INTERNATIONAL PANEL OF EXPERTS (IPoE)

ON

GRAND ETHIOPIAN RENAISSANCE DAM PROJECT (GERDP)

FINAL REPORT

Addis Ababa, Ethiopia

May 31st, 2013

Table of Contents

Volume II. Annexes:

1. IPoE Terms of Reference and Rules of Procedure
2. List of Documents Submitted to the IPoE
3. Minutes of the IPoE Meetings
4. Report of Geotechnical Team
5. Review Notes of IPoE Members
6. Scope of work: Transboundary Environmental Impact Assessment of GERDP
7. Scope of Work: Modelling of the Eastern Nile

FOREWORD

This is the Final Report of the International Panel of Experts (IPoE) on the Grand Ethiopian Renaissance Dam Project (GERDP). The Government of Ethiopia invited in good faith the two downstream countries, Egypt and Sudan to form an International Panel of Experts *to* review the design documents of the GERD, provide transparent information sharing and to solicit understanding of the benefits and costs accrued to the three countries and impacts if any of the GERD on the two downstream countries so as to build trust and confidence among all parties."

This Final Report is the outcome of IPoE's deliberations on the project documents submitted to it by the Government of Ethiopia during May 2012 to May 2013. The IPoE conducted six regular meetings and four field visits to the GERD project site. The IPoE had also established a geotechnical expert group to do a verification study regarding geotechnical issues on the basis of geotechnical documents provided by the GoE and project site visit.

The IPoE appreciates the initiative taken by the Government of Ethiopia to invite the two downstream riparian countries, Sudan and Egypt, to undertake joint consultations on the GERDP. The IPoE also wishes to extend its appreciation for the support provided by the peoples and Governments of Egypt, Ethiopia and Sudan in accomplishing the task assigned to it by the governments of the three countries.

The report provides introduction and background information in Chapter 1. In Chapter 2 a brief overview of the project is outlined. Chapters 3 and 4 explain the approach, methodology and status of reviewed documents and Chapter 5 details out the findings and recommendations with regard to dam safety and engineering, water resources and hydrology and environment and socio-economics. Chapter 6 provides the detailed description of the project.

This Final Report with its Annexes is submitted to the Governments of Egypt, Ethiopia and Sudan on May 31, 2013 following the 6th and final Meeting of the IPoE.

Signed by members of the IPoE on May 31st 2013:

Egypt

Dr Sherif Mohamady Elsayed ....

Dr Khaled Hamed ....Khaled....

Ethiopia

Eng. Gedion Asfaw ....

Dr Yilma Seleshi ....Yilma....

Sudan

Dr. Ahmed Eltayeb Ahmed ....

Eng. Deyab Hussien Deyab ....

International Experts

Dr. Bernard Yon ....
Environment Expert

Mr. John D. M.Roe ....
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Mr. Egon Failer ....
Dam Engineering Expert

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1 INTRODUCTION

1.1 Background

This is the Final Report of the International Panel of Experts (IPoE) on the Grand Ethiopian Renaissance Dam Project (GERDP) that was established by the Governments of Egypt, Ethiopia and Sudan as per the ToR of the IPoE (Annex 1). The mandate of the IPoE is to review the design documents of the GERD, provide transparent information sharing and to solicit understanding of the benefits and costs accrued to the three countries and impacts if any of the GERD on the two downstream countries so as to build trust and confidence among all parties.

The Grand Ethiopian Renaissance Dam (GERD) is under construction. The Government of Ethiopia (GoE) is convinced that the GERDP has huge benefit to all the three riparian countries, namely Egypt, Ethiopia and Sudan. Egypt and Sudan have concerns on the impacts of the dam upon them. To that end, the GoE invited in good faith the two downstream countries to form an International Panel of Experts.

The Ministers of Water Affairs of the three countries in their meeting held on November 29, 2011 in Addis Ababa, Ethiopia, agreed on the terms of reference and rules of procedure of the IPoE. They also agreed that the IPoE shall consist of ten members: two experts from each of the three countries of Egypt, Ethiopia and Sudan and four international experts in the following four disciplines: (i) Dam Engineering, (ii) Water resources planning and hydrologic modeling , (iii) environment, and (iv) Socio-economics.

The Governments of Egypt, Ethiopia and Sudan each nominated two national experts during December 15-23, 2011. The six national experts after careful deliberation on the selection of the four international experts submitted the final list of nominees on February 11, 2012 to the three governments for approval. On March 26, 2012 the Ministers of Water Affairs of the three countries jointly signed the letters of nomination of the four international experts. The members of the IPoE are:

Egypt
Dr Sherif Mohamady Elsayed
Dr Khaled Hamed

Ethiopia
Eng. Gedion Asfaw
Dr Yilma Seleshi

Sudan
Dr. Ahmed Eltayeb Ahmed
Eng. Deyab Hussien Deyab

International Experts
Dr. Bernard Yon, Environment Expert
Mr. John D. M.Roe, Socio-economics Expert
Mr. Egon Failer, Dam Engineering Expert
Dr. Thinus Basson, Water Resources and Hydrological Modeling Expert

The national members of the IPoE were all along supported by their respective teams of experts

The IPoE hired an International Law Firm (Corbett & Co) on April 11, 2012 to administer the contracts of the international experts of the IPoE. The three governments deposited the required funds in the escrow account established by the law firm to manage the payments to the international experts.

Following the completion of the preparatory phase, the launch meeting of the IPoE took place in Addis Ababa, Ethiopia during May 15-18, 2012. The Government of Ethiopia provided the necessary GERDP related hard and soft copy documents for review by the IPoE starting at the launch meeting up to the 6th meeting of the IPoE. A dedicated web-page was established to facilitate documents sharing among IPoE members. Four field visits to the GERD project site were also organized by the Government of Ethiopia including a field visit for the special subcommittee on geotechnical review and verification mission. Table 1 shows the duration and the main tasks accomplished by the IPoE.

Table 1. Meetings and major tasks accomplished by the IPoE

Item	Duration	Activity
1. Launching of the first full IPoE meeting	The IPoE Launch meeting was conducted in Addis Ababa, Sheraton Hotel, during May 15-18, 2012	• IPoE members visited the GERDP and were provided on-site briefing of the project; • IPoE identified issues that are required to be reviewed by panel members and related topics of study and design documents; • IPoE members were provided with project study and design documents in soft copies as per the list attached to the minutes of the launch meeting; • IPoE agreed on working procedures, communications and documents submission including the necessary of using a website to be accessed by members; • IPoE agreed to conduct the next meeting in Cairo.
2. Second Meeting of IPoE	The second meeting of the IPoE was conducted in Cairo, Egypt during June 19-21, 2012	• Discussed GERD project activities and progress • IPoE members exchanged their views and

		reflections regarding structure and gaps on submitted documents • Conducted a detailed technical discussions on the preliminary review of the submitted documents • Conducted discussion on the IPoE work plan and way forward • Web page have been introduced to IPoE for document sharing
3. Third Meeting of IPoE	The third meeting of the IPoE was planned to be conducted in Addis Ababa in Mid-September 2012 but was postponed for October 9-11, 2012 due to the unexpected situations created in Ethiopia (passing away of the prime Minister of Ethiopia)	• Conducted a one day field visit to the GERD project site; • Agreed on fielding a geotechnical verification mission to the GERD project site; • Discussed review notes submitted by members of the IPoE
4. Fourth Meeting of the IPoE.	The fourth IPoE meeting was conducted during November 26-28, 2012 in Addis Ababa, Ethiopia	• Discussed a number of GERDP documents on the basis of review notes prepared by members of the IPoE. • Discussed proposed additional studies; • Discussed the preparation of the final report of the IPoE; • Discussed the necessity of extending the life of the IPoE upto May 2013.
5. Geotechnical Expert group mission	The IPoE organized an expert group mission during February 3-9, 2013 to assess and verify the geotechnical issues related to the GERD. The mission was composed of three international experts accompanied by an expert each from Egypt and Sudan and four experts from Ethiopia.	• Consulted 16 geotechnical documents prepared by the EPC contractor and conducted a three days field visit. The mission submitted its report on March 20 2013. During the 5th IPoE meeting the report was discussed along with the comments and clarifications submitted by the Ethiopian IPoE members.
6. Fifth Meeting of the IPoE	The Fifth Meeting of the IPoE took place during March 25-28, 2013 at Rosseries Township, Sudan	• Discussed the review note on gated spillway design report • Discussed the geotechnical mission report • Discussed the review note of the environment and socioeconomic and water resources experts

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		• Discussed the IPoE final report structure and table of content and assigned sections of the final report to be drafted by individual members of the IPoE • Visited the sites of Roseries and Merowe Dams • Adopted the request for extension of the IPoE.
7. Sixth Meeting of the IPoE	May 26-31, 2013 Addis Ababa, Ethiopia	• Discussed and finalized the IPoE final report • Conducted a one day field visit to the GERD project site

These meetings were instrumental in fostering understanding among members of the IPoE and to expedite the envisaged work programme as per the IPoE ToR. Due to the reasons given in the request for extension as attached in Annex 3. With the approval of the Governments of Egypt, Ethiopia and the Sudan the original envisaged time for the IPoE of nine months was extended by three more months up to the end of May 2013

The IPoE appreciates the initiative taken by the Government of Ethiopia to invite the two downstream riparian countries, Sudan and Egypt, to undertake joint consultations on the GERDP.

1.2 Objective

The overall objective of the IPoE is to build confidence among the three countries around the GERD. The specific objective of the IPoE is to provide sound review/assessment of the benefits to the three countries and impacts of the GERD to the two downstream countries, Egypt and Sudan.

The IPoE's mandate is to review the design documents of the GERD and provide transparent information sharing and to solicit understanding of the benefits and costs accrued to the three countries and impact if any of the GERD on the two downstream countries so as to build trust and confidence among all parties. The role of the IPoE is mainly facilitative focused on promoting dialogue and understanding around GERD-related issues of interest to the three countries and thus contribute to regional confidence and trust building. (See Annex 1, IPoE Terms of Reference and Rules of Procedure)

2 OVERVIEW OF THE PROJECT

As presented in the reports submitted to the IPoE by the Government of Ethiopia, this section summarizes the overview of the project.

2.1 Project Location and Description

The GERD project site is located on the Abbay/Blue Nile River some 20 km upstream of the Ethiopia – Sudan border. The GERD is a Roller Compacted Concrete (RCC) dam with a dam height of 145 meters, complemented by a saddle dam about 5 km long and about 50 meters high. The scheme, from the root of its reservoir to the dam site, extends over a corridor approximately 246 km. Figure 1 shows the locations of the project area for the dam and reservoir.

The reservoir area will cover 1,874 square kilometers at full supply level (FSL) of 640 meters above sea level (m asl). The total storage volume is 74 billion cubic meters with an active storage volume of 59.2 billion cubic meters. For a design flow of 4,305 cubic meters per second and a maximum net head of 133 meters and plant factor of 0.31, the expected average energy production per year is 15,692 GWh.

The plant has two surface powerhouses equipped with sixteen power generating units and a switchyard. Figure 2 shows the overall layout of the scheme. The installed power is flexible (base or peak) and the plant has been designed so that the installed capacity may be built in several stages.

2.2 Description of the Main Project Components

Table 2 summarizes the main characteristics and the technical parameters for the civil, mechanical and electrical works of the GERDP.

Figure 3 shows an aerial photograph of the GERDP area. The two power houses are shown at the foot of the main dam, and then there is the spillway on the left and finally the saddle dam. The photo also illustrates the position of the future reservoir.

Figure 4 is an illustration of GERDP main dam and power house.

