E1093 V. 4

BUMBUNA HYDROELECTRIC PROJECT, SIERRA LEONE

1ST MEETING OF THE DAM REVIEW PANEL

25 OCTOBER TO 4 NOVEMBER 2004

REPORT

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EXECUTIVE SUMMARY

The First Meeting of the Dam Review Panel (DRP) for the Bumbuna Hydroelectric Project was convened in Sierra Leone from 25 October to 4 November 2004. This Executive Summary synthesizes the findings of the Panel. A detailed description of activities, discussion of Project documents, comments related to the site visits, detailed findings and other supporting data and information are presented in the main body of this Report.

1. BACKGROUND PROJECT INFORMATION

The Bumbuna Hydroelectric Scheme (Phase 1) corresponds to the first stage of development of the hydropower potential of the Seli River in Sierra Leone.

The Project includes, as main components:

- A run-of-river power plant with pondage afforded by an 88 m high dam and appurtenant river diversion, spillway and headrace structures. The powerhouse with an installed capacity of 2x25 MW is located at the downstream toe of the dam. Firm power is 18 MW, firm and secondary energy generations are estimated at 157 and 158 GWh/year respectively.
- A transmission system consisting of a local step-up substation, a 200 km long 161 kV transmission line connecting Bumbuna to Freetown and a step down substation in Freetown.

This Scheme corresponds to the first major hydropower development and transmission line in the Country’s history.

2. IMPLEMENTATION ACTIVITIES

The construction of civil works and the procurement of equipment and installations of the Project were developed under different contracts and phases of implementation. In chronological sequence:

- Contract A0—Engineer’s Camps---1981-1982
- Contract A1---Preliminary Civil Works---1983-1984
- Contract A2---Main Civil Works at damsite---1991-1993 and 1996-1997
- Contract B---Hydraulic Steel Structures---1996-1997
- Contract C---Electromechanical Equipment---1992/1993-1997
- Contract D---Transmission Line and Freetown Substation 1993-1997

In May 1997 Project implementation had reached an advanced state (estimated at about 80%) when it was interrupted due to the Civil War in Sierra Leone. Remaining needed implementation activities correspond to the completion of civil works for the dam and appurtenant hydraulic structures, second phase civil works for the powerhouse, control building, assembly and installation of equipment, completion of the transmission line, construction and equipment of the Freetown substation.

Starting in March 2004, after a 7 years interruption, activities related to the assessment of the state of the works and reinstatement of site facilities, camp and plant were initiated. One of the results of these activities was the re-scheduling of civil works and equipment procurement and installation to complete Project implementation until end of 2006.

3. DAM REVIEW PANEL (DRP). FIRST MEETING ACTIVITIES

Under the umbrella of Contract E---Logistic Support for the Bumbuna Project Implementation Unit (BPIU), a Dam Review Panel (DRP) was constituted in October 2004 and a first meeting scheduled and carried out during the period October 25 to November 4. Activities of the DRP were mainly focused on the assessment of the state, safety and quality of the civil works at site, on the provision of technical advice for future implementation activities and on the provision of technical advice aimed at the operation of the Project. Detailed terms of Reference are provided in the Appendix of this Report.

In order to carry out these tasks the Panel composed of Bela Petry (Chairman, Hydraulic Structures), Khalid Jawed (Hydrology), Peter Tschernutter (Dam) and William Moler (Geotechnics), undertook the following main activities in intense cooperation with representatives of BPIU and of the Engineer (Studio Pietrangeli):

- Briefing meetings in Freetown
- Technical inspection visits at the Bumbuna site
- Review of general planning documents related to the Project and its relevance for the Energy sector of Sierra Leone
- Extensive review, analysis, discussion and evaluation of Project documents related to the planning, site investigations, design and implementation of the civil works at site.
- Review and analysis of documents related to the operational characteristics of the civil works and hydro-mechanical equipment.
- Preparation of a Draft Report
- Presentation of the DRP findings and submission of the Daft Report in Freetown.

4. GENERAL QUALITY ASSESSMENT OF THE PROJECT

The DRP reached the general conclusion that basic investigations, planning criteria, engineering studies, design and construction of the civil works in Bumbuna followed sound and updated engineering practices. In spite of several interruptions of the implementation activities, in particular during the period from May 1997 to the present date, the achieved stage and quality of construction warrant a continuation and completion of the Bumbuna Hydroelectric Project, with adequate safety and reliability.

Not-withstanding this favourable general assessment, attention is drawn to a number of main aspects to guide further Project development. These are listed under headings 5, 6, 7, 8 and 9.

5. BASIC SITE INVESTIGATIONS AND BASIC STUDIES

- Hydrology—comparative PMP/PMF studies, using recommended guidelines, to completely justify the selected Spillway Design capacity which is considered to be acceptable but in the lower range of expected values.
- Gauging stations---immediate installation and calibration of a gauging station downstream of the dam site. Future installation of two gauging stations in the reservoir area.
- Reservoir area---field reconnaissance and review of cartographic material, especially of the rim zone, to assess the potential for landslides and other potential occurrences.
- Dam foundation on the left abutment---search of available construction records to clarify the exact nature of the foundation surface underlying the rockfill (occurrence of weathered rock layer).
- Seismic records---review of regional seismic records after 1978 and confirmation of seismic parameters used for the Project.
- Riverbed scouring downstream---analytical forecast of riverbed scouring downstream of the tunnel outlet structures.

6. REHABILITATION AND COMPLETION OF CIVIL WORKS

- Asphalt concrete faced rockfill dam---mapping and condition assessment of the upstream impervious layer; application of an additional impervious layer in recommended areas using constructive details provided (see section 6.2.2.4); optimisation of materials and methods of application of the surface seal; rehabilitation and sealing of the perimetral joint; refurbishment and completion of dam instrumentation.

- Left and right bank tunnels---detailed inspection, mapping and repair of possible damages to tunnel linings and outlet works at the end of the river diversion phase, prior to the execution of the planned constructive modifications of these tunnels needed for the Project operation phase (plugging of diversion intakes, lining, construction of the terminal flip buckets, etc)
- Radial gate structure---inspection and rehabilitation of the gate support and gate block anchoring systems; installation of extensometers to register possible gate displacements
- Manifold and powerhouse structure---inspection and rehabilitation of steel linings and exposed reinforcement bars; testing and replacement of corroded bars where needed.

7. REHABILITATION OF EQUIPMENT AND INSTALLATIONS

The general inspection and assessment of damages to mechanical, hydro-mechanical and electrical equipment and installations has practically been completed. This assessment determined the need for minor and major rehabilitation and repair works and replacement of components.

- Equipment and installations---proceed with needed rehabilitation, repair and replacement activities. In the case of gates and valves these activities correspond mainly to detailed inspection, replacement of linings, cleaning and painting.
- Contingency Plan for Equipment---development of a Plan including provisions to cope with the fact that Manufacturer Guarantees and corresponding Liabilities may not apply in view of the long time since delivery and incurred damages; provision of spares, organizational and financial provisions to cope with this situation.

8. FIRST IMPOUNDMENT AND RESERVOIR OPERATION

- First Reservoir Impoundment---to be achieved in two phases. First phase, starting in December 2005/January 2006 (according to present schedule), partial impoundment of the Reservoir up to 40%-50% of dam height; observation of dam seepage and deformations and possible lowering of Reservoir level in the case of an observed anomaly. Second phase, at the beginning of Project Operation, complete Reservoir filling.
- Reservoir Operation Plan---development of detailed hydraulic operation guidelines for Reservoir operation under normal and exceptional conditions (e.g. flood occurrences) taking into account objectives and constraints of the operation.
    1. Objectives---optimisation of Power and Energy Generation during normal, dry and wet periods; minimizing Plant outages. Forecasts including detailed evaluations at the level of daily averages.

2. Constraints---provision of environmental duty flows downstream during the phase of reservoir impoundment (and later) as required.
3. Use of the Left Bank Spillway as service facility for frequent floods and the Right Bank Spillway as auxiliary facility for exceptional floods.
4. Minimizing/avoidance of exposure of the Radial Gate to dynamic flow impacts and vibrations. Restriction/avoidance of use of this Gate to control flows (at partial opening) under high heads.
5. Emergency Preparedness---completion of the Dam Break Analysis and resulting potential maps of downstream inundations. Development of a stand-alone Plan for Flood related contingencies (forecasting, alarm, evacuation, other measures).

9. OPERATION AND MAINTENANCE

- Operation and Maintenance Manuals---preparation of detailed manuals for monitoring, inspections, operation and maintenance activities of the civil works, equipment and installations of the Bumbuna Project. Preference for an integrated approach for the entire Bumbuna Project including the Power Station and the Transmission System.
- Organizational Structure and Staffing---qualification of key personnel for O&M activities through education and training (schooling, formal education, on the job training, training in host organizations)

10. FURTHER DRP ACTIVITIES

Activities listed under headings 5 to 9 require follow-up actions from the Dam Review Panel to continue providing review and detailed discussion/orientation.

The DRP recommends that further activities are scheduled in accordance with actual Project development.

Recommended further activities for the near future are:

- Keeping follow-up contacts and technical communications with BPIU and the Engineer, by remote communication during the period preceding the first phase of Reservoir impoundment. Possible needed meetings in Sierra Leone and the Engineers Office in Italy, depending on further development of work activities.
- Meeting at site and in Freetown after the first phase impoundment, for an evaluation of results and other actions.

1. INTRODUCTION

1.1. DRP Members

The first meeting of the Bumbuna Hydroelectric Project Dam Review Panel (DRP) was held in Sierra Leone from 25 October to 4 November 2004. DRP members included Bela Petry (Chairman, Hydraulic Structures, Brazil), Khalid Jawed (Hydrology, USA), Peter Tschernutter (Dam, Austria), William Moler (Geotechnics, USA).

1.2. Terms of Reference

The Terms of Reference (TOR) for the 1st meeting of the Bumbuna DRP are attached to this report as Appendix A. The TOR lists in detail subjects to be specifically addressed by the DRP during the meeting. To facilitate the review of this report, Table 1 cross references each of the Specific Actions listed in the TOR and where they are covered in this Report.

TABLE 1 – TERMS OF REFERENCE – CROSS REFERENCE

Item	Specific Action	Page	Subsection
(a)	Review site exploration data for the foundation and material sources including results of drilling, laboratory testing, in-situ tests and regional and local geological characteristics.	15	4.2.3 Geotechnics
(b)	Review designs of foundation treatment, proposed excavation, selected foundation strength parameters and seepage control measures.	19	5.1 Dam Foundation; 5.2 Asphalt Faced Rockfill Dam
(c)	Review strength parameters and characteristics of selected construction materials for the embankment dam including zoned materials, filters, and placement requirements	20, 29	5.2 Asphalt Faced Rockfill Dam; 6.2 Condition of Works
(d)	Review the selected asphalt mixes, material characteristics and placement procedures for the dam membrane including results of durability, gradation and reactivity tests, and construction requirements	20, 29	5.2 Asphalt Faced Rockfill Dam: 6.2 Condition of Works
(e)	Review stability analysis and resulting factors of safety for normal, unusual and extreme loading conditions for the embankment dam, spillway structures and outlet works including determination of seismic loading criteria	20, 17	5.2 Asphalt Faced Rockfill Dam, 4.2.3.3 Seismicity

(f)	Review upstream conditions in regard to formation of landslides and handling of floods caused by the collapse of such natural dams	39	8.2 Reservoir Leakage and Rim Stability
(g)	Review reservoir factors of rim stability, sedimentation, wave action. clearing plans and their effect on dam stability	39, 41	8.2 Reservoir Leakage and Rim Stability; 8.5 Risk Assessment
(h)	Review flood hydrology methodology and computations for determining the project design flood hydrographs, reservoir routing and spillway sizing	10, 23	4.2.1 Design Flood; 5.3 Hydraulic Structures
(i)	Review design of spillway facilities including flow conditions, energy dissipation, including model tests	23	5.3 Hydraulic Structures
(j)	Review inlet and outlet works, including hydraulic design, capacity for emergency reservoir drawdown, sediment handling capability, selective thermal releases, regulation range and other factors	23	5.3 Hydraulic Structures
(k)	Review designs of diversion works, schedule, hydrology and risk factors associated with diversion during construction and with the closure of diversion works at initial reservoir filling	10, 23	4.2.1 Design Flood; 5.3 Hydraulic Structures
(l)	Review risk and hazard evaluations including need for dam breach analysis	41	8.5 Risk Assessment
(m)	Review design of dam instrumentation and program for collecting, evaluating and maintaining data to be obtained.	20	5.2 Asphalt Faced Rockfill Dam
(n)	Review final plans and specifications for design adequacy, construction, scheduling and owner quality control procedures.	20, 38, 38	5. Final Design; 8. Operation and Maintenance; 8.1 Dam
(o)	Review any major field design changes that have occurred because of changed field conditions.	27	6. Construction

(p)	Review operational plan for initial reservoir filling, including the time of closure, maximum allowable filling rate, measurements, emergency release plan, and designation of responsible operating personnel.	38	7. Initial Reservoir Impoundment
(q)	Review and evaluate organization, procedures and program to carry out long term independent monitoring of the dam safety status including inspection frequencies, instrumentation records system, project data files, evaluation criteria and means to provide remedial actions.	38, 38	8. Operation and Maintenance; 8.1 Dam
(r)	Review adequacy of operation and maintenance manuals, and establishment of project operations procedures.	N/A	Operation Manuals were not available at the time of the meeting.
(s)	Review adequacy and propose broad principles for plans to implement a reservoir, fuel and energy management decision support system for optimizing the operations of the electricity system in Sierra Leone when Bumbuna is placed in service.	50	9.2 Project Role in National Power Scheme
(t)	Review and evaluate emergency plans including downstream flooding effects, emergency reservoir drawdown, notification of impending dangers to downstream municipal authorities, major flood early warning systems, major flood spilling operations plans, and site access during emergencies.	44	8.5 Emergency Preparedness Plan
(u)	Review procedures for handling project records, including as built drawings, operation records, inspection records, instrumentation data and other information associated with the long term safety of the dam.	38	8. Operation and Maintenance

1.3. DRP Itinerary and Activities

Panel members arrived in Freetown, Sierra Leone late in the afternoon of Monday, 25 October and were received by representatives of the consultant, Studio Pietrangeli (SP), and the contractor Salini Costruttori (SALCOST).

On Tuesday morning, 26 October the Panel was officially welcomed to Sierra Leone by His Excellency the Minister of Energy and Power of the Government of Sierra Leone (GOSL), and Mr. Nathaniel Vandy, Project Manager of the Bumbuna Project Implementation Unit (PIU) and his assistant Mr. Mustapha Kargbo. In addition, the Panel met with members of the Bumbuna Technical Committee comprised of Mssrs. John Aruna (Special Assistant Technical Advisor, Ministry of Works) Committee Chairman, Syrian Jusu (Director of Environment, of the Ministry of Lands Planning and Environment), Benson Lahai (Economist, Ministry of Development and Economic Planning) and Daniel Coomber (Executive Secretary, Ministry of Energy and Power).

In the afternoon of 26 October, presentations were made to the Panel, by Mssrs. Alberto Bezzi and Hector Lovay, Joe Mattia of Studio Pietrangeli, and Mr. Christian Capitanio of SALCOST covering various issues including: project history, hydrologic and geotechnical investigations, design and construction of the dam, hydraulic structures and power facilities. In addition Studio Pietrangeli provided technical documentation for review by the Panel.

On Wednesday morning, 27 October, the Panel traveled by car to the Bumbuna site. Following lunch a tour was made of the dam and appurtenant facilities.

The Panel remained in Bumbuna until Tuesday morning, 2 November, returning then to Freetown. During the stay at the Bumbuna site the Panel held various meetings with the PIU and Studio Pietrangeli, received and reviewed documentation. Individual members carried out additional visits to the dam site to review specific aspects of the Project. A draft of the DRP Report was prepared during this time.

Tuesday afternoon, 2 November, was spent reviewing and revising the Report together with the PIU and SP. On Wednesday, 3 November the report was finalized and presented to His Excellency the Vice-President of Sierra Leone, the Minister of Energy and Power, and representatives of the Donors led by the World Bank (Bank), and final discussions were held.

In the evening of Thursday, 4 November the Panel departed Freetown.

During the 1st Bumbuna DRP meeting, members held detailed discussions amongst themselves and with key members of the PIU, Studio Pietrangeli and SALCOST. An itinerary of the Panel's program together with overview of the different meetings held are presented in Appendix B.

1.4. Documents Submitted to the DRP

A list of documents provided to the DRP for review are listed in Appendix C.

1.5. Report Organization

The Report is prefaced by an Executive Summary of the findings of the DRP. The body of the Report consists of chapters covering the Background of the Bumbuna Hydroelectric Project; a detailed Project Description; a summary of Planning and Investigations; an evaluation of Final Design and Construction; a discussion of Initial Reservoir Impoundment; an evaluation of Operation and Maintenance requirements; and an assessment of Long -Term Prospects regarding the role of the Bumbuna Project in the overall development of the Energy Sector of Sierra Leone. The Report ends with Conclusions and Recommendations, Acknowledgements, and the Signatures of all Panel members. The TOR, Minutes of Meetings, List of Documents Reviewed, Project Data Sheet, Drawings and Photographs, are included as Appendices.

2. BACKGROUND

2.1. 1970 to 1975 – Preliminary Studies

A series of preliminary studies were performed between 1970 and 1975 to assess the best approach to meet the projected power demands of Sierra Leone. It was determined that the most feasible scheme was to develop the hydropower potential of the Seli River in the northeastern part of the country by constructing a 33 MW power plant at Bumbuna Falls with seasonal river flows regulated by a 320 million m^3 storage reservoir at Yiben, located approximately 30 km upstream of Bumbuna.

2.2. 1980 - Feasibility Study

A feasibility study was completed in 1980 which demonstrated that the Bumbuna Falls Hydroelectric Project was a favorable solution for the electrification of Sierra Leone. The study predicted a potential power and energy production of about 10 times that needed for central Sierra Leone, and therefore, recommended staged implementation. The most economical construction sequence envisaged construction of a 74 m high rockfill dam at Bumbuna with a 2 km long headrace tunnel leading to an underground power house downstream of Bumbuna Falls equipped with two turbine-generator units with a total installed capacity of 53.4 MW. Future construction phases at Bumbuna and Yiben would result in a total installed capacity for the scheme of approximately 300 MW with an annual energy generation of 1,250 GWh of firm energy and 210 GWh of secondary energy, resulting in an average energy generation of 1,460 GWh/year. The feasibility study was reviewed and accepted by the GOSL and the Bank, and the consultants were instructed to prepare tender documents for the construction of Phase I.

2.3. 1981 - Tender Documents for Phase I

The Consultant started preparing the tender documents but when a general procurement and civil works prequalification announcement was about to be published, the Bank temporarily suspended the announcement and the preparation of tender documents.

2.4. 1982 – Updating of Prices and Economic Analysis

Due to the two years elapsed since the completion of the feasibility study, the Bank requested the Consultant to update the cost estimate and economic analysis of the project.

2.5. 1983 – Completion of Tender Documents for Phase I

Based on the favorable results of the updated feasibility study, the Consultants were again requested to prepare tender documents. However, because of a macroeconomic study of the impact of the Bumbuna Project on the economy of Sierra Leone prepared by the Bank, implementation of Phase I was suspended and it was decided to investigate a scaled down solution.

