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Autoridad Del Canal De Panama
División de Proyectos de Capacidad del Canal

# Work Order No.5 Feasibility Design For The Ríos Coclé Del Norte And Caño Sucio Water Supply Projects

# Panama Canal

Contract Number CC-3-536

## VOLUME 4: APPENDICES

MWH

In association with

TAMS

AN EARTH TECH COMPANY

December 2003

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capicidad del Canal

# THE PANAMA CANAL

## ENGINEERING SERVICES

## Work Order No. 5
## The Ríos Coclé del Norte and Caño Sucio
## Water Supply Projects

*Feasibility Study*

## Volume 4 APPENDICES D-E

**DECEMBER 2003**


MWH
In association with
**TAMS Consultants, Inc.**
Ingenieria Avanzada, S.A.
Tecnilab, S.A

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

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# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D
## PART 1

## DAM TYPE SELECTION
## COCLÉ DEL NORTE

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# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D1 – DAM TYPE SELECTION, COCLÉ DEL NORTE

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# FOREWORD

The studies described in this appendix have been performed in accordance with the scope of services for Contract CC3-5-536 - Work Order 005, Feasibility Design and Related Services for the Coclé del Norte and Caño Sucio Water Supply Projects entered into on June, 2000. This appendix covers the selection of the type of dam for the Coclé del Norte project to be further evaluated in the feasibility studies.

These studies have been prepared using the following basic information:

- Reconnaissance Study: Identification, Definition, and Evaluation of Water Supply Projects, prepared by the U.S. Army Corps of Engineers, Mobile District, dated August 1999;
- Topographic mapping of areas of the proposed dam site prepared by Ingenieria Avanzada, S.A. under subcontract to MWH. Services were completed and submitted to the ACP under Contract CC-3-536, Task Order 2, Altimetric and Planimetric Surveys of 13 sites located on the Western Side of Lake Gatun;
- Additional topographic mapping of the dam site developed by digitizing 1:50,000 scale maps obtained from Instituto Geografico Nacional (Tommy Guardia);
- Geological and geotechnical information obtained from two dam site exploration and mapping field programs, and a construction materials investigation program, including both test pit sampling and laboratory testing, and;
- The results of hydrology and meteorology studies presented in the companion Appendix A.

The planned subsurface exploration program comprising boreholes and seismic refraction was not performed.

# 1 INTRODUCTION

As part of a reconnaissance study, the Mobile District assisted ACP to identify and rank 17 water supply projects to augment the existing canal water supply system. The Río Coclé Del Norte Water Supply Project was identified as one of the highest ranked projects, and has been selected for study at the feasibility level. The dam site selected in the reconnaissance study is located about 15 km inland from the Atlantic Ocean on the north-flowing Río Coclé Del Norte, Exhibit 1. The location was selected to provide the maximum size reservoir. Three reservoir elevations were considered in the reconnaissance study: 65 m above mean sea level (El. 65), El. 80 and El. 100. The maximum reservoir elevation is limited to El. 100 by topography. For a normal pool level of El. 100, saddle dams are required.

The dam type selected in the reconnaissance study was a center core rockfill dam with a crest at El. 83.5, providing a full supply level of El. 80.0, and a maximum reservoir flood level of El. 82.5. An ungated spillway was located on the right abutment. The proposed spillway had a crest width of 346 m and a capacity of 5,346 $m^3/s$. The spillway chute was proposed as a sloped and stepped natural rock cut channel.

The project also included a hydropower facility at the dam, a transmission line, and, for alternatives with a full supply level below El. 80.0, an 18 km inter-basin water transfer tunnel to the proposed Río Indio Water Supply Project. The Río Coclé Del Norte Water Supply Project with a full supply level at El. 100.0 was connected to the Río Indio Water Supply Project via the proposed Río Caño Sucio Water Supply Project and a 2 km inter-basin water transfer tunnel. In addition, the project included construction of access roads and other facilities required for this remote location. Exhibit 2 is an area map showing the reservoir and some of the proposed project features in relation to the proposed Río Indio Water Supply Project and Lake Gatun.