Table 2: Summary of Main Characteristics of the Project

Hydrological data	
Catchment area	172,250 km^2
Mean annual flow	1,547 m^3/s
Main Dam	
Type	Roller compacted concrete (RCC) dam
Max. Height above foundation	145 m
Crest elevation	645 m asl
Crest length	1780 m
Dam volume	10.1 Mm^3
Reservoir Data	
Full Supply Level (FSL)	640 m asl
Minimum operating level (MOL)	590 m asl
Operating range	50 m
Total Storage volume	74.01 Bm^3
Live storage vol. (Max. regulated capacity)	59.22 Bm^3
Dead storage volume	14.79 Bm^3
Surface area at (FSL)	1,874 km^2
Surface area at (MOL)	606 km^2
10,000 years return peak flood	26,860 m^3/s
Probable Maximum Flood (PMF)	38,750 m^3/s
Mean annual sediment yield	207 Mm^3/y
Length of reservoir at FSL	246 km
Saddle Dam	
Type	Rock Fill Dam with Bituminous Surface Sealing
Height	45m
Crest length	4800m
Crest elevation	644 m asl
Wave wall elevation	646 m asl
Powerhouse Right powerhouse	
Powerhouse type	Outdoor
Unit # / Type	10/Francis
Installed power	10/375 MW
Left powerhouse Powerhouse type	Outdoor
Unit # / Type	6/Francis
Installed power	6/375 MW

Power and Energy	
Max Net Head	133 m
Total Installed Capacity	6000 MW
Average annual energy generation	15,692 GWh/yr
Plant factor	0.31

The details are in chapter 6 as presented to the IPoE by the Government of Ethiopia.

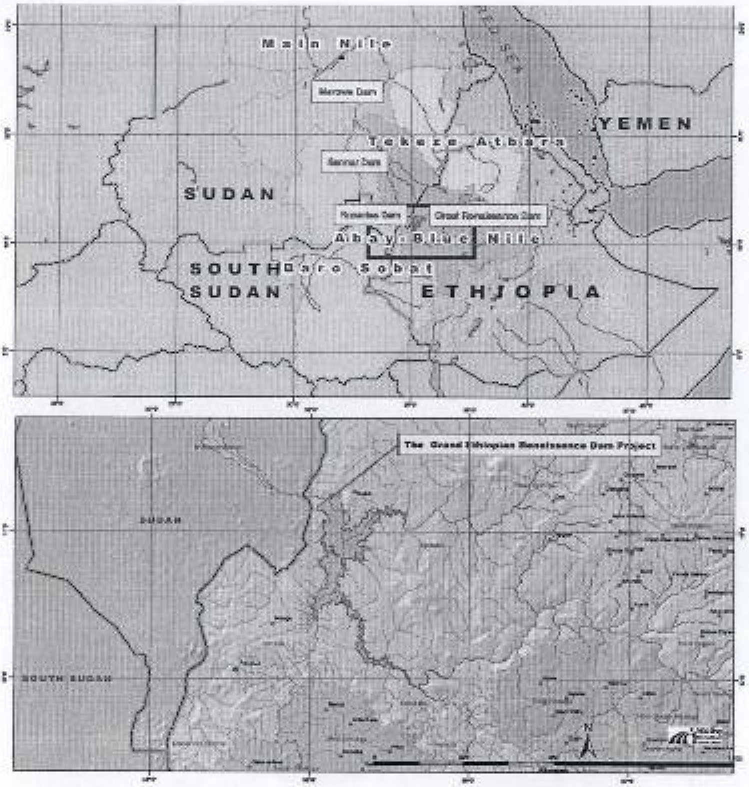

Figure 1. General Location Map

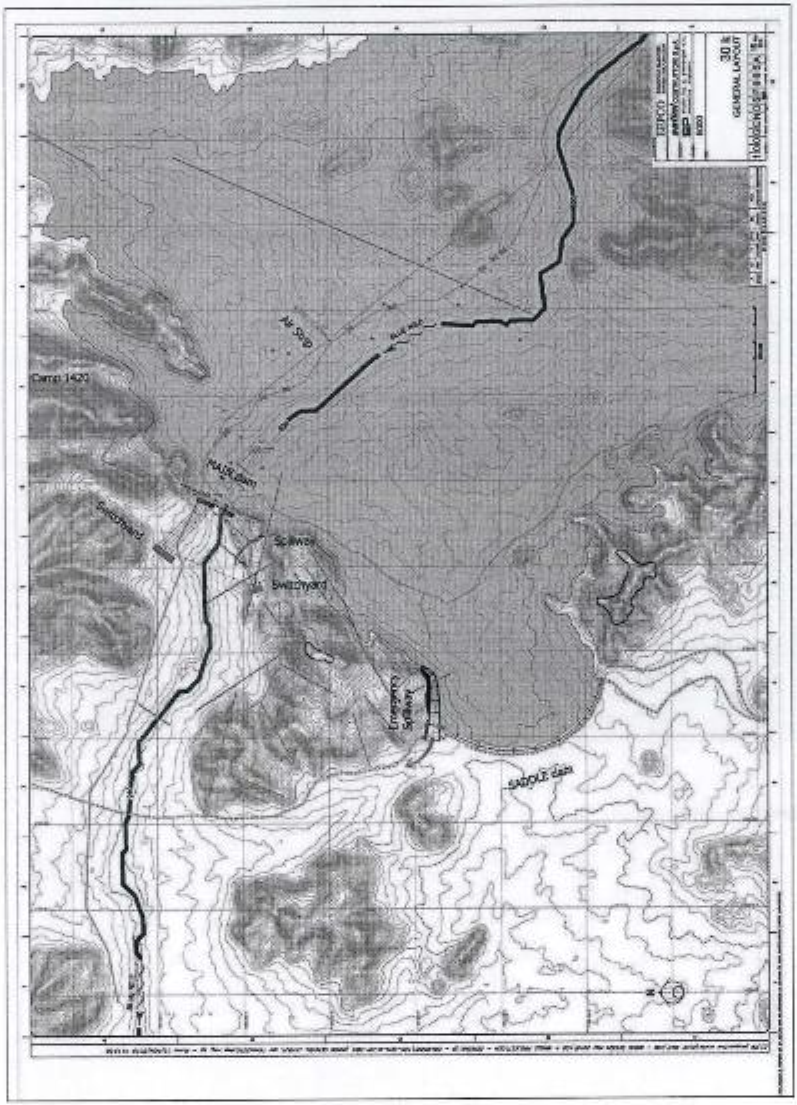

Figure 2 : General Layout of the GERD Project

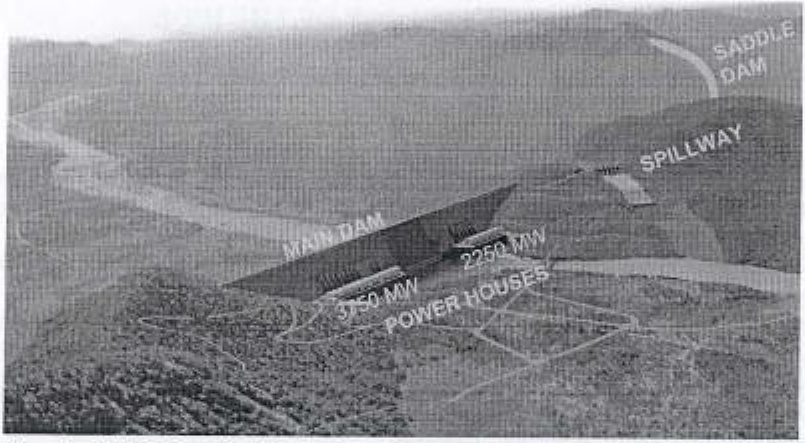

Figure 3: **Aerial Photograph of the GERD Project Area**

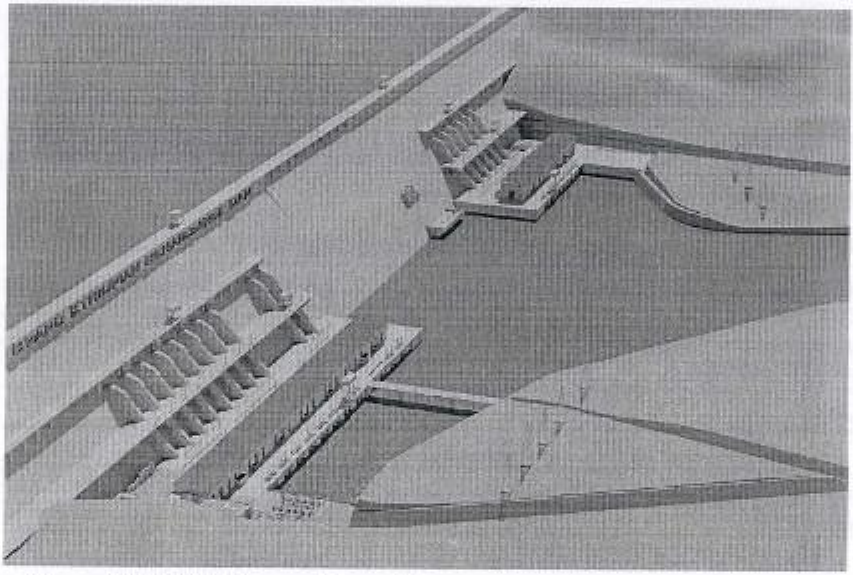

Figure 4: **GERDP Main Dam and Power House**

3 APPROACH AND METHODOLOGY OF THE IPOE

The approach and methodology of the IPoE includes the following:

3.1 Documents review:

- The IPoE at the outset identified important and relevant issues that needed to be assessed with respect to the GERDP and related these issues to specific titles of GERDP design and study documents.
- The identified documents were then made available in soft copies and on a dedicated website as described in the introduction.
- All the IPoE members had equal access to the documents that the GoE provided in soft and hard copies. Members of the IPoE reviewed the documents and submitted their comments/review notes to all IPoE members. The IPoE members deliberated on the review notes submitted by members of the IPoE at their regular meetings and these discussions are captured in the minutes of the IPoE meetings.

3.2 Field visits:

Four visits to the GERD project site were organized for the members of the IPoE to see and understand the status of project implementation

3.3 Technical subcommittee

The IPoE established a geotechnical expert group to review geotechnical documents of the GERDP and conduct site investigation and verification study. The report of the geotechnical expert group is part of the review notes of the IPoE.

3.4 Discussions and documentation at regular IPoE meetings:

The IPoE has conducted six regular meetings in the three countries. Reviewed documents of GERDP are discussed on the basis of review notes prepared by members of the IPoE. These discussions are captured in the minutes of the IPoE at the end of each meeting. The minutes of meetings are annexed.

3.5 Final Report of the IPoE

As per IPoE terms of reference and on the basis of the reviewed GERDP documents, field visits and discussions the final report is to be submitted to the Governments of Egypt, Ethiopia and Sudan.

4 REVIEWED DOCUMENTS

Based on its ToR, the IPoE, in order to fulfill its mandate and be able to assess technically the GERD project, has identified, on its first and second meetings, the required documents to be assessed and the submission modality. The IPoE has also prepared an issue-based document list to make sure that all project related aspects that are needed to fulfill the tasks of the IPOE are covered within the submitted project documents.

The full document list and a table showing the status of review is attached in Annex 2 of this report. In summary:

- 153 documents have been submitted to the IPoE during May 2012 to May 2013, of which **103** are drawings, **7** are maps, and **43** are reports. The IPoE reviewed only the relevant documents.
- **12** Reports have been reviewed, of which: **2** are environment & socio-economics documents, **3** are water & hydrology documents, **7** are dam engineering documents.
- **16** geotechnical documents were submitted temporarily to the geotechnical team during their mission as background information.

