship developed using the records of the 22 stations listed in Table 4.9 explains about 90% of the observed annual maximum mean daily variability and provides a good way to transfer flood information from stations with relatively long records (e.g. Deim and Kessie) to those with no record (Mandaya) or short records (Border).

In carrying out this analysis the catchment area for plotting of data for Kessie, Border and Deim hydrometric stations has been reduced by 15,321 km^2, being the catchment of the upper Abbay to Bahir Dar which does not contribute to flood peaks. For the same reason the data for Abbay at Bahir Dar has also been omitted from the analysis. The transposition factor between stations i and j is given as:

$$TF = \frac{MDD_i}{MDD_j} = \left(\frac{A_i}{A_j}\right)^x$$

where x = 0.7558 from the regression analysis.

Figure 4.10 : Regional Analysis of Mean Annual Maximum Daily Discharge

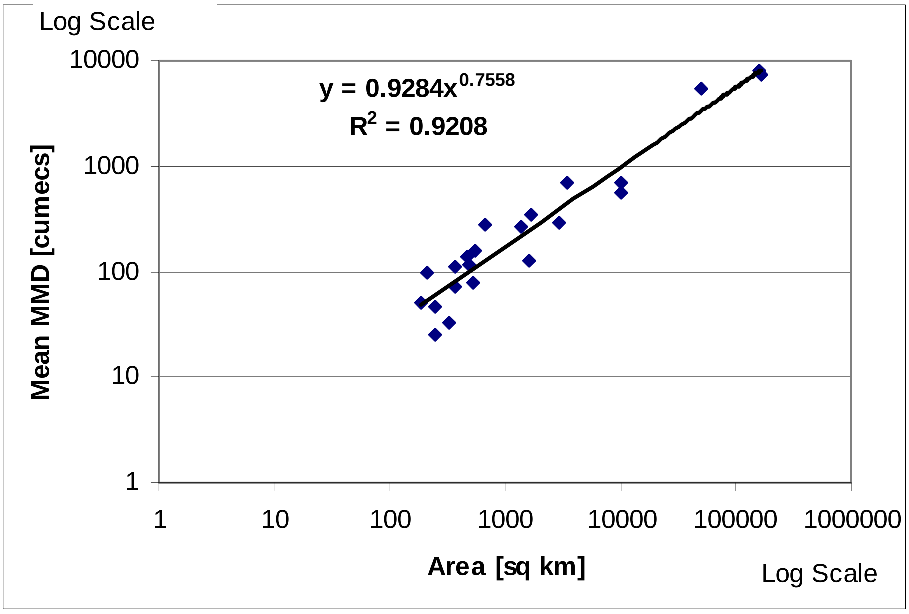
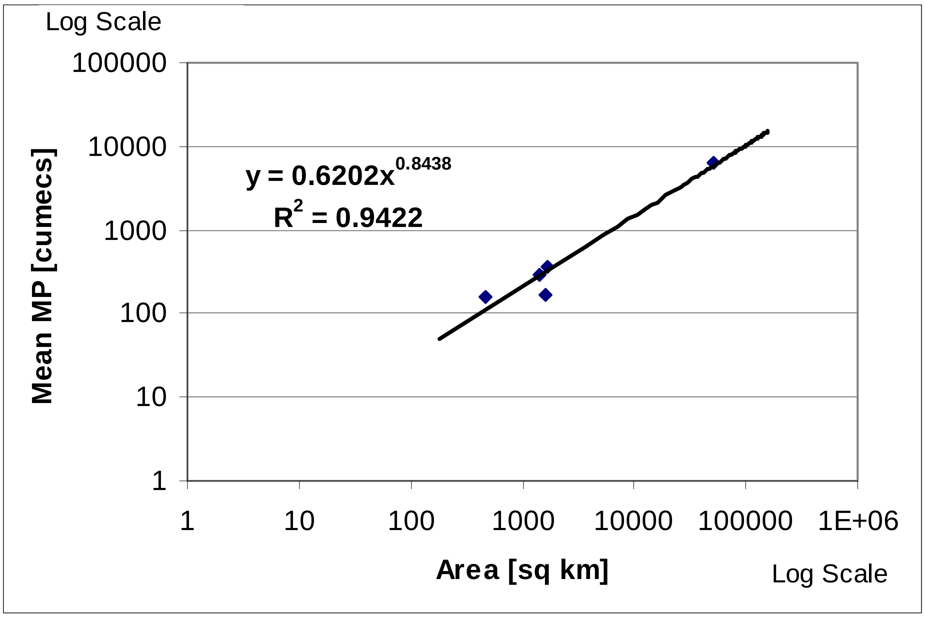


Table 4.9 : Statistics of Annual Maximum Flood Discharge Series

Station No.	River	Site	Complete Years			Annual Max. Mean Daily Discharge (maximum mean daily)				
			Potential	Available	%	Average [m³/sec]	St.Dev [m³/sec]	CV [%]	Max [m³/sec]	Min [m³/sec]
1002*	Gelgel Abbay	Nr. Marawi	46	45	98%	348.0	121.6	35%	964.0	223.7
1003	Koga	@ Merawi	45	38	84%	47.0	35.7	76%	216.7	11.9
1005*	Ribb	Nr. Addis Zemen	44	39	89%	127.5	39.5	31%	235.0	57.8
1006*	Gumara	Nr. Bahir Dar	46	42	91%	267.1	62.3	23%	402.0	170.4
1007*	Megech	Nr. Azezo	45	35	78%	138.9	104.1	75%	540.0	31.4
2001*	Abbay	Nr. Kessie	52	47	90%	5398.3	3021.8	56%	13681.3	1414.7
2002	Mugher	Nr. Chancho	35	35	100%	115.8	56.4	49%	250.0	31.4
2003*	Abbay	@ Bahir Dar	45	45	100%	406.7	177.3	44%	779.1	82.9
2007	Beressa	Nr. Debre Berhan	43	42	98%	99.3	55.0	55%	300.0	17.9
2017	Muga	Nr. Dejen	23	21	91%	111.8	88.1	79%	448.0	49.2
3005	Guder	@ Guder	46	46	100%	79.4	22.5	28%	161.6	49.1
3008	Chemoga	Nr. Debremarkos	43	40	93%	71.6	41.9	58%	283.0	29.0
3023	Dura	Nr. Metekel	41	40	98%	158.6	82.9	52%	431.3	33.0
3026	Neshi	Nr. Shambo	38	38	100%	33.0	11.7	35%	64.8	17.4
3027	Amerti	Nr. Shambo	21	21	100%	25.8	9.1	35%	42.5	13.1
3028	Dondor	Nr. Metekel	12	12	100%	50.7	13.5	27%	75.7	35.8
4001	Didessa	Nr. Arjo	45	26	58%	712.5	211.8	30%	1145.0	311.7
4005	Dabana	Nr. Abasina	24	21	88%	292.1	97.3	33%	611.6	196.0
5002	Dabus	Nr. Asosa	17	12	71%	557.1	82.6	15%	764.2	421.6
6002	Abbay	@ Sudan Border	44	25	57%	7895.0	1773.4	22%	12684.4	5316.0
6004	Gilgel Beles	Nr. Mandura	22	20	91%	283.0	122.2	43%	531.5	99.9
6005	Main Beles	@ Bridge	43	34	79%	696.7	373.8	54%	2060.6	218.7
	Abbay	@ Deim	38	38	100%	7506.0	1890.8	25%	10551.2	5362.7

Yellow Highlighted stations are further analysed for flood frequency   * These stations have MP records

Figure 4.11 : Regional Analysis of Momentary Peak Flows



4.9.4 Maximum Daily Discharge Estimates at Mandaya Site

In estimating the maximum daily discharges for the Mandaya site account has been taken of the incremental catchment areas downstream of Lake Tana since, as discussed previously, the upper catchment upstream of Lake Tana does not contribute very significantly to flood discharges at Kessie and downstream locations.

The estimated maximum daily discharges for Mandaya differ considerably depending on whether the analysis is carried out based on recorded flow series for Kessie or Deim. The values derived by upstream transposition of flows for Deim is not considered reliable as maximum flows at Deim are likely to be affected by in-bank and out-of-bank storage as well as non-coincidence of peak flows from the Dabus and Beles rivers. Therefore, for purposes of this study the values derived from Kessie have been adopted.

The maximum daily discharge for the catchment downstream of Lake Tana to the Mandaya site using the regionalized relationship based on catchment area, results in transposition factor of 1.844 and maximum mean daily discharge estimates as shown in Table 4.10. To these figures must be added an allowance for the coincident attenuated outflow from Lake Tana. A flow of 2000 m^3/s has been adopted as outflow from Lake Tana. This value represents the highest recorded flow over the period 1959-2004.

Table 4.10 : Maximum Daily Discharge Estimates for Mandaya Site based on Catchment downstream of Lake Tana

Return Period (years)	Flow estimates for catchment downstream of Lake Tana (based on analysis of Kessie) (m^3/s)	Assumed coincident outflow from Lake Tana (m^3/s)	Estimated Flood Magnitude at Mandaya Site (m^3/s)
10,000	32,250	2,000	34,250
1,000	25,831	2,000	27,831
100	19,400	2,000	21,400
50	17,455	2,000	19,455
20	14,856	2,000	16,856
10	12,852	2,000	14,852

4.9.5 Flood Hydrograph and Flood Routing for Mandaya Site

In order to determine a typical hydrograph applicable to the Mandaya site a review was carried out of recorded flows for major flood events for the Abbay at Kessie. The flood event selected was that of 18th to 23rd July 1964 for which a clearly defined hydrograph can be obtained for analysis. The peak flow was adjusted based on the catchment area : flood magnitude relationship to obtain equivalent flow at the Mandaya site and further adjusted to take account of the instantaneous peak flow and baseflow contribution relating to attenuated outflow from Lake Tana. A smooth reservoir inflow hydrograph with flows at 2-hour intervals was defined as shown in Table 4.11.

The inflow hydrograph was used for flood routing calculations of the passage of the flood through the Mandaya reservoir. For this purpose a rule curve was adopted for operation of the spillway gates as shown in Figure 4.12. An initial starting condition of the reservoir at full supply level (El. 800m) was adopted. The resulting outflow hydrograph is also shown in Table 4.11

It can be seen from Figure 4.13 that the maximum outflow rises to 30,000 m^3/s in accordance with the operating rule curve for the spillway. The maximum level reached during the flood was El. 801.42 m, a rise of some 1.42 metres above the staring level and well within the freeboard allowance of 3 metres.

Table 4.11 : Mandaya Design Flood Hydrographs

Time (Hours)	Inflow (m^3/s)	Outflow (m^3/s)
0	6,944	1000
2	8,677	1000
4	8,677	2000
6	9,045	4000
8	9,317	4000
10	9,706	6000
12	10,120	6000
14	10,551	6000
16	11,458	8000
18	12,169	8000
20	13,001	12000
22	15,366	12000
24	19,268	12000
26	22,274	16000
28	26,170	16000
30	31,117	20000
32	35,559	28000
34	38,892	28000
36	40,518	30000
38	39,123	30000
40	37,211	30000
42	34,282	30000
44	31,402	30000
46	27,954	30000
48	24,595	30000
50	20,931	30000
52	18,198	30000
54	16,114	30000
56	14,423	28000
58	12,951	24000
60	12,314	20000
62	11,645	16000
64	10,907	16000
66	10,376	12000
68	9,787	12000
70	9,317	12000
72	9,188	12000
74	9,081	8000
76	8,960	8000
78	8,849	12000
80	8,774	8000
82	8,760	8000
84	8,677	8000
86	8,677	8000
88	8,677	8000
90	8,677	12000
92	8,677	8000
94	8,677	8000
96	8,677	8000
98	8,677	8000
100	8,677	8000
102	8,677	12000
104	8,677	8000
106	8,677	8000
108	8,677	8000
110	8,677	8000
112	8,677	8000
114	8,677	12000
116	8,677	8000
118	8,677	8000
120	8,677	8000

Figure 4.12 : Rule Curve for Spillway Gate Operation

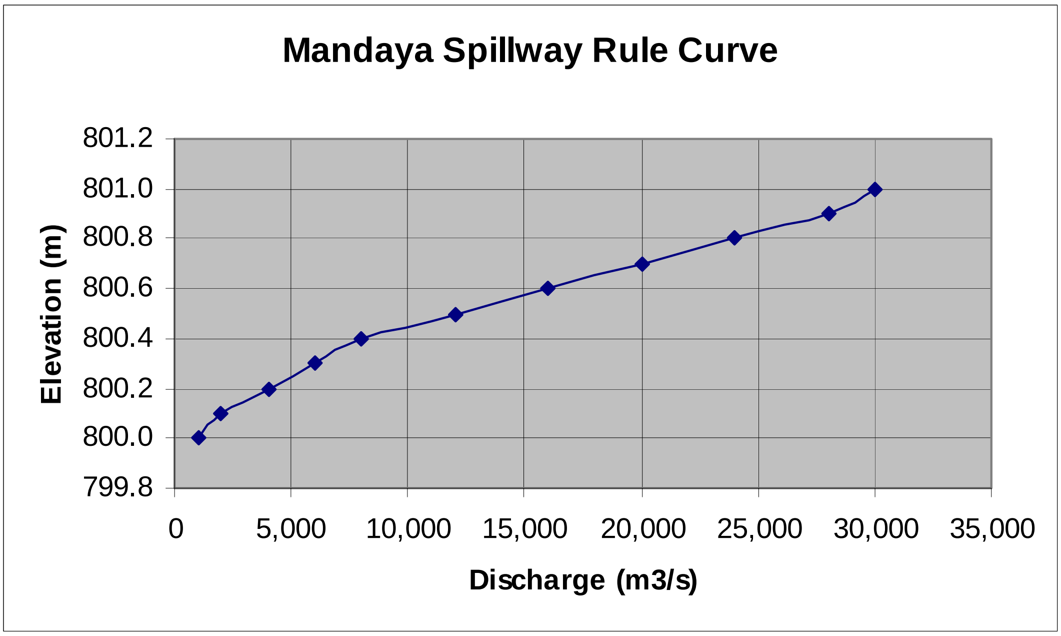
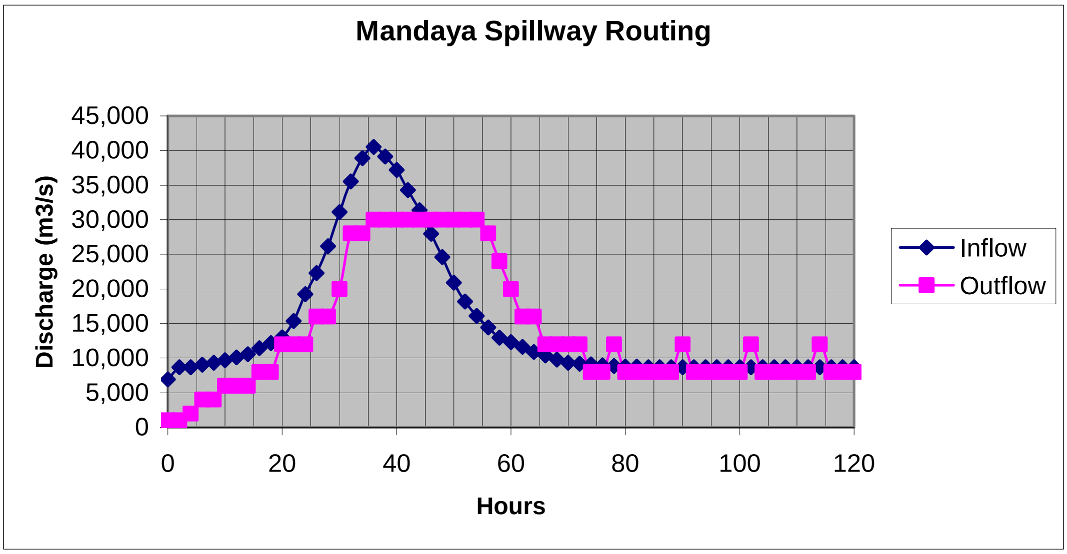


Figure 4.13 : Mandaya Spillway Flood Routing – Inflow and Outflow Hydrographs



It should be noted that because of the very substantial storage within the Mandaya reservoir, the critical floods for design of the spillway may result from the seasonal flood with the greatest volume, rather than a short period PMF with the highest peak discharge. This should be examined in detail during feasibility studies.

In order to be suitably conservative at the present level of study, and taking account of the need to determine reliable cost estimates, a spillway design flow of 30,000 m^3/s with the reservoir at full supply level has been adopted at the Mandaya site.

4.9.6 Flood Discharges for Design of Diversion Works

As stated earlier, a subset of 6 stations have momentary peak flow records for a number of years (10-19 years). Ratios of momentary peaks to mean daily maxima were calculated for each concurrent pair of data and the mean ratio can thus be used to convert maximum daily mean to momentary peak rates as an approximate way. The mean values of these ratios ranged between 1.18 and 1.29 except for one station (111007) where the mean ratio was 2.5 (only 8 data points). The momentary peak/maximum mean daily ratio is inversely proportional to the catchment area. Two of the studied stations (Bahir Dar and Kessie) are on the main Abbay and they have ratios of 1.29 and 1.2 respectively. Bearing in mind that the catchment areas at Mandaya is substantially larger than at Kessie a reduced variability during the course of the day would be expected. Therefore, a ratio of 1.20 seems to be reasonable to convert maximum daily mean to momentary peak rates at the proposed dam site at Mandaya. Applying this factor, the peak discharges for Mandaya for various return periods are given in Table 4.12.

These momentary peak discharges are expected to occur for only few hours during floods and are of significance only for determining the design capacity of river diversion works during dam construction since routing of floods in the Mandaya reservoir will be sufficient to attenuate daily peaks after reservoir impounding and during the operation period.

Table 4.12 : Design Flood Discharges for Diversion Works at Mandaya Site

Return Period (yrs)	Momentary Peak Flow (m^3/s)
1,000	26,591
100	21,345
20	17,975
10	13,225

4.10 SEDIMENT ANALYSIS

4.10.1 Background

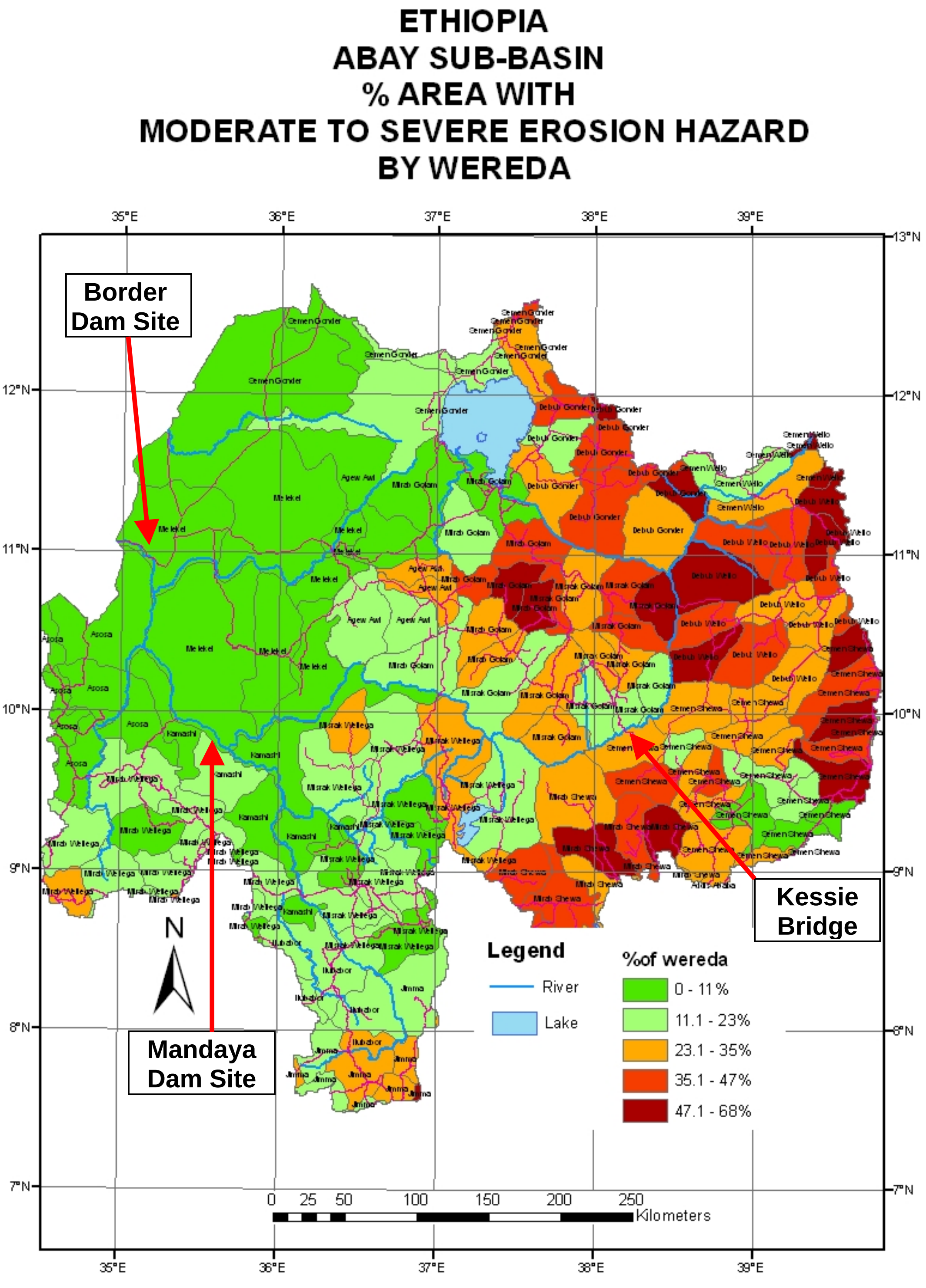
Various studies have described the overall picture of soil erosion and sediment transport within the Abbay river basin in Ethiopia. In the CRA Country Paper for Ethiopia, a comprehensive synopsis of the watershed management problems in the Abbay basin is given. It is noted that the highland plateaus have been deeply dissected by the Abbay and tributaries providing severe constraints to road communications and access to markets. Agriculture expansion on to steep slopes and the consequent loss of vegetation have accelerated geological rates of soil erosion. Steep slopes and lack of vegetative cover result in relatively high rates of sediment delivery to the main rivers. Millennia of cultivation coupled with breaches in soil nutrient cycling caused by residue and dung use as fuel, grain removal and soil erosion have led to low levels of crop and pasture productivity.

Detrimental government policies in the past have left a legacy of tenure insecurity and poverty with severe constraints on farmers' willingness and ability to invest in sustainable land management. Past large-scale programmes of soil conservation and afforestation were top-down and alienated the rural population. High rainfall in the Highlands can cause problems with physical soil conservation structures of poor drainage and of structure breaches and severe erosion.

The western Lowlands (within which the Border project is located) for long sparsely populated because of the prevalence human and livestock diseases, provides the potential for agricultural expansion.

The CRA Country Paper assesses the extent of soil degradation in terms of sheet and rill erosion (Figure 4.14), gully erosion and mass movements.

Figure 4.14 : Abbay Basin - Moderate to Severe Erosion Hazard by Woreda



Source: Final Country Report, Ethiopia, Hydrosult, 2006

With this background to sedimentation, the Country Paper goes on to state "Infrequent, unsystematic and incomplete suspended sediment data for the El Deim gauging station just across the border in Sudan is available. This has been analysed by Group 1 of the NBCBN/River Morphology Research Cluster. They estimated that the long-term mean suspended sediment at El Deim to be 123M tons. They estimated bed load to be 15% giving a total mean annual sediment inflow of 140M tons". These figures give a mean annual suspended sediment yield for the Abbay basin of approximately 700t/km^2/yr, and approximately 800t/km^2/yr for total load (including bed load).

The original NBCBN/River Morphology Research Cluster report (2005) on "Assessment of the current state of the Nile basin reservoir sedimentation problems" describes the sampling data and procedures on which these estimates are based. They are very instructive. The suspended sediment was "measured by bottle sampling taken once a day from the channel bank" at El Deim gauging station. Approximately 125 samples were taken in the months of July, August, September and October in 10 individual years spanning from July 1970 to August 1994. The plotted data reveal hysteresis looping with July and early August data normally giving distinctly greater sediment loads than the same flows on flood recession. Separate ratings were developed for rising and falling flood stages. Flow duration curves for 30-years record at El Deim gauging station (1966 – 1995) were developed for each 10-day period of the flood months (July to September) and sediment ratings applied to these. The resulting sediment loads are summarised in Table 4.13, below.

Table 4.13 : Mean Suspended Sediment Load at El Deim

Month	**July**			**August**			**September**			**All**
Period	I	II	III	I	II	III	I	II	III	
Million tonnes	7	10	19	22	26	27	5	4	3	123

Source: NBCBN/River Morphology Research Cluster Report (2005)

This work is the basis for the estimate of 140M tons total mean annual sediment inflow at Roseires. The following cautionary points may be noted:

- Sediment samples at El Deim were taken at five points in five verticals across the river from a cable car during the station's early history (1960s). The samples giving rise to the estimate of 140M tons (July 1970 to August 1994) are stated to be taken by hand at the water's edge. The relationship between concentrations based on comprehensive sampling (as in the 1960s) and at the riverbank is unknown.

- El Deim sediment ratings include data from as early as 1970, and are therefore weighted in part to conditions more than 35 years ago; similarly, the most recent samples used to establish ratings (in 1994), some 13 years ago, may be unrepresentative of current land use conditions.

- The Abbay Master Plan report estimated sediment transport annual yield of 168M tons at Border dam site, using a rating curve for Border gauging station based on sediment sampling in 1961 only – more than 45 years ago (See below).

All of the above points suggest that the estimate of 140M tons total mean annual sediment load at El Deim is likely to seriously underestimate current sediment transport at Border dam site.

The Ethiopian Country Paper goes on to state that “the Tekezi Medium Hydro Study (1998) quoted a much higher figure of 273M tons per annum as the mean annual suspended sediment load for Roseires”.

The Country Paper presents summary data for 15 selected stations in the Abbay basin (Table 4.14), giving the source as Abbay Basin Master Plan Study. From our understanding of there being no comprehensive sediment monitoring at Border during at least the last 27 years, we are not aware of any sediment rating curve for Border which represents current land use conditions. We have therefore to conclude that the sediment load quoted (140M tons/year) is based on a flow record period from 1980 to 1991 and not on a sediment rating curve developed from comprehensive sampling during these years.

Table 4.14 : Suspended Sediment Loads in Abbay Basin

Station	Length of record	Catchment area (km^2)	Sediment load ('000 tons/yr)	Soil loss ($t/km^2/yr$)	Mean Annual discharge (m^3/s)
Gilgel Abbay, near Merawi	1980-992	1,664	2,821	1,695	58.17
Gumara, near Bahir Dar	1980-1992	1,394	1,937	1,390	27.18
Megech at Azezo	1980-1992	462	263	569	7.5
Abbay at Kessie	1982-1992	65,784	49,404	751	450.5
Muger, near Chancho	1980-1992	489	38	78	9.26
Abbay at Bahir Dar	1980-1992	15,321	2,191	143	111.32
Guder at Guder	1980-1992	524	47	90	12.63
Birr, near Jiga	1980-1992	975	2,075	2,129	17.86
Dura, near Metekel	1980-1992	539	386	717	
Angar, near Nekemte	1980-1985	4,674	702	150	62.79
Dabana, near Abasina	1980-1984	2,881	453	157	57.35
Angar, near Gutin	1982-1983 1986-1992	1,975	176	89	
Beles, near Metekel	1983-1992	3,431	1,563	456	51.38
Abbay at Sudan border	1980-1991	172,254	140,000	700	1555.73

Source: After Final Country Report, Ethiopia, Hydrosult, 2006 (from Abbay Basin Master Plan Study)

In the Abbay Master Plan report itself, we note that sediment transport is presented for potential dam sites including Mandaya and Border. For Border dam site, sediment transport annual yield is given as 168M tons (and for Mandaya 124M tons).

(Phase 2, Data Collection – Site Investigation Survey and Analysis. Section III, Volume 2: Dam Project Profiles). This estimate appears to be based on sediment samples at Border gauging station obtained in only a seven month period in one year (between March and September 1961), now more than 45 years ago (Phase 2, Data Collection – Site Investigation Survey and Analysis. Section II Sectoral Studies, Volume III – Water Resources, Appendix 6).

4.10.2 Available Sediment Data for this Study

Sediment data for this study were obtained from three sources:

- MoWR of Ethiopia,
- ENTRO office.
- Karadobi Pre-feasibility Report

The MoWR dataset (one Excel file) contains water level, discharge, and sediment concentration measurements for 12 stations across the Abbay basin covering the period 1990-present. These raw data included the date, sample measurements (2 or 3 samples at each location/date) taken at different depths. For each sample, the cross section depth and width and the sampling time were included. The average concentration and flow were extracted for the Sediment analysis.

The ENTRO dataset contains processed data from 46 stations (each is a separate Excel file) taken prior to 1996. The start of the record and the number of observations vary from one station to the other. For each observation, the date, head, discharge and mean concentrations are given in addition to the daily flow volume and total daily sediment discharge calculated from the discharge and concentration data.

Overall, very few suspended sediment measurements have been carried out at hydrometric sites within the Abbay river basin in Ethiopia as shown in Table 4.15. The shortage of data means that limited confidence can be placed in the results until further more detailed studies have been performed.

Table 4.15 : Summary of Suspended Sediment Station Records, Ethiopia

Code River	Station	Area (km^2)	Period	Number of Samples
1002 Gilgel Abbay	nr. Merawe	1,664	1968-1996	17
2001 Abbay	at Kessie	65,784	1960-2004	27
2002 Muger	nr. Chancho	489	1975-2004	44
2003 Abbay	at Bahir Dar	15,321	1961-1996	27
2017 Muga	nr. Bichena	375	1983-1995	51
2027 Aleltu	nr. Mukature	447	1985-1996	46
3005 Guder	at Guder	524	1968-1996	29
3008 Chemoga	at Debre Markos	364	1960-1995	65
4005 Dabana	nr. Abasina	3,281	1961-1984	10
6002 Abbay	at Sudan Border	172,254	1961	5
6005 Beles	nr. Metekel	3,431	1962-2003	32

Suspended sediment data of particular interest to the present study comprise the records for Abbay at Kessie Bridge (2001) and Abbay at Sudan Border (6002). Twenty seven measurements have been carried out at Kessie over a period of some 44 years whilst only five samples are recorded at Sudan Border. Because of the paucity of data at Border site and the very small size of the other catchments compared to the Mandaya and Border sites, the analysis has concentrated on records for the Abbay at Kessie gauging station as presented in Table 4.16, although data from other locations has also been considered.

Table 4.16 : Suspended Sediment Measurements, Abbay River at Kessie Bridge

Source*	Year	Date	Gauge Height (m)	Flow (m3/s)	Concentration (ppm)
1	1960	17-Jun		33.0	997
1	1960	13-Jul		276	5,837
1	1960	2-Aug		1587	3,830
1	1960	30-Aug		2013	3,197
1	1960	30-Sep		767	369
1	1961	4-Apr		112.0	4,423
1	1961	11-Jul		1100	16,709
2	1985	09-Jun	0.54	48.9	2,232
2	1989	23-Jun	1.13	47.3	5,549
2	1989	10-Aug	4.40	1099	4,358
2	1989	11-Aug	3.58	826.5	3,468
2	1989	25-Sep	3.07	579.1	675
2	1990	03-Mar	1.10	59.0	302
2	1990	08-May	0.74	23.0	724

Source*	Year	Date	Gauge Height (m)	Flow (m3/s)	Concentration (ppm)
2	1990	20-Oct	2.32	330.7	784
2	1992	26-Sep	3.20	290.0	1,287
2	1995	25-Feb	0.91	35.6	161
2	1995	18-Jul	3.50	712.7	3,153
2	1995	25-Aug	5.07	1926	4,899
2	1995	21-Sep	3.15	627.3	5,606
3	2004	01-Aug	4.91	1392	10,954
3	2004	13-Aug	6.57	1637	17,930
3	2004	28-Aug	4.49	980.2	4,996
3	2004	18-Sep	2.94	398.2	2,022
3	2004	01-Oct	2.40	243.4	2,516
3	2004	07-Oct	2.70	335.0	3391
3	2004	22-Oct	2.08	165.5	372

* 1 = US Geological Survey, 2 = Ministry of Water Resources, 3 = Karadobi Pre-feasibility Study

Measurements of sediment concentrations in the Abbay River at Kessie were first carried out in the period 1960-1961 by USBR in connection with the study of the Land and Water Resources of the Blue Nile River Basin (1964). Further measurements over the period 1985 to 1995 have been carried out by the Ministry of Water Resources. Most recently, in 2004, seven measurements were carried out as part of the pre-feasibility study of the Karadobi hydropower project.

It should be noted that the number of measurements that have taken of sediment concentration in the Abbay River at Kessie is not adequate to define sediment discharge with any degree of confidence. Sediment concentration typically varies substantially depending on the exact time during the wet season when measurements are made, the vegetation cover at the time and whether measurements are made on the rising or falling limb of the hydrograph. A “hysteresis loop” is normally found when plotting sediment data with relatively higher sediment concentrations on the rising limb of the hydrograph and lower concentrations associated with similar discharges on the falling limb of the hydrograph. These variables lead to considerable scatter in data plots as can be seen in Figure 4.15 below. Ideally, because of the inevitable scatter of data when measuring sediment concentration, the number of measurements for any analysis should be not less than 50 and preferably more than 100 for any time period.

4.10.3 Analysis of Sediment Data at Kessie

The suspended sediment data recorded for the Abbay at Kessie Bridge is presented in Table 4.17. It can be seen that the data can be divided into three periods of records namely: 1960 - 1961, 1985 - 1995 and the year 2004 each separated by an intervening period of some 10 to 20 years. Although the amount of data is small and displays considerable scatter (especially in the case of the data for the earlier periods 1960 – 1961 and 1985 – 1995), this nevertheless provides an opportunity to derive sediment rating curves applicable to each period as shown in Figure 4.15.

Table 4.17 : Sediment Concentration and Discharge - Abbay River at Kessie

1960-1961			1985-1995			2004		
Flow (m^3/s)	**Sediment Conc. (ppm)**	**Sediment Discharge (tonnes/day)**	**Flow (m^3/s)**	**Sediment Conc. (ppm)**	**Sediment Discharge (tonnes/day)**	**Flow (m^3/s)**	**Sediment Conc. (ppm)**	**Sediment Discharge (tonnes/day)**
33	997	2,843	23	724	1,439	166	372	5,319
112	4423	42,800	36	161	495	243	2516	52,911
276	5837	139,191	47	5549	22,677	335	3391	98,149
767	369	24,453	49	2232	9,430	398	2022	69,566
1100	16709	1,588,023	59	302	1,539	980	4996	423,108
1587	3830	525,157	290	1287	32,247	1392	10954	1,317,424
2013	3197	556,032	331	784	22,401	1637	17930	2,535,962
			579	675	33,773			
			627	5606	303,838			
			713	3153	194153			
			827	3468	247648			
			1099	4358	413808			
			1926	4899	815225			

Relationships between sediment concentration and flow for the three periods 1960 – 1961, 1985 – 1995 and 2004 have been derived as listed below:

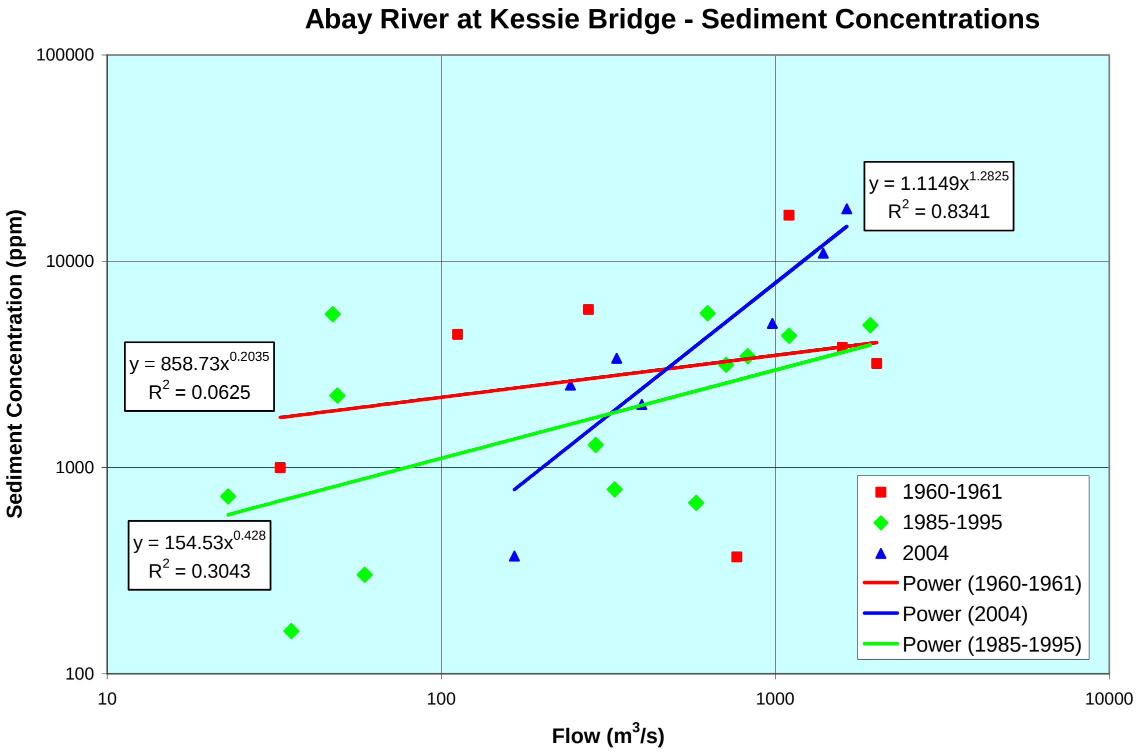
1960 – 1961 Sediment concentration (ppm) = 154.53 x Flow (m^3/s) $^{0.428}$

1985 – 1995 Sediment concentration (ppm) = 858.73 x Flow (m^3/s) $^{0.2038}$

2004 Sediment concentration (ppm) = 1.1149 x Flow (m^3/s) $^{0.8341}$

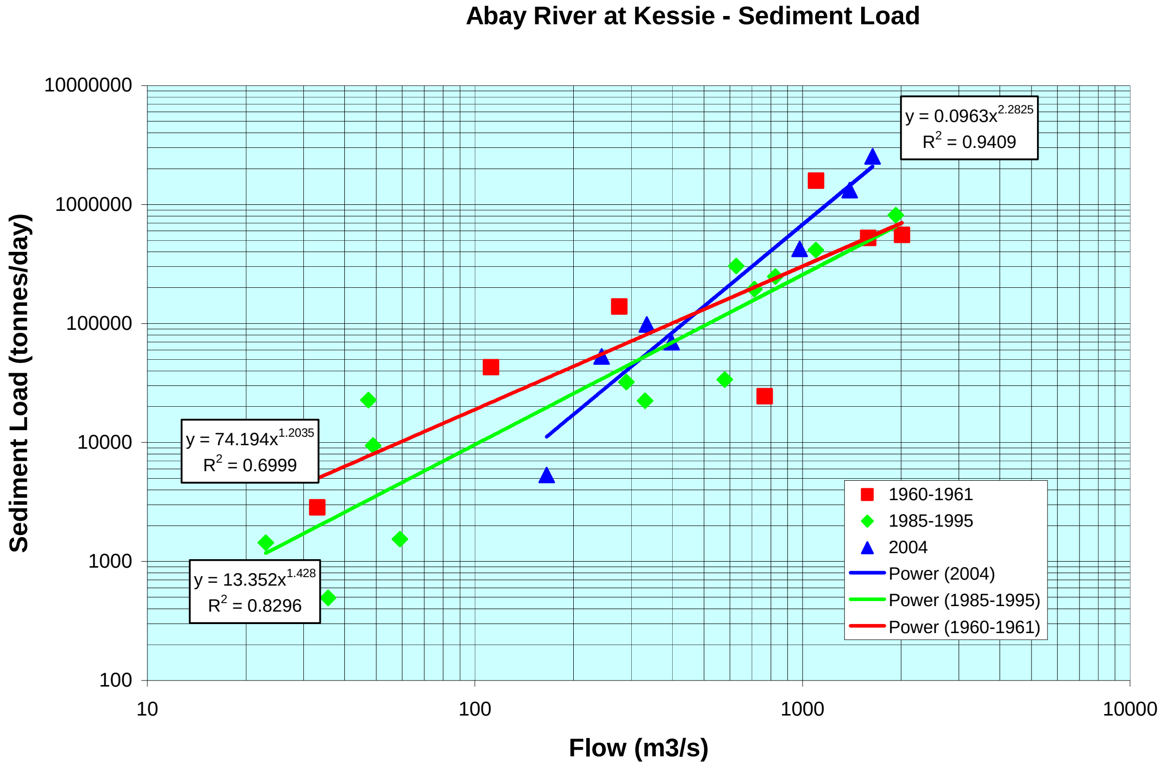
It should be noted that the correlation coefficient for the two data series 1960-61 and 1985-95 are very low (R^2 = 0.06 and 0.3) due to the extremely scattered data points and hence only very limited confidence can be placed in the sediment rating for these series. The 2004 data series exhibits less scatter and the correlation coefficient (R^2) of 0.83 enables a higher degree of confidence in the results.

Figure 4.15 : Sediment Concentrations – Abbay river at Kessie Bridge



Sediment discharge relationships have also been derived from the above data as illustrated in Figure 4.16 below.

Figure 4.16 : Sediment Discharge - Abbay River at Kessie



The sediment discharge relationships for the three data series show significantly higher correlation coefficients than the sediment concentrations, as is to be expected (R^2 = 0.699 to 0.94).

Average annual suspended sediment loads for the Abbay River at Kessie have been computed by applying the above equations to the monthly flow data for the period 1954 – 2003. In the case of the 2004 data the suspended sediment concentration in the analysis has been capped at 18,000 ppm approximately equal to the highest recorded sediment concentration (although it should be noted that higher values were recorded at Bure bridge downstream during the same programme of measurements). The results indicate a dramatic three-fold increase in suspended sediment discharge over the period from some 900 tonnes/km^2/year in 1960 to 2,791 tonnes/km^2/year in 2004, equivalent to an average increase of some 2.6% per year.

It is noted that the estimates derived above for the suspended sediment discharge of the Abbay River at Kessie using the 2004 data are some 2.4 times greater than the "High" estimate presented in the Karadobi Pre-feasibility report.

An analysis has been carried out to examine the sensitivity of use of monthly flow data used in this report compared to daily data (as was used in the Pre-feasibility study of the Karadobi Multipurpose Project) in order to exclude the use on monthly flow data as the cause of the substantially higher sediment discharges calculated. For this purpose the "High" sediment rating curve derived in the Karadobi report has been applied to the monthly flow series and compared with the results calculated by means of the same sediment rating equation using daily data. The results of this analysis are presented in Table 4.18 below. It can be seen that the difference in sediment loads calculated using monthly and daily data is only some 3.4% with the daily data giving slightly higher figures as is to be expected. It was concluded that the use of monthly data did not introduce significant error and that the time period of the sediment concentration measurements as described above was much more consequential in calculation of sediment discharge.

Table 4.18 : Comparison of Suspended Sediment Discharge for Abbay River at Kessie using Monthly and Daily Data

Data Type	Sediment Discharge (tons/year)	Specific Sediment Discharge (tonnes/km^2/year)
Daily*	75,698	1,151
Monthly	73,202	1,113
Difference		3.4%

In calculating total sediment discharge for the Abbay at Kessie an allowance for bedload of 20% of the suspended sediment load has been added to obtain the overall estimates of sediment discharge as shown in Table 4.19 below.

Table 4.19 : Estimated Sediment Discharges at Kessie

Item	1960 – 1961 Data		1985 – 1995 Data		2004 Data	
	Specific Sediment Discharge (t/km^2/yr)	Average Sediment Load (million tonnes / yr)	Specific Sediment Discharge (t/km^2/yr)	Average Sediment Load (million tonnes / yr)	Specific Sediment Discharge (t/km^2/yr)	Average Sediment Load (million tonnes / yr)
Suspended sediment	901	59.3	836	55.0	2,791	183
Bedload (20%)		11.9		11.0		37
Total sediment discharge		71.2		66.0		220

The above-mentioned trend of increasing sediment loads over the period since 1960 is considered likely to be associated with the increasing pressure of population and agriculture within the catchment area since 1960. It is expected that this trend will continue unless a major programme of watershed management and re-afforestation is implemented. If the identified trend of increasing sediment discharge at a rate of 2.6% per year were to continue the sediment discharge at Kessie could be expected to reach 700 million tonnes per year by 2050.

4.10.4 Analysis of Sediment Data at Bure Bridge

Following the Workshop presented in Khartoum on 3 – 4th June 2007 details of sediment samples which were taken at the Bure bridge over the Abbay during the course of the Pre-feasibility study of the Karadobi Multi-purpose project in 2004 were provided to the consultants as shown in Table 4.20, below. Whilst flows and levels were not recorded simultaneously it is notable that observed suspended sediment concentrations were as follows (based on the mean of 3 samples at quarter points across the river). Each of the sets of three samples was reasonably consistent with most samples differing only slightly from the mean.

Table 4.20 : Suspended Sediment Measurements, Abbay River at Bure Bridge

Year	Date	Gauge Height (m)	Flow (m3/s)	Concentration (ppm)
2004	28-Jul	n.a.	n.a.	22319
2004	9-Aug	n.a.	n.a.	10588
2004	29-Aug	n.a.	n.a.	4759
2004	19-Sep	n.a.	n.a.	4729
2004	2-Oct	n.a.	n.a.	1351
2004	8-Oct	n.a.	n.a.	5173
2004	23-Oct	n.a.	n.a.	306

In the absence of recorded gauge heights and discharges it is not possible to derive a relationship between suspended sediment concentration and flow. However, it is noteworthy that the maximum recorded suspended sediment concentration amounts to over 22,000 ppm and that two of the 7 samples had concentration above 10,000 ppm.

The concentration measured on 28th July results is likely to be close to the annual peak flow whilst the other measurements are all on the falling limb of the hydrograph.

4.10.5 Analysis of Sediment Data for Didessa River

Suspended sediment measurements have been carried out at two locations near Dembi (Toba) and Arjo within the Didessa catchment as summarised in Table 4.21 below.

Table 4.21 : Suspended Sediment Records for Didessa River

Site	River	Catchment Area (km^2)	Period of Records	No. of Samples
Nr Toba	Didessa	1806	1990-1993	7
Nr. Arjo	Didessa	9981	2004	3

The suspended sediment data for the two sites is summarised in Table 4.22 below:

Table 4.22 : Suspended Sediment Data for Didessa River

Site	Year	Date	Gauge Height (m)	Flow (m^3/s)	Concentration (ppm)
Toba	1990	15-Mar	0.43	4.2	45
Toba	1990	21-Mar	0.50	5.4	108
Toba	1990	2-Jul	1.81	9.1	180
Toba	1990	18-Sep	2.46	98.5	151
Toba	1990	22-Dec	0.40	4.4	84
Toba	1993	12-Apr	0.64	8.0	65
Toba	1993	16-May	0.46	2.9	65
Arjo	2004	10-Aug	2.45	143.1	1633
Arjo	2004	11-Aug	2.56	196.1	1670
Arjo	2004	1-Sep	3.61	611.2	1376

No analysis has been carried out on the above data as the catchment area at Toba represents less than 1.5% of the catchment area to Mandaya while the number of measurements (3) is inadequate at Arjo.

4.10.6 Estimate of Sediment Discharge at Mandaya

Our aerial survey flight and overland surveys in October 2006 confirmed the stark contrast between the densely cultivated eastern part of the Abbay river basin, with deeply incised tributaries and gullies, and the generally tree-covered west. During the aerial survey, it was noted that the Abbay river was reddy brown in colour throughout its length from near Kessie Bridge to Border. The only clear water seen was in a few small tributaries downstream of the Abbay/Didessa confluence.

The intermediate area between Kessie and Mandaya site is expected to have a lower specific sediment yield than the upstream catchment as a result of the less disturbed natural vegetation cover although there is no sediment data for these lower reaches of the Abbay River to confirm this hypothesis. For purposes of this study the specific sediment yield of the intermediate area between Kessie and Mandaya site in 2004 has been estimated as equal to the specific sediment of the catchment to Kessie as measured in 1960/61 or some 900 t/km^2/year. The estimated sediment discharge at Mandaya is shown in Table 4.23, below.

It is recommended that a major programme of suspended sediment measurements is carried out at Kessie, Mandaya and Border during the course of future feasibility level studies in order to confirm current sediment concentrations and discharges.

Table 4.23 : Estimated Sediment Discharges at Mandaya

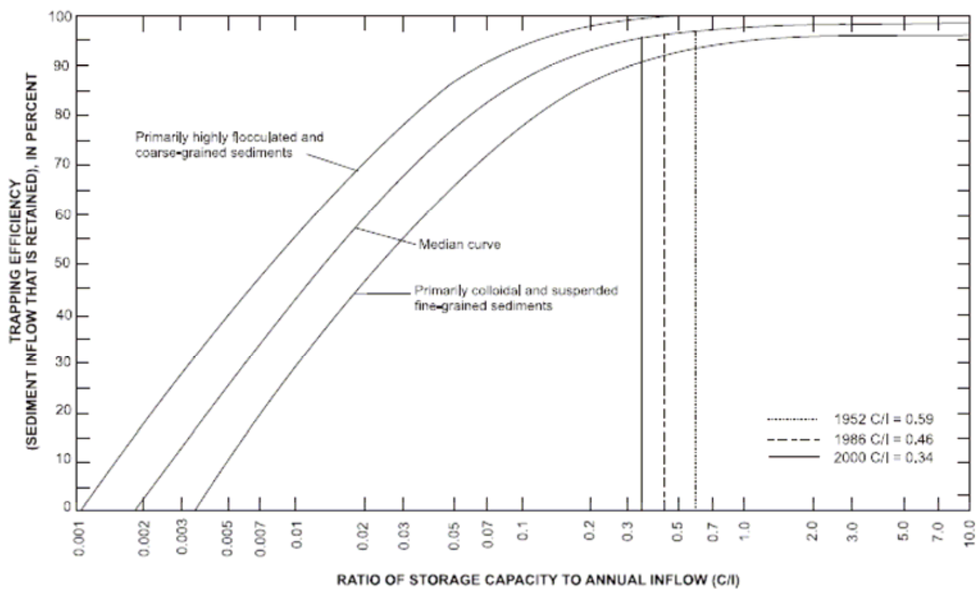
Location	Catchment Area (km^2)	Specific Suspended Sediment Discharge ($t/km^2/yr$)	Average Sediment Load* (million tonnes / yr)
Kessie*	68,074	2,791	220
Incremental catchment area Kessie to Mandaya	60,655	900	65
Mandaya	128,729		285

*based on data for Year 2004 including bedload

4.10.7 Reservoir Sedimentation

The gross storage of Mandaya reservoir is estimated as 49,200 x 10^6 m^3 amounting to some 154% of the mean annual runoff. As such the reservoir can be expected to have a trap efficiency approaching 100% initially, based on the method of Brune (refer to Figure 4.17, below). The configuration of Mandaya reservoir is such that sediment flushing would not be effective.

Figure 4. 17 : Trap Efficiency of Reservoirs (after Brune, 1953)



Long term reservoir sedimentation in Mandaya reservoir over a 50-year period has been estimated based on the above analysis of sediment discharge based on four scenarios:

- Sedimentation of Mandaya based on 2004 sediment estimates
- Sedimentation of Mandaya based on 2004 sediment estimates with Karadobi project upstream (assuming 100% trap efficiency in Karadobi),
- Sedimentation of Mandaya based on sediment discharge continuing to rise at 2.6% annually
- Sedimentation of Mandaya with Karadobi project upstream (assuming 100% trap efficiency in Karadobi) with sediment discharge rising by 2.6% annually.

The results of the analysis assuming a density of sediment deposits of 1.5 tonnes/m^3 are presented in Table 4.24 below.

Table 4.24 : Long-term Sedimentation Estimates for Mandaya Reservoir

Item	50-year Sediment Deposition	
	Million m^3	% Loss of Gross Storage
Mandaya alone based on Year 2004 sediment rates	9,500	19.0
Mandaya with Karadobi (Year 2004 sediment rates)	2,167	4.4
Mandaya alone with 2.6% annual increase in sediment	19,500	39.5
Mandaya with Karadobi with 2.6% annual increase	4,464	9.1

It can be seen that Mandaya reservoir would lose some 40% of its gross storage through sediment deposition within 50 years if the sediment discharges calculated above are correct and the trend for increasing sediment discharge is not reduced by watershed management initiatives. In the event that the Karadobi dam is constructed upstream the majority of the sediment would be deposited in Karadobi reservoir and Mandaya reservoir would be relatively unaffected.

We wish to stress however that because of the very limited data available the above analysis cannot be considered authoritative. However, the point is made that a major programme of sediment measurement will be required during future feasibility studies of the Mandaya and Karadobi projects to provide up to date estimates of sediment discharge which can be used with confidence in project planning.

4.11 EVAPORATION

Evaporation data was obtained for four sites as shown in Table 4.25. As can be seen the data series for Debre Markos is significantly longer than the recorded data the other three sites, Ambo, Chagni and Fiche.

Table 4.25 : Mean Annual Evaporation for Sites in Ethiopia

Name	Elevation (m a.s.l.)	Mean Evaporation (mm/a)	Period	Complete years
Ambo Agri College	2130	1854	1984-1988	1
Chagni	1620	1706	1998-2003	4
Debre Markos	2515	1821	1966-2003	24
Fiche	2750	1437	1988-2003	8

Equivalent pan evaporation was derived based on a relationship between Piché evaporimeter and pan data. Lake evaporation for the Mandaya reservoir has been determined based on a pan factor of 0.8 and the difference in elevation between the various reservoirs as shown in Table 4.26.

Table 4.26 : Monthly Evaporation (mm) for Mandaya Reservoir

Month	Debra Markos pan	Debra Markos Reservoir	Karadobi Reservoir	Mandaya Reservoir FSL 800
January	206	165	185	192
February	200	160	179	186
March	202	162	181	188
April	199	159	178	186
May	165	132	148	154
June	79	63	71	74
July	42	34	38	39
August	41	33	37	38
September	72	58	64	67
October	138	110	124	129
November	155	124	139	145
December	188	150	168	175
Annual	1687	1350	1511	1573

4.12 REFERENCES

(1) The Hydrology of the Nile, J.V. Sutcliffe and Y.P. Parks, IAHS Special Publication no. 5, February 1999.

(2) Trap efficiency of reservoirs, Brune G.M, 1953, Transactions of the American Geophysical Union, Vol. 34, No. 3.