# 2 DAM TYPES AND DEVELOPMENT CRITERIA

This section contains a description of the types of dams that have been considered and the criteria used in sizing the facilities and appurtenant features. Features common to all dam types are also identified, but not included in subsequent comparison.

## 2.1 General Criteria

During the feasibility assessment, at least two project configurations will be studied; a reservoir with a full supply level at El. 100 connecting through the proposed Caño Sucio Reservoir to the proposed Río Indio Reservoir, and a reservoir with a full supply level between El. 100 and El. 65 directly connected to the proposed Río Indio Reservoir. The dam type selected as a result of these studies will be appropriate for either reservoir.

General criteria have been established primarily for the dam type selection. It is anticipated that they will be modified as a result of additional studies performed to optimize the selected dam, as well as the results of the planned geotechnical exploration program. The general criteria for dam type selection are as follows:

- The dam will be located at the damsite identified in the reconnaissance study;
- The reservoir full supply level will be at El. 80;
- The reservoir low supply level will be at El. 60;
- An ungated spillway width of 50 m was selected. This limits flood surcharge to El. 83.4, and;
- The dam crest will be at El. 82.4 with an upstream parapet wall to EL. 84.4.

As a result of these criteria, the gross storage at full supply level will be 7,500 million cubic meters (MCM). The live storage between El. 80 and El. 60 is estimated to be 4,400 MCM [from El. 80 to El. 50 the active storage is 5,700 MCM].

### 2.2 Alternative Dam Types

The dam types considered for this study are the following:

| Alternative | Dam Types | Abbreviation |
|---|---|---|
| 1 | Concrete Faced Rockfill Dam | CFRD |
| 2 | Roller Compacted Concrete Dam | RCC |
| 3 | Conventional Gravity Concrete Dam | CGCD |
| 4 | Earth Core Rockfill Dam | ECRD |

Alternatives 3 and 4 were considered, but not carried forward for study for the following reasons:

> Alternative 3, Conventional Gravity Concrete Dam, will have the same basic geometry as Alternative 2, RCC. Experience over the last 15-20 years is that RCC gravity dam unit construction costs are lower than those for conventional gravity dams, primarily owing to the lower cement content (and therefore cost), as well as less formwork and faster construction. Cost comparisons performed for the Río Indio and the Río Caño Sucio Water Supply Project dams showed the RCC alternative to cost less than a conventional gravity concrete dam. Therefore, Alternative 2 is expected to provide the same benefits and reliability at lower cost. Consequently, a conventional gravity concrete dam was not considered further.
>
> Alternative 4, Earth Core Rockfill Dam, requires a substantial source of suitable impervious material for the core, as well as a relatively long dry season construction period. As presented in Appendix B, Geology, and discussed in Section 3 of this appendix, suitable sources and quantities of impervious material were not located in the vicinity of the dam site. Some heterogeneous sources of impervious materials were identified near the site, and residual soils are available

around the dam site. If of sufficient quantity, these sources would require a piece-meal exploitation procedure resulting in higher costs and unfavorable environmental consequences. The quality of the materials is also quite variable impacting the overall quality of any potential core constructed using them. Experience has shown that unless there are suitable sources of core material in close proximity to the dam site, a CFRD is more economical than an ECRD. In addition, the average annual rainfall is in excess of 4,000 mm, and the extended wet season of eight months, will result in a longer construction period for this type of dam than for a CFRD and at a higher cost. The longer construction period will require increased flood protection for similar levels of protection, also resulting in higher cost. The ECRD alternative was, therefore, discarded, and was not considered further.

## 2.3 Dam Site Location

The dam site is located on the Río Coclé del Norte about 1 km downstream of Cerro Pelado, and approximately 4 km upstream of the village of San Lucas. It is about 5.5 km downstream of the confluence with the Río Toabre, and 13 km from the mouth of the Río Coclé del Norte with the Atlantic Ocean. The axis used for this study was selected primarily to maximize storage and for topographical considerations. It takes advantage of a relatively narrow reach of river valley to reduce the volume of the dam types, provides adequate space for cofferdam and diversion facilities, and does not present any adverse access difficulties. The final alignment of the dam will be confirmed following the site investigation program during final design.