4.1 List of Requested Documents

Table 3 represents the list of documents and their status

	Document	Related Subject	Status	Submission Date
1	Design Criteria-Basic Design, December 2010	Dam Engineering	Submitted and Reviewed	July, 2012
2	Main Report (Volume I)-Basic Design, November 2010	Dam Engineering / Water Resources	Submitted and Reviewed	July, 2012
3	Hydrological Report, April 2012	Dam Engineering / Water Resources	Submitted and Reviewed	May, 2012
4	Gated Spillway-Hydraulic Calculations, August 2012	Dam Engineering / Water Resources	Submitted and Reviewed	October, 2012
5	RCC Trial Mix Design (A), July 2012	Dam Engineering	Submitted and Reviewed	November, 2012
6	Main Dam Stability Analysis (A), July 2012	Dam Engineering	Submitted and Reviewed	November, 2012
7	Main Dam Stability Analysis (C), March 2013	Dam Engineering	Submitted and Reviewed	April , 2013
8	Main Dam Stability Wedge Analysis , February 2013	Dam Engineering	submitted and Reviewed	April , 2013
9	RCC trial Mix Tests (B), Jan.	Dam Engineering	Submitted and	April ,

	2013		Reviewed	2013
10	Hydrological and Reservoir Simulation Study, August 2011	Water Resources	Submitted and Reviewed	July, 2012
11	Environment and Social Impact Assessment (ESIA), November 2011	Environment and Socio-Economics	Submitted and Reviewed	May,2012
12	Initial Transboundary Environment Impact Assessment (ITEIA), October 2012	Environment and Socio-Economics	Submitted and Reviewed	October, 2012
13	The saddle dam design documents	Dam Engineering	Temporarily submitted to the Geotechnical mission	February 3-9, 2013
14	Considerations on Dam Elevation– Dec.2010	Water Resources	Not Submitted	
15	Dam break analysis study	Water Resources	Not submitted	under preparation
16	Energy Production & Reservoir Operation Studies	Water Resources	Not Submitted	
17	Environment and Social Management Plan (ESMP)	Environment and Socio-Economics	Not Submitted	
18	Vegetation biomass removal study	Environment and Socio-Economics	Not Submitted	under preparation
19	Quality Assurance Plan and Manuals	Environments and Socio-Economics / Dam Engineering	Not Submitted	
20	Main Dam Foundation Geotechnical Assessment, January 2013	Dam Engineering	Not Submitted (November 2012 version was temporarily made available to the Geotechnical mission)	Available but not released by the Employers Representative

4.2 Documents Brief Description

4.2.1 Design Criteria - Basic Design, December 2010

The Design Criteria define the data and standards required to design the different dam structures (i.e. shear strength and deformation modulus properties, factor of safety,...etc.). The Design Criteria-Basic Design, had been prepared for 13 design and construction activities and main structures, namely: excavations - curtain and consolidation grouting - drainage - roller compacted concrete (RCC) main dam design - rockfill saddle dam- concrete structures - stability of banks - spillway - outlets - intakes and power conduits - powerhouses - dams instrumentation - river diversion.

4.2.2 Main Report (Volume I) - Basic Design, November 2010

The Main Report (Vol. I) is a preliminary project report which had been prepared at the beginning of the Project (November 2010). Meanwhile, based on other project documents reviewed, the report does not include the updated features of the project. The report consists of 22 chapters, which can be listed as: topography- seismic tomography - other investigations - geology- hydrology - accesses - blue Nile cascade - project concept and layout - dam height- river diversion - dam- saddle dam - spillways - outlets - power house – Electro-Mechanical equipment - hydraulic steel structures - energy production studies - implementation planning - cost estimate and economic analysis land use - environmental study.

4.2.3 Hydrological Report, April 2012

The report illustrates the results of the hydrological studies carried out at Level 1 design stage, on the Blue Nile river basin for the design of the GERD project. The analyses are mainly based on the numerous hydrological and water resources investigations carried out in recent years on the Abbay/Blue Nile river basin. It also illustrates the flood routing studies, evaluation of the sediment, and sedimentation analysis.

The present report is divided in the following chapters: runoff- evaporation net losses - flood analysis - flood routing- sedimentation.

4.2.4 Gated Spillway - Hydraulic Calculations, August 2012

The report is a Level 1 Design report and it covers the methodologies, approaches and the hydraulic calculations of the gated spillway. <u>The report main topics are</u>: general characteristics- spillway crest- spillway chute - spillway flip bucket- plunge pool- excavated outlet channel.

4.2.5 RCC Trial Mix Tests (A), July 2012 and version (B), January 2013

The report illustrates the results of the Level 2 RCC trial mix tests carried out at the GERDP site laboratory and Levelton laboratory in Canada. The results of these RCC trial mix tests will be used for Level 2 design purposes.

<u>The report main chapters are</u>: laboratory equipment and test procedures- test results (cement and pozzolanic materials, aggregate, water content, vebe tests, shear-, compressive- and tensile tests, etc.) - expected values of critical design parameters.

4.2.6 Main Dam Stability Analysis (A), July 2012

It is a Level 1 Design report which is based on design parameters suggested by the USACE EM1110-2-2006 for preliminary design purposes. The principal purpose of the report is to assess the dam stability and the state of stresses in the dam structure. The stability analyses were carried out by applying two-dimensional Finite Element Methods (FEM) and adopting different types of analysis on four typical dam sections which were considered as representative for the dam structure.

The report main topics are: geometrical model- methodology and basic assumptions- loads- design parameters- natural frequencies- stress analysis- displacements- sliding stability analysis- penstock upper bend & thrust block.

4.2.7 Main Dam Stability Analysis (C), March 2013

This report illustrates the global stability analysis of the main dam structure and it is an updating and integration of the study on the RCC trial mix tests version B carried out in January 2013 presented in report 220-STA-R-SP-001-B. The study is based on the following:

(1) Methodologies and basic assumptions described in the Design Criteria, (2) Foundations characteristics illustrated in the relevant report, (3) Seismic Hazard Analysis, (4) Relevant ICOLD bulletins Main Dam stability analysis and, (5) RCC trial mix tests.

The analysis presented in the report has been carried out on the potentially critical failure surfaces within the dam body (on horizontal planes representative of construction joints) and at the dam-rock contact. The study is carried out by means of a bi-dimensional analysis using Finite Element Modeling. The results allow to assess the stability of the dam verifying the stability against sliding and overturning and the stresses in the dam structure.

The report main topics are: geometrical model, methodology and basic assumption- loads- design parameters- response spectrum analysis - stress analysis- displacements- accelerations- sliding stability analysis- overturning stability.

4.2.8 Main Dam Stability-Wedge Analysis, February 2013

This report illustrates the stability analysis of the gravity dam structure with regard to sliding along sub-horizontal joints in the rock mass foundation, and complements the study of dam sliding analysis presented in: 220 STA R SP 001 B – MAIN DAM STABILITY REPORT.

This report is based on:

- Dam layout illustrated in related drawings
- Methodologies and basic assumptions described in USACE manuals
- Rock mass and discontinuities characterization illustrated in the relevant report 220-RMK-R-SP-001- C, Main Dam Foundation Geotechnical Assessment.

The analyses presented in the report are:

- Multiple wedge analysis following the USACE recommendations and based on multi-surface failure mechanisms, carried out for the four sections representative of dam structure already studied in the Main Dam Stability Report
- Limit equilibrium stability analysis carried out for the Dam + Power House section 1+280.

The report main topics are: methodology and basic assumptions- loads- design parameters- results and conclusions.

4.2.9 Hydrological and Reservoir Simulation Studies, August 2011

The present simulation study in this report is materialized to assess the downstream impacts of GERDP construction, first impounding and operation on the Nile downstream flows. It was meant to analyse potential impacts mainly on the High Aswan Dam (HAD), the largest downstream regulating reservoir, and in particular on its operation based on the comparison of water resources management simulation without and with GERDP.

An analysis of the water availability and uses in Egypt, Ethiopia and Sudan identifies irrigation lands location along the Blue Nile, the White Nile and the Atbara River (in Sudan) and along the Main Nile downstream HAD (in Egypt) had been made. The existing water infrastructures in Ethiopia (six existing structures), Sudan (five existing dams) and in Egypt with HAD have been listed and main features shortly described in this report. Simulations have been carried out considering the present Nile water management system at HAD that is to say without GERDP.

<u>The report main topics are</u>: description of the Nile basin hydrology of the Nile basin and the main infrastructure - present Nile water management- construction and first impounding of GERDP- operation of GERDP. Also, it contains detailed annexes for the data used and main study calculations outputs.

4.2.10 Environmental and Social Impact Assessment (ESIA), November 2011

The report presents the background and location of the GERD project as well as the objectives, scope and methodology of the ESIA. It also outlines the various engineering components (i.e. main dam, saddle dam, reservoir, river diversion, spillway/outlets, electro-mechanical equipment, hydraulic structures, access roads, etc.) as well as construction materials, labour and site facilities. Project costs, economic cost/benefit analysis, and the project implementation schedule are summarized. It illustrates the environmental policy, legal and administrative framework within Ethiopia as well as relevant national strategies and sector policies. It summarizes the existing physical, biological and socio-economic environments primarily within the GERD reservoir area (direct impact zone) but also includes the reservoir catchment area, i.e. Blue Nile Basin within Ethiopia (for climate and hydrology). It also outlines the beneficial and adverse impacts of the GERD project on the physical, biological and socio-economic environments. The report outlines the costs of environmental mitigation, management and monitoring as well as the funding mechanism.

<u>The report main topics are</u>: project description, environmental policy, legal and administrative framework, baseline environment, environmental impacts and mitigation measures, project alternatives, public consultation, environmental management plan, environmental monitoring plan, environmental mitigation, management, monitoring and training costs.

4.2.11 Initial Transboundary Environmental Impact Assessment (ITEIA), October 2012

The report objective is to assess the potential impacts that the construction and operation of the GERD may induce on the downstream environment and on the communities living along the floodplains of the Nile River. The downstream impact areas extend from the Ethiopia/Sudan border along the river channel and related adjacent floodplain and wetland areas of the Blue Nile and Main Nile to Lake Nubia/Nasser. This study is based on secondary data and review of relevant literature. The report is meant to identify the beneficial impacts in Sudan and Egypt and also, the adverse impacts in Sudan and Egypt, especially the impacts of reservoir impounding in Egypt.

<u>The report main topics are</u>: project description- international water rights implications of the GERD project- geopolitics and water development in the Nile basin- baseline environment of downstream project influence area- impacts of GERD in Sudan and Egypt- environment management plan- environment monitoring plan.

5 FINDINGS AND RECOMMENDATIONS

5.1 General

This Chapter provides a summary of the findings and recommendations prepared by the IPoE members. This summary is based on a detailed review of the documents submitted to the IPoE members (as listed in Annex 2) and reflect the wide range of technical issues raised and discussed during IPoE meetings. The detailed Review Notes, as well as corresponding responses and clarifications, prepared by the IPoE members are presented in Annex 5.

The findings and recommendations are divided into three areas of technical expertise, namely:

- Dam Safety and Engineering
- Water Resources and Hydrology
- Environment and Socio-economics.

5.2 Dam Safety and Engineering

5.2.1 General

Section 5.2 summarizes the findings and recommendations of the detailed Review Notes prepared by the Dam Engineering Expert during the past 12 months, reflecting the technical issues raised and elaborated by IPOE members. Furthermore, the findings and recommendations of the geotechnical mission conducted in early February 2013 are summarized. The detailed Review Notes, the Geotechnical Mission Report and the corresponding responses of the members of the IPoE are compiled in Annex 5 of this Final Report.