2.6. 1984 – Supplemental Feasibility Study for Scaled Down Solution

The Consultants proposed a scaled down solution in which the dam was raised 13 m and an outdoor power house was located at the downstream toe of the dam and utilizing the right abutment diversion/spillway tunnel as a combined power tunnel, thereby eliminating the long headrace tunnel and tailrace canal. This solution would not prejudice the long-term development of the Bumbuna-Yiben scheme. The Bank found the scaled down solution attractive from the financial point of view, and the Consultants were instructed to finalize their proposal.

2.7. 1982 – 1985 – Construction Works under Contracts A0 and A1

A permanent Camp and Engineer's Camp (contract A0), and Preliminary Works and site installations (contract A1) consisting of excavation of the Right Tunnel and partial excavation of the Left Tunnel were constructed with a US$20 million loan from the Italian government and a Le 11.6 million local contribution.

2.8. 1988 – 1989 – Signature of Contracts A2 and B and Financial Convention with Italian Government

On 28 February 1988 the GOSL signed contracts with the Consultant, SP and Contractor, SALCOST to design and construct the civil works (contract A2), and hydraulic structures (contract B), contingent upon the GOSL obtaining financing for the electromechanical components of the project. Confirmation of financing for electromechanical equipment (contract C), and Transmission line and substation (contract D), was given by the African Development Bank (ADB) in January 1989. A financial convention was signed on 28 June 1989 between the GOSL and Italy for a credit of Lire 138,000 billion. Authorization was given to the Contractor to execute the work, and advanced payment was made by the end of 1989.

2.9. 1991 – Signature of Financing Agreements with ADB

A loan agreement for FUA 34.86 million was entered into on 21 January 1991 between the GOSL and the ADB to fund the foreign component of contracts C, D and E (logistic support for project implementation). A protocol was also signed on the same date under which a grant of FUA 2.76 million was made available to cover the consultants services.

2.10. 1991 – 1993 Construction Under Contract A2 and B

Excavation of the Left Tunnel and lining of both tunnels were completed. The cofferdams were constructed, the Seli River diverted through the Right and Left Tunnels, and excavation, foundation treatment, and placement of cut-off plinth, and rockfill in the Dam began. In addition the morning glory Spillways and Intake tower were constructed.

2.11. 1993 – Signature of Contracts C and D

The GOSL signed contracts C and D at the beginning of 1993 with the Bumbuna Falls European Consortium (Salini Construttori, Turbo-Ganz and COEMSA-Ansaldo) and ABB Sae Saelmi/ABB Schaltanlagen respectively.

2.12. 1993 – Final Design and Budget for Completion of Contracts A2 and B

The Consultant finalized a report describing modifications made during final design of contracts A2 and B together with the estimated final costs and budget for completion of the work.

2.13. 1993 – Cancellation by Italian Government of Sierra Leone's Debts

In order to reduce the GOSL's foreign debts, the Italian government cancelled all principal and interest owed by the GOSL for disbursements made in favor of the Bumbuna project prior to 31 December 1992.

2.14. 1993 – Suspension of Work on Contracts A2 and B.

On 22 November 1993 work was suspended on all work under Contracts A2 and B because available financing of the foreign component had been fully disbursed and the GOSL has not paid the local portion of Interim Certificates issued by the Contractor.

2.15. 1995 – Signed Loan Agreement to Complete Contracts A2 and B

A contract was signed between the GOSL and ADB to finance construction activities to complete A2 and B.

2.16. 1996 – 1997 - Resumption of Work Under Contracts A2, B, and continuation of D.

Work resumed on contracts A2 and B in 1996 with construction of the impervious upstream facing of the rockfill dam and Power House Excavation (Contract A2), included installation of the circular gate at the Intake to the Right Tunnel, and the Radial Gate at the outlet (Contract B). Works under Contract D has continued with the erection of Towers and the stringing of conductors for the HV Transmission Line from Bumbuna to Freetown.

2.17. 1997 – Construction Activities Under Contracts A2 and B Suspended Due to Civil Unrest.

3. PROJECT DESCRIPTION

This section of the report presents a description of the major components of the Bumbuna Hydroelectric Project as currently designed. Project Data is listed in a table that is included as Appendix D.

3.1. Asphalt Concrete Faced Rockfill Dam

Bumbuna Dam is an 88m high asphalt concrete faced rockfill structure with a crest length of 440m comprising a volume of approximately 2.5 million m^3 of granitic rockfill. The upstream face is covered with a asphalt concrete membrane covering an area of approximately 51,000 m^2. A 9 cm thick impervious asphalt layer was placed but not completed. The impervious layer was placed over an 8 cm thick binder layer (regulating) layer of porous asphalt concrete placed over a minimum 8 cm thick leveling layer. The subgrade was treated with a bitumen emulsion priming coat. The impervious asphalt concrete layer will be covered with a surface sealing coat prior to impoundment.

3.2. Reservoir

The Bumbuna Reservoir impounded by the dam, will have a surface area of 21 km^2 at the maximum operating level of El. 241.25 m a.s.l., with a volume of 445 million m^3. The reservoir will be Y-shaped, with the main branch extending 30 km long, with a width varying from 200m to 1 km, splitting upstream into two branches which extend 7 km and 11 km respectively.

3.3. Multipurpose Tunnels

Two 9.0 m finished diameter, concrete and steel lined, circular multipurpose tunnels were constructed through both the left and right dam abutments, each with a length of approximately 620m. Both tunnels are being used for diverting the Seli River around the dam site during construction. The Left Tunnel will be utilized in the future as the Left (Primary) Spillway during plant operation. The Right Tunnel will function as the Right (Auxiliary) Spillway. In addition the Right Tunnel will serve as a Power Tunnel when the installation of a Radial Gate (7.4m high x 7.0 wide) installed at the downstream end of the tunnel is closed. Water will be diverted to the Power House through a branch-off to the left approximately 30 m upstream of the downstream end of the tunnel. The Radial Gate will normally be closed during operation of the generating units but will open automatically to allow passage of large flood flows. The tunnel is steel lined for a distance of 205 m upstream of the radial gate to guard against high internal pressures when the gate is closed. The Right Tunnel will also provide the ability to drain the reservoir should that become necessary.

3.4. Spillways

Two 31.6 m diameter morning glory type spillways have been constructed upstream of the dam, one on each abutment, which will discharge into the multipurpose tunnels. The spillways consist of reinforced concrete towers approximately 36 m high which continue an additional 30 m as shafts until meeting the tunnels approximately 170 m downstream of the Diversion Portals. The Left Spillway over the left abutment tunnel, has a crest at El. 238.0 m a.s.l. In order to guarantee that the Right Tunnel always operates under pressure flow conditions the crest of the Right Spillway is located at El. 236.0 m a.s.l., 2.0 m lower than the elevation of the Left Tunnel spillway. Reinforced concrete flip-bucket energy dissipators have been constructed at the outlets of both tunnels.

Floods will be discharged through the Left Spillway until the reservoir level reaches El. 241.5 m a.s.l, which corresponds to a discharge of 1,000 m^3/s and a return period of approximately 10 years. At that time the Radial Gate will be opened automatically which will enable discharge of floods up to the probable maximum flood of 3,000 m^3/s.

3.5. Intake

A freestanding, 93 m high, hexagonal shaped Intake tower has been constructed over the Right Tunnel approximately 22 m downstream of the Diversion Portal. The Intake consists of six inlet openings with sill elevations at El. 181.0 m a.s.l. leading to a steel lined elbow into the Right Tunnel. The Intake is protected by a 7.5 m diameter cylindrical gate designed to be closed in order to inspect and perform maintenance in the tunnel. Each opening is protected by a removable trash rack. A single trash rake has been installed, which can be used to clean debris from all the trash racks without removal. A 100 m long, 3.6 m wide reinforced concrete footbridge in four spans, connects the intake tower to the right abutment.

3.6. Power House and Control Building

A surface Power House is located at the downstream toe of the Rockfill Dam adjacent to the Right Tunnel outlet. Penstocks and draft tubes have been installed for two generating units. A 115 ton gantry crane has been assembled to the right of the Power House and will be installed to assemble power house equipment and for maintenance purposes. Excavation has been made to the left of the Power House to allow future expansion for two additional units.

A Control Building will be located above the right tunnel outlet, in the area between the radial gate and the excavated slope. The building will be a two story reinforced concrete structure divided into areas for central operations, storage, and workshops.

3.7. Electro-Mechanical Equipment

3.7.1 Turbines and Generators

The Power House will house two vertically mounted Francis Turbines directly coupled to vertical shaft synchronous Generators. The design head is 70 m and the rated power from each unit is 25 MW, operating at a discharge of 40 m^3/s and a speed of 333.3 revolutions/minute. At the maximum and minimum net heads of approximately 80 m and 47 m, the rated power will be 30 MW and 14.8 MW respectively. The Generators will supply 33.7 MVA at a voltage of 13.8 kV.

3.7.2 Transformers

Two step-up 3-phase Transformers will be installed between the Generators and the 161 kV Transmission Line, with a rated power of 33.7 MVA, equal to that of the Generators.

3.7.3 Switchgear

MV cables, voltage and current Transformers, and disconnectors and grounding switches will be installed between the Generators and the step-up Transformers. A 161 kV Switchyard will be constructed on random fill downstream of the Dam. HV Switchgear including 161 kV circuit breakers, disconnectors and grounding switches, voltage and current transformers, surge arrestors, insulators, and bus work will be installed for the connections between the step-up transformers and the 161 kV Transmission Line.

The Freetown Substation will be located near the existing King Tom Thermal Power Station which will facilitate connection of the hydro electric supply from Bumbuna into the existing Freetown distribution network.

3.7.4 Low Voltage Service Installations

Low voltage service installations will include a 415/240 AC system, two 0.4333 kV 630 kVA step-down transformers of the oil immersed, three-phase type, and a 110 V DC system.

3.7.5 Control, Protection, Instrumentation and Metering Equipment

Control equipment will be installed for the two generating units, the MV and HV Switchgear, two auxiliary diesel generator sets, and the low voltage service installations. A protective system and instrumentation and metering equipment will be installed to cover the equipment.

3.7.6 Ancillary Equipment and Services

Ancillary equipment and services will include oil storage and transport systems, drainage and fire fighting equipment, lifting and workshop equipment, and complementary auxiliary services.

3.8. Transmission Line

A 161 kV single-circuit transmission line has been partially constructed between Bumbuna and Freetown with a total length of approximately 200 km. The line is equipped with 400 mm^2 ACSR conductors in a triangular configuration, with two shield wires.

In order to supply electricity to Makeni and Lunsar, the two shield wires will be insulated and energized at 34.5 kV from the Bumbuna and Freetown Substations respectively.

At Freetown the line will supply two 3-winding step-down transformers with a ratio of 161kV 10x1.25%/11.5 kV/34.5 kV, rated at 40/35/15 MVA. Equipment will include: 161 kV switchyards; 11 kV metal clad switchgear and cables; low voltage service installations; control, protection and instrumentation and metering equipment; and domestic installations and low voltage power and control cables.

4. PLANNING AND INVESTIGATION

4.1. Preliminary Studies

A 1970 – 1971 UNDP financed study, prepared by Motor Columbus (Switzerland), included an extensive inventory of the hydroelectric potential of Sierra Leone. The study identified the Bumbuna Falls Hydroelectric Project on the Seli River in northeastern Sierra Leone as the next addition to the power –generation capacity of the Western System.

A feasibility study was carried out in 1972 – 1973 by Italian consultant Carlo Lotti under a subcontract to the consortium Salini/Comstock/Techsult (Italy/Canada). The study proposed a staged development of the hydroelectric potential of the Seli River beginning with a 55 MW plant to be built at the toe of Yiben Dam, a seasonal storage reservoir to be located about 30 km upstream of the Bumbuna Falls site.

The 1973 feasibility study was review in 1974 by the Consultant SP on behalf of the same Consortium. The study compared four 30 MW initial power development alternatives on the Seli River in the vicinity of Bumbuna.

In 1975 SP updated the hydrology of the Seli River and load forecasts, in order to make economic comparisons between alternative schemes to meet the long-term power requirements of the Western System of Sierra Leone. Based on their findings, a staged development of the hydroelectric potential of the Seli River was proposed starting with the construction of a 33 MW power plant at Bumbuna Falls, with seasonal flows regulated by a 320 million m^3 storage reservoir at Yiben.

4.2. Feasibility Study 1980

4.2.1 Design Flood

This sub-section provides a review of the flood hydrology methodology and computations for determining the project design flood, reservoir routing and spillway sizing. The data and information regarding the flood hydrology are provided in the July 1980 Feasibility study and a summary is given in a memorandum prepared in March 1994. The following paragraphs provide a summary of the review and additional recommendations.

4.2.1.1 1980 Feasibility Report

The probable maximum flood (PMF) for the project was estimated using two approaches – a statistical approach and a deterministic approach. In the statistical approach, about eight years of annual maximum daily peak data was used. Six probability distributions were tested but four of these, namely, Gumbel, Pearson III, Log Normal and Log Pearson Type III were used. The adopted flood peaks were average of the peaks using these four distributions. Table 2 presents the results.

TABLE 2 – ANNUAL FLOOD PEAKS, MILLION M^3

Return Period, years	Gumbel	Pearson III	Log Normal	Log Pearson Type III	Average
100	1,580	1,360	1,320	1,450	1,430
1,000	2,050	1,660	1,600	1,920	1,810
10,000	2,510	1,940	1,860	2,480	2,200

The 10,000-year flood was judged to be the PMF. However, the peak was considered too low and not adopted.

In the deterministic approach, the PMF was based on the 72-hour probable maximum precipitation (PMP), infiltration losses and unit hydrograph for the basin. One unit hydrograph was developed for the 3,950 km^2 drainage area. Because of lack of sufficient hydrometeorological data, general approach of storm transposition and maximization to estimate the PMP was not used.

About 12 precipitation stations with long term data (from 1948 to 1973) located south of Bumbuna dam were selected. Statistical analysis was performed using 1-, 2- and 5-day precipitation data. Precipitation amounts of 1,000-year return period were estimated for each station. An average of these was adopted as representative point precipitation over the area south of the dam. Long-term daily rainfall data at Kabala, in the Bumbana watershed near the divide, and Musasia station, north of Kabala, were also used to derive 1,000-year point rainfall. Hourly precipitation data at Kabala was used to estimate 1,000-year, one hour precipitation. The average of 1,000-year precipitation amounts at Makeni, Teko, Musaisa and Kabala was considered as the representative point precipitation for the basin. The resulting 1,000-year, 72-hour point precipitation amount for south area was 241 mm, and about 356 mm for the four stations.

Mass precipitation curves are given in the feasibility report. These curves are in steps. No explanation is provided as to how the curves were developed. The study was done more than 20 years back and no back up data is available.

It is not clear from the report how the basin average PMP was estimated. It appears that 90 percent of precipitation based on southern stations plus 10 percent of the precipitation based on four stations, was assumed to be the basin average PMP. The estimated 72-hour PMP was 252 mm.

A few infiltration tests were carried out in the watershed in September 1979. Based on these tests, the infiltration rate was estimated to be 10 mm per hour. But there appears some error. As part of this revision, preliminary computations indicated that the rate used was about 8 mm per 6-hour period.

A unit hydrograph was developed for the watershed using Snyder's method. Parameters used for deriving the unit hydrograph are not given. A base flow of 750 m^3/s was used. This was equal to 1,000-year persisting 10-day flow at Bumbana gauge.

Using the excess PMP, unit hydrograph and base flow, the estimated PMF has a peak of 3,000 m^3/s and a volume of 480 million m^3 above a flow rate of 1,000 m^3/s. The PMF peak was compared with studies made in the region. An envelope curve of maximum floods measured in French Speaking Countries in the Northern Tropical Belt of Africa, developed by M. Roche (Hydrologe de Surface, gauther-Villars, Paris, 1963), showed that the peak plotted above the curve and factor is about 1.7 times larger than the peak from the curve.

4.2.1.2 Memorandum on PMF, March 31, 1994

This report summarized the PMF analysis given in the July 1980 report. The PMF peak was compared to Creager's diagram and the C value was estimated to be 23. However, the Creager's diagram was considered not applicable for the region.

4.2.1.3 Reservoir Routing and Spillway Sizing

Spillway size was designed based on the PMF peak and volume estimated in the Feasibility Study of July 1980. There are two morning glory ("bellmouth") spillways type, with crest diameters of 31.6 m, which discharge into the Right and Left Tunnels.

The Right Spillway Tunnel always operates under pressure flow conditions. The crest level of the Right Spillway (236 m a.s.l.) is two meters lower than that of the Left Spillway (238 m a.s.l). Floods will be discharged first through the Left Spillway until the water level in the reservoir reaches 241.25 m a.s.l., which corresponds to an inflow of 1,000m^3/s.

The PMF was routed through the reservoir under two conditions – normal operation and emergency operation. Under the normal condition, power generation was stopped at elevation of 240 m a.s.l. The radial gates in the right tunnel were fully opened at reservoir level of 241.25 m a.s.l. The maximum reservoir level reached was 241.95 m a.s.l. The outflow was nearly equal to the maximum inflow. During routing of the recession limb of the PMF hydrograph, the gates were partially closed (about 3.5 m a.s.l) at elevation 240.33 m a.s.l. At reservoir elevation of 239.43 m a.s.l, the gates were fully closed and power generation was resumed.

Under emergency condition, the gates were fully opened when the reservoir level reached 242.10 m a.s.l. Power generation was stopped at an elevation of 241.25 m a.s.l. The maximum reservoir elevation reached was 242.10 m.a.s.l. During recession, the gates were closed at elevation 240.46 m.a.s.l and power operation was resumed.

4.2.1.4 Review Comments

Admittedly, there was not sufficient hydro-meteorological data for a reasonably accurate estimate of the PMF. However, a number of simplifications were made in the analysis that resulted in a relatively low PMF peak. The time distribution adopted for the PMP is not as critical as it should have been. Hourly precipitation data are reported to be available at a few stations but were not used in the study. The runoff coefficient during the PMF, is about 62 percent which is on the low side.

Estimation of PMP and consequently the PMF requires experience and judgement. An estimate could vary over a significant range from one investigator to another. The current estimate is judged to be low over the possible range.

In the tropical region of Africa, a 'K' factor is frequently used to evaluate a PMF estimate. The 'K' value for the Bumbuna PMF is about 4.26. Based on the experience of the Panel, a value of 4.0 to 5.0 could be possible. This relatively low range is because the watershed is located on the lee side of the mountain barrier and precipitation could be lower than that on a watershed located on the windward side.

Another procedure is to review the ratios between the PMF, and maximum historic flood and the 100-year floods. These ratios are about 2.6 and 2.1, respectively. These are on a low side. The 100-year ratio between 3.0 to 3.5 is considered more appropriate for the basin.

In spite of the above observation, the PMF is acceptable. This is because compensating factors were observed in the analysis. When the PMP and time distribution were not critical, high baseflow and a peaked unit hydrograph were used. Re-evaluation of the PMP should be made.

The routing of the PMF through the spillways indicated maximum outflow nearly equal to the PMF peak inflow under emergency conditions. There was some attenuation of the PMF peak under normal conditions. The routing procedures are reasonable.