## 2.4 Spillway Design Flood

The spillway will be designed for the probable maximum flood (PMF). For a project whose failure would result in loss of human life and economic endeavor, it is customary to design the project for the worst conditions that could reasonably be postulated, i.e. the probable maximum precipitation (PMP) resulting in the PMF.

Estimating the PMF consists of analyzing the basic factors that cause the occurrences of great floods, maximizing these factors to their highest reasonable physical limits, and then combining them within acceptable conditions from a hydrologic point of view, in a manner which produces the maximum flood. The studies to determine the PMF are presented in Appendix A, Hydrology and Meteorology.

The maximum peak inflow of the PMF is estimated to be 10,460 $m^3/s$. The PMF has a 5-day volume of about 988 MCM.

### 2.5 Diversion Flood and Diversion Works

The selected diversion flood will impact the cost of the diversion tunnel (or culvert) and cofferdams. For this dam type selection study, the following aspects of dam construction were taken into consideration:

1. Conversion of the diversion tunnel to a low level outlet for control of reservoir filling and emergency drawdown of the reservoir;
2. The length of time and cost of repair to critical components of the project that would be subject to damage due to flooding during construction, and;
3. Diversion structure cost differences for alternative dam types.

At this stage of study, the length of time at risk and cost of repair to components of the project that could be impacted by a flood during construction cannot be differentiated with any certainty. Both RCC and CFRD-type dams will be constructed to a level above proposed upstream cofferdam elevations in two to three years after diversion facilities are completed. Therefore, the diversion flood for the two alternative dam types for this study will be the same. There is less than a 5% probability that a flood greater in magnitude than the 50-year return period flood will occur in two years. A sensitivity analysis to selecting a more frequent flood peak for the RCC alternative is presented in Section 5.1.1 of this appendix.

The diversion cost for the alternative dam types is a function of optimizing the cost of the cofferdam against diversion tunnel cost. As the cofferdam is lowered, the diversion tunnel must be increased in size and cost.

Flood peaks for selected return periods from Appendix A, and are presented below:

| Return Period (Years) | Flood Peak ($m^3/s$) |
|---|---|
| 2 | 1,295 |
| 5 | 1,925 |
| 10 | 2,430 |
| 20 | 2,995 |
| 50 | 3,860 |
| 100 | 4,610 |

Hydraulic analyses for several alternative diversion flood cases and diversion facilities have been prepared. They are presented in Attachment 1, Hydraulic Analysis for Design of Diversion Tunnel and Cofferdam. The 50-year return period flood was selected. The analysis includes development of a tailwater rating curve, diversion tunnel/culvert analysis and reservoir routing of the selected floods for several diversion tunnel/culvert sizes. Flood routing analysis showed that, as for the PMF, the diversion flood is substantially attenuated by the cofferdam and diversion tunnel arrangements being considered. Tunnel size/cofferdam height optimization studies show that the minimum diversion tunnel/culvert size for conversion to an emergency drawdown outlet will result in the lowest overall diversion cost.

The minimum size of the diversion tunnel/culvert is determined by drawdown requirements during filling and operation. Provision of drawdown capability is most easily and cost effectively achieved by conversion of the diversion facilities to a low level outlet. For this dam type selection study the following criteria and assumptions were adopted for sizing the emergency drawdown facilities:

1. Drawdown requirements were adopted for a significant hazard, significant risk dam in accordance with U.S.B.R. ACER Technical Memorandum No. 3, 1982;
2. The average annual inflow is 107.5 $m^3/s$;
3. A provision for sediment build-up will be made.

Emergency drawdown studies are presented in Attachment 1. Three D-shaped diversion tunnels of 6, 8, and 10 m were sized for diversion of the construction flood. Drawdown studies showed that the 6 m diameter tunnel did not meet the emergency drawdown guidelines, even concurrently using a Coclé del Norte to Indio transfer tunnel of 8 m diameter. The 8 m diameter diversion tunnel alone also does not meet all of the guideline times for drawdown, but may be acceptably close. Operated in conjunction with the transfer tunnel, the 8 m diversion tunnel does meet guidelines. Therefore, the 8 m diameter tunnel is selected for diversion and conversion to an emergency drawdown facility.