The subsequent sections contain the summaries of the following Review Notes and Geotechnical Mission Report including the responses of the members of the IPoE:

1 - Design Criteria-Basic Design, December 2010
2 - Main Report (Volume I)-Basic Design, November 2010
3 - Hydrological Report, April 2012 (Chapter 4: Flood Analysis)
4 - Gated Spillway-Hydraulic Calculations, August 2012
5 - RCC Trial Mix Design, July 2012 and January 2013
6 - Main Dam Stability Analysis, Version "A", July 2012 & Version "C", March 2013
7 - Geotechnical Mission Report, February 2013
8 – Main Dam Stability-Wedge Analysis, February 2013

It is noted that the Level 1 Design documents on the Saddle Dam Stability Analysis was made available temporarily to the Geotechnical Mission Group (headed by the Dam Engineering Expert member of IPoE), during the mission. However, it was not made available to the IPoE for review and commenting. The original version had to be modified following the discussion and remarks of the Geotechnical Mission. The preparation and clearance by the Project Office of the modified Stability Analysis Report was not finalized at the time of the preparation of the Final Report of the IPoE.

5.2.2 Design Criteria-Basic Design, December 2010

5.2.2.1 General

The "Design Criteria-Basic Design, December 2010" was made available to the IPoE in early July 2012 through the database of the web site "GERD.GOV.ET". The corresponding Review Note was submitted to the IPoE on July 17, 2012, for review and commenting.

5.2.2.2 Findings

The present document "Design Criteria-Basic Design, December 2010" is of general nature only and does not include project- and site specific conditions. Such basic design criteria are acceptable as an early general guideline at the beginning of the GERDP. This report needs to be updated and detailed as well as to reflect the prevailing geological, geotechnical, seismological, hydro-geological, hydrological and hydraulic conditions at the site of the GERDP.

It is noted that the present Design Criteria refer to a number of international Standards, Codes and Guidelines including ICOLD and USACE which is appreciated.

5.2.2.3 Recommendations

In view of the fact that the construction of the GERDP is already ongoing and most of the corresponding geotechnical field and laboratory investigations are completed, it is highly recommended that the "Design Criteria-Basic Design, December 2010" report is refined and detailed as well as updated to reflect the actual project- and site specific conditions known today. The most essential geotechnical, seismological, hydro-geological, hydrological, hydraulic and structural design data should be compiled in a consolidated Design Criteria Report and should not be scattered in numerous different design reports. For the different main structures such as saddle dam, river diversion, spillways, bottom outlet, powerhouse, more project- and site specific design criteria should be specified.

5.2.3 Main Report (Volume I)-Basic Design, November 2010

5.2.3.1 General

The "Main Report (Volume I)-Basic Design, November 2010" was made available to the IPoE in early July 2012 through the database of the web site "GERD.GOV.ET". The corresponding draft version of the Review Note was submitted to the IPoE by the end of August 2012 for review and commenting.

5.2.3.2 Findings

The present Main Report (Volume I) is a preliminary project report which was prepared by the EPC-Contractor at the beginning of the GERDP. This report provides a general understanding of the GERDP and reflects the status some 2.5 years ago. In view of essential design modifications and/or changes introduced during these past years the present report is outdated. For example, the type of dam for the Saddle Dam was changed from a rockfill dam with central clay

84 KH

core to a rockfill dam with a bituminous surface sealing, and the foundation sealing was changed. The length of the side channel spillway (located at the Saddle Dam) was changed compared to the other recent design report. In addition, based on the new geotechnical and geological findings, the interaction between the main dam, abutments and excavation of the power house should be further studied. The optimization of the spillway capacities and the height of the dams under consideration of the freeboard requirements were not presented.

5.2.3.3 Recommendations

As noted above the original design (2010) of the GERDP was changed due to various new hydrological, geological and geotechnical findings. Therefore, it is highly recommended to update the original Main Report to describe the reasons for the changed design as well as the present design of the changed project components such as the Saddle Dam, its seepage control, the spillways, etc.

The stability of the Main Dam and other main structures should be verified under consideration of the additional geological and geotechnical findings. The interaction between the Main Dam and the Powerhouse should be studied and clarified. The optimization of the system "spillway capacities and dam heights" under consideration of the retention effect and freeboard requirements should be documented.

In view of the scale and importance of the GERDP, it is strongly recommended to prepare an updated version of the Main Report, reflecting all the modification and changes introduced so far.

5.2.4 Hydrological Report, April 2012 (Chapter 4: Flood Analysis)

5.2.4.1 General

The "Hydrological Report, April 2012" was made available to the IPoE through the database of the web site "GERD.GOV.ET". In view of safety aspects it was agreed that Chapter 4: Flood Analysis will be reviewed by the Dam Engineering Expert. The other chapters were reviewed and separately commented by the Water Resources and Hydrology Expert.

The corresponding Review Note on the Hydrological Report, April 2012, Chapter 4: Flood Analysis was submitted to the IPoE on October 4th, 2012, for review and commenting.

5.2.4.2 Findings

The methodology to derive the flood frequency relationship on the basis of the regional frequency analysis is endorsed in general.

The reduction of the PMF from 38,750 m^3/s to 30,200 m^3/s is not supported by the IPoE as the approach to derive the Francou-Rodier coefficient K is questionable. K coefficient of 4.5 was derived and applied by the EPC Contractor which is a very low value for extreme flood events. According to ICOLD Bulletin 125 (2003), Dams and Floods, all datasets of maximum extreme floods collected worldwide showed K values between 5 and 6. A K coefficient of 5 would result in a PMF of about 41,500 m^3/s.

For the purpose of dimensioning the spillways 22 annual maximum flood events were normalized and clustered according to their similarity in shape. At the end of this procedure three different "families" of hydrograph shapes, named Cluster 1, 2 and 3, were identified. For the flood routing process Cluster 3 was selected by the EPC Contractor to determine the design discharge for the spillways and Cluster 2 for the rise of the reservoir water level and the spillway rating curve. This approach was not supported by the Dam Engineering Expert who favors the application of Cluster 2 only.

As part of the response of the Ethiopian IPoE members on the Review Note related to the Gated Spillway, the three different Clusters 1, 2 and 3 were applied to calculate the peak discharges of the spillways and the rises of the reservoir water level for the 10,000-year flood and the PMF of 30,200 m^3/s. The results of this additional analysis showed that the peak discharges and the water level rises of the reservoir for Clusters 1 and 2 are very similar, representing a combined frequency of P=0.59. The peak discharges of Cluster 3 are about 10 % smaller than the ones calculated by Clusters 1 and 2. Also the rise of the reservoir water levels is about 1 m to 1.4 m less than for Clusters 1 and 2.

For the routing of the original PMF of 38,750 m^3/s the application of Cluster 3 appears to be reasonable. Complementary flood routing calculations carried out by the Ethiopian IPoE members showed also that the average runoff values of the PMF with a peak flow of 38,750 m^3/s and Cluster 3 and the PMF with a peak flow of 30,200 m^3/s and Cluster 2 are 123 mm and 125 mm, respectively. The original 2010 basic design PMF flood has an average runoff value of 120 mm. These complementary calculations underline the fact that different PMF flood hydrographs with significantly different peak flows could be based on similar average runoff values.

5.2.4.3 Recommendations

It is strongly recommended to apply Cluster 2 on the 10,000-year flood for the dimensioning of the spillways and of the height of the Saddle Dam under consideration of the freeboard requirements.

Based on the results of the complementary reservoir routing calculations carried out recently by the Ethiopian IPoE members and in view of the philosophy of deriving extreme flood events it is recommended that the originally derived PMF peak flow of 38,750 m^3/s with Cluster 3 flood hydrograph shape remains valid and is used for design purposes.

5.2.5 Gated Spillway-Hydraulic Calculations, August 2012

5.2.5.1 General

The Review Note on the Gated Spillway-Hydraulic Calculations, August 2012, was submitted to the IPoE on November 21, 2012.

It is noted that the reviewed design report is a well prepared design document in view of the Level 1 Design stage. Nevertheless, this design report is explicitly marked as a "Preliminary Issue", "For Comments" and "Not good for construction". The shortcomings are noted below.

5.2.5.2 Findings

Discharge capacity of the gated Spillway

- The main deficiency of this design report is the determination of the design discharge for the dimensioning of the gated spillway. The design discharge and the related rises of the reservoir water levels were derived by the reservoir routing calculations presented in the Hydrological Report, April 2012. Chapter 4 - Flood Analysis of this report was already commented above, therefore, is not repeated again.
- The modification done on the spillway design should be documented, including the influence of the relevant flood conditions on the freeboard.

Hydraulic dimensioning of the Head Works Structure

- For the dimensioning of the head works of the spillway the "n-1" rule was not applied in the report. During the 5th IPoE Meeting the Ethiopian IPoE members informed that according to the Employer's Requirements, the 10,000-year flood should be passed with the assumption that even two (2) gates are jammed. The corresponding results (peak discharges and rises of reservoir water levels) for the 10,000-year flood and the PMF using Cluster 2 as shape of the hydrograph were presented by the Ethiopian IPoE members.
- In this context the freeboard requirements were noted by the Dam Engineering Expert which shall be determined on the basis of the wind setup and the wave height, both depending on the relevant wind velocity. For the different load cases recommendations on the return periods for the winds were given.
- It is understood that the design discharge of the spillway shall be determined by an integrated and combined approach under consideration of different flood events, the "n-1" and/or "n-2" rules, the hydraulic losses along the approach channel and the necessary freeboard requirements. The response to the above comments has been submitted to the IPOE, which is attached in Annex 5.

Duct Aeration System

- The duct aeration system is accepted, however, its location may be optimized.

5.2.5.3 Recommendations

Updating of the design report of Gated Spillway - Hydraulic Calculation, August 2012.

It is strongly recommended that the design report of Gated Spillway - Hydraulic Calculation, August 2012 is updated to reflect all the noted aspects.

Discharge capacity

- It is recommended not to reduce the original peak flow of the PMF (2010) which was estimated at 38,750 m^3/s. After the 5th IPoE Meeting complementary reservoir routing calculations were carried out by the Ethiopian IPoE members which showed that a solution can be developed to discharge the PMF with the original peak flow of 38,750 m^3/s

- It is recommended that the peak outflow from GERD should observe the outlet capacity of Roseries under PMF condition.

Hydraulic dimensioning of the head works

- The head works of the spillway should be designed for the 10,000-year flood using Cluster 2 only and under consideration of the hydraulic losses along the approach channel, the "n-1" or/and "n-2" rule (Employer's Requirements) and the freeboard requirements of the dams. The designed head works / spillway structures should be also capable to discharge the PMF event (after reservoir routing) without causing significant damages to the project.

Side channel spillway - Saddle Dam

- It was noted by the Dam Engineering Expert to consider dropping the side channel spillway with a crest length of 300 m and located at the Saddle Dam in view of its small discharge capacity (93 m^3/s only during the 10,000-year flood) but its high construction costs. It would be much more beneficial to the GERDP to invest the corresponding money in the gated spillway to increase that discharge capacity. It is felt that such design modification would result in a higher discharge capacity for the same amount of investment. Furthermore, the construction and at a later stage the maintenance of the Saddle Dam would be simplified as a complicated interface element would be eliminated.
- If the side channel spillway remains, it has to be designed to avoid erosion critical to the saddle dam.

Hydraulic Model Tests

- It was noted that adequate scales should be applied for the physical hydraulic model tests. A scale of 1:100 as proposed by the EPC Contractor is considered too small. A model scale of about 1:60 is considered to be more suitable for the intended purposes.

Outlet Channel

- The frequency of the operation of the gated spillway and the resulting flow velocities along the outlet channel should be analyzed. Based on the results of this analysis the potential risk of erosion along the outlet channel should be assessed.

The capacity of the bottom outlet

- It is not clear whether the present design considers (capacity, functionality) the minimum mean flows of the dry months release to the downstream countries in case the power generation facilities and the related power transmission system is out of operation and insufficient or no discharge capacity of the gated spillway is available. This should be investigated.
- The need for additional releases after normality is restored, to compensate for possible deficit accrued during the period of shutdown, to be considered.