APPENDIX 4.1

Hydrology Data

Abay at Kessie
Units: m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	111.5	69.3	59.6	34.3	13.7	48.4	1512	3441	2091	871.2	424.1	237	748.9
1955	157.3	110.3	78.8	90	80.1	76.7	1145	2675	1518	759.1	396.5	221.9	613.8
1956	116.5	78.7	52.5	86.8	32.5	34.6	950.1	1953	916.4	869	380.9	230.7	479.4
1957	147.4	94.2	238.4	202.5	65	81.6	571.5	2043	792.6	314.1	190.8	130	409.2
1958	84.8	65.4	39.6	34.1	14.5	55.4	1197	2900	1200	714.7	391.4	239	583.6
1959	158.3	109.8	76.5	47.5	28.6	23.5	997.6	2801	1739	725.8	414.6	264.6	620
1960	175	125.2	99.9	65.7	51.7	36	1206	2433	1288	500.1	278.6	171.9	540.3
1961	127.2	90.8	72.1	117.5	65.7	44.5	1472	2302	1437	798.8	449.7	271.1	608.9
1962	164.4	104.8	83.6	50.5	42.5	49.7	516.8	2201	1385	727.4	333.2	201	491.6
1963	132.1	99.7	77.1	58.5	116	70.3	747.9	2412	1138	408.7	296.6	242.5	487.2
1964	150.5	104.3	58	65.2	34.8	91.7	1941	3206	1650	880.5	460.4	302	752.1
1965	191.4	125.1	81.5	80.4	36.4	26.4	315.3	1351	591.2	394.2	269.2	191.6	306.5
1966	119.5	101.9	62.2	45.6	24.3	36.9	363.2	1471	835.3	320.6	223.1	147.4	314.5
1967	97.2	61.8	62.6	81.4	106.6	38.1	1031	2244	1101	640.3	370.8	233.7	510.2
1968	134	97.1	63.6	64.4	43.8	136.2	1362	1736	780.9	480.3	258.7	176.9	448.6
1969	127.8	115.1	193.5	69.5	73.1	83.6	1064	3146	1602	400.1	258.8	165.2	613.1
1970	117.1	88.6	82.2	56.6	24	28.1	817.2	2742	1308	613	276.2	177.3	532
1971	105.7	66.2	45.7	37.9	39	103.3	858.6	2744	942.3	403	274.7	173	487.5
1972	107.5	68.3	46.6	59.8	35.3	57.4	551.7	979.9	415.4	181.1	122.1	75.7	226.9
1973	53.4	33.8	19.6	12.1	30.7	47.8	720.7	2545	883.3	413.7	236.9	141.7	432.7
1974	95.3	55.2	44.6	32.9	65.6	80.2	1477	2456	995.7	526.9	293.7	185.5	531.2
1975	119.3	95	60.2	39.5	26.4	120.8	1061	3023	2575	773.2	421.2	271.7	719.4
1976	180.9	114.2	90.7	75.2	74	61	685.8	2610	1185	452.3	370.2	202.9	512.4
1977	127.7	93.5	76	38.1	26.6	45.9	1048	2355	1476	628.4	517.1	243	560.2
1978	153.6	104.3	66.4	45.2	35.9	49.3	1039	1972	1020	564.2	270.9	178.4	462.2
1979	125.5	82.2	48	29.6	46.8	62.6	650.3	1680	713.9	338.5	211.6	135.1	346.6
1980	85.9	58.5	43.9	45.6	21.1	44.3	572.7	2028	1691	582.3	315.7	189	475.7
1981	115.7	100	80	70	62.1	30.1	1427	1952	1108	409.4	258.1	168	503.1
1982	120.9	77.6	64.8	56.2	52.4	41.2	261.5	1568	729.6	525.6	220.3	135	323.6
1983	82.9	57.1	50.7	63.5	97.3	86.5	275	1936	851	422.7	219.1	124.2	358.3
1984	75.9	44.2	24.6	16.1	40.8	136.1	601.9	759.2	461.4	152.9	89.8	64.1	207.1
1985	42.5	27.3	19.7	59.4	60.9	55.4	583.6	1942	1381	479.1	266.2	169.1	426.7
1986	108.9	79.4	68.3	90.9	129.2	53.2	1221	1894	1151	492.3	263.7	156.9	479.7
1987	96.1	64.2	100.4	88.7	108.5	148.5	221.4	1124	490.5	307.8	223.3	118.7	259.3
1988	70.4	56.4	32	26.4	14	33.1	1451	3645	1909	929.5	469.6	281.1	749.8
1989	152.1	91.9	83.2	103.5	45	52.4	590.1	1553	941.5	434.5	243.4	184.5	375.5
1990	92.4	64.7	45.9	43.7	22.7	17.4	513.4	1455	951.5	395.3	187.6	106.9	326.9
1991	63.5	49.6	38.3	56.1	55.4	59.5	1333	2593	1350	572.5	304	180.7	559.7
1992	103.9	73.3	52	34.5	38.4	27.8	414.6	2171	1170	707.2	406.9	225.5	455.4
1993	123.8	73.3	43.9	179.4	156.1	156.5	1313	1600	1704	751.5	388.9	210.2	561.5
1994	116.4	64.8	46.7	23.9	62.9	122	1842	3847	1982	685.1	392.9	147.4	784.7
1995	55.5	37.2	44.3	87.4	68.6	76.2	1077	2478	1123	294.1	185.1	107.7	473.9
1996	65.8	42.1	79.3	107.3	185.6	413.3	1992	3476	1416	641.2	369.5	250.3	760.5
1997	179.7	117.7	185.3	162.1	192.3	341.1	1414	1857	557.2	613.6	494.7	238.6	534.1
1998	180.8	65.1	46.2	33.6	100.4	114.8	1830	4238	1562	922.3	385.1	212.5	816.3
1999	155.6	126.3	72.5	62.2	27.7	75.8	1986	3286	1266	923.1	432.5	244.3	728.9
2000	158.3	112.4	35.5	112.5	54.4	52.7	1158	3053	1133	799.3	487.6	232.6	621.4
2001	88.9	88.4	208.5	214.2	178	282	2402	3293	1057	434.2	265.9	202.6	734
2002	237.7	210.5	189.5	196.4	151.8	216.4	846.7	2057	752.7	232.3	164.1	149.4	453.5
2003	129.9	122.7	142	137.3	98	143.4	1457	2553	969.7	275.8	162.4	154.9	533.8

Mean	121.7	85.2	75.5	73.8	65.1	87.4	1041.7	2355.6	1185.8	553.7	311.8	189.3	516.8
Max	237.7	210.5	238.4	214.2	192.3	413.3	2402	4238	2575	929.5	517.1	302	816.3
Min	42.5	27.3	19.6	12.1	13.7	17.4	221.4	759.2	415.4	152.9	89.8	64.1	207.1

Natural flow, does not take account of Beles Diversion

Abay : Incremental Flow Kessie to Karadobi
Units: m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	22.9	14.2	7.8	8.2	12.9	75.6	227.2	434.7	484.1	303.5	97.9	48.3	145.6
1955	33.3	18.0	8.3	11.4	22.2	65.2	216.6	469.4	569.3	326.8	102.0	51.0	158.6
1956	29.2	16.5	11.8	12.2	17.1	112.5	224.8	477.9	481.8	572.8	167.2	64.6	183.7
1957	33.9	20.8	22.7	38.8	25.9	78.9	201.0	569.6	424.1	140.1	61.6	31.9	138.3
1958	17.7	12.9	7.3	11.6	16.7	86.6	223.5	548.6	536.6	377.1	120.4	51.5	168.6
1959	30.7	20.4	12.3	8.1	25.9	52.2	132.7	424.3	581.5	357.0	139.6	61.8	154.5
1960	35.1	20.9	13.2	11.8	19.9	61.0	186.3	477.8	517.2	274.5	86.8	45.7	146.7
1961	22.2	15.6	8.5	10.0	9.0	65.1	246.5	544.2	655.9	434.1	120.0	73.1	184.8
1962	34.5	18.8	13.0	8.0	21.6	78.9	193.4	447.5	534.3	340.0	85.3	45.1	152.5
1963	25.7	13.1	9.5	13.3	45.5	66.9	218.8	536.5	504.0	182.9	93.3	80.1	150.0
1964	26.4	15.9	9.0	11.5	17.0	71.8	179.8	407.4	517.8	400.5	127.2	55.9	154.2
1965	31.1	19.7	11.2	13.9	8.8	56.9	190.5	476.3	394.9	298.7	118.9	59.8	141.0
1966	27.3	17.1	14.7	13.0	23.3	91.2	257.9	446.8	468.9	156.0	84.6	48.4	138.1
1967	20.7	12.6	8.8	5.6	10.2	64.2	187.7	429.0	504.7	384.5	102.1	67.3	150.7
1968	25.4	17.0	8.1	4.1	8.6	63.0	254.2	554.1	420.9	225.3	67.0	37.8	141.5
1969	16.5	10.4	11.0	9.7	24.3	77.3	212.5	537.2	319.8	142.3	54.0	25.3	121.0
1970	13.1	5.5	5.1	4.6	9.5	47.9	177.4	482.5	432.5	249.3	87.2	31.5	129.7
1971	19.1	10.8	5.5	3.1	14.8	70.9	210.1	442.1	451.7	218.9	100.6	39.2	133.0
1972	22.0	12.4	7.6	6.8	19.1	54.9	169.2	340.7	289.8	131.2	67.2	33.8	96.9
1973	18.1	10.2	6.0	6.9	29.8	81.0	167.3	515.2	485.6	259.1	93.1	42.0	143.7
1974	25.3	16.3	12.5	7.7	29.4	94.1	233.5	493.4	473.1	210.9	72.9	39.2	143.2
1975	16.2	13.3	7.6	5.2	11.5	54.2	223.5	443.8	558.2	247.6	80.2	36.3	142.1
1976	20.8	11.6	9.2	4.3	20.2	65.8	180.2	398.1	311.9	130.8	76.8	34.6	106.1
1977	17.6	11.3	6.7	7.7	19.2	81.1	345.4	455.8	401.4	226.9	122.6	40.9	145.7
1978	18.4	10.4	8.6	7.6	19.7	71.2	225.6	353.6	409.0	300.4	87.0	40.6	130.2
1979	23.9	16.4	9.4	8.4	30.9	75.2	185.8	375.7	328.3	166.4	64.5	30.8	110.3
1980	17.0	10.8	7.3	10.2	19.3	59.2	295.3	465.2	232.9	149.5	48.8	24.0	112.8
1981	12.4	3.9	2.6	3.5	15.6	49.5	115.7	418.1	437.3	200.9	58.8	25.3	112.6
1982	14.1	8.3	7.2	3.6	8.7	46.2	177.5	327.7	289.6	187.1	62.0	28.0	97.4
1983	13.6	9.2	5.1	4.2	7.9	43.4	157.2	458.6	397.5	221.2	76.5	33.0	119.7
1984	17.0	10.2	6.1	4.1	8.9	73.9	225.3	321.5	301.7	99.2	36.3	19.1	94.2
1985	9.9	7.0	4.7	3.8	27.6	62.8	217.3	491.5	462.7	158.4	51.9	25.3	127.7
1986	12.0	6.5	5.3	3.0	53.3	64.1	164.3	246.6	284.3	118.8	35.0	15.3	84.5
1987	7.7	5.1	4.1	3.9	25.1	103.6	198.6	343.1	274.7	163.0	67.1	29.8	102.8
1988	15.6	11.6	14.9	7.6	11.4	100.7	417.9	487.1	495.5	366.3	97.7	36.1	173.2
1989	17.6	11.0	7.1	7.7	15.3	50.8	228.7	385.0	412.6	176.4	52.1	29.8	116.9
1990	28.8	15.8	11.0	7.9	11.0	37.6	160.2	426.7	363.3	194.0	58.2	28.0	112.6
1991	16.4	8.9	7.7	9.3	23.4	69.8	234.8	369.4	380.6	153.6	64.0	34.7	115.1
1992	19.4	13.4	8.9	8.1	25.6	67.9	150.2	292.3	361.0	287.7	109.9	50.5	116.9
1993	28.5	17.9	11.7	11.7	34.2	126.6	238.3	527.3	415.3	277.8	116.2	48.8	155.5
1994	28.2	17.5	11.0	10.7	26.9	80.6	163.0	365.6	410.1	127.1	58.0	34.6	111.6
1995	17.6	11.3	7.3	6.1	17.1	60.9	111.6	309.9	293.1	146.1	56.9	29.2	89.4
1996	18.6	10.9	6.7	10.4	42.3	148.4	247.3	371.1	382.4	197.9	66.7	33.0	128.7
1997	18.0	7.4	5.2	5.9	17.8	92.1	218.2	345.6	279.3	158.5	140.0	53.4	112.4
1998	21.2	23.0	18.9	27.0	27.1	68.9	175.2	365.6	579.8	434.7	148.5	67.3	163.8
1999	36.0	21.5	12.6	7.4	38.1	102.3	159.9	393.6	443.3	445.1	142.4	61.6	156.2
2000	32.3	28.1	8.9	15.1	33.3	109.3	227.2	484.8	396.8	342.0	135.1	59.3	157.1
2001	31.9	13.2	9.6	12.4	22.6	99.3	155.5	470.4	477.9	205.3	94.3	42.8	136.9
2002	22.7	11.8	7.8	6.2	3.7	71.5	207.4	332.8	311.2	148.3	65.2	33.3	102.4
2003	17.1	10.7	10.7	8.0	7.9	79.1	233.4	366.5	400.8	203.4	64.6	29.2	120.0
Mean	22.0	13.5	9.2	9.0	20.7	74.6	207.0	429.0	422.8	244.4	87.7	41.8	132.6
Max	36.0	28.1	22.7	38.8	53.3	148.4	417.9	569.6	655.9	572.8	167.2	80.1	
Min	7.7	3.9	2.6	3.0	3.7	37.6	111.6	246.6	232.9	99.2	35.0	15.3	

Abay: **Flow at Karadobi (including effect of Beles Diversion)**
Units: **m3/s**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	84.1	69.3	66.2	47.1	33.4	75.8	1786	3673	2100	758.9	275.9	161.5	767.6
1955	113.9	85.6	64	93.9	89.1	101.4	1366	3003	1676	604	255.8	147.3	638.6
1956	86	70.2	44.6	94.3	36.9	43.2	1146	2567	1077	638.7	261	141.9	522.2
1957	109.6	83.4	292.5	201.2	49.1	87.5	717.3	2541	911.7	261	155.8	81.4	461.7
1958	74.8	69.6	49.1	52.1	35.7	85.7	1434	3182	1332	585.7	272.6	154	616.6
1959	113.9	79.8	51.8	47.3	42.6	45.9	1212	3169	1937	683.9	308	188.2	661.7
1960	132.6	81.6	62.8	37.2	60.7	50.7	1513	3021	1430	438.2	181.5	93.6	597.6
1961	97.3	75.7	70.8	110.8	68.3	70.3	1651	2735	1620	792.8	361.7	255.1	664.8
1962	119.5	73.6	50.8	31.1	54.1	73.6	672.4	2472	1394	541.3	193.3	123.2	487
1963	98.8	83.7	81.4	74.9	156	98.6	946.4	2981	1230	377.5	259.4	179.5	552.2
1964	108	77.3	21.9	56.7	41.6	117.4	2352	3579	1891	725.2	338.4	232.8	802.6
1965	142.5	80.9	62	99.9	45.1	44.3	456.5	2149	679.2	388.1	222.4	131	378.5
1966	91.6	85.2	56.9	52.1	39.4	62.9	536.6	2158	1177	253.2	168.7	100.7	401.2
1967	83.7	59.7	73.7	106.2	144.3	59.8	1298	2842	1390	713.8	317.9	172.8	610.8
1968	100.9	73.2	55.6	78.6	62.2	177.7	1507	2155	881	435.4	178.4	104.2	488.9
1969	95.4	93.7	234.5	65.2	85.8	108.9	1271	3353	1779	379.5	175.5	111.5	651.5
1970	92.5	94.6	97.9	75.4	42.6	52.4	1019	3068	1541	500.4	167.4	103.2	576
1971	81.5	71	55.1	56.9	59.7	144.7	1063	3098	1099	412.6	184.3	99.5	540.7
1972	81.9	70.9	52.3	82.6	54.5	87.4	741.2	1800	474.9	207.7	131.1	77	325.1
1973	60	34.2	31.3	33.8	54.8	80.3	929.6	3003	1091	380	161.2	90.1	500.9
1974	72.3	52	48	49.7	85	109.5	1736	2663	1092	376.9	183.7	110.8	554.1
1975	79.7	79.6	54.7	49.7	43.1	159.4	1286	3331	2437	700.8	301.6	211.1	732.6
1976	150	89.7	87.5	84.1	87.6	83.5	862	2827	1361	245.6	229.2	132.7	524.1
1977	88	86.2	79.9	51.2	43.2	68.1	1250	2581	1691	474.5	430	140.6	585.9
1978	101.5	72.4	49.8	44.8	40.7	69.2	1251	2427	1234	541.4	193.6	116.3	516.5
1979	95.6	81.2	45.8	41.8	61.1	91.9	838.4	2274	842.5	293.3	145.1	84.2	411.8
1980	63.7	55.6	48.8	63.2	43.3	76.1	759.7	2527	1908	556	248.9	137.8	544
1981	94.9	136.2	271.8	117.1	80.7	53.9	1643	2504	1356	371.9	180.9	109.9	581.6
1982	99.2	80.4	67.9	71	68.5	66.9	421.6	2268	890.2	407.9	163.2	92.1	394.8
1983	72.3	59.7	59.5	82	127.3	120	432.7	2512	1067	376.8	179.5	98.4	435.8
1984	70.4	50.8	39.6	38.6	61	186.4	824.3	1705	593.9	210.4	134	84.8	336.4
1985	56.1	27.6	31.7	80.6	81.7	83.7	777.9	2519	1641	417.9	191.1	112.5	505.3
1986	86.8	78.8	74.3	110.7	170.4	79.7	1465	2441	1385	424.3	184.9	104.4	555.2
1987	75.6	62.7	116.1	108.7	135.6	191	354.9	1945	541.9	250.5	163.7	89.7	339.3
1988	58.5	56.2	35.7	42.1	31.7	53.4	1685	3974	1945	855.3	408.2	299.9	794.5
1989	132.6	93	89.2	123.3	57.2	73.1	762.1	2140	1073	327.8	156	119.5	432.2
1990	74.9	68.3	54.5	61.4	40.5	36.6	701.1	2149	1151	325.1	139.8	83.4	410.3
1991	58.3	54.4	51.7	77.9	76.4	90.8	1571	2869	1449	434.4	186.5	111.3	591.4
1992	75.7	73.6	56.4	48.4	53.5	48.8	595.6	2614	1378	564.9	304.1	167.3	502.1
1993	96	76	44.6	224.2	200.9	200.2	1499	2194	1739	623.3	269.8	145	613.4
1994	86.3	64.7	48	34.6	73.9	155.8	2152	4306	2107	639.9	276.3	81.6	843.4
1995	73.7	55	63.3	114.5	92.7	111.6	1299	2894	1431	331.7	151.3	107.1	565.4
1996	82.5	47.4	98	128.8	255.8	508	2401	3847	1573	556.7	260.5	192.6	837.5
1997	154.7	83.3	156.6	119	192.9	356.6	1601	2398	659	471.6	421.7	192.2	572.8
1998	140.3	91.3	62.5	37.3	89.2	153.5	2112	4956	1700	864.3	254.4	130.2	892.3
1999	97.2	56.7	47.9	36.5	33.9	72.6	2323	3597	1493	856.1	309.6	177.3	766.8
2000	103.3	72.2	32.8	76.2	66.5	82.5	1326	3354	1309	653.6	413.5	176.4	644.9
2001	81.6	54.9	156.4	146.5	145.2	264.3	2821	3579	1311	422.9	177.6	116.2	781.7
2002	255.8	52.7	150.4	147.7	114.2	190.9	984.9	2539	955.3	254.4	123.8	72.8	491.5
2003	76.7	67.4	107.2	103.3	67.5	136.5	1679	2961	1296	352.3	141.4	81.3	594.9

Mean	96.5	71.9	78.1	80.2	79.5	112.9	1260.7	2828.9	1346.4	485.2	229.9	132.6	572.0
Max	255.8	136.2	292.5	224.2	255.8	508.0	2821.0	4956.0	2437.0	864.3	430.0	299.9	
Min	56.1	27.6	21.9	31.1	31.7	36.6	354.9	1705	474.9	207.7	123.8	72.8	

Abay: Incremental Flow Karadobi to Mandaya
Units: m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	76.2	47.2	26.0	27.3	43.1	251.6	755.7	1445.9	1610.5	1009.7	325.8	160.5	484.4
1955	110.6	59.8	27.7	38.0	73.8	217.0	720.4	1561.4	1893.9	1087.0	339.2	169.8	527.6
1956	97.2	54.8	39.3	40.7	57.0	374.3	747.9	1589.9	1602.9	1905.4	556.2	215.1	611.0
1957	112.9	69.1	75.4	129.0	86.1	262.4	668.7	1894.8	1410.9	466.2	205.0	106.2	459.9
1958	59.0	43.0	24.4	38.7	55.4	287.9	743.5	1824.9	1784.9	1254.5	400.4	171.3	560.8
1959	102.1	67.8	40.9	26.8	86.2	173.6	441.5	1411.6	1934.4	1187.7	464.3	205.4	514.0
1960	116.8	69.5	43.8	39.4	66.1	203.1	619.8	1589.4	1720.6	913.3	288.8	152.1	488.0
1961	73.7	52.0	28.1	33.4	30.1	216.6	820.0	1810.3	2181.9	1444.2	399.3	243.0	614.6
1962	114.6	62.5	43.2	26.6	72.0	262.5	643.3	1488.5	1777.5	1131.0	283.8	150.1	507.4
1963	85.6	43.5	31.7	44.1	151.4	222.6	728.0	1784.9	1676.5	608.5	310.4	266.6	499.1
1964	87.8	52.8	30.0	38.1	56.6	238.8	598.0	1355.2	1722.5	1332.3	423.1	185.8	512.9
1965	103.4	65.4	37.3	46.3	29.1	189.2	633.6	1584.5	1313.7	993.7	395.7	199.0	469.0
1966	90.8	56.9	48.8	43.3	77.5	303.3	857.9	1486.3	1559.9	518.8	281.6	161.0	459.5
1967	68.7	41.9	29.2	18.5	33.9	213.5	624.4	1427.1	1678.9	1279.2	339.7	223.9	501.3
1968	84.3	56.7	27.0	13.7	28.6	209.7	845.7	1843.3	1400.0	749.4	222.8	125.8	470.8
1969	54.8	34.7	36.6	32.1	80.9	257.3	707.0	1787.2	1063.7	473.3	179.7	84.3	402.5
1970	43.5	18.2	17.1	15.4	31.6	159.4	590.0	1605.0	1438.6	829.3	290.2	104.8	431.4
1971	63.4	35.8	18.2	10.4	49.4	236.0	699.0	1470.7	1502.6	728.3	334.7	130.5	442.3
1972	73.3	41.2	25.1	22.8	63.5	182.7	562.7	1133.3	964.0	436.6	223.6	112.4	322.2
1973	60.3	33.9	20.0	23.0	99.1	269.4	556.5	1713.9	1615.3	862.0	309.7	139.6	478.0
1974	84.3	54.2	41.5	25.7	97.8	313.2	776.9	1641.4	1573.8	701.7	242.6	130.4	476.4
1975	53.8	44.2	25.3	17.3	38.4	180.3	743.4	1476.3	1857.0	823.5	266.7	120.8	472.9
1976	69.3	38.7	30.5	14.4	67.1	218.7	599.6	1324.3	1037.5	435.3	255.6	115.2	352.8
1977	58.4	37.5	22.2	25.6	63.9	269.9	1149.1	1516.2	1335.4	754.7	407.9	136.0	484.7
1978	61.1	34.7	28.7	25.4	65.5	237.0	750.4	1176.2	1360.5	999.5	289.4	134.9	433.0
1979	79.6	54.4	31.2	27.9	102.6	250.2	617.9	1249.7	1092.1	553.6	214.7	102.5	366.9
1980	56.6	35.9	24.4	34.0	64.2	197.0	982.4	1547.6	774.9	497.4	162.5	79.8	375.1
1981	41.3	12.8	8.6	11.6	51.8	164.7	384.9	1390.9	1454.8	668.4	195.7	84.3	374.5
1982	47.0	27.6	23.9	11.9	29.1	153.8	590.4	1090.0	963.3	622.5	206.2	93.1	323.9
1983	45.1	30.6	16.9	13.9	26.4	144.3	522.8	1525.5	1322.2	735.7	254.4	109.7	398.2
1984	56.7	34.0	20.2	13.7	29.6	245.7	749.4	1069.5	1003.8	330.0	120.8	63.5	313.4
1985	33.0	23.1	15.6	12.5	91.7	208.9	722.9	1635.0	1539.4	526.9	172.6	84.1	424.8
1986	39.9	21.7	17.6	10.1	177.2	213.2	546.5	820.2	945.6	395.2	116.4	51.0	281.2
1987	25.7	17.0	13.6	13.0	83.4	344.5	660.7	1141.5	913.8	542.2	223.3	99.2	342.1
1988	51.8	38.4	49.6	25.2	37.8	335.1	1390.1	1620.3	1648.5	1218.4	325.0	120.2	576.1
1989	58.6	36.5	23.5	25.5	51.0	169.0	760.7	1280.7	1372.6	587.0	173.4	99.1	388.8
1990	95.7	52.4	36.7	26.4	36.6	125.2	532.8	1419.6	1208.5	645.2	193.8	93.2	374.6
1991	54.6	29.5	25.5	30.9	78.0	232.0	781.0	1228.9	1266.2	510.9	212.8	115.3	382.8
1992	64.6	44.5	29.5	26.9	85.2	226.0	499.6	972.4	1200.7	957.1	365.6	168.1	388.9
1993	94.7	59.5	38.8	38.9	113.7	421.0	792.7	1754.1	1381.5	924.2	386.7	162.4	517.3
1994	93.8	58.2	36.4	35.5	89.6	268.0	542.2	1216.3	1364.3	422.9	192.8	115.1	371.1
1995	58.7	37.5	24.2	20.4	57.0	202.7	371.3	1030.8	975.2	486.0	189.2	97.0	297.4
1996	61.9	36.3	22.3	34.6	140.6	493.6	822.6	1234.3	1272.2	658.3	221.8	109.7	428.1
1997	59.9	24.5	17.3	19.6	59.2	306.4	725.7	1149.8	929.1	527.3	465.8	177.6	374.1
1998	70.5	76.6	62.8	90.0	90.1	229.0	583.0	1216.1	1928.6	1446.2	493.9	224.0	544.8
1999	119.7	71.5	42.1	24.5	126.6	340.2	532.1	1309.5	1474.8	1480.5	473.9	204.8	519.7
2000	107.5	93.5	29.8	50.2	110.7	363.7	756.0	1612.9	1319.9	1137.8	449.5	197.4	522.5
2001	106.2	43.9	31.8	41.3	75.2	330.2	517.4	1564.7	1589.8	683.0	313.8	142.4	455.4
2002	75.4	39.2	25.9	20.6	12.4	237.9	689.9	1107.2	1035.1	493.3	216.7	110.8	340.7
2003	56.8	35.8	35.7	26.6	26.4	263.2	776.5	1219.3	1333.3	676.7	214.8	97.1	399.1
Mean	73.2	45.0	30.4	30.0	69.0	248.3	688.7	1427.0	1406.5	813.0	291.8	138.9	441.2
Max	119.7	93.5	75.4	129.0	177.2	493.6	1390.1	1894.8	2181.9	1905.4	556.2	266.6	
Min	25.7	12.8	8.6	10.1	12.4	125.2	371.3	820.2	774.9	330.0	116.4	51.0	

Abay : Flow at Mandaya
Units: m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	160.3	116.5	92.2	74.4	76.5	327.4	2541.7	5118.9	3710.5	1768.6	601.7	322.0	1252.5
1955	224.5	145.4	91.7	131.9	162.9	318.4	2086.4	4564.4	3569.9	1691.0	595.0	317.1	1166.6
1956	183.2	125.0	83.9	135.0	93.9	417.5	1893.9	4156.9	2679.9	2544.1	817.2	357.0	1133.4
1957	222.5	152.5	367.9	330.2	135.2	349.9	1386.0	4435.8	2322.6	727.2	360.8	187.6	921.9
1958	133.8	112.6	73.5	90.8	91.1	373.6	2177.5	5006.9	3116.9	1840.2	673.0	325.3	1177.8
1959	216.0	147.6	92.7	74.1	128.8	219.5	1653.5	4580.6	3871.4	1871.6	772.3	393.6	1176.2
1960	249.4	151.1	106.6	76.6	126.8	253.8	2132.8	4610.4	3150.6	1351.5	470.3	245.7	1085.7
1961	171.0	127.7	98.9	144.2	98.4	286.9	2471.0	4545.3	3801.9	2237.0	761.0	498.1	1279.7
1962	234.1	136.1	94.0	57.7	126.1	336.1	1315.7	3960.5	3171.5	1672.3	477.1	273.3	994.6
1963	184.4	127.2	113.1	119.0	307.4	321.2	1674.4	4765.9	2906.5	986.0	569.8	446.1	1051.6
1964	195.8	130.1	51.9	94.8	98.2	356.2	2950.0	4934.2	3613.5	2057.5	761.5	418.6	1315.9
1965	245.9	146.3	99.3	146.2	74.2	233.5	1090.1	3733.5	1992.9	1381.8	618.1	330.0	847.7
1966	182.4	142.1	105.7	95.4	116.9	366.2	1394.5	3644.3	2736.9	772.0	450.3	261.7	860.9
1967	152.4	101.6	102.9	124.7	178.2	273.3	1922.4	4269.1	3068.9	1993.0	657.6	396.7	1112.4
1968	185.2	129.9	82.6	92.3	90.8	387.4	2352.7	3998.3	2281.0	1184.8	401.2	230.0	959.9
1969	150.2	128.4	271.1	97.3	166.7	366.2	1978.0	5140.2	2842.7	852.8	355.2	195.8	1054.3
1970	136.0	112.8	115.0	90.8	74.2	211.8	1609.0	4673.0	2979.6	1329.7	457.6	208.0	1007.8
1971	144.9	106.8	73.3	67.3	109.1	380.7	1762.0	4568.7	2601.6	1140.9	519.0	230.0	983.4
1972	155.2	112.1	77.4	105.4	118.0	270.1	1303.9	2933.3	1438.9	644.3	354.7	189.4	647.3
1973	120.3	68.1	51.3	56.8	153.9	349.7	1486.1	4716.9	2706.3	1242.0	470.9	229.7	979.2
1974	156.6	106.2	89.5	75.4	182.8	422.7	2512.9	4304.4	2665.8	1078.6	426.3	241.2	1030.8
1975	133.5	123.8	80.0	67.0	81.5	339.7	2029.4	4807.3	4294.0	1524.3	568.3	331.9	1205.9
1976	219.3	128.4	118.0	98.5	154.7	302.2	1461.6	4151.3	2398.5	680.9	484.8	247.9	877.1
1977	146.4	123.7	102.1	76.8	107.1	338.0	2399.1	4097.2	3026.4	1229.2	837.9	276.6	1071.0
1978	162.6	107.1	78.5	70.2	106.2	306.2	2001.4	3603.2	2594.5	1540.9	483.0	251.2	949.8
1979	175.2	135.6	77.0	69.7	163.7	342.1	1456.3	3523.7	1934.6	846.9	359.8	186.7	778.9
1980	120.3	91.5	73.2	97.2	107.5	273.1	1742.1	4074.6	2682.9	1053.4	411.4	217.6	919.3
1981	136.2	149.0	280.4	128.7	132.5	218.6	2027.9	3894.9	2810.8	1040.3	376.6	194.2	956.5
1982	146.2	108.0	91.8	82.9	97.6	220.7	1012.0	3358.0	1853.5	1030.4	369.4	185.2	718.8
1983	117.4	90.3	76.4	95.9	153.7	264.3	955.5	4037.5	2389.2	1112.5	433.9	208.1	834.3
1984	127.1	84.8	59.8	52.3	90.6	432.1	1573.7	2774.5	1597.7	540.4	254.8	148.3	649.9
1985	89.1	50.7	47.3	93.1	173.4	292.6	1500.8	4154.0	3180.4	944.8	363.7	196.6	930.4
1986	126.7	100.5	91.9	120.8	347.6	292.9	2011.5	3261.2	2330.6	819.5	301.3	155.4	836.7
1987	101.3	79.7	129.7	121.7	219.0	535.5	1015.6	3086.5	1455.7	792.7	387.0	188.9	681.6
1988	110.3	94.6	85.3	67.3	69.5	388.5	3075.1	5594.3	3593.5	2073.7	733.2	420.1	1371.0
1989	191.2	129.5	112.7	148.8	108.2	242.1	1522.8	3420.7	2445.6	914.8	329.4	218.6	821.3
1990	170.6	120.7	91.2	87.8	77.1	161.8	1233.9	3568.6	2359.5	970.3	333.6	176.6	785.2
1991	112.9	83.9	77.2	108.8	154.4	322.8	2352.0	4097.9	2715.2	945.3	399.3	226.6	974.5
1992	140.3	118.1	85.9	75.3	138.7	274.8	1095.2	3586.4	2578.7	1522.0	669.7	335.4	891.2
1993	190.7	135.5	83.4	263.1	314.6	621.2	2291.7	3948.1	3120.5	1547.5	656.5	307.4	1131.0
1994	180.1	122.9	84.4	70.1	163.5	423.8	2694.2	5522.3	3471.3	1062.8	469.1	196.7	1215.1
1995	132.4	92.5	87.5	134.9	149.7	314.3	1670.3	3924.8	2406.2	817.7	340.5	204.1	863.2
1996	144.4	83.7	120.3	163.4	396.4	1001.6	3223.6	5081.3	2845.2	1215.0	482.3	302.3	1266.0
1997	214.6	107.8	173.9	138.6	252.1	663.0	2326.7	3547.8	1588.1	998.9	887.5	369.8	947.2
1998	210.8	167.9	125.3	127.3	179.3	382.5	2695.0	6172.1	3628.6	2310.5	748.3	354.2	1437.7
1999	216.9	128.2	90.0	61.0	160.5	412.8	2855.1	4906.5	2967.8	2336.6	783.5	382.1	1286.9
2000	210.8	165.7	62.6	126.4	177.2	446.2	2082.0	4966.9	2628.9	1791.4	863.0	373.8	1167.6
2001	187.8	98.8	188.2	187.8	220.4	594.5	3338.4	5143.7	2900.8	1105.9	491.4	258.6	1237.6
2002	331.2	91.9	176.3	168.3	126.6	428.8	1674.8	3646.2	1990.4	747.7	340.5	183.6	832.6
2003	133.5	103.2	142.9	129.9	93.9	399.7	2455.5	4180.3	2629.3	1029.0	356.2	178.4	994.4
Mean	169.7	116.9	108.6	110.3	148.5	361.2	1949.4	4255.9	2753.0	1298.2	521.7	271.5	1013.5
Max	331.2	167.9	367.9	330.2	396.4	1001.6	3338.4	6172.1	4294.0	2544.1	887.5	498.1	
Min	89.1	50.7	47.3	52.3	69.5	161.8	955.5	2774.5	1438.9	540.4	254.8	148.3	

Abay: **Incremental Flow Mandaya to Border**
Units: **m3/s**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	129.4	63.2	28.2	23.8	37.9	309.4	737.4	1703.3	2146.6	1463.8	584.2	290.4	629.6
1955	191.5	104.8	51.8	47.0	89.7	265.8	743.2	1761.9	2376.9	1610.0	594.7	301.8	681.4
1956	160.5	81.9	60.5	47.0	71.9	492.4	805.2	1514.0	1984.8	2780.6	864.3	376.6	775.0
1957	188.9	103.3	46.8	174.0	131.2	345.3	749.3	2038.0	1769.3	677.1	309.4	190.8	563.1
1958	89.0	53.4	23.2	33.9	53.0	355.1	758.1	2160.5	2257.0	1808.1	654.7	314.3	717.6
1959	181.1	120.7	79.4	36.1	101.4	209.9	376.6	1521.3	2391.1	1631.6	728.0	351.4	646.2
1960	198.8	136.6	95.7	81.2	79.5	257.1	522.6	1539.4	2161.0	1284.3	483.7	281.9	595.9
1961	128.6	84.7	39.0	51.4	37.6	264.1	918.6	1990.0	2737.3	1939.0	622.4	341.3	766.7
1962	198.3	114.8	90.6	55.0	84.8	327.5	705.4	1721.3	2370.1	1699.9	519.8	278.7	683.6
1963	147.8	74.2	38.2	42.7	162.6	269.6	775.8	1819.9	2151.8	845.6	452.7	419.8	603.0
1964	160.0	97.6	76.2	59.5	68.9	293.9	389.4	1440.8	2064.4	1938.5	688.2	317.9	636.1
1965	187.3	131.7	69.5	42.4	30.3	235.3	706.9	1322.7	1670.3	1336.1	576.4	327.0	555.6
1966	149.5	92.8	70.6	51.5	88.6	379.9	974.8	1302.3	1746.1	761.8	431.3	262.1	528.1
1967	105.5	58.2	28.0	-0.1	7.7	264.1	568.7	1312.2	1958.1	1638.6	507.5	360.6	570.4
1968	146.0	99.7	44.2	4.1	19.8	239.2	986.9	2048.2	1773.8	1047.9	378.5	241.0	589.9
1969	105.7	67.9	8.0	47.3	95.5	319.0	739.3	2185.1	1246.8	654.1	323.8	166.5	500.2
1970	82.8	18.3	7.2	1.8	23.7	189.0	587.9	1822.2	1692.5	1222.6	497.2	214.4	533.5
1971	109.1	43.1	15.0	-5.1	45.4	274.4	731.2	1614.5	1854.4	965.2	538.4	248.1	538.8
1972	123.7	52.6	28.0	7.7	65.8	214.5	563.6	696.8	1230.8	557.7	290.3	149.2	333.0
1973	74.2	45.0	15.0	9.1	108.6	328.1	536.0	1835.9	1954.2	1187.4	490.2	238.5	571.4
1974	135.8	75.8	52.2	17.6	111.5	389.8	780.9	1990.0	2010.1	1089.1	434.8	249.2	614.7
1975	111.5	74.5	39.4	12.9	34.7	202.7	770.0	1667.9	2623.5	1174.7	476.5	222.2	619.7
1976	123.6	76.3	44.1	10.3	76.2	270.3	626.3	1555.5	1212.6	789.3	483.1	224.4	460.6
1977	117.9	57.6	25.8	21.2	68.9	339.1	1336.0	1803.4	1572.4	1164.0	633.1	284.4	623.0
1978	133.9	78.3	55.0	34.4	82.9	297.2	792.4	1119.3	1606.9	1360.5	464.6	242.7	525.1
1979	136.4	73.9	44.0	25.2	123.1	305.6	638.9	1078.7	1333.1	786.2	353.9	188.1	425.9
1980	97.9	50.9	27.8	27.8	63.7	231.9	1127.9	1572.4	820.2	692.0	284.2	158.0	433.8
1981	76.1	-19.0	-180.3	-31.5	50.7	196.6	299.2	1309.7	1699.2	932.1	339.1	170.9	405.4
1982	84.6	34.1	28.9	1.2	22.8	180.2	630.1	759.0	1128.7	950.9	333.1	167.5	362.2
1983	70.9	38.3	13.9	0.1	5.4	159.7	542.0	1465.8	1553.7	1030.6	380.1	172.7	455.4
1984	81.4	38.9	12.0	-4.1	19.4	278.6	780.7	485.7	1211.0	384.2	117.5	64.3	290.1
1985	30.6	30.7	8.9	-4.4	101.9	251.3	773.3	1611.4	1800.4	766.4	306.1	169.1	489.8
1986	75.5	29.7	17.5	-6.2	196.0	258.8	487.4	550.8	1031.7	597.0	234.6	120.8	300.8
1987	54.9	24.2	2.5	-2.5	84.5	418.6	750.8	706.8	1171.6	783.0	358.4	161.7	377.9
1988	81.2	51.7	62.7	18.0	32.9	428.2	1626.6	1839.6	2170.4	1705.0	496.4	142.1	726.3
1989	98.0	47.8	25.5	14.4	56.0	205.5	846.1	1127.2	1705.6	892.3	319.5	197.6	463.6
1990	145.5	66.6	40.5	17.6	31.2	148.3	525.4	1206.1	1418.1	933.8	307.1	148.2	417.9
1991	78.2	34.7	20.8	19.6	83.3	279.3	807.3	1368.8	1595.8	821.9	402.3	223.8	480.6
1992	114.6	59.2	35.1	22.1	98.9	281.5	487.7	858.5	1399.1	1423.3	592.1	283.2	473.7
1993	154.5	76.9	51.3	7.3	107.4	519.8	875.0	1753.7	1814.0	1365.2	636.7	282.6	640.5
1994	155.6	78.0	47.5	36.8	108.9	324.9	415.7	1168.9	1701.0	611.3	374.7	219.8	438.0
1995	60.4	32.4	13.4	0.2	52.2	235.9	275.0	963.7	997.2	612.9	287.1	130.4	306.5
1996	66.1	43.3	11.2	24.8	118.1	566.0	692.1	1281.1	1545.7	965.6	405.9	204.5	496.0
1997	105.2	67.2	51.9	69.3	78.6	394.5	784.3	997.9	1141.8	847.8	696.5	284.2	461.9
1998	134.8	76.4	67.7	116.7	131.8	267.9	498.3	909.7	2443.3	1993.7	791.8	382.2	653.1
1999	218.6	165.3	80.9	58.5	163.3	458.5	375.1	1441.7	1746.9	2048.6	757.1	341.1	657.6
2000	198.9	165.3	42.5	103.4	136.1	457.1	843.8	1857.8	1590.7	1668.6	675.7	320.4	675.9
2001	149.5	92.3	94.6	123.0	133.5	459.7	273.4	1808.3	1873.8	925.4	508.3	277.0	561.8
2002	82.9	210.3	73.8	76.3	54.2	343.9	785.2	999.9	1182.8	638.2	330.4	224.9	417.9
2003	129.3	103.2	82.6	69.6	65.9	359.2	817.3	1224.0	1458.3	829.2	308.5	203.6	473.1

Mean	123.2	73.6	38.2	33.8	78.0	306.9	702.8	1436.7	1721.9	1156.7	472.5	242.7	535.0
Max	218.6	210.3	95.7	174.0	196.0	566.0	1626.6	2185.1	2737.3	2780.6	864.3	419.8	
Min	30.6	-19.0	-180.3	-31.5	5.4	148.3	273.4	485.7	820.2	384.2	117.5	64.3	

Nile at El Deim
Units: m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1954	290	180	120	98	114	637	3279	6822	5857	3232	1186	612	1882
1955	416	250	143	179	253	584	2830	6326	5947	3301	1190	619	1848
1956	344	207	144	182	166	910	2699	5671	4665	5325	1682	734	1904
1957	411	256	415	504	266	695	2135	6474	4092	1404	670	378	1485
1958	223	166	97	125	144	729	2936	7167	5374	3648	1328	640	1895
1959	397	268	172	110	230	429	2030	6102	6262	3503	1500	745	1822
1960	448	288	202	158	206	511	2655	6150	5312	2636	954	528	1677
1961	300	212	138	196	136	551	3390	6535	6539	4176	1383	839	2046
1962	432	251	185	113	211	664	2021	5682	5542	3372	997	552	1678
1963	332	201	151	162	470	591	2450	6586	5058	1832	1023	866	1655
1964	356	228	128	154	167	650	3339	6375	5678	3996	1450	737	1947
1965	433	278	169	189	105	469	1797	5056	3663	2718	1194	657	1403
1966	332	235	176	147	206	746	2369	4947	4483	1534	882	524	1389
1967	258	160	131	125	186	537	2491	5581	5027	3632	1165	757	1683
1968	331	230	127	96	111	627	3340	6047	4055	2233	780	471	1546
1969	256	196	279	145	262	685	2717	7325	4090	1507	679	362	1555
1970	219	131	122	93	98	401	2197	6495	4672	2552	955	422	1541
1971	254	150	88	62	154	655	2493	6183	4456	2106	1057	478	1522
1972	279	165	105	113	184	485	1868	3630	2670	1202	645	339	978
1973	195	113	66	66	263	678	2022	6553	4660	2429	961	468	1551
1974	292	182	142	93	294	813	3294	6294	4676	2168	861	490	1645
1975	245	198	119	80	116	542	2799	6475	6917	2699	1045	554	1826
1976	343	205	162	109	231	573	2088	5707	3611	1470	968	472	1334
1977	264	181	128	98	176	677	3735	5901	4599	2393	1471	561	1694
1978	297	185	133	105	189	603	2794	4723	4201	2901	948	494	1475
1979	312	209	121	95	287	648	2095	4602	3268	1633	714	375	1205
1980	218	142	101	125	171	505	2870	5647	3503	1745	696	376	1350
1981	212	130	100	97	183	415	2327	5205	4510	1972	716	365	1362
1982	231	142	121	84	120	401	1642	4117	2982	1981	703	353	1081
1983	188	129	90	96	159	424	1498	5503	3943	2143	814	381	1290
1984	208	124	72	48	110	711	2354	3260	2809	925	372	213	938
1985	120	81	56	89	275	544	2274	5765	4981	1711	670	366	1420
1986	202	130	109	115	544	552	2499	3812	3362	1417	536	276	1138
1987	156	104	132	119	303	954	1766	3793	2627	1576	745	351	1059
1988	191	146	148	85	102	817	4702	7434	5764	3779	1230	562	2092
1989	289	177	138	163	164	448	2369	4548	4151	1807	649	416	1285
1990	316	187	132	105	108	310	1759	4775	3778	1904	641	325	1203
1991	191	119	98	128	238	602	3159	5467	4311	1767	802	450	1455
1992	255	177	121	97	238	556	1583	4445	3978	2945	1262	619	1361
1993	345	212	135	270	422	1141	3167	5702	4934	2913	1293	590	1771
1994	336	201	132	107	272	749	3110	6691	5172	1674	844	417	1653
1995	193	125	101	135	202	550	1945	4889	3403	1431	628	335	1170
1996	210	127	132	188	514	1568	3916	6362	4391	2181	888	507	1757
1997	320	175	226	208	331	1057	3111	4546	2730	1847	1584	654	1409
1998	346	244	193	244	311	650	3193	7082	6072	4304	1540	736	2091
1999	436	293	171	119	324	871	3230	6348	4715	4385	1541	723	1944
2000	410	331	105	230	313	903	2926	6825	4220	3460	1539	694	1839
2001	337	191	283	311	354	1054	3612	6952	4775	2031	1000	536	1799
2002	414	302	250	245	181	773	2460	4646	3173	1386	671	408	1250
2003	263	206	226	199	160	759	3273	5404	4088	1858	665	382	1467

Mean	293	190	147	144	227	668	2652	5693	4475	2455	994	514	1547
Max	448	331	415	504	544	1568	4702	7434	6917	5325	1682	866	
Min	120	81	56	48	98	310	1498	3260	2627	925	372	213	

5. RESERVOIR MODELLING

5.1 INTRODUCTION

The objective of the reservoir modelling studies that have been carried out comprise definition of the reservoir operation, energy outputs, downstream flows and impacts of the Mandaya project. Computer simulations have been carried out as necessary to estimate on a comparable basis the energy characteristics of the potential alternative scheme configurations.

The simulations have been performed employing a program named RAPSO that has been developed over a long period of years to represent seasonal and annual operation of any combination of hydroelectric schemes in some detail, and of which an application was set up and calibrated for the recent National Electricity Corporation (NEC) long-term power system planning study to represent all existing and potential schemes in the Sudanese Nile system. That application was supplied to NEC under licence and subsequently employed also for a feasibility study of possible irrigation as might be associated with the Merowe hydroelectric scheme now under construction on the Main Nile. For the current pre-feasibility studies the program application has been extended to include potential Ethiopian schemes and also High Aswan in Egypt.

The configuration of the main irrigation and hydroelectric system now modelled for the application is shown diagrammatically in Figure 5.1. As can be seen in that figure, the existing and potential future systems are represented as a series of interconnected nodes, each representing either a reservoir and power station, or a reservoir, or a water inflow or water extraction or flow calibration point. As defined by the user, any particular case study may utilise only a selection of the nodes shown in the figure, while for simulation of any one scheme the reservoir inflows reflect the upstream flows as measured at the perimeter of the system and automatically within each program run make due allowance for:

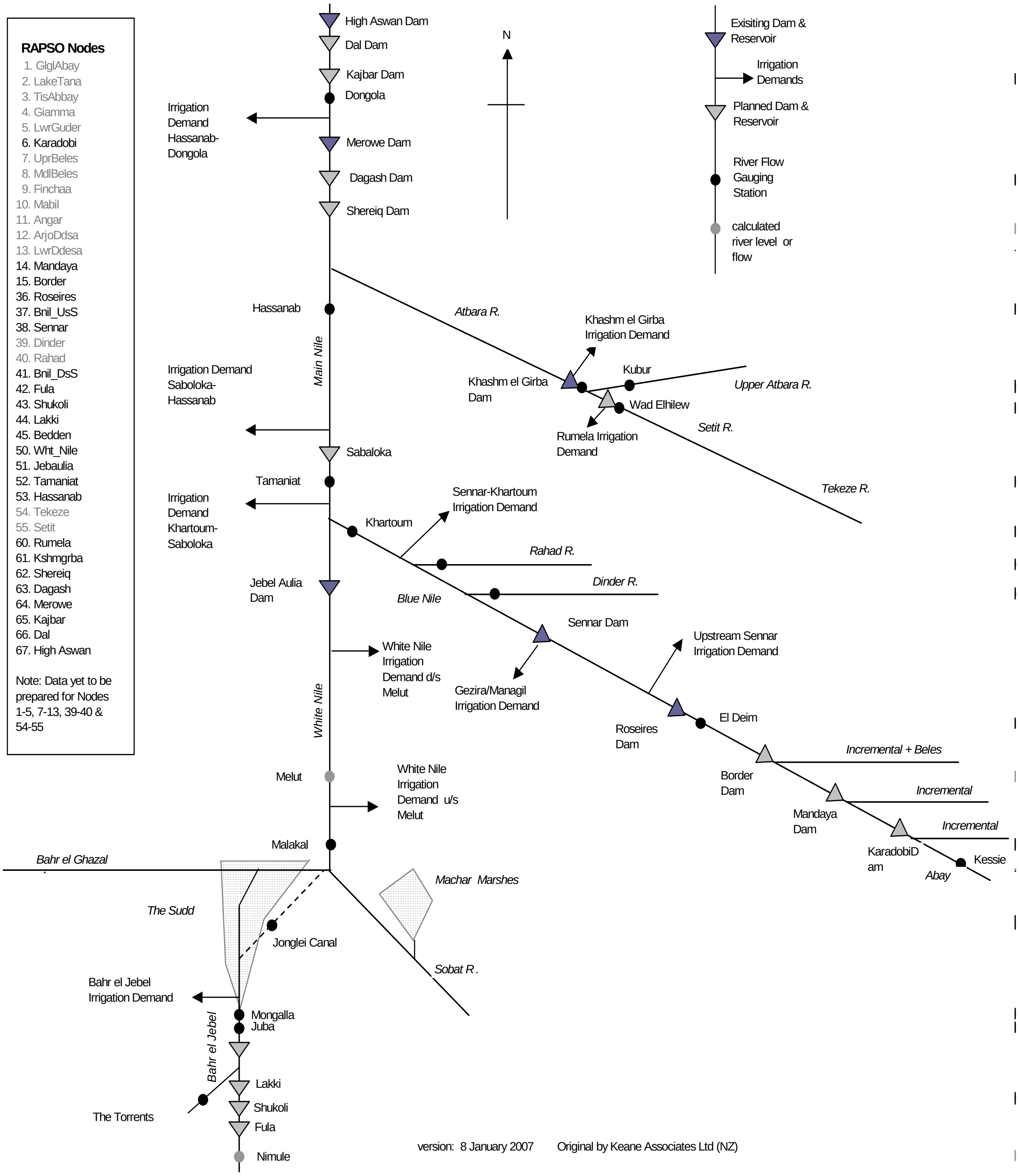
- water abstractions at the various irrigation supply points,
- optimisation of the operation of all upstream reservoirs and power plants in the system simulated, and
- losses from reservoirs and the various river reaches.

The modelling for this study is based on conventional methodology whereby system operation is simulated continuously over a period of hydrological record defined in terms of data time series, and supply reliabilities are measured over the hydrological period in terms of incidences of failure to supply demands in full. As appropriate, the various reservoir operating policies are represented by applying water demands, rule curves and time-of-filling rules and then using the program automatically to:

(a) maximise firm energies with the desired reliability and without irrigation supply reliabilities being adversely affected, and then
(b) optimise other rule curves so as to maximise secondary energies without adverse effect on the firm supply reliabilities.

Consistent with previous studies and published data supplements for *The Nile Basin*, this program application employs three simulation time steps per month (these being of lengths 10 days, 10 days and balance-of-calendar-month days).

Figure 5.1 : Abbay and Nile System as Currently Modelled with Program RAPSO



5.2 DESCRIPTION OF THE RAPSO PROGRAM

RAPSO (Reservoir And Power Station Operation) provides a detailed computer model of operation of any system of reservoirs, hydroelectric power stations and water supply for other than or in conjunction with hydroelectric purposes. Each "node" of the system is represented by selection of the appropriate combination of the facilities illustrated in Figure 5.2. Extensive facilities enable a model to be calibrated against hydrological records, and the program also provides automatic derivation of:

- firm and average energy characteristics or operating policy defined in terms of various rule curves and demand levels with or without thermal plant available in a supporting role; optimisation can be either to meet water and electricity demands with defined levels of reliability or to maximise the value of energy output against a price forecast or to meet some combination of requirements, for example to supply domestic demands on a firm basis and otherwise maximise the monetary value of exports; and

- statistical results of applying a fixed operating policy from known starting conditions.

All program inputs are arranged as a series of options, with only the selected options having any influence on subsequent calculations. The program is thus entirely data driven and requires no coding modifications when changing from one system to another.

Simulation detail is itself optional, for example the program time step is variable from half an hour to a month and the same program can be used for all stages of scheme development, from initial calculations through to detailed operational analysis for the completed scheme.

Similarly, the program can be used to investigate effects of including greater detail and hence determine the extent appropriate for the circumstances. Thus, for example, representation of water flow and storage can allow for variations such as in i) tunnel and penstock friction losses with water flow, ii) turbine efficiency with both hydraulic net head and flow, iii) generator efficiency with output, and iv) tail-water level with flow. It is thus readily possible to assess errors arising from common simplifying assumptions, such as:

- a constant value of efficiency instead of the real variations with net head and flow

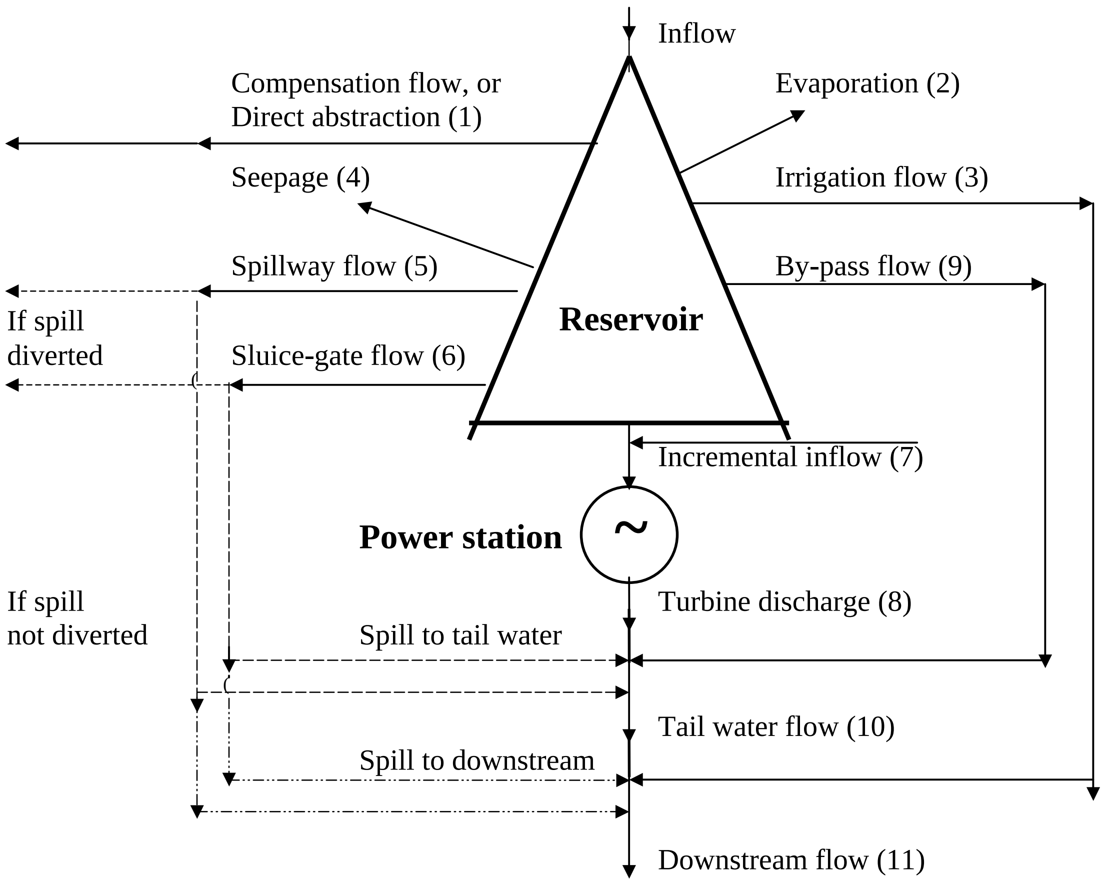
- average rates of flow and reservoir and tailwater levels for each month

Calculations in RAPSO are controlled according to water or energy demands or both and also by various reservoir seasonal control levels: in all cases an iterative technique with rapid convergence is employed (as outlined in Figure 5.3), ensuring that a compatible solution is obtained for each time step in turn. Cascade effects can be fully evaluated with any applicable water flow limits, times of water travel and losses between successive nodes being explicitly accommodated. Auxiliary software provides automatic data or results time series manipulation and presentation in tabular form, and also graphically using Microsoft Excel.

RAPSO has facilities for automatic determination of “hydro conditions” as commonly required for input to computer programs for power system expansion planning.

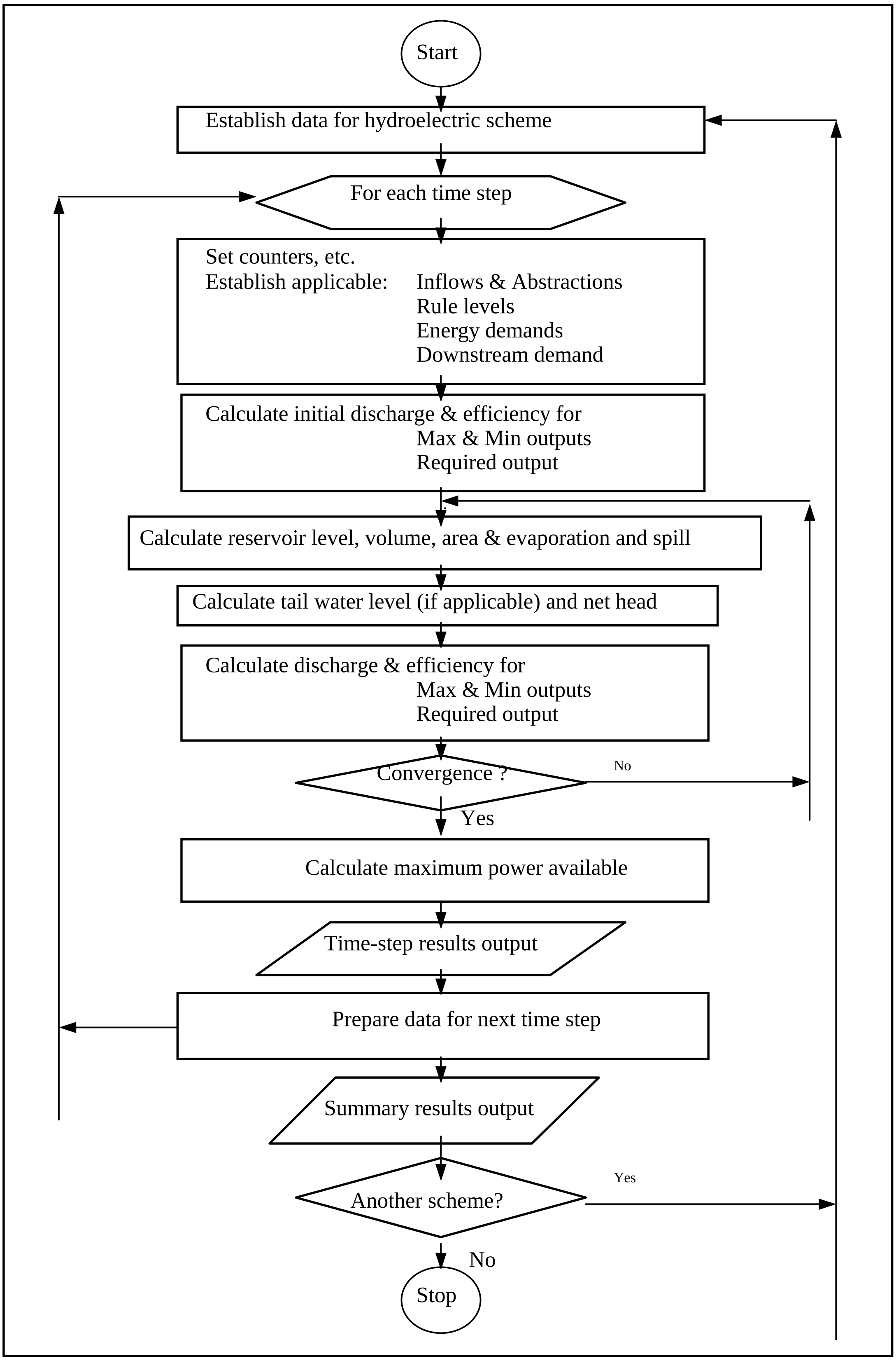
The program is written in FORTRAN 77 and is now applied via a data-management, operation and graphical / tabular results-display system implemented in Microsoft Excel. RAPSO does, however, remain fully backwards compatible with earlier DOS-based versions.

Figure 5.2 : Reservoir / Power Station Module and Water Flows



Notes : 1. Compensation or direct abstraction (not available for power generation and excluded from downstream flow) is as input for the calendar month and given priority over all other demands 2. Evaporation is obtained from the applicable input or derived net evaporation rate and the calculated reservoir surface area. 3. Irrigation flow is as input for the particular time step, and is given priority over turbine discharge. 4. Seepage is the input value. 5. Spillway flow is calculated from a spillway characteristic if present, or else is the surplus with the reservoir at full supply level. 6. Sluice-gate flow is the surplus leaving the reservoir at flood protection level interpolated within the calendar month or, if this level is above spillway crest level, the surplus over spillway capacity. 7. Incremental inflow is as input for the particular time step.	8. Turbine discharge for each time step is limited by water availability or discharge capacity, or : - that satisfying the greater of the energy or downstream flow demand, or - limited by generator capacity or turbine capacity under the available net head and otherwise the flow leaving the reservoir level as close as possible to secondary control level. 9. By-pass flow is either zero or, if the turbine discharge is limited as in 8. above, that leaving the reservoir level as close as possible to secondary control level, but subject to by-pass capacity. 10. Tail water flow, whether including or excluding spill flow as adjusted for time-of- travel, is used with the tail water characteristic, if present, to calculate tail water level. 11. Downstream flow, adjusted for time-of-travel, is the inflow to a downstream scheme, if present, in addition to any further incremental inflow.

Figure 5.3 : Hydroelectric Time-Step Calculation Outline



5.2.1 Data Input

Data entry to the program is via a variety of comma-separated-value files created and edited within the Windows environment as illustrated in Figure 5.3. This process is facilitated by:

- detailed instructions for use of all files given in the program user manual,
- extensive provision made for the user to include within the files his own annotations and comments, perhaps in his own language, and
- comprehensive data checking facilities, complemented by run-time error messages.
- Items of input data, most being optional and in almost any combination, include:
- system hydraulic configuration
- electricity price forecast
- selection of optimisation methods together with supply reliability requirements
- transmission constraints and loss factors
- length of simulation period
- starting conditions
- length of time step
- values of acceleration due to gravity
- inflows and incremental inflows in defined sequences
- rainfall records and evapo-transpiration rates
- reservoir level / area / volume characteristics with allowance for future siltation
- evaporation or seepage rates
- by-pass or bottom-outlet capacities and flows
- compensation flows and minimum releases
- water demands
- maximum retention levels (with sluice-gate operation assumed)
- spillway configurations and level / flow characteristics
- retention levels above which supplies are greater than demands
- restriction levels below which supplies are less than demands by defined amounts
- minimum drawdown levels
- dead-storage levels (which may be lower than the minima above)
- downstream abstractions unavailable for power generation

- channel capacities and losses
- head-pond levels
- numbers and configurations of tunnels and penstocks
- flow / friction loss characteristics
- numbers of different sizes or types of hydroelectric machines (i.e. impulse or reaction)
- generator capacities and allowances for transmission constraints and losses
- turbine rated outputs and heads
- turbine discharge limits on account of channel capacities or cavitation constraints
- maintenance programmes
- maximum running-plant capacity factors
- whether or not numbers of running machines are to be matched to total plant outputs
- peaking periods and minimum spinning-reserve contributions
- turbine efficiencies either as constants or as variations with net head and flow
- generator efficiencies varying with output
- flow / tailwater level characteristics
- energy demands and whether or not greater supplies are required when available
- output formats and variables
- times of upstream and downstream water travel

5.2.2 Results Output

For confirmation purposes much of the input data is automatically repeated in the RAPSO. output. The calculated results outputs, for each time step, include any combination of:

- electricity and water supply reliabilities
- monetary values of electricity outputs
- downstream flows
- excesses or shortfalls of downstream flows compared with required minimum values
- turbine discharges
- bypass or direct abstraction flows
- evaporation losses

- reservoir levels
- tailwater levels
- gross heads
- net heads
- efficiencies
- energy outputs
- excesses of energy outputs over required minimum values
- shortfalls of energy outputs below required values
- total energy output from all schemes simulated
- maximum power outputs available
- spillway flows
- sluice-gate flows
- totals of spillway and sluice-gate flows
- numbers of machines in operation

The flow values above can be presented either as total flows or as average rates of flow.

Various statistical analyses of input values and calculated results may also be obtained in the output, and the Windows software automates graphical display of selected results.

5.3 APPLICATION OF RAPSO MODEL TO NILE RIVER SYSTEM

In order to model the water balance of the Nile system using RAPSO (the Model) for the purpose of estimating hydroelectric generation under a range of possible scenarios, a limited number of gauging stations were selected to represent the flow balance of the Nile system in Ethiopia and Sudan. The components of the water balance model are as shown in Figure 5.1. Recent flow records for these sites were obtained from the MoI in Sudan and MoWR in Ethiopia. Estimates of abstraction for irrigation and estimates of seasonal net evaporation have been assembled for both countries.

On the Blue Nile the gauges at El Deim, and on the Dinder and Rahad rivers have been assumed to be upstream from any significant irrigation demand on those rivers. Inflow regime changes have been observed in Sudan and reported at Roseires and are attributed to hydroelectric development on the Blue Nile and its tributaries in Ethiopia. Flow data from Ethiopia has been included for the Blue Nile (Abbay) at Kessie.

Existing reservoir and hydroelectric power station characteristics have been collected to enable the operation of reservoirs to be modelled under a range of future development scenarios.

The core data for the White and Blue Nile flows in Sudan contained within the RAPSO model was provided by Ministry of Irrigation in Sudan for the Merz & McLellan 1997 Report (M&M1997). These data include inflows to the White Nile at Malakal and to the Blue Nile at El Diem, Rahad and Dinder for the period 1912-94, with some of the series extending to April 1996. The paragraphs below describe the establishment and calibration of the model up to 2001. These data were subsequently updated to 2003 using data provided by the Ministry of Irrigation. These various time series incorporated all data improvements made for different studies up to that time and therefore formed a robust platform for time-series extension using more recent data. Comments on the various data records are provided in the following sections.

5.3.1 Blue Nile

El Deim

Data at this site are taken from M&M1997 and then extended using river level data provided by the MoI for the period 1992-2001. The river level hydrographs for 2000 and 2001 were back-calculated from Roseires inflow data and are consistent with the observed pattern at Khartoum.

Roseires & Sennar Reservoir and Tailwater Levels and Discharges

Time series of these data were provided by the MoI for the period 1992-2001 and were used for model calibration purposes. Initial modelling of flows at Sennar revealed a discrepancy in the water balance. To assist in resolving this, the tailwater level rating for Sennar Dam was checked and found to be inconsistent with the modelled flows. The tailwater level rating was therefore revised using measured water levels (H) and modelled discharges, and a best-fit curve was obtained for the 1992-2001 data. This curve is described by the equation:-

Flow (Mm^3/day) = $6.9335 \times (H-400)^2 - 33.44 \times (H-400) + 42.363$ $r^2=0.96$

Dinder and Rahad Rivers

Data defining the outflows from these rivers were taken from M&M1997 Report and extended using 1992-2001 river level data and rating curves provided by the MoI. This record is consistent with MoI's computerised (1965-2001) data.

Blue Nile at Khartoum

Water level and flow data for this site from 1992-2001 were obtained from the MoI during our visit to Khartoum in March 2002. The flows were checked for consistency with the El Deim site upstream and these flow records have been improved in consultation with MoI.