Preliminary layouts have been prepared for a diversion tunnel. The dam site topography favors a diversion tunnel through the left abutment. The design flood and diversion facilities selected for the dam type study are:

1. The 50-year event, with a peak inflow of 3,860 $m^3/s$, is selected as the design flood;
2. The diversion tunnel will be an 8.0-m-diameter, D-shaped tunnel. The CFRD alternative requires a 530 m long tunnel, and the RCC dam alternative requires a 440 m long tunnel. It will be located in the left abutment. An access shaft adjacent to the crest centerline on the left abutment will provide access to the emergency drawdown gates.
3. Maximum discharge of the diversion tunnel will be 650 $m^3/s$;
4. The upstream cofferdam will be sized to retain a flood with a peak elevation of El. 22.3. The cofferdam will have a crest at El. 22.5 m, and;
5. The downstream cofferdam will have a crest at El. 4.0 m.

## 2.6 Spillways

In the reconnaissance study, the USACE selected an ungated spillway located on the left abutment. It was proposed with a crest width of 346 m (measured as the open width of the control structure) and a capacity of 5,346 $m^3/s$ and a sloped and/or stepped natural rock cut channel spillway chute. Review of the supporting cost information showed this to be a relatively expensive spillway arrangement.

ACP has indicated a preference for an ungated spillway because of its lower operation and maintenance costs. From earlier studies of spillways for the hydraulically similar Río

Indio Water Supply Project, ungated and gated spillways of this capacity were determined to have substantially the same initial construction cost for CFRD dams. The RCC dam alternative was also of similar cost for both ungated and gated spillways.

Therefore, for this dam type selection analysis, the crest of the ungated spillway was set at El. 80.0, and flood routing performed for several widths with hydraulic widths varying from 25 m to 346 m (selected for the Reconnaissance study). These are presented in Attachment 2, Evaluation of Spillway Sizes and Estimation of Freeboard for Río Indio Project. The flood routing showed that the reservoir provides substantial attenuation of the inflow flood: the 346 m wide spillway limits the flood surcharge to El. 82.6 m, the 25 m wide spillway to El. 83.5 m. Dam and spillway cost studies performed for the similar Río Indio Water Supply Project demonstrated that the low cost combination of dam (height) and spillway (width) option is for a spillway hydraulic crest width between 25 and 50 m. For the dam type selection study, an ungated spillway with a crest width of 50 m is selected, with a corresponding maximum water surface at El.83.4.

### 2.6.1 Ungated Spillway for CFRD Alternative

Layouts for an ungated spillway adjacent to the CFRD showed the right abutment to have preferable topographical characteristics. A spillway located on the left abutment would result in the construction of a longer spillway chute through more variable topographical, and potentially, geological terrain. The chute would also terminate at an unfavorable angle to the downstream river channel, or would need to be increased in length.

The chute spillway would include an approach channel excavated to El. 75. The spillway ogee crest would be at El. 80.0, the reservoir full supply level. The selected spillway width to pass the PMF is 50.0 m. The maximum discharge is 600 $m^3/s$. A spillway bridge will span the ogee from the dam crest to the right abutment. The spillway chute will taper to 14 m at the flip bucket. The chute will have an overall length of about 250 m, and a drop of approximately 75 m. A smooth concrete chute will be provided with training walls of about 4 m. The flip bucket will have a lip at El. 4 that is one meter above the expected maximum tailwater elevation under PMF conditions. All spillway structures will be constructed of conventional mass or reinforced concrete founded on rock. Anchors and drains under the spillway chute are also provided. The spillway will discharge back into the Río Coclé Del Norte by means of a short excavated discharge channel.

### 2.6.2 Ungated Spillway for RCC Alternative

The ungated spillway for the RCC alternative will be located on the dam and aligned to discharge directly into the Río Indio. It will include a crest at EL. 80.0 m and an open crest width of 50 m. The crest road will be supported by means of two piers. A smooth chute of conventional concrete will be provided with training walls. The spillway chute will terminate in a flip bucket at El. 4.