5.2.6 RCC Trial Mix Design, July 2012 and January 2013

5.2.6.1 General

The first version of the Level 2 Design report "RCC Trial Mix Tests", July 2012, was made available in October/November 2012 which was updated in January 2013. This updated version 520-RCC-R-SAR-002-B was made available to the IPoE in middle of April 2013.

The purpose of this design report is to present the results of all the tests carried out for the Level 2 RCC mix design at the site laboratory of the GERDP and the Levelton laboratory in Canada. In total 165 mixes were prepared and tested using different materials to study the key properties of the RCC. The EPC Contractor was supported by the international consultant E. Schrader.

5.2.6.2 Findings

For the RCC mixes the aggregates were obtained from the quarries QR3 and QR4 as well as from the dam excavation. Six different types of cement, three different cementious materials and nine different additives retarder were tested. In addition to these mixes, 50 tests were carried out during the execution of the shear pads and full scale trial embankment.

The principal purpose of the RCC trial mix design was to confirm the dam design parameters adopted in the Level 1 Design, to optimize the dam zoning, to verify the property of the horizontal joints with mini pads and shear pads and to test specific mix properties.

The main RCC laboratory, installed on the right side of the GERDP dam site, is well and fully equipped to prepare and cure the test cylinders, carry out compressive, split and tensile tests, stress-strain tests, permeability tests, etc.

For each mix 26 cylinders had been prepared to test the strength at 3, 7, 14, 28, 56, 90, 180 and 365 days. The modulus of elasticity at 25%, 50%, 75% and 100% of the f_c was computed for each compressive strength test.

As the tests are ongoing, this report will be updated with further results and comments. Based on the available results the following main findings and conclusions can be derived:

- Aggregates: Both quarries result in similar very good aggregates and thus, very similar RCC properties. Weathered material presently being evaluated can be used at about 15% to 35% of the total aggregates, which may positively result in a lower modulus of elasticity and more strain capacity of the final mix.
- Cement: Both Cementir and Messebo cement result in essentially the same fresh mix and hardened material properties.
- Compressive Strength: With a cement content of 75, 100 and 125 kg/m3 an average compressive strengths of 12, 16 and 19 MPa is reached after 90 days, respectively. These figures show that the compressive strength of the RCC will be higher than the assumed design data, thus will not be the decisive parameter.

- Tensile Strength: The indirect split tensile strength is about 11% to 12% of the compressive strength, while the direct tensile strength is expected to be from 67% to 74% of the same.
- Modulus of Elasticity: The stress-strain curves show a non-linear behavior. The modulus of elasticity decreases with increasing load (softening of material with increasing stress level). The secant modulus of elasticity range from 18 GPa for strength of 10 MPa to 25 GPa for strengths of 15 MPa, at 25% of ultimate load. Note: there is a typing mistake in the design report. The strength of "25 GPa" shall be corrected to "15 MPa".
  The modulus of elasticity is higher than desired for lean and crack resistant concrete which may be lowered if the portion of the weathered rock is increased for the aggregates production. This influence is presently tested.
- Strain Capacity and Thermal Properties: The corresponding tests are underway or were completed at the Levelton laboratory. The available results are within normal ranges.
- Shear Strength: In general friction angle is excellent, reaching 50° and more. The average cohesion is good (>1MPa) even if the next layer is placed within 4 to 5 hours, however, the cohesion value are scattered, ranging from 0.57 to 1.50 MPa for joints without bedding mix. For correctly treated joints with specific air-water jetting plus bedding mix, cohesion are the highest, ranging from 1.93 to 2.57 MPa.
- Permeability: It is underlined that the critical issue in respect of the permeability is the quality and the performance of the horizontal joints, rather than the mass of the RCC. For this reason further tests are foreseen in the next Full Scale Trial embankment.

Based on the available results the expected values for the critical parameters such as the compressive and tensile strengths of the RCC and the tensile strength, cohesion and friction angle of the lift joints are endorsed for further design purposes, provided the lift joints are executed in a professional manner. The installation of a proper QMS will be of utmost importance during construction.

5.2.6.3 Recommendations

The results of the ongoing tests should continue to be incorporated in the present assessment. The same professional care, responsibility and detail is expected from the EPC Contractor as done in the past.
In case weathered rock is mixed with sound rock for aggregate production, the long term performance, durability and Alkali reactivity of the RCC should be studied and confirmed.

5.2.7 Main Dam Stability Analysis, Version "A", July 2012 & Version "C", March 2013

5.2.7.1 General

The version "A" of the "Main Dam Stability Analysis", July 2012, was made available to the IPoE at the end of October/beginning of November 2012. The corresponding Review Note was issued in December 2012. The updated version "C" of this Level 1 Design Report 220-STA-R-SP-

84

001-C, March 2013, was made available to the IPoE at the middle of April 2013. The updated Review Note, May 2013, was issued in early May 2013.

The present updated Design Report is a well prepared and detailed design report in view of the Level 1 Design stage which will be refined and updated for construction purposes. The principal purpose of this stability analysis report has been to assess the following:

- the safeties against sliding and overturning on any horizontal planes within the dam structure and at the dam-rock contact, and
- the state of stress in the dam structure under static and dynamic loading conditions.

The sliding stability of the rock foundation in view of the sub-horizontal discontinuity set K0 has been studied and presented in the separate design report 220-STA-R-SP-002-A, Main Dam Stability-Wedge Analysis, February 2013. This separate design report was reviewed and commented below.

5.2.7.2 Findings

The stability analyses were carried out by applying two-dimensional Finite Element Methods (FEM) and adopting different types of analysis on four typical dam sections which were considered as representative for the dam structure. The stability report covers the methodology, the basic assumptions, load and design parameters and results of the analyses of the stresses, displacement, acceleration and sliding and overturning stabilities.

The global stability analysis is based on design parameters (friction angle and cohesion) as suggested by the USACE EM 1110-2-2006 for preliminary design purposes, which are assessed as conservative shear parameters. Nevertheless, the assumed shear parameters will be updated once the results of the on-going RCC Trial Mix Tests are available.

As far as the verifications of the stresses are concerned updated tensile strength values obtained from the RCC Trial Mix Tests were used in the updated stability anaysis. At the Level 2 Design stage all the analyses will be updated, adopting parameters resulting from the RCC full scale trial tests.

The stress analysis indicated that in all dam sections the following was observed:

- The effective principal compressive stresses are within the acceptable limits. It is underlined that the compressive stresses are not the decisive parameters;
- No tensile stresses were found under the normal operation conditions, and
- Tensile stresses for unusual and extreme loading conditions were high but within acceptable limits, depending on the quality of the RCC.

In order to reduce the peak tensile stresses in the dam body caused by the extreme loading condition SEE (Safety Evaluation Earthquake) the Response Spectrum Analysis (RSA) applied at the Level 1 Design will be replaced by the more sophisticated "Acceleration Time Histories" method.

According to the sliding analysis all factors of safety against sliding along the horizontal lift joints and at the dam-rock contact are above the required factors of safety. The sliding stability can be improved by extending the length of the bedded lift joints, if needed. The calculated factors of safety against sliding in the rock foundation are rejected as the effect of clearly identified sub-horizontal discontinuities (joints) was not taken into account. Reference is made to the design report 220-STA-R-SP-002-A, "Main Dam Stability-Wedge Analysis", February 2013.

It is noted that the present updated stability analysis (version "C") and its results is endorsed as a Level 1 Design document, provided few topics addressed in the updated Review Note are clarified with the EPC Contractor/Designer. Nevertheless, the Level 2 Design documents are urgently needed in view of the on-going construction activities.

5.2.7.3 Recommendations

As noted in the updated Main Dam Stability Analysis (version C), the IPoE support that the Level 2 Design documents will take the following into account:

- The geomechanical design parameter as obtained from the RCC Trial Mix Tests;
- The non-linear stress-strain behavior of the RCC material;
- The refined Acceleration Time History method for the dynamic analysis.

Under consideration of the above, it is expected that the peak tensile stresses presently calculated and caused by the earthquake loadings will be reduced.

Depending on the results and the interpretation of the geological / geotechnical mapping of the dam foundation and the sliding stability of the dam foundation (including the abutments) which still need to be carried out, the need of a 3-D based FEM model will be confirmed / justified.

5.2.8 Geotechnical Mission Report, February 2013

5.2.8.1 General

During the IPoE Meetings No.3 and No.4 the Dam Engineering Expert requested strengthening the technical team regarding geological and geotechnical topics which was accepted by the national members of the IPoE. The corresponding Geotechnical Mission took place during February 3rd and 9th, 2013. The Geotechnical Expert Group was composed of three international and seven national experts. The Mission Report of the Geotechnical Expert Group was submitted to the IPoE by the end of February 2013.

By end of March 2013 the Ethiopian members of the IPoE in consultation with the GERD Project Office (EPC Contractor/ER) commented/responded to the Mission Report of the Geotechnical Expert Group. These comments are reflected in the subsequent assessment and findings below.

5.2.8.2 Findings

The geotechnical investigations carried out by the EPC Contractor reflect the scale of the GERDP, although additional and complementary geotechnical field and laboratory tests and surveys will have to be carried out. The geotechnical investigations and their results are professionally documented.

The areas of concern are the status of the various analyses and design documents (Level 1 Design) in view of the on-going construction works. This is particularly true for the sliding stability of the Main Dam, the newly adopted design of the Saddle Dam (asphalt core replaced with bituminous face) and the seepage control measures in its foundation. These and other less important issues are addressed in detail in the Mission report.

In light of some of the suggestion given in the Mission Report and of the Employer's Representative comments the following documents/reports should be specifically issued by the EPC Contractor for the Main Dam and the Saddle Dam:

Main Dam:

1) A Level 2 Design Report, Sliding Stability of Dam utilizing a FEM model which simulates an in-homogenous rock mass including discontinuities and considering the strength reduction after failure and plastic stress redistribution.
2) A review of geological and geotechnical maps and sections in order to provide a comprehensive and synoptic presentation of all available information, including lithology, geotechnical units, discontinuities and hydrogeology.
3) A report dealing with hydrogeological monitoring results so far available.
4) A comprehensive Report dealing with the monitoring system of the Main Dam and its foundation.
5) Comparative tests on saturated rock samples (to test the fill materials would be recommended).
6) A Level 2 Design Report dealing with reservoir reconnaissance aimed to verify slope stability

Saddle Dam:

1) A Level 2 Design Report dealing specifically with the description, classification and assessment of the WEAK ZONES of the Saddle Dam foundation.
2) Revision B of the Level 1 Design GEOTECHNICAL REPORT.
3) A revision of the Level 1 Design Report SADDLE DAM STATIC CALCULATIONS.
4) Clarifications regarding Geological Issues and investigations.

Note: The Level 1 Design documents on the Saddle Dam were made available to the Geotechnical Mission of the IPoE on temporary basis during the Geotechnical Mission in February 2013.

Other answers and clarifications will be provided by the EPC Contractor in due time with the development of the Level 1 and Level 2 Design.