5.3.2 Main Nile

Tamaniat, Hassanab and Dongola

Data for these sites from 1992-2001 were obtained from the MoI during the visit to Khartoum in March 2002. Subsequent revisions of flow ratings by MoI have resulted in more consistent Main Nile flow records.

5.3.3 Atbara River

Atbara River at Kubur & Setit River at Elhilew

10-daily flow records for both these sites were obtained from the MoI for the period 1966-2001. The records were extended back to 1912 assuming Kubur and Elhilew flows are 35% and 65% of el Girba Dam inflows.

Khashm El Girba

Inflows to Kashm el Girba reservoir were obtained from MoI for the period 1992-2001. A composite inflow record from 1912-2001 was compiled based on gauge records at the old El Girba gauge, a gauge a Showak and the combined flows of Kubur and Elhilew gauges. A detailed description of the derivation of these flows is included in Appendix A.

5.3.4 Reservoir Characteristics

The existing multi-purpose reservoirs on the Nile River system in Sudan, shown in Table 5.1, are used primarily to store water for irrigation purposes. Roseires, Sennar and Khashm el Girba have existing hydroelectric plant and the fourth, Jebel Aulia, has been retro-fitted with low head generating plant. Work to raise the Roseires Dam, though started, has not progressed as had been planned.

Table 5.1 : Characteristics of Existing Reservoirs

Reservoir	River	Dam Completed	Live Storage MDm^3 +	Full Supply Level (masl)	Minimum Operating Level (masl)	Installed capacity (MW)
Jebel Aulia	White Nile	1937	3.89	377.4	372.5	28.8*
Roseires	Blue Nile	1966	2.12	481	467.6	280
Sennar	Blue Nile	1925	0.48	421.7	417.2	15
Khashm el Girba	Atbara	1964	0.617	474	463.5	12

5.3.5 Reservoir Storage

The storage volume of reservoirs has been reduced owing to accumulation of sediment since impounding and this process is continuing at varying rates in each individual reservoir. The volume in the reservoirs has been reduced by between 25% at Roseires and 40% at Sennar and Khashm el Girba.

The relationships for Roseires and Sennar adopted for this study were supplied by MoI. The method employed for calculating varying reservoir area and volume for Jebel Aulia is also as reported in M&M1997. Meanwhile the Khashm el Girba reservoir characteristics are taken from the previous Long Term Power System Planning Study (Acres 1993).

In the light of the information currently available on likely sedimentation effects, future trends in reservoir capacity will be assumed for this study as:

1. At Jebel Aulia, the reservoir storage capacity will not be significantly reduced over the next 20 years.

2. At Roseires, reservoir sedimentation will continue at an average rate of 10 Mm^3/year over the next 10 years and 8 Mm^3/year for the 10 years after 2012.

3. At Sennar, sedimentation will not reduce the capacity of the reservoir significantly over the next 20 years (M&M1997).

4. At Khashm el Girba, roughly the existing storage capacity will be maintained by the current sediment flushing practices.

5. For proposed and yet to be completed reservoirs (such as Merowe) details of future reservoir characteristics are as presented in available detailed project reports.

5.3.6 Operating Rules

Hydroelectric performance is determined not only by scheme design but also by the operating rules in force and, in the context of long-term planning, operation is conveniently defined in accordance with a variety of seasonal demand and reservoir rule curves.

The Roseires, Sennar and Jebel Aulia reservoirs provide seasonal regulation of river flows to meet the needs of flood control together with irrigation and electricity supply. Another constraint on reservoir operation is the need to preserve storage capacity by controlling reservoir siltation.

At Roseires this has dictated that the reservoir be held at minimum level each year until the bulk of the flood and entrained silt load has passed downstream, and then be filled at the very end of the flood season. Rules determining this operation have previously been reviewed in the context of the heightening of Roseires dam, and simulations for this study have now confirmed that they remain appropriate.

The reservoirs are currently operated between minimum and full supply levels as set out in Table 5.1. The filling rules adopted for the White and Blue Nile reservoirs are those reported in M&M1997 as modified in accordance with recent information from the MoI, and are outlined below.

Jebel Aulia:

The first filling of the dam starts on 1 July each year from MOL of 372.50 m, and continues for one month reaching a level of 376.50 m by the end of July. This level is held for one month until the peak flood of the Blue Nile has passed. Filling then continues, reaching a maximum level of 377.40 m by early October where it is held until the beginning of 'draw-down' during the last period in March. Drawdown continues until the end of June when the reservoir returns to MOL of 372.50 m.

Roseires and Sennar:

During the flood period July-August, Roseires is assumed to be held at the MOL of 467.60 m with Sennar held at 417.20 m. Filling of Roseires commences during the last week of August as the earliest date in accordance with the following:

a) At the last week of August if the flow from El Deim is below 350 Mm^3/day or has risen above 350 Mm^3/day and fell below that before the end of August.

b) After the end of August if the flow at El Deim reached 350 Mm^3/day and continued for three days.

c) On 26 September as the latest date if the river flows continued above 350 Mm^3/day.

Khashm El Girba

Initially a filling rule for Khashm el Girba reservoir was developed based on filling behaviour demonstrated in the reservoir level and inflow records for the period 1992 to 2001 which had been obtained from the MoI. Following the provision of further information by the MoI and then completion of the reservoir inflow record as described above, operating rules for use in this study have now been finalised, these being in outline as below.

Depending on whether the inflow has or has not increased to a defined value, reservoir filling commences towards the end of August or early September and is completed by the end of September.

From completion of filling until June, releases are made to satisfy irrigation demand and then, until the end of June, to suit energy demand while still meeting reduced irrigation requirements. These releases are made so that the reservoirs are empty at the end of June in anticipation of the arrival of increasing inflows.

The justification of additional hydroelectric plant may be greatly affected by considerations of reservoir operation. At existing sites much of the additional hydroelectric output will be generated in the flood season since most of the water available in the dry season can be fully utilised by the existing plant. It follows that any new plant at these sites will be operated predominantly at minimum reservoir level, and both plant design and future operation will be particularly sensitive to any changes to minimum levels as may be decided.

The Roseires and Sennar reservoir operating rules have accordingly being reviewed, as discussed with the NEC and MoI, to ensure that operation of the base system is reasonably optimal before considering future additions. In order for all comparisons to be made on a comparable basis, a set of guide-lines and procedures for reservoir operation have then been defined which in principle will remain unchanged for the duration of the study.

5.3.7 Irrigation Demand

Detailed below are the key assumptions made in estimating the existing seasonal irrigation demands and their forecast future growth. Average seasonal irrigation demand patterns have been adopted or modified from previous studies. All irrigation demand patterns represent gross abstractions, with no estimate of return flows from irrigation projects into the rivers having been made. This is a conservative approach to estimating these important components of the water balances, but is considered appropriate given the uncertainties in the irrigation demand data.

It is unclear which of the proposed irrigation projects, whether in new areas or as expansions of existing schemes, are directly dependent on the completion of specific water conservation projects. It is also unclear when the various conservation projects are likely to be completed. It has therefore been necessary to make broad-brush assumptions on these aspects, consistent with the Long-Term Strategy Report.

Expansion in demand and changes in the demand profiles on the Blue Nile are dependent on the completion of the heightening of the Roseires Dam or development of reservoir projects in Ethiopia. Later seasonal releases of flows from additional storage in Roseires or upstream will also impact in a similar way on water available to the Main Nile pump schemes where access to water is currently limited when river levels are low. Changes in Blue and Main Nile irrigation profiles are therefore also dependent on the heightening of Roseires, and these changes are assumed to develop over the next 25 years.

5.3.8 Existing and Future Irrigation Schemes on the Blue Nile and Main Nile

Blue Nile

Blue Nile irrigation consists of the Gezira/Managil project that is gravity fed from Sennar reservoir and is otherwise divided into demand upstream between Roseires and Sennar and downstream between Sennar and Khartoum. Existing irrigation schemes upstream from Sennar comprise the pump-fed Rahad, El Suki, Abou Naama Sugar and North West Sugar projects as well as the public and private pump projects. Downstream from Sennar, pump schemes include Al Gnaid and Al Slait and Waha.

The M&M1997 Report developed 10-day water demands for many of the schemes with the assistance of the MoI in 1996. For the Al Gnaid and North West Sugar projects we have used demand profiles developed by Acres (1993). All these demand profiles are assumed not to have changed significantly in the intervening years.

Two demand patterns are used for Gezira-Managil. One pattern represents a normal year (4 in 5 year condition) with a wheat area of 400,000 feddans while the second pattern represents a dry year (1 in 5 year condition) with reduced wheat area of 70,000 feddans. The flood-flow condition characterised by the sum of July, August and September (JAS) flows is then used each year over the period of hydrological record to determine whether in that year demand will follow the normal or dry year pattern. The normal year pattern is assumed if the JAS flow is greater than the JAS value exceeded 80% of the time (the 80% exceedance probability). For the present study the demand patterns thus derived have been scaled to match the demands given in the Long-Term Strategy Report, so as to retain the important distinction between normal and dry-year demand.

Future expansion of irrigation demand on the Blue Nile will be based on development of the Rahad II, Kenana and South Dinder schemes in association with increased storage provided by raising the Roseires Dam or by upstream reservoir developments in Ethiopia. Estimates of additional Rahad and Kenana irrigation demand are based on those agreed with MoI and reported in M&M1997, but scaled down slightly to match the values given in the Long-Term Strategy Report. In the absence of detailed information on the South Dinder project, or indeed as to which crops are expected to be grown there, a generic seasonal crop-dominated monthly demand pattern (after Acres 1993) has been assumed. During years following the completion of Roseires heightening, it has been assumed that the peak period of pump scheme demand will lengthen ultimately through to April so as to exploit the additional water available. It has been assumed that there will be no additional intensification of demand in the Gezira/Managil Project.

Main Nile

The existing irrigation demand includes both public and private pump schemes. No detailed information on the locations of pump projects is currently available, and so we have estimated a spacial distribution of demand based on a map of irrigation areas provided by MoI (Topo Map S H 35). This map indicates that the demand is concentrated in two areas, one downstream of Shendi and the other between Merowe and Dongola. Based on relative land areas shown on the map we have assigned 40% of Main Nile demand upstream from Hassanab and the remainder to downstream of Merowe township. Upstream from Hassanab we have assumed that 61% of the demand occurs upstream from Saboloka. These estimates are based on the lengths of the various river reaches, assuming an orderly distribution of riverbank pumps. In the absence of information on crop types and detailed irrigation demand information we have assumed a representative dominant seasonal crop-demand profile (after Acres 1993). For this study we have assumed that future increases in irrigation demand from the Main Nile will take place in the existing areas and that expansion of demand will be tied to the heightening of Roseires Dam.

5.3.9 Irrigation Demand Modelling

For modelling purposes the Nile system has been divided into convenient river reaches as shown in the current RAPSO arrangement illustrated in Figure 5.1. Thus the following demands are used in the water balance analysis:

- Bahr el Jebel irrigation demand,
- White Nile irrigation demand upstream of Melut,
- White Nile irrigation demand downstream of Melut,
- Blue Nile upstream of Sennar,
- Gezira/Managil irrigation demand,
- Blue Nile irrigation demand (Sennar to Khartoum),
- Main Nile irrigation demand (Khartoum – Sabaloka),
- Main Nile irrigation demand (Sabaloka – Hassanab)
- Rumela irrigation demand,
- Khashm el Girba irrigation demand, and
- Main Nile irrigation demand (Hassanab – Dongola).

5.3.10 Total Irrigation Water Requirements

In total the existing irrigation demand adopted for this study is an average of 14.45 MD m^3 per annum. This is similar to 1997-99 total irrigation estimates provided by the MoI and slightly lower than the often quoted irrigation demand of around 18.5 MD m^3 in The Water Resources of Sudan (1977). The average irrigation demand is projected to increase to 23.57 MD m^3 by 2012.

Short- and medium-term plans could see the area of irrigated land increase and irrigation demand grow by 1.47 MD m^3 from the Atbara river, 4.9 MD m^3 from the Blue Nile, 5.2 MD m^3 from the White Nile and 1.7 MD m^3 from the Main Nile. A summary of projected water requirements for the Sudan 2002 - 2012 is set out in Table 5.2, and a breakdown by area is given in Table 5.3.

Table 5.2 : Projected Water Requirements – Summary

Nile Tributary	Cultivated Area (1000 Feddans)		Water Requirement (Mm3)	
	2002	2012	2002	2012
The Blue Nile#	2112	3186	9050	11481
The White Nile	480	1067	2050	4968
Atbara River##	282	572	1270	2123
Main Nile	311	571	1300	1903
Reservoir Evap.			880	3170
Total	3185	5396	14450	23645
Other usage			1080	2500
Total			15530	26145*

Source: Long-Term Agricultural Strategy (2002-2027)

Table 5.3 : Projected Water Requirement by Area

Nile Tributary	Project	Cultivated Area (1000 Feddans)		Water Requirement (Mm3)	
		2002	2012	2002	2012
The Blue Nile Available Area is 6,271.5 million feddan	Gazira & Managel	1,500	1,800	6,100	6,100
	Rahad	220	280	1,100	1,100
	El Souky	62	78	300	300
	Public Pumps	175	270	780	1,200
	Private Pumps	40	150	140	490
	Al gnaid Sugar	40	43	280	301
	Sugar NW Sennar	35	45	250	315
	Abu Naama	20	30	70	105
	Al slait and Waha	20	40	30	70
	Kenana II & III		300		1,000
	Rahad II		150		500
	South Dinder				
Sub-Total		2,112	3,186	9,050	11,481
The White Nile Available Area is 1,791 million feddan	Public Pumps	280	350	1,000	1,250
	Private Pumps	60	160	210	538
	Kenana Sugar	90	90	580	613
	(Crops)	-14	-40		
	Hagar Asalaya Sugar	36	42	260	303
	White Nile Sugar		100		1,322
	Melut Sugar		75		663
	Mongalla Sugar		40		50
	Malakal Rice		20		80
	Pengco - Jonglei		50		90
	Others - South		100		180
Sub-Total		452	987	2,050	5,089
Atbara Available Area is 1,361 million	New Halfa	240	290	950	1,072
	New Halfa Sugar	42	42	320	320
	Upper Atbara		180		732
	(Sugar)		-60		
Sub-Total		282	452	1,270	2,124
The Main Nile	Public Projects	103	151	470	503
	Private Projects	208	420	730	1,400
Sub-Total		311	571	1,200	1,903

Source: Long-Term Agricultural Strategy (2002-2027)

5.3.11 Evaporation and Losses

It is important to note that, in accordance with the 1959 Nile Treaty, quantities of water lost to evaporation from reservoirs are deducted from Sudan's share of the Nile waters. Hence evaporation has to be particularly carefully considered in water-use planning.

Table 5.4 sets out the anticipated water losses to evaporation from the Blue Nile reservoirs (post Roseires heightening) and from existing and planned reservoirs on the Atbara river and Main Nile (Merowe reservoir).

Table 5.4: Annual Evaporation from Reservoirs

Nile Tributary	Project	Water Lost by Evaporation M m^3		
		2002	2012	2027
The Blue Nile	Roseires Reservoir	410	750 post heightening	750
	Sennar Reservoir	300	300	300
Atbara River	Girba Reservoir	170	170	170
	Upper Atbara Reservoir		400	400
The main Nile	Al Hamdab Reservoir		1550	1550
Total		880	3,170	3,170

Source: Long-Term Agricultural Strategy (2002-2027)

Profiles of the estimated monthly evaporation at each reservoir have been taken from previous studies where the detailed information is available. Where only annual net evaporation information is reported the amounts in each month have been estimated from published Climatic Normals (194070). Representative net evaporation profiles were estimated from climatic data collected by the Sudan Meteorological Department at Karima (northern Sudan), Wadi Medani (central Sudan) and Juba (southern Sudan) and these estimates have been applied to annual evaporation estimates at each project according to geographical location.

5.4 DATA FOR RAPSO MODELLING OF MANDAYA

Considerable amounts of data are required for the modelling and various data items of particular relevance to Mandaya that have been employed are summarised below.

5.4.1 Period of Hydrological Record

For the Sudanese applications the period of record has been progressively extended and now runs for the 92-year period July 1912 to June 2005. As has been explained in the hydrology section, however, data for the Abbay are currently available only for the 50-year period January 1953 to December 2003 and so, for the sake of consistency of approach, this shorter period has been adopted for all simulations performed for these studies. It is, however, noted that the driest and wettest years found in the 92-year period both occur prior to 1953.

5.4.2 Water Inflows

The derivation of monthly flow series at various locations down the Abbay has been described in the hydrology section. All of these monthly series have been converted to a 3-period-per-month basis by for each time step applying a factor derived from the gauging records at El Deim just downstream of the Ethiopian/Sudanese border. The inflows to the Mandaya reservoir are then taken as the sum of:

- the flows at the Karadobi site (as have been derived on the assumptions that throughout the 50-year period both a constant 77 m^3/s had been diverted from Lake Tana to supply the Beles scheme - now under construction - and also Lake Tana had been operated to provide the maximum possible firm outflow), and the

- incremental flows between Karadobi and Mandaya.

5.4.3 Electricity Supply Reliability

The standard (NEC) criterion for Sudanese planning is 95 per cent. For Ethiopia, however, the (EEPCO) planning criterion is 98 per cent and for the sake of consistency of approach this higher value is applied for all these pre-feasibility analyses. With 50 x12 x 3 = 1,800 time steps this allows a maximum of 36 failures to supply demand in full.

5.4.4 Reservoir Characteristics and Minimum Operating Levels

The level/area/volume characteristics employed and minimum operating levels assumed for the three Mandaya reservoir alternatives are as have been presented in the hydrology section.

5.4.5 Evaporation Losses

For each time step the evaporation loss is calculated by applying the relevant average calendar monthly net loss, as described in the hydrology section, to the simulated reservoir surface area.

5.4.6 Spillway Characteristics

Until such time as spillways have been designed in detail it is assumed for the purposes of the simulations that all spill takes place from the relevant full-supply level.

5.4.7 Generating Sets Installed and Allowances for Plant Maintenance

The plant installations and rated heads assumed for the three Mandaya reservoir full-supply level alternatives are:

- 741 m : 12 x 135 MW, 117.4 m
- 800 m : 8 x 250 MW, 130 m
- 860 m : 8 x 300 MW, 170 m

For all simulations it is assumed that every installed generating set in turn is taken out of service for maintenance for a period of 2 weeks each year, the weeks chosen being as far as possible during the dry season.

5.4.8 Penstocks and Friction Losses

For all Mandaya alternatives it has been assumed that each installed generating set would be supplied through a separate waterway (i.e. penstock), and for each simulation time step in turn the friction losses are derived as proportional to the square of the penstock flow, in each case the constant of proportionality having previously been derived on the assumption that a 5 m head loss would be experienced under rated conditions.

5.4.9 Turbine and Generator Characteristics

For all alternatives it has been assumed that the peak turbine efficiency is 92.5 per cent and the total electrical efficiency is a constant 97 per cent. For consistency of approach with the Karadobi pre-feasibility study, standard Francis turbine efficiency matrix and operating limits have been employed over ranges of 70 to 115 per cent of design net head and 30 to 110 per cent of design discharge.

5.4.10 Electricity Demands

Also for the sake of consistency of approach with the Karadobi study, the electricity demands applied are seasonally invariant. In each RAPSO run therefore all electricity demands are raised and lowered by the same amounts until the desired reliability of supply is just achieved. Thus, although it is recognised that the value of power output is likely to be considerably higher in the summer than the winter, at this stage of study no attempt has been made to investigate the possible extent to which seasonal variation of output would be feasible. Similarly the effects and consequences of dry-season peaking operation have yet to be investigated. It is, however, clear that there would be considerable flexibility in the operating regimes that could be adopted.

5.4.11 Generation Monthly Rule Levels

These reservoir control levels are optimised also within each program run, this being on the basis that supply is limited to meeting the demand as above whenever reservoir level is below the applicable control and otherwise, to the extent there is additional generating capacity available, supply is increased such as to bring the reservoir level down to the control.

5.4.12 Numbers of Generating Sets Operated

In each time step the number of generating units operated is optimised such that the total electricity output as defined in the previous two subsections is provided with minimum total release.

5.4.13 Environmental Releases

For all alternatives the same calendar-monthly minimum (environmental) releases have been simulated as have been described in the hydrology section. Because no releases for power generation are provided when the reservoir is below its minimum operating level and also the reservoir is never entirely emptied, all the simulations ensure that these environmental releases are maintained on a 100 per cent firm basis.

5.4.14 Tailwater Characteristic

The tailwater level has been assumed to vary from El. 615m at a discharge of 966 m^3/s to El. 612m at 161 m^3/s.

5.5 RESULTS

As described below, for all alternatives various results are presented in tabular and graphical forms at the end of this section.

5.5.1 Mandaya Alone

The firm and average energies together with some other key indicators that have been calculated for the various alternatives are presented in Table 5.5. It is most notable that a change from the 741 m to 800 m alternative increases the firm energy by over 200 per cent. Operation of the 800 m FSL reservoir alternative over the 3 hydrological years 2001-03 is illustrated graphically in Figure 5.4.

5.5.2 Mandaya with Karadobi

Karadobi commands and to a considerable extent could regulate some 57 per cent of the natural flow at Mandaya. For calculation with Karadobi and Mandaya in cascade it was of course necessary first to simulate Karadobi. This has been done on the basis of data that as far as could be determined are identical to those that were employed for the Karadobi pre-feasibility study. The firm and average energies together with other key indicators that resulted are compared with those previously reported for Karadobi in Table 5.6. Three RAPSO results are presented, the first is without rule-curve optimisation and would be the same as that previously reported except that three time steps per month are employed. Measured on this basis, the supply reliability is less than 98 per cent although the results are otherwise very close. For the second simulation the reliability is corrected but, naturally, only with a slight loss of firm energy being incurred. The only change for the third RAPSO simulation is for the rule-curve optimisation to be introduced so as to maximise secondary energy without affecting firm energy, and it can be seen that an increase in average (i.e. firm + secondary) energy of 2 per cent is obtained. Results of this third simulation are illustrated graphically for the 3 hydrological years 2001-03 in Figure 5.5.

For Mandaya in cascade below Karadobi, the firm and average energies together with the other key indicators for the various alternatives are presented in Table 5.7, and operation of the 800 m FSL reservoir alternative over the 3 hydrological years 2001-03 is illustrated graphically in Figure 5.6.

By comparing Table 5.7 with Table 5.5 it can be seen, as is to be expected, that while providing the same reliability of supply as before the increased upstream regulation allows Mandaya to be operated both at higher reservoir levels and with reduced spill. Energy output is thus increased although so also is evaporation loss. Not surprisingly these differences reduce with increase in Mandaya storage capacity. The greatly reduced Mandaya reservoir seasonal operating range that results with Karadobi can be seen by comparing Figure 5.6 with Figure 5.4.

Table 5.5 : Summary Results for Mandaya alone

Case	Average					Energy difference	Firm energy	No. periods of failure	Firm power
	Reservoir level	Net head	Spill	Evapo-ation	Energy				
	(m)		(m3/s)		(GWh/a)	(%)	(GWh/a)	in 50 years	(MW)
741m FSL, 12x135MW	734.6	117.5	241.2	9.8	6,799	-	3,559	36	406
800m FSL, 8x250MW	785.8	167.5	55.0	18.4	12,119	78.2	11,194	36	1,277
860m FSL, 8x300MW	847.2	228.6	43.8	30.3	16,467	35.9	15,676	36	1,788

Table 5.6 : Summary Results Comparisons for Karadobi (FSL 1,146m, 1,600MW)

Case	Average					Energy difference	Firm energy	No. periods of failure	Firm power
	Reservoir level	Net head	Spill	Evapo-ation	Energy				
	(m)		(m3/s)		(GWh/a)	(%)	(GWh/a)	in 50 years	(MW)
Pre-feasibility Table 8-2, Sec 2, Variant 2	1,132	215	45.3	8.7	8,634	-	8,293	n/a	946
As above but RAPSO 3 period/month	1,129.7	215.5	28.7	8.6	8,683	+ 0.6	8,293	45	946
As above but demand for 98% reliability	1,130.9	216.7	24.6	8.7	8,626	- 0.1	8,276	36	944
As above but with monthly rule curve	1,130.2	216.0	20.9	8.7	8,802	+ 1.9	8,276	36	944

Table 5.7 : Summary Results for Mandaya with Karadobi

Case	Average					Energy difference	Firm energy	No. periods of failure	Firm power
	Reservoir level	Net head	Spill	Evapo-ation	Energy				
	(m)		(m3/s)		(GWh/a)	(%)	(GWh/a)	in 50 years	(MW)
741m FSL, 12x135MW	734.1	116.0	49.8	9.9	8,405	-	7,086	36	808
800m FSL, 8x250MW	788.2	169.8	42.1	18.2	12,291	46.2	11,608	36	1,324
860m FSL, 8x300MW	849.2	230.7	30.2	30.3	16,628	35.3	15,733	36	1,795

Figure 5.4 : Operation of Mandaya with 800 m FSL and 8x250 MW

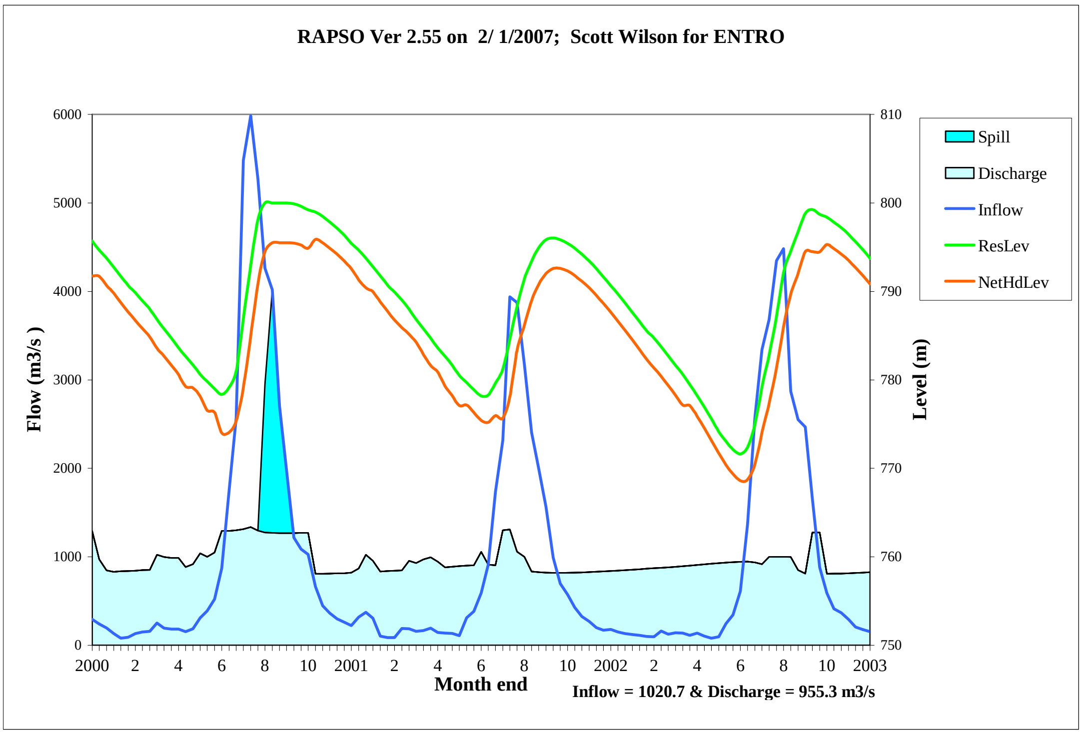


Figure 5.5 : Operation of Karadobi with 1,146 m FSL and 8x200 MW

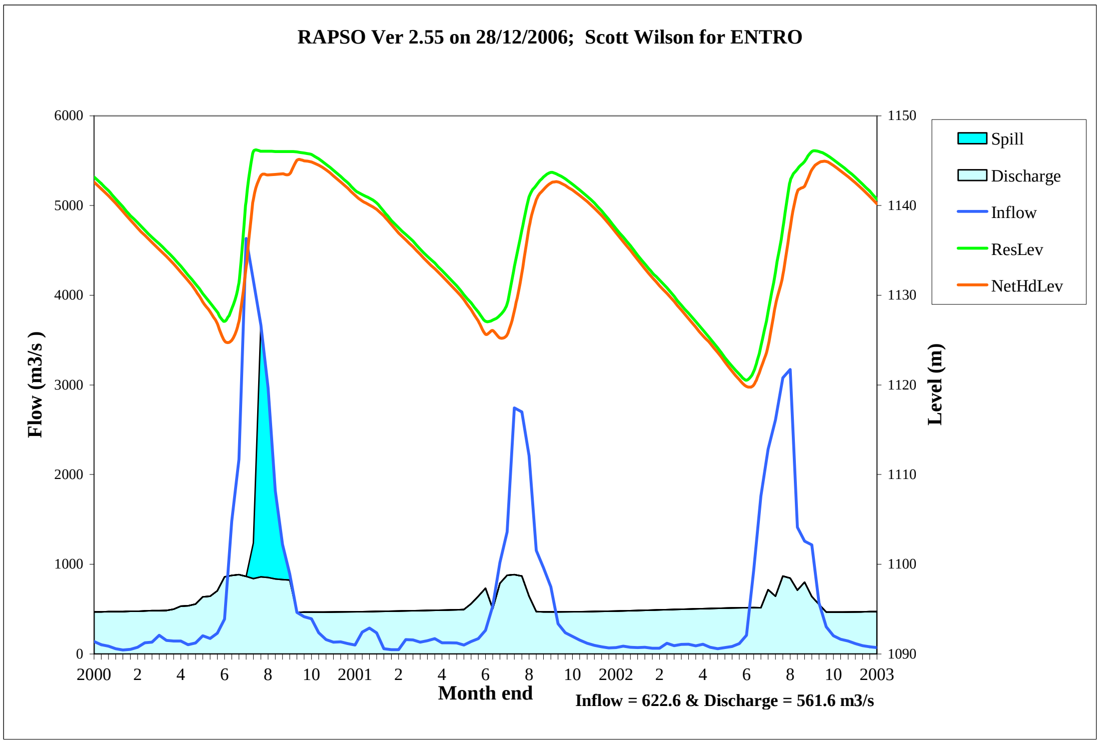
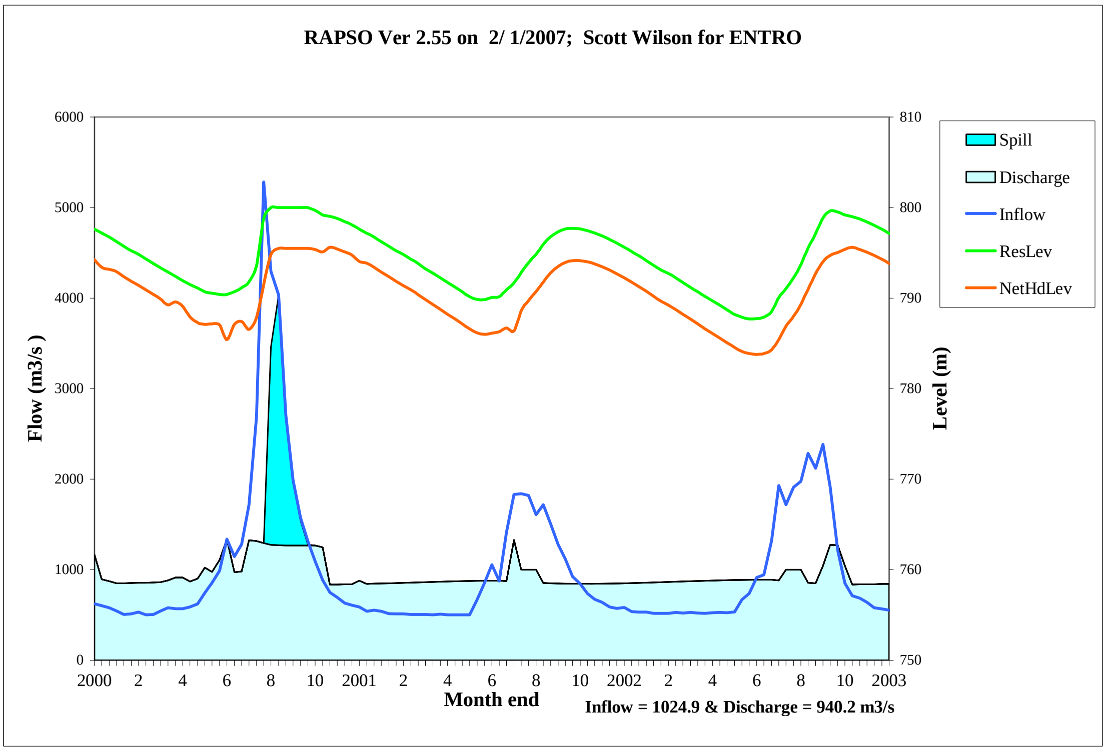


Figure 5.6 : Operation of Mandaya with 800 m FSL and 8x250 MW and Karadobi



5.6 DOWNSTREAM EFFECTS IN SUDAN

5.6.1 General

Construction of new large storage reservoirs on the Abbay will have substantial downstream effects. Positive benefits would be in the forms of:

- less frequent and reduced flooding, particularly in Khartoum but also down the Main Nile,
- increased irrigation supply reliabilities, most importantly in Gezira/Managil, and the possibilities of some irrigation expansion and greater double cropping elsewhere on the Blue Nile and on the Main Nile,
- reduced heads for irrigation pumping from the rivers downstream,
- reduced siltation, particularly of Roseires but also to some extent of Merowe,
- increased power and energy outputs from Roseires and Sennar on the Blue Nile, Jebel Aulia on the White Nile (because of tailwater effects) and Merowe on the Main Nile, these all being enhanced because power increases will coincide with seasonal peaks of the Sudanese electricity demand, and

- enhanced feasibilty of a number of presently only marginally economic hydroelectric projects on the Sudanese Main Nile.

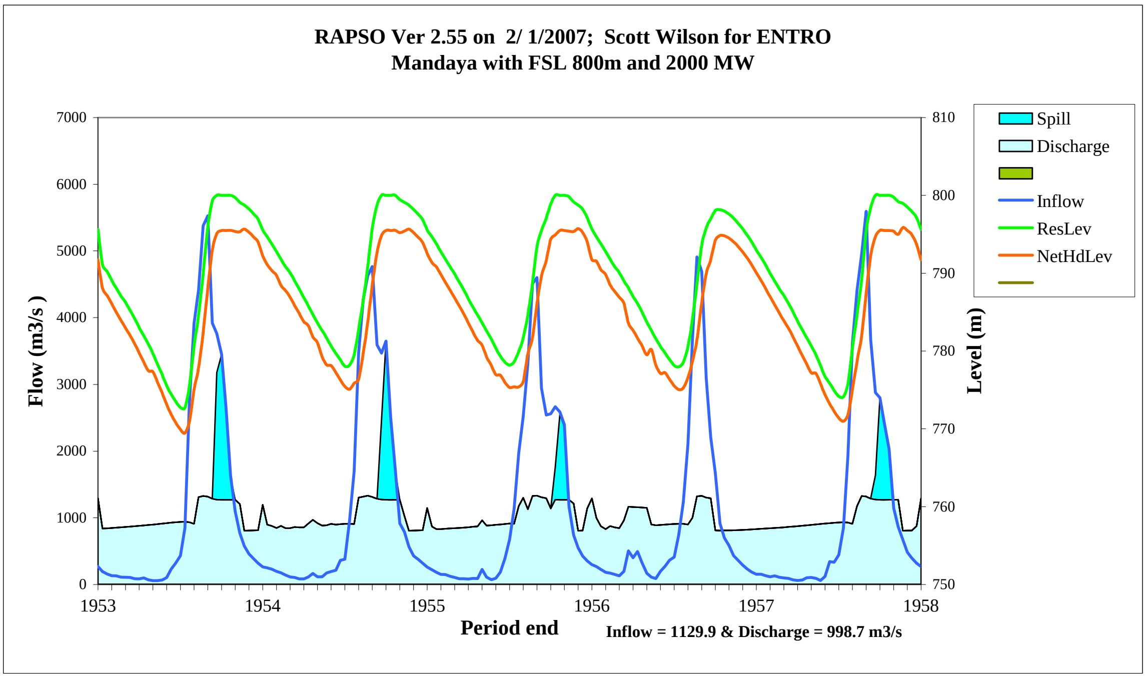
There would also be negative impacts, particularly with regard to impacts on traditional flood-recession agriculture and possibly also on plant and fish life. Environmental impacts and mitigation measures for negative impacts are discussed in the Environmental Impact Assessment reported separately.

Negative impacts could be reduced and possibly if Mandaya and other new reservoirs were to be operated each year in such as way as to provide a controlled, albeit much smaller than at present, downstream flood.

5.6.2 Uplift in Energy Generation at Sudan Hydropower Projects

The Mandaya project will substantially regulate flows in the Abbay river and will in particular result in an uplift of dry season flows in the Blue Nile downstream in Sudan. It can be seen from Figure 5.7 that the regulated flows from Mandaya will typically be in the range of 800 – 900 m^3/s. This can be compared with typical dry season inflows to Mandaya reservoir of 100 – 120 m^3/s, an uplift of some 700 m^3/s. This uplift in dry season flows in the Blue Nile downstream of Mandaya will enhance energy output of existing hydropower stations in Sudan as illustrated in Table 5.8, below.

Figure 5.7 : Typical Operation of Mandaya Reservoir and Power Station

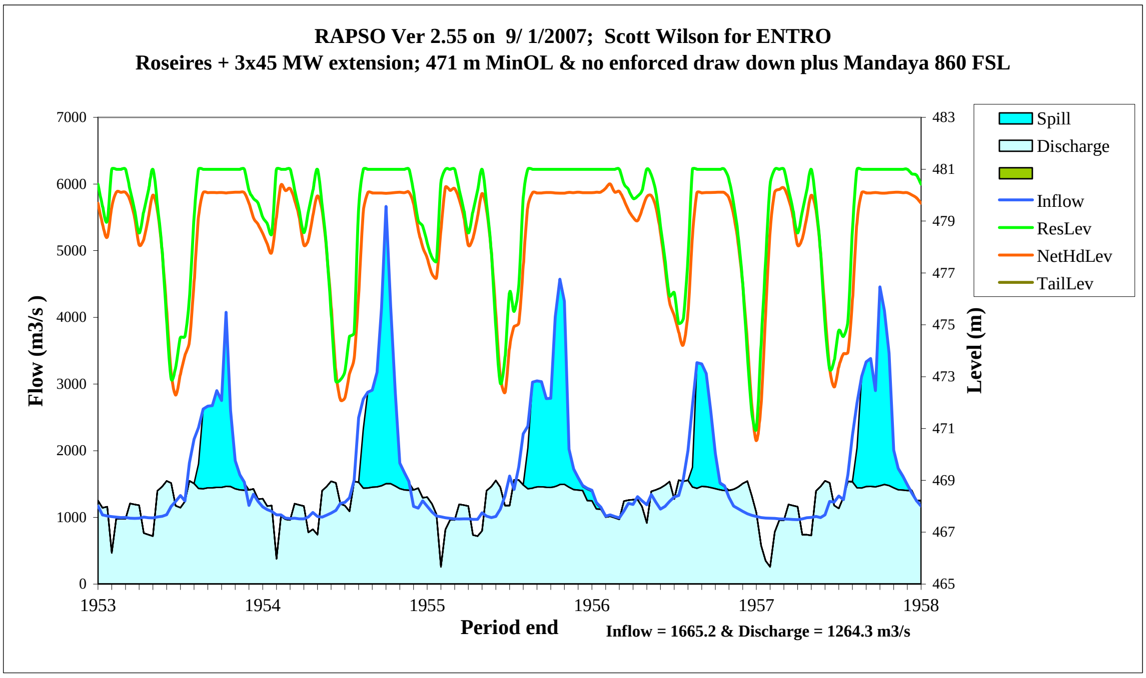


The pattern of operation of Roseires dam and power station (with 135 MW increase in installed capacity) with Mandaya upstream is illustrated in Figure 5.8.

Table 5.8 : Uplift in Generation at Sudan Hydropower Projects due to Mandaya

Option	Average Energy Output GWh/year				
	Roseires	Sennar + Ext.	Merowe	Total	Uplift
Base Case, Existing with Roseires flushing operation	1436	302	5903	7640	0
With Mandaya, with Roseires flushing operation	2142	490	6263	8895	1255
With Mandaya, without Roseires flushing operation	2304	521	7026	9851	2211
Roseires MOL raised to El. 471 and 3 x 45 MW extension	2750	521	7026	10297	2657

Figure 5.8 : Operation of Roseires with Mandaya



5.6.3 Flood Alleviation

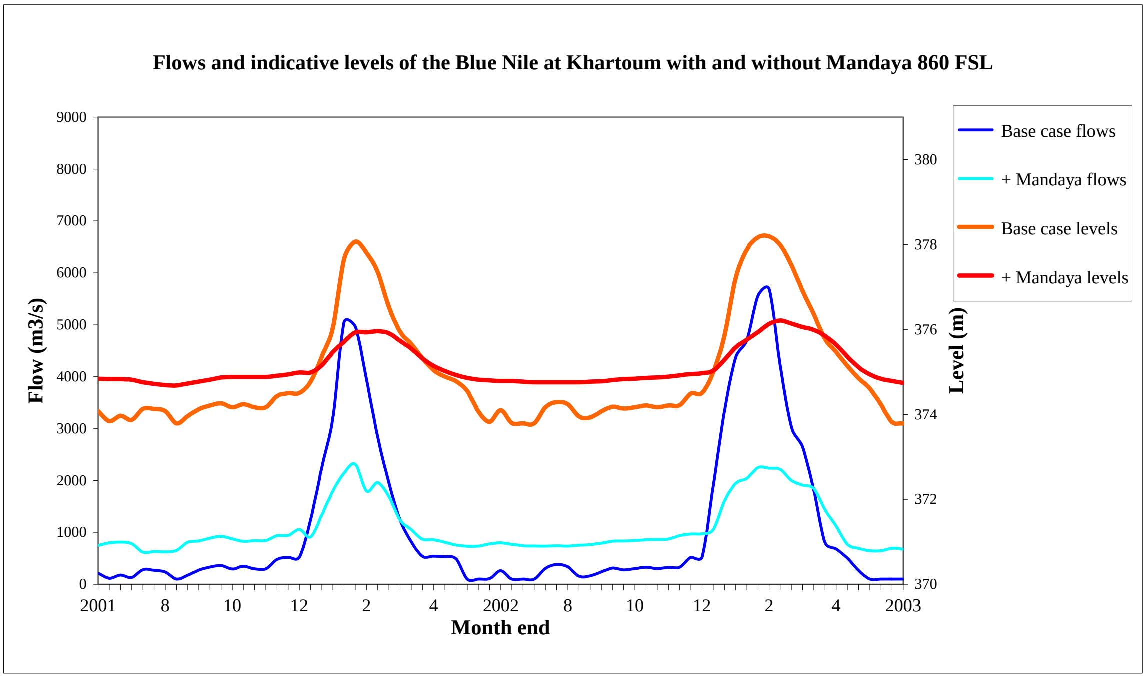
The Blue Nile in Sudan experiences substantial floods each year which at times result in significant damage to crops, housing and infrastructure along the river. The city of Khartoum is prone to flooding particularly when heavy rainfall coincides with high river levels.

Significant reductions in flood risk and flood damage would result if upstream reservoirs in Ethiopia at Border, Mandaya and Karadobi were to have dedicated flood control storage and were operated to minimise downstream flooding. However, such flood protection would be relatively costly and would reduce potential energy generation.

Trials have therefore been carried out using the RAPSO model to investigate the extent of flood alleviation that could be achieved as a secondary benefit associated with operation of the Mandaya reservoir to optimise energy generation, without specific storage allocated for flood control. Inspection of the RAPSO model results reveals that the Mandaya reservoir would be drawn down by 20 metres to El. 780m each year as part of normal operation. The subsequent filling of the reservoir in the following year results in a substantial increase in storage and reduction in the magnitude of peak flood released downstream as can be seen in Figure 5.7 where the inflow is shown as a dark blue line whilst regulated outflow and spillage are shown by light and bright blue shading. It can be seen that over the years 1953 to 1958, which is one of the wetter 5 year periods in the flow record, monthly peak outflows would be reduced by some 2,000 m^3/s. Daily peaks would be expected to reduced to a significantly greater extent.

The reduction in peak flows downstream would be accompanied by a reduction in river levels. Figure 5.9 below illustrates the typical reduction in water levels in Khartoum associated with the development of the Mandaya reservoir and operation of the power station to optimise energy output. It can be seen that for the 2001 and 2002 flood seasons the "with Mandaya" levels are some 2 metres lower than the "base case" levels (without Mandaya). Such a reduction in water level is likely to avoid flooding of Khartoum in all but the most severe events. In these circumstances it is not considered likely that allocation of specific storage at Mandaya for further flood alleviation would be economically justified.

Figure 5.9 : Impact of Mandaya on Flood Levels in Khartoum



5.6.4 Sedimentation of Roseires Reservoir

Construction of major reservoirs on the Abbay within Ethiopia will intercept sediment which currently discharges down the Blue Nile in Sudan particularly in the flood season months of July to September. Estimates of sediment discharges have been discussed in Chapter 3. The sediment has both positive and negative impacts in Sudan.

In order to maintain live storage within Roseires reservoir the water level is drawn down annually to enable the heavily sediment laden flows of the early part of the flood season to pass through the dam. Impounding of the reservoir is delayed until later in the season. This lowering of water level reduces the available head for hydropower generation with consequent reduction in energy output. The additional energy which can be generated with Mandaya has been described in Section 4.6.2, above.

Despite the regime of lowering of water level and flushing of sediment the live storage in Roseires has progressively reduced and it has been reported that sediment deposits close to the dam are now inhibiting the drawdown of the reservoir. In the absence of a major regulating reservoir on the Abbay river in Ethiopia the ability of Roseires reservoir to regulate flows for use in irrigation projects downstream will progressively reduce over the forthcoming years, particularly if sediment discharge rises in future as is anticipated. The positive benefit of the Mandaya reservoir will be to substantially reduce the sediment deposition and to enhance the remaining life of Roseires.

Based on the assessment of sediment discharge at Mandaya presented in the previous chapter, it is considered probable that construction of Mandaya will reduce sediment discharge entering Roseires by some 90%, with the remaining 10% being contributed by the Dabus and Beles rivers downstream of Mandaya and which will continue to accrue in Roseires reservoir.

5.7 DOWNSTREAM IMPACTS IN EGYPT

Computer simulations have been carried out to estimate the downstream consequences in Egypt of first filling the Mandaya reservoir to an El. 800 m full-supply level and on the long-term operation of Mandaya. Representation of Lake Nasser and High Aswan have been included in the RAPSO simulations for this exercise. All data employed and assumptions made are the same as described previously with the addition of those summarised below. During reservoir filling the simulated bypass flows are up to an assumed maximum capacity of 1,000 m^3/s.

5.7.1 High Aswan Data

The necessary data have been compiled from various sources, including:

- Information from ENTRO
- Placards on Aswan High Dam wall,
- FAO published information.

In the absence of details of how High Aswan has been and is operated, for the purposes of this exercise the needs of Egyptian irrigation supplies are not explicitly considered but otherwise generally the same assumptions are made as for the other hydroelectric schemes. Thus:

- each of the twelve 175 MW generating sets in turn is assumed to be taken out of service for maintenance for a period of 2 weeks each year, the weeks chosen being as far as possible during the dry season,
- a seasonally invariant electricity demand is optimised such that the reliability of its supply over the 50-year hydrological period 1954-2003 is 98 per cent,
- reservoir monthly control levels are optimised to maximise secondary energy, control being on the basis that supply is limited to meeting demand as above whenever simulated level is below the applicable control and otherwise, to the extent there is additional generating capacity available, supply is increased so as to bring the reservoir level down to the control,
- in each time step the number of generating units operated is optimised such that the total electricity output as defined above is provided with minimum total release, and
- the Lake Nasser starting, i.e. January 1954, level and a minimum generation level are both determined such that the ending, i.e. December 2003, level is equal to the starting level.

Reservoir elevation – area – volume data for Lake Nasser/Nubia is presented in Table 5.9 below.

Table 5.9 : Elevation- Area – Volume Relationship for High Aswan Reservoir (Lake Nasser / Nubia)

Elevation (m)	Area (km^2)	Volume ($10^9 m^3$, or km^3)
120	450	5.2
125	600	7.8
130	749	11.3
135	988	15.6
140	1,242	21.2
145	1,589	28.3
150	1,962	37.2
155	2,414	48.1
160	2,950	61.5
165	3,581	77.9
170	4,308	97.6
175	5,168	121.3
180	6,118	149.5
185	7,174	182.7

5.7.2 Time Period for Mandaya Filling

Five simulations have been performed, these starting at 10-year intervals through the hydrological record to investigate the range of time period required for filling the Mandaya reservoir. The 1984 hydrological year is the driest in the 50-year record and so a sequence starting in that year was used to establish by-pass flows during the first year of Mandaya filling (whilst below minimum generation level). The objective adopted was to ensure that Roseires reservoir could always be filled as usual at the end of the flood season. This was just achieved with Mandaya first-year bypass monthly flows set to 250 percent of the environmental releases that had been defined previously, but capped at the assumed 1,000 m^3/s bypass capacity. These same flows were retained for the first year of each of the other five filling simulations.

Results of these five simulations in terms of base-case and filling-simulation energy outputs are shown in Table 5.10, and the months when Mandaya first reaches its minimum-generation and full-supply levels are shown in Table 5.11. Mandaya operation trajectories for the driest (1984 start) and wettest (1954 start) five-year periods are shown in Figures 5.10 and 5.11

Figure 5.10 : Mandaya Filling with 1984 Start (Driest-period)

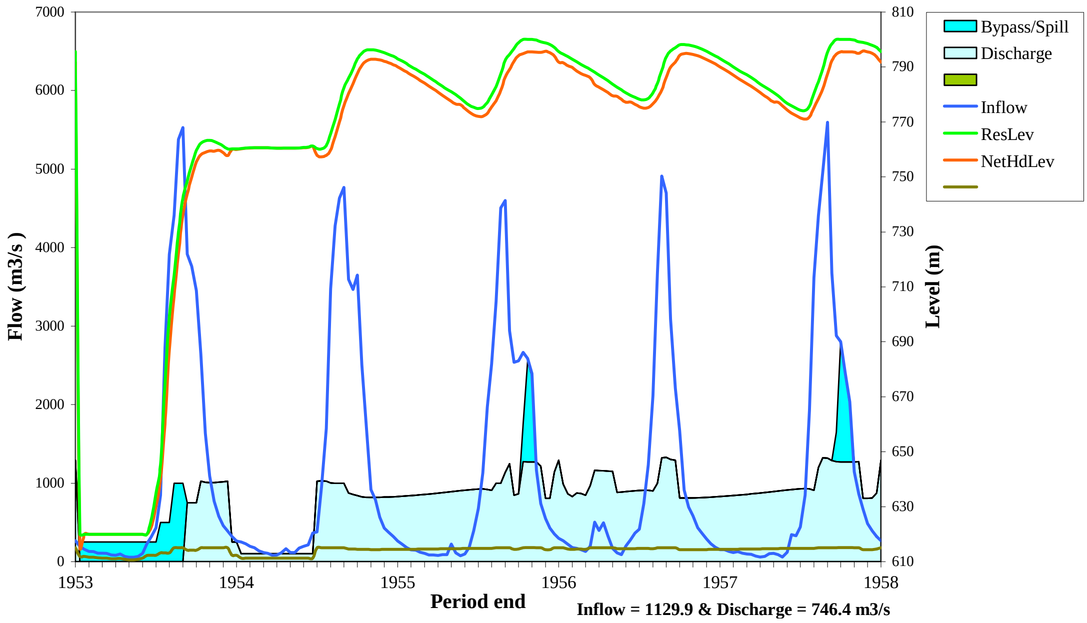


Table 5.10a : Effects of Mandaya Filling on Energy Outputs (Part 1)

Year	1954		1955		1956		1957	
	Base	**Filling**	**Base**	**Filling**	**Base**	**Filling**	**Base**	**Filling**
Mandaya	13,044	2,912	13,273	6,453	13,562	12,742	12,617	12,610
Roseires	2,048	1,426	2,153	1,451	2,149	2,151	2,159	2,159
Sennar	465	298	481	312	478	482	493	493
Jebel Auilia	78	93	126	144	127	129	133	132
Kashm el Girba	31	31	29	29	31	31	20	20
Merowe	6,565	4,872	7,110	4,984	7,145	7,135	5,994	5,968
Subtotal Sudan	9,187	6,719	9,897	6,920	9,931	9,928	8,799	8,772
Sudan loss	2,468	26.9%	2,977	30.1%	3	0.0%	27	0.3%
High Aswan	6,798	6,798	6,798	6,798	6,798	6,798	6,817	6,817
Sudan + High Aswan	15,985	13,517	16,696	13,718	16,729	16,726	15,616	15,589
Loss	2,468	15.4%	2,977	17.8%	3	0.0%	27	0.2%
Year	**1964**		**1965**		**1966**		**1967**	
	Base	**Filling**	**Base**	**Filling**	**Base**	**Filling**	**Base**	**Filling**
Mandaya	13,711	3,789	11,597	6,134	11,310	10,066	12,553	10,091
Roseires	2,151	1,429	2,161	1,518	2,153	2,134	2,156	2,087
Sennar	475	299	498	332	495	497	489	494
Jebel Auilia	123	134	143	154	154	153	142	147
Kashm el Girba	39	39	47	47	35	35	34	34
Merowe	7,770	6,753	8,238	7,315	6,650	6,747	6,873	6,530
Subtotal Sudan	10,559	8,655	11,087	9,366	9,486	9,564	9,694	9,293
Sudan loss	1,904	18.0%	1,722	15.5%	-78	-0.8%	401	4.1%
High Aswan	11,322	6,798	9,787	6,817	6,798	6,798	8,008	6,814
Sudan + High Aswan	21,881	15,453	20,875	16,183	16,285	16,363	17,702	16,107
Loss	6,428	29.4%	4,692	22.5%	-78	-0.5%	1,595	9.0%
Year	**1974**		**1975**		**1976**		**1977**	
	Base	**Filling**	**Base**	**Filling**	**Base**	**Filling**	**Base**	**Filling**
Mandaya	11,284	1,306	12,595	5,615	11,865	11,325	13,152	12,970
Roseires	2,154	1,418	2,153	1,267	2,156	2,159	2,157	2,158
Sennar	493	325	486	247	498	500	489	489
Jebel Auilia	140	119	136	156	151	154	138	140
Kashm el Girba	35	35	37	37	47	47	31	31
Merowe	6,037	4,801	7,059	5,023	5,987	5,868	5,860	5,865
Subtotal Sudan	8,858	6,697	9,871	6,731	8,839	8,727	8,675	8,682
Sudan loss	2,161	24.4%	3,141	31.8%	112	1.3%	-7	-0.1%
High Aswan	6,798	6,798	7,773	6,798	6,802	6,798	6,817	6,817
Sudan + High Aswan	15,657	13,495	17,645	13,529	15,641	15,525	15,492	15,499
Loss	2,161	13.8%	4,116	23.3%	116	0.7%	-7	0.0%

Table 5.10b : Effects of Mandaya Filling on Energy Outputs (Part 2)

Year	1984		1985		1986		1987	
	Base	Filling	Base	Filling	Base	Filling	Base	Filling
Mandaya	10,342	0	7,022	4,234	11,242	6,432	9,797	9,490
Roseires	2,152	1,331	1,601	1,271	2,163	1,449	2,106	2,040
Sennar	502	298	380	245	502	322	504	500
Jebel Auilia	138	121	140	146	136	145	130	130
Kashm el Girba	22	22	31	31	41	41	39	39
Merowe	4,724	3,279	4,879	3,973	5,458	4,033	4,985	4,916
Subtotal Sudan	7,538	5,052	7,031	5,666	8,299	5,990	7,763	7,625
Sudan loss	2,486	33.0%	1,365	19.4%	2,309	27.8%	138	1.8%
High Aswan	6,798	6,798	6,817	6,817	6,798	6,798	4,712	4,712
Sudan + High Aswan	14,336	11,850	13,848	12,483	15,098	12,788	12,475	12,337
Loss	2,486	17.3%	1,365	9.9%	2,309	15.3%	138	1.1%
Year	**1994**		**1995**		**1996**		**1997**	
	Base	**Filling**	**Base**	**Filling**	**Base**	**Filling**	**Base**	**Filling**
Mandaya	13,167	2,575	11,561	6,430	13,356	10,882	12,561	12,446
Roseires	2,150	1,428	2,162	1,323	2,145	2,154	2,159	2,159
Sennar	483	310	502	283	480	497	497	497
Jebel Auilia	133	117	145	155	137	147	153	154
Kashm el Girba	43	43	29	29	32	32	44	44
Merowe	6,360	4,645	5,485	4,235	6,538	6,054	5,910	5,873
Subtotal Sudan	9,169	6,543	8,324	6,025	9,332	8,884	8,763	8,727
Sudan loss	2,626	28.6%	2,299	27.6%	449	4.8%	36	0.4%
High Aswan	6,798	6,798	6,798	6,798	6,798	6,798	6,817	6,817
Sudan + High Aswan	15,967	13,342	15,122	12,823	16,131	15,682	15,580	15,544
Loss	2,626	16.4%	2,299	15.2%	449	2.8%	36	0.2%

Average for 5 years	Base	Filling	Base	Filling	Base	Filling	Base	Filling
Mandaya	12,309	2,116	11,210	5,773	12,267	10,289	12,136	11,521
Roseires	2,131	1,406	2,046	1,366	2,153	2,009	2,147	2,120
Sennar	484	306	469	284	491	459	494	495
Jebel Auilia	122	117	138	151	141	145	139	141
Kashm el Girba	34	34	35	35	37	37	34	34
Merowe	6,291	4,870	6,554	5,106	6,356	5,967	5,924	5,830
Subtotal Sudan	9,062	6,733	9,242	6,941	9,178	8,619	8,739	8,620
Sudan loss	2,329	25.7%	2,301	24.9%	559	6.1%	119	1.4%
High Aswan	7,703	6,798	7,595	6,806	6,799	6,798	6,634	6,395
Sudan + High Aswan	16,765	13,531	16,837	13,747	15,977	15,417	15,373	15,015
Loss	3,234	19.3%	3,090	18.4%	560	3.5%	358	2.3%

Figure 5.11 : Mandaya Filling with 1953 Start (Wettest-period)

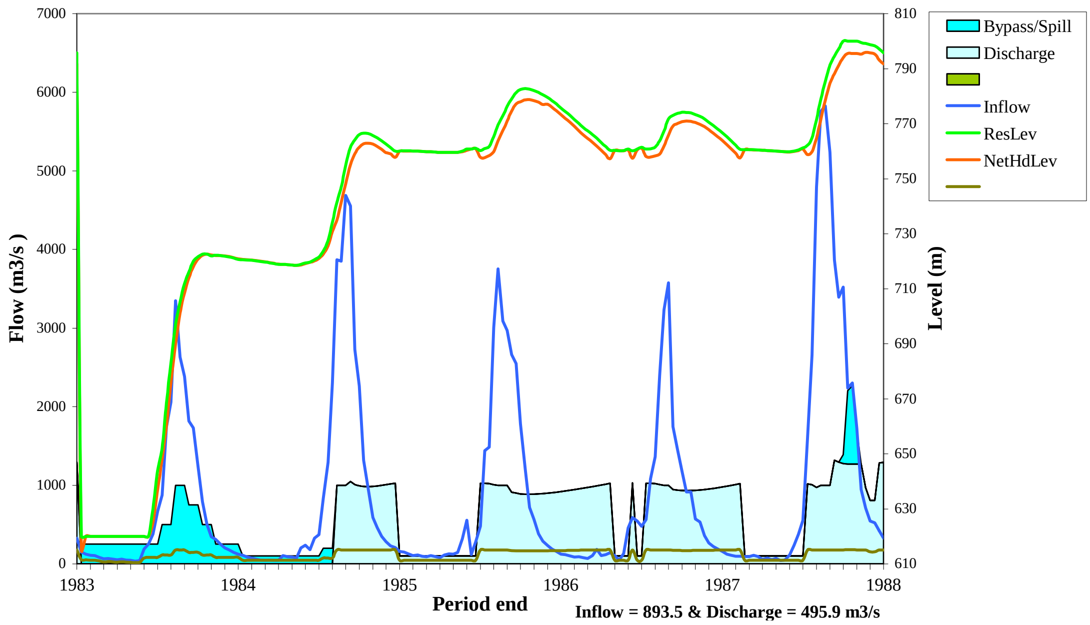


Table 5.11 : Months for Mandaya Filling to Minimum Operation and Full Supply Levels

Filling Start (January)	Months to Minimum Operation Level (EL. 760 m)	Months to Full Supply Level (El. 800 m)
1954	10	22
1964	10	70
1974	19	58
1984	23	58
1994	9	56
Average	14.2	52.8

In all cases the impact of filling Mandaya reservoir would be to reduce the volume of water stored in Aswan by a similar amount (49.2 x 10^9 m^3) over the filling period compared to the level that would otherwise occur. Assuming that Aswan reservoir was at a level of El. 175 m at the start of filling of Mandaya, the volume would reduce from 121.3 x 10^9 m^3 to some 72.1 x 10^9 m^3. The corresponding reduction in water level would be from El. 175m to El. 163.2m, a drop of 11.8 metres, although the exact amount would depend on the hydrology over the Mandaya filling period. This reduction in level would reduce the head for energy generation at Aswan by some 16 %.