4.2.2 Power Generation

This subsection describes the power generation potential of the Bumbuna Hydroelectric Project. The Project will be equipped with two power units comprised of vertical Francis turbines directly coupled to vertical shaft synchronous generators. The design head is 70 m and the rated power of turbines is 25 MW each, operating at a discharge of 40 m^3/s and a speed of 333.3 revolutions per minute. At the maximum and minimum net heads of approximately 80 m and 47 m, the rated power will be 30 MW and 14.8 MW, respectively.

4.2.2.1 July 1980 Feasibility Study

The energy generation potential of the Bumbuna and Yiben projects were investigated using various combinations of the two dams to find optimal construction sequences. Estimated head losses and tailrace levels were lumped into a single value and held constant for eight years of simulation period. A simplified mathematical model was used.

Based on the above preliminary results, three sequences were selected for investigation. Monthly flow data for 58 years was developed and used in the simulation. Firm energy was defined as the average power that would be delivered in all but three months over the 58-year period. A mathematical model was used. Friction losses, efficiencies of turbine, generator and transformer, and operational losses were considered.

4.2.2.2 April 1994 Analysis

Detailed analyses were made to study the power and energy potential of the current project. A sequential streamflow routing model was developed and used. A routing interval of one day was selected. Daily flow data was obtained by uniform subdivision of the 58 years of monthly data developed during the July 1980 Feasibility Study. Three-day stoppage for power plant maintenance was considered in the simulation. Friction losses, efficiencies of turbine, generator and transformer, and operational losses were computed and used.

The firm power output was defined as that which could be guaranteed for 99.5 percent of the time during the lifetime of the plant, equivalent to the power which can be delivered in all but three months of the 58-year period. Secondary energy was computed as the difference between the total energy and firm energy. The 95 percent guaranteed energy were the fourth lowest values of every calendar month of the 58 years of record.

The estimated annual energy productions were as listed below:

- Firm energy 158 GWh
- Average energy 315 GWh
- 95 percent guaranteed 285 GWh
- Secondary energy, average 157 GWh
- Secondary energy, 95 percent 127 GWh

The results were presented as figures.

The report also provided variations in daily load , and load factor. A brief discussion of the use of the Bumbuna Hydropower Station in the power system of Sierra Leone was also discussed.

4.2.2.3 Review Comments

The computations of the energy generation are simple and satisfactory. However, as part of this review, the methodology used to generate the 58-years of monthly and daily inflow series, was checked. The accuracy of an inflow series significantly affects the power generation estimates.

The monthly streamflow analysis was made in 1980. The streamflow data was estimated using a Tank model developed in Japan. This model has been used quite extensively in Southeast Asia and some African countries.

Streamflow records at Bumbuna gauging station was reviewed. A field visit was made to check the hydraulic channel control downstream of the station. Based on these observations, the streamflow data was judged to be of fair quality.

The precipitation data at the stations used to develop the rainfall-runoff relationship was reviewed. Of the four stations selected to compute basin average rainfall, three were outside the basin. The data at these stations were extended or filled –in to a common period of 58 years (1921 to 1978) through correlation. The correlations were acceptable but not very significant. The average of four stations was assumed to be the basin average precipitation. This computed average precipitation was certainly significantly higher than what should be expected in the basin. This is primarily due to much higher precipitation south of the dam site, from where two of the four stations were selected. The flow series at one of the long-term station was checked for consistency and homogeneity. The series indicated a decreasing trend, but the trend was judged to be insignificant.

A correlation between the precipitation data at Kabala, located near the northern boundary (within the basin) of the basin and flow data at Bumbuna Gauging Station should have been attempted. This could improve the results of the Tank model. The monthly streamflow series generated by the Tank model was also checked for consistency. The series was judged to be consistent and homogeneous. Given the data collection procedures and practically no precipitation data in the basin, the computed monthly time series is acceptable for power generation computations.

The 1994 analysis for power generation should be re-checked by using a better estimate of daily inflow series. Currently, the daily flows have been obtained by uniform subdivision of the monthly flows. This is not a correct procedure. Daily streamflow data is available at the Bumbuna gauge. Representative daily flow distribution curves should be developed for typical dry, average and wet months. More than one such months could be potential candidates when the monthly flows are nearly equal but with a different daily distribution. These distributions should be used to derive the daily data for the 58-year period. This would improve the energy estimates.

Energy estimated should also be determined for dry periods of 7-, 14- and 30-day, and 1- to 3-month periods. Probability of occurrence of such periods should be determined. This will be used to check the role of Bumbuna Hydro in the energy system of Sierra Leone.

4.2.3 Geotechnics

4.2.3.1 Geological and Geotechnical Site Investigations

A comprehensive investigation was made of the geological and geotechnical conditions at the Yiben and Bumbuna Dam sites from 1972 to 1973 and again from 1977 to 1979. The 1972-73 investigations concentrated mainly on the Yiben Dam site with only a seismic refraction survey carried out at Bumbuna. The 1977 – 79 investigations focussed on the Bumbuna site. The results of this investigation are presented in the feasibility study, which was completed in 1980. The results of these investigations were considered sufficient for both the feasibility study and final design.

The Panel made a brief review of these investigations and found them to be adequate in terms of quantity and quality for a project of the nature and size of Bumbuna Dam. The investigations appear to have been carried out using best practices at the time the investigation were carried out.

<u>Field Investigations</u>

Investigations consisting of surface and subsurface activities covered the areas of the planned foundation for the dam and structures, as well as possible sources of construction materials. Surface investigations comprised a review of available literature on regional geology and seismicity, existing geologic maps, and site specific geologic mapping in the field.

Subsurface exploration consisted of the following:

- 94 Boreholes totaling 4,480 m
- 70 Geolectric Profiles totaling 4,415 m
- 14 Seismic Profiles totaling 4,310 m
- 34 Trial Excavations (pits, trenches and galleries)
- 376 Water Pressure Tests
- 2 Grout Tests
- 29 In-Situ Permeability Tests

Field investigations also included experimental grouting in the area of the Bumbuna dam foundation, and a trial embankment utilizing materials from the Bumbuna quarry.

Laboratory Testing

A full suite of laboratory tests were performed on soil and rock samples collected from the field investigations. Testing included petrographic analysis, specific gravity, sieve analyses, uniform soil classification, triaxial testing, and direct shear tests. Laboratory testing of water samples was also performed.

4.2.3.2 Geologic Conditions

The Bumbuna Dam site is located on the Seli River which runs north to south through a relatively deep, narrow valley in the Sula Mountains, cut into pre-Cambrian, crystalline basement rock. The region is characterized primarily by gneissose granite and granodiorite of the West African Craton. The left abutment at the dam site however, is formed by amphibolite which strikes north northeast, parallel to the river, and dips steeply to the northwest (toward the valley). The amphibolite is in contact in the riverbed with a granitic body, which outcrops on the right abutment up to the crest of the dam where it is again in contact with the amphibolite. Further up the abutment the amphibolite is in contact with a massive granodiorite complex with inclusions of ultramafic schist. A relatively younger, intrusive, isotropic, granitic body was mapped on the right side of the river upstream of the dam site. The rock mass is frequently cut by aplite and granite pegmatite dikes which trend roughly parallel to the river.

The contact between amphibolite and granite which occurs approximately in the river bed, was thought originally to have been a fault, however the investigations proved that this was not the case.

A hard granodiorite sill crosses the river about 2 km downstream of the dam site forming Bumbuna Falls.

Alluvium is nearly absent in the riverbed at the dam site, where bedrock outcrops are fresh and sound.

Borings showed the upper part of the rock mass to be less fractured with depth. Up the abutments the rock mass becomes increasingly weathered. This weathering extends to a depth of up to 30m on the left abutment and to 20m on the right. The weathering profile starts with residual soil at the surface and passes to weathered rock with depth until the rock mass is sound.

The rock mass at the Bumbuna site was considered to offer adequate foundation strength and watertight characteristics for the rockfill dam contemplated.

A quarry was located about 1.5 km northwest of the dam site in the younger granitic body which is sound where it outcrops over a large area. The site was determined to easily provide the volume of rockfill required to construct the dam.

4.2.3.3 Seismicity

Regional Seismicity

A seismotectonic study of the Bumbuna Dam site was carried out as part of the feasibility study to assess seismic risk and determine the design earthquake and seismic parameters to be used in design. The crystalline rocks of the West African Craton on which the Bumbuna project is located, has been geologically stable since the Pre-Cambrian. Faults identified in this basement complex do not represent planes of weakness which could be reactivated due to seismic forces. There is no evidence of movement of faults within the craton since the Cretaceous Period some 65 million years ago.

Bumbuna is located well within the craton approximately 150 km from the coast where the majority of regional earthquakes have been recorded. In fact only five seismic events have been reported in the region between 1947 and 1978, and it is unlikely that the intensity of these events could have exceeded V on the Modified Mercalli scale.

Seismic Design Parameters

The seismic evaluation suggested that an acceleration at the dam site of 0.04g together with a standard spectra design procedure should be used to determine the appropriate seismic loading factors for design of a long period structure such as the Bumbuna Dam.

Reservoir Induced Seismicity

Considering the historical record of reservoir induced seismicity in the vicinity of reservoirs impounded on Pre-Cambrian cratons around the world, it was determined that an appropriate magnitude earthquake of 4.5 on the Richter scale with a hypocenter at a distance of 5 km from the site would be appropriate for design purposes.

4.2.4 Preliminary Design

4.2.4.1 Dam (July 1980)

Table 3 describes the characteristics of the preliminary dam design.

TABLE 3 – PRELIMINARY DAM DESIGN CHARACTERISTICS

Dam type: Rockfill dam with upstream asphalt concrete facing	
Max. height of the dam	74 m
Total embankment volume (excluding random fill and coffer dam)	2.2 mill. m^3
Total reservoir volume	225 mill. m^3
Upstream slope	1:1.8
Downstream slope	1V:1.7H, 1V:2.5H to 1:4H
Upstream cofferdam incorporated in main dam	
Crest length	370 m
Crest width	4 m

Maximum water level	228.75 m a. s. l.
Dam crest elevation	231.00 m a. s. l.
Asphalt concrete lining: Two impervious layers with drainage layer (sandwich type) Sub-grade Leveling course Binder layer, 8 cm thick, pervious 1st impervious layer, 5 cm thick Drainage layer, 8 cm thick, pervious 2nd impervious layer, 8 to 10 cm thick Mastic sealing (surface seal coat)	
Grouting and inspection gallery, controlled seepage collection system	
Straight dam axis	
Downstream slopes below el. 211 m protected with Rip Rap to resist overflow during construction caused by higher floods.	

4.2.4.2 Hydraulic Structures and Power Generation Facilities

During the feasibility studies carried out in1980 a comparison of possible options for the Bumbuna Dam type, layout of associated structures and power generation facilities resulted in the recommendation of a scheme consisting of an Asphalt Concrete Faced Rockfill Dam, two Morning Glory Spillways combined with Left and Right Bank Diversion Tunnels, and Powerhouse located downstream of the Dam site utilizing the Head provided by Bumbuna Falls. In the recommended solution water for the Power Generation facilities would be conveyed through an Intake Tower, Headrace Tunnel and Penstock. The Tailrace System would consist of a Downstream Surge Tank, Tailrace Tunnel, Tailrace Canal and connection to the Seli River at a short distance upstream of the Seli Bridge.

In subsequent phases of Project development the type and location of the Dam and the combination of two diversion tunnels with Morning Glory Spillways remained unchanged as being the most suitable solution for Bumbuna. The Project down-scaling introduced, however, substantial changes in the location of the Powerhouse, relocated to the area immediately downstream of the Dam-and elimination of the comparatively long waterways at the cost of not exploiting the head available at Bumbuna Falls. A compensation for this loss of head is the raise of the Dam height. An additional and important modification introduced at this stage was the further combination of functions of the Right Bank Tunnel, serving also as headrace for the newly positioned Powerhouse facility—a rather unconventional engineering solution.

During the Feasibility Studies the scanning of Alternatives and options was comprehensive and it may be concluded that the matter of layout, type of Dam, type of spillway facilities and diversion tunnels has received sufficient attention and optimisation efforts.

4.3. Supplemental Feasibility Study for Scaled Down Solution (1984)

This study was initiated as a result of a World Bank "Macroeconomic Impact of Bumbuna Project on the Sierra Leone Economy". The scaled-down solution involved a slightly higher dam, about 13 m increase, and an outdoor power house at the foot of the dam. The right spillway diversion tunnel was proposed as a power tunnel.

The scaled-down project reduced the total plant cost from US$ 192 Million to US$ 100 Million. The construction period was reduced from 4.5 years to 3 years. Installed power capacity was 47 MW. An energy simulation analysis was performed. Annual energy was estimated to be about 290 GWh compared to the original production of 424 GWh.

This project was considered viable by the World Bank and Government of Sierra Leone. The Consultants were advised to refine the project at a feasibility level.

4.4. 1994 Project Summary

The status of the Bumbuna Hydroelectric Project was summarized in 1994 by SP in order to support the GOSL in their negotiations to secure additional financing to complete the civil works component of the Project. The report presents background information, describes the project and the status of construction at that time, and synthesizes studies, engineering design, construction schedule, project costs, economic analysis, power generation, and operation and maintenance.

5. FINAL DESIGN

5.1. Dam Foundation

The asphalt concrete faced rockfill dam is designed to be founded on sound to moderately weathered bedrock with a cut-off to sound rock at the upstream toe of the dam in the form of a reinforced concrete plinth.

Seepage through the foundation is designed to be controlled by means of a double line grout curtain below the plinth. A shallow upstream curtain of vertical grout holes extends to a depth ranging from about 12 m to 32 m, and a deeper downstream line to a depth of approximately 20 m to 50 m. In areas where it is not possible to found the plinth on sound rock, a cut off trench is envisioned to the top of the sound rock surface, to be backfilled with concrete. Where it is not possible to reach sound rock with a trench, the design calls for construction of an impervious wall utilizing 300 mm diameter concrete micro piles.

Foundation drainage is provided by seven transverse drains, consisting of pre-cast concrete pipes installed in trenches in the dam foundation spaced at varying intervals. Upstream of the dam axis the top of the pipes are slotted with the lower part encased in concrete, and downstream they are completely encased in concrete. Three 500 mm diameter drains are located in the left abutment, two in the right abutment, and two 600 mm diameter drains in the river bed.

The specifications call for covering areas of erodible soil exposed in the foundation with a sandwich filter/drain layer in order to prevent the migration of fine grained soils. The foundation for the main body of the dam is compacted with a vibratory roller prior to placement of rockfill.

Deformation and water pressures within the foundation are monitored by means of a settlement gauges through the dam and electric and standpipe piezometers, located in three transverse instrumentation section in the dam.

5.2. Asphalt Concrete Faced Rockfill Dam

5.2.1 Basic Data

Table 4 lists the basic data of the asphalt concrete faced rockfill dam final design:

TABLE 4 – FINAL DAM DESIGN CHARACTERISTICS

Damtype: Rockfill dam with upstream asphalt concrete facing	
Max. height of the dam	88 m
Total embankment volume (excluding random fill and coffer dam)	2.5 mill. m^3
Total reservoir volume	445 mill. m^3
Asphalt concrete facing	51,000 m^3
Upstream slope	1: 1.65
Downstream slope	1V:1.4H to 1:7H (below berm)
Crest length	440 m
Crest width	4 m
Freeboard up to dam crest	2.06 m
Freeboard up to top parapet wall	3.0 m
Maximum water level	241.94 m a. s. l.
Minimum operation level	210.00 m
Dam crest elevation	244.00 m a. s. l.
Elevation parapet wall at dam crest	244.95 m

Main embankment:	
Crushed rock from quarry (granite)	
Construction requirements: D_{15}, D_{max},	> 25 mm, 600 mm
Layer thickness, minimum density, roller passes	1.0 m;18 KN/m³;4-6
Transition zone between embankment and asphalt concrete lining: Width	5 m
Crushed rock from quarry (granite)	
Construction requirements: D_{15}, D_{max}, gradation	> 25 mm, 300 mm, WG
Layer thickness, minimum density, roller passes	0.5 m;18 KN/m³;4-6
Asphalt concrete lining: Single impervious layer system Sub-grade sprayed with bituminous emulsion Leveling course Binder layer, 8 cm thick, pervious Impervious layer, 10 cm thick up to el. 215 m; 8 cm thick above el. 215 m Surface seal coat	
Plinth: No grouting and inspection gallery, no seepage collection system between plinth and asphalt concrete facing	
Dam axis curved and shifted to upstream at the right bank	

5.2.2 Asphalt Concrete Facing:

Due to the order to decrease the overall cost of the project, the design of the asphalt lining system was changed in the Final Design Phase from a "Two Impervious Layer plus a Drainage Layer System – Sandwich Type" to a "Single Impervious Layer System". Table 5 compares the characteristics of the Bumbuna Dam lining system with other asphalt concrete faced rockfill dams around the world.

TABLE 5 – COMPARISON OF BUMBUNA DAM LINING WITH OTHER ASPHALT CONCRETE FACED ROCKFILL DAMS

Name	Height (m)	Country Year	Type*	Impervious Layer (cm)	Drainage Layer (cm)	Binder Layer (cm)	Slope 1V : xH
Huesna	73	Spain,1988	O	6 + 6	-	8	1.6
El Siberio	82	Spain, 1978	S	9-12, 6	8		1.6
Yashio**	90.5	Japan, 1992	S	5+5+5, 6	8	4	2.0
Miyama	75	Japan, 1973	S	6+6, 6	8	3.5	1.9
Menta	90	Italy, 1997	S	6+6, 5	8	6	1.7
Archichiaro	80.5	Italy, 1997	O	3+3	-	6	2.0
Marchlin	70	UK, 1979	O	8	-	6	2.0
Oschenik	81	Austria,1978	O	8 + 6	-	8 - 10	1.5
Gösskar	55	Austria, 1975	O	8	-	6	1.6

* S = sandwich type, 1st impervious layer + drain layer + 2nd impervious layer + binder

O = single or multiple impervious layers, impervious layer + binder or 1st impervious layer + 2nd impervious layer etc. + binder

** Dam located in area with high seismicity

5.2.3 Dam Design, Construction Materials, Zoning and Placement Requirements

The design of the rockfill dam with an asphalt concrete facing, the zoning of the dam, and the selected construction materials meet international standards.

Review Comments:

- The design of a rockfill dam with an asphalt concrete facing is endorsed by the Panel. The decision made during the final design phase to construct a single impervious layer system instead of a lining system with two impervious layers and a drainage layer (sandwich system) as well as for a plinth without separate leakage detection and grout facilities, decreased the cost but will require in the operation phase, a more advanced monitoring and maintenance program. In case of any leakage a faster and more efficient reaction will be needed to take appropriate measures.
- All fill materials used, zoning of the main dam, and the most important requirements for dam construction as well as the stability analysis of the dam - for normal, unusual load cases and earthquake loading (0.07 g) – is endorsed by the Panel.

- The high shear resistance of the available rockfill material, as determined in the field by a tilting test, and the proper placing and compaction method, allowed the inclination of the upstream and downstream dam slopes to be increased to 1V:1.65H and 1V:1.4H respectively.
- The evaluation of the asphalt concrete mix design and the selection of raw materials, laboratory testing etc. and the final decision of the most important technical details as well as the placing procedure and the basic construction requirements are endorsed by the Panel.