## 2.7 Other Features

In addition to the dam and spillway, there are a number of other features that comprise or are required for construction of the Río Coclé del Norte Water Supply Project including:

- Cofferdams;
- Saddle Dams;
- Multi-level Outlet Structure;
- Hydropower Facilities;
- Access, and;
- Construction Area (laydown and around dam).

These are described below together with how they are addressed in the dam type selection study.

### 2.7.1 Cofferdams

Cofferdams will be constructed upstream and downstream of the project works and will be of sufficient height to protect the working area against flooding during the selected diversion flood. The cofferdams will be constructed along an alignment approximately parallel to the main dam at a location far enough upstream and downstream to avoid conflicts between construction of the main dam and the cofferdam. For the dam type selection study, a minimum distance of 25 m will be provided between the toe of the cofferdam and the foundation excavation limits. The upstream and downstream slopes of the cofferdams will be 2.5H: 1V and 2H: 1V respectively. The cofferdams will be constructed of compacted and dumped random fill on the in-situ alluvium. Less pervious material will be placed on the water retaining face, and a filter and drain will be provided. The crest width will be 5 m. Crest elevations, which are the same for both dam types, are given in Section 2.5 Diversion Flood.

### 2.7.2 Saddle Dams

Creation of a reservoir with a normal full supply level at El. 80 m will not require construction of saddle dams.

### 2.7.3 Multi-level Intake for Outlet Structure

Provisions for a multi-level intake for the outlet structure may be required for the Río Coclé Del Norte Water Supply Project to provide control of water quality for ecological downstream releases. The outlet structure will be capable of releases at various elevations from El. 80.0, the normal reservoir elevation to EL. 10.0, approximately 10 m above the current river elevation. If required, the outlet structure would be sized to provide the minimum release presented in the USACE's HEC-5 analyses, of 10.9 $m^3/s$. This is assumed to be the seven-day low flow exceeded 10% of the time ($7Q_{10}$).

The relatively small multi-level outlet structure will be constructed on the upstream face of the RCC and CFRD dam type alternatives. Slide gates or valves will be housed in the intake structure. Operation of valves at selected elevations will provide withdrawal at the required level. Discharge will be through the intake structure to a steel pipe located at dam foundation elevation. The required pipe diameter is 2.2 m. The pipe will terminate at control valve and flume for measurement and variation of required minimum releases. A bifurcation will be included for possible future addition of hydropower. Differences in complexity and cost are too small to be captured in this dam type comparison study. Therefore, the multi-level outlet structure is not included in the dam type selection cost comparison.

### 2.7.4 Hydropower Facilities

The project has been planned with provision for incorporating hydroelectric generation. On-going studies are being performed to identify the generation potential and the hydropower facilities that will be constructed at the Río Coclé Del Norte dam as well as at the trans-basin transfer tunnel to Río Indio and Lake Gatun. These are dependent on future operation studies for the combined Río Coclé Del Norte and Río Indio Water Supply Projects.

For the dam type selection studies, the principal cost difference is the intake structure and power tunnel required for the CFRD alternative. The hydropower tunnel will not be larger than the diversion and low-level outlet tunnel. A potential location for the power tunnel will be identified and, using cost estimates derived from the diversion and low level outlet tunnel, an order of magnitude cost estimate will be made for the addition of a power tunnel for the CFRD alternative.

### 2.7.5 Access

New access roads (and bridges) to the dam site and to quarries will be required. Access roads are not specifically included in the dam type selection study as cost differences are small and have not been defined.

### 2.7.6 Construction

Construction camps and facilities will be required prior to commencement of the main Río Coclé Del Norte dam and facilities construction contract. For the dam type selection study, they have been estimated to be similar and have not been included in comparative cost estimates. The RCC dam will require specific installations for material storage and handling and the costs of these installations are included in the general costs of the RCC.

# 3 GEOLOGIC AND GEOTECHNICAL CHARACTERISTICS

Geologic and geotechnical information used as the basis for input to the dam type selection process was obtained during two visits to the proposed Río Coclé del Norte dam site, one in September 1999 and another in December 2001. Investigations included general reconnaissance of the project area, basic geologic mapping at the damsite and appurtenant structures, identification of potential construction material sources, and material sampling and testing. Although further investigations to investigate subsurface conditions by drilling and geophysical surveys have been planned, the results of these additional investigations were not available for the dam type selection study.