5.7.3 Long-term Operation of High Aswan

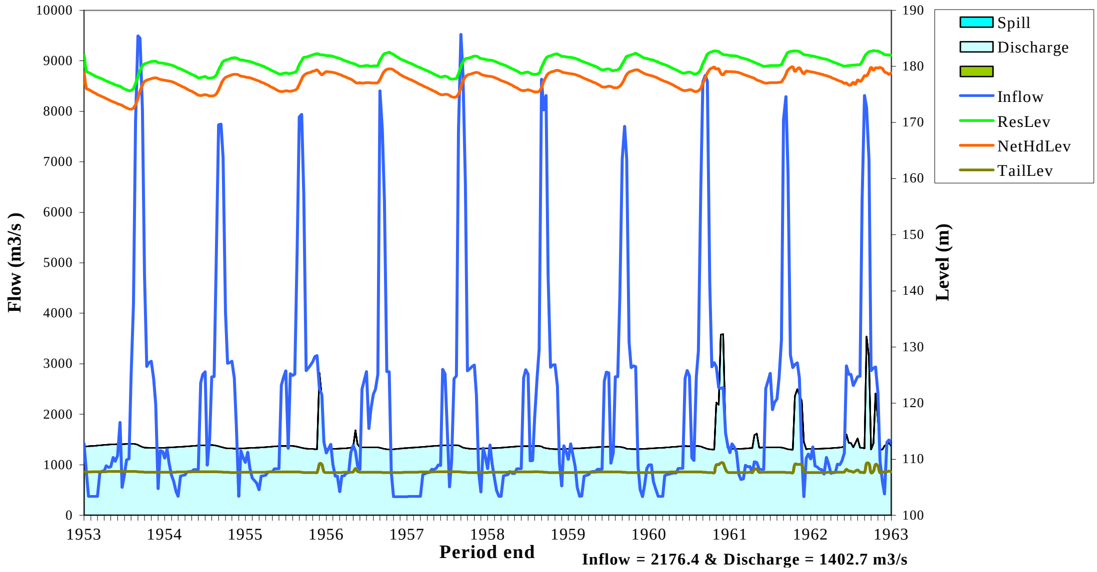
The base-case system simulated consists of the Sudanese hydroelectric schemes Roseires and Sennar (the latter with 4x12.5 MW extension) on the Blue Nile, Jebel Aulia on the White Nile, Kashm el Girba on the Atbara and Merowe on the Main Nile, all the Sudanese irrigation areas that are supplied from these rivers as have been forecast for 2012 (with it thus being assumed that the Sudan is fully utilising her share under the 1959 Nile Waters agreement with Egypt) together with Lake Nasser and High Aswan. With minimum generation level set to 162 m, the Lake Nasser finishing level was found to equalise to a starting level of 179.25 m, and the High Aswan firm and average energy outputs over the 50-year simulation period without Mandaya are shown in Table 5.12, below. The first 10 years of this sequence is illustrated in Figure 5.12.

A second trial was then carried out with the same starting level of Lake Nasser and with Mandaya (assuming Mandaya reservoir was already impounded). The objective of this trial was to establish the loss of generation at Aswan due to evaporation from Mandaya reservoir, excluding the effects of reservoir filling. It can be seen from Table 5.12 that the long-term loss of generation at Aswan due to Mandaya is some 117 GWh/yr, due primarily to the reduction of inflow associated with evaporation losses from Mandaya reservoir. Separate trials were carried out to determine loss of energy due to filling of Mandaya – these are described in Section 5.7.4.

Table 5.12 : Impact of Mandaya Evaporation on Energy Output of Aswan

	High Aswan Energy Outputs (GWh/yr)	
	Firm	**Average**
Base Case	6,857	7,052
With Mandaya (FSL 800)	6,803	6,935
Reduction due to Mandaya	54	117

Figure 5.12 : Base case (i.e. without Mandaya) High Aswan Operation from January 1954



5.7.4 Effects of Mandaya Filling

The long-term operating policies, in terms of generation demands and monthly control levels, that had been optimised for the above simulations to provide 98 per cent supply reliability from each of Mandaya, Roseires, Sennar, Kashm el Girba, Merowe and High Aswan were all kept unchanged for simulations with Mandaya filling from the initial 610 m through the assumed minimum generation level of 760 m up to the 800 m full-supply level.

It can be seen from Table 5.10 that the simulated losses of total Sudanese hydroelectric energy production average to some 25 per cent during the first two years of Mandaya operation but thereafter rapidly tail off. It must be emphasised, however, that the figures in both Tables 5.10 and 5.11 will be highly sensitive not only to the manner in which Mandaya is operated but also to the minimum generation level that in practice proves feasible, and clearly if a reduced rate of filling or a lower minimum generation level could be achieved the magnitudes of Sudanese hydroelectric energy losses in the early years would be greatly reduced. It is accordingly strongly recommended that these aspects be studied in depth at the Mandaya feasibility-study stage so that the best compromise can be found.

Figures 5.13 and 5.14 illustrate the impact of filling Mandaya on water levels at Aswan (Lake Nasser / Nubia) for the two cases of filling commencing in a wet year (1954) or a dry year (1984).

Figure 5.13 : Aswan 10-year Operation with Mandaya Filling from January 1954

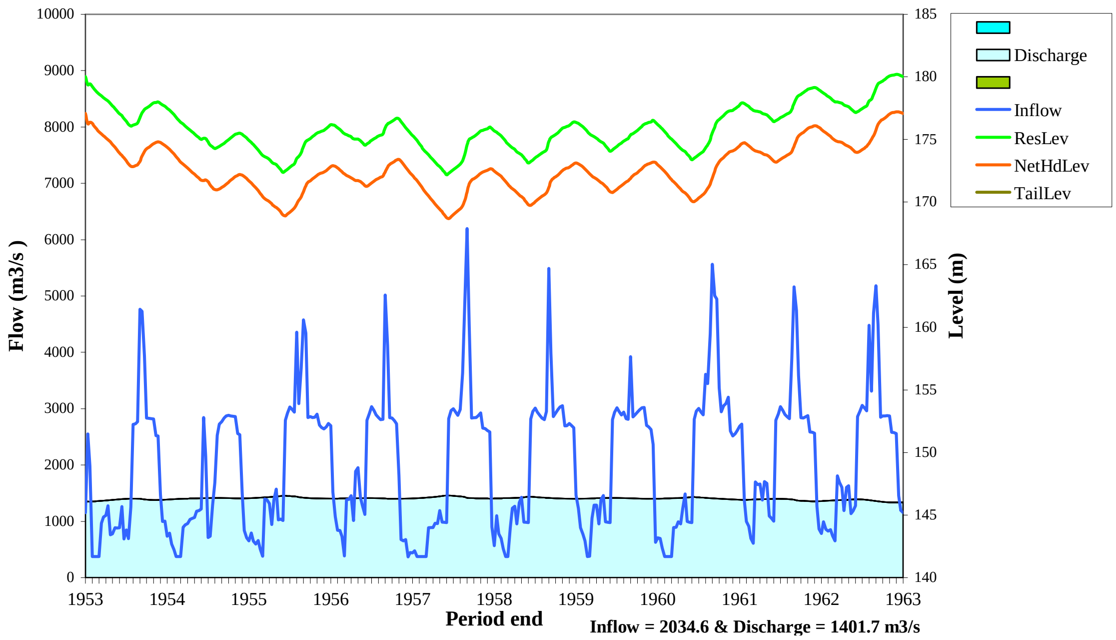
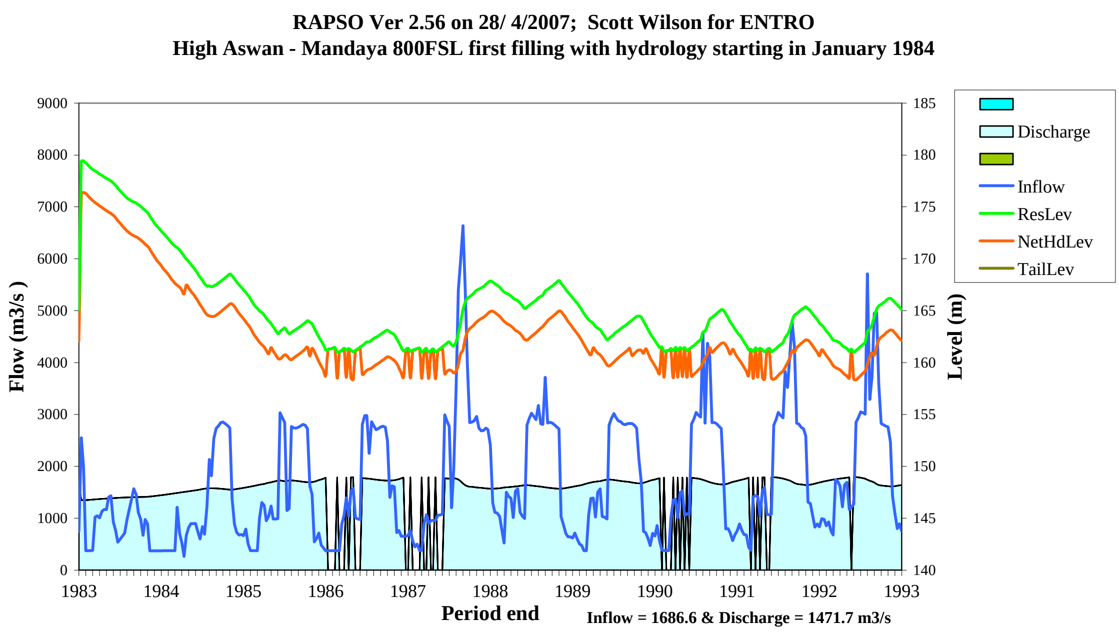


Figure 5.14 : Aswan 10-year Operation with Mandaya Filling from January 1984



It can be seen that in the "wet year " case the reservoir level at Aswan is would be drawn down by some 7 metres from El. 179.4m to El. 172.4m before rising gradually over the following years. In the 1984 "dry year" case the drawdown in water level of the reservoir at Aswan would be some 18 metres to El. 161m over a three-year period. Energy output would be reduced over the first two years by some 11% on average (based on the results of five trials) but would thereafter rise progressively although there are substantial differences between individual years).

It can also be seen from Tables 5.10a and 5.10b that the losses of High Aswan energy production are small. Within the RAPSO model the release of flow from Aswan for power generation is determined by the required firm energy generation. Hence additional flow is released in the early years to compensate for the reduced reservoir level and hence generating head. There is, however, a price to be paid for this in that during the Mandaya filling period the Lake Nasser level is significantly lowered. Level recovery is then generally quite slow, reflecting the fact that reductions in evaporation losses at the lower levels only slightly exceed increases in discharge required to sustain the same energy outputs under the correspondingly reduced head, and also because the base-case simulation shows the lake rarely spilling. Thus for example base-case (i.e. without Mandaya) and 1954 Mandaya filling-start results of High Aswan operation for the 10-year period 1954-1963 are shown in Figures 5.12 and 5.13, where attenuation of flood peaks arising from Mandaya regulation can also clearly be seen.

The overall impact on energy generation from High Aswan of construction and operation of Mandaya (50 year average, based on impounding start in 1954) would be a reduction of some 202 GWh/yr as shown in Table 5.13. However, it should be noted that this figure could vary considerably depending on the river flows at the time of impounding of Mandaya.

Table 5.13 : Impact of Mandaya on Energy Output of Aswan

	High Aswan Energy Outputs (GWh/yr)	
	Firm	Average
Base Case	6,857	7,052
With Mandaya (Filling start in 1954)	6,802	6,850
Reduction due to Mandaya	55	202

The long-term performance of High Aswan with Mandaya is illustrated in Figure 5.15, which shows the performance of Aswan reservoir over the 50 year hydrology sequence with Mandaya filling commencing in 1954. It can be seen that during the period of Mandaya filling (1954 – 1956) Aswan reservoir level drops from an initial level of El. 179.2 m to El. 172.6m. Thereafter the reservoir level gradually rises with the normal seasonal pattern reflecting the varying inflows (from catchments downstream of Mandaya plus Mandaya spillage). Aswan reservoir regains an elevation of El. 179 m in 1962 as a result of reduced evaporation and favourable inflows. Thereafter it can be seen that Aswan reservoir remains relatively full until approximately 1980 following which drought conditions cause the level of Aswan to fall substantially. However, it should be noted that this fall is due to low inflows and not due to Mandaya.

It can also be seen in Figure 5.15 that the discharge for generation at High Aswan rises over the period 1983 to 1998 compared to the earlier years. This is a consequence of setting a required firm energy in the RAPSO model. The model then increases outflow to compensate for the lower reservoir level and generating head. In practice it is probable that High Aswan would be operated to give priority to irrigation needs rather than energy output and the increase in outflow over this period would not occur. In this event Aswan reservoir would remain at a higher level but the loss of energy would be greater than described above.

The above effects on High Aswan are totally dependent on how that scheme is operated, and much faster level recovery of the reservoir could be obtained (if desired) if generation at High Aswan were to be slightly reduced in the early years during and after filling of Mandaya.

5.8 EVAPORATION FROM ASWAN RESERVOIR

The impact of evaporation from Mandaya reservoir on water availability in High Aswan reservoir has been examined by comparison of the High Aswan base case (without Mandaya) with the 50 year “with Mandaya” case. The average annual evaporation in the base case, without Mandaya was found to be 19751 Mm^3/year, whilst that with Mandaya (filling commencing in 1954) was found to be 19066 Mm^3/year. The reduction in High Aswan evaporation with Mandaya upstream compared to the base case was found to be 685 Mm^3/year, equivalent to 21.7 m^3/s. This compares to the evaporation loss from Mandaya of 580 Mm^3/yr, equivalent to

18.4 m^3/s. It can thus be concluded that the net result of development of Mandaya is to make more water available for use in Egypt.

5.9 REFERENCES

(1) National Electricity Corporation, Building of Electricity Sector Database and Long-term Power System Planning Study, Interim Report No. 3, Volume 1 – Hydrology and Hydroelectric Power Plant.

(2) Long-Term Agricultural Strategy (2002-2027). Report by the Water Resources Working Group, prepared by Dr Seif Eldin Hamad Abdalla, Ministry of Irrigation and Water Resources, Khartoum.

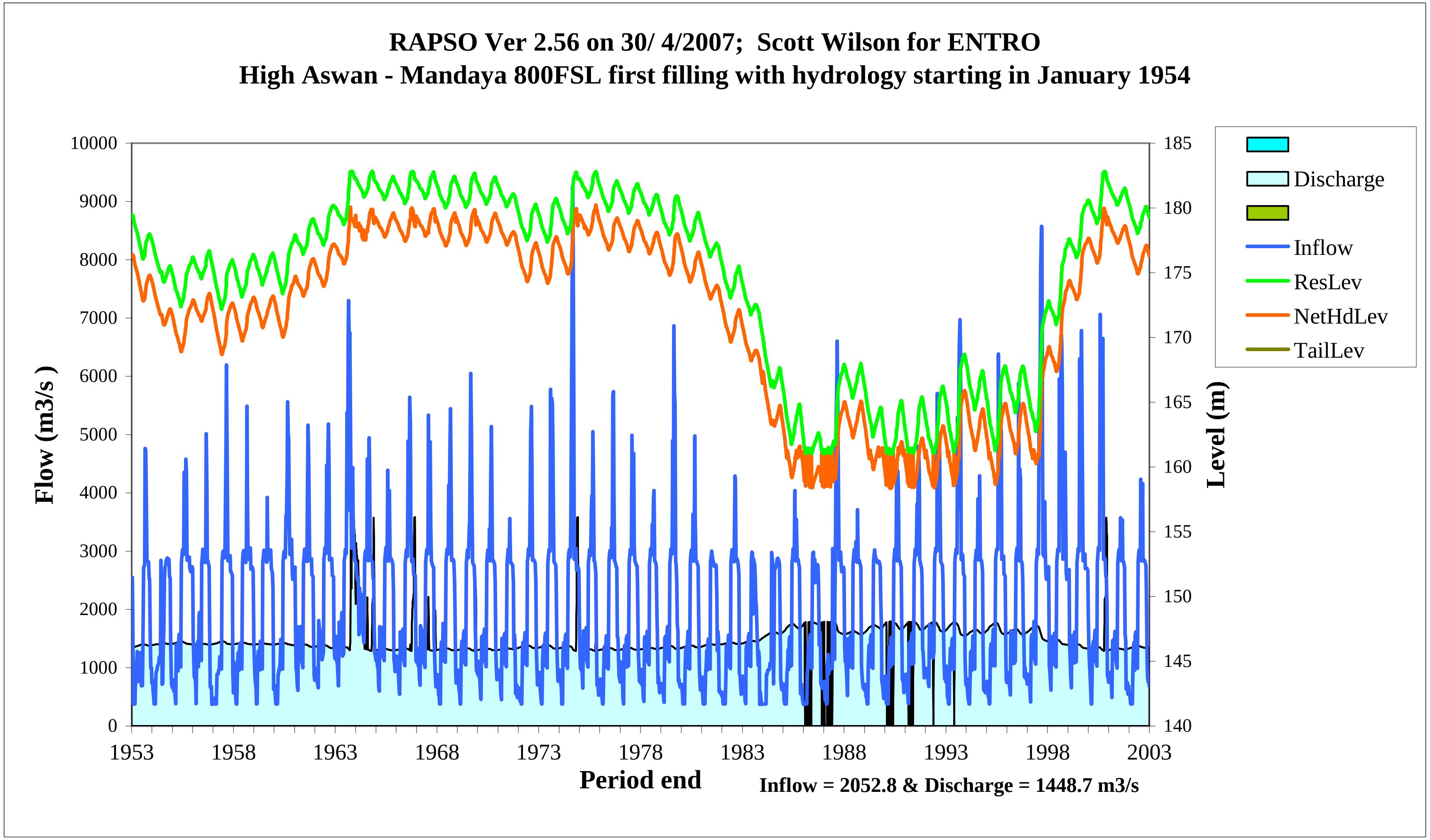


Figure 5.15 : Aswan 50-year Operation with Mandaya Filling from 1954

6. GEOLOGY

6.1 SITE LOCATION

Mandaya dam site is located on the Blue Nile (Abbay) River, 6.5km upstream of it's confluence with the Gember River, and 19km downstream of the Abbay/Didessa confluence (See Drawing M2 Locality Map). The site is approximately 370km West, North West of Addis Ababa. To reach the site by road it is necessary to follow the main Assosa road which heads out of Addis towards the west. The route passes through Ambo, Nekemte, Gimbe (first overnight stop after 14 hours of driving). The 'road' continues through Najo (last diesel point), to a little town called Mendi. (480km on odometer from Addis). Mendi is about 8 hours drive from Gimbe. From Mendi it is necessary to locate a side road heading north west towards marble quarries and the administrative village of Koncho, which is about 40km from Mendi. From there it is necessary to proceed 3km north east on a well-maintained marble quarry access-road before turning north east onto a track to the Boka Mission Station, which is a further 8.5km away along an extremely poor track requiring 4 wheel drive and occasional repairs using shovels and picks. The mission is run by the Mekan Eyessus Church of Ethiopia. The drive from Gimbe to the Mission takes 12 hours allowing for stops for food, fuel, and to make contact with the administrators at Koncho.

The mission station, which has a guest house, is the last access point for vehicles. To reach the base camp it is necessary to walk 22km to the east following a foot path which crosses the Boka river and passes through the villages of Boka extension, Sirba Abbay, Abbay Goli, and then closely follows the river for about 4km, before crossing rocky terrain for a further 3km before descending to the confluence of the Abbay and Gember rivers. This is a full days walk and a camp has to be established at this locality. The path can be traversed, with some difficulty, by laden donkeys.

The dam site lies a further 6.5km to the East, South East of the Gember confluence base camp. There is no path, but the country is quite open after grass burning, except for dense riverine thorn-thicket. The walk to the site takes about 3 hours.

The coordinates of the dam centre-line where it intersects the left bank of the river according to the GPS are as follows:

Easting 36 P 0780819m, Northing UTM 1113849m, elevation 619m. The approximate river level on this centre line is 611m. The coordinates are based on GPS positional format of UTM/UPS, and map datum ADINDON. This is the same system used on the Ethiopian 1 to 50 000 scale topographic maps.

6.2 HISTORICAL BACKGROUND AND PREVIOUS WORK

The hydro electric power potential of the Abbay river basin was first studied by the USA Bureau of Reclamation as part of an aid scheme funded by the US Department of State. The study started in 1958 and was completed in 1964, with the presentation of the main report[1]. The "Mandaya Project" at locality BN-26A is described on

[1] Land and water resources of the Blue Nile Basin, Appendix II Geology, 221 pages, dated 1964.

page 205 to 208 of the above-referenced report. The geology and geotechnics are briefly described and 2 photographs and one contour map, and a simple geological section are attached to the report.

The report noted the local geology as comprising pre-Cambrian hornblende gneiss, overlain by a capping of horizontal younger basalt defining an upper plateau area. The valley was described as u-shaped, with all of the dam foundations occurring within the gneissic rock, which was outcropping in the river section and adjacent valley slopes. The possible existence of a ‘buried gorge’ (in filled river channel?) was mentioned, but without further explanation.

The report concluded that the dam was feasible for a concrete or rockfill type structure. Appendix I of the same report stipulated a 164m high dam of thick arch type and a crest width of 1134m. Diversion would be through 3 tunnels of design capacity of 1100 m^3/sec, situated in the left abutment. The completed dam was estimated to have storage capacity of 16 835 000 000 m^3, and an output capacity of 1620 MWatt.

The Mandaya site was mentioned again in 1997, as part of the Abbay river Basin Integrated Development Master Plan Project undertaken by the Consultant BCEOM. Their report to the Ministry of Water Resources includes a brief description of the dam site geology but offers no real new information from that provided by the USBR study of 1964.

6.3 PRELIMINARY DESIGN AND POWER OUTPUT OF THE DAM

The Mandaya site is the second most downstream of the Nile river hydropower sites presently under consideration within Ethiopia. The following extract from the Inception Report[2] is pertinent:-

The USBR (1964) study recommended a dam some 150 metres in height (FSL 741 m) with a reservoir extending upstream to the next identified site at Mabil. The Mandaya site is capable of accommodating a dam of up to 260 metres in height (FSL 860 m) or thereabouts, obviating the need for the Mabil project and with the reservoir extending upstream close to the Karadobi site.

The reservoir area and volumes have yet to be established by digitising and measurement from the 1:50,000 maps or from new mapping. However, it is clear that the reservoir will provide a high degree of regulation of inflows and flood mitigation as well as having a sufficiently large volume to ensure a long period of life prior to significant storage losses due to sediment deposition.

River flows at Mandaya are approximately 60% greater than Karadobi. As a consequence the installed capacity of the Mandaya project is preliminarily estimated as some 2400 – 2800 MW with potential energy generation estimated as some 16,000 to 18,000 GWh/year. The firm and average energy output and installed capacity will be studied in detail in the forthcoming reservoir modelling task.

[2] Eastern Nile Power Trade Program Study: Inception Report, 7th December 2006, page 36 of 43

A preliminary dam design has been produced by Scott Wilson in February 2007, (Drawing M3). This most-recent design concept incorporates a 190m high RCC dam with foundation level at -611m, and FSL 800m, and crest width 1400m. The dam has a central spillway and a power station at the downstream toe of the dam adjacent to the right bank of the river. The lower crest level, reduced from 860m to 800m, must mean a commensurate reduction of energy output compared to the Inception Report estimate. The river diversion is shown as a narrow chute on the left flank, in place of the 3 diversion tunnels, originally suggested by the Americans.

The Consultant EDF/Scott Wilson, with TROPICS flew over the site in November 2006 as part of the Preliminary Assessment of the "Study", and observations were included in the Inception Report, to ENTRO, dated 7th December 2006.

Following the completion of the inception report, the second phase of pre-feasibility investigations commenced on 8th February 2007. During technical discussions between Scott Wilson and ENTRO, it was agreed that effective seismic reflective profiling and drilling of the Mandaya site was not practical in the time frame allotted, due mainly to the remoteness of the site. For this reason it was decided to carry out the pre-feasibility investigation by relying only on regional geological mapping, previous investigations, surface mapping of the site, and interpretation of air photographs. This report presents the findings of these secondary investigations.

6.4 TOPOGRAPHIC MAPS AND AERIAL PHOTOGRAPHS

1 to 250 000 scale maps, sheets NC 36-8, and NC 36-12, NC 37-5 and NC 37-9, of series EMA 3, 1st edition, cover the dam site/upper basin, and lower basin respectively, and are available at the local Government Trig. Survey Department.

1 to 50 000 scale, topographic sheets are also available: sheet 1035 C4, 'Sirba Abay' covers the area downstream of the dam, whereas sheet 1035 D3, 'Re-Iti' covers the dam site. All the adjacent 1 to 50 000 sheets, that cover the dam basin area, are also available.

The various topographic maps are based on positional format of; UTM Zone 36 P, and map datum ADINDAN.

The 1 to 50 000 scale air photos that cover the dam area and nearby basin are as follows:

Flown for USBR in 1957 and 1958, job V BNRB

- Strip M6, 1957, nos. 0025 & 0026, and 1430 to 1432.
- Strip M 7, 1958, nos. 0072 to 0076.

6.5 REGIONAL AND LOCAL GEOLOGY/GEOMORPHOLOGY

6.5.1 Regional geological history

The geologic history of Ethiopia is well known; the entire country is part of the ancient African craton formed of pre-Cambrian basement crystalline rocks. These have been folded and faulted and later eroded and peneplained (planed-off over a huge area) in the Palaeozoic era.

Continental subsidence caused marine transgressions and regressions during the Mesozoic and Early Tertiary eras, with the incursion of the sea and marine sedimentation, followed later by regression of the sea and uplift creating a new peneplain that developed from the South - East to the North–West. Miocene marine sedimentary deposits occur in the lower part of the upper reaches of the Abbay gorge, where they form a 2400m thick, sub horizontal, sedimentary pile, lying unconformably above the basement rocks.

In the main part of the Tertiary period there occurred enormous uplift of the North African continent associated with rifting and trans-current faulting leading to a vast outpouring of basaltic rock to form the familiar plateau basalts of the Ethiopian highlands. The flood basalts lie with conformity above the Miocene sedimentary pile, or else unconformably above the pre-Cambrian basement. After the formation of flood basalts later-stage volcanic activity from distinct epicentres, resulted in late-stage out pouring of acid and intermediate lava such as rhyolite , andesite, trachyte etc.

Up-doming was followed by rifting in the late tertiary leading to the formation of the main Ethiopian Rift and the Afar Depression. Recent tectonic activity and volcanism are associated with the rift valley and along some transverse faults.

6.5.2 Regional Geological map, and Related Studies

The geology of Ethiopia has been mapped by the Ethiopian Geological survey on a scale of 1 to 50 000, with geological maps published on a scale of 1 to 250 000. This mapping is the basis of the geological history outlined previously. The published geological map that covers the Mandaya dam site area is covered by sheet; NC 36-8; “Assosa”.

A fragment of the Assosa geological map, covering the Mandaya dam site area is shown as Drawing M4. The dam site is situated within the extensive unit: “Ptn”, which on the map legend corresponds to the syntectonic, pre-Cambrian, intrusive rock: “*Metatonalite; Medium grained, weakly foliated, containing xenolithic gabbro and amphibole gneiss*.” The term xenolithic means small to huge blocks of older country rock that became included in the intruded granodiorite magma. The term ‘syntectonic’, means the rock was intruded whilst severe deformation was still taking place, so that the tonalite takes up a foliation parallel to the regional structural trend. Tonalite is an intrusive sub-acidic, or intermediate rock, in composition it is half way between granite and gabbro.

The regional geological map indicates dissected remnants of late Tertiary basalt on each side of the river at Mandaya. These basalt layers are horizontal and have table-top landform, around elevations 860 to 910m.

On Drawing M4 several lineaments are marked within an 8km radius from the dam site, but importantly no fault or lineament is shown as actually intersecting the dam founding area. A lineament is shown 2km to the NW of the centreline, having strike of 310 degrees, this line could be theoretically extended towards the SE, and therefore go through the river section of the dam, but there is no evidence of any fault seen in the outcrops around the dam site. Another lineament of similar trend is mapped along a prominent gully about 2.3km south of the dam.

A regional fault system is suggested with one set of faults striking NNE and the other ESE. Some faults belonging to the former set, are shown displacing the Tertiary basalt rocks, which if correct, would indicate quite recent tectonic activity.

6.5.3 Regional Geomorphology

By cause and affect, the early-Tertiary uplift, mentioned in the geological history, resulted in the formation of huge drainage basins due to high relief and high rainfall, and very large river systems were formed within the Tertiary period, even before the uplift had finished. One such river system is the Blue Nile or Abbay River that rises in Lake Tana and follows a tortuous path through Ethiopia before entering Sudan and eventually meeting the White Nile in Khartoum. From the Abbay / Didessa confluence, upstream to Lake Tana, the Abbay river flows within a spectacular dissected gorge, here the whole geological sequence is preserved with basement overlain by Miocene sediment, overlain in turn by Tertiary flood basalt. In this section the river is relatively fast flowing with numerous rapids and waterfalls.

Downstream of the Abbay / Didessa confluence the Abbay gorge is less spectacular, and downstream of the Mandaya dam site the gorge disappears altogether. From here on the river has created a broad rolling pedeplain eroded into the pre-Cambrian basement rocks. This plain extends all the way through Sudan with ever-decreasing river grade in the downstream direction. Remnants of plateau basalt rise above the pre-Cambrian terrain, usually forming “table-top” mountains, such as those seen around the Mandaya site.

The drainage pattern in the Precambrian terrain is trellised indicating structural control. Streams are eroded along preferential weakness paths such as faults, dykes and master joints.

6.6 LOCAL GEOLOGY AND LOCAL GEOMORPHOLOGY

6.6.1 Local Geomorphology

Mandaya dam site is situated some 19km downstream of the Abbay / Didessa confluence. About 8km downstream of the confluence the Abbay enters a well-defined narrow gorge which extends all the way to the dam, and then a further 1.5km where it abruptly terminates. From here on the river enters a broad dissected pedeplain as mentioned previously. The narrow gorge at Mandaya is strongly controlled by geology. The gorge is cut through a flat layer of very strong durable basalt of Tertiary age. The horizontal basalt flow results in “table-top”, plateau, morphology. The edge of the plateau elements is formed by a vertical cliff of 15 to 45m height, depending on the local thickness of the basalt flow. At Mandaya site the top of the basalt on the left side is 901m. and about 910m on the right side. Below the basalt caprock the Abbay has carved out a symmetric u-shaped valley in the underlying gneiss, with a distinct rocky river section of 300m width. The river bed level is around 611m.

The valley flanks are corrugated with gullies that in their upper reaches expose decomposed metatonalite gneiss. Large boulders of basalt, of up to 1000m^3 volume, have detached from the upper escarpment and rolled down the steep valley slopes. Accumulations of boulders and talus are evident at the lower reaches of the side valley gullies.

In the USBR study the possibility of a ‘deeper, buried gorge’ was mentioned. However the symmetry of the valley argues against the existence of such a buried river channel on either flank, for such a feature would promote asymmetry. The USBR scientists were worried that there might be deep deposits of alluvium somewhere across the river section and lower valley. If this were the case then the deep alluvial deposits would have to occur below the existing river channel. However the numerous rock outcrops on both sides of the river, and sometimes in the middle of the channel, would not support such an hypothesis. At present it appears that the river bottoms on rock, or shallow boulder deposits, and that on either flank there is an elevated terrace of alluvium of up to 10m thickness.

The optimum position of the Mandaya dam site, in a narrow u-shaped gorge, is shown on Drawing M5. The gorge at the dam site extends 7 km upstream where the valley opens up due to the erosive effect of the Didessa River, and other secondary rivers. This, and the very low grade of the river bed, results in a potential huge basin area and very high storage volume. The existing combination of morphological factors determines the favourable characteristics of the Mandaya dam site.

6.6.2 Local Geological Formations and Petrography

Geological mapping at the site confirmed the existence of the two major, broad geological formations divisions; namely the Precambrian, **Biotite Gneissic Tonalite Formation** and the late Tertiary **Basalt Formation**. The boundary of the 2 formations is easily mapped or delineated from air photos.

Biotite Gneissic Tonalite Formation (Metatonalite)

The biotite gneissic tonalite is the foundation rock for the entire dam. One sample of the metatonalite was taken at the centreline and submitted to the Geological Survey for petrographic analysis (see Appendix 5.1 for detailed results). In hand specimen the rock is a dark grey or black, speckled white, medium to coarse grained rock, with incipient fabric defined by parallel alignment of mafic minerals. It appears to be intermediate in composition, comprising mainly feldspar and biotite, with significant quartz content. This is confirmed by thin section which indicates about 40%

plagioclase/orthoclase, 17% biotite, 15% quartz, 12% epidote, and 16% accessory minerals.

Frequent ellipsoid xenoliths of foreign rock are proof of the intrusive origin of this rock type.

The typical rock mass condition, as seen in the scoured river section is as follows: the rock material is unweathered to slightly weathered, and hard to very hard with weak foliation, sometimes the foliation is dispersed and the rock is geomechanically massive with estimated UCS in the range 150 to 200 MPa., with some degree of strength anisotropy caused by the foliation..

At all occurrences the weak foliation is oblique to the river bed, having strike of 322^0, dipping on average 85^0 towards the south-west, the river channel at the dam has the same strike, indicating structural control. Foliation results from parallel alignment of mica laths, in hand specimen this has a spacing of around 3 to 5mm. Foliation joints (separated surfaces) may be formed by stress relief. These have spacing in the range of 30cm to 3m.

Apart from foliation joints (set 1) two other sets are sometimes developed, set 2 is orientated at 019^0@86^0 dip, and set 3 at 292^0@87^0 dip. These sets are spaced from 50cm to 3m.

A notable feature is the absence of stress relief horizontal exfoliation joints, and the lack of continuity of the set 2 and 3 joint populations. This results in rather massive and intact outcrops in the scoured river section. Away from the river section the rock tends to be chemically disintegrated and flaky due to preferred weathering along foliation.

Random joints are also present.

Discontinuity data is provided in Appendix 5.2 to this report, “DIPS” software was used to plot angular data.

Within the scoured unweathered to slightly weathered rock masses the rock mass quality is rather constant, suggesting good to very good rock mass quality.

Away from the river section outcrops are chemically decomposed and moderately to completely weathered, indicative of poor or very poor rock mass quality. Depth of moderately to completely weathered rock is unknown but estimated as from 3 to 10m, depending on slope form.

At certain localities there were seen minor dykes intruding the metatonalite. Fine-grained acidic or felsic dykes, of up to 3m width, displayed incipient schistosity, indicating Precambrian age; the dykes have north south strike.

Amphibolite Schist /Quartzite Formation

These rock types were found outcropping along a narrow belt extending from Gember River confluence towards the South East. They must be older than the metatonalite perhaps this narrow zone of alien rock is a huge xenolith within the main intrusive body, or alternatively it may be a faulted outlier. In any case these rocks do not occur at the dam site so they are of little engineering consequence.

Tertiary Olivine Basalt Formation

The rock in hand specimen is black, massive, homogenic, fine grained and very heavy with SG>3.0. With a hand lens porphyritic igneous texture can be observed. Always the outcrops display hexagonal or octagonal columnar joint systems, which may be vertical or irregularly formed. Loose rock pieces tend to be hexagonal prisms bounded by columnar joints and sub horizontal joints, which form the prism ends.

Outcrops occur all along the cliff which surrounds the plateau areas.

The detailed petrography of the basalt is given in Appendix 6.1. Typically the rock is composed of 50% plagioclase feldspar, 30% pyroxene, 10% metallic minerals, 5% olivine, and 5% volcanic glass and accessory minerals. It can be termed porphyritic olivine basalt.

Joint orientations were not measured in the basalt formation. Typically there are seen well developed vertical joints with random strike. Average spacing between adjacent vertical joints is around 30 to 50cm. Horizontal joints break up the rock columns into lengths of 30 to 100cm.

The lower contact of the basalt formation is not exposed in the field study-area. From observations at other localities in Ethiopia, it is possible that a thin layer of residual clay overlain by gravel might be found at this contact. The residual clay, if it exists, would be termed a palaeosoil, as it would have been formed on an ancient pre-Tertiary land surface. Between way-points 45 to 47, at high elevations, some well-rounded pebbles of basalt were noted in the soils below the basalt cap. These might be derived from a hidden, gravel layer found at the base of the basalt. The contact zone will have to be investigated during the feasibility study.

6.7 MINERAL RESOURCES IN THE DAM BASIN

Gold and Base Metals

The Precambrian rocks falling within the Blue Nile basin contain a significant proportion of greenstone rocks, these are ancient metasediments, marbles, and metavolcanics having a low grade of metamorphism. The main green stone belt forms a broad swathe, about 20 to 50km wide, and orientated north south, which intersects the Abbay River in the upper part of the Mandaya basin area, i.e. along a strip which is East of Najo, and West of Gimbi. This suite of rocks contains gold, and other base metals, disseminated within minor quartz veins. To date; no vein deposits have been found that are large enough to sustain gold mines. The gold over geological time is eroded away and ends up as tiny grains in the alluvial sands of the Abbay flood plain, and older river terraces. The Abbay River does not carry much coarse or medium grained sand. Instead the alluvium comprises silt, very fine micaceous quartz sand, and channel lag gravels. Durable and heavy minerals, like gold and base metals tend to become incorporated into the channel lag gravels, where they form a loose, fine to medium grained, black sand-matrix, usually in pockets.

For a very long time gold has been extracted from alluvium by the indigenous peoples that live next to the Abbay River and its major tributaries. The method of extraction is to sieve the channel lag gravels in order to concentrate the metallic rich sandy matrix. These matrix-fines are then panned to isolate the gold fraction. Every year the waters of the Abbay recede over a 3-month period, and it is during this period that panning is carried out. Annual flooding of the Abbay causes replenishment of the gold bearing sands as the channel lag deposits are re-distributed during maximum flow events.

The extent of the alluvial and primary gold resource in the Abbay Basin is unknown and unknowable. The Environmental Team working for the **EDF/Scott Wilson Consortium,** report that in the Assosa and Guba provinces there are 50 000 people who seasonally extract alluvial gold. This figure appears to be wildly exaggerated. The author walked along 40km of the Abbay River, during the months of February and March 2007, and saw only 2 locations where gold was being extracted, one close to Border dam site, and one at Abbay Goli village, downstream of Mandaya site. A combined total of about 40 people were busy panning.

In recent times the alluvial gold deposits of the Abbay Basin have attracted the attention of South African, Sudanese and local mining companies. For example JCI have a concession somewhere near Gimbi, and Sudanese financiers have prospective interests near Assosa, and the local company; ARDCO, are said to have obtained a gold concession in the Beles Valley.

It would be prudent if the Ethiopian government were to stop issuing mining concessions for extraction of alluvial gold in the basin area of Mandaya Dam. The owners of these concessions would demand compensation for inundation of their concession areas. The same applies to primary gold concessions that might fall within the Mandaya basin area.

Construction of Mandaya dam would flood a great length of the Abbay River and important side valleys like Didessa. All these lengths of river contain alluvial gold, and therefore this renewable resource will be lost to the people who go into these areas to pan for gold. It must also be noted that the Mandaya dam will halt migration of alluvial gold downstream of Mandaya and this could also have long term detrimental affects on the casual alluvial diggers. It is understood that all of these gold diggers, living both upstream and downstream of the dam, are unlicensed.

In all likelihood the gold resources lost by construction of the dam would be paltry compared to the economic benefits. However gold always attracts attention and the compensation for lost resources will no doubt, become a vexed issue.

Marble

Minor outcrops of marble may occur in the reservoir area, but if they do exist, they were too small to be individually mapped by the Ethiopian Geological Survey. Therefore no commercially viable reserves of marble will be covered by the reservoir.

6.8 RESULTS OF SITE INVESTIGATIONS

6.8.1 Geological map and longitudinal section

A geological map of the site is presented as Drawing M6. The map is based on air photo interpretation and detailed geological mapping performed at, and between, 65 way- points defined by GPS.

A longitudinal geological section through the dam centre line is presented as Drawing M7. The section is based on the existing 1 to 50 000 scale topographic map. The section shows outcrops, rock types and assumed depths of colluvium and alluvium.

6.8.2 Joint Surveys

The joint data are given in Appendix 6.2, along with DIPS plots of stereographic data, such as scatter diagrams, contoured plots of poles and main planes plot. The significance of the joint pattern has already been described above.

6.8.3 Geomechanical Properties of foundation Rocks

No test data exists, the following table is empiric and based on the field soundness of the unweathered rock samples.

Table 6.1 : Estimated Index Properties of Unweathered Rock Types at Mandaya Dam Site

ROCK TYPE	UCS	'STRENGTH RATIO[3]'	SPECIFIC GRAVITY
Precambrian biotite gneissic <u>tonalite</u>	150 to 200 MPa	0.8	2.85
Tertiary olivine porphyritic <u>Basalt</u>	>250 MPa	1.0 (there is no fabric)	>3.0

6.9 RESERVOIR STABILITY AND LEAKAGE

Reservoir Side Slope-Stability

As way of introduction it is important to note that the entire reservoir area of Mandaya dam is underlain by Precambrian rocks. This is fundamentally favourable for slope stability. Landslides in the Abbay gorge are often caused by undercutting of basalt cliffs where they are underlain by weak, easily 'erodeable', Miocene sedimentary rock. They may also occur in saturated zones of sedimentary rock, especially gypsum and mudstone. Both of these adverse geological environments are absent in the Mandaya reservoir area.

[3] The ratio of UCS tested at i) load at 45 degree angle to the foliation, and ii) load perpendicular to the foliation,

Examination of the available geological maps confirms that the entire basin is underlain by basement crystalline rocks, with granite types more prevalent than schist types. The foliation of the rock is generally steeply dipping usually in the range of 80 to 90 degrees, and joint sets are usually vertical or sub horizontal, but never inclined. This arrangement is quite favourable for slope stability.

The Mandaya reservoir divides into two separate branches: the Abbay branch and the Didessa branch. Concerning the latter, this whole part of the basin is typified by gentle slopes and favourable geology, and the risk of large scale instability after impoundment, is low.

Concerning the Abbay branch the worse case scenario occurs within Mandaya gorge itself, from the dam wall to a point 7km upstream. In this section there occurs maximum depth of water, very steep side slopes, and vertical cliffs along the basalt cap rock, with **possibility** of weak palaeosoil/conglomerate separating the basalt and underlying Precambrian rock. Air photos indicate no landslide along these slopes. Field inspection suggests very shallow soil cover with gullies exposing decomposed gneiss. Small colluvial fans are found at the base of these gullies, but these are formed during flash floods and by slope ravelling. The existence of huge perched blocks of basalt indicate toppling due to undercutting. Some blocks have rolled down to river elevation. The slopes appear to be quasi stable, with possibility of basalt blocks toppling and sliding under extraordinary conditions, such as during seismic events, or under adverse weather conditions. The question to be posed here is how the quasi stable condition might be altered for the worse following permanent inundation? To analyse this question it would be necessary to get data on the depth of weathering of the gneiss, the frictional properties of the soil cover and gneissic regolith, and the precise condition of the basalt/gneiss contact, as well as the precise slope morphology. The overall geological environment appears to preclude a huge scale slope failure as the weathered gneiss layer appears to be limited in depth. The contact of the basalt/gneiss is above the FSL of the reservoir, however it must be considered as possible for blocks of basalt to be dislodged during the life of the dam, and such blocks might be up to $1000m^3$ in volume, as discussed previously in Section 6.6.1. If these blocks fell onto the dam wall during or after construction this could cause great damage. So prior to construction it would be prudent to trim-of the basalt cliff above the dam working area, and to closely inspect any existing, perched, detached basalt blocks.

Very steep slopes tower above the Abbay branch of the reservoir in a section upstream of the point where the river intersects longitude 36 degrees 10 minutes. This point is about 70km upstream of the dam. According to the 1 to 1 million scale geological map of Ethiopia, the extreme topography in this area coincides with a gneissic granite intrusion. In fact there must always be a direct relationship between steep, high, slopes and favourable bedrock geology. Nevertheless this area should be checked during the feasibility studies, and so should other similar stretches which occur even further upstream. Here it is merely noted that any bow-waves created by landslides in these zones would be quite attenuated by the time they reach the dam wall.

Reservoir Seepage

In terms of reservoir leakage there is low risk at Mandaya site. The shortest possible seepage path occurs at the dam on the right side. This seepage path from the reservoir to the due north is 2km long. Along this seepage path, which is 120m below ground surface, the basement gneiss will be unweathered and therefore, will have very low rock mass permeability, and zero porosity.

6.10 CONSTRUCTION MATERIALS

6.10.1 Rock-Fill Material

There are abundant resources for rock fill as detailed in the next section.

6.10.2 Coarse Aggregate

One possible source of hard rock for aggregate would be pebble beds in the river alluvium particularly near the river channel. Such materials are found close Abbay Goli (see Drawing M5) where high river terrace deposits are found just east of this village. Gravels are also present on the islands north of Abbay Goli. Pitting of these gravel beds would be worthwhile to determine if significant reserves are available. These gravels are about 12 km downstream of the dam.

A much more reliable source of aggregate would be the basalt capping. This rock is considered as ideal for aggregate as it is very hard and durable, and homogenic. The basalt cap rock is considered to be 25m thick on average, and it appears to be quite unweathered throughout the layer. The basalt is massive and without vugs, vesicles or amygdales, this is also most favourable. The basalt contains no deleterious materials apart from a small fraction of volcanic glass, and therefore adverse alkali-reactions will not happen. Petrographic analysis of the basalt confirms the suitability of this rock type for aggregate use.

A very good quarry site could be established anywhere within the various plateau areas that are adjacent to the dam. Two possible quarry sites are shown on Drawing M5, but these are merely 2 out of numerous other possibilities.

6.10.3 Sand

High quality sand for can be obtained from crushed rock from the basalt quarry, there being no other obvious sources.

6.10.4 Impermeable Soils

Deposits of active and organic clay are found on the central parts of the Plateau.

6.10.5 Pozzuolana Materials

A large body of serpentinite occurs 47 km east of the dam. Such rock is comprised of serpentine, tremolite, talc ands smectite-clay. The rock is devoid of quartz or free silicon. The rock is soft and therefore easy to quarry and pulverise. All the minerals are under-saturated aluminium silicates with various metallic cations. Such material might be an alternative to pulverised fly ash, and is worth investigating in the feasibility stage.

6.11 GEOTECHNICAL EVALUATION OF THE DAMSITE AND RECOMMENDATIONS FOR FURTHER WORK IN THE FEASIBLITY STAGE.

Position of Centreline

The position shown on Drawing M3 is considered optimal. If the centreline is moved upstream or downstream, the crest length will increase in both cases. Furthermore there is no geotechnical advantage to be gained from shifting the dam, therefore the position on Drawing M3 is correct.

Type of Structure

A rolled compacted concrete gravity dam is considered ideal in view of the very large size of the dam and the ready availability of rock for aggregate and crushed sand. The valley profile is too wide for a concrete arch dam. Rockfill and earth fill dams are not viable due to the lack of suitable materials for the cut-off, and difficulty in establishing a side spillway.

Full Supply Level

A full supply level of 800m is considered optimal as this prevents flooding of the Nekemte/Bure Bridge. However the site could accommodate a full supply level up to 905m. For environmental reasons such a dam is considered not viable.

Dam Foundations.

River Section

The river section is 400 m at the centreline. There are many large, scoured outcrops of metatonalite at and nearby to the centreline. These indicate an unweathered very hard rock with incipient foliation and discontinuous vertical joints. The unconfined uniaxial strength of the rock material is high generally above 150 MPa. Such rock is considered uniform through the centreline area. These foundation conditions are considered to be excellent for the purpose of constructing an RCC dam, including all the various peripheral concrete elements, such as plunge pool, tailrace training wall, etc.

The active river channel may bottom on rock or on alluvial deposits such as pebble beds.

The USBR report considered the possibility of a deep buried river channel at Mandaya. Suggesting that there might exist a great depth of alluvium below the river bed. This does seem unlikely in view of the numerous outcrops in the river banks and as small islands. Nevertheless for design purpose it is essential to investigate the depth of alluvium below the river. This is not an easy task. Diamond drilling of the alluvium and underlying strata would require use of a moored drilling barge.

Seismic profiling by refraction or reflection simply does not work under water, contrary to what might be said by geophysics contractors.

Therefore angled drilling from the bank edge, and from a suitable barge appears to be unavoidable. On Drawing M3 are shown recommended borehole positions for the river section (nos. 4, 5 for centreline, 16 for plunge pool, 18, 19, and 20 for the upstream coffer dam.).

It is recommended that each hole, be drilled 25 m into sound unweathered rock. The main purpose of these holes is to determine depth of alluvium and quality of bed rock., as well as the usual reasons of sampling, rock testing and Lugeon permeability testing, etc.

Left and Right Flanks

The Mandaya gorge is symmetric and there the two flanks can be described as one. Each flank of the dam has three foundation elements lower slope, mid slope and top slope. .

The lower slope is a flat section corresponding to the upper alluvial terrace. Here there is up to 10m of alluvium comprising mainly fine sand and silt with a basal layer of conglomerate or loose boulders. It is expected that the alluvium will overly a scoured rock bed of metatonalite as found in the river section. For the RCC dam all the alluvium has to be excavated, and also the top meter of rock. Boreholes 3, 4 and 6 will be drilled to investigate the lower slopes of each flank. Each hole has to be drilled 25m into solid rock.

The alluvial terrace will merge and interdigitate with the lowermost colluvial- fan deposits in the mid slope section. The mid slope is concave and corresponds to the repository for all talus transported from above. At the end of gullies there may occur colluvial fans of depth up to 20m, but normal depth will be in the range of 2 to 10m. The colluvium comprises chaotic deposits of boulders, gravel, sandy clayey silt, etc. it is likely that the colluvium will overlay weathered metatonalite. For an RCC dam it will be necessary to excavate down to slightly weathered or unweathered metatonalite bed rock. Boreholes 2, 3, and 7 are recommended to will investigate the depth of colluvium, and the nature of the bedrock weathering profile in the two mid slope flank areas (Drawing M3). The estimated founding depth is 5 to 10m.

The top slopes are bare of soil and colluvium due to continued ravelling and mass wastage. Highly weathered to moderately weathered metatonalite is exposed on the surface. Here the investigative holes 1 and 8 are needed to determine the nature of the weathering profile. As elsewhere this part of the dam has to founded on slightly weathered rock at worse. Estimated founding depth is less than 5m.

Plateau Area

The recommended Borehole 17, is situated on the basalt plateau immediately above the left flank (Drawing M3). This hole has the purpose to investigate the stability of the basalt cliff above the dam. In particular it is important to determine the nature of the basalt/metatonalite contact. This hole will have to be drilled 20m below the base of the basaltic layer. Borehole 17 will also yield valuable information about using the basalt as a source for aggregates.

Injection Grouting

The high mica content of the metatonalite means that it is liable to chemical decomposition and mechanical disintegration. In hot arid climate there is likelihood of a disintegrated weathered layer, without sealing fines like secondary clay. This means that the weathered section of the metatonalite rock mass may have high secondary permeability. One of the important aspects of the foundation drilling is to determine rock mass permeability by Lugeon testing. It is likely that curtain grouting will be needed beneath the dam footprint.

Diversion Trench

Preliminary design indicates a 200m wide diversion trench for river diversion. The trench will have to cut 45m deep at its deepest part. A significant part of the trench will have to be excavated in colluvium and disintegrated metatonalite. Such material will be unstable in over-steepened slope and this may be problematic for such a deep excavation. Boreholes 13, 3, 14, and 15 investigate the diversion channel. These holes have to be drilled at least 5m into sound rock. Their purpose is to determine the viability of the trench, and the slope stability requirements. Bad results from these boreholes might force consideration of diversion tunnels to replace the trench, or in combination with the trench.

Tailrace Chute, Powerhouse and Penstocks

This composite structure is placed on the lower slope part of the right flank where, as explained previously, the foundation conditions are expected to be good in general. Boreholes 9, 6, 10, 11 and 12 will investigate the foundation conditions for each structure. Each hole should be drilled into 25m of solid rock. It is estimated that excavation depth to remove alluvium, and found on sound rock, will require 5 to 10m to remove alluvium, and a further 2m to find unweathered tonalite foundations.

Basalt Quarry

After the quarry site as been determined by non geological consideration, the chosen site should be investigated with one or two boreholes (not marked). It is expected that the basalt is unweathered at surface, thin clay and peat deposits may be present in the central plateau area, but these should be less than 2m thick. The basalt layer is expected to be 15 to 40m thick, with local variations. The lower 3m of basalt may be scoriaceous and weak. The central part, on average 20m thick, should provide first class material for aggregates. Below the scoriaceous layer there may exist a weak clayey pebbly layer preventing downward drainage of the quarry. Boreholes cores will be required to test the quality of the rock for use as aggregate and crushed sand.

Materials Investigations

Some wide ranging investigations are justified, of natural gravel deposits in the Abbay River and adjacent alluvial terraces. For pozzolanic material some regional investigation is warranted. One possible source is the Serpentine body found east of the dam site.

6.12 SEISMICITY AND EARTHQUAKE PARAMETERS

The Mandaya project area appears to be located in a relatively low seismic hazard zone. Seismic activity in Ethiopia and the neighbouring regions is illustrated on Figure 6.1. This sketch shows all epicentres recorded from 1906 until 2003. Clearly Mandaya dam site is 200km away from the nearest epicentre. A 'classification' of Seismic-tectonic zones of Ethiopia is shown in Figure 6.2. The Geophysical observatory of Addis Ababa University has used the epicentre map to identify so-called 'seismo-tectonic' zones, which are areas of modern seismic activity. These zones are listed below:

- The Western Branch of the East African Rift, 1a, 1b confined to Uganda Sudan border areas.
- The main Ethiopian Rift, 2a,b,c,d,
- The Western Escarpment of the Afar Depression consisting of marginal grabens, 3a,b,c.
- The Afar Depression, 4.
- The Leading edge of the Gulf of Aden Propagating Rift, 5.
- Transform Zone Connecting the Red Sea Rift to Northern Afar, 6a,b.
- The Red Sea Rift, 7a,b,c.

All of these zones are seismically unstable due to continuing movement along rift (normal) faults, and transform (wrench) faults, relating to crustal extension and concomitant plate collisions. Mandaya site falls outside of these active zones.

A Seismic Hazard Map of Ethiopia (Figure 6.3), was prepared by the Geophysical Observatory of Addis Ababa University (Asfaw and Kebede 1994) based on all earthquakes recorded in Ethiopia since 1906. Mandaya site lies outside of the 0.05g peak horizontal acceleration contour. The hazard is for "*a probability of exceedance of 0.0033 (return period of 300 years)".*

Table 6.2 are extracted from the Karadobi Dam, pre-feasibility report[4]. It indicates the seismic hazard calculated for Karadobi Dam, which is similar in design and similar in geological environment to Mandaya Dam. In fact Karadobi site is 100km closer to

[4] Karadobi Multipurpose Project. Pre-feasibility study. Draft final Report. May 2006. NorPlan/ NorConsult

the Ethiopian rift valley than Mandaya site, so logically the seismic hazard will be less at Mandaya by some small amount.

No analysis of reservoir-induced seismicity has been made in this study. For such a large dam as Mandaya this aspect has to be considered. Such analysis will be done during Feasibility Studies.

Table 6.2 : Karadobi Dam Seismic Hazard by Norplan/Norconsult

Table. Ground motion amplitude in fraction of gravity for different periods of ground motion and for different return periods.

RETURN PERIOD YEARS	PERIOD IN SECONDS FOR ROCK SITE		PERIOD IN SECONDS FOR SOIL SITE	
	1.0	2.0	1.0	2.0
100	.062	.040	.085	.052
200	.073	.046	.102	.061
300	.081	.05	.111	.067
500	.091	.056	.122	.075

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). It would be sufficient to check the dam for the MDE using Ground Motion Amplitude for calculation. Design Earthquake should be selected at a return period of 200 years, which corresponds to acceleration of 0.073 g, i.e. 0.72 m/s^2 for structures founded on rock.

Figure 6.1 : Seismic Epicenters in Ethiopia and Neighbouring Regions, during Period 1906 1to 1993, Magnitudes 5 upwards.
The magnitude is proportional to square-size
Original drawing by the Geophysical Observatory of Addis Ababa University.

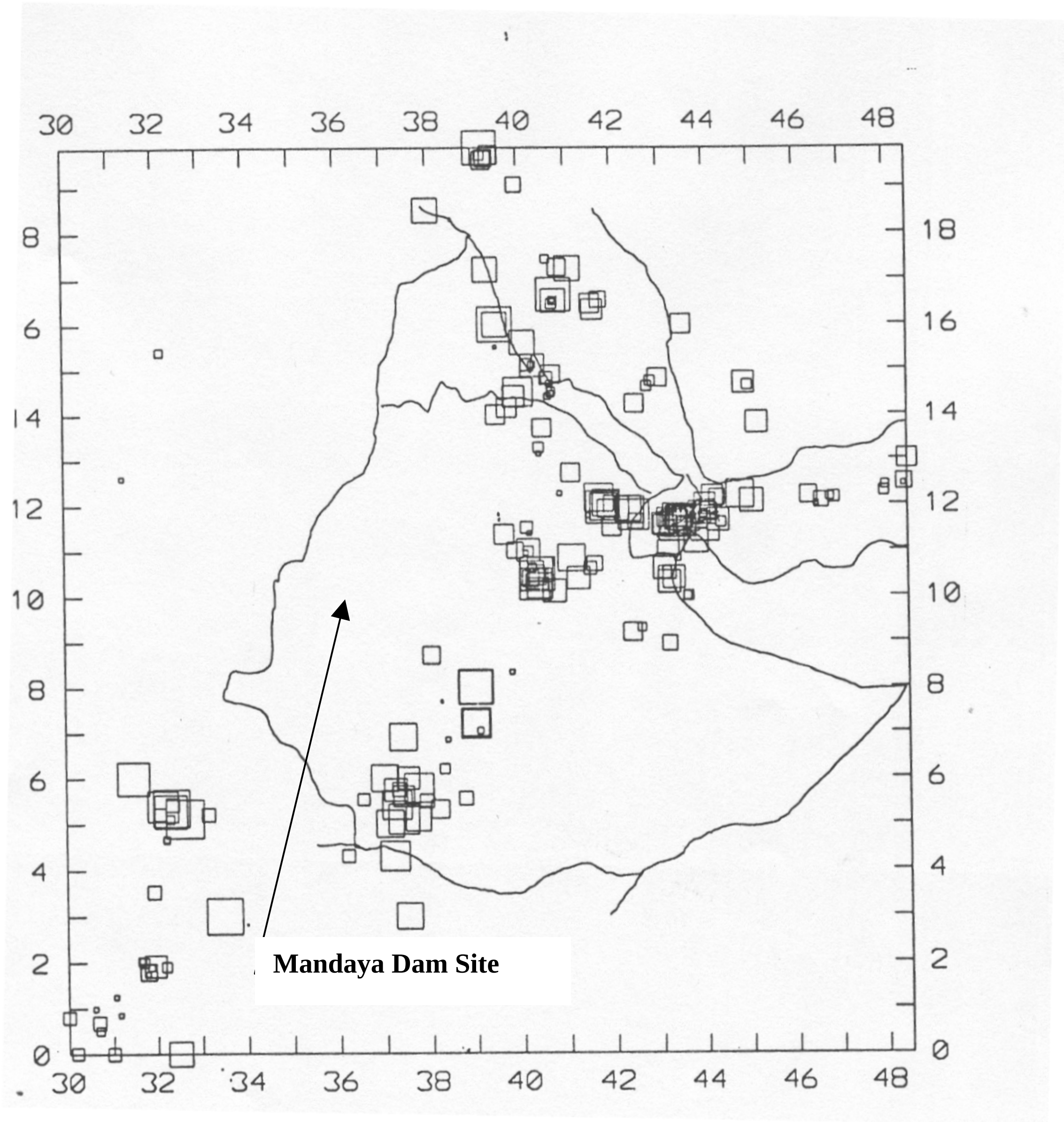


Figure 6.2 : Seismic-Tectonic Zones in Ethiopia and Neighbouring Regions, as explained in Text of Report.

Original drawing by the Geophysical Observatory of Addis Ababa University.