The comments of the Ethiopian IPoE members on the Main Dam comprised also the following topics:

- Regarding the peak and residual shear strength of the K0 joints frequently references are made to the Design Report 220-RMK-R-SP-100-C "Main Dam – Foundation Geotechnical Assessment", January 2013. Unfortunately, this report is not available to the IPoE. Nevertheless, the understanding of the Geotechnial Expert Group on the assumed shear strength was expressed in the separate Review Note on the "Wedge Analysis Report".
- Regarding the foundation treatment the question arose by the Geotechnical Expert Group how the K0 joints below the dam-rock contact will be treated. How can the strength of the weathered material (sometimes clay) found in the joint be improved?
- The EPC Contractor confirmed that a "time histories analysis" will be carried out for the dynamic analysis at the Level 2 Design stage.
- The Alkali reactivity tests were commented by the Ethiopian IPoE members as follows: "Alkali reactivity tests were extensively carried out and are presented in the following documents submitted to EEPCo/ER:
  - 202-GEO-R-SAR-001-F
  - 202-GEO-R-SAR-002-A
  - 202-GEO-R-SAR-003-A
- These documents present all tests carried out since the beginning of the project on concrete aggregate sources. Alkali reactivity risk was analyzed for each potential quarry site using different methods as follows: etc." Finally it was stated by the EPC Contractor that all methods applied confirmed that the aggregates are innocuous.
- As the Alkali reactivity of the concrete aggregates is a particular concern of the Sudanese IPoE members, the corresponding documents are requested to be made available to the IPoE.

The comments on the Saddle Dam can be summarized as follows:

- The existence of faults or weak zones in the foundation area of the Saddle Dam is of paramount importance, therefore, was treated in the dedicated report 532-GEO-R-SP-002-A, March 2013. This report was not available to the IPoE.
- The EPC Contractor agreed to include also stability verification along surfaces of minor resistance (residual soils disturbed by excavation).
- The design of the Saddle Dam related to the crest width, the camber, the freeboard, the seepage control measures such as the plastic concrete diaphragm, the bituminous surface sealing, etc. will be commented by the Dam Engineering Expert once the corresponding drawings, reports and analyses are available.
- As far as the sealing element of the Saddle Dam is concerned the comments of the Ethiopian IPoE members are well understood and respected, however, under consideration of the long term performance and safety aspects it needs to be clarified

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whether a central asphalt core or a bituminous face solution is the more suitable sealing element.
- Particular tests recommended or already planned before the visit of the IPoE will be carried out and evaluated for further design purposes. Those tests rejected by the Contractor to be carried out will have to be discussed with the Geotechnical Experts.

5.2.8.3 Recommendations

In order to understand the peak and residual strength of the K0 joints and their specific orientations and characteristics, the Level 1 Design Report 220-RMK-R-SP-100-C, "Main Dam-Foundation Geotechnical Assessment", January 2013, was not made available to the IPoE. Depending on the content of that design report further more detailed investigations and surveys need to be carried out.

The technical documents and reports listed above by the Ethiopian IPoE members and related to the Main Dam and Saddle Dam should be followed up.

This is particularly true for the Level 2 Design Report dealing with the stability analysis of the Main Dam, simulating an inhomogeneous rock mass including discontinuities and considering the strength reduction after failure and plastic stress redistribution. For the avoidance of doubts the sliding potential on the K0 joint set is meant.

In order to understand the functioning and performance of the changed Saddle Dam, the corresponding design reports, analysis and drawings need to be followed up. The Level 1 Design report on the Saddle Dam Stability Analysis, October 2012, was made available temporarily only to the Geotechnical Expert Group during the field inspection in February 2013
The saddle dam design has not fully reviewed by IPoE, therefore the IPoE recommends that the GoE should follow up.

5.2.9 Main Dam Stability – Wedge Analysis, February 2013

5.2.9.1 General

The Level 1 Design Report "Main Report Stability-Wedge Analysis", February 2013, was made available to the IPoE at the middle of April 2013 through the data base of the web side "GERD.GOV.ET". The corresponding Review Note, May 2013, was prepared by the Dam Engineering Expert supported by the Dr. Riemer, Consultant for Engineering Geology and Rock Mechanics.

In the Level 1 Design Report "Main Dam Stability Analysis", July 2012, the foundation of the Main Dam was considered to be a pseudo-continuum with geomechanical parameters derived from general rock mass ratings. The effect of the identified sub-horizontal discontinuities K0 on the sliding stability of the rock foundation was not taken into account. The impact of the existing discontinuities (joint) recorded at the dam site was highlighted by the Geotechnical Expert Group in their Mission Report, February 2013, and the need to analyze the sliding stability by means of "Wedge Analysis" and Finite Element Method or equivalent was addressed.

5.2.9.2 Findings

The purpose of this study was to verify at the Level 1 Design stage the sliding stability of the rock foundation at four typical dam cross sections, applying the Multiple Wedge Analysis as presented by the USACE EM 1110-2-2200, Gravity Dam Design.

The sub-horizontal discontinuity set K0 was identified to form a potentially critical slip plane, predominantly dipping less than 10° in downstream direction. This sub-horizontal stress relief planes in conjunction with two sub-vertical joint sets form blocks or prisms in the foundation, allowing displacement in the direction perpendicular to the dam axis.

Under consideration of the features of the K0 joints, the undulation angle and the positive impact of material bridges of the intact rock, the EPC Contractor/Designer adopted the following peak shear strength:
Friction angle of 50° and a cohesion of 723 kPa.

The Geotechnical Expert Group is of the firm opinion that this shear strength is too high to verify the sliding stability of the foundation of the Main Dam for the following reasons:

- First, when studying and considering the long-term stability of a rock foundation the **residual shear strength** of the joint system shall be used instead of the peak shear strength. This procedure and approach is recommended by ICOLD and other professional organizations as the residual strength is the only reliable parameter.
- Second, according to USACE EM 1110-1-2908, Rock Foundations, the selected design shear strength must reflect an **increased conservatism** in view of the scale and importance of the project, the consequences in case of failure, the availability of reliable test results, the uncertainties related to the unknown conditions of the joint system, etc.
- Third, the strains/displacements necessary to cause failure of the intact rock are typically an order of magnitude (a factor of 10) smaller than the ones of the discontinuities. Hence, the peak strength of the intact rock portion will already have been mobilized and will likely be approaching their residual strength before peak or residual strength along the discontinuities can be mobilized **(strain compatibility)**.
- Forth, the slope stability on the left abutment presented in the design report 520-RMK-R-SP-002-A dated April 2012, was carried out by the EPC Contractor/Designer applying a reduced residual friction angle of 32° on the natural joints. The contribution of the cohesion of the joint was not taken into account.

Against this background and allowing for a substantial dilation due to large scale undulations, a **friction angle of not exceeding 45° and "zero" cohesion is recommended for the Level 1 Design stage**. For the Level 2 Design stage the geological records need to be updated, detailed, compiled and evaluated.

Finally, it is emphasized that the deep excavations required for the construction of the two powerhouses at the toe of the Main Dam and the expected scours downstream of the flip bucket will eliminate the supporting forces of the resisting wedge, thus will further reduce the factor of safety against sliding.

5.2.9.3 Recommendations

For the Level 1 Design stage the methodology applied (2-D Multiple Wedge Analysis) is endorsed in principal. However, the shear strength parameters used in the analysis are considered too optimistic in view of long-term stability aspects. Therefore, the EPC Contractor/Designer has to reassess its original judgment, taken into account the results of its previous studies and reports.

It is also strongly recommended to perform urgently a detailed field survey on the actual orientations and features of the discontinuity K0 set at the excavation area of the dam foundation. The corresponding documentation and evaluation shall be certified by a qualified and independent party. Also the performance of complementary shear test has to be taken into consideration to derive at reliable design shear parameters.

As it is felt that the required factors of safety against sliding may not be achieved if more realistic and conservative shear strength parameters will be applied, a more sophisticated 3-D model applying the <u>Finite Element Method</u> should be employed as soon as possible. The application of such model requires also a better and clear understanding of the non-linear behavior of the rock and joint materials.

The application of the effective ground water pressures acting on the rock wedges is not entirely clear. In order to understand the hydrostatic pressures in the foundation, it is strongly recommended to perform FEM seepage analysis, reflecting the effect of the grout and drainage curtains. The calculation of the seepage flow underneath the dam would also provide more reliable information on the uplift pressure. This statement is particularly true regarding the dam cross sections with the power house.

In view of the on-going construction works and the uncertainties related to the shear strength of the sub-horizontal slip planes (K0 joints) in the foundation of the dam, highest priority shall be given to clarify this particular topic as soon as possible. Structural measures might be needed to stabilize the foundation to achieve the required safety against sliding.

5.3 Water Resources and Hydrology

5.3.1 General

The following documents relevant to the water resources and hydrology aspects of the GERDP were submitted to the IPOE for review:

i. Hydrological Report: Document 204 – GEN-R-SP-001-B of April 2012.
ii. Hydrological and Reservoir Simulation Studies: Document RP1-002582 / REV-C of August 2011.
iii. Relevant parts of the Basic Design Volume 1 – Main Report: Document 100-GEN-R-SP-001-A of November 2010.

The overall objectives of the reviews were to assess whether the information contained in the reports is complete and in compliance with international practice and guidelines as would apply to a project of this magnitude and importance, in order to be able to assess the downstream impacts.

The main findings from the respective reports are summarized below:

5.3.2 Hydrological Report

5.3.2.1 Findings

- The report is focussed on the GERDP site only. No upstream developments (existing or into the future) are taken into account as is standard practice, and no downstream flow records and hydro-meteorological information are given as would be needed to assess the downstream impacts of the GERDP. This information is partially covered in the simulation report. Particularly given the proposed upstream cascade development of similar magnitude than the GERDP, the upstream flow records could be of significant importance.
- Runoff records at the GERDP site are considered as reliable and representative. There does not appear to be any meaningful long term trend. No mention is made about sensitivity analysis related to possible climate change and of the potential impacts that may result.
- The estimation of evaporation losses at the GERD does not reflect the typical analyses performed. Although the estimated net evaporation is of the right order, the estimation is not sufficiently conclusive. There appears to be some confusion with respect to the use of "Potential Evapotranspiration", "Reservoir Evaporation" and "Potential Evaporation" which have different meanings and are not interchangeable.
- Substantial work was done with respect to the flood assessments. The corresponding comments and details are covered under Section 5.2 on Dam Safety and Engineering.
- The assumed sediment yield and trap efficiency are viewed as realistic for the estimation of sediment accumulation in the reservoir. However, the sediment deposition profile and densification of sediment over time have not been considered.

5.3.2.2 Recommendations

- The potential influence of the proposed cascade development on the flow regime and sediment load at the GERDP and further downstream needs to be investigated.
- The potential influence of climate change on the flow regime at the GERDP and further downstream to be investigated.
- Further assessments with respect to evaporation at the GERDP need to be performed, including verification against the actual evaporation at Roseires. Time series of rainfall and evaporation that are synchronized with the stream flow, need to be developed.
- The sediment deposition profiles in the GERD as well as the impacts (positive and negative) on downstream countries as a result of sediment reduction needs to be studied, including long term change in trap efficiency.

5.3.3 Hydrological and Reservoir Simulation Study

5.3.3.1 Introduction

- The Hydrological and Reservoir Simulation Study of August 2011 assessed/analyzed the potential benefits and impacts of the GERDP quantitatively in Egypt and qualitatively in Sudan.
- The report assessed downstream impacts on HAD during GERDP first impounding, considering three different scenarios: a normal case which corresponds to a sequence of average hydrological years at HAD, a sequence of dry years and a sequence of wet years. Analyses were also performed with respect to the normal operation of GERDP after first filling.
- Preliminary findings of the report are that the water supply in Egypt will not be affected during first filling of the GERD, given wet or average years, although power generation at the HAD will be decreased by about 6% due to the general lower water levels in Lake Nasser. Should the first filling occur during dry years, the HAD will reach the minimum operating level during at least 4 consecutive years which would significantly impact on water supply to Egypt and cause the loss of power generation at HAD for extended periods.
- As stated in the report the GERD project will increase the overall regulation capacity of the Eastern Nile Basin by about 60,000 Mm^3 which will add resilience to impacts of climate extremes including droughts and floods. It will also add substantially to the generation of hydropower in the region. Sediment loads downstream of the GERDP will be substantially reduced, flows downstream of the GERDP will in general be stabilized and floods largely be attenuated; these could have both positive and negative impacts.
- Whilst the GERD can stabilize downstream water supply, the report also shows that this may result in the GERD being drawn down to the minimum operating level for about 15 consecutive years.
- More detailed reviews and comments on the report are contained in Annex 5.