5.2.4 Seepage Control and Drainage System

The technical solution of the dam foundation drainage system was basically described in item 5.1. The design allows for collection of seepage eventually coming through the dam and its foundation (grout curtain) or from the dam abutments, but the system is not able to separate the source of the seepage (for example seepage from the lining, seepage through grout curtain, or seepage from the abutments, etc.).

All pipes can separately be measured at the downstream toe of the dam or in the drainage pumping station. Along both downstream dam abutments a surface water collecting system was designed and constructed.

Furthermore all drainpipes are connected at the upstream toe of the dam to the filter/ transition zone placed just downstream of the asphalt concrete facing.

A filter layer between the dam foundation and the rockfill material of the dam was basically designed to prevent internal erosion between the remaining fine material and the coarse rockfill zone. See also item 5.1.

Review Comments:

- The design of the drainage zone (transition zone) at the upstream slope of the dam and underlying the asphalt concrete lining is endorsed by the Panel.
- A disadvantage of the foundation drainage system design is, that it does not allow for separation of seepage flow coming from different locations, like the asphalt concrete lining, the grout curtain or from the abutments.
- The construction of a drainage layer (inverse sand and gravel filter or gravel filter) on top of the remaining, and potentially erodable fine material, at least on the left abutment, or the entire weathered rock foundation, would have been a more conservative solution.

5.2.5 Dam Instrumentation

In the Final Design Phase, it was decided to locate the dam monitoring station in the Power House, and transmit the data from the most important monitoring instruments. The dam is equipped with the following instruments:

Seepage control:

5 measurement points (pipe drains from abutments)

2 measurement points (pipe drains river bed – pumping station)

Piezometers:

14 piezometers upstream (foundation and contact foundation/dam)

6 piezometers downstream (foundation)

Deformation devices:

4 magnetic settlement gauges - downstream

4 USBR settlement gauges with piezometric base – downstream

Geodetic surveying grid - several mobile and fixed targets

7 clinometers upstream in transition zone below lining

Review Comment:

- The dam instrumentation, as well as the installation of the dam monitoring center at the Power House and the transmission of data from the most important monitoring devices, is endorsed by the Panel.

5.3. Hydraulic Structure

In its final concept the hydraulic appurtenances of the Bumbuna Dam consist of the following structures:

5.3.1 River Diversion Tunnels

River Diversion during dam construction is achieved by provision of two diversion tunnels located on each side o the valley at the dam site. Both tunnels have an approximate length of 620 m, internal diameter of 9.0 m and are concrete lined. Their discharge capacity corresponds to a total discharge of 1,200 m^3/s (flood of return period 20 years) at an upstream water level of 179.0 m.a.s.l . Closure of these tunnels at the end of the construction period is made possible with lowering stop-logs at the inlet structure of each tunnel and plugging with concrete. In general the task of river diversion is taken by the Left Bank tunnel and the Right Tunnel is only used during the rainy season.

During the period of operation of the Project the downstream parts of the diversion tunnels serve additional purposes: the Left Tunnel as the discharge waterway for the Left Spillway; the Right Tunnel as the discharge waterway for the Right Spillway as well as a headrace for the power generation facilities and also as a bottom outlet.

5.3.2 Spillways

Two surface spillways of morning glory type connected to the Left and Right Tunnels respectively are provided to handle the floods reaching the Bumbuna Reservoir. The crests topping the 36 m high tower-like structures have a diameter of 31.6 m, at elevation 236.0 m a.s.l. (Right Spillway) and 238.0 m a.s.l. (Left Spillway) respectively. Flood discharges up to 1,000 m^3/s (return period 10 years) will be handled by the Left Spillway alone and the total combined capacity of both spillways is 3,000 m^3/s corresponding to the PMP/PMF estimate. The Bumbuna Reservoir provides very little flood routing capability and therefore the inflow hydrograph peak defines the required spillway capacity.

The release of spillages to the downstream river reach is accomplished by means of a flip bucket dissipator located at the downstream end of each tunnel. The plunge pool will develop by natural scouring in the riverbed.

5.3.3 Power Intake Works

The Intake to the Right Tunnel is a hexagonal shaped tower with a height of 90 m consisting of a trashrack protected inlet, a drop mouth entrance and a vertical shaft connecting the tower with the tunnel. Closure of the intake is done by a 7.5 m diameter cylindrical gate. The upper platform of the Intake tower is connected to the reservoir shore by a footbridge.

5.3.4 Terminal Structure of the Right Tunnel.

The Right Tunnel is used as a headrace structure for power generation. In order to control the outflow at the downstream end of the tunnel a gravity type control structure equipped with a 7.4 m high x 7.0 m wide radial gate is provided. During normal operation of the project the gate remains closed. It is fully opened during the occurrence of floods in excess of 1,000m^3/s (return period around 10 years). During these occasions the Powerhouse operation has to be discontinued.

The stability of this terminal structure as well as the watertightness of the radial gate are of primary importance for the safety of the structure. In order to achieve this, safely taking into account the high hydrostatic load acting on the closed gate (about 4,000 ton), the terminal structure is anchored to an upstream gravity block by means of tensioned cables and the trunion supporting beam is also anchored into the piers of the structure by cables.

5.3.5 Hydraulic Aspects

The final hydraulic design of the Left Bank Spillway facilities and the Right Bank combined Spillway/Headrace facilities were based on the results of Hydraulic Model Test investigations carried out at the Imperial College Department of Civil Engineering Laboratory (UK), during the period July 1991—September 1993.

Hydraulic model tests conducted on a 1:58.8 scale model, using Froude similarity included the investigation of flow conditions, measurement of pressures, determination of heads losses, observation and measurement of scouring downstream. Main aspects of these investigations (Hydraulic Model Test Report-September 1993) are:

- Left Bank facilities---head-discharge characteristics, flow conditions along the tunnel, conditions of occurrence of a hydraulic jump in the tunnel, terminal flip bucket pressures, jet trajectories and jet impact areas.
- Right Bank facilities---head losses during powerhouse operation, head losses and pressure fluctuations in the manifold conveying water to the Powerhouse, transition upstream of the radial control gate, head-discharge characteristics of the spillway, flip bucket, jet characteristics, loading on the radial gate, tunnel filling transients.

On the basis of test results several design improvements were introduced in the original design. Main points are:

- Left Bank facilities---improved pier layout at the spillway crest; provision of two aeration slots to control cavitation potential; provision of aeration grooves along the discharge tunnel; structural strengthening of the tunnel outlet structure and a monolithic concrete chute to guide the lower range of discharges and the jet is not yet launched.
- Right Bank facilities---incorporation of a by-pass valve in the cylindrical intake gate to control tunnel filling operation; lowering the spillway crest elevation to control air entrainment when the radial control gate is open; modification of the manifold geometry to improve hydraulic operation conditions.

Review Comments:

Model studies and hydraulic design of the Left and Right Bank facilities have been carried out using updated knowledge and appropriate engineering procedures.

Model studies have provided a sufficient overview of flow conditions in both spillways, discharge tunnels and terminal structures during spilling operations and also provided the verification of flow conditions in the Right Bank tunnel and manifold during normal Powerhouse operation. The recommended design improvements, incorporated in the Final Design, are appropriate and seen as favourable.

There was no investigation carried out on the intensity and extent of scouring downstream by action of the spilling operations. This was not requested from the Laboratory and the investigations were limited to define the location of the jet impact zones. Since no tests on a movable bed were carried out, an analytical investigation of scouring potential should be carried out in order to complete this missing information.

5.3.6 Structural Aspects

The structural design of the concrete, reinforced concrete and steel structures of the Project was based on stability analyses, verification of stresses and verification of required reinforcements using commonly adopted engineering methodologies and procedures. Major analyses carried out for the design include:

- Shaft spillways—structural model of a membrane with stiffeners; critical loading conditions: reservoir full/shaft empty; reservoir empty/shaft full
- Intake Tower---slender structure with thick base; critical loading condition: reservoir full/tower empty

- Powerhouse---concrete shell; critical loading condition: uplift and full load rejection
- Right Outlet Structure---block structure supporting the full hydrostatic load transmitted by the radial gate. Tensioned anchors.
- Tunnel linings---in hard rock, self supporting rock mass, 300mm thick concrete lining for hydraulic purpose, skin reinforcement;

  in soft soil, 600 mm thick reinforced concrete lining supporting the overburden pressures, cast in situ concrete piles down to bedrock;

  at the downstream end of the Right Tunnel---steel lining to support both internal and external water pressures

These analyses considered the action of applicable own weight, wind, hydrodynamic pressures forces, gate reaction forces and a pseudo-static earthquake induced inertia force corresponding to a seismic coefficient of 0.07.

Among the seven different concrete mixes used during construction, the predominant application in the hydraulic structures is mix C25D25, with a cement content of up to approximately 330 kg/m^3 and maximum aggregate diameter of 25 mm which was pumped. This type of concrete represents some 80% of all the concrete applications in Bumbuna. Typical values of compressive strength achieved are of 25 MPa at the age of 28 days. Some use of lower strength concrete mixes (10-20 Mpa) in structurally less important components.

Steel bars used in reinforced concrete elements utilized steel with typical yield stress of 430 N/mm2 and 540 N/mm2 (tensile strength of 640 N/mm2) mainly in the form of primary and distribution reinforcements and skin meshes.

Review Comments

On the basis of a partial and selective evaluation of the available calculations, drawings and additional technological information the Panel is satisfied that the criteria, loading cases and procedures used for the structural design are fully satisfactory and lead to safe and reliable concrete structures.

5.3.7 Observations related to the expected hydraulic performance of the Hydraulic Structures

The Left Bank Spillway facilities, which make use of the downstream part of the Diversion Tunnel, are a relatively common solution adopted for reasons of project economy in many dam projects throughout the World. There are numerous examples of this type of hydro-combined arrangements in the practice of dams located in small rivers with discharge capacities up to about 2000 m**3/s and heads less than 100m (e.g. Oued el Makhazine in Morocco in operation since 1975, with a capacity of about 1500 m**3/s). The behaviour of this type of spillway is well known not only from extensive studies but also from prototype observations. Typical hydraulic problems occurring during the operation are associated with the intensity of time variable hydrodynamic pressures generated at the bend connecting the vertical spillway shaft and the horizontal tunnel, the need to control cavitation potential and the possible instability when the free overflow spillway becomes submerged. These problems are more severe with increasing discharge capacity and head. Factors controlling these problems are the bend geometry, the provision of aeration reaching the zones prone to cavitation and to avoid, if ever possible, to reach the submergence of the spillway. In Bumbuna appropriate provisions were made to achieve adequate hydraulic operation conditions.

The solution given to the Right Bank facilities is unconventional. It combines the shaft spillway, diversion tunnel and Power Headrace functions together. Neither is there the possibility of a favourable bend geometry nor the provision of aerators. The resulting flow conditions during spillway operation are disturbed as evidenced by the model studies. In the continuation of the Project development careful consideration should be given to minimize the exposure of the system to unfavourable flow conditions. The Panel recommends the establishment of a detailed plan for Reservoir operation taking this criterion into account. The following operation rules could be used as a preliminary guideline:

Diversion during construction:

- Uncontrolled release of river flows using both diversion tunnels

Normal operation during dry season:

- Reservoir level below elevation 238.0 m.a.s.l.
- Power plant operation and release of discharges through the turbines only.
- Radial Gate in the terminal structure of the Right Tunnel completely closed.

Normal operation during wet season:

- Reservoir level between elevations 238.0 m a.s.l. and 241.0-242.0 m a.s.l.
- Power plant operation and release of flood discharges through the Left Spillway (up to 1000-1500 m^3/s).
- Radial gate completely closed
- Optimization needed to better define the upper limit of this range.

Exceptional operation during wet season:

- Occurrence of exceptional floods, reservoir inflows above 1,000-1,500 m^3/s and up to PMF.
- Reservoir levels above 241.0-242.0 m a.s.l.
- Short term interruption of Power plant operation and use of both tunnels to release floods.
- Progressive opening of the radial gate.
- Operation still to be optimized.
- Avoidance of free surface flow conditions in the right tunnel.
- Limitation of dynamic actions on the radial gate at partial opening.

- Minimization of the time of interruption of power plant operation:

Exceptional operation during dry season.

- Release of duty flows downstream of the dam during a planned or accidental interruption of power plant operation at low reservoir levels.
- Controlled releases using the radial gate at partial opening.

First filling of the Reservoir; exceptional drawdown.

- Controlled operations which may be needed at least at level of forecasts and planning
- To optimize the first Reservoir filling and possible dam inspection/maintenance during the Project operation phase.
- To be further detailed in terms of gate operation and possible complementary measures.

5.4. Power Generation Facilities (Phase 1)

The final design of the Power Generation Facilities of the Project (Phase 1) consist of the main components described in the sequence.

Observation: Provisions for future expansion of these facilities, compatible with the expansion of market requirements and the stepwise development of the Seli River potential (including discharge regulation to be provided by the upstream Yiben Dam located 30 km upstream of Bumbuna) have also been included in the final design but are not the direct object of this Report. They consist in the possibility of a duplication of generating capacity in Bumbuna with construction of an additional Powerhouse and the hydraulic connection with Bumbuna Falls using the existing Intake Structure.

5.4.1 Water Conveyance System

Water for the operation of the Powerplant is drawn from the Right Tunnel through an off-take designed for a total discharge of 80 m^3/s feeding two, short steel penstocks.

5.4.2 Power House

Semi-outdoor type located at the downstream toe of the dam. Compact arrangement with an overall length of 41.0 m, width 17.0 m, depth 24.0 m housing the main generation equipment, galleries, draft tubes, auxiliary services.

Main equipment consists of:

- Two Francis type turbines, vertical shaft, rated head 70 m, rated speed 333.3 rpm, rated discharge 39.0 m3/s
- Two 33.7 MVA synchronous generators, exit voltage 13.8 kV
- Two butterfly valves
- Switchgear, auxiliary services

5.4.3 Substation and Transmission Line

Power generated in the Powerhouse will be stepped up to 161 kV by two three-phase transformers of 33.7 MVA each. Outgoing 161 kV transmission line to Freetown.

The single circuit Transmission Line, with a total length of 200 km, connects to the Freetown Substation located adjacent to the existing King Tom Substation.

Review Comments:

The Panel did not visit the Transmission Line nor the Freetown Substation areas. The review of project documents related to electrical installations and equipments, which are not part of the TOR, was only done for general information purpose.

The Panel concurs in the opinion that the layout and main characteristics of the civil structures are well suited for their purpose. Further comments related to the structural design are found in 5.3.6. The choice of hydro-mechanical equipment such as turbines and valves also corresponds to good engineering practice.

6. CONSTRUCTION

This Chapter presents a history of construction activities at the Bumbuna Hydroelectric Project and summarizes the present status of the works, presents the requirements and activities still to be carried out for the completion of construction, and beginning of operation as well as pertinent observations.

6.1. Construction History

The execution of civil works and manufacture of equipment for the Bumbuna Project have been carried out to date following a sequence of contractual arrangements subject to specific financial provisions and can be summarized as follow:

Contract A0—Permanent and Resident Engineer's Camps

- The camps were completed from 1981 to 1982

Contract A1---Preliminary Works

- Excavation of the Left and Right Diversion Tunnels was carried out in 1983 and 1984

Contract A2---Civil Works

The following work was completed from 1991 to 1993

- Excavation and treatment of the foundation for the rockfill dam
- Placement of the reinforced concrete plinth at the upstream toe of the dam
- Placement of approximately 2.5 million m^3 of granitic rockfill in the main body of the dam, completing the structure to 1.0 m below the crest elevation of 244.0 m a.s.l.
- Reinforced concrete morning glory spillways connected to the multipurpose tunnels on each abutment.

- Reinforced concrete intake tower connected to the Right Tunnel
- Lined both multipurpose tunnels with concrete and steel as required.
- Repaired the landslide scarp at the entrance to the Left Tunnel.
- Completed excavation and concrete lining of Left Tunnel.
- Constructed Intake Tower

The following work was completed from 1996 to 1997:

- A two layer asphalt concrete lining was placed on the upstream face of the Dam comprising approximately 51,000 m^2, the third layer (impervious course) is about 85% complete and the application of the surface seal coat has not been started.
- Installed a trash rake at the Intake.
- The reinforced concrete shell of the Power House downstream of the dam was started and is approximately 80% complete
- Penstocks and Draft tubes of unit nos. 1 and 2 have been installed.

Contract B---Hydraulic Steel Structures

The following Hydraulic Steel Structures were installed from to 1997

- Installed the 7.5 m circular intake gate
- Installed but did not concrete the steel elbow from the intake to the Right Tunnel.
- Installed the 7.5 x 7.0 m Radial Gate at the Downstream end of the Right Tunnel
- Installed partial steel lining of Right Tunnel.

Final Design and Construction Supervision

- Final design was completed.
- Construction was carefully monitored up to the stoppage of construction activities in 1997.

Contract C---Electromechanical Equipment

- The 115 ton gantry crane was assembled but not installed
- The two 13.8/161 kV step-up Transformers were delivered to the site but not installed
- The scroll case of the turbines have been delivered to site but not installed
- Two butterfly guard valves were delivered but not installed.
- Four ½ generator stators arrived in Freetown.
- Upper and lower generator bearing arrived in Freetown

Contract D---Transmission Line and Freetown Substation

The following work was carried out from 1993 to 1997:

- 500 galvanize towers were erected.
- Approximately 84 km (41%) of ACSR conductor was installed between Freetown and Waterloo, and between Bumbuna and Makeni.

From 1997 to the present, 32 galvanized steel transmittion line towers were destroyed and another five vandalized.

Contract E---Logistic Support for the Project Implementation Unit

A detailed account of the historical development of the Project related activities is provided in the document 'Project Summary'—Studio Pietrangeli, April 1994.

In summary the works under Contracts A0 and A1 were carried out between end of 1982 and the beginning of 1985. Civil Works under Contract A2 started in July 1990, discontinued in 1994-1995 and interrupted in May 1997. In similarity, Contract B activities started in 1990, were also discontinued after 1992 and resumed during the period 1995 until May 1997. Contracts C and D related to Electromechanical manufactures and the Transmission System/Substation were developed during the period 1992/1993 and almost entirely interrupted in 1997.

6.2. Condition of Works

The Panel reviewed documentation and inspected in the field, all aspects of the project accessible at the time of the meeting as follows:

6.2.1 Tunnels

During the visit it was not possible to inspect the Right and Left Tunnels as both were being utilized to handle diversion flows. However, a review of the construction of the tunnels was made in conjunction with SP personnel who were present during these activities. Construction of the tunnels can be summarized as follows:

6.2.1.1 Right Tunnel

The Right Tunnel has been serving as a primary and then secondary conduit for river diversion since 1993. In the future, after the diversion gate is closed and the upstream portion of the tunnel is plugged, it will receive flows from the Right Spillway and the Intake. With the downstream Radial Gate in the closed position, the Right Tunnel will act as a headrace tunnel for the power facilities.

The approximately 620 m long, circular tunnel was excavated to a diameter of 11.0 m in 1984 by drill and blast methods. The rock encountered was sound granite over the entire length of the tunnel and only rock bolts were required for support. In 1992 - 1993 the tunnel was lined with steel and concrete to its finished diameter of 9.0 m.