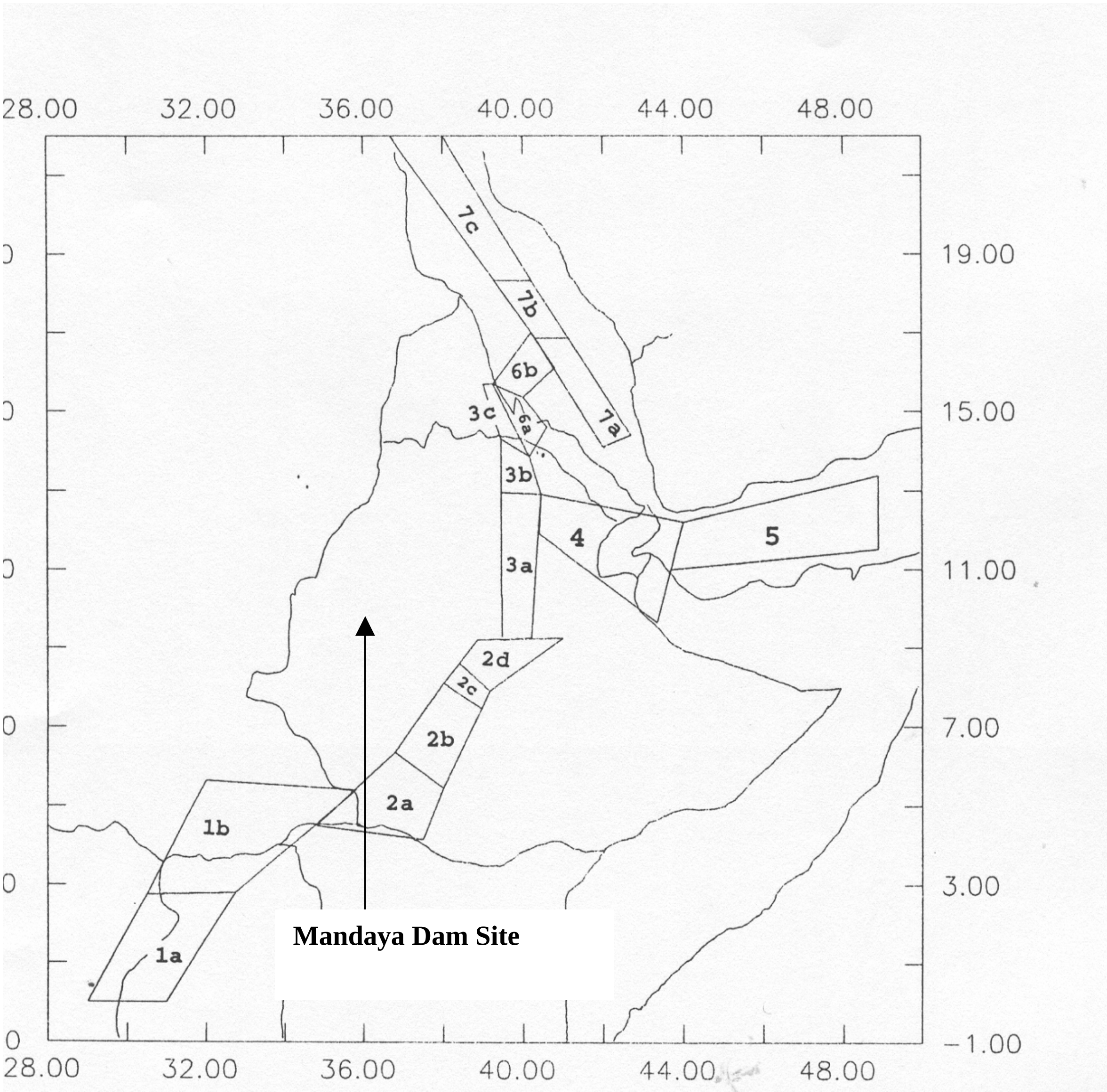
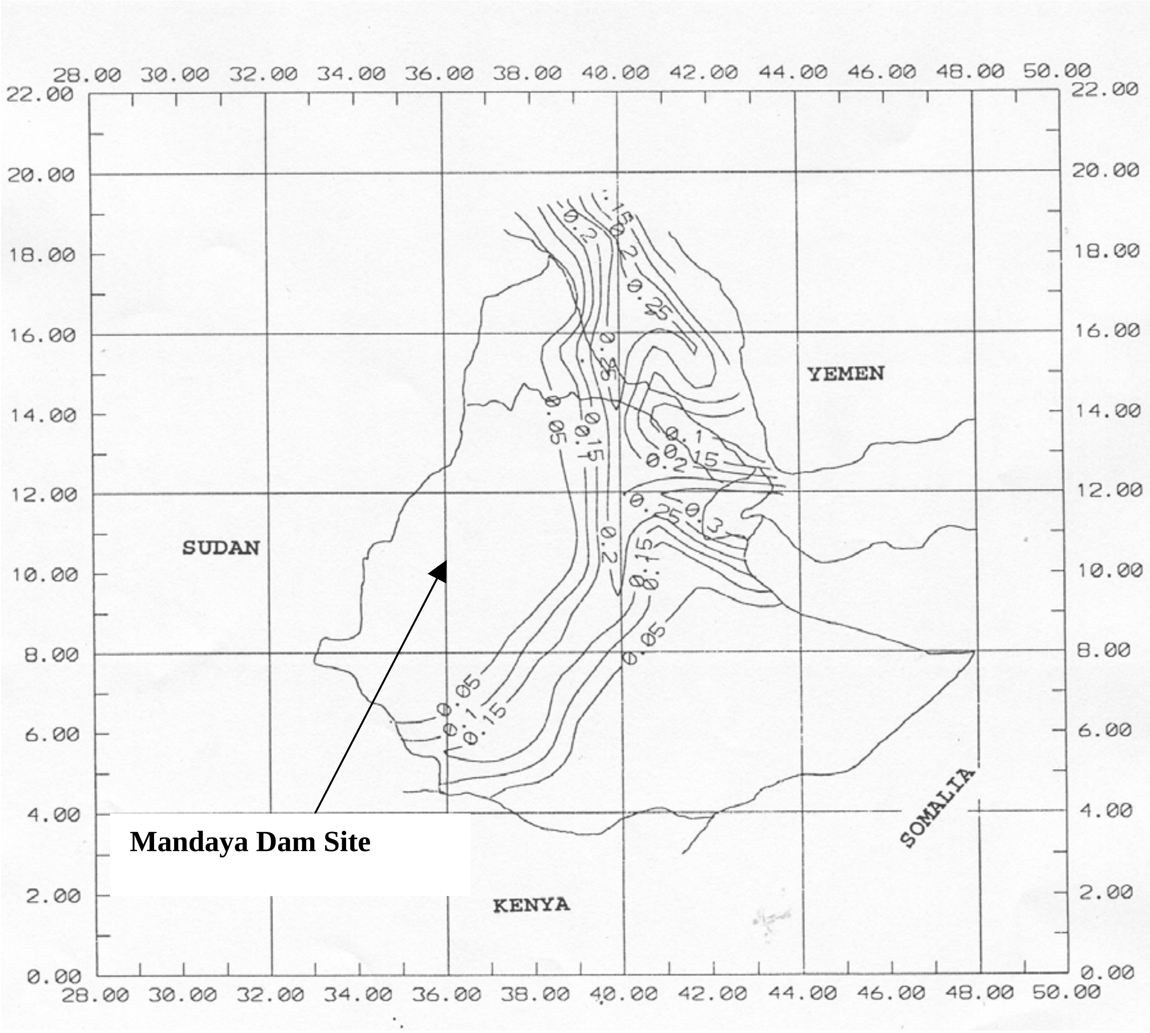


Figure 6.3 : Seismic Hazard Map of Ethiopia. The hazard is for probability of exceedence of 0.0033 (for return period of 300 years). Contours indicate peak horizontal acceleration as a proportion of g (acceleration of the Earth's gravity).

Original drawing by the Geophysical Observatory of Addis Ababa University.



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APPENDIX 6.1

Petrography of Rock Samples

Ethiopian Geological Survey
Mineralogy & Petrography Laboratory
Petrographical Data (Rock and Ore Samples)

Dept./Proj:. Tropics Consulting Engineers	**Originator:** Mengesha Teferra	**Date Submitted:** 13/06/99 EC. **Request No.:** 0785-2007. PVT.
Sample No. MD-WP-60	**Lab. No.:** 0787/2007	**Sample type:** Rock
Rock Name: Porphyrithic Olivine Basalt	**Type of Analysis:** Thin section preparation & petrographic analysis.	
Hand specimen description:	Black in color and fine grained in texture	

Mineral content

Mineral	Mode %	Texture
Plagioclase	46	Tabular
Pyroxene	32	Anhedral
Volcanic glass	10	-
Opaque (Fe-oxide)	7	Anhedral
Olivine	5	Subhedral

Textures And Descriptive notes: - Porphyrithic texture

The ground mass is composed of lath plagioclase, Anhedral pyroxene, opaque and volcanic glass. Phenocrysts of lath plagioclase, Anhedral pyroxene and Euhedral olivine are seen over the ground mass. Some plagioclase crystals show zoning.

Described by: Workelul G/K & Adise Mekonnen

Checked by: Workelul G/K

Head, Mineralogy/Petrography Lab

Date Completed: 16/06/99E.C.

Ethiopian Geological Survey
Mineralogy & Petrography Laboratory
Petrographical Data (Rock and Ore Samples)

Dept./Proj:. Tropics Consulting Engineers	**Originator:** Mengesha Teferra	**Date Submitted:** 13/06/99 EC. **Request No.:** 0785-2007. PVT.
Sample No. MD-WP-34	**Lab. No.:** 0788/2007	**Sample type:** Rock
Rock Name: **Porphyrithic Olivine Basalt**	**Type of Analysis:** Thin section preparation & petrographic analysis.	
Hand specimen description:	Black in color and very fine grained in texture	

Mineral content

Mineral	Mode %	Texture
Plagioclase	49	Tabular
Pyroxene	30	Anhedral
Opaque (Fe-oxide)	10	Anhedral
Olivine	5	Subhedral
Volcanic glass	5	-
Calcite	1	Anhedral

Textures And Descriptive notes: - Porphyrithic texture

Phenocryst of tabular plagioclase, Anhedral pyroxene and Euhedral Olivine are seen over the ground Mass composed of pyroxene plagioclase opaque and volcanic glass. The phenocrysts form cluster or Glomeroporphyrithic texture.

Described by: Workelul G/K & Adise Mekonnen **Checked by:** Workelul G/K **Date Completed:** 16/06/99E.C.

Head, Mineralogy/Petrography Lab

Ethiopian Geological Survey
Mineralogy & Petrography Laboratory
Petrographical Data (Rock and Ore Samples)

Dept./Proj: Tropics Consulting Engineers	**Originator:** Mengesha Teferra	**Date Submitted:** 13/06/99 EC. **Request No.:** 0785-2007. PVT.
Sample No. MD-WP-48	**Lab. No.:** 0786/2007	**Sample type:** Rock
Rock Name: **Feldspar- Biotite- Epidote Schist**	**Type of Analysis:** Thin section preparation & petrographic analysis.	
Hand specimen description:	Black in color and fine grained in texture.	

Mineral content

Mineral	Mode %	Texture
Epidote	25	Xenoblastic
Feldspar	20	Relict
Biotite	20	Platy
Quartz	15	Xenoblastic
Muscovite	10	Thinly-Flaky
Chlorite	7	Platy
Sphene	2	Idioblastic
Opaque (Fe-Oxide)	1	Idioblastic -Xenoblastic

Textures And Descriptive notes: - Sub Schistose and Relictic texture

The matrix is intensively Epidotized, Sericitized, and slightly carbonitized. Large crystals of calcite and quartz are seen as porphyroblasts over the matrix. Platy mica minerals (Biotite & chlorite) show sub parallel alignment. Grains of Epidote, quartz and feldspar are strained to the schistose plane.

Described by: Workelul G/K & Adise Mekonnen **Checked by:** Workelul G/K **Date Completed:** 14/06/99E.C.

Head, Mineralogy/Petrography Lab

Survey of Ethiopia Geological Laboratory

Ethiopian Geological Survey
Mineralogy & Petrography Laboratory
Petrographical Data (Rock and Ore Samples)

Dept./Proj:. Tropics Consulting Engineers	**Originator:** Mengesha Teferra	**Date Submitted:** 13/06/99 EC. **Request No.:** 0785-2007. PVT.
Sample No. MD-WP-36	**Lab. No.:** 0785/2007	**Sample type:** Rock
Rock Name: **Biotite Gneiss**	**Type of Analysis:** Thin section preparation & petrographic analysis.	
Hand specimen description:	Black and white in color and fine to coarse grained in texture	

Mineral content

Mineral	Mode %	Texture
K-feldspar	20	Relict
Plagioclase	20	Relict
Biotite	17	Platy
Quartz	15	Xenoblastic
Epidote	12	Xenoblastic
Chlorite	5	Platy
Muscovite	4	Thinly-Flaky
Sphene	3	Idioblastic
Calcite	2	Xenoblastic
Opaque (Fe-Oxide)	1	Xenoblastic
Apatite	1	Idioblastic
Zircon	Trace	Idioblastic

Textures And Descriptive notes: - Gneissose texture

The matrix is highly Epidotized, Chloritized and Sericitized. Biotite crystals show preferred parallel alignment along the schistosity plane, and some of them are curved. Mafic and felsic minerals are Oriented and show discontinuous segregation. Pokiloblastic Biotite crystals are seen on the matrix. Some Biotite Crystals are replaced by chlorite and Epidote. Some Plagioclases are altered to calcite and Epidote.

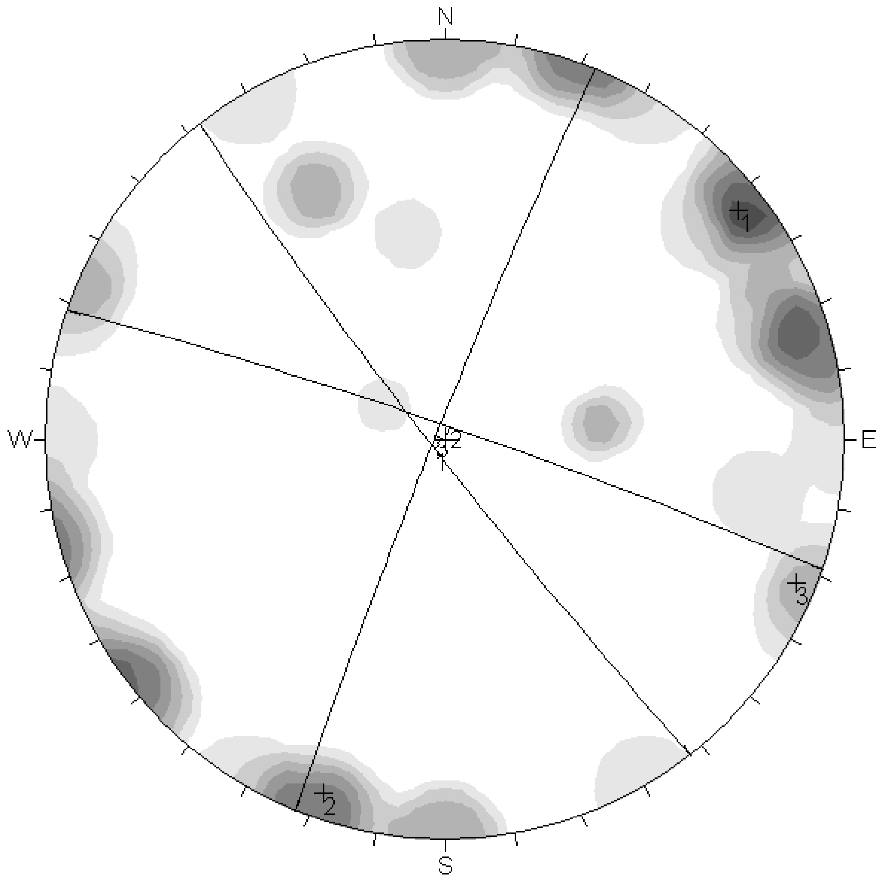
Described by: Workelul G/K & Adise Mekonnen **Checked by:** Workelul G/K **Date Completed:** 16/06/99E.C.

Head, Mineralogy/Petrography Lab

Geological Survey of Ethiopia

APPENDIX 6.2

Discontinuity Data and Stereographic Plots using “DIPS”



Orientations

ID	Dip / Direction	
1	86 / 232	=foliation planes
2	86 / 019	
3	87 / 292	

MANDAYA DAM ALL JOINTS &

FOLIATION PLANES

Equal Angle
Lower Hemisphere
26 Poles
26 Entries

Dip	Bearing
80	250
85	255
40	265
45	263
80	230
70	150
70	155
87	20
90	200
89	15
90	230
90	230
90	210
90	330
270	90
76	280
90	180
90	235
20	120
55	170
90	110
90	296
90	180
87	256
85	240
90	255

MANDAYA JOINT MEASUREMENTS

APPENDIX 6.3

Plates

Plate 1 : Gold panning near Abbay Goli

Plate 2 : Metatonalite left bank at dam site

Plate 3 : Metatonalite, typical rock mass in river section

Plate 4 : Decomposed metatonalite half way up left flank centreline

Plate 5 : Basalt cliff above left side centreline

Plate 6 : Terrace gravel deposits near Abbay Goli

Plate 7 : Clay deposits on basalt plateau

Plate 8 : Right flank centreline (the line is one third in from the left side of the photo)

Plate 8 b : Right flank centreline (close up)

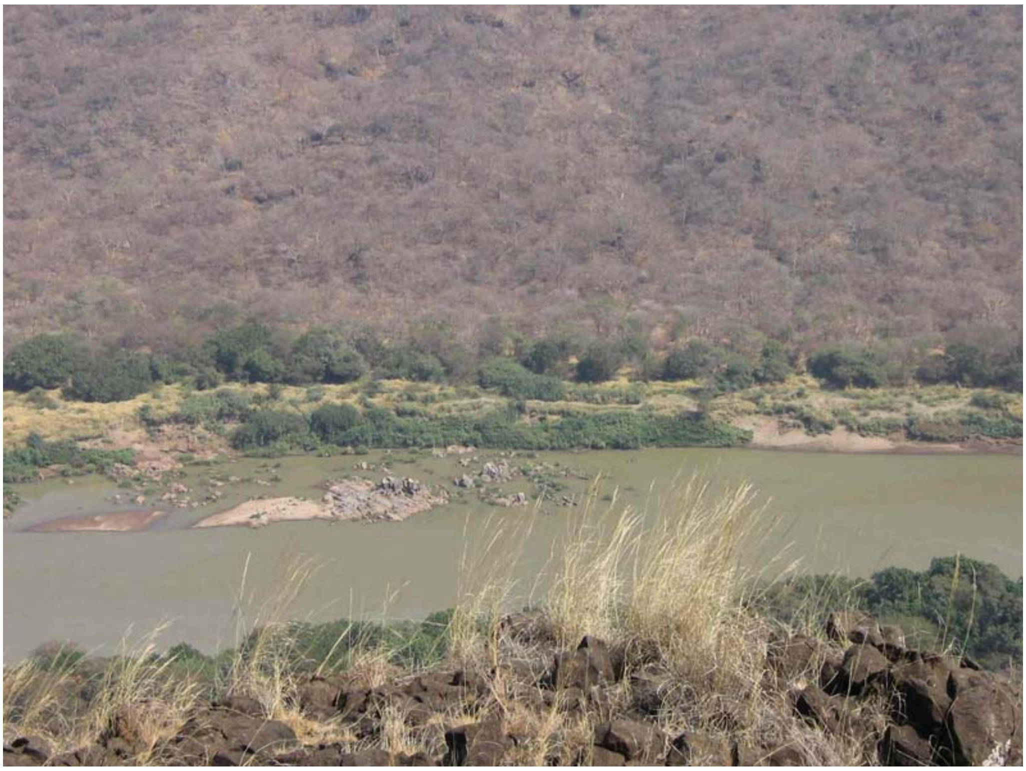


Plate 9 : River section centreline through rock islands

7. DESCRIPTION OF THE PROPOSED PROJECT

7.1 MANDAYA PROJECT SITE

The Mandaya dam is located at the downstream extremity of the Blue Nile gorge at a point where the steep topography of the gorge opens out into gentler and more rolling terrain. The site is characterised by a relatively wide valley between progressively steepening slopes on each abutment. On both banks of the river the steep upper slopes of the abutments terminate in a level plateau at an elevation of approximately El. 900 m, some 290 m above the river.

The wider valley profile at the site compared to the narrower sections in the upper reaches of the Blue Nile gorge allow development of the dam, diversion works and power station as surface structures without the need to resort to underground works with their relatively higher cost and risk profile.

The site is suitable for dams up to some 260 – 280 metres in height and appears to be limited only by the elevation of the plateaux on each bank and a slightly lower elevation of a saddle in the reservoir rim at an elevation of approximately El. 880 m.

The general arrangement of the propose project is presented on Drawing M8.

7.2 SELECTION OF RESERVOIR FULL SUPPLY LEVEL

The proposed reservoir full supply level of El. 800 m has been selected following review of the results of the reservoir operation simulation using the RAPSO model. Summary results of the RAPSO modelling for the Mandaya project are shown in Table 7.1. below.

Table 7.1 : Summary Results of RAPSO Simulation Modelling

FSL (m)	Minimum Operating Level (m)	Operating Range (m)	Installed Capacity MW	Gross storage $m^3 \times 10^6$	Live storage $m^3 \times 10^6$	Firm energy %	Generation Flow %	Spillage Flow %
741*	724.8	16.2	1600	16,200	5,600	52%	75.9	24.1
800	760	40	2000	49,200	24,600	92%	94.4	5.6
860	820	40	2400	106,700	41,400	95%	95.5	4.5

* As proposed by USBR, 1964

A reservoir full supply level for Mandaya of El. 741 was proposed by USBR in the “Land and Water Resources of the Blue Nile “ (1964). It can be seen from Table 7.1 above that the project as proposed by USBR would utilise 75.9% of the available river flow for generation with spillage accounting for the remaining 24.1%. The firm energy output which reflects the degree of regulation would be only 52% of energy generated. These values are relatively low due to the modest size of the reservoir live storage which amounts to only 17.5% of the volume of mean annual runoff.

By contrast, a development at Mandaya with a full supply level of El. 800m would capture some 94.4% of flow for energy generation with only 5.6% of flow lost to spillage. Firm energy generation would amount to 92% of total generation as a result of the improved flow regulation with live storage of 154% of MAF. This development is clearly far superior to the lower level option proposed by USBR in terms of energy generation and provision of regulated flow downstream in Sudan.

It can also be seen from Table 7.1 that further increase of the full supply level from El. 800 to El. 860 would result in an increase in the percentage of flow used for energy generation of only 1.1%, to 95.5%, with a similar reduction of spillage. It was concluded that the increase in height of the dam by 60 m to provide a full supply level of El. 860 m provided little benefit in flow regulation, the main effect of the higher dam being to increase the generating head. However, the reservoir with a higher full supply level would have significantly greater adverse impacts associated with inundation and would take a much longer period to fill with greater impact on water levels in Lake Nasser.

A development of the Mandaya reservoir with a full supply level of El. 800 m would inundate the Mabil dam site upstream. Trials have been carried out to simulate the operation and energy output of the Mandaya and Mabil projects as summarised in Table 7.2, below:

Table 7.2 : Comparison of Mandaya and Mabil Project Options

Project	FSL (m)	MOL (m)	Operating range (m)	MW	Firm energy GWh/yr	Average energy GWh/yr	Gross storage $m^3 \times 10^9$	Live storage $m^3 \times 10^9$
USBR (1964)								
Mandaya USBR	741	724.8	16.2	1620		7800	16.2	5.6
Mabil USBR	906	837.8	68.2	1200		5314	13.25	10
Total (1953-63)						13114		
Adjusted Total (1953-2003)						11431		
RAPSO								
Mandaya USBR	741	724.8	16.2	1600	3559	6799	16.2	5.6
Mandaya 800	800	760	40	2000	11194	12119	49.2	24.6
Mandaya 860	860	820	40	2400	15676	16467	106.7	41.4

It can be seen from Table 7.2 that the average energy output for the 50-year period 1953-2003 for the Mandaya FSL 800 option of 12,119 GWh/yr exceeds the combined output of the USBR proposed developments of Mandaya FSL 741 plus Mabil, which have a combined average energy output for the same period of 11,431 GWh/yr, an increase of some 6%.

Detailed energy simulation modelling of the Mabil project has not been undertaken, however it can be seen that the total live storage of the combined Mandaya FSL 741 project and the Mabil project comprises some 15.6 x 10^6 m^3, only some 63% of the live storage of the Mandaya FSL 800 project. It can be concluded therefore that the magnitude of flow regulation offered by the Mandaya FSL 741 and Mabil projects would be substantially less than the Mandaya FSL 800 option.

This, together with the identification of the Beko Abo site upstream of Mandaya as described in Section 2.3 and which would replace the Mabil site, have lead to the conclusion that the development of Mandaya to a full supply level of approximately El. 800 m is preferable to other options. Accordingly, a full supply level of El. 800 metres has been adopted for the purposes of the pre-feasibility study.

It is recommended that the selection of the dam full supply level is reviewed during detailed feasibility studies considering range of levels from approximately El. 775 m to El. 825 metres in order to determine the optimum dam height and reservoir volume configuration.

7.3 DAM

7.3.1 Dam Site and Alignment

At the downstream extremity of the Blue Nile gorge, some 25 km downstream of the Didessa confluence, the river passes through a 5 km long reach with parallel valley sides with only very minor side valleys. The selected dam alignment lies at the downstream end of this reach where the valley is at its narrowest. At the site bedrock is exposed both in the river channel and at higher elevations on the abutments (as described in more detail in Section 3). Various alternative alignments would be possible but would appear to be likely to require an increased dam volume and associated higher costs.

The Mandaya dam at the selected site will have a crest length of some 1,400 m and will have an overall height of some 200 metres.

7.3.2 Dam Type

Since 1980, roller compacted concrete (RCC) has to a large extent become the technology of choice for large dams. The term roller compacted concrete, describes concrete used in the construction process which combines the economical and rapid placing techniques used for embankments with the strength and durability of concrete. The advantages of an RCC dam are numerous including, for example:

- Material savings. The unit cost per cubic metre of RCC is considerably less than that of conventional concrete; and RCC dams have considerably less volume of construction material than embankments of the same height. The lower cost arises from highly mechanised and continuous placement at high rates which gives very good plant utilisation.
- Rapid construction. The rapid construction techniques and reduced concrete volume account for major costs savings in RCC dams. RCC can be placed at a vertical rate in excess of 10 m per month. Maximum placement rates in excess of 100,000 m^3/month have been achieved. When compared with

embankment dams, construction time for a large dam can be reduced by 1 to 2 years.

- Spillways and appurtenant structures. The location and layout alternatives for spillways, outlet and hydropower works, and other appurtenant structures in RCC dams provide additional economic advantages compared with embankment dams.
- Diversion and cofferdam. RCC dams provide cost advantages in river diversion during construction and reduce damages and risks associated with cofferdam overtopping. The diversion conduit will be shorter compared with embankment dams.
- The RCC dam is inherently safe against internal erosion, overtopping, and seismic ground motions.
- Other advantages. The smaller volume of an RCC dam makes the construction material source less of a driving factor. The borrow source will be considerably smaller and more environmentally acceptable.

Having regard to the site topography and geology at the Mandaya site, together with the substantial flows which must be accommodated both during construction and in the spillway facilities it is considered that an RCC dam is the most appropriate choice of dam type and offers considerable advantages over alternative dam types such as concrete-faced rockfill (CFR).

7.3.3 Sources of Materials for Dam Construction

The principal materials for dam construction comprise coarse and fine aggregates, ordinary Portland cement and pozzolan. Coarse and fine aggregates are expected to be sourced from quarries to be developed in the immediate vicinity of the Mandaya dam site.

The pozzolan may be fly-ash, a natural pozzolan or ground granulated blast-furnace slag. In addition inert filler is commonly used. The filler may be crusher dust or imported fines which typically display no or little pozzolanic activity. The addition of pozzolan has the desirable effects of reducing cement content, thus lowering costs and reducing the heat of hydration and giving slower strength development which benefits bonding of RCC layers and reduces thermal stresses. The paste/mortar ratio is increased, thus reducing the potential air voids in the concrete.

It is expected that the mix design for the dam construction will be of the “high paste” type and have a cementitious content of approximately 180 - 200 kg/m^3. The permeability of completed dams has been shown to be low, less than 10^{-8} m/s, provided the cementitious content exceeds 150 kg/m^3, (see ICOLD Bulletin 123, *State-of-the-art of roller compacted concrete dams)*. For high dams a lower permeability is desirable and the cementitious content should be between 180 to 200 kg/m^3. Other criteria may give higher cementitious contents than these.

Use may be made of lower contents of cementitious material in appropriate zones of the dam. It is anticipated that pozzolans will comprise some 70% of the cementitious material. In the interests of economy the maximum use will be made of locally occurring pozzolans. In this respect, the existence of a volcanic cone some km downstream of the Mandaya site may offer a suitable local source of material with pozzolanic properties.

Cement is manufactured in Ethiopia at four plants with a combined capacity of 1.57 Mt/yr of cement and 1.36 Mt/yr of clinker (2004-2005). Several new cement plants are planned to meet the shortfall in supply in the domestic market.

The search for, and the choice of, the most appropriate pozzolan will be undertaken during the feasibility studies. The cost of the cementitious materials in an RCC dam can be as much as one quarter or more of the total cost of the dam. It is thus important that the most suitable solution is found.

7.3.4 Dam Construction

RCC Placement

RCC is normally placed in continuous layers extending between abutments. Speed of construction is an important factor as each layer of concrete needs to be placed on the underlying layer before the latter has aged to such an extent that a good bond between the layers cannot be achieved.

The concrete is commonly transported to the dam using conveyors and may be placed directly by a conveyor or may be transferred to trucks for final placement. The concrete is spread in layers, normally 30 cm thick, using bulldozers and is compacted by 10 to 12 tonne vibrating rollers.

Until recently, all RCC was placed in horizontal layers. The capacity of the concrete manufacturing plant is then geared to placing the largest lift in the dam within one day, commonly 14 or 16 hours and such that the next lift can be placed within 24 hours. With this procedure regular, time-consuming and expensive lift joint treatment is avoided. The sloped layer method has now been developed, in which the RCC layers are placed on a slope. The size of the layer is such that the next layer can be placed before its initial set and the total height of the lift, which may be 1.5 m or more, defines the slope angle. With this method it may take several days to complete one lift from abutment to abutment. Each lift is homogeneous as each layer is placed on fresh concrete. The top surface, however, becomes a cold joint and requires treatment to ensure a good bond with the next lift.

The methods of joint treatment are the same as for conventional concrete and give a similarly good bond. The cleaning and preparation of the surfaces is not on the critical path. The method has several further advantages. In the event of any disruption to the RCC production or delivery, the exposed surface is at any time relatively small and can more easily be prepared as a cold joint (on a single horizontal layer the entire area from abutment to abutment would have to be prepared.) The requirement to place a minimum of one 30 cm lift per day, or about 10 m per month, no longer applies. Instead of the concrete manufacturing and transport plant being designed for placing the largest layer in one day, the plant can be designed for a desired typical placement rate.

The sloped layer method of RCC concrete placement for a dam of this size has significant merits, despite the fact that the engineering community may to some extent resist adopting this method because to date the horizontal layer method has produced the highest placement rates. We would not preclude either option, both of which should be considered at feasibility stage.

Forming of Dam Faces

The faces of the dam can be formed using various methods. Slip-formed kerbs have been used, but more often formwork is the chosen option. RCC can be placed directly against formwork or conventionally vibrated concrete can be used. In the latter case CVC (Conventional Vibratable Concrete) is placed against the formwork just in advance of the RCC layer. In recent years the GEVR (Grout Enriched Vibratable RCC) has been developed. A variant is the GE-RCC (Grout Enriched RCC) method.

In the former, grout is placed adjacent to the formwork just in advance of the RCC placement. In the latter the grout is placed on top of the fresh RCC adjacent to the formwork. The RCC thus enriched is then consolidated using poker vibrators and either method can work well and produce a fair face to the dam without honeycombing or voids. This method, in its two variants, has proven to be the lowest cost option for most dams where it has been used.

Placement Rates

The Mandaya dam with full supply level of El. 800 m will have an RCC volume of some 13 million cubic metres. As such it will be one of the largest volume RCC dams in the world. The rate of placing of the RCC will be of critical importance to the overall construction programme. Table 7.3, below lists the planned and completed RCC dams that have had an average rate of placement in excess of 100,000 m^3/month. It should be noted that peak placing rates achieved at Longtan exceeded 400,000 m^3/month and therefore the proposed placing rate at Basha Diamer appears to be achievable and could also be achieved at Mandaya.

Table 7.3 : Average Placing Rates of Major RCC Dams

Dam	Height (m)	Volume of RCC (M m^3)	Placement period (months)	Average rate (m^3/month)
Basha Diamer (design stage)	285	10.50	32.3	325,000
Longtan	217	4.95	33.0	150,000
Upper Stillwater	91	1.13	9.0	125,325
Tha Dan	95	4.90	40.0	122,500
Olivenhain	97	1.07	8.8	121,895
Beni Haroun	118	1.69	16.4	102,860

7.4 RIVER DIVERSION WORKS

The width of the valley at the river level allows development of a river diversion arrangement based on a number of surface conduits in the base of the dam rather than use of tunnels. The diversion works have been designed to have an ultimate capacity of 12,000 m^3/s with upstream water level of El. 652.5m.

River diversion during construction will take place in a number of stages as follows:

Stage 1

Excavation of diversion channel and construction of diversion conduits on left bank of the river.

Stage 2

Construction of initial upstream cofferdam to El. 629m and downstream cofferdam. Diversion of dry season flow through diversion conduits. Diversion capacity 3,600 m^3/s with upstream level of El. 628.5m.

Stage 3

Excavation of dam foundation in river channel. Construction of RCC cofferdam to El. 640. Commence placing of RCC in river channel section. Diversion capacity 8,250 m^3/s with upstream level of El. 640.0m.

Stage 4

Allow flood flow to pass over RCC cofferdam in wet season if necessary

Stage 5

Continue placing of RCC to main dam to raise dam to El. 740m. Construct permanent mid-level outlet facility. Construct power intake structure and erect penstocks.

Stage 6

Close diversion conduits 1 and 2 with wheeled stopgates and construct low-level outlet control gates in those conduits. Continue placing of RCC to main dam. Construct reinforced concrete spillway chute and control structure. Install intake gates.

Stage 7

Open low-level outlet gates. Close remaining diversion conduits with wheeled stopgates and place concrete plugs. Erect spillway gates.

Stage 8

Control release of flow and commence impounding. When water level reaches 5m above mid-level outlets progressively close low-level outlets. Continue impounding. Control release through mid-level outlets.

Stage 9

When impounding reaches El. 760 m commence generation with available units. Complete turbine and generator installation and commissioning of remaining units.

The diversion stages are presented on Drawing M9.

7.5 OUTLET WORKS

The outlet works will allow release of flows from the Mandaya reservoir by means other than release through the power generation facilities or the spillway. The main purpose of the outlet works is to allow controlled release of flows during reservoir filling to ensure security of supply to downstream users and to allow release of flow in the unlikely event that release through the power generation facilities is not possible.

The outlet works comprise two facilities:

- Low-level release facility in the diversion conduits at an elevation of approximately
- Mid-level release facility with invert level of approximately El. 642 m.

7.5.1 Low-level Outlet

The low-level release facility would be constructed at Diversion Stage 6 as described above. Two of the diversion conduits would be closed by wheeled stop gates at the upstream end and stoplogs at the downstream end. High pressure steel-lined conduits would then be constructed within the diversion conduit. Each conduit would have a height of 4 metres and width of 3 metres and would be provided with aeration ducts to minimise the risk of cavitation damage occurring during operation. Hydraulically operated high-pressure control gates and maintenance gates would be erected at the upstream end of the low-level outlet to control flow and allow maintenance.

7.5.2 Mid-level Outlet

As the low-level outlet gates would be subject to very high pressure of up to 190 m (when the Mandaya reservoir is at full supply level) and associated high velocity flows it is considered advisable to minimise risk of damage by incorporating a mid-level outlet which would allow release of flow at lower pressure. The mid-level outlet would therefore allow for release of flow at lower pressure whilst also providing flexibility for release of flows during reservoir filling.

The mid-level outlet facility would comprise three separate outlet conduits, each 4 metres high by 3 metres wide. The invert of the mid-level outlet conduits would be set at an elevation of El. 624 m. Each conduit would be provided with a hydraulically operated control gate and a maintenance gate. The outlets would terminate in a flip bucket discharging flow into the plunge pool downstream of the dam.

7.6 SPILLWAY

7.6.1 Spillway Structure

The spillway will comprise 12 radial gates bays with a total discharge capacity of approximately 30,000 m^3/s with the reservoir at full supply level. The spillway structure will comprise six chutes of reinforced concrete construction separated by dividing walls and will be anchored to the underlying RCC dam body.

The spillway gates will be located on the dam crest and will discharge into the six chutes. The design has been arranged such that each of the six chutes will be independent of others in respect of access and operation and hence it will be possible to carry out maintenance of one chute with others remaining in service.

The spillway crest will have a hydraulic profile in accordance with the standards and recommendations of the US Army Engineer Waterways Experimental Station in order to minimise uplift and cavitation potential. A typical cross section through the spillway is presented on Drawing M10.

7.6.2 Spillway Gates

The radial spillway gates will each be 16 m wide by 18 m high and will be operated by hydraulic servomotors in accordance with a rule curve defining the magnitude of spillway discharge required for any reservoir level in order to ensure safe passage of major floods without adverse impact on dam safety.

Each of the spillway gate bays will be equipped with stoplog guides. It is envisaged that two sets of stoplogs will be provided to allow two gates or one chute to be isolated at any one time for maintenance to the radial gates, seals and the spillway structure.

7.6.3 Routing of Floods over Spillway

The spillway gates have been sized to be capable of discharging the 1 in 10,000 year flood. Incoming flood peaks will be significantly attenuated as the flood passes through the Mandaya reservoir, particularly if the reservoir is drawn down at the time of commencement of the flood event. It should be noted that the reservoir will normally be drawn down by 20 metres or more at the start of the flood season.

The 1 in 10,000 year flood inflow peak of approximately 38,500 m^3/s will be attenuated to 30,000 m^3/s during routing through the reservoir assuming that the reservoir is at full supply level at the commencement of the flood event. The peak level reached would be 801.24 m, a rise of some 1.24 metres during the passage of the flood.

In addition to the capacity of 30,000 m^3/s, it should be noted that there would be significant additional discharge capacity and greater attenuation at higher reservoir levels, albeit with some encroachment on the 3 m freeboard allowance.

7.6.4 Spillway Chute and Flip Bucket

The six spillway chutes will be separated by divide walls providing freeboard to avoid overtopping in accordance with internationally accepted design criteria established by the US Bureau of Reclamation and US Army Corps of Engineers taking account of bulking of flow associated with air entrainment.

Each spillway chute will be equipped with aerators to protect against damage by cavitation associated with the high velocity flow. The first aerators will be located at the downstream end of the gate piers at which point an offset would be provided in both the side walls and chute floor. Further aerators would be located at intervals downstream.

The chutes will each terminate in a flip bucket and will discharge into a downstream plunge pool for energy dissipation. The flip bucket would have a radius of 14 m and would have a take-off angle of 20° above the horizontal.

A solid flip bucket is proposed without teeth or other dissipation features. As each chute will be controlled by a gate, formation of a hydraulic jump within the flip bucket at low flow rates can be avoided thus allowing immediate initiation of the initial “flip” of the spillway discharge.

The depth of flow will vary from 19.25 metres at the gate location to 3.1 m at the entry to the flip bucket where the maximum velocity will exceed 50 m/s. The trajectory downstream of the flip bucket will extend to some 230 metres horizontally, depending on the precise flow rate and tailwater level.

7.7 POWER WATERWAYS

The power waterway system will comprise eight independent intake works, penstocks and turbines discharging into a common and tailrace. Typical cross sections through the power waterways are presented on Drawings M10 and M11.

7.7.1 Intake Structure

The reinforced concrete intake structure will be located on the main dam and will incorporate unitised intake gates and associated control equipment for each of the eight turbine-generator units. The intake structure will also be equipped with trash screens and trash raking mechanism, and slots to allow bulkhead gates to be deployed for gate, waterway and unit maintenance. Each unit waterway in the intake structure will be split by a central wall to keep gate and trash screen spans to manageable proportions. Each intake gate of the unit pair will be 5.4 m high by 3.0 m wide.

The invert of the intake structure will be set at El. 743.8 m and overt at El. 749.2 m. This will provide a submergence of 10.8 m above the waterway overt and 1.2 m above the top of the screens at minimum operating level, in order to minimise the risk of vortex formation.

7.7.2 Penstocks

Downstream of the intake eight 5.4 m diameter surface-mounted steel penstocks each approximately 245 m in length descend the face of the dam and connect directly to individual turbine units. The preliminary design of the penstocks has been based on a maximum flow velocity of 7 m/s at full turbine output. The penstocks have been designed in accordance with the CECT “Recommendations for the Design, Manufacture and Erection of Steel Penstocks of Welded Construction for Hydro-electric Installations”. The penstocks will range in thickness, depending on the internal pressure, from 19mm close to the intake to 42 mm leading into the turbine inclusive of a 2mm corrosion allowance.

Friction losses in the waterway have been calculated as approximately 4 metres taking account of hydraulic friction losses and “minor” losses at trash screens, entrance, gate slots, transitions and bends.

7.8 POWERHOUSE STRUCTURE AND TAILRACE

The powerhouse will be a surface type structure of reinforced concrete and structural steel, construction, completely detached from the dam structure and located on the right bank. The powerhouse accommodates a loading/service bay, one bay for each of the 8 Francis turbine units, control block and offices. Single-phase transformer bays (3 per turbine unit) will be located to the rear of the powerhouse on a terrace at elevation El. 631.5 m.

Principal approximate dimensions and elevations are given in Table 7.4 with typical details being presented in Drawings M11 and M12.

Table 7.4 : Mandaya Powerhouse Principal Dimensions and Elevations

Description	Dimension/Elevation (m)
Overall Length (m)	217.0
Machine Hall Width (m)	22.0
Foundation Width	46.0
Overall Height	61.5
Unit Centre Line Spacing	22.0
Crane Beam Elevation	640.0
Loading/Service Bay Elevation	631.5
Machine Operating Floor Elevation	623.5
Generator Floor Elevation	616.5
Turbine Floor Elevation	609.5
Turbine Setting Elevation	605.4
Draft Tube Invert Elevation	593.2

7.9 TAILRACE SYSTEM

The tailrace system of the Mandaya scheme consists of the following elements:

- an open channel that joins with the existing river bed approximately 350 m downstream of the powerhouse, and
- an RCC separation wall to limit the interferences between the tailrace channel and the dam spillway plunge pool.

7.10 SWITCHYARD

The switchyard will be located on the right bank, downstream of the dam site, at a horizontal distance of approximately 500 m from the powerhouse. The switchyard will be constructed on a terrace at elevation El. 640 m with approximate dimensions of 300 m by 200 m.

7.11 POWERHOUSE MECHANICAL AND ELECTRICAL PLANT

7.11.1 Turbines and Governors

The turbines will be vertical shaft Francis type with steel spiral casing. Each turbine will be directly connected to a vertical shaft synchronous generator. The water for each turbine will be supplied through a separate intake structure and penstock. Intake gates will be provided for emergency shutdown of the units. At the outlet, draft tubes stoplogs will also be provided to permit dewatering of the turbine for inspection and maintenance purposes.

The rated output of each turbine will be 250 MW assuming a design net head of 171.9 m. The synchronous speed of the unit has been selected at 176.5 rpm. Each turbine will be equipped with an electronic digital type governor. The runner will have an approximate external diameter of 4.6 m and a height of approximately 1.9 m.

7.11.2 Draft Tube Stoplogs and Hoist

The following equipment will be installed:

- 4 sets of draft tube single-leaf sliding stoplogs (height = 6.9 m and width = 6.5 m), and
- one open air travelling gantry crane at elevation 631.5 m. (rated capacity = 30 t).

7.11.3 Powerhouse Travelling Overhead Crane

Main equipment will be handled by two identical overhead travelling cranes, having a total approximate capacity of 750 - 1000 t and a span of approximately 23 m.

7.11.4 Generators

The generators will be of conventional air cooled, self-ventilating type, with a rated capacity of approximately 288 MVA. Voltage will be in the range11–18 kV (to be confirmed during detailed studies undertaken at Feasibility Stage). The speed of each generator is 176.5 rpm which corresponds to a 17 pole pairs generator.

The generators will be connected to single phase transformers by metal-enclosed, isolated phase bus ducts. A coupling circuit breaker SF6 type (rated voltage 24 kV) is provided to connect the generator to the grid through the generator transformers.

7.11.5 Main Transformers

The 24 single-phase transformers will be placed on a terrace at elevation El. 631.5m, upstream of the power station building in open-air separate concrete-enclosures.

Each main transformer will be a single phase, two winding, oil-immersed transformer, with oil forced, water-forced (OFWF) cooling system.

The connection between the transformers and the Mandaya switchyard, located approximately 500 m downstream of the powers station, will be by means of overhead lines. HV circuit breakers SF6 type (rated voltage 400-500 kV) will be provided at the Mandaya switchyard.

7.11.6 Control and Protection System

Operation will be carried out through a Computerised Supervision Control and Data Acquisition System (SCADA).

7.11.7 Mechanical and Electrical Auxiliary Equipment

The power house will be equipped with all necessary mechanical auxiliary equipment as listed hereafter:

- cooling water system,
- compressed air system,
- oil supply, handling, purification and storage system,
- unit dewatering and powerhouse drainage system,
- fire protection system,
- heating, cooling and air ventilation system,
- domestic water system, and
- elevators and lifts.

The power house will be equipped with all necessary electrical auxiliary equipment as listed hereafter:

- AC station services auxiliaries,

- emergency diesel generators (powerhouse, water intake and dam),
- DC station service,
- un-interruptible power supply (UPS),
- earthing system,
- cables, cable trays and conduits,
- lighting and receptacle systems,
- luminaries supplied for areas,
- fire alarm system,
- communication system, and
- master clock system.

7.12 TRANSMISSION SYSTEM

It is envisaged that the transmission system would connect the Mandaya power station to both the Ethiopian and regional electricity network. The proposed transmission system is described in detail in Section 11.

7.13 ACCESS

7.13.1 Roads and Bridges

Reliable access to the project site will be required to be available under all weather conditions for efficient and timely construction and subsequent operation and maintenance of the Mandaya hydropower project.

The access arrangements will need to be capable of carrying all envisaged construction traffic including transport of construction plant, materials and equipment to the site, together with normal construction traffic around the site. In particular, the roads and bridges will need to be capable of carrying the heavy loads associated with the main items of the permanent mechanical and electrical equipment for incorporation in the project, specifically the turbine components, generator components and transformers.

Construction plant, materials and the major items of permanent equipment for the project will be transported to the site over the existing national road network to Mendi. Beyond Mendi an existing road is reported to extend approximately 20 km towards the project location and will require upgrading. A new access road will be required from the existing road system to the site. Inspection of available mapping indicates that seven minor bridge structures will be required on the new access road.

Downstream of the Mandaya project a major multi-span bridge structure will be required across the Nile to permit construction access to the North bank and future connection to the existing road system North of the project location.

7.13.2 Airstrip

It is envisaged that an airstrip suitable for light aircraft will be required for use during both construction and operation stages.

7.14 CONSTRUCTION INFRASTRUCTURE

Construction of the Mandaya project will require the following infrastructure:

- Construction camp.
- Construction works areas (e.g. concrete batching plant, cable crane plant).
- Quarry locations.
- Site access roads (not included those dependent on the contractor's methodology).

Drawing M13 presents the overall project layout and provides approximate locations for the above components.

8. COST ESTIMATION

8.1 INTRODUCTION

This section describes the methodology adopted for preparation of cost estimates for the Mandaya hydropower project and presents details of the estimated costs of the selected project.

The cost estimate has been broken down into 7 main sections as follows:

1. Environmental mitigation measures
2. Access roads and site facilities
3. Reservoir costs
4. Civil works
5. Electro-mechanical equipment
6. Engineering and supervision
7. Owners administration

The cost estimates given in this Report are based on unit and lump sum prices applied to the quantities of major work items calculated for various components of the Project. These cost estimates provide an estimate based upon the price level of 2005 thereby providing a price direct comparison with the Pre-Feasibility Study of the Karodobi Multipurpose Project.

No taxes and import duties are included in the cost estimate.

The summary of cost estimates has been used for economic and financial analysis.

The currency used in the cost estimates is the US Dollar and the following rate of exchange has been adopted:

US$ 1.00 (US Dollar) = ETB 8.7 (Ethiopian Birr)

8.2 CIVIL WORKS

The cost estimates for the civil works have been established from the following principles:

- Based on the methods of construction and programme for the major cost items.
- Unit rates based on the Consultant's in-house data-base from other projects in the region, experience curves and present market prices.
- Measuring the principal construction items and extending those items by the unit rates and adopted prices.

- Making allowances for establishment items such as mobilisation and demobilisation of construction plant, contractor's site installation, etc.
- Making appropriate allowances for unmeasured items.
- Applying appropriate allowances for contingencies, to both estimating and construction aspects of the work.

Some items which have no specific details at pre-feasibility stage have been treated as lump sums based on previous experience of other projects.

A list of the main unit rates adopted for costing of the project is given in Table 8.1 below.

Table 8.1 : Unit Rates

Description	Unit	USD/Unit
Clearing Light Vegetation	Ha	500
Clearing and grubbing	Ha	5000
Soft excavation (unconfined)	m^3	4
Soft excavation (confined/difficult)	m^3	6
Rock excavation (unconfined)	m^3	12
Rock excavation (confined, difficult)	m^3	18
Backfill and compact	m^3	5
Cofferdam fill	m^3	9
Foundation preparation for concreting	m^2	6
Formwork	m^2	59
Mass concrete	m^3	115
RCC medium paste	m^3	75
RCC grout enriched	m^3	85
C35 Structural concrete	m^3	130
C45 Structural concrete	m^3	140
Reinforcement steel	t	1600
Drilling and grouting	m	150
Steel Conduit	t	8720
Structural Steelwork	t	5938
Crushed rock surfacing	m^2	4

The different unit rates used in compiling the cost estimate include all direct costs including purchase costs of construction plant and the operation and maintenance cost and the relevant portions of site installations.

It has been assumed that most of the heavy construction plant and the heavy concrete batching, mixing and transportation plant will have to be brought into the country.

The contractor's preliminaries and general costs amounting to about 25% of direct cost for the dam and the power plant work have been included in the unit rates. The contractor's preliminaries and general costs includes the contractor's mobilisation, operation of yard 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.

For all major structures (e.g. dam, spillway, diversion works, low level outlets, powerhouse and tailrace) preliminary designs were developed and drawings to appropriate scales have been prepared. Materials and quantities required have been computed using the engineering design drawings consisting of plans and sections of the major components of the Project. Topographic maps having 10 m contours have been digitised from satellite images in conjunction with existing 1:50,000 scale mapping where available.

The civil construction works are broadly defined as follow:

Infrastructure Requirements

These works cover aspects such as:

- Access Roads.
- Major bridge over the Abbay River downstream of the dam.
- Minor bridge crossings.
- Housing, comprising low and high density accommodation, community buildings, amenities areas and places of worship.
- Electricity supply, sewerage and water reticulation.
- Road improvements.
- Road maintenance.

Site Establishment

This covers major cost expenditures, which would normally be included in a contractor's tender, to enable the contractor to establish himself on site. For the Mandaya project they are deemed to comprise:

- Site access roads (not accounted for in the Infrastructure Requirements).
- Establishment of principal works areas and fill platforms, e.g. materials storage, concrete batching and aggregate crushing plant platforms at the powerhouse and substation areas.
- Other contractor's site installations, e.g. offices, workshops, saw yard, reinforcement bending yard, canteen, etc.
- Mobilisation and demobilisation of contractor's plant.

Diversion and River Closure Works

The stages of diversion and river closure comprise the following works:

- Excavation works for diversion conduits and the inlet and outlet channels.
- Excavation support and stabilisation measures in the form of rockbolts, shotcrete and mesh.
- Structural concrete works to diversion conduits.
- Permanent RCC Cofferdam structures.
- Construction of earth infills
- Construction of temporary upstream and downstream cofferdams.
- Placing of rockfill and earthfill, some underwater.
- Removal of the downstream cofferdam, involving excavation of rockfill, some underwater.
- Plugging and pressure grouting of diversion conduits

Dam and Spillway (including Plunge Pool)

The civil works for the dam and spillway will comprise:

- Excavations in soft and rock material.
- Foundation preparation for the dam.
- Roller compacted concrete (RCC) to the dam body together with grout enriched RCC to upstream and downstream facings.
- Formation of dam galleries formed in both insitu concrete and in RCC.
- Structural concrete works to the low level outlets and to the spillway piers, chute and bridge.

- Pressure grouting works to dam curtain.
- Dam instrumentation and instrumentation houses.
- Drilling of drainage relief holes.
- High capacity pre-stressed anchorages to the radial gate trunnions.

Surface Penstocks

The cost of the steel penstocks form part of the Mechanical and Electrical Equipment costs. The civil works associated with the liners comprise the following:

- Excavation works in soft and rock material.
- Concrete support and anchoring works.

Powerhouse and Tailrace Channel

The powerhouse and tailrace channel civil works comprise the following:

- Excavation in soft and rock material.
- Structural concrete works forming the powerhouse sub and superstructure, and concrete placed in stages to suit the phased erection of the turbine draft tube linings and spiral casings, and the generator.
- Building finishes.

Switchyard Civil Works

The switchyard civil works will entail site clearing, excavations and concrete works for switchgear foundations and cable trenches, drainage measures, gravel surfacing around equipment bases and the construction of security fencing and gates.

External Works

These works will involve landscaping, planting of trees and shrubs, grassing, laying of kerbings, miscellaneous drainage and the like to the powerhouse and intake structure environs.

8.3 ELECTRICAL & MECHANICAL EQUIPMENT COSTS

8.3.1 General Assumptions

The process used for arriving at the estimated costs for the equipment and installations includes an analysis of the costs of the various plant components derived from the Consultant's database and adapting them to the characteristics of the Mandaya project.

Cost estimates for the M & E equipment are based largely on budgetary prices from reputed manufactures, both local and foreign.

The cost estimates include ready-for-service installations appropriate for this pre-feasibility design stage.

A contingency allowance of 5% has been added to the direct costs for hydraulic steel structures and mechanical and electrical works resulting from the unallocated risks inherent in the scheme layout at this pre-feasibility stage.

Most of the equipment has to be imported. The local component essentially comprises the costs for minor ancillary equipment, local erection staff and on-shore transportation.

The prices include for the suppliers' on-costs and margins. Indirect costs, e.g. site establishment for offices and workshops, housing for employees, etc. are included in the spread of costs.

8.3.2 Hydraulic Steel Structures

Costs of gates, trash racks, stoplogs, and associated embedded parts, steel linings of waterways etc. have been built up from calculated weights of the equipment and current costs of manufacturing from recent quotations for similar equipment. Special allowances for sea and overland transport as well as costs for erection, testing and commissioning have been included.

The scope of supply for the hydraulic steel structures will be as follows:

Diversion Conduits:

- Fixed wheel gates, hoists and cranes

Low Level Outlets:

- Trash screens
- Fixed wheel gates
- Stoplogs and gantry crane

Spillway:

- Radial gates
- Stoplogs and gantry crane

Intake structure:

- Trash screens and trash raking machine

- Vertical gates
- Stoplogs and gantry crane
- Waterway transition pieces rectangular to circular

Steel Penstocks

Powerhouse draft tube stoplogs and crane

8.3.3 Mechanical Powerhouse Equipment

A computer model has been used to generate the speed, setting, turbine dimensions, weights and costs of the 8 vertical axis Francis turbines and auxiliary equipment with input of discharge capacities and heads appropriate to the scheme.

The cost estimates for the mechanical powerhouse equipment include delivery, erection and commissioning. The scope of the mechanical powerhouse equipment covers the following items:

- Turbines and governors
- Unit cooling water systems
- Draft tube steel linings
- Powerhouse cranes
- Dewatering and drainage systems
- Compressed air systems
- Mechanical auxiliaries:
- Sanitary water system
- Fire protection system
- Oil handling and treatment system
- Air conditioning and ventilation

8.3.4 Electrical Powerhouse Equipment

The costs for the electrical equipment comprise ready-for-service installations. The electrical equipment is assumed to be largely manufactured offshore and has to be imported. The scope of the electrical powerhouse equipment covers the following items:

- Synchronous generators and ancillaries
- Voltage regulator and excitation system
- MV circuit breakers
- MV bus bars

- Power transformers 18/400kV, single phase
- HV circuit breakers
- Control and protection systems including SCADA, unit protection and unit measurement

Electrical auxiliaries:

- MV and LV distribution
- DC UPS distribution
- Earthing network
- Cables and cable racks
- Fire detection system
- Flood detection system
- Lighting and small power
- Service transformers
- Diesel back-up units

8.4 TRANSMISSION SYSTEM

The transmission system improvements necessary to evacuate power from Mandaya to both Ethiopia and elsewhere in the Eastern Nile region have been identified as part of the generation expansion planning under in Module 6 of this study. Accordingly the cost estimates and time sequence of construction for the various transmission line developments are reported separately.

8.5 ENVIRONMENTAL MITIGATION COSTS

The environmental costs in Table 8.2 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 Mandaya scheme 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.

8.6 ENGINEERING ADMINISTRATION AND PHYSICAL CONTINGENCIES

To arrive at the total cost for the project, the costs of engineering, supervision, administration and contingencies have to be added to the construction costs.

Feasibility Study, 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 10% of the total construction cost.

The owner's administration costs have been taken as 4% of the total construction and environmental costs.

To cover unforeseen costs, contingencies have been added to the construction costs with 5% for electrical and mechanical work, 10% for environmental mitigations and infrastructure works and 15% for civil works.

8.7 TOTAL PROJECT CAPITAL COST

A summary of the costs for the Mandaya Hydropower Project is given in Table 8.2 with detailed costs presented in Table 8.3.

Table 8.2 : Summary of Costs

Item	Total Cost (MUSD)
ENVIRONMENTAL MITIGATIONS	
Environmental Mitigations	20.0
Contingencies(10%)	**2.0**
TOTAL ENVIRONMENTAL MITIGATION	**22.0**
INFRASTRUCTURE	
Access Roads & Bridges	68.2
Operators village & infrastructure	10.3
Sub-Total	**78.5**
Contingencies(10%)	**7.8**
TOTAL INFRASTRUCTURE	**86.3**
RESERVOIR	
Clearance	39.7
TOTAL RESERVOIR	**39.7**
CIVIL WORKS	
Diversion Works	60.6
RCC Dam and Spillway	1,283.4
Powerhouse & Tailrace	116.4
Workshop and Stores Building	0.4
Switchyard & Plant Buildings	5.1
Sub-Total	**1,465.8**
Contingencies(15%)	**219.9**
TOTAL CIVIL WORKS COST	**1,685.7**
MECHANICAL, ELECTRICAL & HYDROMECHANICAL WORKS	
Generating plant	198.0
Hydromechanical Equipment	77.0
Switchgear	43.5
Subtotal	**318.5**
Contingencies (5%)	**15.9**
TOTAL M & E and HYDROMECHANICAL	**334.4**
Engineering, admin. & construction management (10%)	**216.8**
Owners Administration (4%)	**86.7**
TOTAL PROJECT COST (MUSD)	**2,471.7**

Table 8.3 : Detailed Costs

Item	Quantity	Unit	Rate ($)	Cost ($)	Totals ($)
ENVIRONMENTAL MITIGATIONS					
Environmental Mitigations	1	Sum	20,000,0000	20,000,000	**20,000,000**
TOTAL					**20,000,000**
Contingencies(10%)					**2,000,000**
TOTAL ENVIRONMENTAL MITIGATION					**22,000,000**
INFRASTRUCTURE					
New roads in mountainous terrain	75	km	530,000	39,750,000	
Construction access roads	12	km	200,000	2,400,000	
Major Bridge Crossing	1	No.	22,000,000	22,000,000	
Upgrading to existing roads	20.0	km	150,000	3,000,000	
Minor bridge crossings	7	No.	155,000	1,085,000	
Operators village & infrastructure	1.0	Sum	10,250,000	10,250,000	
TOTAL					**78,485,000**
Contingencies(10%)					**7,848,500**
TOTAL INFRASTRUCTURE					**86,333,500**
RESERVOIR					
Clearance	66,100	Ha	600	39,660,000	
TOTAL RESERVOIR					**39,660,000**
CIVIL WORKS					
Diversion Works					
Clearing and grubbing	16	Ha	5000	80,000	
Soft excavation (unconfined)	1,717,260	m^3	4	6,869,040	
Soft excavation (confined/difficult)	0	m^3	6	0	
Rock excavation (unconfined)	369,056	m^3	12	4,428,672	
Rock excavation (confined/difficult)	0	m^3	18	0	
Foundation preparation	18,372	m^2	6.0	110,232	
Drilling and grouting	5,512	m	150.0	826,800	
Roller compacted concrete	69,300	m^3	75.0	5,197,500	
Reinforced concrete	131,244	m^3	130.00	17,061,720	
Formwork	64,760	m^2	59.0	3,820,840	
Cofferdam Fill	503,550	m^3	9	4,531,950	
Cofferdam Removal	199,550	m^3	4	798,200	
Reinforcement	9,187	t	1600.00	14,699,200	
Unmeasured Items (5%)				2,186,248	
Subtotal					**60,610,402**
RCC Dam and Spillway					
Clearing and grubbing	32.5	Ha	5000	162,500	
Soft excavation (unconfined)	1,556,870	m^3	4.0	6,227,480	
Soft excavation (confined/difficult)	396,760	m^3	6.0	2,380,560	
Rock excavation (unconfined)	667,230	m^3	12.0	8,006,760	
Rock excavation (confined/difficult)	170,040	m^3	18.0	3,060,720	
Foundation preparation	157,044	m^2	6.0	942,264	
Drilling and grouting	47,113	m	150.0	7,066,980	
Roller compacted concrete	12,529,854	m^3	75.0	939,739,050	
Grout enriched roller compacted concrete	199,035	m^3	85.0	16,917,975	
Formwork (vertical/horizontal/sloping)	536,575	m^2	59.0	31,657,925	
Mass concrete (Intake, spillway crest)		m^3	115.0	0	
Reinforced concrete	523,415	m^3	130.00	68,043,950	
Reinforcement	39,116	t	1600.00	62,585,600	
Penstock steel	8,655	t	8720	75,471,600	
Unmeasured Items (5%)				61,113,168	
Subtotal					**1,283,376,532**

Item	Quantity	Unit	Rate ($)	Cost ($)	Totals ($)
Powerhouse & Tailrace					
Clearing and grubbing	7.0	Ha	5000	35,000	
Soft excavation (unconfined)	574,320	m^3	4.0	2,297,280	
Soft excavation (confined/difficult)	99,820	m^3	6.0	598,920	
Rock excavation (unconfined)	313,860	m^3	12.0	3,766,320	
Rock excavation (confined/difficult)	194,623	m^3	18.0	3,503,214	
Compacted Fill	236,915	m^3	5.0	1,184,575	
Foundation preparation	23,779	m^2	6.0	142,674	
Drilling and grouting	7,134	m	150.0	1,070,055	
Formwork	168,425	m^2	59.0	9,937,075	
Cofferdam Fill	55,400	m^3	9	498,600	
Cofferdam Removal	55,400	m^3	4	221,600	
Roller compacted concrete	225,039	m^3	75.0	16,877,925	
Mass concrete		m^3	115.0	0	
Reinforced concrete	195,606	m^3	130.00	25,428,780	
Reinforcement	18,774	t	1600.00	30,038,400	
Structural steel	277	t	5938.00	1,644,826	
Unmeasured Items (20%)				19,120,084	
Subtotal					**116,365,328**
Workshop and Stores Building					
Common excavation	250	m^3	4.0	1,000	
Reinforced Concrete	450	m^3	130.00	58,500	
Formwork	300	m^2	59.0	17,700	
Reinforcement	27	t	1600.00	43,200	
Structural steel	25	t	5938.00	148,450	
Unmeasured Items (40%)				107,540	
Subtotal					**376,390**
Switchyard & Plant Buildings					
Clearing and grubbing	6.0	Ha	5000	30,000	
Soft excavation (unconfined)	68,000	m^3	4.0	272,000	
Rock excavation	0	m^3	12.0	0	
Compacted Fill	457,400	m^3	5.0	2,287,000	
Reinforced Concrete	2,800	m^3	130.00	364,000	
Formwork	7,922	m^2	59.0	467,398	
Reinforcement	224	t	1600.00	358,400	
Structural steel	40	t	5938.00	237,520	
Crushed rock surfacing	60,000	m^2	4.00	240,000	
Unmeasured Items (20%)				845,264	
Subtotal					**5,101,582**
TOTAL					**1,465,830,233**
Contingencies(15%)					**219,874,535**
TOTAL CIVIL WORKS COST					**1,685,704,768**
MECHANICAL, ELECTRICAL & HYDROMECHANICAL WORKS					
Generating plant	1	sum	198,000,000	198,000,000	
Hydromechanical Equipment	1	sum	77,000,000	77,000,000	
Switchgear	1	sum	43,500,000	43,500,000	
Subtotal					**318,500,000**
Contingencies (5%)					**15,925,000**
TOTAL M & E and HYDROMECHANICAL					**334,425,000**
TOTAL					**2,168,123,268**
Engineering, admin. & construction management (10%)					**216,812,327**
Owners Administration (4%)					**86,724,931**
TOTAL PROJECT COST ($)					**2,471,660,526**

9. CONSTRUCTION PLANNING

9.1 INTRODUCTION

This section presents a commentary on the construction planning aspects for the selected development at Mandaya. The proposed implementation programme for the project is shown in Drawing M14. The construction period indicated is derived from the quantities and typical construction plant outputs of the main civil works activities, combined with the manufacturing, shipping, erection and commissioning time scales required for the mechanical, electrical and transmission system equipment.