5.3.3.2 Findings

- This report reflects a preliminary attempt to assess the downstream impacts of the GERDP on water resources and power generation, both during initial impoundment and under regular operation. No detail is given on the simulation model (software) that was used. The analysis presented is very basic, and not yet at a level of detail, sophistication and reliability that would befit a development of this magnitude, importance and with such regional impact as the GERDP.
- The above analysis was not performed with respect to hydraulic structures in Sudan.
- Operating rules are not given for the existing dams/hydropower installations and very little detail on the planned operation of the GERDP.
- Mention is not made of the planned cascade developments upstream of the GERDP and of the potential impacts of these on the GERDP and further downstream.
- The mass balances presented in the report of water between the GERD and the HAD, could not be reconciled given the information presented.
- The use of average-, wet-, and dry periods in the analyses is very empirical.
- Account was not taken of losses due to infiltration during first impoundment of the GERD.
- Account was not taken of the potential use of the regulation capacity of Tekezi, Lake Tana, Roseires, Merowe during filling.

5.3.3.3 Recommendations

A comprehensive study of the GERDP in the context of the Eastern Nile System using a proven, sophisticated and reliable water resource system/hydropower model is strongly recommended to be able to assess and quantify the downstream impacts in detail with confidence. Items such as the following need to be covered:

- Probabilistic analyses based on multi-site stochastic stream flow generation .
- More detailed assessment and quantification of impacts on water resources and power generation in Sudan and Egypt.
- Probabilistic analyses of the impact of first impoundment of the GERD, until equilibrium of water levels is again reached at the HAD.
- Assessment and developing of different filling options and operating rules in the context of the Eastern Nile System.
- Some assessment of the influence of proposed upstream developments.

The proposed modelling and assessments can broadly be categorized into three components:

i. The core and main emphasis of which will be the Water Resource System/Hydropower Simulation Model. Key items to be assessed include studying the impacts of the GERDP on downstream water resources and developments during initial filling of the GERD and normal operations thereafter as well as develop the best operation rules for the Eastern Nile System.

ii. A Hydraulic River Model for assessing changes in water levels and riverbank flooding as well as sediment regime changes.

iii. A Water Quality component for assessing changes in dissolved oxygen and salinity.

A draft Scope of Work has been prepared for the 'Modelling Study', incorporating the relevant recommendations from the preceding sections (Annex 7), to be conducted jointly by the three countries through appropriate arrangement to be decided by the three Governments of Egypt, Ethiopia and Sudan.

5.3.4 Basic Design Volume 1 – Main Report (Relevant Parts)

5.3.4.1 Findings

The observations below are from a water resource and power generation perspective and are complimentary to the findings under Section 5.2.3 on Dam Safety and Engineering.

- In most instances the information given in the report with respect to the water resources and power generation aspects is very basic. Only general observations and remarks could therefore be made. This applies to optimization of power generation, implementation planning, the cost estimate and economic analysis.
- The definition of how reliability of power generation is determined is not given. Under certain circumstances an assurance of power generation of 95% as mentioned in the report, can be regarded as low.
- The GERDP is economically attractive. The economic justification is not given with respect to the installed capacity of 6000 MW. Particularly with consideration to the apparent low load factor and the cost of transmission to the main load centre, the economic considerations are not clear as far as the installed capacity is concerned.
- The dam size is consistent with the inflow at the GERDP site, but should also be considered in relation to the impacts downstream. Similarly, account should to be taken of future upstream storage.

5.3.4.2 Recommendations

- The need for generation of peaking power versus base power needs to be assessed in more detail. The relative needs for power generation at the GERDP during peak periods and as base load are also likely to change over time as the national power system develops, and need to be taken into account in the planning and sizing. Also the installed capacity of 6000MW should be verified.
- A clear definition and common understanding of the reliability of power generation is required.

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5.4 Environmental and Socio-Economics

5.4.1 General

Two key reports dealing with environmental and social impacts of the GERD were submitted to the IPOE:

- EEPCO, GERD Project Environmental and Social Impact Assessment, Vol. 1;November 2011
- EEPCO, GERD Project Initial Transboundary Environmental Impact Assessment, October 2012

These two reports reflect the present information regarding potential impacts, either beneficial or detrimental, of the GERD project on Ethiopia, Sudan and Egypt.

The findings and recommendations are presented separately for each of the two key reports, and introduce successively issues related to environment and socio-economics.

5.4.2 Environmental and Social Impact Assessment (ESIA) Report

5.4.2.1 Findings

- In terms of structure and content, the ESIA satisfies the recommendations of most international funding agencies, as its sections include Project Description, Institutional Framework, Baseline Situation, Impact Evaluation, Project Alternatives, Public Consultation, Environmental Management and Monitoring Plan. Detailed technical reports from the various specialists are presented in a set of 16 annexes. As intended, the ESIA is strictly limited to the impact zones located upstream of the dam site in Ethiopia. Sediment transport and sedimentation are addressed, but on the basis of existing information. Organic matter content in sediment, to better appreciate the evolution of water quality in the reservoir, is not provided.

- The ESIA provides comprehensive information on the existing water quality of the Abbay/Blue Nile River and its main tributaries feeding the proposed GERD reservoir, and provides a water quality forecast in terms of eutrophication risk, based on classical empirical models.

- However, the most important water quality issue, which concerns the reduction of dissolved oxygen because of the decay of flooded vegetation and soil, is not adequately addressed in the report. The impact is considered in the ESIA as insignificant because vegetation clearance will be carried out prior to first impoundment. The IPoE expresses reservation on such conclusions considering that: (i) large amounts of labile carbon in the top soil cannot be removed, (ii) vegetation clearance removes only a fraction of the existing biomass, and (iii) the area to be cleared is very large (1874 km^2) challenging the technical and financial feasibility of the clearance program. A study on vegetation clearance was reported to the IPOE as being in progress, but the report was not submitted for review.

- Based on information obtained from detailed socio-economic surveys, the ESIA report provides a good description of the socio-economic conditions currently prevailing within the proposed reservoir area (i.e. direct impact zone). The report also discusses the socio-economic impacts of GERD within the direct impact zone with respect to adverse impacts on the local population, household/livelihood assets, public infrastructure, and social services. A range of mitigation and livelihood enhancement measures are also outlined.

- The ESIA report also summarises the findings of the economic cost/benefit analysis which indicated that the GERD is an economically attractive project. However, the detailed cost/benefit analysis, including downstream costs and benefits was not made available, so the accuracy and reliability of these findings could not be verified by the IPoE.
- The report noted that the dam height was determined on technical criteria, such as energy production, reservoir filling, dam site morphology and upstream dam site location, so the optimization of the dam height does not consider environmental and socio-economic impacts downstream.

5.4.2.2 Recommendations

- For further appreciation of downstream impacts and dissolved oxygen balance, it is recommended that the assessment of sediment transport and its organic matter content is improved through a sediment monitoring program at the dam site and at least during the rainy season.
- The IPOE also recommends assessing the impact of first impoundment on water quality and particularly on methane gas content and dissolved oxygen depletion.
- More generally, the IPOE recommends that a trans-boundary impact assessment is undertaken for the downstream impact zones within Sudan and Egypt as detailed in the proposed scope of work (Annex 6).

5.4.3 Initial Trans-boundary Environmental Impact Assessment (ITEIA) Report

5.4.3.1 Findings

- As reflected by its title, the ITEIA is a preliminary desk study based on secondary information. The study identifies the main beneficial and adverse impacts of GERD in Sudan and Egypt, but does not provide a detailed assessment of the magnitude and extent of these trans-boundary impacts. This document may therefore be regarded as a scoping report.
- The Baseline Situation section delivers an environmental and social overview of the Nile basin and of the Blue Nile sub-basin. The overview is rather comprehensive but remains very general. Except for some information extracted from the GERD Hydrological and Reservoir Simulations Study and few data on Roseires reservoir, most of the information is too general to provide any effective basis for quantitative impact assessment.
- The Section "Impacts of GERD on Sudan and Egypt" is also preliminary, providing a general and qualitative overview of the potential impacts, except for those hydrological aspects reproduced from the GERD Hydrological and Reservoir Simulations Study report which provides tentative quantification of water resources (e.g. seasonal flows and evaporation).

- The downstream impact zone is defined as the area extending from the Ethiopian border along the river channel to Lake Nasser.

In addition to the findings on water resources aspects, already presented in Section 5.3 , the following specific environmental and socio-economic comments are highlighted in the ITEIA review:

- The water balance presented takes consideration of evaporation losses from the GERD reservoir and of changes in evaporation losses at HAD, but overlooks losses through deep percolation during first filling of the reservoir;
- The downstream impact of seasonal flow regulation is assessed in terms of beneficial impacts related to flood reduction in wet season and improved water supply in dry season, but the potential negative impact on recession agriculture and riparian forest as well as impact on the seasonal replenishment of ground water along the blue Nile and the main Nile river are not addressed;
- Impact of sediment load reduction through trapping by the GERD reservoir is also analyzed in terms of beneficial impacts for Roseires and for intake structures further downstream. However, potential negative impacts related to the loss of suspended organic matter, risks of riverbed and banks erosion and their consequences on agriculture livelihood and brick industry in Sudan are not addressed;
- On the basis of the ESIA conclusions, the ITEIA does not consider water quality released downstream GERD as an issue for Roseires reservoir. The IPOE considers that this statement is over optimistic, particularly regarding dissolved oxygen and methane gas, and that it must be adequately demonstrated as implications on Roseires fisheries and biodiversity may be significant;
- The ITEIA does not provide an economic assessment of the GERD project from a regional perspective which takes account of the project's benefits and costs in downstream countries;
- The socio-economic characteristics of local communities within the downstream impact zone are not provided in the ITEIA;
- The report concludes that the main adverse impact in Egypt will be a reduction in power generation at HAD due to a fall in the water levels of Lake Nasser. Furthermore, during GERD impounding, there could be an irrigation deficit in dry years;
- A number of potential positive benefits for Egypt are noted in the ITEIA including an increase in irrigated area, a decrease in sedimentation at Lake Nasser, and a reduction in flooding. These potential benefits are not all quantified and confirmed.
- The ITEIA report states that the GERD only reduces the mean annual flow at Ethiopia-Sudan border by about 3% through evaporation which is not significant. Yet the GERD storage system water saving benefit against flooding, seepage and spillage in the downstream are not quantified. That GERD Project will increase the overall regulation capacity of the Eastern Nile Basin from 134,210 Mm^3 to 194,210 Mm^3 . Such additional storage will add resilience to

impacts of climate extremes including drought and flood. The most significant positive impact of GERDP for the three countries (Ethiopia, Sudan and Egypt) is the generation of clean energy of about 15,692 GWh/yr.

The IPoE is of the opinion that although the above mentioned report stated that the outflow would be reduced by 3% in the long term on average, potential downstream impacts result from reservoir first impoundment and actual operation strategy which have not been adequately addressed. In addition all the above aspects need to be verified .

- Several socio-economic impacts in the downstream impact zone are not addressed by the ITIEA, mainly because primary environmental impacts have not been considered by the report as being significant;
- A study of the impact of a dam break was also not presented in the ITIEA, but it was reported to the IPoE that such a study was on-going.