6.2.1.2 Left Tunnel

The Left Tunnel is presently being used as the primary conduit to divert flow from the Seli River around the dam site. In the future, after the upstream part of the tunnel is closed and plugged, it will receive flow from the Left Spillway. The Left Spillway will be the Service (Primary) Spillway and is expected to operate for extended periods every rainy season. The spillway is designed to discharge in excess of 1,000 m^3/s.

The length and diameter of the Left Tunnel are identical to the Right Tunnel. Construction began in 1983 from the upstream portal. The first 587 m were mined through sound amphibolite which only required rock bolting for support. At chainage 587.55 the tunnel encountered highly weathered rock and the roof collapsed forming a cavity that extended upward to the ground surface. Steel sets were installed and the crown was re-constructed as a reinforced concrete plug. The cavity was backfilled with concrete. Still in 1984, the crown of the tunnel was exposed from the surface from chainage 653.37 to the downstream portal at chainage 758.37, and a reinforced concrete canopy constructed. In 1991 the soil and highly weathered rock under the canopy were mined out from the downstream end of the tunnel. Excavation of the remaining portion of the tunnel in weathered rock and residual soil from chainage 587 to 653 was carried out from the upstream end. Support was provided over the crown by an umbrella of grouted steel spilling pipes prior to excavation. Walls of the discharge chute were stabilized with 800 mm diameter steel reinforced piles. As mining progressed in two stages, the ground was stabilized with steel sets, rock bolts, wire mesh, and shotcrete. The invert of the Left Tunnel and energy dissipator, from approximately chainage 587 to the flip bucket, has been underpinned with three rows of 300 mm diameter cast-in-place concrete mini-piles, spaced at intervals of 3.0 m, which extend to 1.5 m into the top of sound rock. Soil under the flip bucket was replaced with mass concrete. River diversion was effected through the tunnel in 1994.

Since the Left Tunnel will serve as the outlet of the Left Spillway, it is extremely important that it be carefully inspected following closure of the diversion gate in order to assess the condition of the downstream portion with respect to damage from erosion and settlement. Repairs, if required, will have to be made in a timely manner in order to allow the project to come on-line as scheduled.

6.2.2 Asphalt Concrete Faced Rockfill Dam

During the construction of the dam some changes of design were necessary due to various field conditions. These changes were approved by the Engineer. The most important changes and results achieved are listed below in Table 6:

TABLE 6 – DESIGN CHANGES DURING CONSTRUCTION

Main embankment:	
Results quality control (average, range)	
Gradation: D_{15}, D_{max},	> 25 mm, 600 mm
D_{15} (25 mm) range	4 - 15 %

Layer thickness; density; roller passes (17/32 tons weight/dynamic load)	0.9 m; 19.5 KN/m³; 6
Transition zone between main embankment and asphalt concrete lining:	
Results quality control (average, range)	
Gradation: D_{15}, D_{max},	> 20 mm, 300 mm,
Layer thickness; density; roller passes	0.5 m; 18.8 KN/m³; 6

Note: Table 6 should be read in conjunction with Table 4.

The construction of the rockfill dam was finished in 1993 and the upstream dam slope was compacted and finally leveled by hand with crushed rock material (gradation range 5 mm to 30 mm). This leveling was necessary to smoothen the surface of the transition zone and to prepare a suitable working surface for the application of the asphalt concrete leveling layer.

The thickness of the impervious layer was changed from 10 cm to 9 cm below elevation 215 m a.s.l. and from 8 cm to 9 cm (minimum) above elevation 215 m a.s.l.

Review Comments:

- Based on the evidence available at the site, it was not possible to review in detail the construction data of the main embankment dam.
- Backfill material gradation for the area adjacent to the cut-off (plinth) was changed from maximum 200 mm (design) to 40 mm. According to the Technical Specifications (item 4.6 etc.) backfilling must be done in layers not exceeding 25 cm in thickness and up to a dry density value of at least 80%. A deformation modulus was not requested.

6.2.2.1 Asphalt Concrete Lining Work

The lining work started in December 1996, and several years after completion of the rockfill dam. An additional preparation and leveling (1996) of the sub-grade was necessary to prepare a suitable working surface for the application of the asphalt concrete lining. The sub-grade was also recompacted.

The lining work consisted of:

- Spraying a tack-coat (emulsion 1.5 kg/m²) on the subgrade,
- Applying the Leveling Layer – December 1996 to February 1997 -(minimum thickness 8 cm, gradation 0/22 mm, filler content in the field about 4 – 5% - design 4.4%, bitumen content in the field about 3.6 to 4.1% - design 3.8%, void content design about 14.6 % on Marshall specimen after 25 blows)

- Applying the Binder (Regulating) Layer – February to May 1997 (thickness at least 8 cm, gradation 0/16 (0/22) mm, filler content in the field about 5.8 – 7.2% - design 6.1%, bitumen content in the field about 4.5 to 5.0% - design 4.6%, air void content in the field on Marshall specimen after 25 blows about 7 to 8% - design 7.5%);
- Placing of the Impervious Layer started on April 7, 1997 and had to be suspended because of the beginning of the civil war on May 27th, 1997.

The Construction Method Statement as well as the results of initial laboratory tests (done in Germany), the site laboratory tests and the trial test results at the dam slope were approved by the Engineer.

The impervious layer was placed in vertical lanes and basically without horizontal joints (except working joints caused by rainfall or joints related to other reasons). At the dam slopes, an ABG-TITAN 323 finisher was used and at the area of dam toe and near the less inclined abutments, a smaller finisher applied the impervious layer. The maximum length of a lane applied in one run from the dam toe up to the dam crest, was about 165 m.

During the whole construction period an agreed quality assurance program was executed at a site laboratory (daily tests of the mix) and the placing of the various layers was permanently inspected.

After placing and compacting the impervious layer other quality control tests (vacuum test, tests on drilled cores etc.) were carried out. Most of these test results are available, only the results of the last placing month (May 1997) are missing.

Final Mix Design of the Impervious Layer:

Minimum thickness	9 cm
Aggregate grading	0 – 16 mm
Aggregate type	crushed granite
Bitumen content (per weight = 100%)	6.5 %
Bitumen	B 60/70
Adherence aggregate/bitumen	about 80%
	(without adhesion promoter)
Adhesion promoter (additive)	0.3 %
Marshall stability (25 blows)	8.3
Void content	1.9%
Content filler (granite filler)	11.6%

Bitumen Properties B60/70:

Before heating:

Penetration	54/10 mm
Softening point R+B	49°

After heating:

Penetration	35/10 mm
Softening point R+B	54°
Loss of penetration	- 35%

During placing of the impervious layer the Contractor proceeded to utilize an alternative bitumen source (about April 18th or 19th, 1997) of the same brand (B60/70).

Summarized Results from Monthly Reports:

February 1997:

Monthly rainfall 0 mm

Leveling layer finished on February 14, 1997, placed 12,000 m²

Binder layer placed 21.000 m²

Trial tests impervious layer

March 1997:

Monthly rainfall 0 mm

Binder layer finished on March 21, 1997, placed 30,000 m²

Placed impervious layer (cut-off wedge) about 350 m²

April 1997:

Placed impervious layer about 24,000 m²

Monthly rainfall about 99 mm, on April 7th, 12 mm

320 Vacuum tests - 5 % results failed (marked to repair later)

2 cores, void content 1.8 % (joint) and 0.8%

Vacuum tests carried out daily on a systematic grid (3 – 4 m horizontal, 15 – 20 m vertical)

May 1997: (no report available)

Placed impervious layer about 20,000 m²

Work suspended on 27th May

Not completed impervious lining area about 6,800 m²

The Surface Seal Coat was not applied due to the suspension of the work in May 1997.

Proposed mix design:

69% cement OPC

1% Inorphil 061-30 (fibre additive)

30 % bitumen B60/70

Review Comments:

- The asphalt concrete lining work was reviewed up to the suspension of the work in 1997.
- The binder layer has a relatively low air voids content.

6.2.2.2 Asphalt Concrete Lining Inspection and Investigation 2004:

The asphalt concrete lining was inspected in August 2004, about 7 years after suspension of the work and 4 cores drilled. In September 2004, detailed surveying and mapping of the asphalt concrete lining was carried out and damaged or poor areas were marked.

Laboratory tests results 2004:

Core 1:

Filler content	13.4 %
Void content	not determined
Bitumen content	about 6.3 % (by weight)
Recovered bitumen:	
Penetration	43/10 mm
Softening point R+B	about 53°
Penetration index	- 0.82

(Remark: Bitumen from the second source)

Core 2:

Filler content	13.7 %
Void content	5.7 % (6.5 % original thickness)
Bitumen content	about 6.3 % (by weight)
Recovered bitumen:	
Penetration	42/10 mm
Softening point R+B	about 54°
Penetration index	- 0.67

(Remark: Bitumen from the first source)

Permeability test (24 h 100 kpa, stepwise increasing from 100 kpa per 24 h to max. 500 kpa; observation time 5 days):

Impermeable	up to 300 kpa (3 bar)
Permeable	for higher water pressures

Core 3:

Void content 3.8* % (3.0* **%** original thickness)

Bitumen content about 6.3 % (by weight)

Recovered bitumen:

Penetration	42/10 mm
Softening point R+B	about 54°
Penetration index	- 0.67

(Remark: Bitumen from the second source)

* Specific gravity not determined but calibrated on cores 1,2 and 4 (average)

Permeability test (24 h 100 kpa, stepwise increasing from 100 kpa per 24 h to max. 500 kpa; observation time 5 days):

Impermeable up to 500 kpa (5 bar)

Core 4:

Filler content	13.7 %
Void content	3.9 %
Bitumen content	about 6.2 % (by weight)

Recovered bitumen:

Penetration	39/10 mm
Softening point R+B	about 54°
Penetration index	- 0.74

(Remark: Bitumen from the second source)

Adhesion test: About 75 % of the surface of tested aggregates were covered with bitumen (water bath).

Review Comments:

- Further investigations of the existing impervious asphalt concrete layer, mapping and assessing the condition before starting the rehabilitation are recommended by the Panel.
- In the adhesion test, a medium low adherence between the aggregate and the bitumen was noticed. The adherence should be improved for the rehabilitation work as well as the completion of the impervious layer.

6.2.2.3 Asphalt Concrete Lining Assessment 2004

The designer did an assessment of the present situation of the asphalt concrete lining and evaluated three different classes with varying levels of rehabilitation work required(details see draft report Study Pietrangeli, 2004).

- Larger cracks, rehabilitation necessary (zone A7, about 1,000 m²)
- Deep fissures, rehabilitation necessary (zone A1 to A6, about 9,500 m²)
- Medium fissures (zone C, about 3,000 m²) – rehabilitation method as well as quantity must be assessed separately – and critical area at upstream toe (zone B, about 2,000 m²)
- Small superficial fissures; no rehabilitation necessary, after cleaning application of the surface sealing coat – as basically designed, but not executed.

Review Comments:

- The long-term atmospheric influences (sun and ultraviolet radiation etc) and the non-application of the surface seal coat, caused an aging of the existing impervious layer. This aging phenomena led to an opening and widening of the deep, medium wide and small superficial fissures.
- The embrittlement of the bitumen extracted from some cores was not too high and the remaining flexibility of the lining was deemed by the Panel to be sufficient.
- Some local de-lamination phenomena between the upper layers caused blisters and cracks.
- At some locations cracking of the lining probably occurred due to the influence and/or insufficient support of the sub-grade and the foundation.
- For the final assessment of the condition of the impervious layer further investigations are necessary.

6.2.2.4 Proposed Rehabilitation Measures and Completion of the Asphalt Lining:

Review Comments:

Based on the results of the asphalt concrete lining inspection and the assessment the following measures are needed to be done to complete and rehabilitate the asphalt concrete lining.

- The rehabilitation of the existing impervious layer by applying an additional impervious layer (at least 6 cm thick) should basically include all areas proposed by the designer but must be extended to both abutments, between plinth and the overlapping area to the dam slope up to at least elevation 210 m (draw down level).
- The application of an additional layer at the toe of the dam must be at least extended up to elevation at least 180 m.

- Before applying an additional impervious layer, the existing impervious layer must be milled off (milling depth to a minimum of about 2 cm), cleaned and tack-coated. The mix design must be adjusted in terms of a optimized workability in the field and should have a lower air void content (average) than the remaining layer.
- The new layer must by applied by a modern spreader equipped with a high frequency vibrating screed, and the hand placing area must be minimized.
- The connection of the lining and the plinth was not finished. The parametric joint which was supposed to have been backfilled with stable and flexible material, is presently in a poor condition. Therefore, the whole joint gap must be rehabilitated and stable sealing material applied.
- The material for the surface seal coat as well as the application method should be adjusted to the present state-of-the-art and optimized for the conditions at the Bumbuna Project.
- A detailed Method Statement should be elaborated for rehabilitation of the asphalt concrete lining and all final decisions must be adjusted to the results of the investigations.
- If the rehabilitation and the completion of the asphalt concrete lining can not be done in 2005 a water spraying system should be installed at the dam crest and the existing lining should be sprayed with water during the hot and dry season to reduce aging influences.

6.3. Activities and Schedule for Completion of Project Implementation.

In recent times, starting in March 2004, activities related to the assessment of the state of the works and reinstatement of site facilities, camp and plants were developed. One of the results of these activities was the re-scheduling of civil work and equipment procurement to complete Project implementation until the end of 2006, and the quantification of the works to be done. This information is included in Figure 1 and Table 7 respectively.

FIGURE 1: PROGRAMME OF WORKS up to PROJECT COMPLETION (2004-2006)
Revision MARCH 2004

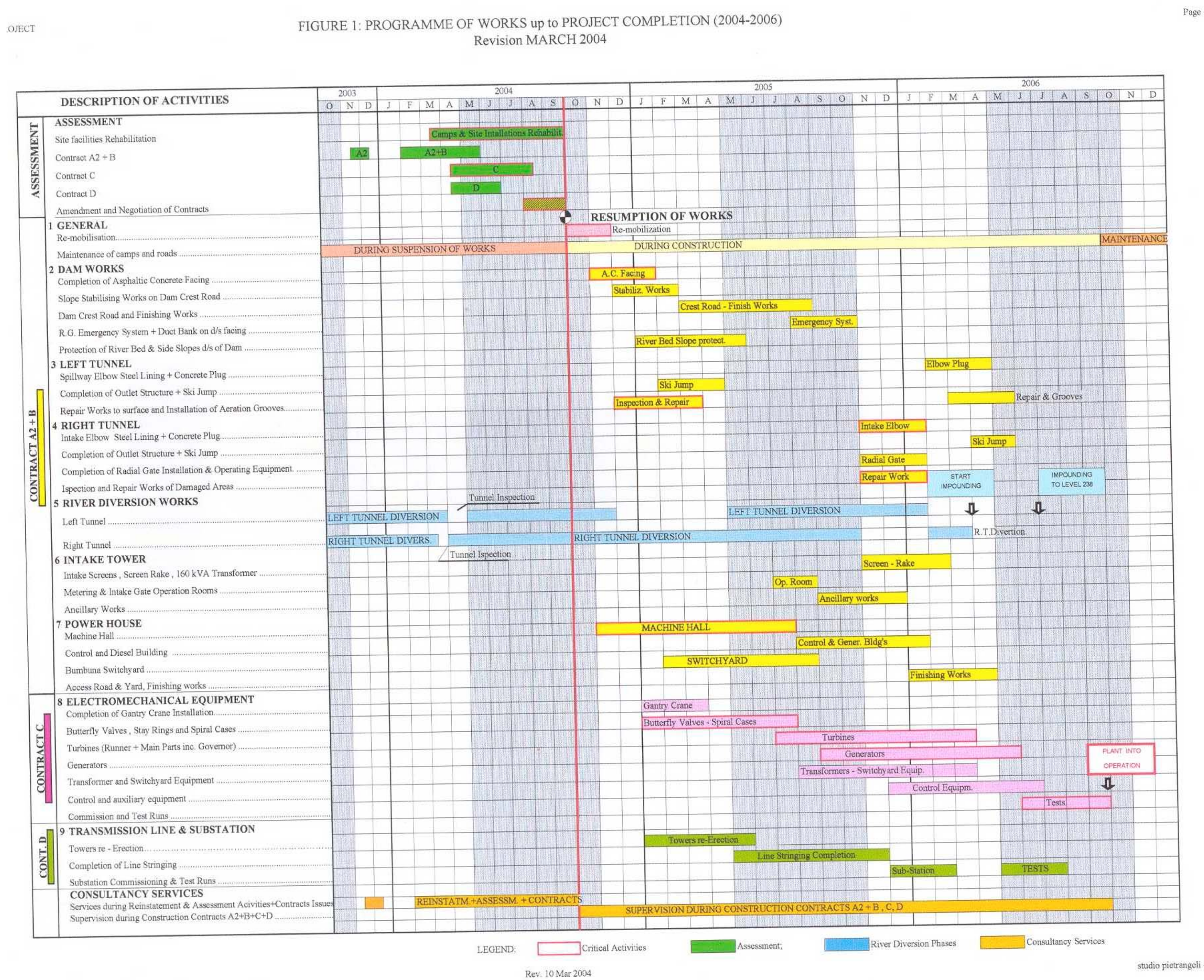

TABLE 7: SUMMARY of MAIN ACTIVITIES and QUANTITIES for PROJECT COMPLETION

LIST OF ACTIVITIES	MAIN WORKS and QUANTITIES		
	Description	U.M.	Q.ty
1 GENERAL			
Re-mobilisation	Expatriate Staff (70 pers.), Mobile Plant & Equipment		
Refurbishment of Access roads to site	Makburaka-Bumbuna, Binkolo-Bumbuna	km	81
2 DAM WORKS and SLOPE PROTECTIONS			
Dam Embankment construction	Downstream random fill zone	m3	30000
Completion of Asphaltic Concrete Facing	Milling of weathered material	m2	15000
	Impervious Layer for completion plus reconditioning	m2	21500
	Provide and apply Sealing coat	m2	51000
	Cut-Off Joint	m	450
Slope Stabilising Works on Dam Crest Road	Excavation	m3	500
	Rockfill	m3	5500
	Concrete works	m3	800
Dam Crest Road and Finishing Works	Paved roads	m2	7000
	Concrete works (wave wall, kerbs and cable ducts)	m3	950
	Stone pitched drains	m2	900
	Guardrails	m	940
Protection of River Bed & Side Slopes d/s of Dam on left and right bank	Common bulk excavation	m3	32400
	Rock bulk excavation	m3	12000
	Random fill	m3	43050
	Mass concrete	m3	2505
	Geotexile	m2	14550
	Gabbions and "Reno" Mattressess	m3	5240
	Rockfill and rip rap	m3	23365
Spillways protection	U/S Floating barrier	m	400
3 LEFT TUNNEL			
Spillway Elbow Steel Lining + Concrete Plug	Concrete plug	m3	1800
Completion of Outlet Structure + Ski Jump	Concrete works	m3	1500
Repair Works to surface	Concrete lining repair and finishing	m2	4500
Aeration Grooves	Installation and finish	n	45
4 RIGHT TUNNEL			
Intake Elbow Steel Lining + Concrete Plug	Stoplogs and Concrete plug	m3	2230
Completion of Outlet Structure + Ski Jump	Concrete works	m3	1277
Completion of Radial Gate Installation & Operating Equipment	Side steel linings, top seals, instrumentation and monitoring sys.		
Ispection and repair works of concrete damaged areas	Concrete lining repair and finishing	m2	1600
R.G. Pipelines for Normal and Emergency Opening Systems	Flanged Steel pipes PN 10 D 300 mm, Valves, fittings	m	50
	Flanged Steel pipes PN 10 D 150 mm	m	300
5 RIVER DIVERSION WORKS			
Left Tunnel	inspection and repair works, ski jump and plug	nr	2
Right Tunnel	repair works, ski jump and intake elbow	nr	1
6 INTAKE TOWER			
Intake Screens, Screen Rake, 160 kVA Transformer	Set of 6 screens and cleaning trash rake equipment		
Metering & Intake Gate Operation Rooms	water level metering, inclinometer		
Ancillary Works	Concrete and building works, Structural steel and metal works for upper structure		
7 POWER HOUSE			
Machine Hall	Backfill with selected rock	m3	5000
	Concrete works	m3	3500
	Gres ceramic flooring	m2	650
Control and diesel generators buildings	blockworks, doors and windows, tailing, plastering and painting	m3	1500
Bumbuna Switchyard	earthworks, concrete works, fencing	m2	6600
Access Road & Yard, Finishing works	paved road (chippings and bitumen)	m2	6600
8 ELECTROMECHANICAL EQUIPMENT			
Completion of Gantry Crane Installation	115 ton Main hoist, 15 ton Aux. hoist	nr	1
Butterfly Valves, Stay Rings and Spiral Cases	2500 mm batterfly valve, 1 Mpa des. Pressure	nr	2
Turbines (Runner + Main Parts inc. Governor)	25 MW Francis turbine, vertical axis, design head of 70 m	nr	2
Generators	33.7 MVA 50 Hz vertical axis generator, 13.8 kV, 333.3 rpm	nr	2
Transformer and Switchyard Equipment	33.7 MVA ONAN cooling 13.8 / 170 KV step-up trasformer	nr	2
Control and auxiliary equipment	Distribution boards, inverter and battery equipment, diesel set with accessories, auxiliary MV/LV trasformers, instrumentation and metering equipment and services		
Commission and Test Runs			
9 TRANSMISSION LINE & SUBSTATION			
Towers re - Erection	Condition assessment in progress	nr	40
Completion of Line Stringing	" "	km	130
Substation Commissioning & Test Runs	" "		

6.4. Comments Related to the Completion of Works.

In view of the long time of abandonment of materials, equipment and civil structures and their exposure to natural deterioration and vandalism, careful inspection is needed in order to define what rehabilitation action and repair work may be required in order to achieve adequate quality and functionality.