The achieving of Financial Close will be the trigger for start of construction works.

It can be seen that a total construction period of approximately 10.5 years is anticipated, commencing in the last quarter of 2011 with the award of the preparatory works contract to establish access roads and bridges, construction camp housing and facilities; followed a year later by the commencement of the main works contract, with completion during the fourth quarter of 2021. However, it should be noted that by adopting a staggered commissioning process as shown in Drawing M14, generation will commence approximately 1.5 years earlier, in the first quarter of 2020.

The construction planning aspects of the project is described below.

9.2 PREPARATORY WORKS

Infrastructure Requirements

It is essential that access to the project site is available to construction traffic at the programmed commencement of the main works, therefore the construction of access roads will be undertaken in advance of the main works under a separate preparatory works contract.

<u>Access Roads</u>

The access road works principally entail upgrading of some 20 km of existing metalled road and the construction of approximately 75 km of new road in mountainous terrain between Mendi and the Mandaya project site. Approximately 22 km of the new road is routed along the line of an existing drivable track and the remaining 52 km is currently inaccessible to motor vehicles. The road works include seven new “Bailey Bridge” or similar type river crossings.

It is estimated that all access roads, including connecting roads to the contractor’s works areas, offices, housing area, quarries and temporary Abbay crossing will be completed within a time frame of some 21 months between late 2011 and mid 2013.

<u>Housing</u>

The housing areas, together with associated water supply, sewerage and electrical reticulation works are also scheduled to start in advance of the main contract so that accommodation is made available to the construction workers and their families as soon after main contract mobilisation as practicable. The houses are to be constructed using blockwork and will have high quality finishes - on the assumption that they will be integrated into a Mandaya township in the future. It has been assumed that housing facilities would be constructed by local companies (it is anticipated that there would be several packages within the preparatory works contract). The required construction period for timely release of housing would be of the order of 7 months.

9.3 MAIN WORKS

Abay Bridge

The bridge will constitute a major and high profile construction project in its own right. The Abbay bridge has been configured as a multiple span structure with a cable-stayed main central span of 200 m. The roadway will be set 25 m above the dry season river level to accommodate the maximum flood levels. As the construction period of some 21 months is not generous, it will be imperative to ensure that these works are executed by a contractor with a well-proven record in the required type of bridge construction.

Site Establishment

Site Access Roads and Works Platforms

From the outset it will be important to establish access to the diversion channel works on the left bank. A bench for the access road will extend from the Abbay Bridge site, along the foot of the valley slope to the upstream end of the diversion channel. Spoil from the road cutting will be transported to temporary disposal areas located some 2 to 3 km downstream.

Site access roads will be excavated into the valley sides on both banks to provide access for construction plant and access for transportation of penstock and gate components onto the RCC dam at appropriate levels of construction. Access roads to dam crest level will become permanent private roads for gate and screen maintenance.

Works areas will be established on both sides of the river, at low level on platforms established on the valley floor, levelled and raised above flood level using spoil from excavations, and at high level on the naturally level platforms at the top of the valley sides at El. 900 m. The right bank will not be accessible before completion of the Abbay Bridge, so the contractor will establish works areas on the left bank first.

The left bank high level works area will overlook the site and will incorporate offices, workshop facilities, batching and cement/PFA storage facilities dedicated to RCC production, a bar bending yard and saw yard. Workshop facilities for fabricating spillway gates and diversion culvert closure gates are also likely to be established on the left bank. The left bank works platforms at low level will be established downstream of the main works, one adjacent to the proposed quarry site to accommodate aggregate stockpiles and crushing plant, another adjacent to the

Abbay Bridge abutment to accommodate batching and cement/PFA storage facilities dedicated to conventional concrete production.

The right bank works platform at low level will be situated downstream of the powerhouse and will incorporate workshops and stores for the electromechanical plant that will be installed in the powerhouse, and workshops for fabricating the steel penstocks and intake gates. The right bank works platform at high level will accommodate the second batching and cement/PFA storage facilities dedicated to RCC production.

A cable crane for formwork and concrete handling will span over the area of the dam, intake and spillway, having towers or runways founded on the high level works areas on opposite banks.

River Closure Works

The well-managed execution of the permanent river closure works will be one of the key features for ensuring timely completion of the project. Permanent river closure will be achieved in the following stages:

1) Excavate the diversion channel on the left bank of the river.

2) Construct a gated reinforced concrete diversion culvert structure and downstream RCC diversion channel training wall within the diversion channel.

3) Breach the river bank at both ends of the channel and flood the channel.

4) At the end of the 2013 wet season, earthfill cofferdams will be pushed into the river channel upstream and downstream of the works; the upstream cofferdam first, to divert the river flow into the diversion channel, followed by the downstream cofferdam. The riverbed between cofferdams will be dewatered and maintained dry by pumping.

5) During the 2014 dry season, excavation of the dam footprint area to bedrock will commence in the river channel. When the 2013 wet season floods overwhelm the diversion cofferdams, the excavation work will shift to the dam flanks. When the floods recede the cofferdams will be made good, the riverbed will be dewatered and foundation preparations for the dam will resume.

6) At the end of 2014, at the end of the wet season, placement of dam RCC will commence with the RCC cofferdams within the dam footprint that will be permanently incorporated into the dam. The upstream RCC cofferdam serves to protect the RCC works being undertaken in the riverbed. The downstream RCC cofferdam, together with the RCC tailrace training wall, serves to protect the powerhouse excavation. The intended purpose of the upstream cofferdam is to prolong the period for RCC placement in the dam well into the flood season, but not to prevent flood overtopping completely because RCC is not susceptible to flood damage. Flood flows are predictable and notice of high flood flows can be obtained in ample time to suspend

working and remove plant from vulnerable areas. With a crest at El. 640 m the RCC cofferdam will protect against maximum flows of approximately 8,250 m^3/s.

7) Flows in excess of 8,250 m^3/s will flood the diversion channel and the RCC works in the dam footprint below the cofferdam crest. The powerhouse works will be protected behind the downstream RCC cofferdam. At the end of the flood period the downstream temporary earthfill river closure cofferdam will be repaired if necessary, the dam works dewatered, and placement of dam RCC will resume.

8) Low-level outlets will be installed through the dam after the dam has been raised above RCC cofferdam level.

9) When the dam is sufficiently high that floods can pass safely through four of the six diversion culvert openings, gated outlets will be installed in two of the diversion openings. This involves lowering wheeled bulkhead gates under flowing water conditions to close their upstream ends, installing stoplogs under balanced conditions to close their downstream ends, and placing concrete to embed control gates and reform the water passages. On completion the bulkhead gates and stoplogs are removed.

10) Construction of the reinforced concrete intake structure will commence when the RCC dam reaches the intake platform level.

11) Construction of the reinforced concrete spillway rollway will commence when the RCC dam reaches spillway crest level.

12) Impounding commences by installing wheeled bulkhead gates under flowing water conditions in the remaining four diversion culvert openings. At the same time the low-level outlets will be opened to return compensation water to the river, the rate of flow will be equivalent to dry season flow. Inside the diversion culvert openings, behind the bulkhead gates, any remaining foundation grouting will be undertaken and permanent concrete plugs will be installed. On completion the bulkhead gates are removed.

13) When the reservoir has impounded to a level above the low-level outlets, after the plunge pool has been excavated and the downstream closure cofferdam removed, the low-level outlets will be utilised to return compensation water to the river.

14) Intake screens, stopgates and emergency gates will be installed before the reservoir has impounded to that level, allowing penstock installation to proceed behind.

The key activities pertaining to the construction schedule are described below.

Diversion Works

Provision of access to the diversion channel and commencement of channel excavation is a critical activity following mobilisation. Excavation is programmed to start as the 2012 flood season recedes with concreting of RCC training walls and reinforced concrete culverts commencing during the 2013 dry season. The reinforced concrete culvert will become an integral part of the RCC dam.

Excavation will commence in those areas that will receive concrete so that foundation preparation and concreting can commence as early as possible, and concreting can progress at the same time as the channel excavation is extended upstream and downstream. Early commencement of concreting will be paramount to reducing the vulnerability of the concrete works to flood delays during the 2013 flood season.

During the following dry season, the foundation below the diversion culvert will be consolidated and curtain grouted through the base concrete, and foundation drainage wells installed as deemed necessary. There will be one later opportunity to regrout the foundations if necessary during closure of the diversion structure prior to full impounding. Gate sealing frames will be installed and tested by lowering a gate into each slot. This is the only time the gate frames will be accessible in the dry, and it is imperative to demonstrate the gates and frames function as intended or the ability to impound the reservoir on time is put at risk.

On completion of the RCC training wall, reinforced concrete culverts and gate embedments, and after the concrete has matured, the river bank will be breached upstream and downstream to flood the diversion excavation.

It is anticipated that the excavation works, excepting the breach, will take approximately 7.5 months to execute, and later, the excavation works to breach the riverbanks will take another 2 months. The quantities of soft (i.e. Class 1) and rock excavation during this period are as follows:

	Soft	Rock
Diversion channel	1,717,000 m^3	369,000 m^3

Selected excavation spoil will be stockpiled for reuse in river closure cofferdams, the remainder will be transported to the left bank disposal area. Rock, if suitable for processing as concrete aggregate, will be transported to the crushing plant on the left bank.

Concreting of the RCC training wall (69,000 m^3) and reinforced concrete culvert (131,000 m^3) will run concurrently and take approximately 8 months to complete, the majority being undertaken between flood seasons. Nevertheless, it would be prudent to provide measures to alleviate the risk of flooding of the excavation, including stand-by pumps, contour drains on the valley slope above, and possibly raising of the river bank.

River Closure Earthfill Cofferdams

The river closure cofferdams will redirect the river flow through the diversion channel. They are temporary earthfill structures on largely submerged unprepared alluvium foundations. The cofferdam material will be selected site arising granular fill pushed into place by bulldozer after the 2013 flood period. If it proves necessary to reduce the permeability of the cofferdams to reduce pumping costs, the cofferdams and their insitu alluvium foundations can be jet grouted or diaphragm walled down to bedrock.

The upstream cofferdam will be raised to El. 629.00 m which will divert flows up to 3600 m^3/s. The downstream cofferdam will initially be raised to El. 618.00 to be above the downstream river level for this flow magnitude. Later, when the permanent RCC upstream cofferdam is in place, the downstream cofferdam will be raised to El. 620.00 m to match the higher floods the RCC cofferdam can divert.

Excavation of riverbed alluvium between river closure cofferdams will commence in the last quarter of 2012 after the flood period.

RCC Cofferdams

The upstream RCC cofferdam will eventually be incorporated into the upstream shoulder of the RCC dam. Ideally it should be raised to EL. 640.00 m before the peak of the 2014 flood season to prolong the period of excavation work into the flood season. To achieve this, the excavation of alluvium to bedrock must initially be concentrated in the cofferdam footprint, and thereafter be widened to the rest of the dam footprint, in parallel to placement of cofferdam RCC.

The volume of RCC in the upstream cofferdam, based on a crest width of 10 m at El. 640.00 m is 451,000 m^3, and placement in 5 months requires a rate of 90,000 m3/month

During the 2014 flood season the upstream temporary earthfill cofferdam will almost certainly overtop and the permanent upstream RCC cofferdam may overtop, interrupting excavation and RCC placement, but the permanent works will be undamaged and work can resume when the floods recede.

The downstream RCC cofferdam protects the powerhouse excavation from inundation, and will eventually be incorporated into the downstream shoulder of the RCC dam. Excavation for the cofferdam foundations and the associated RCC tailrace training wall foundations will commence afterthe 2013 flood season, behind the protection of the upstream RCC cofferdam and the downstream river closure earthfill cofferdam. The RCC cofferdam will be raised to El. 631.5 m.

Dam

The RCC dam will have an RCC volume of some 13 million m^3 and as such will be one of the largest of its type in the world. The rate of RCC placement therefore, will be of critical importance to the overall project construction period. There are several precedents for built projects achieving average rates of placement of more than 100 000 m^3 per month with peak placement rates up to 400 000 m^3 per month at Longtan. One project currently at the design stage will have an average placement rate of 325 000 m^3 per month. The Mandaya construction programme has taken the view that an average placement rate of 250 000 m^3 per month is achievable and this equates to a 4.5 year period for placement of the RCC in the dam.

To be able to place 250 000 m^3 per month, it will be necessary to deliver concrete simultaneously from both banks, and have competing concrete placing teams, starting each layer at the ends of the dam, and meeting towards the middle. Separate quarries, crushing plant, concrete batching plant and concrete delivery system will be required on each bank.

250 000 m^3 per month translates to an average placing rate of 10 000 m^3 per day or 500 m^3 per hour, with peak rates possibly rising to 800 m^3 per hour. The average consumption of cement, PFA and aggregates to meet these placing rates will be approximately as follows:

Cement	800 tonnes per day
PFA	400 tonnes per day
Aggregates and sand	22 400 tonnes per day

In recognition of the above it is envisioned that two pug mills will be dedicated to batching RCC, one each bank, and each plant will be rated at 550 m^3 per hour. The planting is based on a duty plus standby basis where the duty plant will cover the average hourly placing requirement and the standby plant will supplement the duty plant during peak placing or breakdown. The plant will be equipped with substantial storage for cementitious materials. A stock of 20 to 30 days supply on site would be reasonable. Consideration also needs to be given to organising much larger storage provisions at strategic staging points which can be drawn down to supplement site supplies during placement peaks or shortfalls from suppliers.

Separate dedicated batching facilities will be required for production of conventional concrete. A single batching plant, rated at 200 m^3 hour, will be set up, initially, on the left bank close to the Abbay Bridge abutment.

Aggregate quarrying and processing is a critical activity scheduled to start at the beginning of 2013 immediately after mobilisation. A quarry will initially be set up on the left bank, high on the slope to exploit the basalt cap and to supply aggregates for diversion structure concrete. A second quarry and aggregate processing plant will also be established high on the slope above the right bank, again to exploit the basalt cap.

Delivery of RCC will be carried out by proprietary, articulated conveyor systems, from the batching plants on each bank, down the slopes to handling points at the ends of the dam, then distributed to the working areas. They offer the ability to place high volumes; they are flexible and obviate the need for a large fleet of concrete transporters.

Delivery of conventional concrete for reinforced concrete structures, i.e. the mid-level outlets, the intake and the spillway, will be by skip, handled by the cable cranes. It obviates the risk of concrete transporters contaminating the RCC.

The placing of RCC will almost certainly adopt the sloped layer method, in preference to horizontal layer placement, because it facilitates higher placement rates, as well as offering improved joint strengths.

Grout enriched vibratable RCC (GEVR) will be used to make the upstream face of the RCC impervious enough to avoid the need for an upstream impervious membrane. The technique introduces grout into the RCC, either before or after it has been spread, so that it has a workability suitable for compaction with immersion vibrators. It can be used against forms on the upstream and downstream faces. Compared to the alternative of placing an outer skin of conventionally vibrated concrete ahead of the RCC, it avoids the need to transport a separate concrete, just the grout.

Spillway

Spillway reinforced concrete activities will commence when the dam RCC has reached El. 777.00 m, about 5 metres below the spillway rollway crest. Placement of 248 000 m^3 of reinforced concrete will be undertaken in 18 months, this equates to an average placing rate of 550 m^3 per day. Reinforcement quantities are estimated to total some 20 000 tonnes.

The spillway bridge will comprise pre-stressed concrete beam sections with an in-situ concrete deck, spanning between the spillway gate piers. The reinforced concrete spillway piers will contain built-in parts for bridge bearings, gate servomotor and trunnion beam anchorages. The pier walls and rollway crest will contain built-in parts for stoplog and radial gate guides and seals. The components will typically be fixed to anchorages built into first stage concrete, aligned, then embedded into second stage concrete.

The spillway bridge will be erected first on the gate piers, allowing mobile cranes to traverse the spillway and set-up above the gate piers for erection of the 12 nr. radial gates.

Intake Structure

Intake reinforced concrete activities will commence when the dam RCC has reached El. 742.00 m approximately. Placement of 252 000 m^3 of reinforced concrete will be undertaken in 18 months, this equates to an average placing rate of 560 m^3 per day. Reinforcement quantities are estimated to total some 18 000 tonnes.

The intake reinforced concrete box will be advanced ahead of the surrounding dam RCC. The construction joint between the RC and RCC will be provided with shear keys and waterstops. Grout enriched RCC, suitable for compaction with immersion vibrators, will be placed against the formed reinforced concrete joint faces.

The reinforced concrete structure will contain built-in parts for screen and gate guides, gate sealing frames, gate servomotors, dogging beams etc. The mechanical components will typically be fixed to anchorages built into first stage concrete, aligned, then embedded into second stage concrete. The intake structure will also serve as the upper anchorage for the steel penstocks. The penstocks and penstock thrust flange assemblies will be received into openings in the first stage structure, and ultimately will be embedded in second stage reinforced concrete.

Penstocks

Between the intake structure and the dam toe, the 8 nr. steel penstocks, one per turbine, are surface-mounted on the downstream face of the RCC dam. Between the toe and the powerhouse the penstocks are buried and concrete encased. The intake, the dam toe and the powerhouse are anchorage points; the penstocks with thrust flanges will be assembled then encased in second stage concrete at those locations. An expansion joint will occur at the top of each penstock immediately below the intake. The surface mounted section of penstock will comprise steel ring girders with moveable supports, carried on reinforced concrete foundations cast on the RCC.

Penstock construction will be unitised, to complete one penstock before the next, to match the commissioning interval of the turbine generator units.

The penstocks will be installed over a 14 month period after completion of the dam and powerhouse primary concrete. Flat or curved plate sections will be delivered to workshops on site for rolling, shop welding and fabrication into cylindrical cans. The fabrication yard will be established on the low level works platform on the right bank. Total tonnage of steel is estimated to be approximately 8700 tonnes in thicknesses up to 42 mm.

Powerhouse and Tailrace Channel

Excavation of the powerhouse and tailrace channel will commence in October 2015, protected from river floods by the permanent RCC tailrace channel wall and the temporary tailrace cofferdam. Excavation will commence as soon as cofferdamming permits, starting at the downstream end of the tailrace channel and working down-slope towards the invert of the powerhouse. The total volume of material to be removed will be substantial, comprising 575 000 m^3 of soft material and 314 000 m^3 of rock in the tailrace and 100 000 m^3 of soft and 195 000 m^3 of rock in the powerhouse. The estimated duration is some 12 to 13 months in total, based on an excavation rate of 170 000 m^3 per month in soft material and 50 000 m^3 per month in rock, with parallel soft and hard working in the powerhouse area overlapping between 1 to 2 months.

Concrete work in the powerhouse is scheduled to start in the third quarter of 2016, commencing with the Stage 1 powerhouse substructure. The substructure comprises the below-ground elements, whereas the superstructure comprises above ground elements such as columns, crane beams and roof. Stage 1 substructure concrete comprises the external walls, piers and slabs that will be in place prior to the installation of the turbine and generator units. Stage 2 substructure concrete includes the concrete embedding the penstock and turbine spiral casing and the generator foundation concrete that stands above it.

During Stage 1 substructure works the powerhouse will be constructed with openings to receive electro-mechanical plant at Stage 2, and consequently will be vulnerable to flooding. Hence it is important that the tailrace channel cofferdam arrangement can offer protection against, as a minimum, a 1 in 10 year flood event. The substructure will be made watertight only during Stage 2 working, following the embedment of the penstocks into the upstream wall, and after the draft-tube bend steel liners are installed, embedded in concrete and temporarily sealed with domed ends; note permanent draft-tube gates will be supplied for just two of the eight units.

On completion of Stage 1 substructure work, superstructure concrete work will be undertaken to make the powerhouse weather proof and allow installation of the overhead travelling cranes. Stage 2 substructure work follows.

Stage 2 concreting includes embedment of the draft-tube bend steel liner and embedment of the steel spiral casing, both of which will impose restrictions on concrete pour heights and rate of pouring to minimise the risk of concrete pressures or flotation causing displacement of the linings. Cranes will be required at an early stage to handle the placing of draft tube liner sections for the first unit. If necessary, mobile cranes can be used initially because the draft tube liners are relatively light, but handling the steel spiral casings will require the overhead travelling cranes to be commissioned and available. Concrete placing will be by conveyor or mobile pumping units. Each steel spiral casing will be assembled, welded, aligned, secured and water pressure tested on the Stage 1 foundations. Prior to, and during, concrete embedment it is normal to pressurise the spiral to approximately the minimum operating head, and maintain the pressure until the concrete has hardened.

The duration of Stage 2 concreting, including the generator foundations and generator barrel, is expected to be about 6 months per unit, with a 3 month interval between units. The total volume of Stage 1 and 2 concrete is 170 000 m^3. Reinforcement is estimated to total some 17 000 tonnes.

Commissioning of individual units will follow on a unit by unit basis at the same 3 month interval. Commissioning will require that the power waterway for the unit being commissioned is complete and fully functional, including the intake stoplogs, intake emergency gates, the penstock, and the draft tube gates. Commissioning also requires that the substation is complete with a functioning connection to the Ethiopian grid. Prior to commissioning the first unit, the tailrace channel cofferdam will be removed so temporary stoplogs will be required in those draft tube openings not equipped with draft tube gates. Generation from each unit will commence as soon as possible after commissioning to maximise revenues.

Power Transmission System

The transmission works are non-critical in terms of the overall programme but should be carried out in good time to avoid any risk of delay and to allow backfeed of power for plant testing and commissioning.

Overall Construction Programme and Critical Path

As shown in Drawing M14, the overall implementation programme covers 11 years, with construction extending to 9 years, 9 months after Financial Close, with the first unit available for commercial operation after 8 years, 2 months.

The critical path is shown to be through the contracting phase, preparatory works, diversion works and the powerhouse civil construction and associated E & M equipment installations.

10. GENERATION EXPANSION PLANNING AND ECONOMIC ANALYSIS

10.1 OBJECTIVE

The overall objective of generation expansion planning was to evaluate the benefits for the region (Egypt, Ethiopia and Sudan) provided by an interconnection of the three power systems according to various level of integration (or coordination) of these systems. This Section summarises the results of the generation expansion planning study. The full generation expansion planning study which was carried out as Module 6 of the Eastern Nile Power Trade Study is presented separately.

Accordingly the generation expansion planning has covered:

- determination of least-cost generation expansion plan for the three isolated systems,
- determination of least-cost generation expansion plan for the coordinated system,
- determination of the least cost interconnection option in terms of technology,
- transmission system analysis,
- recommendation of a Regional Investment Program.

The generation expansion planning has been carried out using the SDDP and OPTGEN commercial software packages.

SDDP,is a hydrothermal dispatch model with representation of the transmission network used for short, medium and long term operation studies. The model calculates the least-cost stochastic operating policy of a hydrothermal system, taking into account the following aspects:

- Operational details of hydro plants (water balance, limits on storage and turbined outflow, spillage, filtration etc.)
- Detailed thermal plant modeling (unit commitment, "take or pay" fuel contracts, concave and convex efficiency curves, fuel consumption constraints, multiple fuels etc.)
- Representation of spot markets and supply contracts.
- Hydrological uncertainty: it is possible to use stochastic inflow models that represent the system hydrological characteristics (seasonality, time and space dependence, severe droughts etc.) and the effect of specific climatic phenomena such as the El Niño.
- Detailed transmission network: Kirchhoff laws, limits on power flows in each circuit, losses, security constraints, export and import limits for electrical areas
- Load variation per load level and per bus, with monthly or weekly stages (medium or long term studies) or hourly levels (short term studies).

Besides the least-cost operating policy, the SDDP model calculates several economic indexes such as the spot price (per submarket and per bus), wheeling rates and transmission congestion costs, water values for each hydro plant, marginal costs of fuel supply constraints and others.

OPTGEN is a computational tool for determining the least-cost expansion (generation and interconnections) of a multi-regional hydrothermal system. It represents details of the system operation taking into account inflow uncertainties, emission constraints, and minimum capacity constraints, among other features. OPTGEN has a built-in feature for joint use with SDDP.

10.2 METHODOLOGY

10.2.1 Minimizing Regional Costs

The benefits for the region resulting from the interconnection will be evaluated by the comparison of two situations:

S1: independent development of the three power systems assuming the presence of no interconnection, this situation would lead to the determination of one investment program for each system : P_{Egypt}, $P_{Ethiopia}$, P_{Sudan}.

S2: development of the three power systems assuming the presence of an interconnection and various level of coordination between the power systems. This would lead to the determination of a coordinated investment program $P_{Intercon}$.

The benefits would be given by the difference of costs between these two situations:

Benefits from the interconnection = Cost [P_{Egypt}, $P_{Ethiopia}$, P_{Sudan}] – Cost [$P_{Intercon}$]

10.2.2 Economic Power Trades

Economic power trades are justified by the cost differences of power generation units in neighbouring countries and the objective of minimising the global fuel cost. The presence of an interconnection allows to supply one country at some particular moment with lower cost generation units available in other country. This supply may not be continuous, and may vary in direction and level according to the nature of the power mixes (demand variation, hydrology, etc).

In the present economic study the amount of power trade between Egypt, Ethiopia and Sudan, and the resulting benefits for the region, have been assessed according to two approaches: tight pool model and loose pool model. These two models described hereafter, can be understood as two different stages of development of a power market.

10.2.3 Loose Pool Model: Coordination of Generation Operation

In the loose pool model, the generation investment is the same as when the power systems are left isolated. In other words, each country keeps the ability to be self-sufficient and cover its own peak demand. The GEP of each country remains identical to the ones without interconnection. The operation is coordinated on a regional basis (or regional dispatch centre) on the global merit order, within the limits set by the interconnection capacities.

The loose pool model represents the first stage of development of a regional power market providing the relevant price signals for operation (spot market and market for forwards within the current year). The resulting saving is a global reduction of operation costs (main fuel costs).

10.2.4 Tight Pool Model: Coordination of Generation Investment and Operation

A fully integrated regional power system would lead to the lowest cost for the region. In this theoretical situation, all the interconnected power mixes would be operated as a single one, on the basis of a global (i.e. regional) merit order (i.e. from least cost to the most expensive generations units) from a single dispatch centre. At any partial moment (hour, day, year) the total demand would be supplied by the lowest cost generation unit available in the region.

Furthermore, in this model, the investment generation expansion plan would be also optimised at a regional level allowing to take advantage of the countries complementary resources (low cost hydro generation in a country, low cost thermal generation in another, etc).

In a nutshell, operation and investment are coordinated in the tight pool model. Of course, even in this theoretical case some part of the generation would be still dispatched on a non economic basis (e.g. irrigation), and the transmission and distribution network would set limits to amount of power exchanges possible between the different areas.

This tight model can be understood as a representation of a regional mature power system providing the relevant price signal for:

- operation decision: through the existence of a spot market and a forward market, the actors decide whether to buy energy on the market or operate their own generation units,
- investment decision: through the existence of a forward market with a relevant time horizon (>3 to 4 years), the choice whether to buy now energy delivered in next years, or investment in their own new generation units.

This regional operation and investment regional optimisation (or coordination) would result in:

- operation cost savings (expensive fuel in one country would be substituted by lower cost generation fuel available in another country),
- investment savings (the commissioning of some "expensive" plants might be postponed if firm capacity is available from another country through the interconnection, leading to a larger development of lower cost generation in another country).

10.2.5 Summary Table

Table 10.1 : Tight and Loose Pool Models - Main characteristics

Model	Level of coordination	GEP	Savings
Isolated system	No	GEP Egypt, GEP Ethiopia, GEP Sudan	Reference situation
Loose pool model	Operation	Idem as above	Fuel costs
Tight pool model	Operation and investment	Updated GEP	Fuel costs and investment costs

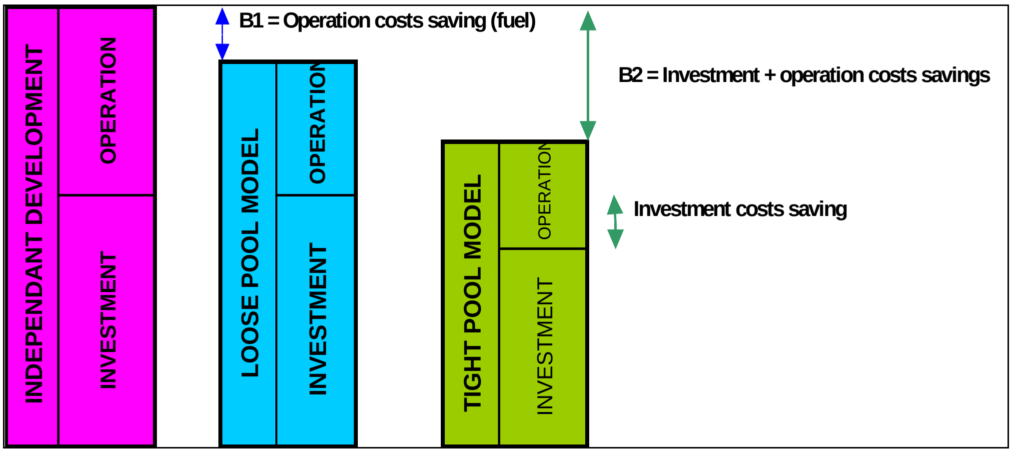


Figure 10.1 : Savings from Tight and Loose Pool Models

10.2.6 Point of View of the Economic Analysis

In the generation planning, the point of view of the economic analysis is regional, meaning the objective is to measure the global benefit (i.e savings) for the three countries, and not the benefits specifics for each country.

A cost approach is considered (including externalities e.g. non-energy benefits and mitigation costs). The global (and real) cost for the region is evaluated and considered. What is evaluated and analysed is the modification of the global cost (generation investment, interconnection investment, operation cost) with and without interconnection. This means, for example, that the share of cost of projects (interconnection or HPP) between the different countries is not considered or relevant at this stage, because it does not change the global cost of investment for the region.

Subsidies to fuel are not considered either, nor duty or taxes, or the selling price of energy for the same reason. In the same way, the allocation of the benefits to the different stakeholders is not relevant. In other words, the possible selling price of power and wheeling tariff are not relevant in the economic analysis.

In this way, the global benefits (i.e. the global cost reduction) for the region could be evaluated. As a result, the economic study will evaluate the potential benefits for the region according to various options (interconnection, power pool models, etc).

10.3 COMPARISON OF ECONOMIC GENERATION COSTS IN THE THREE POWER SYSTEMS

A view of the generation costs in the region can be acquired through the analysis of:

- the economic cost of generation (or levelised cost of generation, which includes fixed and variable cost of generation),
- the variable cost of generation (which includes solely the part of cost dependant on the amount of generation.

The first approach is pertinent when generation investments are specifically decided for export purposes, in substitution for new possible investments in the importing country.

The second approach is pertinent when investments are decided only for the requirement of internal demand, and if surplus are available for exports, in substitution for more expensive generation in the importing country.

10.3.1 Comparison of the Economic Costs of Generation

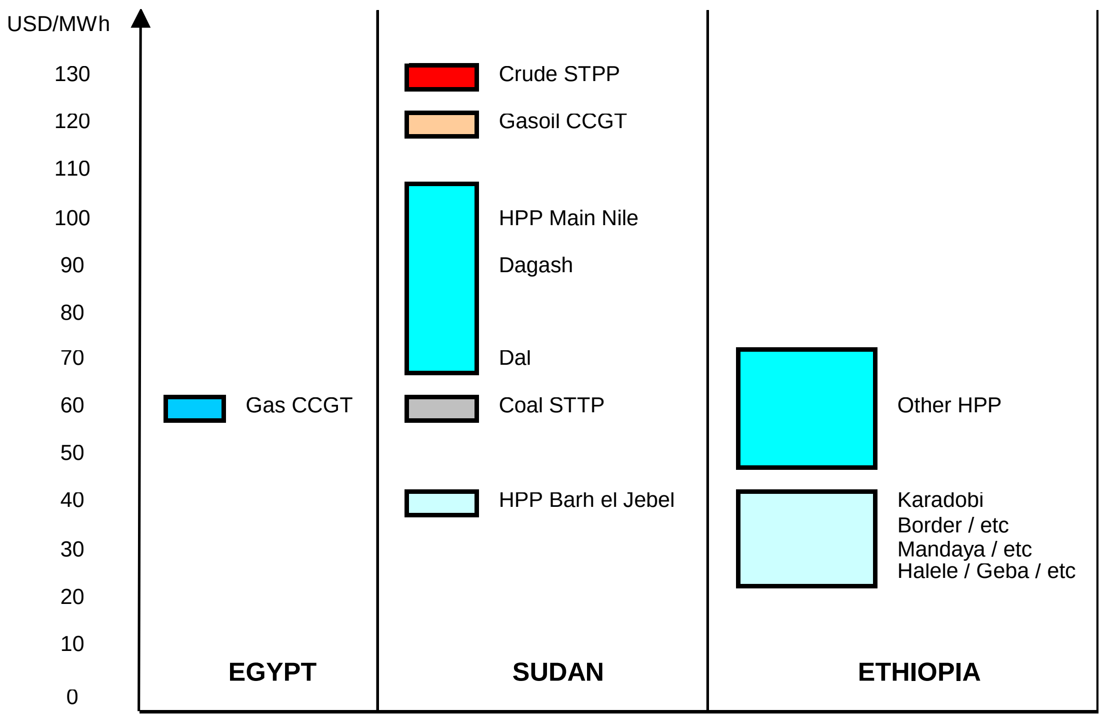


Figure 10.2 : Comparison of the Economic Cost of Generation in Different Generation Mixes - Year 2020 - Medium Fuel Price Scenario - 10% Discount Rate

This cost evaluation has been done on the basis of international market fuel price projection (because the purpose of the Study is the evaluation of power exchanges) which might be very different than the present fuel cost paid by the National Utilities. The figure above is based on year 2020, medium fuel price projection and TPP with load factor from 5 000 to 6 000 hours/year.

From the most cost effective projects to the more expensive it was found that:

- the lower cost generation projects are composed by a group of Ethiopian HPP projects (Halele, Geba, Karadobi, Mandaya, Border etc) with economic cost from 25 to 40 USD/MWh;
- then close to 40 USD/MWh we found the Bahr el Jebel HPP project in South Sudan;
- then close to 60 USD/MWh, we found CCGT in Egypt, coal-fired STPP in Sudan (but the number of coal-fired STTP is Sudan is limited by transmission capacity), and a group of hydro projects in Ethiopia;
- then from 70 to 110 USD/MWh, we find the HPP projects in the Main Nile river in Sudan including projects;
- finally, the most expensive units are gas oil-fired CCGT and crude oil-fired STPP is Sudan.

Accordingly, considering cost and power surplus, the bulk of power export will come from cost effective HPP projects in Ethiopia (all cost effective hydro power in Sudan being absorbed by Sudan internal demand).

The Sudanese power mix is clearly the destination of the bulk of power exports considering the high generation costs.

Power export from Ethiopia to Egypt are profitable, but provide less economic advantage than from Ethiopia to Sudan considering the lower cost difference and the greater transmission cost.

10.3.2 Comparison of the Variable Costs of Generation

While the economic cost of generation (related to what is often called long term marginal cost of generation) includes investment and operation costs, the variable cost (related to what is called short term marginal cost) only includes fuel and variable O&M cost.

The following table compares, for year 2020, and for the high fuel price projection (crude oil = 89 USD/bbl, to be compared to the current market price 78 USD/bbl in September 2007), the economic cost and the variable cost of generation for the main TPP candidates:

Table 10.2 : Comparison of Economic and Variable Costs Of Generation – Year 2020 – High Fuel Price Projection – 10% Discount Rate

	Economic cost (6000 hrs/year) USD/MWh	Variable cost USD/MWh	Ratio Var. cost / Economic cost
(Egypt) gas-fired 750 MW CCGT	68	52	74%
(Sudan) 500 MW gasoil-fired CCGT	179	164	92%
(Sudan) 500 MW crude-oil fired STPP	182	154	85%
(Sudan) coal-fired STPP	57	28	50%

It is notable that the variable cost represents most of the generation cost of CCGT and STPP (between 75 to 92%). This proportion increases in time along with the general increase of fuel prices. It also means that most the future savings resulting from power trade will come from fuel savings (an not investment savings).

10.4 GENERATION EXPANSION PLAN FOR THE ISOLATED SYSTEMS

The following paragraphs present the main characteristics of the first version of the least cost generation expansion plan of the three isolated systems (i.e. with non interconnection between them).

10.4.1 Egypt

Main hypothesis:

- Medium demand projection (5.6% average annual growth rate),
- Medium fuel price projection (crude oil 60 USD/bbl, NG = 8.6 USD/MBTU in 2030).
- Power export to Jordan (200 MW) and Libya (200 MW).
- No exchange with Sudan or Ethiopia.

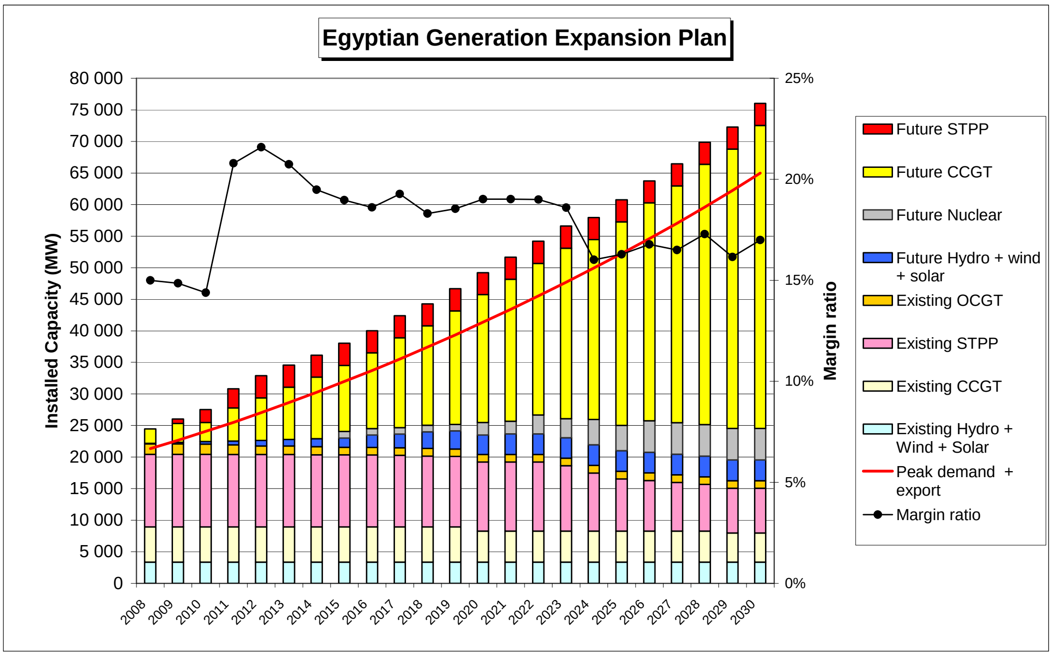


Figure 10.3 : Generation Expansion Plan – Egypt – No interconnection with Sudan / Ethiopia

10.4.2 Ethiopia

Main hypothesis:

- Medium demand projection (average annual growth rate 10.9%).
- Medium fuel price projection (crude oil 60 USD/bbl in 2030),
- No exchange with Egypt or Sudan.
- Power export to Kenya (from 200 MW in 2011, 600 MW in 2020, and 1200 MW in 2030)
- Power export to Djibouti (<53 MW).

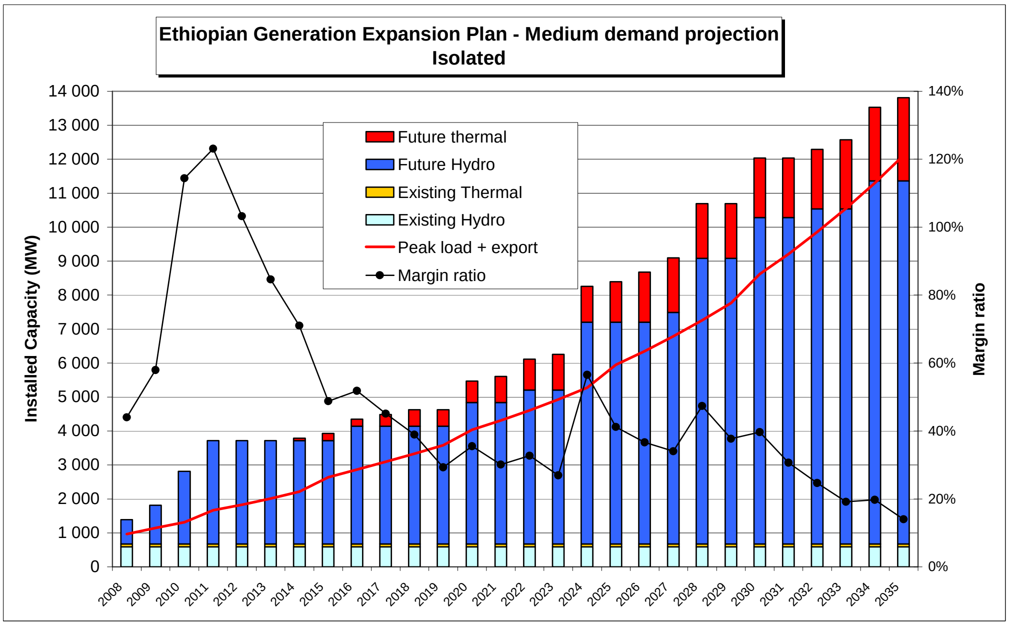


Figure 10.4 : Generation Expansion Plan - Ethiopia - No interconnection Sudan / Egypt

The associated schedule of HPP commissioning is the following:

Table 10.3 : Generation Expansion Plan - HPP Ethiopia

Commisioning Date	Hydro Project	Capacity MW	Average Generation GWh	TPP	Capacity MW
2008	Gibe II	420	1 600		
	Tekeze	300	1 200		
2009	Beles	420	2 000		
2010	Neshe	97	225		
2011	Gibe III (I)				
2012	Gibe III (II)	1 870	6 240		
2014				OCGT	70
2015				OCGT	140
2016	Halele Worabesa	420	2 245		
2017				OCGT	140
2018				OCGT	140
2019					
2020	Baro I + I + Gengi	700	4 409	OCGT	140
2021				OCGT	140
2022	Geba I + II	368	1 788	OCGT	140
2023				OCGT	140
2024	Mandaya	2 000	12 100		
2025				OCGT	140
2026				OCGT	280
2027	Chemoga Yeda	280	1 415	OCGT	140
2028	Karadobi	1 600	6 000		
2029					
2030	Border	1 200		OCGT	140
2031					
2032	Genale III	254			
2033				OCGT	280
2034	GenaleIV - Aleltu E&W	569		OCGT	140
2035				OCGT	140
Total		10 498			2 310

From 2010 to 2014, Ethiopia can take advantage of a significant surplus of hydro generation which can be exported to Sudan through the future 200 MW Ethiopia – Sudan interconnection.

10.4.3 Sudan

Main hypothesis:

- Medium demand projection (average annual growth rate 9.8%).
- Medium fuel price projection (crude oil 60 USD/bbl in 2030).
- No exchange with Egypt or Sudan.

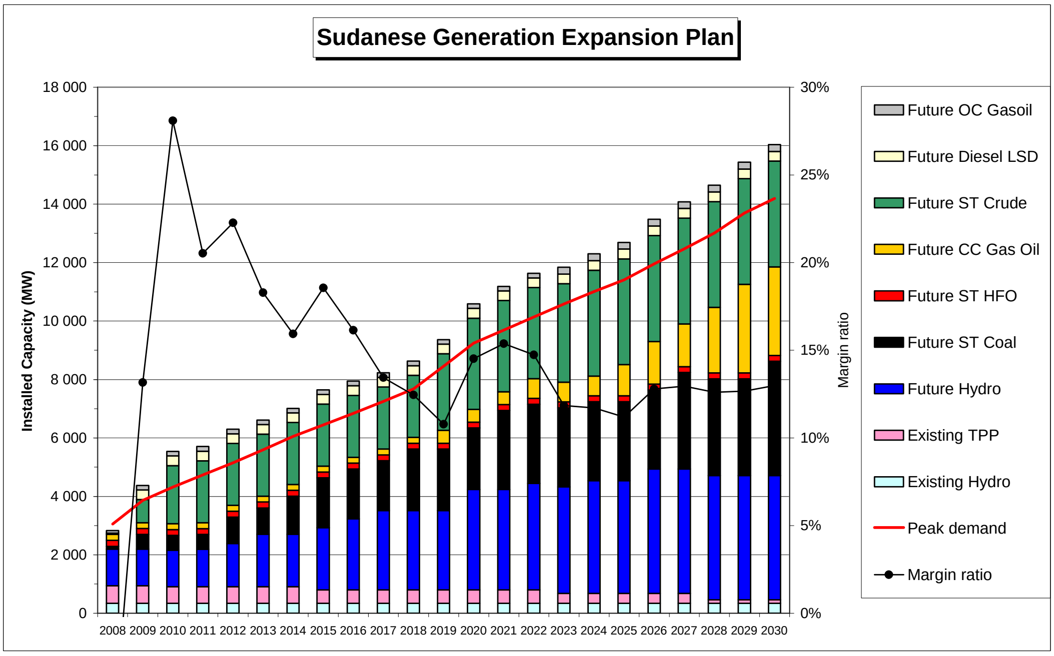


Figure 10.5 : Generation Expansion Plan – Sudan

10.5 LOOSE POOL MODEL: POWER EXCHANGES & REGIONAL SAVINGS

The loose pool model refers to a scheme where the operation of the generation is coordinated regionally (either by direct coordination or through a power pool) while each country keeps its independence for the decision of generation investment. Accordingly, the investment cost of the regional generation plan is identical as in the independent development of each power system, while the operation cost is reduced through regional coordination and the use of Ethiopian hydro surplus. This approach is similar to the one carried out for the Ethiopia – Sudan Interconnection Study (2005).

The operation optimization software SDDP allows to simulate the optimal operation (i.e. least cost dispatch) of the integrated system according to the capacity of the interconnection.

10.5.1 Origin of the Hydro Surplus

Basically, the hydro surplus in Ethiopia are inherent to the development of a purely hydro system based on large size HPP for two reasons:

- Due to the large size of Ethiopian HPP projects compared to the Ethiopian internal demand (e.g. Mandaya represents more than 1/3 of the Ethiopian demand in 2024), hydro power surpluses are available for export during the first years following the commissioning of these large HPP projects, during the period of time when the Ethiopian demand does not completely absorb the new generation. Smaller projects would be included at a quicker step in the Ethiopian GEP, and would be absorbed more rapidly by the demand growth, and would result in much less hydro surplus, but would lack the economic competitiveness of largest HPP projects.

- In a hydro power system, in order to have a proper supply / demand balance all year long and even on the driest years, a large amount of installed overcapacity is required.

The resulting hydro surplus, can be provided for export, when available, at no additional cost for the Ethiopian power system.

10.5.2 Characteristics and Costs of the Hydro Surplus

The amount of hydro surpluses is variable with the planting of new hydro plants (reaching maximum on the commissioning of large HPP, and minimum before new commissioning), and during each year (higher during wet season).

All the hydro project investment decisions are justified by the internal demand requirement. In other words, the supply of power export is made at no additional cost for the hydro exporting country[1].

Finally, hydro surplus are available on the average at no additional cost, but are variable in amount and duration.

This type of power exchanges is typical of spot market and future market (month to month). For instance, after the wet season Ethiopia could assess the amount of stored energy in its reservoirs and evaluate the amount available for export and contract exchange for a period of a few months.

10.5.3 Reference Situation

The reference situation for the evaluation of the operation savings is characterized by:

[1] Obviously, this does not mean the selling price must be null. On the opposite, the selling price is to be negotiated of the basis of the sharing of the global savings between the exporting country and the importing country.

- commissioning of the Ethiopia-Sudan 200 MW interconnection in 2010,
- generation expansion plans of Egypt, Ethiopia and Sudan identical to those determined without any interconnection.

In order to determine the savings related only to the new interconnection (and not to the 200 MW Ethiopia Sudan interconnection), the savings described below are relative to this reference situation.

10.5.4 Earliest Date of Commissioning of the Interconnection

Based on the duration of technical studies, tender process and construction, the earliest date of commissioning of the interconnection is close to 2015.

However, it makes more sense to link the commissioning date of the interconnection with the commissioning of the first large HPP project close to Sudan (i.e. Mandaya). In the isolated development of the Ethiopian system, Mandaya is commissioned in 2024. In the scenario with interconnection, it is considered that Mandaya is commissioned at its earliest date of commissioning: 2020 and this same date of commissioning is considered for the interconnection. This 4 years shift forward is the only difference with the Ethiopian generation expansion plan determined previously without interconnection. In the evaluation of the generation savings the additional investment cost (anticipation of 4 years) will be taken into account.

10.5.5 Power Exchanges for the Reference Hypothesis

The power exchanges and generation savings have been evaluated for a variety of interconnection capacities. For example, the following figure presents the evolution of the economic power exchanges for a scheme with 1200 MW capacity between Ethiopia and Sudan and 700 W capacity between Ethiopia and Egypt :

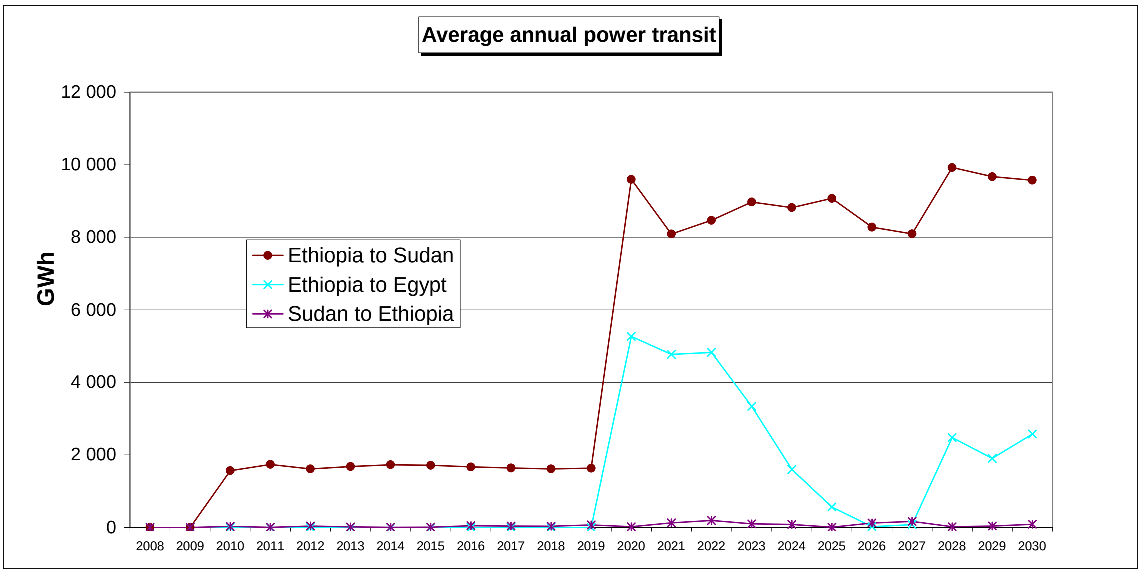


Figure 10.6 : Average Annual Power Transit – ET-SU=1200 MW – ET-EG= 700 MW – Loose Pool

In order to minimize the regional operation costs, the economic exchanges develop preferably toward Sudan where the fuel savings are higher (because of higher generation cost). The average annual power export from Ethiopia to Sudan, arises to 9 000 GWh/year over the 2020-2030 period, and nearly saturates the 1 200 MW capacity continuously.

The average annual power export from Ethiopia to Egypt, arises to 2 500 GWh/year over the 2020-2030 period, peaking during the first years after commissioning Mandaya (2020), Karadobi (2028) and Border (2030).

10.5.6 Sensitivity Analysis

The basic principle in the sensitivity analysis is to change one single key hypothesis of the Study at a time to check its impact on the results.

A number of analyses could be carried out, the focus here is to check how much the global savings for the region are affected by adverse evolution of key hypothesis. The potential negative factors are:

- lower evolution of fuel price leading to lower fuel savings,
- higher evolution of the Ethiopian demand, leading to possible less hydro surplus available for export,
- lower evolution of the Ethiopian demand, leading to possible less hydro surplus because of longer time span between commissioning of large HPP.

Low fuel price projection:

The simulations show that the volume of export remains close to the reference situation with medium fuel price projection. The regional fuel cost savings are reduced by about 1/3.

High demand projection for Ethiopia:

With the high demand projection in Ethiopia, the Ethiopia hydro surplus are absorbed more rapidly by the rise of the Ethiopia own demand. The regional fuel cost savings are reduced by about 1/3 compare to the situation with de Medium Ethiopian demand projection.

Low demand projection for Ethiopia:

The simulations show that the volume of export and the regional generation savings remain close to the reference situation with medium Ethiopian demand projection.

10.6 TIGHT POOL MODEL: POWER EXCHANGES & REGIONAL SAVINGS

10.6.1 Introduction

In the tight pool model, the countries coordinate their decision of generation investments, in order to minimize the regional generation cost (investment + operation). The hydro generation investments in Ethiopia are anticipated (compared to the loose pool approach) in order to provide more power available for export to Egypt and Sudan.

Strictly speaking some generation investments could be delayed in Egypt and Sudan due to the increased power import. However, due to the increase of the projected fuel prices all over the period of the Study, the investment represents only 15 to 25% of the total generation cost of new thermal plants. Accordingly, the Consultant would not recommend any modification of the Generation Expansion Plans of Egypt and Sudan, which means these countries would still keep their ability to balance their power demand with their own supply whenever power import are not available (and would not depend on financing / construction / hydrology risks of large HPP projects).

The tight pool approach has been studied for the medium and the low Ethiopian demand projections. Indeed, the generation expansion plan for the high demand projection in Ethiopia (isolated case) gives no room for anticipation of any HPP projects.

10.6.2 Economic Power Exchanges

Medium demand projection for Ethiopia

The following figure presents, for example, the evolution of the economic power exchanges for a scheme with 1200 MW capacity between Ethiopia and Sudan and 2000 MW capacity between Ethiopia and Egypt, and the medium demand projection for Ethiopia:

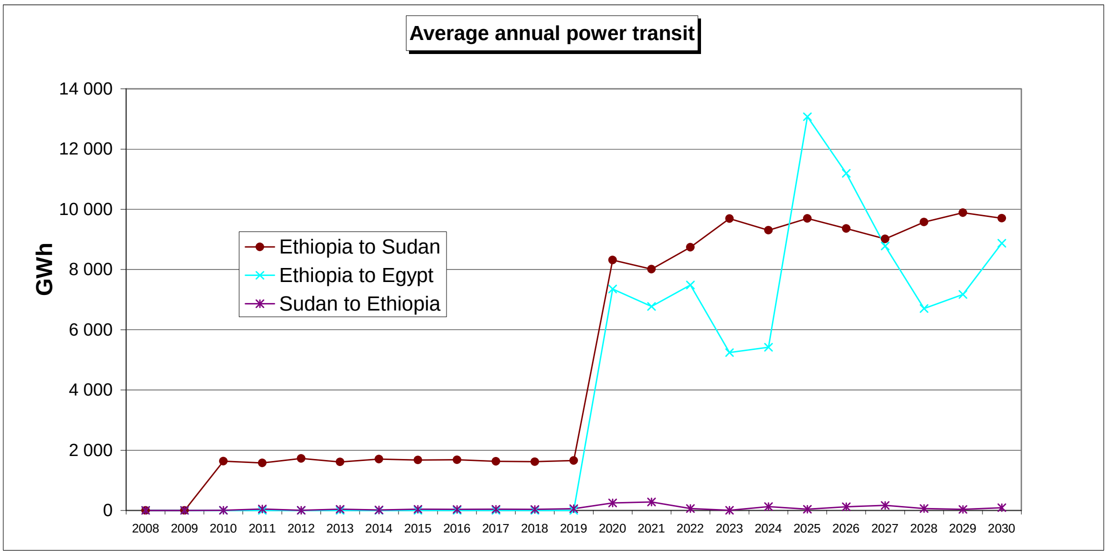


Figure 10.7 : Average Annual Power Transit - ET-SU=1 200 MW, ET-EG=2 000 MW- Tight Pool – Medium Demand Projection for Ethiopia

The increase of power exchange is readily appearing with comparison to the loose pool situation:

- The average annual power export from Ethiopia to Sudan arises to 9200 GWh/year over the 2020-2030 period, and saturates the 1200 MW capacity continuously (equivalent to 7700 h / year at 1200 MW).
- The average annual power export from Ethiopia to Egypt arises to 8000 GWh/year over the 2020-2030 period (equivalent to 4000 h / year at 2000 MW).

The underlying generation expansion plan for Ethiopia includes the following modifications compared to the isolated situation:

- anticipation of Mandaya from 2024 to 2020,
- anticipation of Geba I+I: from 2022 to 2021,
- anticipation of Chemoga Yeda from 2027 to 2022,
- anticipation of Karadobi from 2028 to 2025,
- Genale III enters the GEP in 2022,
- Genale IV enters the GEP in 2023,
- Aleltu East and West enters the GEP in 2029.

The Border commissioning date is left unchanged at 2030 in order to keep a 5-year interval between the commissioning dates of Mandaya, Karadobi and Border, compatible with the reduction of the negative downstream effect during the successive filling of these reservoirs.

Low demand projection for Ethiopia

Apart from the hydro projects identified for Ethiopia in Module 3, other medium scale hydro projects might cover part of the internal Ethiopian power demand. Accordingly, the low demand projection is probably more relevant to the scope of the Study with respect to the amount power that could be exported from Ethiopia.

In these conditions, and for a scheme with 1 200 MW capacity between Ethiopia and Sudan and 2 000 W capacity between Ethiopia and Egypt, the amount of power exchanges to Egypt increases significantly reaching 12 700 GWh/year over the 2020-2030 period (equivalent to 6 300 h / year at 2 000 MW):

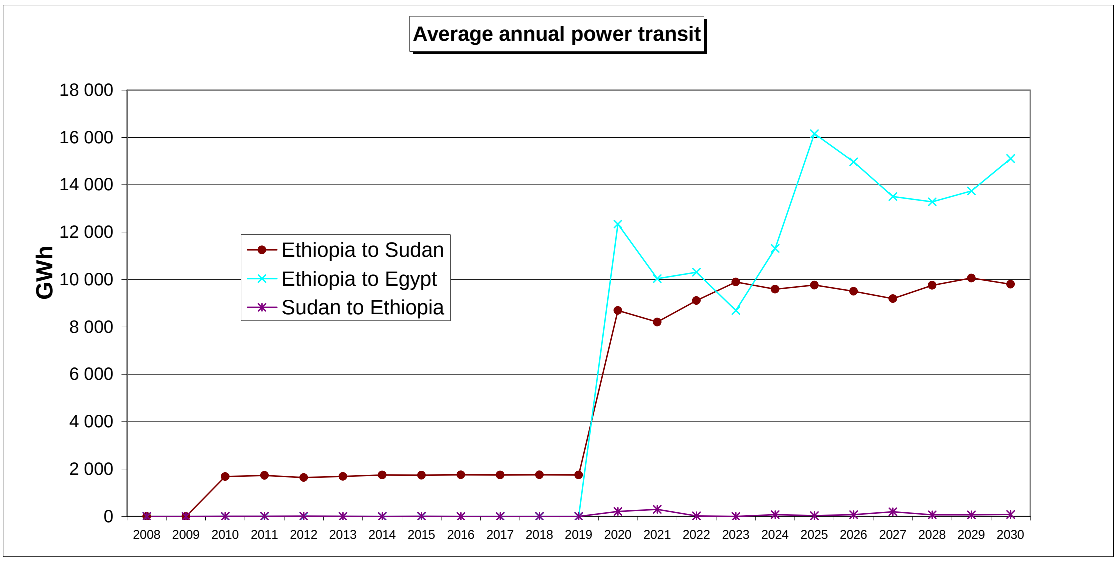


Figure 10.8 : Average Annual Power Transit - ET-SU=1 200 MW, ET-EG=2 000 MW- Tight Pool – Low Demand Projection for Ethiopia

10.7 CO_2 SAVINGS

10.7.1 Loose Pool Model:

The following table provides the annual quantity of CO_2 savings in tons, and the present worth value of the CO_2 savings in 2008 based on a 5 and 10 USD/t value:

Table 10.4 : Present Worth Value of CO_2 Emission Savings

Case	Additional export	CO2 reduction	Present worth value					
			8% discount rate		10% discount rate		12% discount rate	
			5 USD/tCO_2	10 USD/tCO_2	5 USD/tCO_2	10 USD/tCO_2	5 USD/tCO_2	10 USD/tCO_2
	TWh/year	M ton	MUSD	MUSD	MUSD	MUSD	MUSD	MUSD
Ethiopia-Sudan : 700 MW	4.00	3.00	80	161	53	105	36	72
Egypt-Ethiopia : 700 MW	3.60	1.55	41	83	27	54	19	37
Total	7.60	**4.55**	122	244	80	159	54	109
Ethiopia-Sudan : 1200 MW	7.10	5.33	143	285	93	187	64	128
Egypt-Ethiopia : 700 MW	2.00	0.86	23	46	15	30	10	21
Total	9.10	**6.19**	166	332	108	217	74	148

This present worth value would have to be included in the benefits of the project if eligible to Clean development Mechanism (CDM).