5.4.3.2 Recommendations

- In Section 5.3, referring to water resources and hydrology, the IPOE recommends a more comprehensive assessment of downstream impacts of the GERDP, based on a sophisticated water resources/hydropower system simulation model. Potential positive and adverse impact should be quantified and confirmed by a detailed study. Furthermore, the impact area should extend down to the Nile Delta.
- The IPOE also recommends that additional investigations are carried out in the three countries in order to link the results of the modeling exercise with the anticipated environmental and social impacts resulting from flow alteration by GERDP and to quantify these impacts in technical, economic and social terms.
- Additional investigations are recommended to address the following subjects:
    - Evaluation of carbon stock available in the GERD reservoir area including above ground biomass and top soil and review of the vegetation clearance study.
    - Water quality modeling of dissolved oxygen in the reservoir during and after the first filling and simulation of oxygen and organic matter content of water released downstream.
    - Suspended sediment sampling and analysis program over a full year, to assess the organic content of the suspended sediment.
    - Detailed quantitative assessment of downstream status of recession agriculture in Sudan and Egypt.
    - With the provision of regulated flow, there is the potential to expand irrigated cropping in Sudan. A detailed study is recommended to determine the likely increase in irrigated area, size of the beneficiary population, impact on crop production and household incomes in Sudan, as well as related impacts in Egypt.
    - Downstream aquatic biodiversity and fisheries may be adversely affected by deteriorating water quality. So the environmental and socio-economic impact on

aquatic biodiversity, fish stocks and fishing communities particularly related to Roseires reservoir should be studied.

- GERD by trapping most of the transported sediment will have beneficial impact on Roseires present sediment management issue. This beneficial impact should be assessed and quantified.
- Sediment trapping could also affect downstream river morphology, so a technical and economic assessment of the impact on riverbed erosion and river navigation downstream Roseires is also recommended;
- The ITEIA indicated that beneficial impacts for Sudan could include (i) increase in power generation, (ii) decrease in reservoir dredging costs, and (iii) reduction in flood losses. These socio-economics benefits of GERD require further detailed quantitative analysis;
- Similarly, socio-economics benefits for Egypt as stated in the ITEIA need to be verified and quantified.
- A comprehensive Environmental and Social Management Plan (ESMP) should be prepared for the downstream impact zone involving the 3 countries.

- All the potential impacts, either negative or beneficial, result from the alteration of water quality and of water flow in the Abbay/Blue Nile River. The IPoE therefore recommends that a full trans-boundary environmental and social impact assessment (TESIA), integrating all the components addressed previously, should be conducted jointly by the three countries through appropriate arrangement as decided by the three countries. .
- The IPoE has prepared a draft scope of work for the conduct of the study for consideration by the three countries, and presented in Annex 6.

6 DETAILED DESCRIPTION OF THE MAIN PROJECT COMPONENTS

The purpose of this chapter is to give a detailed description of the project component. All the information presented in this chapter is quoted from the Main Report (Volume I)-Basic Design, November 2010 submitted on July 2012 by the Government of Ethiopia

6.1 Dam and Reservoir

6.1.1 Dam Height

A sensitivity analysis has been carried out in order to select the optimum dam height. Selection of dam height is based on the following criteria:

- Optimization of firm and average energy productivity
- Construction and impounding programme
- Morphological aspects of the dam site
- Location of the upstream Mendaia dam site

The range of dam crest elevations between 630 m asl and 660 m asl has been investigated (dam height above ground 130 m and 160 m respectively).

Sensitivity analyses have defined the optimum dam height to be 145 m corresponding to Full Storage Level of 640 m asl.

The dam will be approximately 1,780 m long with a volume of about 10.1 Mm^3 creating a reservoir of about 74 billion m^3 to satisfy the Firm Energy requirements during the dry season.

6.1.2 Dam Type

Dam design studies have been undertaken to develop the layout of the least-cost dam that will meet internationally recognised safety standards. These design studies have drawn information from the site topographic surveys, the hydrological studies, the geological and geotechnical investigations, the seismic, the reservoir operation and the cost studies. The available investigation results have shown that the foundations are all in solid bed rock and that excavation depths are modest, i.e., usually less than 10 m.

Different dam types were investigated and finally Roller Compacted Concrete (RCC) type dam has been selected. The Designer has opted for a concrete dam since:

- the flows to be diverted are large that only this type of structure can resist erosion during the river diversion phase (in which the dam will be overtopped);
- a traditional earth-fill dam would require river diversion through tunnels and therefore the construction time would be far longer; and
- given the shorter construction time, energy production can start earlier.

6.1.3 Dam Sections

The dam is divided into 2 major parts. The shoulders with the 2 powerhouses downstream (3,750 MW on the right bank and 2,250 MW on the left bank), and the central block (which will serve as a spillway for river diversion during dam construction and as an ungated emergency spillway during the life of the plant).

The shoulders incorporate also the four outlets (2 on the left and 2 on the right) that will be used during river diversion and during reservoir operation.

Gated spillway: This work is separate and independent and discharges into the Abbay/Blue Nile downstream of the dam.

There will be no spillage over the left and right sections since the central section (Low Block) will be used for river diversion during the entire construction time and, in exceptional circumstances, as an emergency spillway once the plant is completed.

6.1.4 Saddle Dam

The saddle dam is shown schematically in the Figures 2. The saddle dam raises the watershed at el. 600 m asl. (approx.) up to 646 m asl. This will be a Rock Fill Dam with Bituminous Upstream Face approximately 5.2 km long and 50 m high. It includes the emergency side spillway that gathers the waters into a natural gully which allows flood flows to be discharged directly into the Abay River.

6.1.5 Reservoir

The Grand Ethiopian Renaissance Dam project aims to dam the Abay (Blue Nile) River thereby creating a reservoir with a total storage of about 74 billion m^3 and a total surface area of 1,874 km^2 at full supply level (640 m asl).

The reservoir extends for about 246 kms over the Abay River gorge from elevation 500 to 640 m asl. The Minimum Operating Level (MOL) is set at elevation 590 m asl corresponding to a live storage capacity, between FSL and MOL of 59.22 billion m^3. The dead storage capacity beneath the MOL is of about 14.8 billion m^3.

The reservoir level will rise during the rainy season (June to September) and draws down during the dry season.

This large capacity allows flexibility to the plant operation adapting the operating rules, during the operation life of the plant, to the possible variation in the requirements both of the energy market and of the downstream environment.

The large reservoir volume, together with the kind of spillways adopted, make it possible to control the floods in safe condition.

6.1.6 Spillways and Bottom Outlets

Three different spillways have been considered:

- Gated spillway on the left bank of the main dam, with sill at el. 624.9 m asl and a net length of 84 m
- Ungated spillway on the crest of the main dam, with sill at el. 640 m asl and a net length of 205 m
- Ungated emergency spillway on the right abutment of saddle dam, with sill at. el 642 m asl and a net length of 300 m

When reservoir water level is between 624.9 m a.s.l. and 640 m a.s.l. the gated spillway operates alone, as the water level rises from elevation 640 m asl the ungated spillway on the main dam enters into operation, and finally, if the level during extreme events (i.e. exceeding 10,000 y RP) reaches 642 m asl the emergency spillway starts and the three spillways work together.

Low Block Emergency Spillway (ungated): The central part of the main dam is constituted by the so-called Low Block. This spillway is extremely important during the entire construction period of the project. Once the dam is finished, this will remain as an emergency spillway only (ungated). This spillway discharges directly into the Blue Nile where the gneiss outcrops everywhere. Therefore the energy is dissipated into a plunge pool.

Emergency Spillway on Saddle Dam (ungated): On the right bank of the saddle dam there is a very long lateral spillway (ungated). This spillway exploits the large excavation required as a gneiss quarry for the saddle dam. It is about 1.2 km long. Also in this case the chute discharges into a gully which leads into the Abay River course. No plunge pool is necessary given the morphology and the geology of the area.

Neither of the emergency spillways has a dissipater since they will be used (if at all) only in extremely rare cases and therefore they are not subject to erosion.

Bottom Outlet: The two Bottom Outlets are constituted by a twin 6000mm barrel and positioned on the LEFT side of the river, embedded in the Dam body, with inlet invert elevation of 542.25m a.s.l. and a longitudinal slope of about 0.43% and a total length of approximately 87 m.

The Bottom Outlet operation will be limited to the following phases:

- during impounding phases, above elev. 570 m a.s.l, after closure (concrete plugging) of all four culverts to control reservoir raising rate and assure minimum downstream discharge, in addition to early generation discharges.
- during outage periods of the plant, if any, to guarantee the minimum downstream discharge
- during Plant life time, to lowering and control the reservoir water level in the dry season, mainly below the minim operating level, for extraordinary inspection and maintenance activities on the upstream face of the dam.

Each of the two bottom outlets is designed to properly operate within the following working ranges:

1) Max discharge capacity of 886m3/s with water in the reservoir at maximum operating level (F.S.L. = 640m a.s.l.).

2) Discharge capacity at the minimum O.L. 565m a.s.l., with radial gate fully opened 386 m3/s.

6.2 River Diversion

River diversion is the most important element of the entire project since it controls the construction time and therefore the start of energy production. Together with the Low Block, these works play an extremely important role in the construction and operation of the project.

There are four gated outlets: 2 on the right bank and 2 on the left. Each outlet is steel lined with a diameter of 8 m and a length of 210 m. They have a two-fold function and they will be used for:

- river diversion during the construction period, and
- de-watering purposes in extraordinary circumstances when the project has been completed.

On the basis of the hydrological study, a return period of 10 years has been assumed equivalent to 14,700 m^3/s. This value has been adopted in consideration of:

- the short period of diversion
- the type of river diversion works that will be in concrete and will therefore not be subject to major damages during overtopping
- the effect of reservoir flood routing in the second and third year of diversion

6.3 Electro-Mechanical Equipment

6.3.1 Powerhouse

The project foresees construction of two power houses. The two Powerhouses are of the open-air type and are situated immediately downstream of the dam on the left and right banks of the river. The first power house will be built before the dam has actually been raised to its final height in order to utilize the available water resources as early as possible for power generation (thereby creating revenue).

The second power house will be built once the dam has been completed to meet the increase in energy demand. It will house the largest turbines in Ethiopia. For this reason all the roads leading to the project area must be suitable for heavy duty vehicles transporting all the necessary electromechanical components.

The two power houses are located downstream of the left and right shoulders. The right power house will have 3750 MW of installed power while the left power house will have 2250 MW.

6.3.2 Selection of Number of Units

The number of units has been selected so that the capacity of the single unit will be compatible with the Ethiopian grid size at the time of plant commissioning and with the transport facilities and capability of the Ethiopian grid system.

6.3.3 Selection of Turbine Type

Taking into account that the turbine output is 375MW, the net operating head ranging between 83 m and 133 m, the vertical axis Francis Turbine type has been selected.

6.4 Project Costs

The total construction cost of the Grand Ethiopian Renaissance Dam Project is estimated at EURO 3,422 million of which EURO 2,414 million for Civil Works and EURO 1,007 million for H/E&M Equipment of the total, some 41% will be in local currency and the remainder in foreign currency.

6.5 Implementation Plan

The project owner is the Ethiopian Electric Power Corporation (EEPCO)which is a semi-autonomous body under the Ministry of Water and Energy. The GERDP is planned, designed and executed under Engineering, Procurement, Construction (EPC) arrangement. The EPC contractor is Salini Construttori S.p.A along with his designer Studio Pietrangeli who jointly have designed and constructed over 200 large dams around the globe. The owner's representatives are TRACTEBEL Engineering S.A and COYNE ET BELLIER who also have extensive experience in similar projects in the region and Ethiopia. The construction of the Project begun in January 2011 and will take more than seven years to complete and will be in operation by the end of the year 2017. However, it will take some 3 years to commencement of generation of 216 MW from the first two units. Final installation and commissioning of all turbine-generator is anticipated to require 7.5 years from commencement of construction.