The following comments are intended as a contribution to the current planning and specification of main inspection and rehabilitation work to be done mainly concerning the civil structures and which became necessary as a consequence of the long interruption of the construction activities:

- Inspection of the state of tunnel linings and possible repairs is needed. It is not unlikely that damages to the lining of the diversion tunnels may have occurred in view of the almost 10 years of exposure of these tunnels to water flows. As a first step, cleaning, visual inspection and mapping of the state of the tunnel lining is needed as soon as these tunnels may become accessible to inspection.

- Reinforcement bars and steel linings in the Powerhouse area are covered with rust and may have lost their expected strength. Cleaning, visual inspection and possible testing of a representative sample of reinforcement bars to verify their tensile strength characteristics and replacement of lost reinforcement bars, should be done.

- A very important structure in terms of dam safety is the Radial Gate structure located at the downstream end of the Right Tunnel. This structure and the gate itself have to withstand the full Reservoir pressure over the lifetime of the Project and, in this sense are an integral part of the Dam itself, a rather uncommon situation in view of the exposure to a hydrostatic pressure acting on the gate reaching the value of 70 m. This structure has as important structural element, the post-tensioning cables which anchor the gate trunnion supporting beam to the lateral walls and the lateral walls to the upstream gravity block. A potential relaxation of these cables has to be prevented for the purpose of keeping the water-tightness and the good operation condition of the gate. A number of control actions are needed including the cleaning of anchor bolts, inspection and possible re-tensioning cables and grouting. As far as the gate itself is concerned, the required works need a careful inspection of the gate skin plate, the supporting arms, the state of the trunnions, cleaning and painting of the metallic structure and replacement of the sealing rubber elements.

- The inspection of mechanical, hydro-mechanical and electrical equipment has been completed. Detected damage varies greatly from case to case, ranging from substantial repairs, to be done at the factories of origin (e.g. the shaft of one of the generating units), to small repairs to be done on site (e.g. replacement of sealing elements in hydro-mechanical equipment), and to total replacement of highly damaged material (e.g. some panels of the control room). A complete inventory of these damages has almost been completed.

- A concerning fact is that, due to the long time elapsed since the delivery of major equipment as well as the specific circumstances, the usual guarantees of performance from Suppliers may not be effective any more and are certainly not easy to negotiate. Procurements of equipment and deliveries certainly include the provision of spare parts and accessories. In spite of this fact it is advisable to start, as early as possible, to plan the organization of a Reserve Fund to cope with possible contingencies related to the need for increased maintenance, repairs and possible reposition of component parts of this equipment. This is done, as a standard practice, in hydropower plants, however at a later stage of the operation phase when supplier guarantees expire.

7. INITIAL RESERVOIR IMPOUNDMENT

The first impoundment of the Bumbuna Dam, Reservoir and all other related structures is a very important task and has to consider in addition to all technical requirements, the long period of interruption of the project. At this time an impoundment program has not yet been prepared, however one should be drafted soon.

Review Comment:

- The Panel recommends that a “Impoundment Plan” and an “Impoundment Instruction Manual” be prepared considering all relevant items related to the safety of the dam foundation, dam and reservoir, all appurtenant structures and the power plant. The Impoundment Plan must define the limits of allowable seepage, increases of pore water pressures, deformations, and the monitoring program and actions to be taken in case of unexpected events.
- The Panel recommends a two phase impoundment of the dam and reservoir. In a first phase a partial impoundment up to about 40-50 % of the total height of the dam is contemplated. A safety assessment must be made at the end of the first phase before raising the water level and entering into the second phase.
- In the second phase, the impoundment of the Reservoir will be completed.

The reason for a two phase impoundment, which is not uncommon in the case of large dams, is to provide a real test of the water-tightness and deformation behaviour of the dam in time to take action should excessive leakage occur.

8. OPERATION AND MAINTENANCE

8.1. Dam

According to present scheduling, the implementation of the Bumbuna Dam is reaching its last phase, with an expected duration of about two years. At this time an O&M Program as well as the Dam Monitoring Program have not been prepared.

The DRP endorses the concept that ongoing preparatory activities for the operation phase of the Dam proceed as quickly as possible.

These activities entail:

- The preparation of Operation and Maintenance Manuals for the Dam and appurtenant Hydraulic Structures.
- The qualification, through education and training, of key personnel for the Operation and Maintenance tasks of the Dam in accordance with an organizational framework has to be defined.

The Panel recommends that such actions will be given high priority in the immediate future and endorses the concept that O&M activities should be organized in an integrated manner for the entire Project, i.e. including the Works and Facilities at the Bumbuna site and the Transmission System.

8.2. Reservoir Leakage and Rim Stability

Bumbuna Reservoir will be located in the bottom of a deep canyon cut by the Seli River into the crystalline rocks of the Sula Mountains. Subsurface geological investigations showed that the permeability of the rockmass decreases with depth, and is essentially impervious tens of meters below the surface. In addition there are no valleys parallel to the Seli River Basin at a lower elevation to where the reservoir might drain. Investigations have also shown, that in all cases, the phreatic surface within the granitic rock mass always falls steeply toward the river valley. Therefore, all of these factors indicate that there will be minimal leakage from the reservoir.

Slopes adjacent to the reservoir rim are relatively steep, and considering the deep weathering of the upper slopes in conjunction with the ongoing deforestation of the basin and the fluctuation of reservoir elevation, there is a potential for landslides into the reservoir. Such a landslide, triggered by the excavation of the Left Tunnel, occurred during construction on the left abutment just upstream of the dam. The lower part of this slide has been stabilized with a free-draining rockfill berm. In the future, such a landslide, depending on its size, could encroach on the dead storage volume of the reservoir or could conceivably produce a wave that might overtop the dam. The Panel was informed that aerial photography of the basin will be available soon. Therefore it is recommended that these photographs be reviewed for the existence of historical landslides in order to evaluate the potential for damage from future landslides.

8.3. Power Generation and Transmission Facilities

The Generation and Transmission facilities of the Bumbuna Project consist of:

- Powerhouse with a rated electrical output of 2x33.7 MVA.
- Local step-up substation from 13.8 kV to 161 kV with a capacity of 2x33.7MVA
- 161 kV Transmission line connecting Bumbuna Substation to Freetown over a distance of approximately 200 km. Small capacity derivations in Makeni and Lunsar.
- Step down Substation in Freetown, to be located adjacent to the King Tom Thermal Power Station.

These facilities are of conventional type and require the usual procedures for an adequate operation and maintenance which are already well established in the experience of numerous hydropower installations and associated transmission systems in different countries of Africa (e.g. Republic of South Africa, Egypt, Ghana, among others) who have developed and implemented their operation and maintenance standards and procedures along the years of their experience.

Independently of the institutional aspects involved, which are not the scope of this Report, particular attention in the Bumbuna Project should be given to the matter of capacity building including the education and training of local personnel for maintenance and operation of the system in view of the pioneering character of the Project in Sierra Leone. Qualified personnel in the mechanical, electrical and civil areas is needed to accomplish a variety of tasks such as:

- Routine and exceptional inspections
- Powerhouse operation; operation of the associated transmission system
- Maintenance of hydro-mechanical, mechanical and electrical equipment of the power generation facilities and of other equipment located in the dam area and appurtenant hydraulic structures
- Maintenance of civil works at the dam site.
- Maintenance of civil works, mechanical and electrical equipment along the transmission line and the substations
- Additional technical tasks related to monitoring, instrumentation and recording information

Other supporting tasks include administration, security, vigilance, logistic support, cleaning, etc.

The idea of dealing with all these tasks in an integrated way for the entire Project, i.e. including the Power Station, Dam and Appurtenances, Substations and Transmission Line is appealing and corresponds to a commonly followed model for its advantages in coordination, lines of responsibility and efficiency.

Key factors for the successful implementation of the operation and maintenance activities are:

- The establishment and dissemination among members of the Operation/Maintenance Team of clear and detailed Manuals containing instructions and procedures for the required tasks, their reason, the expected levels of performance, the states of normality, alert and emergency, required actions. The preparation of Manuals is commonly a task requiring a strong participation of the Designer and the Operator of the System, and is based on recommendations and maintenance manuals of the equipment Suppliers.

- Education and Training of qualified Personnel. Including formal technical education; Training at a foreign Hydropower and Electricity Authority (preferably in another African Country), training during the installation of equipments in Bumbuna, on-the job training. These Education and Training activities require time and have to start as early as possible.

8.4. Hydraulic Structures

After conclusion of the construction activities, the hydraulic structures at site include: a) the Left Bank Spillway facilities, an uncontrolled Morning Glory Surface Spillway, Discharge Tunnel and Flip Bucket Dissipator, and b) the Right Bank Facilities consisting of the Power Intake Tower and its equipments, the Morning Glory Spillway, the Discharge Tunnel, the Offtake for water supply to the Power Station, the gate controlled Terminal Structure and the Flip Bucket Dissipator.

Instrumentation of these structures is concentrated in the right bank Facilities and consists of:

- Inclinometer installed in the Intake Tower
- Piezometers installed along the Discharge Tunnel
- Gage for the Radial Gate opening
- Extensometers installed in the Terminal Gate Structures

From the operation point of view, the Left Spillway does not require any intervention. As for the right bank Structures, operation decisions are centered on the opening of the intake gate (normally open) and the operation of the radial gate (normally closed, except in the rare events of a major flood when it should be open).

The basic principle for the maintenance of these structures is to carry out systematic inspections to verify the state of linings, state of metallic structures, state of equipments and their operating conditions. While this is easy to achieve for the Left Spillway during the dry period of the year, the Right Bank Structures require a careful planning taking into account the required outages of the Power Station at least for the visit to the tunnel. An important matter is to test the operation conditions of the Radial Gate at least once a year since this gate is an important component of dam safety. The frequency of inspections of the structures and equipment should be higher during the first years of operation and could be decreased at a later stage after verification of the good performance of these structures.

8.5. Risk Assessment

This sub-section describes an evaluation of potential risk and hazard to the successful operation of project. The risk and hazard situation could arise due to any of the following factors.

- Accumulation of sediment in the reservoir thus causing a loss of storage capacity.
- Rim stability problem
- Wave action

In various volumes of the Feasibility Report, these factors are discussed. Based on a review of these reports, the following conclusions are derived.

8.5.1 Reservoir Sedimentation

Discussions on reservoir sedimentation are provided in the Feasibility Report. As part of this review, some additional computations were made to reach the following conclusion.

Suspended sediment samples were collected from the Seli River for the period from September 1978 to August 1979. During dry period, two samples were collected during a month. Weekly sampling was done during the wet season. A total of 120 samples were collected and analyzed for total concentration. The samples were collected in the upper 1.0 to 1.5 meter depth and it was assumed that suspended concentration is uniform throughout the whole depth due to turbulence in the river. This is a valid assumption.

Suspended concentration varied from 1.1 milligram per liter (mg/l) to 105.3 mg/l. An average concentration of 30 mg/l was assumed. This resulted in a mean annual transport of about 90,000 m^3 using a specific weight of 1.3 metric tons per cubic meter (t/m^3). Looking at the range of concentrations, selection of a mean concentration of 30 mg/l was reasonable. During a field visit to the river downstream of the dam, the sediment deposited in the river was inspected. The material mostly likely carried by high flows in suspension and then deposited on the bank during receding flows was in the range of 2 to 5 mm diameter.

Three bed material samples were collected and analyzed for particle size distribution. The median diameters were about 36, 50 and 60 mm. The bed material smaller than 2 mm diameter (most likely to be in suspension during high flows) was about 10%, average of the three samples.

A conservative estimate of bed load could be about 20% of the suspended load, about 18,000 m^3. Being of large sizes, most of this load would settle at the upper rim of the reservoir, and would slightly affect the live storage of the reservoir.

The total sediment inflow is about 108,000 m^3 (suspended plus bed load). Most of the suspended sediment would pass through the dam. The deposited sediment would be quite small compared to an inactive storage of 95 million m^3.

Sediment particles about 2 mm in diameter would pass through the turbine. The vertical Francis turbines installed, would not be affected by this size.

The downstream channel consists of boulders, cobbles and gravel. The flow in the river has high potential to carry bed material but there is no much bed material available to be transported. Therefore, the water free of bed load, passing through the turbines or spillway, would not degrade the downstream bed to any significant extent.

Based on the above discussion, it is concluded that reservoir sedimentation due to suspended or bed load would be insignificant.

8.5.2 Rim Sediment Problem

The Feasibility Study discussed this problem in Volume VI "Geology and Geotechnics." The discussion was based on field observations and sampling data.

The rim stability is discussed under sub-section 8.2 in regard to geology of the slopes. Based on the description of the material on steep slope, it can be concluded that there would be some sliding and the material would directly go to the inactive storage of the reservoir, which is about 95 million m^3. This is a large capacity and can accommodate the potential volume of material. Therefore, any problem in the reduction of active power volume is not foreseen.

8.5.3 Wave Action

The Seli River flows in a general southern direction from Yiben to Bumbuna. At Bumbuna, it takes a 45^0 turn and flows in a general southwest direction. The dominating wind direction is from southwest or south during the wet months of July through September as per record of Kabala climatological station.. Thus, the wind blows against the direction of flow. The river valley is shadowed by the mountain on the southwest and south. Thus, the surface of the reservoir is protected against the wind. Therefore there would be no significant wave action against the upstream face of the dam. However, it is recommended that wind wave height computations should be made to check this conclusion.

Analysis of the above risk factors indicates that hazardous conditions would not develop at the project. However, if due to some unavoidable circumstances, the spillway gates cannot be opened, the dam embankment most likely would be overtopped and fail. Therefore, dam break analysis are needed for the project.

8.6. Dam Safety Program

A Dam Safety Programme, Broad Framework has been prepared by the Consultant in October 2004. The framework includes both routine safety measures at the dam site and emergency preparedness plan for the downstream population in case of failure of the dam. This section provides a review of the routine dam safety programme. The emergency preparedness plan is discussed in section 8.7.

8.6.1 October 2004 Report

Routine monitoring, and operation and maintenance procedures are discussed in the report. The monitoring includes, "monitoring and inspection programme," "evaluation and inspection programme," and "dam documentation." The operation and maintenance procedures include cleaning trash rack, flushing power tunnel, civil works, etc. An organization chart and list of monitoring instruments are provided.

<u>Review Comments:</u>

Instrumentation for monitoring the safety of civil works is adequate. Frequency of inspections for each major structure is defined. The following recommendations are provided to improve the programme.

- Two water level measuring instruments are listed under "dam instrumentation." It is assumed that one of these will be for measuring reservoir levels and monitored from the control room. Two additional recorders should be included in the list. One of these should be installed downstream of dam with an overhead cableway to measure tail-water levels and discharges. The second water level recorder should be installed near the upstream end of reservoir. These two recorders should also be monitored from the control room. This is also discussed in section 8.7.
- Routine visual inspections is proposed to be carried out every two weeks. During the initial filling of the reservoir and for about six months after that, the daily inspections should be made.
- The current manual combines the routine and emergency programmes. As also suggested in section 8.7, the emergency preparedness plan should be separated to be stand-alone document.

8.7. Emergency Preparedness Plan

8.7.1 Dam Safety Programme, October 2004

The consultant, SP, for the Bumbuna project have prepared a draft plan entitled, "Bumbuna Falls, Hydroelectric Project-Phase 1, Dam Safety Programme, Broad Framework, October 2004." The report is organized to include both the normal dam monitoring, operation guidelines and maintenance, and the Emergency Preparedness Plan (EPP). The report is organized into two parts. The first part describes the organization, procedures for dam operation, ordinary dam monitoring activities, and operational and maintenance works. The second part briefly describes the EPP. The report is well written and includes nearly all necessary actions required in future for the routine monitoring for the safety of the dam. However, the EPP needs significant improvement.

8.7.2 Emergency Preparedness Plan (EPP)

This sub-section provides a review and evaluation of the EPP including downstream flooding effects, emergency reservoir drawdown, notification of impending dangers to downstream municipal authorities, major flood early warning systems, major flood spilling operation plans and site access during emergencies.

In addition to the text provided in the October 2004 report, an initial dam break analysis has been performed. The dam break model developed by the United States National Weather Service and commercialized by the Boss International Corporation was used. The input data for the model was prepared using the data and information available in various reports and through a general literature search. A dynamic routing sub-routine of the model was used. Five cross sections upstream of the dam (river reach about 44 km) and sixteen cross sections downstream(river reach of about 50 km) represented the configuration of the river channel. River cross sections were derived from 1:50,000 scale topographic maps with 50 ft contour interval. Interpolated cross sections were developed through a model sub-routine. The minimum distance between the two adjacent cross sections was set at 0.2 km near the dam and 0.5 km in the downstream channel. The data input for the model included:

- Twenty one river cross sections.
- Upstream boundary condition, represented by the PMF hydrograph.
- Downstream boundary condition represented by a rating curve derived by the model.
- Initial reservoir level.
- Reservoir level at time of breach.
- Bottom width of the breach.
- Side slope of the breach.
- Time to develop full breach.
- Bottom elevation of the breach.