10.7.2 Tight Pool Model:

In the tight pool model, the additional hydro power from hydro power leads an additional reduction of the CO_2 emissions in Egypt and Sudan as described in the following table:

Table 10.5 : Present Worth Value of CO_2 Emission Savings – Tight Pool Model

Case		Additional export	CO2 reduction	Present worth value					
				8% discount rate		10% discount rate		12% discount rate	
				5 USD/tCO_2	10 USD/tCO_2	5 USD/tCO_2	10 USD/tCO_2	5 USD/tCO_2	10 USD/tCO_2
		TWh/year	M ton	MUSD	MUSD	MUSD	MUSD	MUSD	MUSD
Ethiopia-Sudan :	1200 MW	8.20	6.15	165	330	108	216	74	147
Egypt-Ethiopia :	700 MW	5.20	2.24	60	120	39	78	27	54
Total		13.40	**8.39**	225	450	147	294	100	201
Ethiopia-Sudan :	1200 MW	7.40	5.55	149	298	97	195	66	133
Egypt-Ethiopia :	2000 MW	6.20	2.67	71	143	47	93	32	64
Total		13.60	**8.22**	220	440	144	288	98	197

10.8 ECONOMIC ANALYSIS

The economic consists in comparing the net balance between :

- the cost of the interconnection.
- the "benefits" provided by the interconnection : generation cost savings and CO_2 savings ;

The classic economic criteria "Net Present value" and Benefit to Cost ratio will be used.

10.8.1 Cost of the Interconnection

The following table summarizes the present worth cost of interconnection project for the three main options of capacity in MUSD $_{2008}$:

Table 10.6 : Present Worth Value of the Interconnection Cost

SU : 700 MW, EG : 700 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
407	490	1040

These present worth of costs are calculated on the base of the expenditure schedule of the interconnection and 0% discount rate. This cost includes :

- the cost of the project
- the annual O&M cost.

10.8.2 Loose Pool Model

The following table summarizes the present worth of generation savings for the main options analyzed previously in the loose pool model (10% discount rate):

Table 10.7 : Present Worth Value of Generation Savings - Loose Pool (Million USD)

$MUSD_{2008}$	SU : 700 MW, EG : 0 MW	SU : 700 MW, EG : 700 MW	SU : 700 MW, EG : 2000 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Demand median - Fuel median	1 280	1 910	2 010	2 270	2 380
Demand median - Fuel low	840	1 120	1 340	1 520	1 520
Demand ET low - Fuel median	1 170	1 920	2 260	2 540	2 590
Demand ET high - Fuel median	820	1 140		1 550	1 600

These generation savings (fuel cost reduction from substitution of thermal power by hydro power) results from the coordination of the operation of three generation mixes allowed by the interconnection. These are potential benefits which would be achieved with a fully coordinated operation of the three interconnection power mixes (regional generation dispatch center). The actual benefits would obviously be lower, depending on the nature and importance of the power market, the type of contracts, and the actual level of coordination between the different Utilities.

These generation savings are net of the interconnection transmission losses and from additional investment cost in some scenario (i.e. Mandaya commissioned in 2020 instead of 2024 in the medium demand projection). The present worth value is given in $MUSD_{2008}$ discounted in 2008.

It should be noted that other "non power" benefits resulting from new hydro projects (such as downstream benefits) remain the same whether the interconnection is committed or not.

The following table presents the net savings (savings minus cost) under the loose pool model according to the various capacity options and key parameters of the study :

Table 10.8 : Net Present Value of the interconnection – Loose Pool Model

NPV ($MUSD_{2008}$):	SU : 700 MW, EG : 700 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Demand median - Fuel median	1 500	1 780	1 340
Demand median - Fuel low	710	1 030	480
Demand ET low - Fuel median	1 510	2 050	1 550
Demand ET high - Fuel median	730	1 060	560

The interconnection Net Present Value is positive for every capacity option and key parameter.

In case of low fuel cost evolution, the profitability of the interconnection would be significantly lower (NPV divided by 2 or 3 depending on interconnection capacity). The same is true if the Ethiopian demand follows the "high demand projection". If the Ethiopian demand follows the "low demand projection" the results are equivalent to the reference case with the "medium demand projection".

While still positive, the NPV decreases significantly going up to a 2 000 MW (for Egypt) and 1 200 MW (for Sudan) scheme. This is due to the significantly higher cost for the 2 000 MW interconnection link, while additional fuel savings are low because of the main part of the Ethiopia hydro surplus has been provided for export.

Comparing options

The next table provides the Benefit to Cost Ratio (also called BCR) which is a convenient and classic ratio for comparing options:

Table 10.9 : Benefit to Cost Ratio – Loose Pool Model

Benefit / Cost ratio :	SU : 700 MW, EG : 700 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Demand median - Fuel median	4.7	4.6	2.3
Demand median - Fuel low	2.7	3.1	1.5
Demand ET low - Fuel median	4.7	5.2	2.5
Demand ET high - Fuel median	2.8	3.2	1.5

The benefit to Cost ratio is equal to the Net Present value of the benefits divided by the Net Present value of the cost. A value greater than one means the benefits outbalances the cost of the project.

The decrease of the profitability of the interconnection is apparent in case of low evolution of fuel costs or if the Ethiopian demand follows the high projection.

On the whole, the option with the higher BCR is the 700 MW (for Egypt) 1 200 MW (for Sudan) scheme.

10.8.3 Tight Pool Model

Present worth of generation benefits

The following table gives the present worth of generation savings for the main options analyzed previously in the loose pool model (10% discount rate):

Table 10.10 : Present Worth Value of Generation Savings – Tight Pool Model

Present worth of savings (generation) - MUSD$_{2006}$	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium demand for Ethiopia - Fuel medium -Tight pool	2 810	2 960
Low demand for Ethiopia - Fuel high -Tight pool	3 140	4 020
Low demand for Ethiopia - Fuel medium -Tight pool	2 380	2 990

These generation savings are net of interconnection transmission losses, and of the additional investment costs resulting from the anticipation of several HPP in Ethiopia compared to the loose pool model.

Net savings

The following table presents the net savings (savings minus cost) according the various capacity options and key parameters of the study:

Table 10.11 : Net Present Value of the Interconnection – Tight Pool Model

NPV (MUSD$_{2006}$):	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium demand for Ethiopia - Fuel medium -Tight pool	2 320	1 920
Low demand for Ethiopia - Fuel high -Tight pool	2 650	2 980
Low demand for Ethiopia - Fuel medium -Tight pool	1 890	1 950

The tight pool approach, along with an increase of power exports, provides an increase of the Net Present Value of the interconnection project for the region.

Comparing options

The next table provides the Benefit to Cost Ratio (also called BCR):

Table 10.12 : Benefit to Cost Ratio – Tight Pool Model

Benefit / Cost ratio :	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium demand for Ethiopia - Fuel medium -Tight pool	5.7	2.9
Low demand for Ethiopia - Fuel high -Tight pool	6.4	3.9
Low demand for Ethiopia - Fuel medium -Tight pool	4.9	2.9

While the benefit to cost ratio would favors the ET-SU: 1 200 MW – ET-EG: 700 MW scheme, the NPV is equivalent with ET-SU: 1 200 MW – ET-EG: 2 000 MW scheme. Accordingly, this latter scheme is preferable for the region.

10.8.4 Savings per Country and Pay Back Period

The pay-back period is the period of time necessary for the savings (= mainly fuel savings) to balance the expenses (cost of the interconnection and anticipation of HPP investment). At the end of the payback period the present value of the savings is equal to the present value of the expenses.

Loose pool model

For a scheme with a 1 200 MW capacity to Sudan and a 700 MW capacity to Egypt, the interconnection investment is paid after 3 full years of operation (medium demand projection for all countries, medium fuel price projection, 10% discount rate). This very short pay back period is consistent with the high benefit to cost ratio of the interconnection project.

The average export to Egypt would be 2.5 TWh/year, with 130 $MUSD_{2006}$/year average fuel savings, while the average export to Sudan would be 9 TWh/year, with an average fuel savings of 750 $MUSD_{2006}$/year (450 $MUSD_{2006}$/year from crude oil and 210 $MUSD_{2006}$/year from gasoil).

Tight pool model

For a scheme with a 1 200 MW capacity to Sudan and a 2 000 MW capacity to Egypt, the interconnection investment is paid after 6 full years of operation (medium demand projection for all countries, medium fuel price projection, 10% discount rate).

Whenever the Ethiopia demand follows the low demand projection (or if additional low cost Ethiopian HPP projects are identified) the pay back period would be 7 years.

The average export to Egypt would be 12.7 TWh/year, with 680 $MUSD_{2006}$/year average fuel savings, while the average export to Sudan would be 9.4 TWh/year, with an average fuel savings of 750 $MUSD_{2006}$/year.

10.8.5 Analysis

The interconnection project is characterized economically by a good profitability, a short payback period and a high benefit to cost ratio.

Loose pool model

The loose pool model, which consists basically in exporting the hydro surplus inherent to the Ethiopian power system (at no additional cost for Ethiopia), is characterized by:

- some variability of the amount exported power to Egypt (export to Sudan being more base-load) along the period of study,
- lower amount of power export (compared to the tight pool approach), but with the advantage of low HPP additional investment cost (the only additional investment cost is the anticipation Mandaya from 2024 to 2020 in time with the commissioning of the interconnection[2]).

Accordingly very good BCR and short payback periods are achieved, the variability of the hydro surplus being balanced by the low global additional generation investment cost.

This model is typical of the actual power exchanges between European countries (spot market, month to month exchanges) which take benefits of temporary (short to medium term) power surplus in one or other country.

In this context, the best scheme, from a strictly economic point of view, would be ET-SUD: 1 200 MW ET-EG: 700 MW, with a benefit to cost ratio of 4.5 and a very short 3 year-payback period.

However, going to 2 000 MW capacity to Egypt would still be profitable for the region (BCR=2.3), and would give more freedom and flexibility for a future evolution to a tight pool model, and in a latter stage to an extension of the market to Kenya and SAPP.

Tight pool model

In the tight pool model adopted in this Study, HPP investments in Ethiopia are anticipated (with respect to their schedule when Ethiopia remains isolated) in order to provide an additional amount of power export. Thus, the power exports arise for one part, from the "natural" hydro surplus inherent to the Ethiopian hydro generation mix, and for the other part from the anticipation of some Ethiopian HPP.

The generation expansion plans of Egypt and Sudan are left unchanged because, due to the projected fuels price increase all over the period of the Study, the investment represents only 15 to 25% of the total generation of new thermal plants. Accordingly, the Consultant would not recommend any modification of the

[2] For the Ethiopian low demand projection, Mandaya is anticipated from 2025 to 2020, while for the high demand projection no anticipation is required because the "natural" date of commissioning of Mandaya is 2020.

Generation Expansion Plans of Egypt and Sudan, which means these countries would still keep their ability to balance their power demand with their own supply whenever power import are not available.

The tight pool model is characterized by:

- increased amount of exports (compared to loose pool),
- lower variability of the power export to Egypt along the period of study,
- at the expense of higher generation investment cost in Ethiopia.

Accordingly the BCR and payback period is lower than in the loose pool model, but still very good.

The best scheme, on the basis of the Ethiopian HPP listed in Module 3, and from a strictly economic point of view, would still be ET-SUD: 1 200 MW ET-EG: 700 MW.

However, the Net Present Value of the scheme with ET-EG: 2000 MW being very close to the scheme with ET-EG: 700 MW. Going to 2 000 MW is certainly preferable, the pay back period is still short (6 to 7 years according to hypothesis considered), and giving more flexibility for the evolution of power trade in the future.

10.9 SUMMARY OF ADVANTAGES / DISADVANTAGES RESULTING FROM THE INTERCONNECTION PROJECT

The purpose of the present economic Study was to evaluate the potential economic benefits resulting from the interconnection project. While these benefits can be evaluated in terms of monetary values, they do not represents all the possible benefits resulting from the project. In order to widen the view, the following simplified tables summarizes for the region and for each country, the main advantages and the disadvantages from the interconnection project. In order to be more specific, the tables indicated what is the origin of the advantages or disadvantages:

- Electric market: when the advantage/disadvantage exists if and only if the interconnection exists.
- HPP projects in Blue Nile River: when the advantage/disadvantage exists even in the absence of the interconnection (e.g. large HPP project on Blue Nile in Ethiopia is necessary to the Ethiopian system even without interconnection, accordingly the positive downstream impacts are related to the HPP project and not to the interconnection).

10.9.1 Region

Table 10.13 : Advantages / Disadvantages for the Region

Origin	Advantages
Power market	Creation of a power pool: - global generation cost savings, - reduction of the cost of electricity for the final user would favor overall development, - economies of scale in new generation capacity : development of larger low-cost hydropower plants made possible through the creation of larger power market, - hydro-thermal complementarity between Egypt, Ethiopia and Sudan, - mutual assistance in case of disturbances, - first step to the connection of the North Africa power systems to the South East African power pool. Regional cooperation, trust building and coordinated development of Nile Basin
Hydro projects	Coordination of the operation of HPP on the Nile river for an overall benefit for the region. Regulation of inflows and continuous availability of water. Reduction in CO_2 emissions

Origin	Disadvantages
Power market	None

10.9.2 Egypt

Table 10.14 : Advantages / Disadvantages for Egypt

Origin	Advantages
Power market	Fuel savings (mainly Natural gas). Reduction in CO_2 emission. Securisation of the long term cost of generation (hydro power base import have a generation cost independent of the variation of crude oil price). Possibility for Egyptian generator companies to invest in low-cost hydro generation in Ethiopia.
Hydro projects	Regulation of inflows: - improved guarantee for irrigation. - opportunity to operate Aswan at lower level for a reduction of evaporation and a conversion to usable supply yield which may more than offset the reduction in power generation. Reduced sediment: extension in life of High Aswam dam

Origin	Disadvantages
Power market	None
Hydro projects	Head loss on Aswan during filling large reservoirs on Blue Nile river: Impact along time to be studied under a variety of conditions (hydrology, sequence of HPP, reservoir sizes, etc) in term of irrigation, capacity (MW), energy (GWh).

10.9.3 Ethiopia

Table 10.15 : Advantages / Disadvantages for Ethiopia

Origin	Advantages
Power market	Valorisation of the hydro power surplus inherent to the Ethiopian power system. Valorisation of the hydro potential of Ethiopia for the benefit of Ethiopia and the interconnected countries. Boost for the development of the Ethiopian power mix, and consequently to the electrification rate in Ethiopia. Securisation of power supply in Ethiopia in case of drought conditions (power import from Egypt and Sudan). Important role for the connection to Kenya and at a latter stage to the SAPP. Increase foreign exchange earnings. Construction employment, new skills for the future.
Hydro projects	Low-cost renewable energy. Regional development (new roads, bridge, development of rural electrification, etc). Poverty reduction. Construction employment, new skills for the future. Development of irrigation.

Origin	Disadvantages
Hydro projects	Capital intensive projects may take time to be finance. Negative ES impacts (but can be mitigated through identified measures)

10.9.4 Sudan

Table 10.16 : Advantages / Disadvantages for Sudan

Origin	Advantages
Power market	Fuel savings. Saved fossil fuel could be exported at a higher price rather than be burned in TPP. Access to the Mediterranean power market, and at a latter stage to the SAPP. Re-enforcement of the complementarily between the Ethiopian hydro system and the Sudanese hydro system (power sales to Ethiopia in drought conditions)
Hydro projects	Regulation of inflows (additional irrigation, navigation, uplift effect at Roseires, Sennar and Merowe: 2 200 GWh/year, equivalent to Dal generation) Reduced sediment: reduction in dredging costs at Roseires, reduction in drainage canal desilting maintenance cost, reduction in pump replacement cost. Development of Irrigation agriculture: two crops per year. Flood reduction.

Origin	Disadvantages
Hydro projects	Reduction in flooding and sediment will lead to the conversion of recession agriculture to irrigation agriculture (but can be mitigated through identified measures).

10.10 CONCLUSION

The present power trade Study is the first quantitative Study analysing the evolution of the three power systems of Egypt, Ethiopian and Sudan up to 2030, and evaluating the benefits that would result from the establishment a regional power market between Egypt, Ethiopia and Sudan.

Previously, the generation expansion plan of Sudan (LTPPS 2006) was studied up to 2030, the Egyptian generation expansion plan covered the period up to 2028, while the Ethiopian expansion plan covered the period up to 2015.

Accordingly, the present Study is the first one giving a quantitative and economic evaluation of the Ethiopian hydropower surpluses available for export up to 2030. This was done on the basis of the data made available to the Consultant and validated by the different Utilities in the course of the present Project.

The Study demonstrates there are significant benefits for the Egypt, Ethiopia, and Sudan to develop an interconnection between their three power systems.

The economic analysis shows that the interconnection will allow to provide Egypt and Sudan with the hydro surplus available from the large Ethiopian HPP projects, and consequently save fossil fuels and reduce CO_2 emissions in Egypt and Sudan.

10.10.1 Ethiopian Hydro Surplus

Ethiopia is well endowed with hydro resources. The hydro potential is estimated at about 30 000 MW, with only a fraction of which has been exploited so far. Accordingly, Ethiopia power systems will be the source of power export to Egypt and Ethiopia.

Part of the Ethiopian hydro surplus available for export are inherent to the internal development of the Ethiopian hydro mix:

- Due to the large size of Ethiopian HPP projects compared to the Ethiopian internal demand (e.g. Mandaya represents more than 1/3 of the Ethiopian demand in 2024), hydro power surpluses are available for export during the first years following the commissioning of these large HPP projects.
- Furthermore, in order to have a proper supply / demand balance all year long and even on the driest years, the Ethiopian hydro power system requires a large amount of installed overcapacity. Resulting hydro surplus can be provided for export when available.

Futhermore, additional hydro surplus could be made available if the commissioning dates of hydro plants are anticipated (with respect to their original schedule when Ethiopia remains isolated).

Finally, the amount hydro surplus will also depends on the growth rate of the Ethiopian demand, the amount of power exported to other countries (e.g. Kenya) and the cost of the Ethiopian hydro projects.

10.10.2 Earliest Date of Commissioning of the Interconnection

It is recommended to time the commissioning of the interconnection in accordance to the earliest commissioning date of the first large Ethiopian HPP project: 2020 (considering time necessary to carry out technical studies, tender process, construction).

10.10.3 Economy of the Interconnection

The present Study shows that the interconnection project is characterized economically by a good profitability, a short payback period and a high benefit to cost ratio.

The economy and optimal capacity of the interconnection were analyzed for two levels of coordination (or two types of power markets) between the three power systems : the loose pool and the tight pool models.

Loose pool model

The loose pool model, which consists basically in exporting the hydro surplus inherent to the Ethiopian power system (at no additional cost for Ethiopia), is characterized by:

- no modification of the generation expansion of Egypt and Sudan,
- slight modification of the Ethiopian generation expansion plan (anticipation of Mandaya to 2020),
- some variability of the amount exported power to Egypt (export to Sudan being more base-load) along the period of study,
- lower amount of power export (compared to the tight pool approach),
- but with the advantage of low HPP additional investment cost (the only additional investment cost is the anticipation Mandaya from 2024 to 2020 in time with the commissioning of the interconnection[3]).

Accordingly very good BCR and short payback periods are achieved, the variability of the hydro surplus being balanced by the low global additional generation investment cost.

This model is typical of the actual power exchanges between European countries (spot market, month to month exchanges) which take benefits of temporary (short to medium term) power surplus appearing in one or other country.

In this context, the best scheme, from a strictly economic point of view, would be ET-SUD: 1 200 MW and ET-EG: 700 MW, with a benefit to cost ratio of 4.5 and a very

[3] For the Ethiopian low demand projection, Mandaya is anticipated from 2025 to 2020, while for the high demand projection no anticipation is required because the "natural" date of commissioning of Mandaya is 2020.

short 3 year-payback period for the reference hypothesis (medium demand projections, medium price projection).

However, going to 2 000 MW capacity to Egypt would still be profitable for the region (benefit to cost ratio =2.3), and would give more freedom and flexibility for a future evolution to a tight pool model, and in a latter stage to an extension of the power market to Kenya and SAPP.

Tight pool model

In the tight pool model adopted in this Study, HPP investments in Ethiopia are anticipated (with respect to their schedule when Ethiopia remains isolated) in order to provide an additional amount of power export. Thus, the power exports arise for one part, from the "natural" hydro surplus inherent to the Ethiopian hydro generation mix, and for the other part from the anticipation of some Ethiopian HPP.

The generation expansion plans of Egypt and Sudan are left unchanged because, due to the projected fuel price increase along the period of the Study, the investment represents only 15 to 25% of the total generation of new thermal plants. Accordingly, the Consultant would not recommend any modification of the Generation Expansion Plans of Egypt and Sudan, which means these countries would still keep their ability to balance their power demand with their own supply whenever power import are available or not.

The tight pool model is characterized by:

- increased amount of exports (compared to loose pool),
- lower variability of the power export to Egypt along the period of study (compared to loose pool),
- higher generation investment cost in Ethiopia (because of HPP anticipation).

The benefit to cost ratio is lower, and payback period is longer, than in the loose pool model, but these economic indicators remain still very good.

The best scheme, on the basis of the Ethiopian HPP listed in Module 3, and from the benefit to cost ratio criteria, would be ET-SUD: 1 200 MW and ET-EG: 700 MW.

However, the Net Present Value of the scheme with ET-EG: 2 000 MW being very close to the scheme with ET-EG: 700 MW (or even greater for some hypothesis), going to 2 000 MW is certainly preferable, with still a short pay back period of 6 to 7 years according to hypothesis considered.

Preservation of the benefits on adverse evolution of key hypothesis

The interconnection project results in a net profit (benefits greater than costs) even on adverse evolution of key hypothesis (low fuel cost evolution which would reduce fuel savings, or high evolution of Ethiopian demand, which would reduce the amount of hydro surplus).

Potential and actual benefits

The generation savings evaluated in this Module 6 are potential (i.e. theoretical) savings resulting from the optimal coordination of the three generation mixes. The actual savings will depend on the proper development of the power pool, the establishment of short-term and medium term contracts, type of power exchanges (firm, non firm energy), policy to share of cost of investment and the benefit of investment, selling price, wheeling tariff, etc.

Looking into the future

The interconnection between Egypt, Ethiopia and Sudan has a short pay back period (<10 years) for the most relevant projections (high or medium fuel price projections, medium or low demand projections for Ethiopia).

After the payback period (before 2030-2032), the investment cost of the interconnection will be paid, and the remaining cost associated with the transmission of power will be the cost of losses, and to a lesser extend the O&M costs. This will boost the relative economic advantage of hydro power export from Ethiopia, giving opportunity to more hydro investments, for the benefit of the interconnected power systems (lower cost of electricity and reduction of emissions).

Finally, when the perspective is widen to the development of the African power markets, the commissioning of the interconnection between Egypt, Ethiopia and Sudan will be a determining step forward the completion of the connection between the North Africa power markets and the South African power markets (SAPP).

11. TRANSMISSION

11.1 GENERAL

This Section summarises the transmission studies which have been carried out as part of the Power Trade Study. The transmission studies have examined the transmission enhancements in each of the three Eastern Nile countries required to meet the increasing demand together with interconnection options specifically related to the Mandaya and other hydropower developments on the Abbay (Blue Nile) River in Ethiopia.

The transmission studies are reported in detail separately under Module 6.

11.2 ASSESSMENT OF THE TRANSMISSION SYSTEMS

The transmission systems of the three countries, Egypt, Ethiopia and Sudan were examined for the year 2015/2016. This analysis was based on the master plan proposed by the companies.

For EEPCO, the master plan is described in the report "Ethiopian Power System Expansion Master Plan Updated – June 2006".

For NEC, the master plan is described on the "Long Term Power System Planning Study".

For EEHC, the analysis was based on computer files containing the 2006/2007 network and excel files listing the elements of the transmission system for the years 2002, 2005, 2010 and 2015, and other files with the network modifications.

The Ethiopian and Sudan power systems were examined for the year 2015/2016 with the 220 kV interconnection between Ethiopia and Sudan (planned for the year 2009) in operation. Ethiopia exported 100 MW to Sudan.

The behaviour of the power systems was analysed in steady state. This analysis enabled to point out the possible weak points of the future transmission system. Several load flow calculations were performed in normal and in contingency situations for the annual peak.

The results of this analysis are presented hereafter.

11.2.1 Egypt

The behaviour of the transmission system planned for the year 2015/2016, based on the 2015 planning data, was analysed.

Load Flow calculations were performed in normal, N-1 and in N-2 situations for the peak demand.

To face the N situation, the proposed reinforcements are listed hereafter:

- a second circuit between North Delta and Abu Zaabal
- a second circuit between Nobaria and Cairo 500
- a new circuit between Suez 500 and Heliopolis
- a new circuit between Sidi-Krir and a new 500 kV substation in Abu Kir
- a new circuit between Abu-Kir and Nobaria
- a fourth and a fifth 500 MVA 500/220 kV transformer in Cairo 500
- a third and a fourth 500 MVA 500/220 kV transformer in Abu Zaabal
- a second, third and fourth 500 MVA 500/220 kV transformer in Heliopolis
- a second 500 MVA 500/220 kV transformer in Bassous
- a second 500 MVA 500/220 kV transformer in Tebbin
- a second 500 MVA 500/220 kV transformer in High Dam
- a second 500 MVA 500/220 kV transformer in Kurimat
- two 500 MVA 500/220 kV transformers in Abu Kir

In Normal situation, taking into account the previous reinforcements, the behaviour of the system was satisfactory. The flows over the lines and through the transformers were below the rating of the equipment. The voltage profile was within the limits.

Due to the number of reinforcement proposed around Cairo, the N-1 situations were analysed on the backbone between High Dam and Cairo, where the interconnection is most likely to be connected.

- the 500 kV line N-1 criteria was satisfied on the network except for the line Samalut - Kurimat, an additional circuit would be needed
- the 500/220 kV transformer N-1 criteria was not satisfied in High Dam and Nag Hammadi, and additional 500/220 kV transformer is necessary in both substation
- the 500/132 kV transformer N-1 criteria was not satisfied in Nag Hammadi and Samalut, and additional 500/132 kV transformer is necessary in both substation
- the 220 kV line N-2 criteria was satisfied between Kurimat and High Dam, except for the lines Nag Hammadi - Qena West, Kurimat - B.Suif East, Kurimat - Fayoum, and Sohag - Sohag East, additional circuit would be needed.

The proposed reinforcements described above will be included in the Egyptian transmission system for the study of the interconnection between Ethiopia, Sudan and Egypt.

11.2.2 Ethiopia

The VHV/132 kV transformation was examined. Some reinforcements of this transformation were necessary to satisfy the N-1 criterion. The proposed reinforcements are listed hereafter:

- Gefersa: Replacement of the four existing 24 MVA transformers by one new 100 MVA transformer (total installed capacity: 4 x 100 MVA);
- Kaliti I: Replacement of the three existing 45 MVA transformers by two new 100 MVA transformers (total installed capacity: 6 x 100 MVA);
- Two of these 45 MVA transformers could be installed at Melka Wakana and one at Gilgel Gibe;
- Woleita Sodo: Addition of a third 100 MVA 400/132 kV transformer (total installed capacity: 3 x 100 MVA);
- Melka Wakana: Replacement of the existing 22 MVA transformer by two new 45 MVA transformers (total installed capacity: 2 x 45 MVA);
- Addis North: Addition of one new 63 MVA transformer (total installed capacity: 3 x 63 MVA);
- Cotebe: Addition of one 63 MVA transformer (total installed capacity: 2 x 63 MVA);
- Kombolcha: Addition of one 63 MVA transformer (total installed capacity: 2 x 63 MVA);
- Gilgel Gibe I: Addition of one 45 MVA transformer (total installed capacity: 2 x 45 MVA);
- Sebeta: Addition of one 100 MVA transformer (total installed capacity: 3 x 63 MVA and 2 x 100 MVA).

In Normal situation, taking into account the previous reinforcement of the VHV/132 kV transformation, the behaviour of the system was satisfactory. The flows over the lines and through the transformers were below the rating of the equipment. The voltage profile was within the limits.

In N-1 situations:

- The 400/230 kV transformer at Bahir Dar was overloaded following the tripping of the 400 kV Debre Markos – Bahir Dar line.

To overcome this problem, it is proposed to install a second 400/230 kV transformer at Bahir Dar.

Whatever the other N-1 situations, there are no constraint on the system.

The proposed reinforcements described above will be included in the Ethiopian transmission system for the study of the interconnection between Ethiopia, Egypt and Sudan.

11.2.3 Sudan

In Normal situation, the behaviour of the transmission system was not totally satisfactory. Indeed, the three 300 MVA 500/220 kV transformers of Hasaheisa were slightly overloaded by 3%. Therefore, a fourth 300 MVA 500/220 kV transformer was assumed to be installed at Hasaheisa to recover a satisfactory behaviour and to comply with planning criteria adopted by NEC.

In N-1 situations, several constraints appeared on the system:

- Overload of the 500/220 kV transformations of Hasaheisa, Merowe and Nyala.
- Collapse of the western part of the system (Darfur area) following the tripping of the 500 kV line Fula - Nyala.
- Overload of the two 220 kV circuits between Bager and Giad, following the tripping of the third circuit.
- To overcome these constraints and recover a system that satisfies the N-1 criterion, the following reinforcements are proposed:
- A fifth 300 MVA 500/220 kV transformer at Hasaheisa (or commissioning of a new 500/220 kV substation at Meringan).
- A third 150 MVA 500/220 kV transformer at Merowe.
- Operation of Bager 220 kV substation with two separate bus bars in N-1 situation.
- A fourth 150 MVA 500/220 kV transformer at Nyala and a second 500 kV line Fula - Nyala with the convenient shunt reactors.

The proposed reinforcements described above will be included in the Sudanese transmission system - proposed by NEC Master Plan - for the study of the interconnection between Ethiopia, Egypt and Sudan.

11.3 STUDY OF THE INTERCONNECTION ALTERNATIVES

Hydropower studies reported herein and in separate reports for the Border and Karadobi projects have investigated the hydro generation resources along the Blue

Nile River. They selected three sites, Mandaya, Border and Karadobi to develop major hydropower stations able to provide a large amount of energy for which the generation cost would be much lower than thermal generation cost.

Economic studies demonstrated that exporting hydropower generation from Ethiopia to Egypt and Sudan in substitution to thermal generation was profitable for the three countries. Simulations of the generation equipment operation in the interconnected system were performed. They gave the following results; Ethiopia has to commission a new hydropower plant at Mandaya, of which the proposed installed capacity is 2000 MW, to export:

- 690 MW to Egypt during about 7400 hours per year
- 700 MW to Sudan during about 8000 hours per year

Mandaya HPP can produce annually 12 TWh that corresponds to an average generation of 1700 MW during 7000 hours per year.

11.3.1 Interconnection options

Based on these data, network studies were launched to investigate different solutions to interconnect the three countries and propose the least cost interconnection alternative that would be able to transmit the expected power exchanges and satisfy the technical requirements and the planning criteria. Ethiopia and Sudan are expected to be interconnected by the year 2010 with one 220 kV double circuit line between Gonder and Gedaref.

The amount of transmitted power and the distance between the countries are the main parameters to design an interconnection link. With about 1400 MW exported from Ethiopia over a distance of 700 km to Sudan and 2100 km to Egypt, DC technology appeared as the best suitable solution. But with the presence of the Sudanese system, that allows controlling the voltage along the interconnection path, AC alternatives are technically possible and could also be competitive solutions to interconnect the three systems and transmit consequent power.

DC alternatives consist in a DC double pole line connecting Ethiopia to Egypt with a tapping station located in Sudan. Three voltage levels, 500 kV, 600 kV and 800 kV were used to design the interconnection link.

AC alternatives consist in two 500 kV AC lines, the first line between Ethiopia and the South of Sudan close to the border. A 500/400 kV transformation was installed at Mandaya HPP substation. The power exchange to Egypt flows over the Sudanese transmission system. The second line connects the North of Sudan to the South part of the Egyptian transmission system. The 500 kV voltage level, the highest voltage in operation in the interconnected system, was selected because it allows a maximum power transfer over long distance.

Several interconnection points were selected in order to minimize the length of the interconnection line and to avoid as much as possible constraints on the transmission system of the three countries. Reducing the length of the line allows reducing the investment cost of the interconnection and the amount of losses and leads obtaining the least cost alternative.

In Ethiopia, Mandaya HPP 400 kV substation was the interconnection point for AC and DC alternatives.

In Sudan, for AC alternatives, Hasaheisa, Meringan and Rabak 500 kV substations, the main load centres close to the border with Ethiopia, were selected as interconnection points to receive power from Ethiopia. Merowe HPP and Port Sudan TPP 500 kV power stations, in the North of the country, were interconnections points to send power to Egypt.

For DC alternatives, Hasaheisa, the huge load centre close to the border, was the interconnection point selected to receive the tapping DC/AC converter.

In Egypt, for AC alternatives, Nag Hammadi, Sohag and Assiut 500 kV were the interconnection points. Beyond Assiut in the North, AC alternatives would not be technically feasible.

For DC alternatives, Nag Hammadi, Sohag, Assiut, Cairo 500 and Suez 500 kV substations were interconnection points. High Dam HPP 500 kV substation, close to the border with Sudan, cannot be extended and cannot receive the interconnection link.

Load flow calculations were performed to simulate the operation of the interconnected system and analyse its behaviour in normal operation and in emergency situation, one network equipment being out of operation. The system must satisfy the N-1 criterion. In emergency situation, the main electrical parameters, current, voltage, generated power, frequency, must be kept within the limits defined by the planning criteria without any adverse effect on the interconnection and on the three systems.

The study examined the connection of Mandaya HPP to the Ethiopian system, the interconnection with Egypt and Sudan being in operation. The different AC and DC interconnection alternatives were examined and the impact of the power exchange on the three systems was investigated. For AC alternatives, the power exchange devoted to Egypt flowed through the Sudanese system. Consequently, the impact of this exchange on Sudan was deeply investigated. Transmission losses over the interconnection were determined. The investment cost and the transmission cost of each alternative were calculated. The transmission cost, expressed in $/MWh, included the investment cost, the cost of losses and the operation and maintenance cost. The main results are presented hereafter.

11.4 RESULTS

11.4.1 Connection of Mandaya HPP to the Ethiopian Transmission System

It is proposed to connect Mandaya HPP to Debre Markos 400 kV substation with a 400 kV double circuit line equipped with 2x450 mm² bundle conductors. To discharge the power flow arriving at Debre Markos, the 400 kV system has to be reinforced with a single circuit line Debre Markos-Sululta and a third 400/220 kV 250 MVA transformer must be installed at Sululta.

11.4.2 Description of AC Alternatives

The interconnection between Ethiopia, Sudan and Egypt includes:

- 500/400 kV substation located on Mandaya HPP site, equipped with two 500/400kV 660 MVA transformers. This transformation is composed by six 220 MVA single-phase units + one 220 MVA single-phase unit as a spare part.

- 500 kV AC double circuit line between Mandaya HPP and Meringan 500 kV substation, (or Hasaheisa, or Rabak). The length of the line is 620 km (respectively 670 km, 570 km). The two circuits of the line are equipped at each end by one 255 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.

- 500 kV AC double circuit line between Merowe HPP (or Port Sudan) and Nag Hammadi 500 kV substation. The total length of the line is 1120 km (1030 km). To control the voltage profile along the line and to facilitate the energizing of the line, an intermediate switching substation is installed in the middle of the line, close to the border between Sudan and Egypt. The two sections of the line are equipped at each end by one 230 MVAr reactor. Moreover, one 100 MVAr reactor is connected on the 500 kV bus bar of the intermediate switching substation, to facilitate the energizing of the line.

In Egypt the other interconnection points are Sohag (length of the line = 1210 km) and Assiut (length of the line = 1325 km).

11.4.3 Description of DC Alternatives

Each DC link, built with a double pole line, includes two sections:

- First section between Mandaya AC/DC converter station and Hasaheisa tapping DC/AC converter station.
- Second section between Hasaheisa and DC/AC converter station in Egypt.

The cross section of the conductors and the number of conductors of the DC line are determined to respect a maximum value of the field strength and to respect a value of voltage drop or an amount of Joule losses along the line. The lines were designed to respect a 5 % voltage drop that is equivalent to an amount of losses equal to 5 % of the transmitted power.

Higher is the DC voltage larger is the total cross section of the conductors to respect the field strength and lower is the voltage drop.

Longer is the DC line higher is the voltage drop and larger is the total cross section of the conductors.

The size of the AC/DC converters is:

- Mandaya = about 1300 MW
- Hasaheisa = 500 MW
- Egyptian converter = 700 MW

It has been assumed that 200 MW of the 700 MW Sudanese import flowed over the 220 kV AC interconnection Gonder-Gedaref.

+/- 500 kV alternatives:

One double pole line equipped with 6 bundle Linnet conductors between Mandaya and Hasaheisa. Section between Hasaheisa and Egyptian converter, double pole line equipped with:

- 6 bundle Ibis conductors for Nag Hammadi (length = 1530 km)
- 6 bundle Hawk conductors for Sohag (length = 1620 km)
- 6 bundle Hawk conductors for Assiut (length = 1735 km)
- 6 bundle Dove conductors for Cairo 500 (length = 2095 km)
- 8 bundle Hawk conductors for Suez (length = 2165 km)

+/- 600 kV alternatives:

One double pole line equipped with 6 bundle Oriole conductors between Mandaya and Hasaheisa.

One double pole line equipped with 6 bundle Ibis conductors between Hasaheisa and Egyptian converter

+/- 800 kV alternatives

The field strength was the most severe constraint, 8 Hawk bundle conductors were used for the double pole DC line from Mandaya to the Egyptian converter.

11.5 IMPACT OF THE POWER EXCHANGE ON THE TRANSMISSION SYSTEMS.

Sudan

Without new interconnection, the area of Hasaheisa, Meringan and Rabak was mainly supplied by the power stations located in the North of the country and close to Khartoum such as Merowe HPP, Port Sudan TPP. Power flowed over the 500 kV lines and the under laying 220 kV network from the North to the South.

The power exchange coming from Ethiopia has a benefit effect on the transmission system. It discharged the transmission system, reduced the power flows over the lines and decreased the amount of losses. The lines close to the interconnection points were loaded below 50 % of their rating. Whatever the tripped element, no constraint appeared on the system.

Egypt

The Upper Egypt transmission system was supplied from High Dam HPP. Power flowed over the two 500 kV circuits from High Dam to Nag Hammadi and Sohag.

The power imported by the interconnection has a positive effect on the behaviour of the Egyptian system, since it reduce the power flow from Cairo area to the south. The N-1 criteria is satisfied on the 500 kV backbone between Cairo and High Dam, including the 500/220 kV and 500/132 kV transformation, and the N-2 criteria is similar to the N-2 without interconnection.

11.6 BEHAVIOUR OF THE INTERCONNECTION IN N-1 SITUATION

11.6.1 AC Alternatives

The interconnected system satisfied the N-1 criterion. Whatever the tripped line, 500 kV or 220 kV, the behaviour of the interconnected system was satisfactory.

Nevertheless, following the tripping of one of the two 500/400 kV transformers at Mandaya, the remaining transformer would be overloaded by 51 % of its emergency rating (1197 MVA). To overcome this constraint, two or three 250 MW units of Mandaya HPP should be automatically tripped. The loss of generation in the interconnected system would be compensated by the delivery of the primary reserve without any adverse effect of the systems. The power exchange would be reduced to about 700 MW until the replacement of the faulted single-phase element by the spare element.

Another solution would be to install three 510 MVA transformers at Mandaya (9 + 1 x170 MVA single phase elements).

11.6.2 DC Alternatives

The tripping of one pole or the blocking of one converter induced the lost of half of the power exchange. The three systems remained interconnected with a single pole that can operate with a return path by earth. Moreover, the AC 220 kV double circuit line Gonder-Gedaref interconnected Ethiopia and Sudan.

In Egypt, the loss of 50 % of the power exchange (345 MW) induced a frequency drop. The speed governor of the machines operated to increase the generation and recover the missing generation without any adverse effect on the system.

The excess of power in the interconnected system Ethiopia + Sudan amounted to about 400 MW (half of the power exchange to Egypt and generation produced to compensate the losses) would induced a frequency surge.

To reduce the excess of generation in Ethiopia and the constraint on the system, it is necessary to reduce Mandaya generation. Two or three 250 MW units should be automatically tripped.

11.7 COSTS

The investment cost of each interconnection alternative was calculated.

The costs of AC alternatives were similar, with the interconnection point at Nag Hammadi in Egypt,

The average value amounted to about (discount rate i = 10%): **USD 1,150 million**

For DC alternatives, with the interconnection point at Nag Hammadi in Egypt,

The average value amounted to about: **USD 1,200 million**

To compare the alternatives, transmission costs were calculated. The results are displayed below.

AC Alternatives:

Table 11.1 : Transmission Cost of AC options between Ethiopia and Egypt by Merowe

Mandaya to	Hasaheisa			Meringan			Rabak		
Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Connection point Nag Hammadi	24.9	29.2	20.9	24.7	29.0	20.7	24.2	28.4	20.3
Connection point Sohag	25.7	30.2	21.6	25.5	30.0	21.4	25.0	29.4	21.0
Connection point Assiut	26.7	31.4	22.5	26.5	31.2	22.3	26.0	30.6	21.9

Table 11.2 : Transmission cost of AC options between Ethiopia and Egypt by Port Sudan

Mandaya to	Hasaheisa			Meringan			Rabak		
Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Connection point Nag Hammadi	24.0	28.2	20.1	23.8	28.0	19.9	23.3	27.4	19.5

Table 11.3 : Transmission cost of AC Alternatives between Ethiopia and Sudan

Mandaya to	Meringan			Hasaheisa			Rabak		
	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Total Transmission Cost ($/MWh)	7.8	8.8	6.9	8.3	9.4	7.3	7.3	8.2	6.5

DC Alternatives:

Table 11.4 : Transmission costs between Ethiopia and Sudan for 500, 600 and 800 kV DC

Transmission cost ($/MWh) Sudan	**+/- 500 kV**			**+/- 600 kV**			**+/- 800 kV**		
	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Mandaya - Hasaheisa	14.3	16.2	12.7	14.7	16.7	12.9	15.6	17.9	13.6

Table 11 5 : Total Transmission Cost between Ethiopia and Egypt

	500 kV			**600 kV**			**800 kV**		
Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Hasaheisa - Nag Hammadi	24.4	28.6	20.6	24.1	28.5	20.3	27.4	32.6	22.9
Section Hasaheisa – Sohag	25.7	30.3	21.7	24.9	29.4	20.9	28.3	33.7	23.6
Section Hasaheisa – Assiut	26.8	31.6	22.5	25.9	30.6	21.8	29.5	35.1	24.6
Section Hasaheisa – Cairo	30.6	36.3	25.6	29.0	34.3	24.3	33.2	39.6	27.7
Section Hasaheisa – Suez	31.6	37.6	26.4	29.6	35.0	24.8	34.0	40.4	28.3

Based on the calculated values of the transmission cost, it is possible to conclude the following.

Ethiopia exports 700 MW to Sudan: AC alternatives were the less expensive solution. The transmission cost reached within 8 and 9 $/MWh, then it reached 14 $/MWh for DC alternatives.

Ethiopia exports 690 MW to Egypt: the transmission cost was similar for AC and DC alternatives. It reached about 24 $/MWh for the less expensive alternative, Nag Hammadi interconnection point.

12. FINANCIAL ANALYSIS

12.1 INTRODUCTION

This section describes the Financial Model used in the financial analysis of the project, and for the determination of tariff and IRR requirements and for determining the Royalty and tax payments.

Economic analysis has been carried out separately as part of Module 6 Generation Expansion Plan and is reported separately.

12.2 MODEL STRUCTURE

The financial model used in preparation of this proposal is based on Scott Wilson's model for evaluation of hydroelectric power projects. This model is spreadsheet based, using MS Excel, and comprises three parts:

- Input data
- Financial calculations
- Reporting and financial indicators.

The model has been structured for maximum flexibility in the analysis and evaluation of projects; the input variables can be specified separately and altered easily, enabling alternative scenarios to be analysed quickly.

In order to analyse the Eastern Nile Power Trade Program, which comprises three hydroelectric schemes in Ethiopia and Sudan, the input data has to be specified separately for each of the projects. Hence the model has been developed to provide one common data input sheet and up to five separate project data input sheets. Each project can be selected, either to be included or excluded from the analysis.

Apart from the five input data sheets (Common Data and separate sheets for each of the schemes), no other data can be input to the model, and the sheets are protected against changes to non-input data cells. In many cells the data is either selectable from a drop-down menu, or is verified to prevent erroneous inputs

12.2.1 Inputs – Common Data

The analysis is carried out in a single selectable currency. The base dates for all costs and tariffs, can be selected independent from the dates of scheme commissioning, and the escalation rates can be specified separately.

Provision in the model is made for:

- Concession Period: this defines the period of commercial operation, which can be selected to start from the commercial operation date of either the first or last project;

- Tariffs – there is provision for one capacity related tariff and four energy related tariffs (typically firm peak, firm off-peak, secondary peak, secondary off-peak);
- Royalty Payments – according to the share of revenue margin formula detailed in Section 7;
- Equity : Debt ratio (specified for the whole project);
- Three types of loan finance (typically ECA, Commercial and development bank), each with separate terms and conditions; the proportion of each loan can be specified separately for each scheme;
- Wheeling charges, based on a capacity charge and an energy charge, with provision for escalation at a specified rate from a nominated base date;
- Carbon Finance revenue, based on CO_2 abated by the energy generated, with the value per tonne specified and with provision for escalation of the value at a specified annual rate from a nominated base date;
- Advance payments, which are independent of any of the individual schemes;
- Working Capital, which is specified in terms of months of revenue;
- Tax and fiscal parameters, including tax rate, exemption period (from the start of commercial operation of the first project) and duty rate (which is set at zero for this study);
- Depreciation life: the normal depreciation life is specified, however in the modelling the life from commercial operation to the end of the concession period is used for each scheme if this is shorter than the normal life.

12.2.2 Inputs – Scheme Data

For each scheme the following data can be specified:

- Date of commercial operation – this is the date on which each scheme is planned to commence operation; it is assumed in the modelling that commercial operation starts at the beginning of the specified year; this year is used as the base year (Year 1) for all calculations relating to the scheme up to the stage when the data from all the schemes is collated;
- Pre-construction costs relating to the individual scheme; this amount is not subject to escalation, and is applied in a specified calendar year;
- Capital costs: the capital costs are specified at base year price levels, and can be separated into civil, E&M, transmission and ancillary works; this separation is used for the depreciation calculations. Separate items are included for Engineering & Project Management and Developer's

Administration costs. Duty, if payable, is applied at the average of the applicable rates to the transmission and E&M equipment;

- Cost scheduling is specified in terms of percentage of capital cost expended in each year prior to commercial operation; this is used for calculation of Interest During Construction;
- Operating costs are specified at base year levels, with provision for general O&M, spares and consumables, insurance and a sinking fund for major overhauls;
- The percentage of the three loans applicable for each scheme can be specified separately, to reflect the difference in characteristics between different types of project (typically more ECA for transmission, less ECA for regulatory dam with no significant M&E plant);
- The capacity and energy outputs for each project must be specified; provision is made for station losses, station consumption and line losses, where these are not covered in the basic scheme data; energy output can be positive or negative; for example a regulatory dam may provide little additional energy, but may increase the firm energy and reduce the secondary energy; the total energy associated with the scheme may be negative if the additional evaporation exceeds the additional flow capture;
- The power and energy generated is reduced by the specified percentage losses to derive the power and energy sales.

12.2.3 Financial Calculations

The financial calculations are carried out on separate sheets for each scheme, to cover the following:

- Financing
- Energy and Tariff Revenue
- Royalty Payments

These parameters are collated and summarised for the whole Project, and in addition summary calculations are performed for the entire project in respect of:

- Capital Cost;
- Operation ad Maintenance Costs
- Carbon Financing
- Wheeling Costs
- Depreciation.

Whereas all the individual scheme analyses are carried out relative to the commercial operating date of the individual scheme, the summaries are collated by calendar year, with Year 1 being six years prior to the start of commercial operation of the first scheme.

The financial calculations carried out are as follows:

- **Financing**: The total scheme capital cost, including escalation and duty but excluding IDC, is divided between equity and debt according to the target ratio. The equity finance is scheduled pari passu with the debt finance, according to the specified capital expenditure schedule. Financing fees are calculated and added to the equity sum, and pre-construction costs are also financed from equity. IDC is calculated up to the second year of commercial operation for each loan, and rolled into the total debt for each loan. It is assumed, although not a pre-requisite of the model, that the loan grace period will cover the duration of debt drawdown, which is typically one year after the start of scheme operation. Repayment of principal (the maximum amount of each loan including IDC) is assumed to be in equal tranches, starting in the year following expiry of the grace period. Interest on the loan is calculated on the basis of the average outstanding sum for the year. The total equity drawdown and total loan drawdown and service for each of the three loans is collated for all five schemes;

- **Energy and Tariff Revenue**: the capacity and energy sales for each year are multiplied by the appropriate escalated tariff rates for the type of energy, and summed to calculate the total tariff revenue each year for each scheme; the totals for all schemes are then collated in a summary;

- **Royalty Payments**: the annual costs for each scheme are calculated according to the formulae in Section 6; the costs are then summed and subtracted from the tariff revenue to derive the revenue margin, and the sharing factor is then applied to determine the Royalty Payments;

- **Capital Expenditure**: the capital expenditure for each scheme included in the analysis is collated for each year, in order to derive the overall capital expenditure profile;

- **O&M Costs**: the escalated O&M Costs for each scheme included in the analysis is collated in order to calculate the overall O&M expenditure;

- **Carbon Financing**: the carbon finance revenue, based on the total energy generated in each year by each scheme included in the analysis, is valued using the escalated value of CO_2;

- **Wheeling Costs**: the costs of wheeling energy through other power systems, if any, is collated and summed for each scheme in the analysis for each year, and then multiplied by the capacity and energy wheeling tariffs;

- **Depreciation**: the annual depreciation allowances for each scheme are calculated for three types of capital cost – civil works, M&E equipment and other expenses / IDC. The annual depreciation allowance is calculated on the basis of the specified normal life, or operating period if this is lesser. All depreciation allowances are then summed for each year for use in the tax calculations.

12.2.4 Output Data

Output data sheets are provided to show:

- **Cashflow Statement**: the overall project cashflow is calculated for each year during the construction and operation periods. The cashflow includes all revenue streams, and all cost streams including capital cost, O&M cost, wheeling, royalties, changes to working capital, debt service and tax. Both pre-tax and post-tax cashflow are presented.

- **Income Statement**: the income statement includes the cost and revenue streams for the project, and in line with standard accounting practice uses depreciation allowances in determining the taxable profit. Corporation tax is calculated, and the post-tax profit determined. In years where adequate cashflow is available the post-tax profit is distributed as dividends, and when there is insufficient cashflow, earnings are retained an distributed when cash is available.

- **Financial Indicators**: a sheet of financial indicators is presented; the key financial indicator is the Internal Rate of Return (IRR) of the equity cashflow (the sum in each year of the equity investment and the dividend/retained earnings), which provides the principal measure of the attractiveness of the project to the equity investors. Other key financial indicators, including NPV of post-tax cashflow and Debt Service Cover Ratio (DSCR) are also presented.

- **Charts**: a series of charts are presented to show annually the components of the Cashflow Statement, the Income Statement and the Royalty and Tax payments (which provide income from the project to the Government).

12.3 PARAMETERS USED IN MODELLING

The parameters used in the modelling are as follows:

12.3.1 Common data

Currency

Currency	USD
Modelling units	$1,000

Base Years for Costs

Base year for capital costs	2005
Base year for O&M Costs	2007
Base year for Tariff	2007
Base year for wheeling charge	2007
Base year for carbon value	2007

Escalation Rates

Escalation for capital costs	2.0%
Escalation for O&M Costs	2.0%
Escalation for Tariff	2.0%
Escalation for wheeling charge	2.0%
Escalation for carbon value	2.0%

Concession

No of Years	30
Start of Concession	COD of last scheme

Tariffs (at base year)

Energy Tariff ($/MWh)	Peak	Average
Firm Energy	Not used	38
Secondary Energy	Not used	38

Carbon Finance (at base year)

CO_2 Abatement (tonnes/MWh)	0.750
Value of ($/tonne)	10.00

Equity Debt Ratio

Equity	25%
Debt	75%

Loan Terms

Loan	Type	Term	Grace Period	Interest Rate	Commitment Fee	Arrangement Fee
1	ECA	12	5	6.0%	0.75%	
2	Commercial	10	5	8.0%	0.75%	1.00%
3	Development Bank	14	5	7.0%	1.00%	

Working Capital

Working capital requirement	3 months

Tax and Duty

Corporation Tax Rate	0%
Exemption Period	Indefinite
Start of exemption period	COD of first project
Rate of Duty	0%

Depreciation (Normal Life)

Civil and infrastructure works	40 years
Mechanical, Electrical and Transmission	20 years
Other costs, including IDC	20 years

12.3.2 Project Data

Data for the Mandaya hydropower project which is under consideration as part of the Eastern Nile Power Trade Study are presented in the project data sheets of the financial model and summarised below:

Power & Energy Generation

Scheme	P1
	Mandaya
Installed Capacity (MW)	2000
Energy generation (GWh/yr) as independent project	Firm: 11,194 Secondary: 925

Project Costs

Scheme	P1
	Mandaya
Capital Cost-escalated ($m)	2,849.7
IDC ($m)	925.6
Cost incl. IDC & fees ($m)	3,867.6
Annual O&M cost ($m)	14.25

Loan Percentages

Scheme	P1
	Mandaya
Loan 1 percentage	30%
Loan 2 percentage	40%
Loan 3 percentage	30%

12.4 RESULTS OF MODELLING

The Financial Model has been run with a range of scenarios in order to establish the financial viability of the project. The conclusions of the modelling are presented below.

12.4.1 Transmission Line

The transmission interconnections and associated wheeling charges have not been included in the analysis as these are reported separately in the report for Modules 6 and 7 of the Program Study.

12.4.2 Carbon Finance

In order to achieve acceptable financial performance the revenue from sale of emission reduction units under the Clean Development Mechanism (CDM) of Kyoto has been included in the Base Case financial model.

12.4.3 Financial Indicators

The key financial indicators derived from the Base Case financial model based on a sales tariff of USD 38 / MWh (2007 Prices) are as follows:

Year of Operation	Calendar Year	Post-tax Internal Rate of Return	NPV of Post-tax Cashflow USD Million
5	2025	7.8%	-$38.4m
10	2030	16.0%	$189.6m
15	2035	18.6%	$385.3m
20	2040	19.5%	$527.6m
25	2045	19.9%	$639.3m
30	2050	20.1%	$716.5m
Minimum Debt Service Cover Ratio			1.17

Notes:

1. Post-tax IRR is the Internal Rate of Return (Equalising Discount Rate) of the post-tax equity cashflow, which comprises equity drawdown, dividend and retained earnings;
2. NPV of post-tax cashflow is discounted at 10% to year 1 of the financial model;
3. Minimum DSCR is the ratio of Operating Cashflow (all revenue less all operating costs) to the sum of the interest and principal repayments. Typically this ratio is required by financiers to be a minimum of 1.4. However in this instance, because of cash surpluses in the preceding two years, the surplus will be invested in a debt service accrual account to cover the four or five years when the DSCR is less than the required minimum value.

13. CO_2 EMISSIONS

13.1 INTRODUCTION

The proposed Mandaya hydropower project on the River Nile in Ethiopia offers potential for generating low priced and reliable energy to support regional economic growth. In the following sections the CO_2 emissions resulting from the project's construction activities and the decomposition of biomass in the project reservoir are quantified and compared with the potential CO_2 emissions from generating the same electrical energy through burning fossil fuels.

13.2 CO_2 EMISSION BY THE MANDAYA HYDROPOWER PROJECT

The CO_2 emission associated with a hydroelectric power project are those produced during the manufacture and construction of the project structures and equipment and those produced by slowly decomposing biomass in the reservoir during the project's lifetime.

13.2.1 CO_2 Emission related to Construction

It is well known that the implementation of a hydroelectric powerplant involves considerable construction activities and large quantities of construction materials which, in turn, require a large energy input. For the construction of the Mandaya the required quantities of major construction materials and consumables are summarized in Table 13.1.

Table 13.1: Quantities of major Construction Materials and Consumables

MATERIALS / CONSTRUCTION	QUANTITIES
Civil Works	
- Soil excavation	5,075,000m^3
- Rock excavation	1,972,000m^3
- Roller compacted concrete	15,000,000m^3
- Conventional concrete	981,000 m^3
- Reinforcement steel	77,000 tons
- Diesel fuel	172,000 tons
Electro-mechanical equipment	
- Steel	30,000 tons

Based on the volume of concrete and other construction activities such as grouting, shotcreting, etc. a cement requirement of about 2,150,000 tons is calculated. The production of one ton of cement requires approximately 4 GJ of energy. Hence the energy input for all concrete works results in approximately 8,560,000 GJ.

The weight of reinforcement steel, hydraulic steel structures and steel for the electro-mechanical equipment totals about 107,000 tons. It takes approximately 40 GJ of energy to produce one ton of steel. Therefore, the energy input into steel and equipment is about 4.3 million GJ.

The energy requirement for the excavation, transport and placing of soil and rock material is covered under the diesel fuel requirements of 172,000 tons.

If it is assumed that the energy required to produce the cement and steel is generated by a thermal mix as described below (coal/gas = 50/50 per cent) then some 222,000 tons of coal and 146,000 tons of gas would be needed. The burning of these fossil fuels would ultimately lead to a CO_2 emission of approximately 1,000,000 tons.

The burning of 172,000 tons diesel fuel will result in a CO_2 emission of about 557,000 tons. The total emission of CO_2 associated with the construction of the Mandaya hydropower project will thus be approximately 1,570,000 tons.

13.2.2 CO_2 Emission caused by the Biomass with the Future Reservoir

The Mandaya hydropower project will inundate a gross area of about 736 km^2, which, after exclusion of the existing river channel, will result in a net area of about 700 km^2 of land. The biomass of open woodland is in the order of 60 t/ha dry weight and, based on this assumption a total biomass of about 3,600,000 tons (dry weight) is estimated.

All living plants grow by absorbing water and carbon dioxide to form reserves of carbohydrate, known as biomass. This process is fuelled by sunlight and is termed photosynthesis. In simple terms the process is as follows:

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2\uparrow$$

When plants die, decomposition by oxidation takes places which is the photosynthesis process in reverse:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

The same amount of CO_2 absorbed during photosynthesis is released during complete oxidation of the biomass.

By considering molar weights, one ton of carbohydrate produces 1.47 tons of carbon dioxide during complete decomposition as follows:

$$180\text{ g } C_6H_{12}O_6 + 192\text{ g } O_2 = 264\text{ g } CO_2\uparrow + 108\text{ g } H_2O$$

$$1\text{ t } C_6H_{12}O_6 + 1.07\text{ t } O_2 = 1.47\ CO_2\uparrow + 0.6\ H_2O$$

Using the same relationship on the total estimated quantity of biomass affected by the Mandaya hydropower project the decomposition of the biomass in the reservoir area could lead to a maximum CO_2 emission of about 2,600,000 tons, assuming that 50% of the woodland was used cut and as fuelwood.

13.2.3 The Total CO_2 Emission of the Mandaya Hydropower Project

Approximately 1,570,000 tons of CO_2 will be produced with the construction of the Mandaya hydropower project. The maximum potential CO_2 emission associated with the aerobic decomposition of the biomass located in the reservoir is estimated to be approximately 2,620,000 tons. Thus the implementation of Mandaya hydropower project will lead to a total CO_2 emission of about 4,200,000 tons.

13.3 CO_2 EMISSION BY EQUIVALENT THERMAL POWERPLANTS

This section quantifies the CO_2 emissions resulting from generating the same average energy as Mandaya but by burning fossil fuels. Present thermal plant technology does not include the recovery of carbon dioxide from flue gases. Hence the carbon content of the fuel and the efficiency characteristics of the thermal plant are the governing parameters in calculating CO_2 emission levels. The following formula may be used to compute the CO_2 emission from fossil fuels:

$CO_2 = A \times (B + C \times HV)$

where:

CO_2 = emission of CO_2 in metric tons per ton of fuel;

A = multiplier for indirect emissions (exploration, mining);

B, C = regression constants for the particular type of fuel;

HV = lower calorific value of fuel in GJ/ton.

Typical CO_2 emissions for various type of fossil fuel are shown in Table 13.2. Approximate CO_2 values per MWh delivered to the grid would be as shown in Table 13.3 for various types of powerplant.

Table 13.2 : Typical CO_2 Emissions for various Type of Fuel

Fuel Type	A	B	C	HV (GJ/ton fuel)	CO_2 (ton/ton fuel)
Lignite	1.08	0.20090	0.08693	7	0.87
Coal	1.06	0.20090	0.08693	29	2.90
Oil	1.04	2.50291	0.01494	41	3.24
Gas	1.01	0.55159	0.04463	44	2.53

Table 13.3 : Approximate CO_2 Emission per MWh for various Types of Thermal Powerplants

Plant Type	HV (GJ/ton fuel)	CO_2 (tons/ton fuel)	Efficiency (per cent)	CO_2 (ton/MWh)
Lignite-fired steam	7	0.87	36	1.24
Coal-fired steam	29	2.90	37 - 39	0.97
Oil-fired steam	41	3.24	38 - 40	0.75
Gas-fired combined cycle	44	2.53	48 - 52	0.43

Note: Efficiencies shown include station consumption.

The annual average energy to be generated by the Mandaya hydropower project would amount to 12,119 GWh/yr. If the same quantity of energy was to be generated by a thermal mix consisting of 50 per cent coal-fired and 50 per cent gas-fired combined cycle power plants, some 8.5 million tons of CO_2 would be discharged to the atmosphere annually as shown in Table 13.4.

Table 13.4 : Approximate CO_2 Emission of equivalent Thermal Power Mix

Plant Type	Annual Energy GWh	CO_2 Million tons
Coal-fired steam	6,060	5.88
Gas-fired combined cycle	6,060	2.60
Total	**12,119**	**8.48**

It is noted that the CO_2 emission of 8.48 million tons annually is related purely to the fuel consumption (equal proportions of coal and gas) and does not include the CO_2 emission related to the construction of the thermal power plants.

Assuming that the annual average energy generated by the Mandaya hydropower project would be generated by an "environmentally friendly" gas-fired combined cycle power plant only, which is a most optimistic scenario, then the annual CO_2 emission into the atmosphere would be approximately 5.2 million tons.

13.4 CONCLUSION

The energy sector is the greatest single source of CO_2 emissions into the atmosphere and within that sector the burning of fossil fuels to generate electricity accounts for some 25 per cent of global warming. The Mandaya hydropower project will produce an average of 12,119 GWh of electrical energy annually. During construction of the project, energy is required to manufacture cement and steel and to excavate and construct the project structures. The generation of this energy will result in the release of CO_2 into the atmosphere. During operation of the project, the biomass submerged within the reservoir will slowly decompose also releasing CO_2

into the atmosphere. The estimate of the total quantity of CO_2 released into the atmosphere during construction and operation of Mandaya will be some 1,570,000 tons.

Generating the same energy by burning fossil fuels (equal proportions of coal and gas) would release into the atmosphere some 8.48 million tons of CO_2 every year. Over a period of 50 years, the assumed commercial life of Mandaya, this annual CO_2 emission would result in a total of 424 million tons of CO_2.

Consequently the generation of hydro-electric energy at Mandaya will result in CO_2 emissions 100 times less than if the same energy were generated by burning fossil fuels.

14.1 ENVIRONMENTAL IMPACT

14.1 INTRODUCTION

The Mandaya project is located in Ethiopia at the head of an existing and developing hydropower cascade on the Blue Nile and Main Nile in Sudan and Egypt. The project is therefore on an international waterway and impacts on three countries (Figure 14.1).

The energy produced by the 2000 MW Mandaya project (12,119 GWh/year), and the uplift in energy at hydropower facilities in Sudan (2,211 GWh/year), resulting from Mandaya's regulation of the river and substantial raising of dry season flows, will make very valuable contributions to economic development in the region. These energies may be valued at close to USD 450 million and USD 90 million per year, respectively. The energy generation is expected to be sustainable for many years, and many more years than necessary to recover development costs. The long-term sustainability of the project's energy generation and the energy uplift in Sudan requires implementation of watershed management measures in the Abbay catchment area. Plans for these are under development.

The engineering of the project has been studied at pre-feasibility level. None of the key engineering parameters of the Mandaya project have been optimised. Optimisation awaits a feasibility study. Initial examination of the engineering project as currently presented indicates that the project will have many secondary benefits and that its adverse impacts are all capable of mitigation provided national and World Bank safeguard policies are rigorously pursued.

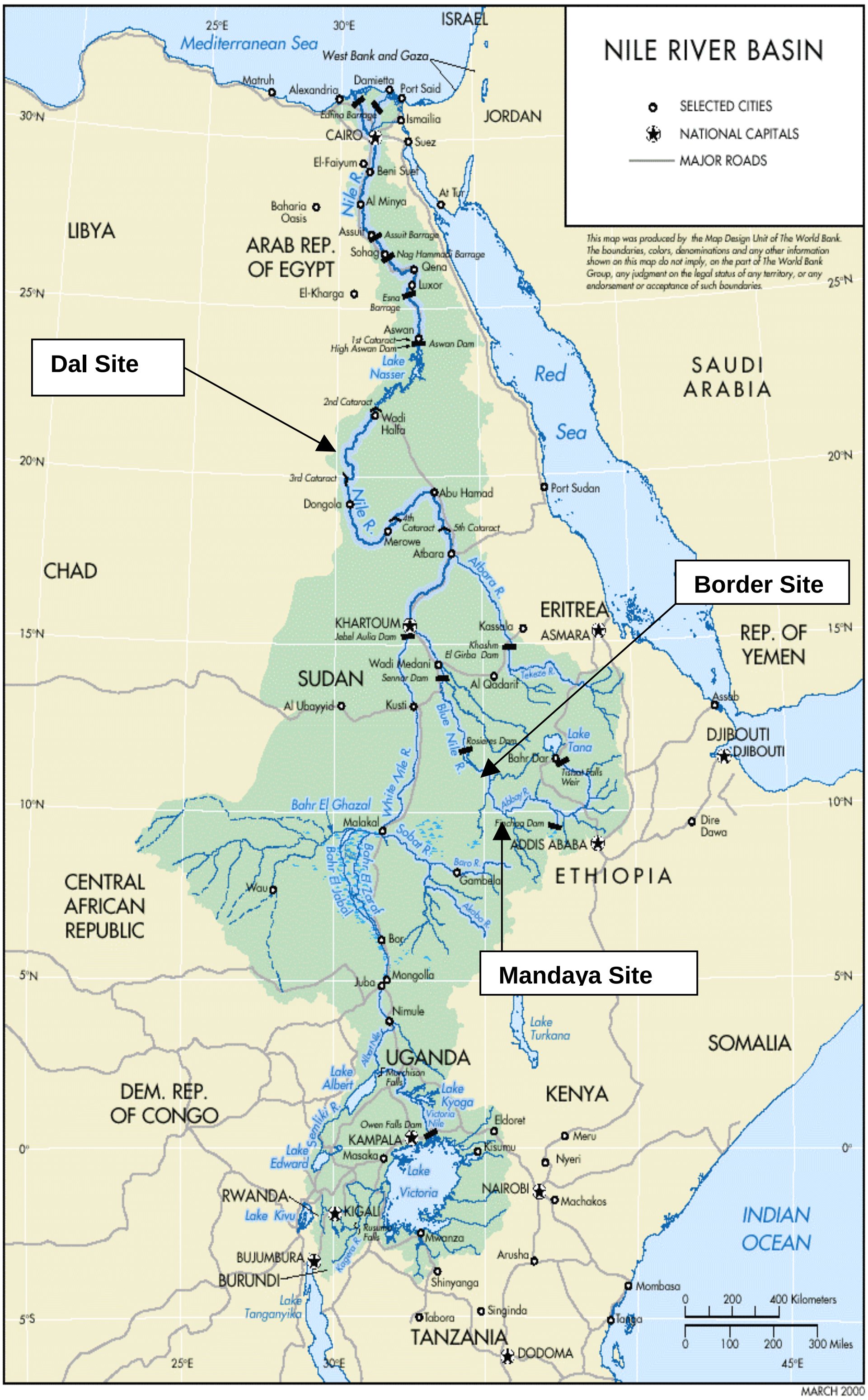
All project-related countries share the Nile Basin Initiative's vision of promoting sustainable and equitable development in principle, including promotion of power trading providing, *inter alia*, that energy tariffs compete with alternative sources. Owing to the size of the proposed dam and long construction period, the earliest year that Mandaya could become operational would be 2021. Depending on river flow conditions in subsequent years and downstream release requirements during the first filling of the reservoir, it is expected to be a further three years or so before Mandaya is operational at maximum output.

14.2 POLICY, LEGAL AND ADMINISTRATIVE FRAMEWORK

There appears to be no policy, legal or administrative obstacles to the development. The policy and legal instruments in Ethiopia and Sudan are conducive to development of more energy projects in the interests of national development goals, and provide the safeguards required for environmental and social protection and mitigation of adverse impacts. The recently implemented Gilgel Gibe hydropower project by EEPCO in Ethiopia has been acclaimed for successful implementation of national and international safeguard policies with regard to environment protection and resettlement. This recent history lends great support to successful promotion of Mandaya and other hydropower projects on the Abbay river.

Figure 14.1 : Location of Mandaya, Border and Dal Sites

IBRD 30785



The Mandaya project will trigger several World Bank safeguard policies, namely Environmental Assessment, Projects on International Waterways, Involuntary Resettlement, and Dam Safety. It may also trigger safeguard policies on Natural Habitat, Forests and Physical Cultural Resources but it appears not to trigger safeguard policies on Indigenous Peoples, Pest Management or Projects in Disputed Areas.

14.3 EXISTING ENVIRONMENT

The biological database of the Mandaya project area in terms of terrestrial and aquatic ecology is generally poor or very poor, though better for fish. It is a vast wooded area with very small areas of cultivation and has never attracted sustained detailed field studies. Communications within the area are rudimentary, making surveys difficult. As Ethiopia is endowed with rich floral and faunal resources, and possesses some of the richest endemic fauna and flora in the African continent, resulting from the immense topographic and climatic diversity in the country, it may be expected that that detailed surveys of the project over a considerable period of time would produce impressive lists of plant and animal species. Such surveys will be required because baseline information is not sufficient for comprehensive impact assessment. However ecologists, at this scoping level, following site visits, literature reviews and consultations with other professional ecologists and local people, record that among the reported species of mammals, birds and aquatic life, none are recorded to be endemic to the project area and none are critically threatened. There is therefore, at this stage, no known impediment with regard to terrestrial or aquatic ecology to proceeding to more studies of the project. Nevertheless, because the database is so incomplete and rare species, with restricted range distributions, are not easily sampled and brief surveys can easily miss these species, future studies must include generous provision for detailed ecological surveys. It is considered that these surveys will take a minimum of two years.

The Mandaya dam site and reservoir area (736 km^2) is close to but does not encroach on the Dabus Valley Controlled Hunting Area (1,227 km^2). Information about the wildlife habitat and wildlife of this area is scanty, and it is understood to be a part of the 84% of protected areas in Ethiopia that are unmanaged. It has therefore been proposed that future detailed ecological surveys include this area, and that the Mandaya project considers its adoption, with a sustainable environmental management and monitoring plan, as an environmental offset for the loss of wildlife habitat and wildlife in the project's reservoir area. Such surveys would also contribute markedly to the Ethiopian Wildlife and Natural History Society that wishes to determine the status of the Dabus Valley area regarding its future designation as an Important Bird Area.

The population of the project-affected area in Benishangul Gumuz and Amhara regions comprises several ethnic groups, including the Gumuz. The population is principally engaged in cultivation, with some livestock. Other activities relate to those typical of rural areas – non-timber woodland products, trading, etc. The population density is low and the people are among the poorest in Ethiopia, with more than half having incomes less than USD 1 per day. Regional government's provision of services in the area in terms of road communications, water supply, sanitation, education and health are basic, handicapped by the immense geographical area with its dispersed population. It is estimated that some 600 persons (122 households) live in the reservoir area and will require compensation and resettlement. A larger number (1,020 persons in 204 households) live in areas generally affected by project construction activities and, until detailed studies refine impact areas, compensation and resettlement costs have been included in provisional budget estimates for them also. Owing to regional government's difficulties in providing adequate infrastructure and services to communities in the area, government-led resettlement is already taking place and more is planned, though not necessarily for all the communities which would be affected by the project.

Some small areas of flood recession agriculture are cultivated in the reservoir basin by families living outside of the area. These, and other lost resources, have been assessed and included in compensation and mitigation measures.

Preliminary social and archaeological assessment of the project-affected area in Benishangul Gumuz and Amhara regions has not revealed physical cultural resources. As with ecology, past research has been at a basic level. Additional surveys are required in future studies.

The areas of downstream impact in Ethiopia, Sudan and Egypt in future, owing to the Mandaya project's reservoir first filling and then regulating flows and storing sediment, are hydraulic, hydrological and morphological, and relate to the uses made of the lower Abbay, Blue Nile and Main Nile. These are principally hydropower, irrigation, water supply, fisheries, river communication facilities and flood recession agriculture as far north as Lake Nasser/Nubia where flows of the Main Nile are stored behind High Aswan Dam. Apart from the many benefits of the Nile in this desert reach, periodic flooding causes major disruptions to community and farming activities and much damage to properties and infrastructure, whilst seasons of poor rainy seasons in the Ethiopian Highlands produce low Nile discharges, low power generation, reductions in commanded irrigation areas, reduced production from flood recession agriculture and food security crises – particularly in Nile and Northern states.

Downstream of High Aswan Dam in Egypt, which became operational some 40 years ago, flows of the Nile are completely regulated. These have generally made Egypt secure in water and food supply over these years and the acute problems of extreme floods and extreme low flows, described for Sudan above, a distant memory.

14.4 PRINCIPAL IMPACTS, MITIGATION AND ENHANCEMENT MEASURES

14.4.1 Construction – Bio-Physical Impacts in Ethiopia

Construction of the project is expected to take ten years. Mitigation of the bio-physical impacts of the project in Ethiopia, following detailed assessment of these in a future EIA study, will require conscientious attention by contractors to planning and implementing environmental protection measures for every aspect of construction. It is envisaged that some 17 environmental management and monitoring plans will be required for the roads, dam site area and for reservoir impoundment. For the transmission lines, including the line to Hasaheisa in Sudan, similar plans but lesser in number will be required. There is no reason currently to believe that mitigation measures cannot be successfully implemented.

It is suggested that compensation for loss of woodlands and wildlife habitat be provided by the project providing pro-active support to the ecological survey of the Dabus Valley Controlled Hunting Area, and thereafter contributing resources for the management of this protected area and others which may be adopted in partnership with responsible government bodies and local communities.

In addition, Mandaya reservoir itself would be a very large wetland resource, supporting fisheries development and being habitat for many local and migratory water birds. With a visitors' centre established by the project, it would become a focal point for studies of natural history for residents of Benishangul Gumuz region and from more distant regions.

No known commercial mineral deposits would be adversely affected by the project. However, any contribution made by the Abbay from upstream of Mandaya to alluvial gold found in the river bed and banks downstream of Mandaya, where gold panning is an important dry season activity, will be permanently curtailed by reservoir impoundment.

14.4.2 Construction – Socio-Economic Impacts in Ethiopia

Mitigation of the socio-economic impacts of the project in Ethiopia, following detailed assessment of these in future EIA and RAP studies, will require conscientious attention to land and property acquisition (all land is owned by the state), compensation for loss of property, natural resources and livelihoods, and an all embracing resettlement and development program, following national and international safeguard procedures for involuntary resettlement. Both are now well developed and were successfully implemented at Gilgel Gibe in recent years. There is no reason currently to believe that socio-economic mitigation measures in Ethiopia cannot be successfully implemented and sustained following much more detailed assessment and planning.

14.4.3 Regional Impacts in Ethiopia

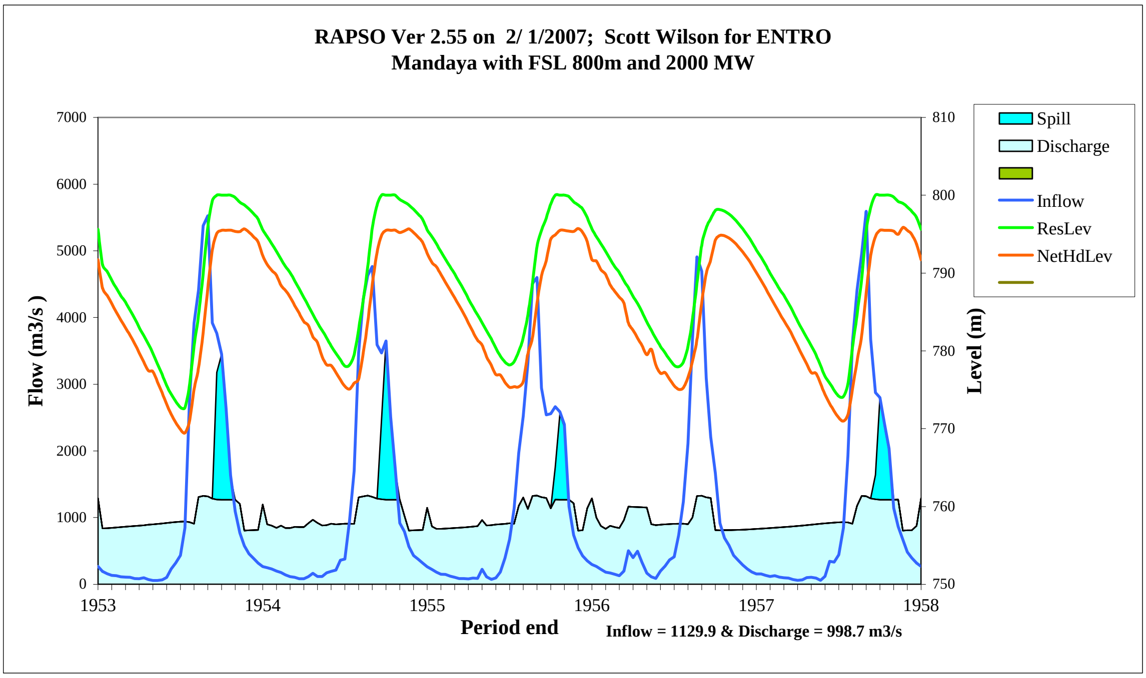
A new bridge across the Abbay, downstream of the dam site, and some of the project's upgraded and new roads, will make an important contribution to development of the region. Employment, and learning and development of new skills by the construction workforce, will improve the socio-economic conditions of many families, both inside and outside of the project area, and assist those with new skills to find productive employment after project construction. New road communications, water supplies, sanitation, education and health facilities, and energy supplies in the host and resettlement communities, coupled with health awareness, fisheries and other development programs, should improve livelihoods immeasurably and further contribute to regional development.

The contribution of the project to wildlife habitat and wildlife in terms of creation of a new (reservoir) wetland for aquatic life and habitat for resident and migratory water birds, and by assistance in improving management of one or more environmental offsets, as compensation for destruction of habitat, is considered imperfect but a positive feature of the project proposals. Coupled with development of the project itself, the new Abbay bridge and road network, and new schools, opportunities will exist for enhancing the environment further and for enjoyment of it by local adults and children alike and visitors to the area.

14.4.4 Operational Impacts in lower Abbay Valley

Some of the impacts on the lower reaches of Abbay experienced and mitigated in the construction phase will continue in the operational phase. These mainly result from the change in Abbay river's regime, with greatly reduced flood flows and greatly increased dry season flows (Figure 14.2).

Figure 14.2 : Mandaya Hydropower Project Simulation, 1954 – 1958



Flow forecasting and warning. Changes in turbined release rates and spillway discharges at Mandaya will require attention to health and safety measures for downstream riparian users through an effective flow forecasting and warning system.

Agriculture. The loss of flood recession agricultural areas, estimated at 2,400 ha, will have been mitigated in the construction phase, either by monetary compensation or by provision of small-scale irrigation facilities. If the earlier mitigation has been to provide small-scale irrigation facilities, these should continue and, if successful, may expand. There will be potential for two crops each year instead of one.

Gold panning. In the operational phase, when dry season flows are significantly raised, opportunities for gold panning in the lower Abbay river channel will probably effectively cease. Compensation will have been provided during the construction phase. Gold panning will be able to continue in Abbay tributaries as before.

14.4.5 Operational Impacts in Sudan

Impacts of the Mandaya project in Sudan are expected to be very beneficial for hydropower, irrigation, water supply, fisheries and flood relief.

The holding back of sediment will improve operations and reduce maintenance costs at Roseires, Sennar and Merowe hydropower projects, at gravity fed and pumped irrigation schemes and at water supply offtakes and treatment works. The large augmentation of dry season flows will also benefit Roseires, Sennar and Merowe hydropower projects, irrigation schemes and water supplies. Currently, these facilities suffer from sedimentation and some of them are restricted by availability of flows in the dry season. The raising of dry season flows, and reduction in sediment loads, resulting in new modes of operation in the Sudan hydropower cascade (conjunctive use), will increase energy generation and is expected to improve reservoir fisheries.

It is a remarkable feature that none of the above benefits require explicit or substantial capital expenditure to reap the rewards of river regulation. This is particularly demonstrated by the expected uplift in energy generation at Roseires, Sennar and Merowe (2,211 GWh/year) resulting directly from Mandaya holding back silt and regulating flows, without any capital expenditure at these projects. This uplift in generation is a secondary beneficial impact of the Mandaya project and is greater than the preliminarily estimated energy generation at Low Dal that would involve a substantial capital outlay (project engineering cost USD 1,131 million), loss of productive land, a major resettlement program, a major archaeological survey and salvage program and a large loss of water by evaporation. Dal's annual evaporation losses, expressed as cubic metres per GWh/year generation are nine times greater than for Mandaya. Thus, the uplift of energy generation in the existing power cascade is not only to be valued in energy terms but may be valued in much wider environmental, social and cultural terms also.

The substantial reduction in sediment transport in the Blue and Main Nile is expected to cause changes in river channel morphology. Some changes may be expected to begin to occur when Mandaya releases its first turbined and spillway discharges (no longer charged with high concentrations of suspended sediment, and with no bed load). Thus the hydraulic conditions will change and the river will have greater energy to entrain alluvial bed and bank materials. Mitigation works in the form of river training and bank protection can be expected. Surveys will be required during future studies in order to estimate the magnitude and extent of changes and to recommend designs of mitigation measures and a management and monitoring plan for these.

The expected impacts on river communications, flood relief and flood recession agriculture are mixed. There are benefits and disadvantages but, as in Egypt 40 years ago, the disadvantages relating to loss of flood recession agriculture can be converted into a reliable and more productive system in the desert.

The raising of dry season flows, and therefore river levels, is expected to benefit navigation (in the form of small fishermen's boats and ferries) but cause some inconvenience and danger to any pedestrians and livestock crossing of the Blue Nile when flows would normally be very low at the end of dry seasons. This assessment has not been confirmed by field inspection and is speculative. This will need following up in future studies, and linking with impacts of changes in river morphology.

Mandaya's reservoir capacity is very large and simulations of its behaviour over 50 years indicate that spillway flows will account for as little as 5% of all water discharged. A comparison of annual peak discharges (using 10-day records) released from Mandaya with recorded annual maximum daily flood levels has suggested that the degree of flood reduction would be large (Table 14.1). This would provide a very significant benefit for flood relief for communities, properties and infrastructure along the Blue and Main Nile downstream, including Khartoum and the Dongola region.

Table 14.1 : Indicative Changes in Annual Flood Levels at Khartoum and Dongola

Year	Blue Nile at Khartoum			Main Nile at Dongola		
	Without Mandaya	With Mandaya	With Mandaya	Without Mandaya	With Mandaya	With Mandaya
	Observed Peak Level Gauge height m	Estimated Peak Level Gauge height m	Change in Gauge height m	Observed Peak Level Gauge height m	Estimated Peak Level Gauge height m	Change in Gauge height m
1988	16.94	13.72	-3.22	15.69	14.00	-1.69
1989	16.04	12.50	-3.54	14.15	11.89	-2.26
1990	15.20	11.77	-3.43	13.6	11.39	-2.21
1991	16.14	12.58	-3.56	14.72	12.69	-2.03
1992	16.05	12.72	-3.33	14.64	12.73	-1.91
1993	16.53	13.21	-3.32	14.76	12.79	-1.97
1994	16.94	15.65	-1.29	15.69	15.00	-0.69
1995	15.81	12.93	-2.88	14.74	13.15	-1.59
1996	16.67	14.41	-2.26	15.17	13.90	-1.27
1997	15.97	13.32	-2.65	14.48	12.92	-1.56
1998	17.09	14.90	-2.19	15.91	14.77	-1.14
1999	16.75	14.91	-1.84	15.72	14.76	-0.96
2000	16.60	12.75	-3.85	15.37	13.32	-2.05
2001	16.74	15.05	-1.69	15.93	15.07	-0.86
2002	15.52	12.87	-2.65	14.44	12.95	-1.49
2003	16.38	13.36	-3.02	15.29	13.68	-1.61

Note: the colour coding of flood levels in these 16 years follows the system adopted by the Ministry of Irrigation and Water Resources, Khartoum

Flooding	Critical	Alert	Normal

Owing to Mandaya's major impacts on flood levels, recession agriculture along the Blue Nile and Main Nile's alluvial strip will be adversely affected. In all years, the build up of Nile flood levels in June, July and early August will be reduced and delayed as Mandaya reservoir refills; some build up in flood levels will occur as normal because of the tributary rising floods of Dabus, Beles, Dinder, Rahad and Atbara rivers but these are normally small compared to Abbay's contribution.

Because of the reductions in annual flood flows, many floodplain areas will not be reached by flooding, and the depth and duration of flooding will be correspondingly less. Significant reductions in crop production will result and groundwater resources will not be replenished as under normal conditions. These conditions would have knock on impacts for livestock in terms of reduced vegetation for grazing, less crop residues, less dung as manure for subsequent cropping, etc. In harsh desert conditions as exist along the course of the Nile, any reduction in the annual flood (except the extreme floods which cause damage) will be sorely felt. Also, the deposition of silt on farmlands, for millennia regarded as a free and natural fertilizer, will be greatly reduced.

A number of autonomous mitigating factors must be seen against this background. There occur a number of extreme drought years (e.g. 1972, 1984, 1986) when the Nile does not flood out of its banks and recession agriculture is severely reduced or doomed for that year, causing a food shortage crisis[1]. Meanwhile, farmers with pumps continue to cultivate. With Mandaya regulation, and with conjunctive use of Roseires reservoir, regulated flows will be more than sufficient for irrigating the whole of the Nile's alluvial strip throughout the year if required, even in these drought years. Secondly, it is the intention of the Ministry of Irrigation and Water Resources to implement more irrigation schemes in flood recession areas in order to produce crops in the non-flood summer season. This will facilitate two crops per year. Those farmers enjoying irrigation already, and those who will benefit from new schemes (121,000 feddan) already planned, will be immune to reduction in flooding, except for additional pumping costs in the annual flood season. Thirdly, the highest floods which cause damage to properties (and these occurred regularly in the 16 years shown in Table 14.1) are a "mixed blessing" for farmers; they provide more water than needed, and their duration may spoil or delay cultivation.

Thus, the proposed mitigation measures for Mandaya's reduction in floods is to introduce pumped irrigation schemes universally and to produce two crops every year, making use of artificial fertilizers where needed. Although the main report has preliminary figures for the riverine areas to be commanded by additional pumping to maintain productivity in the Blue and Main Nile's fertile alluvial strip (434,700 feddan), it was noted that the annual energy required for pumping would amount to about 0.5% of the average annual energy generated at Mandaya, and under 3% of the average annual energy uplift in the Sudan cascade made possible by Mandaya's regulation and storage of silt.

[1] a "normal" flood condition, coloured green, did not occur in the 16 years of observed floods shown in the table, but Mandaya's regulation converts many "flooding", "critical" and "alert" conditions to "normal".

This universal conversion to pumped irrigation would be a big undertaking and will require thorough examination in future studies. The proposed conversion would need to be implemented before Mandaya becomes operational.

14.4.6 Construction and Operational Impacts in Egypt

There are several impact areas of the Mandaya project in Egypt, and some secondary ramifications of these depending on mitigation and enhancement measures taken in Sudan. They all relate to the yield and operation of High Aswan Dam.

Firstly, the period of first filling of Mandaya reservoir will reduce downstream flows in Sudan and at High Aswan Dam. This is not seen as a major problem and one that will be overcome by future studies and forward planning. Downstream release rates will be determined and agreed by the three countries and lending banks before there is agreement for the project to proceed, and once agreed these releases will be made according to the schedule.

Secondly, the holding of most of Abbay's suspended sediment load and all of its bed load in Mandaya reservoir will cause significant reduction in the siltation rate of Lakes Nubia/Nasser. This will extend the life of High Aswan Dam and maintain its yield for irrigation, domestic and public water supply and industry for a much longer period of years (more than a century) than might otherwise be the case. This benefit will be extended as watershed management measures are increasingly implemented in the Abbay basin.

There may be a secondary benefit of this. Whilst High Aswan Dam loses dead and live storage to sedimentation, the water surface area exposed to high evaporation is progressively reduced in exposed siltation areas during drawdown but increased elsewhere. In the longer term, the balance of gains and losses in water surface areas exposed to evaporation may change in favour of increased evaporation. The reduction of Abbay's sediment load may therefore have a net benefit at Aswan in terms of reduced evaporation losses. Modelling is required to investigate this.

The next impact relates also to evaporation and is an option for Egypt to pursue or not. The storage and regulation of annual flood flows by Mandaya reservoir, and the guarantee of regulated releases from it, means in reservoir storage and yield terms that High Aswan Dam could be operated at a lower level. In a desert where all water is so valuable and where losses from a reservoir surface area are very large and useless, the potential for converting water losses into usable yield is likely to be regarded as extremely important for Egypt, and for Sudan. However, the operation of High Aswan Dam at a lower level for the purpose of reducing water losses would imply less head and therefore less power generation at Aswan. On balance, the value of additional water availability in future is expected to be greater than foregone energy.

The secondary ramifications on Egypt depend on mitigation and enhancement measures taken in Sudan. These are not yet determined. In particular, the water balance resulting from reduced flooding caused by Mandaya and the conversion of recession agriculture areas to irrigation may impact on the amount of water received at High Aswan Dam. On the one hand, reductions in flooding areas (by flows staying within the Nile channel for longer durations) should reduce evaporation and evapo-transpiration losses. On the other hand, the on-going development of irrigation schemes for the summer season, and the proposed extension of irrigation schemes to make farmers independent of Nile flood recession farming as mitigation for Mandaya, with the potential for two crops per year, may or may not reduce flows reaching High Aswan Dam compared to existing conditions.

All flows and evaporation losses are relevant to the Nile Waters Agreement. Thus, the working up of Mandaya's impacts and mitigation measures on the Nile's water resources at High Aswan Dam requires further studies. In the meantime, this scoping study concludes that large reservoir storage, with low evaporation losses, and major power generation at Mandaya in Ethiopia will be found very attractive and that most impacts down river will be beneficial and most of those that appear adverse can be converted into benefits.

14.4.7 Summary of Mandaya's Principal Impacts

Table 14.2 : Summary of Principal Project Impacts of Mandaya Project

Positive Impacts	Principal Benefits	Negative Impacts	Mitigation measures
Ethiopia			
Mandaya project	Mandaya power generation, a major national energy benefit and increase in foreign exchange earnings	Involuntary resettlement	Resettlement and development program
Mandaya project	Construction employment, new skills for the future	Loss of wildlife habitat and wildlife	New reservoir wetland and management of environmental offset(s)
Mandaya project	New roads, Abbay bridge, promoting regional development	Loss of natural resources	Development of reservoir fisheries
Mandaya project	Extension of rural electrification		
Sudan			
Regulated flows and reduced sediment	Uplift of energy at Roseires, Sennar and Merowe	River morphology changes	River training works
Regulated flows	Additional irrigation		
Regulated flows and higher dry season river levels	Reduction in energy costs for pumping for irrigation		
Reduced sediment	Reduction in dredging costs at Roseires		
Reduced	Reduction in irrigation		

Positive Impacts	Principal Benefits	Negative Impacts	Mitigation measures
sediment, e.g. at Rahad and Gezira-Managil	canal and drainage canal desilting maintenance costs		
Reduced sediment	Reduction in water supply treatment costs		
Reduced sediment	Reduction in pump replacement costs		
Regulated flows and reduced sediment	Incremental fisheries production		
Regulated flows, higher in dry season	Navigation	Higher Blue Nile river levels in dry season	Facilitate river crossings for pedestrians and livestock, or compensation
Reduction in flooding	Reductions in health problems, urban flooding, property flooding, and infrastructure maintenance	Reduction in flooding	Conversion of flood recession agriculture to irrigation, and two crops per year
		Reduction in sediment	Application of artificial fertilizers
Egypt			
Reduced sediment	Extension in life of High Aswan Dam		
Opportunity to operate High Aswan Dam at lower level	Reduction in evaporation losses and conversion to usable water supply yield	Opportunity to operate High Aswan Dam at lower level	Reduction in evaporation losses and conversion to usable water supply yield may more than offset reduction in power generation
Regional			
Mandaya project	Carbon emissions savings of some 210 million tonnes compared with equivalent thermal generation		
Count of benefits and mitigations	**16**		**7**

14.5 ENVIRONMENTAL MANAGEMENT AND MONITORING

It is assumed that shareholders in the power company at Mandaya, the Owner of the project, will include the governments of Ethiopia, Sudan and Egypt and one or more private investors. This multinational participation will, *inter alia*, ensure that a water release regime is defined and agreed before construction and financial closure, and then followed to the letter. There should therefore be no political risk of water not being released according to the established program.

Mandaya project is a large project requiring a number of mitigation measures which are in themselves very considerable undertakings. Each component will require careful management and a first class public relations and communication system which delivers accurate and updated information to stakeholders as the project is planned, constructed and operated. In summary, some existing institutions will need greatly strengthening, with the possibility of new departments being created in Sudan.

In Ethiopia, overall management will be carried out by the project Owner, supported by a project Environmental Monitoring Unit and a project Resettlement Management Unit. The principal onus for management of construction impacts will rest with contractors – for roads, dam and associated construction, and transmission lines. Monitoring will be carried out by all of these bodies as well as the Environmental Protection Authority in Benishangul Gumuz and Amhara regions. Staff of the project Owner, Environmental Monitoring Unit and Resettlement Management Unit will be appointed and newly equipped for the job. The contractors will provide staff and equipment according to contract documents.

The two regional Environmental Protection Authorities will require very substantial strengthening by project funding. Other regional government departments will need assistance also. In principle, any one or all of the 12 government departments listed at Asosa in the main report will require assistance. This project support will also extend to zonal, woreda and kebele levels. Details can only be made known during further studies and development of a comprehensive project environmental management and monitoring plan (EMMP) during future EIA studies and during development of a comprehensive resettlement action plan (RAP). At this time, any required support for EEPCO's environmental management team for new transmission lines in Ethiopia, and for NGO's like the Ethiopian Wildlife and Natural History Society in relation to surveys and wildlife management of Mandaya reservoir and environmental offsets (e.g. Dabus Valley) should be determined.

Depending on decisions concerning rehabilitating and upgrading the Border and/or El Deim river gauging stations, provision should be made for assisting one or both Ministries of Water for the rehabilitation and upgrading works including provision of suitable accommodation and related facilities, and then for supporting gauging teams in all areas they may require. This is considered a fundamental requirement as the monitoring of water resources and sediment transport at one or both of these stations may or will be paramount in any legal Concession Agreement or other legal instrument for this project on an international waterway.

In Sudan, the principal management and monitoring agencies are contractors, NEC, Ministry of Irrigation and Water Resources, Higher Council for Environment and Natural Resources and affected State Councils for Environment and Natural Resources. A very considerable amount of support for these agencies may be expected. Some states do not yet have State Councils for Environment and Natural Resources and, if still not existing, will require establishment. Also, the Sudanese Environmental Conservation Society may be expected to play an important role in mitigation projects (field inspection, review of designs and plans, independent monitoring) and will require assistance.

In Sudan, with regard to river gauging, morphological surveys and river training and conversion of flood recession agriculture to irrigation, assistance will be required to the Ministry of Irrigation and Water Resources. Others are at Khartoum, Shendi (a level only station), Atbara and Dongola. All stations, except Shendi, will need to monitor flows and sediment transport according to existing requirements and according to any others stated in the comprehensive project environmental management and monitoring plan (EMMP). Any new or expanded departments in the Ministry, such as for morphology and river training and/or for converting flood recession agriculture to irrigation, will require staffing and appropriate budgets.

In Egypt, no mitigation management measures are currently foreseen but consideration should be given by the project to assisting authorities with increasing the frequency with which sedimentation surveys of High Aswan Dam are conducted.

The main report envisages that the project Owner will wish to ensure not only that habitat loss and involuntary resettlement in the Mandaya reservoir area has been competently and generously addressed but also that riparian users along the Blue Nile and Main Nile are similarly satisfied by mitigation measures being physically and socially feasible and culturally acceptable. For these important objectives to be realized, it is expected that an independent Panel of Experts for the Environment and Community Protection will be appointed and be pro-actively involved in reviewing all mitigation measures from the outset. This panel will be in addition to the Panel of Experts on Dam Safety.

At intervals, independent auditing and monitoring will be required. Targets set in the mitigation and development plans must be capable of being monitored realistically, and provide no possibility of political or other interference. Results of auditing and monitoring require to be made known to the Owner, the independent Panel of Experts for the Environment and Community Protection, local communities and local administrations, government, NGOs and project financiers.

Failures to achieve targets should result in immediate measures to improve conditions.

14.6 PROJECT COMPENSATION, MITIGATION, MANAGEMENT AND MONITORING COSTS

In this initial environmental examination of the project, it has been possible to make assessments of the compensation and socio-economic mitigation costs of the Mandaya dam project and transmission lines, and to include some allowances for management and monitoring in Ethiopia.

It has not been possible to estimate the costs and benefits of each and every mitigation and enhancement measure in Sudan and Egypt, nor of the management and monitoring costs. These measures and needs are scoped but insufficiently defined and studied to permit cost estimation, and are beyond the scope of this study. Where some indication of these costs and benefits are available, they are mentioned in the report.

A provisional sum of USD 28.6 million has been included for environmental costs in Ethiopia and a further USD 39.7 million for reservoir basin clearance. Together, these represent some 2.8% of the estimated overall project cost.

14.7 CONCLUSIONS

Initial environmental examination of the Mandaya project indicates that it has many positive impacts and that its negative impacts are capable of mitigation. Some of the latter, such as resettlement and conversion of recession agriculture to irrigation, provided they are generously supported and follow known safeguard policies, should become worthwhile development projects in their own right.

Engineering parameters are not optimised. During feasibility studies, full EIA and RAP studies are required in Ethiopia. Examination of biodiversity and physical cultural matters in Ethiopia reveals that not enough is known about these to draw firm conclusions. Detailed surveys are required of terrestrial and aquatic ecology. These require a minimum of two years to raise the baseline status to permit more competent environmental assessment. ENTRO's project boat may be used to gain access to sites on the river where systematic transect surveys are required, extending from the river beyond the reservoir margins into buffer zones. Further assessment of archaeology is required, leading to a contingency salvage plan for contractors.

An early decision is required concerning the financing of rehabilitation and upgrading the Border river gauging station. Sediment transport has not been monitored comprehensively for more than 27 years and is believed to be at a high rate and increasing. The 2007 wet season should be the last season without comprehensive monitoring. This is considered a fundamental requirement as the monitoring of water resources and sediment transport at one or both of these stations is vital for planning and may or will be paramount in any legal Concession Agreement or other legal instrument for this project on an international waterway.

Important sub-studies are required in Sudan (river morphology, conversion of flood recession agriculture to pumped irrigation, quantifying benefits of regulated flows and reduced sediment loads) and in Egypt (exploring by models opportunities for converting Lake Nasser/Nubia evaporation losses into usable water supplies when Ethiopian storage provides regulation) in order that they feed into a project EIA report. With the most optimistic estimate, further studies, which must include very considerable fieldwork and consultations, will require at least two years of continuous committed work and report preparation.

Following submission of this report on Mandaya, and parallel reports on Border and Dal, a strategic environmental assessment will be prepared and submitted. It is the strategic assessment that will compare aspects of these projects and explore the strategy for a hydropower development sequence on the Abbay, Blue Nile and Main Nile cascade in the context of power trading and regional development.

The strategic assessment may indicate that there will be merit in conducting surveys of terrestrial and aquatic ecology of the Mandaya reservoir and Border reservoirs together, as one synchronised survey rather than as staggered surveys, so that future planning of the first development may be seen in the broader context of proposals for the developing cascade.

15. CONCLUSIONS, RECOMMENDATIONS AND TERMS OF REFERENCE FOR FEASIBILITY STUDIES

15.1 CONCLUSIONS

It is concluded from the studies described in the earlier Chapters that the Mandaya hydropower project offers an exceptional opportunity for energy generation to meet some of the future energy demands within the Eastern Nile region. A 2000 MW development at Mandaya will provide an average energy output of 12,119 GWh/yr of which some 11,192 GWh/yr would be firm energy (98% reliability).

The Mandaya project was selected in the generation planning studies as the first project on the Nile river in Ethiopia to form part of the least-cost development programme.

In addition to the energy output the Mandaya project would provide a wide range of other positive benefits including:

- Provision of regulated flow with potential enhancement of agricultural production in irrigation schemes downstream,
- Enhancement of energy generation at existing and planned hydropower projects in Sudan as a result of regulated flow by up to 2657 GWh/yr,
- Flood alleviation along Blue Nile and main Nile rivers including at Khartoum,
- Reduction of sedimentation of Roseires reservoir (albeit by storing sediment in Mandaya reservoir),
- Savings in cost of removal of sediment from irrigation canal systems in Sudan, estimated as some USD 7.5 million / year,
- Reduction in cost of pumping at existing pumped irrigation projects,
- Reduction in damage to hydropower projects downstream caused by sediment,
- Savings in CO_2 emissions associated with alternative thermal generation options of some 400 million tonnes over 50 years.

As with any major hydropower development, there will be negative impacts associated with development of the Mandaya project. Fortunately, the population within the proposed Mandaya reservoir area is very small (approx. 600 persons) and it is anticipated could be resettled, subject to appropriate planning and compensation arrangements.

Impacts of the Mandaya project would be felt throughout the Blue Nile and Main Nile river downstream as far as Egypt. Within Sudan communities living along the river which rely on the annual flood for irrigation of crops and pasture will be adversely affected and appropriate mitigation measures will be required as discussed in detail in the separate Environmental and Social Impact Assessment report.

Impacts in Egypt will primarily be associated with a reduction in water level of Lake Nasser and consequent reduced energy generation potential at High Aswan power station. Studies have shown that the long term impact would be an average loss of energy output of some 212 GWh/yr over a 50 year period, the loss being greater in the early years.

15.2 RECOMMENDATIONS

15.2.1 General

The three largest hydro power identified in Module 3 for Ethiopia are all in the least-cost generation expansion plan determined by the Consultant. On the basis of present available studies (pre-feasibility studies) for Mandaya, Karadobi and Border, Mandaya is potentially the project with the lowest economic cost. Considering the time necessary to carry out feasibility study, detailed study, call for tender, construction, the earliest date of commissioning for these projects is in the range of 2020-2025, which is about the time when the first large hydro project is need in the Ethiopian generation expansion plan (depending on demand projection and export scenario to Kenya).

Accordingly, the Consultant recommends to carry out the feasibility study of Mandaya at the earliest, in order to confirm whether Karadobi or Mandaya presents the most overall benefits.

The Consultant also recommends to carry out the feasibility study of Border, which although being ranked after Karadobi and Mandaya, might be one of the most interesting large hydro projects in Ethiopia.

15.2.2 Blue Nile River Optimisation Study

The Blue Nile river scheme, mainly composed of Karadobi, Mandaya, Border and Beko Abo projects has the potential to become one of the main source of power export in the region in the next 15 years.

The first three of these projects have been studied to pre-feasibility stage, each pre-feasibility study being obviously focused on each project, while including some analysis of downstream impact and relative impact of one project to the other. Furthermore, these studies were carried out independently of the Ethiopian power demand evolution, assuming that all the generation will be absorbed by the power system.

The Consultant recommends to carried out a Study of the overall Blue Nile river scheme whose objective would be to optimise the overall design of the Blue Nile hydro scheme: size of reservoirs, installed capacities, operation strategy, schedule of commissioning, filling strategy, overall downstream impact analysis during filling and operation.

This Study should consider the overall supply / demand balance of Ethiopia (including export) an its evolution, and possibly the overall supply / demand balance projection of Sudan (including irrigation need, evaporation, etc).

15.2.3 Feasibility Study of Mandaya Project

It is recommended that feasibility studies are carried out of the Mandaya project at the earliest opportunity. Having regard to the regional nature of the project benefits and impacts (both positive and negative), it is important that these studies are carried out under a framework of regional cooperation. Extensive studies will be required in the vicinity of the Mandaya site in Ethiopia, in the affected zones along the Blue Nile downstream in Sudan and to assess in detail the impacts on energy generation and operation of High Aswan in Egypt.

Particular attention will be required to a number of topics including:

Access to Mandaya site

It is recommended that an access track suitable for use by four-wheel drive vehicles is constructed from Boka Mission to the Mandaya site. This will allow vehicles and equipment required for the feasibility study to reach the site without need for extensive use of a helicopter.

Climate

It is recommended that a climate station is established near the Mandaya site (a site at Boka Mission is recommended) to record rainfall, temperature, evaporation and other climate parameters.

Hydrology

It is recommended that a fully equipped hydrometric gauging station is established at the Mandaya site (with staff gauge, recorder and cableway) and that a series of flow measurements is carried out by current meter over a wide range of flows

Sediment

Analysis of current sediment discharge in the Abbay river presented in this report has highlighted possible sediment loads some three times greater than previous estimates. It will be essential to carry out a major programme of sediment measurements at the existing Kessie hydrometric station and at Mandaya to determine current sediment discharge with confidence.

Geological and Geotechnical Investigations

It will be necessary to carry out a major programme of geological and geotechnical investigations of the Mandaya site and the proposed construction materials. It is anticipated that the programme will include some 3000 metres of core drilling (20 holes) with associated insitu and laboratory testing.

Environmental and Social Impact Assessment

It is recommended that a detailed ESIA is carried out including preparation of a resettlement action plan. This is described in more detail in the ESIA Report.

15.3 TERMS OF REFERENCE FOR TECHNICAL FEASIBILITY STUDIES

15.3.1 General

These terms of reference (ToR) cover the requirements of consulting services for feasibility studies of the Mandaya hydropower project in Ethiopia with the objective of developing the project for supply of electricity within the Eastern Nile region. All the services of the Consultant described in the following shall be performed in close co-operation with the project executing agency, ENTRO and with the Ministry of Water Resources in Ethiopia.

The Feasibility Study shall comprise the following deliverables:

(1) Geological Report

(2) Hydrology and Water Management Report

(3) Environmental and Social Impact Assessment Report

(4) Design, Engineering, and Generation Report

(5) Transmission Report

(6) Cost Estimate Report

(7) Financial and Economic Analysis Report

(8) Draft Feasibility Report and Executive Summary

(9) Final Feasibility Report and Executive Summary

The Consultant shall be responsible for carrying out all necessary fieldwork and investigations to compile data and information for the feasibility study. This includes the preparation of tender documents for field investigations, the tendering process where necessary, and the award and management of sub-contracts in agreement with the Client.

15.3.2 Data Collection

This stage has the objective to compile all relevant basic information for the project, to prepare new data and to deepen the information whenever necessary and possible. This encompasses the following amongst others:

Electricity system – Update of data on electricity systems, supply and demand in the Eastern Nile countries

Topography - Preparation of additional topographical maps and information, which are needed for the desk and subsequent feasibility studies.

Hydrology - Processing of raw hydrological stage gauge data to produce discharge data of the gauging stations in the Abbay river catchment. Establishment of long-term run-off data series for the different stages of the hydropower complex.

Sediment – Observations of sediment concentrations and calculation of sediment discharge ratings and estimated sediment loads.

Geology - Review of geological information and preparation and supervision of a programme of field investigations for the Mandaya project site.

The detailed requirements are described in the following sections. Results of the collection of data and information will be presented in separate thematic reports.

15.3.3 Topographic Survey

Maps have been produced at a scale of 1:10,000 with 10 m contour interval during the course of the pre-feasibility study.

The Consultant shall organise the procurement of a GPS ground control system and all additional maps needed for the feasibility study.

A high accuracy GPS ground control system shall be established at the Mandaya site. This will include a network of not less than 6 permanent primary reference stations on both banks of the river and including reference stations at or close to river level as well as on the plateau on both banks.

The Consultant shall procure maps of the project site at a scale of 1:2000 with 2 m contour interval. The mapping shall cover an area of at least 2 km upstream and 3 km downstream of the dam centreline and shall extend at least 2 km from the river edge on each bank.

The Consultant shall thereafter organise all additional survey work in the field to locate site investigation works and the procurement of additional maps needed for the feasibility study.

The Consultant shall also arrange for cross-sections of the Abay river to be carried at at intervals of 100 metres for 1km upstream and 2 km downstream of the dam centreline and shall record observations of the water surface gradient for use in hydraulic calculations.

15.3.4 Meteorological Data

The Consultant shall establish a meteorological station at Boka Mission some 30 km downstream of the Mandaya site and shall make arrangements and train personnel as necessary to carry out regular observations. The meteorological station shall be equipped to record rainfall, temperature (maximum and minimum) and evaporation. Suitable recording instruments shall be provided as well as manually observed gauges.

15.3.5 Hydrological Data

The existing hydrometric station at Kessie for which data is available for some 50 years shall form the key reference station for the project. The Consultant shall carry out a detailed analysis of all recorded data for the Abbay River at Kessie and shall derive long-term daily and monthly records for use in analysis. If considered necessary the Consultant shall arrange for additional measurements to be carried out to supplement the normal programme of measurements by MWR.

The Consultant shall procure the necessary equipment and shall manage the installation of a new hydrometric station at the Mandaya site. The Mandaya hydrometric station shall be equipped with a staff gauge covering a range of not less than 15 metres and shall be equipped with a solid-state data logger to record water levels at hourly intervals. The station shall be equipped with a cableway and all equipment necessary to carry out current meter gaugings safely at all flows. The data logger shall be equipped with solar panel battery charge and shall be capable of operating unattended for up to 6 months.

The Consultant shall establish the rating curves for the above stations and compute the run-off at the locations of the gauging stations. Establishment of the stage-discharge rating curve shall be based on not less than 20 measurements on differing dates and with differing flows over the full annual range of flows.

15.3.6 Sediment

Relatively few measurements have been made of sediment concentration in the Abbay river. Accordingly, recognising the importance of an accurate assessment of current sediment loads to the planning of hydropower developments on the Abbay river, the Consultants shall carry out a major programme of observations of sediment concentrations in the Abbay river over at least two flood seasons.

The programme of sediment concentration measurements shall be carried out by two separate teams which shall be stationed at each of Kessie hydrometric station and Mandaya site for the entire period from 1st June to 31st October in each year. The sediment concentration in the river at each site shall be observed daily over this period using depth integrating samplers or multiple point sampling techniques.

15.3.7 Geological Studies

The Consultant shall study the results of the work done during the pre-feasibility studies.

The Consultant shall carry out studies as are necessary for design at feasibility level of all the project components. The work shall be directed towards determining all relevant parameters, e. g.

- Thickness of alluvial deposits in the river bed;
- Occurrence and nature of joint sets;
- Extension of weathering zones;
- Permeability of the rocks and reservoir tightness;
- Nature of contact zones of geological strata;
- Slide risks at steep valley sections;
- Groundwater level effects due to additional loads and pressures;
- Geomorphology of areas within acceptable transport distances from where to draw construction materials.

It is necessary to clarify the geological and geotechnical conditions at the selected dam site and powerhouse area. The investigations shall include the following work:

- Establishment of the bedrock conditions between the river banks by means of trenches, boreholes, and seismic profiling; the purpose is to confirm the geometry and characteristics of the colluvial deposits that partially hide the underlying bedrock of the abutments, and to assess the jointing pattern and the opening of discontinuities in depth;
- Exploration of the overall geometry of the bedrock in the riverbed by some borehole drillings and seismic profiling;
- Determination of the bedrock conditions at all structures, appraisal of its geotechnical characteristics (permeability, strength, alteration); a number of boreholes is required to determine the weathering sequence of the bedrock;
- Assessment of the seismic risk at the Project site, including the determination of earthquake-induced stresses, accelerations, and forces to be taken into account for dam safety and other design work;
- Investigation of the grout curtain configuration and drainage at the dam foundation;
- Definition of quarry areas for construction materials for the dam and the powerhouse complex (including the identification and avoidance of environmental impacts due to borrowing and mining); local potential for concrete aggregates shall be ascertained.

15.3.8 Geotechnical Investigations

The Consultant shall make a recommendation of the scope of site investigation works to be carried out during in the feasibility study. The Consultants shall prepare bid documents, procure, manage on behalf of ENTRO and supervise all necessary site investigation contracts.

It is envisaged that the geological investigations (to be undertaken under separate contracts by an experienced Contractor) to be managed and supervised by the Consultant will comprise:

- Core drilling with appropriate down-the-hole testing and observation. Some 20 drillholes totalling 3000m are anticipated.
- Laboratory tests to determine physical, chemical, and mineralogical characteristics of samples taken from the boreholes, trenches, test pits and adits.

All findings, test reports, calculations, and conclusions shall be presented in the Geological Report as per 4.1 (1).

It is considered important to record data regarding ground motion in the project area. The Consultant shall procure and arrange for the installation of a Strong Motion Accelerograph (SMA) in the general project area. The Consultant shall coordinate the installation of he SMA stations in the project area with MWR.

15.3.9 Hydrology and Water Management

Separately from the investigations and calculations dedicated to the Mandaya Project itself, the Consultant shall calculate and optimise the conjunctive operation of Mandaya together with the downstream power plants in Sudan and Egypt both during the Mandaya reservoir filling period and in the long term.

The joint optimised energy output shall be determined and compared with the actual output of the existing plants. If relevant, recommendations shall be made as to the future operation mode of the cascade (with and without Mandaya).

If the conjunctive operation of the cascade of power plants produces additional energy at the existing plants (as compared with the present condition), this shall be valued and introduced into the financial and economic analysis of the Project.

All necessary flood calculations and assessments shall be made as required for the dimensioning of cofferdams, waterways, spillways, and other parts of the Project.

A tailwater rating curve shall be established for the Mandaya power station based on hydraulic calculations and on the underwater topography surveyed downstream of the powerhouse.

The Consultant shall present all findings, calculations, and conclusions in the Hydrology and Water Management Report.

15.3.10 Project Design and Optimisation

The Consultant shall review and comment on the design and layout proposed in the Pre-feasibility Study Report and shall propose and justify any amendments. The pertaining calculations, descriptions, and designs shall be on feasibility level throughout, which means that they are basically sufficient for the development of full tender documents for implementation without further engineering studies.

The entire design work, including all calculations, descriptions, and drawings shall be presented in the Design, Engineering, and Generation Report. A separately bound Design Parameter Memorandum shall be added.

Dam and Power Plant

The design work shall be broken down into the following main parts:

- River diversion;
- Dam wall;
- Intake and waterways;
- Powerhouse and appurtenant facilities
- civil works
- turbines, valves, and their controls
- alternators and their controls
- cabling and panels
- metering, protection, control, and telecommunication
- auxiliary equipment
- Other permanent site installations.

15.3.11 Infrastructures

The Consultant shall study the existing and required infrastructures to ascertain capabilities to support construction and transport activities for the Project, and identify any upgrading and expansion requirements to be included in the Project. This may include items such as:

- Accommodation;
- Roads and bridges for equipment transport to site;
- Air transport;

- Medical and educational facilities;
- Local supply of materials (steel, cement, etc.);
- Security.

15.3.12 Design Parameters

The Consultant shall prepare a design parameter memorandum summarising all parameters used for the feasibility design, and to be used again for the detailed / final design to be done later. The memorandum shall present in a clearly organised manner all required parameters, but not the theoretical or scientific justification and/or calculations used in the Study itself to arrive at the said parameters.

15.3.13 Transmission

The components and details to be considered for the feasibility of the transmission grid extending from the HV yard of the power plant to the Ethiopian and regional transmission grid are the following ones:

- Power line(s);

preliminary line routes and profiles on 1 : 50,000 scale maps (or better, if available), definition of voltage(s); number of circuits, conductor size, types of towers, bills of quantities; environmental impacts;

- Substation(s)

site definition and layout, single line diagram, capacities and voltages of main components, type of switchgear, buildings.

Network calculations shall be made for zero-to-full load and for all relevant outage and switching conditions, in order to fix the design and operation parameters concerning electric stability, voltage and reactive power control, fault levels, and surges.

- Telecommunications

optical fibre based system for transmission of voice and data (protection and measuring) between the power plant, the relevant substations, and the national load dispatch centre (once implemented); number and speed of channels and interfaces in accordance with the proposed grid layout.

All calculations, descriptions, and drawings shall be presented in the Transmission Report.

15.3.14 Construction Time Schedule

The Consultant shall prepare an implementation schedule for the hydropower project, including the detailed design, preparation of tender documents, international competitive bidding, contracting, detailed / final engineering, manufacturing, transport to site, construction and erection, testing and commissioning. The schedule shall be established using an accepted computer programme such as MS Project (or equivalent) and shall be used as basis for the calculation of interest during construction.

15.3.15 Cost Estimates

Based on the identified requirements of the various project components, the Consultant shall prepare a detailed cost estimate including:

- Mobilisation cost and infrastructure
- Surveys and investigations
- Civil works
- Manufacturing, transport, erection, installation, testing, and commissioning of:
    - Hydro-mechanical equipment
    - Mechanical equipment
    - Electrical equipment
    - Other equipment
- Costs for environmental and social mitigation
- Taxes and import duties (incl. regional or project-related exemptions / reductions, if any)
- Administration and legal costs
- Engineering and supervision
- Insurance's
- Physical contingencies corresponding to the degree of reliability of the estimate of each major cost item.

The construction costs shall be determined on the basis of a quantity survey and adopting unit costs calculated by using material and labour costs valid for the project region. About 70% of the total construction costs shall be computed using this contractors method to calculate prices; these shall include risk and profit as well. The remaining 30% of the costs may be estimated based on experience.

The costs of the electro-mechanical equipment shall be computed on the basis of equipment lists and tentative quotations from qualified manufacturers and broken down into CIF prices, transportation to site, erection and commissioning.

Costs for engineering services shall be calculated on the basis of a man-months estimate for the various tasks to be identified.

The cost figures established in this manner shall be broken down into local and foreign costs expressed in USD. The capability of the local industry to carry out civil works portions of the project shall be investigated in order to arrive at a realistic estimate of the local component.

Cost estimates must all be valid at the same date. All cost shall be broken down into foreign and local currency portions, and the exchange rates used indicated.

All cost elements shall be structured according to the construction time schedule, cover 25 years of operation, and comprise the following:

- disbursements for construction and related cost;
- additional disbursements resulting from escalation since the reference date;
- interest during construction, to be calculated until the commissioning of the hydropower plant;
- annual cost of operation, maintenance, rehabilitation, and administration.

15.3.16 Power Sector Studies

The Consultant shall gather the most recent information on the power sector of the Eastern Nile region and compile the relevant data in a separate power sector report. This shall comprise a load and electricity consumption forecast up to the years 2015, 2020 and 2025. The capabilities of all existing projects and those presently under construction (priority hydropower projects and thermal projects) shall be compiled and the total installed and dependable capacities shall be shown and compared with the load forecast. The deficits of firm power and energy shall be computed for three different load growth scenarios.

As result of the above work, the Consultant shall estimate the economic and financial value of the energy generated by the Mandaya project and its first implementation stage for at least the first 10 years of operations (peak and firm power, primary and secondary energy). This information would form the basis to elaborate the subsequent economic analyses.

15.3.17 Economic and Financial Studies

The economic and financial analysis shall include all components of the projects. The analysis shall provide a bankable basis for scrutiny by ENTRO and potential lenders.

<u>Project Benefits</u>

The energy production of the project shall be computed based on the water management plan and the variable gross head due to the reservoir operation. Net heads shall be computed with hydraulic losses related to actual flow and the efficiency of the equipment shall be taken as function of flow and actual head. The energy produced will be indicated for monthly periods over 20 years of operation simulations.

The value of the energy produced, for the computation of the EIRR, will be computed, based on capacity and energy rates for equivalent thermal power plants.

The energy sold will be computed, based on the actual production minus losses and a reduction of the income for transmission, distribution and administrative costs will be made.

Economic Analysis

The economic analysis of the project shall be done according to international financial institution's standards.

The scenarios to be used for the financing of the project will be agreed with ENTRO in consultation with stakeholders. Appropriate assumptions and sensitivity analyses shall be made as to the anticipated value of the energy produced by the project. The Consultant shall calculate the net present value (NPV), cost-benefit ratios and the economic internal rate of return (EIRR) of the project.

Financial Analysis

Identify the profitability of the present operations and assess the future financial performance (business plan). Net financial cash flow of the project over the economic life of the project's assets (with particular emphasis on the cash flow of the first 10 years) and based on this, calculation of the Financial Internal Rate of Return (FIRR), the Net Present Value (NPV) and the Debt Service Cover Ratio (DSCR). The financial projections shall include the base case scenario and the sensitivity analysis.

Risk Analysis

Assessment of risks which might occur during the project's implementation. Assessment of risks which might jeopardise the project's goal. The consultant shall outline risk mitigation measures in the report.

15.3.18 Feasibility Study Report

The Consultants shall submit each Draft Feasibility Study Report within 24 months after the commencement of the work. The report will comprise the full documentation of the technical characteristics of the project, together with the results of the above cited environmental, economic and financial assessments.

15.3.19 Reporting

As the Consultant will be working in close co-operation with ENTRO and MWR, they shall be kept aware of the Consultant's performance through regular meetings and reporting.

Moreover, the Consultant shall submit the following reports:

- Inception Report: Besides normal reporting on project progress the Consultant shall review actual conditions in the project area with those anticipated in the ToR and propose any alterations of the project schedule and any other measures if deemed necessary and decisive for project success.

- Progress Reports (Monthly). The Consultant shall report briefly on project progress and staff inputs each month. The Consultant will prepare on the last day of every month a brief summary of the main activities and extraordinary events. Such Monthly Report must be limited to two pages and shall be transmitted to ENTRO and MWR by e-mail.

- Progress Reports (Quarterly). Every three months the Consultant shall prepare Quarterly Progress Reports in order to keep ENTRO, MWR and other involved parties informed in detail about the progress of project. The Consultant shall report on project progress and staff inputs during the period. The Consultant shall review actual conditions in the project area with those anticipated in the ToR and propose any alterations to the project schedule and any other measures if deemed necessary for project success.

- Thematic reports. Thematic Reports shall be submitted for each major work topic as soon as the respective activity is completed.

- Interim Report. An Interim Report shall be submitted at the end of Year 1 of the assignment. The Interim Report shall summarise the progress over the twelve month period and shall make recommendations for the further progress and success of the project.

- Draft Feasibility Study Report: This shall be in compliance with international standards for projects of this nature. The full set of documents will be submitted 24 months after commencement of the consultancy contract.

All reports/documents have to be prepared in 10 copies in the English language. All reports will have executive summaries not exceeding 10 pages length.

The Feasibility Study Report shall be submitted in 50 copies and has to comprise one volume (main report) containing results, summary and conclusions and an appropriate number of volumes accommodating the annexes which provide all details, relevant data, analyses, calculations, design considerations and the like, necessary to understand the main report. An Executive Summary Report of about 10 pages shall present a brief summary on basic situation, results, actions to be taken, implementation strategy, time schedule, schedule of cost, etc. as appropriate.

All reports have to be prepared in A4 format. A separate volume in A3 format is to be prepared containing all plans, drawings and photographs. All final versions of reports shall be firmly bound, no spiral binding is accepted. The title of the study and identification of the specific volume has to be indicated on the spine of every final version. In addition, the Consultant shall provide ENTRO with a soft-copy on CD.