8.7.3 Review Comments

The dam safety programme manual written by the Consultant should be divided into two separate documents. A manual for the routine operation, maintenance and dam safety monitoring is generally for the use of the dam operator and his staff, and the dam owner. It is not circulated among any agency involved with the safety of the general public. The EPP chapters included in the Dam Safety Program, therefore, should form a separate document. The recommendations for expanding these chapters are discussed below.

Before the preparation of EPP, it is important that all the agencies responsible for the safety of the people in the areas of potential flooding should be identified and contacted. The agencies have to be involved in the preparation of the plan because they must sign off the plan. Most recent street names, locations of high ground level spots for evacuation, names of persons that should be contacted during an emergency and the type of logistics locally available in case of evacuation can be provided by these agencies. A format for the EPP is provided below that can be modified to suit the local conditions.

Title Page/ Cover Sheet

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I. Notification Flowchart

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A. Investigation and Analysis of Dambreak Floods
B. Plans of Training, Exercising, Updating, and Posting the EPP
C. Site Specific Concerns
D. Documentation
E. Approval of the EPP

Some of the above material has been included in the October 2004 report but it needs to be reorganized.

The EPP should describe the arrangement and guidelines to detect an emergency and immediate decision required based on its severity. Generally two failure conditions – "Failure is imminent or has occurred" and "Potential failure situation is developing," and one non-failure condition (sudden release of water or high flood condition) are included in an EPP. This should be separately discussed in clear term to be understood by a common person. For each condition, a separate flowchart (notification) should be prepared. Each notification flowchart should identify the order in which the emergency situation is to be reported, from the observer of the emergency condition to the highest management and the concerned agencies. It should include names and positions of individuals and their alternates, their home and office telephone numbers, and means of communication with a backup communication system, if possible. A potential list of persons for notification may include:

- Observer
- Supervisor of dam operation
- Dam operation manager
- Dam owner
- Local police
- Local emergency management official and agencies
- Government offices involved in emergency management

- Representative from villages where other agencies are not available
- Operator of other facilities downstream from the dam, if any
- News media, radio and television

Guidelines for handling an emergency situation, prepared by other agencies in Sierra Leone should be consulted. The EPP should be tailored to the local conditions. Because the EPP would be used by local representatives and/ or local agencies, the responsibility of each individual should be described in clear terms in the text of EPP.

8.7.3.1 Dam Break Analysis and Inundation Maps

Additional dam break analyses are needed. This was discussed with the Consultant. The format of the model output was also discussed. At this stage of development of the EPP, it is recommended that the location of the downstream cross sections should be rechecked. There should be a cross section at the upstream end and a cross section at downstream end of a village, a cross section near a bridge, and near any other place that is important to inform the local people. The cross sections at important locations should be surveyed. The cross sections taken from 1:50,000 scale topographic maps with 50 ft contour interval, will not provide a reliable indication of height of the flood wave. The additional recommended analyses are listed below.

- Dam failure under fair weather condition with the reservoir level at maximum operating pool level.
- Dam failure under PMF condition when the reservoir is at the maximum pool level.
- No dam failure under PMF condition.
- Sensitivity analysis for time to develop full breach.
- Sensitivity analysis for size of the breach

For a worst case scenario, the average breach width should be in the upper portion of recommended range, the time to failure should be in the lower portion of recommended range and the Manning's "n" value should be in the upper portion of recommended range. It should be realized that "n" values to be used in dam break analysis should be more than that observed in the field because of high turbulence associated with the flood wave.

In most cases, the worst case scenario is not required. The sensitivity analysis may be performed to select a reasonably critical dam break scenario as discussed below.

- Reasonably maximum breach width, reasonably minimum time to develop breach and reasonably maximum "n" value.
- Reasonably minimum width, reasonably maximum time and reasonably minimum "n value."

A time of about 3.5 hours to develop the full breach width adopted for the preliminary analysis appears to be large. This should be rechecked. A time of about 1.0 or 1.5 hours would be more appropriate.

The results of each dam break scenario should be presented in tabular form. The table should identify the locations of bridges and villages. The following data should be presented in the table for each cross section.

- River cross section number
- Distance from the dam axis
- Maximum discharge
- Maximum river stage reached
- Time of occurrence of maximum river stage since failure of the dam, or in case of non-failure scenario, the time since the highest flow observed at the dam
- Time of arrival of the leading edge of flood wave since failure of the dam or occurrence of highest discharge at the dam.
- Maximum velocity observed during the passage of flood.

The inundation maps are most important and critical for a successful emergency warning and evacuation process. These should be produced on a convenient scale so that all features of the downstream area can be identified. For the Bumbuna Hydroelectric Project, the maps should be prepared for two scenarios: a) fair weather breach, under normal operating condition when the reservoir is at the maximum operating pool level; and b) breach under the PMF condition, as discussed above. Both scenario should be shown on the same maps with different color schemes. The area affected by inundation should also be described in the text of the EPP. The accuracy and limitation of the maps should be described so that the agency or persons using these maps should know what to expect from the maps.

The cross sections should be marked on the map. At each cross section, a rectangular box should be drawn with the following information:

- Initial water level
- Maximum water level
- Maximum discharge
- Arrival time of leading edge of flood wave
- Arrival time of the peak

Times refer to the failure of the dam or since the occurrence of maximum flow at the dam under non-failure condition.

The inundation maps should be clearly marked with the main evacuation routes, and alternate evacuation routes. This should be done through meetings with local agencies. The availability of emergency supplies with local agencies or obligation of the dam owner to make available such supplies should also be discussed.

8.7.3.2 Non-Failure Emergency Conditions

Actions required under these conditions are discussed in the October 2004 Report. Non-failure emergency conditions would be more common during the operation of the dam. This may include high releases from the dam during floods or high releases to evacuate the reservoir for some purposes. The downstream population should be informed prior to such releases. This should be included as a section in the EPP. The notification flowchart would be simpler in this case.

8.7.3.3 Warning Systems

The October 2004 report describes the basis for activating "evacuation alarm." But, it is not discussed who will be responsible for triggering the alarm and who will authorize this. The police person or representative of an agency is not identified. This sub-section should be reorganized with specific details on the notification flowchart.

It is recommended that sounding the alarm would be the responsibility of the operator of the dam. Mobile evacuation teams should be organized by the emergency management agencies and police, and not by the dam operator. The logistics for the warning system should be discussed.

8.7.3.4 Water Level Recorder

For a better understanding of emergency conditions two recorders should be installed upstream of the dam. One near the dam to monitor the head over the spillways and the second near the upstream end of the reservoir to provide an early indication of flood conditions.

A third water level indicator should be installed downstream of the dam to monitor the full range of water levels and flow conditions. A flume or weir should be constructed to measure low flows. To measure medium to high flows by current meter and sounding weight, an overhead cableway should be installed.

9. LONG-TERM PROSPECTS

9.1. Reservoir Operation Plan

9.1.1 Flood Management

Currently, the Consultant have not developed any flood management plan for the operation of Bumbuna hydro, except a few routing scenarios of the PMF. Such a plan is necessary to provide an advance information of flood magnitude and its arrival time. This will be helpful for the emergency preparedness plan to alert the people in affected areas and also for handling the major flood. With the construction of Yiben dam in future, the plan could be used to optimize the use of stored water.

A flood management plan requires development of an automated data collection and transmission system, and a mathematical model to predict the daily and hourly streamflows in advance of their occurrences, based on the real time hydrometeorological data. A network of precipitation and stream gauging stations is established in the watershed. The data are transmitted via a communication system to a central control station where the data is processed. The processed data are used by a mathematical model to compute the real time streamflow. The model is pre-calibrated using historic rainfall and streamflow data. The following paragraphs briefly describe the components of such a real time data collection system for Bumbuna catchment.

9.1.1.1 Existing Hydrometeorological Network

The locations of the existing hydrometeorological stations in the Bumbuna watershed were identified. Two stream gauging stations, Badela and Bumbuna installed under a UNDP program, were operated for some period. A few discharge measurements are available at these locations. Daily flow record for the Bumbuna station have been computed for the period from 1971 through 1978.

Three precipitation stations were established in the watershed. The station at Kabala is still operative while the other two at Mongo Bendugu and Gberia Timbako, were discontinued.

9.1.1.2 Proposed Network

The size of the watershed, about 3,950 km^2, is relatively small and, therefore, an efficient network can be established with less stations. A recording rain gauge already exists at Kabala. This would be upgraded. Mongo Bendugu and Gberia Timbako stations would be put in operation with new recording gauges. An additional recording rain gauge would be installed at Badela.

The stream gauging station at Badela would be reactivated. The station would be equipped with an automatic gauge height recorder, and an overhead cableway to measure discharges.

9.1.1.3 Communication System and Central Control Station

A VHF or microwave telecommunication system would be established. The system would receive the data from the rainfall and stream gauging stations and transmit to the central control, where it would be checked for consistency and used for making the forecast.

9.1.2 Power and Energy

The Bumbuna Project in its present stage of implementation should be understood as a first phase of the development of the hydroelectric potential of the Seli River in the region.

In this phase the installed capacity is 50 MW and the average generation is evaluated at 157 GWh/year (firm energy) and 158 GWh/year (secondary energy).

The hydro-energetic potential of the Seli River in the region, estimated during the 1980 feasibility studies, corresponds to approximately 300 MW of installable capacity, an energy generation of 1250 GWh/year (firm energy) and 210 GWh/year (secondary energy).

Possible future options for further development of this potential are, in logical sequence:

- Implementation of the Yiben Project, which provides own generation capability and needed discharge regulation

- Implementation of the Bumbuna Project Phase 2, with a possible duplication of the installed capacity at Bumbuna, i.e. the construction of a second Powerhouse
- The development of the additional 40 m head at Bumbuna Falls.

In all of these options there are different alternatives to be considered in terms of phasing and characteristics of the component works. They should be the object of detailed consideration in scenarios of expansion of the Energy Sector and of the Country's Social and Economic Development.

9.2. The Role of the Bumbuna Project for the Energy Sector of Sierra Leone

There can be no doubt about the fact that the implementation of the first phase of the Bumbuna Project will have a very significant impact on the Energy Sector of Sierra Leone in view of its significance and pioneering character. It corresponds at the same time to a first development of Hydropower Resources in the Country, as an economically attractive alternative to Thermal Generation, as well as a first important step towards the establishment of an Electricity Transmission Grid in the Country. For these reasons it may be expected that the Project and the experience gained from its implementation and operation will not only provide a very relevant direct contribution to increase the electricity supply but will also set the standards for future developments of the Energy Sector of the Country as a whole. Further technical/scientific developments; the development of planning, implementation and operation/maintenance criteria and procedures and further developments of organizational and institutional frameworks may well be expected as consequence of the implementation and operation of the Bumbuna Project.

10. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analysis and evaluation of the Project documents which were made available (listed in Appendix C), and field visits and technical discussions during the period October 26 to November 1, 2004 (see Record of Daily Activities and Meetings in Appendix B), the DRP reached its conclusions regarding the technical aspects of the Project in its present state, and also with respect to future activities planned for the completion of Project implementation and future operation.

Main conclusions drawn from this work, suggestions and recommendations related to the continuation of investigations, planning and design, construction and operation and maintenance are presented in this section.

10.1. Hydrology and Water Resources

In general terms, the Panel agrees with the results of studies and investigations carried out so far and considers these to be of good quality.

The Panel wishes however to emphasize the following topics for the continuation of activities:

a. The DRP recommends the installation of three gaging stations at the Bumbuna site, two upstream and one downstream of the Dam.

b. The value of the PMF used to define the Spillway capacity is considered acceptable but lies in the low range of expected values. Since the PMP/PMF study results are influenced by the methodology used, the Panel recommends that a comparative study be conducted using the guidelines described in Section 4.2.1.

c. A complementation of information on Power and Energy Generation by Bumbuna is desirable. The DRP suggests to refine previously done analyses on the basis of daily, rather than monthly distribution of river discharges and a Reservoir operation considering dry, medium and wet hydrological periods separately.

10.2. Geology and Geotechnics

a. The Panel reviewed the geological and geotechnical investigations made for the Project and finds that they were carried out using the best practices at the time they were realized. The scope, quantity and quality of the investigations were adequate for the type and size of the Bumbuna Dam and appurtenant facilities.

b. Following a review of grouting records, the Panel concludes that the double line grout curtain in the foundation rock below the Dam plinth was properly executed out and should achieve the desired reduction in foundation permeability.

c. In spite of the wealth of information made available to the DRP, it was not possible to completely evaluate the condition of the foundation on the left abutment of the dam where a thickness of up to 18 m of weathered rock was left in place under the Rockfill Dam. There is a concern that the occurrence of erodible material in the foundation could result in migration of soil particles resulting in settlement, thereby potentially compromising the integrity of the upstream dam zone. The DRP recommends that the Engineer carry out a thorough search of available construction records including geologic mapping and construction photos to ascertain the exact nature of the foundation surface underlying the rockfill.

d. A review was made of foundation and rockfill dam settlement data. The Panel determined that the relatively thick foundation of weathered rock on the left abutment settled at a rate of about 0.7%/m of thickness, whereas the rockfill in the dam settled at a rate of about 0.4%/m of thickness. Although it seems unusual that the foundation for a rockfill dam would settle at a faster rate than the rockfill, the data is in agreement with the Engineer's design expectations. In fact total settlement is significantly less than predicted at the time of design. After about 12 years, settlement in the dam and foundation have essentially stabilized. However, settlement is expected to resume upon reservoir loading.

e. Excavation of the downstream 160 m of the Left Tunnel was carried out in weathered rock and residual soil. Measures that were taken during construction to stabilize the tunnel, such as construction of a reinforced concrete canopy over the tunnel, spilling in the crown, steel sets, concrete struts in the invert, concrete piles underpinning the conduit, and replacement of soil with mass concrete at the flip bucket are all considered appropriate by the Panel. However, the tunnel should be carefully inspected for damage following closure of the diversion facilities, especially with respect to differential settlement between tunnel segments and energy dissipator invert slabs and walls.

f. The Panel suggests that seismic records since 1978 be reviewed in order to verify the seismic design parameters used for the stability analyses of component works.

10.3. Asphalt Concrete Faced Rockfill Dam

The Panel considers that the design of the embankment dam and the instrumentation as well as the installation of a separate monitoring center in the powerhouse control room corresponds to good engineering practices and meets international standards. The decision to design a single impervious layer system instead of a lining system with two impervious layers and a drainage layer (sandwich system) as well as a plinth without separate leakage detection or drainage and grouting gallery, decreased the cost but will require a more advanced monitoring and maintenance program. In addition, a faster reaction will be needed in case leakage occur.

A review was made of the available quality control data for the construction of the main embankment dam and the asphalt concrete lining work carried out prior to the 1997 interruption, and the Panel endorsed the results. The long term atmospheric influence on the asphalt concrete lining as well as the lack of a surface seal coat, accelerated the aging of the impervious layer. The embrittlement of the bitumen was not too great and the lining has remained sufficiently flexible.

a. The Panel recommends further investigations of the impervious layer, with mapping and assessment of its condition before rehabilitation work starts. This rehabilitation, by application of an additional impervious layer, must include all areas proposed by the designer, extending to both abutments at least up to the minimum operating level of elevation 210 m a.s.l. In the dam toe area the rehabilitation should extend at least up to elevation 180 m a.s.l. Execution details are described in Section 6.2.2.4.

b. Finally the Panel suggests that the materials and method of application of the surface seal coat should correspond to the state-of-art and be optimized for the Project. Also a Method Statement for all rehabilitation works should be prepared and rehabilitation methods adjusted based on the results of the recommended investigations.

c. The Panel also recommends the complete rehabilitation and sealing of the perimetral joint (contact between lining and plinth)

d. Furthermore the Panel also recommends the refurbishment and completion of dam instrumentation, and the setting up of the monitoring center to be done before Reservoir impoundment.

10.4. Hydraulic Structures

The Panel reviewed information regarding the design and construction of the civil works; the general data and characteristics of hydro-mechanical equipment as well as other pertinent information related to the river diversion, spillway, power intake and headrace facilities. The Panel is satisfied with the quality of the final design and construction of the civil works and choice and specification of equipment of these facilities.

10.4.1 Tunnels

It was not possible to visit the Tunnels. The access to the Left Tunnel will only be possible at the beginning of Reservoir impoundment. The Panel recommends that, at that opportunity, a careful inspection, mapping and repair of any damage to the lining be carried out together with the planned constructive modifications needed for the operation period (lining, construction of the plugs, etc)

10.4.2 Spillways

The DRP recommends the use of the Left Spillway as the Service Spillway to release the more frequent floods (say up to return periods of 10 years). The Right Spillway should be used for the release of exceptional floods, a policy which is in line with the least disturbance to the operation of the Power House, and to limit the occurrence of unfavorable flow conditions affecting the Right Tunnel and the Radial Gate.

10.4.3 Intake

The DRP is satisfied with the executed activities of inspection and verification of operation conditions of the metallic structures (trashracks, linings etc.) and equipment (cylindrical gate, trashrack cleaning equipment etc.).

10.4.4 Radial Control Gate Structure.

The Radial Control Gate structure is an essential component of the safety of the Project. The Panel recommends:

a. Careful inspection, testing and rehabilitation where needed of the post-tensioned cable systems used for anchoring the gate structure and the trunnion supports.

b. Installation of extensometers to register possible displacements of the gate structure and the possible relaxation of cable tensioning during the period of plant operation.

c. Already planned rehabilitation of the Radial Gate structure and of its operating systems (servo-mechanisms, counterweight, manual control).

d. Limit, as much as possible, the operation of the Radial Gate with partial opening of the this gate. In principle, the gate should be completely opened during the occurrence of exceptional floods. Under normal conditions, it should remain completely closed, except during the less common occasions when a reservoir outflow control at low impoundment levels is needed.

10.5. Generation Facilities.

The Panel reviewed documentation related to the design and construction of the Power House structure and waterways. The Panel also received information related to the characteristics of major equipment such as hydro-mechanical (butterfly valves, turbines) and electrical (generators, step-up transformers).

The Panel considers that the quality of design and construction of the civil works is appropriate and corresponds to good engineering practices. The long interruption of construction activities leads however to the following recommendations:

a. To carry out the inspection, testing and rehabilitation of exposed steel reinforcement bars and steel linings as well as minor repairs in the concrete work.

b. To proceed with the activities of rehabilitation of the mechanical and electrical equipment to ascertain its reliable operation conditions.

In view of the long time elapsed and the unclear situation of Supplier Guarantees, the Panel suggests the development of a Contingency Plan to cope with this problem should start as early as possible.

10.6. Reservoir

Documentation related to the future impoundment area was also reviewed by the Panel. There was no time available to carry out a detailed field visit of the area. On the basis of the documentation made available, the Panel recommends a number of actions to be carried out during the planning stage related to the impoundment of the Reservoir and to its future operation.

10.6.1 General Investigations

The Panel recommends a careful field reconnaissance and review of cartographic material (topographic maps, aerial photographs) of the impoundment area and especially of the zone of the future Reservoir rim (normal water level and its variations) in order to assess the potential for landslides or other objectionable occurrences.

10.6.2 Impoundment

The DRP recommends that the first Reservoir impoundment be accomplished in two phases. In a first phase, to be started in December 2005/January 2006 (dry season) a partial impoundment up to about 40-50% of the total height of the dam. Dam seepage and deformation behavior should be observed with the possibility of reverting to the diversion condition in the event of any anomaly. In the second phase completion of the Reservoir impoundment operation. The reason for this two-phased impoundment, which is not uncommon in the case of large dams, is to provide a real test of the watertightness and deformation behavior of the Dam in time to take action should excessive leakage occur.

10.6.3 Reservoir Operation

The DRP also recommends the preparation of the following plans to serve as guidelines to orient the operation of the Bumbuna Reservoir:

a. Reservoir Operation Plan, to serve as a detailed guideline for the hydraulic operation of the Reservoir under normal and exceptional conditions (e.g. flood events), taking into account the: energy and power generation objectives; the security of the dam, appurtenant structures and the area downstream of the dam; the Reservoir monitoring system; the operation and restrictions of equipments; the flood management objectives and restrictions. This Plan should incorporate available information and proceed to further detailing and optimization of the Reservoir operation rules.

b. A stand alone Emergency Preparedness Plan should be prepared. The Engineer should complete the dam break analysis already begun.

10.7. Operation and Maintenance Plan

According to present scheduling, the implementation of the Bumbuna Project is reaching its last phase, with an expected duration of about two years. The DRP endorses the concept that ongoing preparatory activities for the operation phase of the Project proceed as quickly as possible.

These activities entail:

- The preparation of Operation and Maintenance Manuals for the Civil Works and Equipment of the Project, including the Dam and appurtenant Hydraulic Structures; the Generation Facilities; the Substations and Transmission Line.
- The qualification, through education and training, of key personnel for the Operation and Maintenance tasks of the Project in accordance with an organizational framework to be defined.

The Panel recommends that such actions receive high priority in the immediate future and endorses the concept that O&M activities should be organized in an integrated manner for the entire Project, i.e. including the Works and Facilities at the Bumbuna site and the Transmission System.

11. ACKNOWLEDGEMENTS

The DRP wishes to express its appreciation to the PIU and to its Manager, Mr. Nathaniel Vandy and Assistant Manager Mr. Mustapha Kargbo, to SP and its Project Manager Mr. Alberto Bezzi and its Resident Engineer Mr. Alberto Lohay, and to SALCOST, and its Manager Mr. Christian Capitanio, for the organization, hospitality and support provided to the DRP members during the meeting. The DRP would also like to thank the engineers and Bumbuna Camp employees from SP and SALCOST for accompanying the Panel during the site visit, providing all technical data requested, and contributing to discussions over the course of the meeting.

12. SIGNATURES

The Report of the Bumbuna Hydroelectric Project, Dam Review Panel, Meeting No.1, has been read and signed below in Freetown on 4 November 2004 by the members of the Panel.

______________________________	______________________________
Bela Petry – Chairman, Hydraulic Structures	**Khalid Jawed – Hydrology**
______________________________	______________________________
William Moler – Geotechnics	**Peter Tschernutter - Dam**

APPENDICES:

A TERMS OF REFERENCE

B RECORD OF DAILY ACTIVITIES AND MEETINGS

C LIST OF DOCUMENTS REVIEWED

D PROJECT DATA

E DRAWINGS

F PHOTOGRAPHS

APPENDIX A – TERMS OF REFERENCE

SIERRA LEONE: Bumbuna Hydroelectric Project (BHP)

TERMS OF REFERENCE

DAM REVIEW PANEL

Introduction

1. The Bumbuna Hydroelectric Project (BHP) is located on the river Seli about 250 kms northwest of Freetown, the capital of Sierra Leone. It consists of an asphalt-faced rockfill dam 88 meters high, two multipurpose tunnels and a powerhouse at the toe of the dam with a design capacity of 50 MW. A single-circuit 161 kV transmission line will transfer Bumbuna's power to Freetown and intermediate towns. The Project is substantially complete (85%), with work being suspended due to the conflict situation in Sierra Leone. The Government of Sierra Leone wishes that work would recommence on the Project at the beginning of the next dry season (December 1, 2004).

General and Purpose

2. A Dam Review Panel (DRP) shall be established for the BHP by the Government of Sierra Leone (GOSL) to undertake two comprehensive and independent reviews (the first to be held in 2004 and the second after the completion of the first rainy season after impoundment of the dam) with the objective of evaluating features and actions pertaining to the safety of the dam and providing recommendations to the Government of actions that may be needed to upgrade the dam and appurtenances to acceptable safety standards. The DRP shall be guided by the Dam Safety Assurance objectives of the Government of Sierra Leone and the related legislative regulations, standards and guidelines

Organization and Membership

3. The DRP shall contain members with expertise in the following disciplines required for the project:

- A geotechnical engineer/engineering geologist/dam instrumentation expert;
- A dam engineer specialist in asphalt faced rockfill dams (impervious element, control of foundation seepage, dam deformations and displacements, filter protection and drainage capacity, etc.);
- A water resources engineer/hydrologist; and
- A specialist in hydraulics and hydraulic structures

4 The hydrology expert would be released upon review and acceptance by the expert, of the computation and flood routing of the project design flood, and sizing of spillway facilities.

5. A Chairman shall be appointed amongst the members by the GOSL to coordinate the communications of the DRP, to call and chair its meetings, to ensure the memberships objectivity and to provide balance to its reviews and recommendations. The person responsible for the official correspondence with the DRP Chairman shall be the Head of the Bumbuna Project Implementation Unit (BPIU).

6. The DRP meetings will normally be at the project site and shall be attended by all members. Inspection of the site, designs or of the dam under construction individually should occur only under special circumstances and in such cases the member will send his report of findings to other panel members for issuance jointly after concurrence by all panel members.

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Specific Actions

7. While the DRP will review and evaluate mainly technical elements of the dam designs, they shall not be concerned with the project scope, general features or economic characteristics. The specific elements to be reviewed and evaluated by the DRP shall include but not be limited to the following:

Design Review:

(a) To review site exploration data for the foundation and for material sources including results of drilling or boring, laboratory testing, in-situ tests and regional and local geological characteristics;

(b) To review the designs of the foundation treatment, proposed excavation, selected foundation strength parameters and seepage control measures;

(c) To review the strength parameters and characteristics of the selected construction materials for embankment dams including zoned materials, filters, and placement requirements;

d) To review the selected asphalt mix , material characteristics and placement procedures for the dam membrane including results of durability, gradation and reactivity tests, and construction requirements;

(e) To review stability analysis and resulting factors of safety for normal, unusual and extreme loading conditions for embankment dams, spillway structures and outlet works including determination of seismic loading criteria;

(f) To review upstream conditions in regard to formation of landslide and handling of floods caused by the collapse of such natural dams;

(g) To review the reservoir factors of rim stability, sedimentation, wave action. clearing plans and their effect on dam stability;

(h) To review the flood hydrology methodology and computations for determining the project design flood hydrographs, reservoir routing and spillway sizing;

(i) To review the design of spillway facilities including flow conditions, energy dissipation, including model tests;

(j) To review the inlet and outlet works, including its hydraulic designs, capacity for emergency reservoir drawdown, sediment handling capability, selective thermal releases, regulation range and other factors;

(k) To review the designs of diversion works, schedule, hydrology and risk factors associated with diversion during construction and with the closure of diversion works at initial reservoir filling;

(1) to review the risk and hazard evaluations including need for dam breach analysis;

(m) To review the design for dam instrumentation and the program for collecting, evaluation and maintaining data to be obtained; and

(n) To review the final plans and specifications for design adequacy, construction, scheduling and owner quality control procedures;

<u>Construction Phase</u>

(o) To review any major field design changes that have occurred because of changed field conditions;

(p) To review the operational plan for initial reservoir filling, including the time of closure, maximum allowable filling rate, measurements, emergency release plan, and designation of responsible operating personnel;

<u>Long Term Operation Phase</u>

(q) To review and evaluate the organization, procedures and program to carry out long term independent monitoring of the dam safety status including the inspection frequencies, instrumentation records system, project data files, evaluation criteria and means to provide remedial actions; and

(r) To review the adequacy of operation and maintenance manuals, and establishment of project operations procedures;

(s) To review the adequacy of and propose the broad principles for plans to implement a reservoir, fuel and energy management decision support system for optimizing the operations of the electricity system in Sierra Leone when Bumbuna is placed in service;

(t) To review and evaluate emergency plans including downstream flooding effects, emergency reservoir drawdown, notification of impending dangers to downstream municipal authorities, major flood early warning systems, major flood spilling operations plans, and site access during emergencies;

(u) To review the procedures for handling project records, including as built drawings, operation records, inspection records, instrumentation data and other information associated with the long term safety of the dam.

Support services

8. The GOSL's engineering consultants (Studio Ing. G. Pietrangeli) shall be present during DRP meetings at the request of the DRP. The DRP will be provided the necessary background information, any relevant data, notes or explanations regarding the designs, computations or methods used. The Project donors (including the African Development Bank (AfDB), the Government of Italy (GOI) and the World Bank) may participate as observers in these meetings. The Head of the Bumbuna Project Implementation Unit (BPIU) will coordinate the assembling of such information. The DRP may ask the designers to conduct additional studies to assist in evaluation of the matters relating to the dam' s safety status.

9. The GOSL shall provide clerical, drafting and reproduction services for the preparation of DRP reports. The Government shall take necessary actions to allow prompt travel clearance-s of DRP members or specialists requested by the DRP and shall provide full physical access to the project sites.

Reporting

10. The minutes of the meetings shall be prepared by and signed by all members and presented to the GOSL prior to departure of the members from Sierra Leone. The minutes shall briefly outline areas of concern, request for additional analysis and present recommendations for action, if any. Within three weeks, the minutes may be supplemented by additional analysis, discussion, or reference materials provided by the DRP members.

11. A copy of each minutes of meeting and supplementary reports will be transmitted by the Government to the Project Donors, The GOSL may append a statement of actions taken on recommendations of the previous panel meeting.

APPENDIX B
RECORD OF DAILY ACTIVITIES AND MEETINGS

Monday, 25 October 2004

- Arrival in Freetown Airport
- Meeting and acquaintance of the Dam Review Panel Members: Khalid Jawed, William Moler, Bela Petry, Peter Tschernutter.
- Meeting and acquaintance with other persons involved in the Bumbuna Project:
  Alberto Bezzi---Project Manager, Studio Pietrangeli
  Christian Fabio Capitanio---Director, Salini Construttori
  Hector Alberto Lohay---Resident Engineer, Studio Pietrangeli
  Two engineers from Studio Pietrangeli
- Flight to Freetown by helicopter
- Meeting Joe Matia---Local Representative, Studio Pietrangeli
- Check-in Hotel Bintumani

Tuesday, 26 October 2004.

- Meeting of DRP members with Mr Nathaniel Vandy and Mr Mustafa Kargbo, Manager and Deputy Manager of Bumbuna Project Implementation Unit (BPIU). Welcome and initial briefing on the purpose and programme of the DRP mission.
- Brief meeting of the above mentioned with H.E. the Minister of Energy and Power. Welcome and statement by H.E.The Minister on the importance of the Bumbuna Project for the economic and social development of the Country.
- Meeting of BPIU Management and DRP members with the Technical Steering Committee of the Bumbuna Project and other persons related to the Project. This meeting included:

  Mr John Aruna, Chairman, Special Assistant, Technical Advisor, Ministry of Public Works
  Mr Syrian Jusu, Director of Environment, Ministry of Lands, Planning and Environment
  Mr Benson Lahai, Economist, Ministry of Development and Economic Planning
  Mr Daniel E. Coomer, Executive Secretary, Ministry of Energy and Power
  Mr Graziano Carboni, Branch Manager, Salini Construttori

  Welcome and introduction of all participants of the meeting. Briefing and discussion on the importance of the Bumbuna Project.

- Meeting of DRP members with Mr Capitanio-SALCOST, Mr Bezzi and Mr Lohay-Studio Pietrangeli.
  Briefing on the historical development of the Bumbuna Project.
  Briefing on available documentation.
  Detailed discussion of the Programme.
  Working session with compilation and reading of available documentation by DRP members.

Wednesday, 27 October 2004.

- Trip of DRP members, Mr Vandy, Mr Kagbo, Mr Bezzi and Mr Lohay from Freetown to the Bumbuna Camp.
- First guided visit of DRP members to the Dam site, including all of its main components works and structures. Discussion of different issues related to the visited structures. Briefing and information provided by Mr Bezzi and Mr Lohay. Photographic records of visited places.
- Analysis of Project documents.

Thursday, 28 October 2004.

- Individual visits by DRP members, according to their speciality, to the Powerhouse area, Storages of Equipment, Concrete and Soils Laboratory, Gaging Station, Workshops in company of Studio Pietrangeli staff. General inspection of the present state of structures and facilities at site.
- Reading and analysis of Project documentation by DRP members.
- Meetings of DRP members with Pietrangeli staff for complementary information, explanations and discussions of Project issues.
- Special meeting on concrete technology and quality control during past construction activities.
- Definition and discussion of the table of contents of the DRP Report.
- Begin of writing activities.

Friday, 29 October 2004.

- Visit of DRP members to the Dam. Special attention to excavation, foundation treatment, cut-off, plinth and asphalt concrete face.
- Reading and analysis of Project documents.
- Complementary meetings with Studio Pietrangeli Staff.
- Internal discussions between DRP members.
- Continuation of writing activities.

Saturday, 30 October 2004.

- Report writing activity.
- Further analysis of Project documents

Sunday, 31 October 2004

- Report writing activity
- Further analysis of Project documents
- Internal discussions

Monday, 1 November 2004

- Report writing activity
- Analysis of Project documents
- Internal discussions

Tuesday, 2 November 2004

- Travel to Freetown
- Presentation of the Draft Report and Conclusions to the PIU, World Bank and Environmental Panel of Experts

Wednesday, 3 November 2004

- Completion of the DRP writing
- Meeting with H.E. the Vice President of Sierra Leone and H.E. the Minister of Energy and Power. Presentation of the DRP conclusions.
- Participation in a meeting of the Environmental Panel of Experts for the Bumbuna Project.

Thursday, 4 November 2004

- Meeting with PIU regarding finalization of the DRP Report and administrative matters related to the DRP activities.
- Transfer from Freetown to the Lungi Airport.
- Departure from Sierra Leone

APPENDIX C – LIST OF DOCUMENTS REVIEWED

July 1980, Feasibility Study, Volumes I to XII, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli, Consulting Engineers, Inc., Rome/Italy and Motor-Columbus, Consulting Engineers, Inc., Baden/Switzerland.

Volume	Title
I	Synopsis
II	Site Information: Geognostics, Laboratorytests and Geophysics
III	Site Information: Grouting Tests, Trial Embankment and Seismotectonic Assessment
IV	Site Information: Hydrological Data
V	Site Information: Topography
VI	Geology and Geotechnics
VII	Hydrology, Energy Generation and Flow Regulation, Ecology, Resettlement and Agricultural Effects
VIII	Power Market Study, Alternative Hydroelectric and Thermal Schemes
IX	Optimization
X	Proposed Plants: Civil Engineering
XI	Proposed Plants: Electromechanical equipment
XII	Cost Estimate, Construction Program and Economic Analysis

July 1984, Supplemental Feasibility Report Bumbuna Falls Hydroelectric Project Phase 1, Studio Ing. G. Pietrangeli S.r.l., Consulting Engineers-Rome/Italy and Motor-Columbus Consulting Engineers, Inc. Baden/Switzerland

February 1988, Contract A2: Civil Works, Volume 2, Part III: Technical Specification, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

February 1991, Left Tunnel, Calcoli Statici, Volumes 1 and 2, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

February 1991, Right Tunnel, Calcoli Statici, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

February 1991, Design, Calcoli Statici, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

April 1993, Contract A2: Civil Works and Contract B: Hydraulic Steel Structures, Final Design and Budget for Completion, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

April 1993, Drawings, Final Design and Budget for Completion, Contract A2: Civil Works and Contract B: Hydraulic Steel Structures, Bumbuna Falls Hydroelectric Project, Studio Ing. G. Pietrangeli S.r.I, Consulting Engineers-Rome/Italy

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APPENDIX D - PROJECT DATA

RESERVOIR	
Maximum Water Level	241.96 m a.s.l.
Maximum Operating Level	241.25 m a.s.l.
Minimum Operation Level	210.00 m a.s.l.
Total Capacity at Maximum Water Level	480 M m^3
Flood Routing Capacity	35 M m^3
Total Capacity at Maximum Operating Level	445 M m^3
Operating Capacity	350 M m^3
Inactive Capacity	95 M m^3
Surface Level at Maximum Operating Level	21 km^2
ROCKFILL DAM	
Maximum Height	88 m
Crest Length	440 m
Crest Width	4 m
Embankment Volume	2.5 M m^3
Upstream Asphaltic Concrete Area	51,000 m^3
Foundation Grouting:	
• Curtain Area	21,500 m^2
• Drilling Length	39,000 m
• Total Cement Tak	1,200 t
Cut-Off Concrete	7,000 m^3
DIVERSION TUNNEL	
Type	Two Circular
Diameter	9 m
Length	620 m
Total Concrete Lining Volume	15,800 m^3

SPILLWAY

Type	Two Morning Glory
Bellmouth Diameter	31.6 m
Maximum Height	65 m
Total Concrete Volume	23,600 m3
Total Design Discharge	3,000 m3/s

INTAKE

Internal Diameter	7.5 m
Height	93 m
Cylindrical Gate	7.5 x 6.0 m
Total Concrete Volume	7,400 m^3

INTAKE ACCESS BRIDGE

Internal Diameter	7.5 m
Length	100 m

POWER TUNNEL

Steel Lining	205 m
Radial Gate	7.4 x 7.0 m

POWER HOUSE

Machine Hall Dimensions	41 x 17 x 24 m
Total Concrete Volume	9,200 m3
Turbines	Two x 25 MW Francis
Maximum/Minimum Head	80/47 m
Maximum Turbine Discharge	80 m3/s
Vertical Synchronous Generators 13.8 kV	Two x 33.7 MVA at
Step Up Transformers Rated at 33.7 MVA	Two x 13.8/161 kV,

POWER AND ENERGY PRODUCTION

Installed Power	50 MW
Firm Power	18 MW
Total Average Annual Energy Production	315 GWh
Annual Firm Energy Production	158 GWh
Annual Average Secondary Energy Production	157 GWh

HYDRAULIC STEEL STRUCTURES

Total Weight	4,000 t

TRANSMISSION LINE

Type	161 kV Single Circuit
Length	200 km
Galvanized Steel Towers	500 Towers
ACSR Conductors	400 mm2

SUBSTATIONS

Freetown, Step Down Transformers	Two 161/34.5/11kV, Rated at 40/30/15 MVA
Makeni, Step Down Transformer	Single 34.5/11kV, Rated at 3,500 kVA