Only those geologic and geotechnical characteristics pertinent to the dam selection studies are addressed in this section. A more detailed description of the local geology and geotechnical characteristics is contained in Appendix B, Geology and Seismicity, of the main report.

## 3.1 Site Geology

Bedrock units at the Río Coclé del Norte dam site area consist of Tertiary age volcanic rocks, mostly basalt flows with minor agglomerate units, belonging to the Tucué Formation. Other volcanic and intrusive igneous formations occur in the reservoir area belonging to the Petaquilla Formation. Sedimentary rock units also occur in the Coclé del Norte region but based on site reconnaissance, there is no evidence that they occur in the dam site area.

At the dam site, the Río Coclé del Norte flows north, forming a relatively steep-sided valley. The river is only slightly above sea level at the site and minor tidal fluctuations (reportedly up to 30 cm) are evident. The sides of the river rise steeply to a little over 100 m on the left side and to above 140 m on the right side. The width of the valley bottom at the site varies, but averages about 100 m with the streambed occupying about 50-80 m.

Both abutments are densely vegetated with primary and secondary forest growth, and are almost entirely covered with talus, colluvial, and residual soils. Most of the dam site area is characterized by a moderately deep weathered profile with locally thick soil cover typical of the sub-tropical climate.

Small, scattered rock outcrops can be observed throughout the site area on both abutments, especially in gullies. Bedrock at the dam site is found to consist mostly of porphyritic basalt and, less commonly of basic agglomerate. The basalt is thick-bedded to massive in nature. Based upon reconnaissance mapping and test pits, it is considered that the same rock types occur in the foundation areas of all proposed principal structures and on both sides of the river. It is also interpreted that sound, strong bedrock can be reached at reasonable depths at most structure locations.

River terrace deposits are found along the valley at many locations, mostly at about 5-10 m above present river level, on the inside of meanders, and at the confluence of tributaries. The terrace deposits appear to be largely silty-sand and clayey-silt. No significant gravel deposits have been found.

### 3.2 Materials Available for Construction

Materials available in the vicinity of the proposed dam site include alluvial deposits in terraces and the river bottom, overburden, and rockfill from quarry operations.

**Alluvial Deposits**. Small alluvial terraces are found at various locations along the river and are found to consist of clayey and sandy silt with fragments of weathered basalt. These are limited in size and volume and do not provide a suitable resource for construction materials. Gravel deposits in the river bottom are used as a source of materials by local inhabitants but are also thought to be limited in quantity for use in dam construction as zone material in fill dams or as concrete aggregate.

**Colluvial and Residual Soils**. Based on current interpretations of overburden conditions in the vicinity of the proposed dam site, the overburden in this area can be classified as a bouldery and gravely silty clay or clayey silt with sand. Such overburden could be suitable for use in random fills for access roads, ramps or in cofferdams, and also as random fill zones for a zoned earthfill dam type. However, it is considered that the predominance of boulder-sized, weathered basalt blocks precludes the overburden from use as a core material, or as either coarse or fine filter zones in a zoned fill dam alternative. Removing boulder-sized blocks from the overburden could potentially produce core material, but alteration of the remaining cobble sized fragments due to breakage could lead to a gap-graded or open graded material in-place. Although most of the bedrock in the project area is covered by horizons of talus, colluvial, and residual soils, it is thought that the relatively shallow depth of overburden at the dam site would necessitate opening other additional borrow sources.

**Basalt.** Bedrock throughout the dam site area consists of basalt rock units. Rockfill could be obtained from materials removed from the required excavations (e.g. spillway and diversion tunnel excavation). However, the quantities of rockfill required for a fill dam type would most likely require opening of one or more rock quarries in the area in addition to use of materials from required excavation. The area downstream of the proposed dam site on the right side of the Río Coclé del Norte contains high hills that could be stripped and opened as quarries. This currently seems to be the most attractive location for quarry operations to supply not only rockfill for dam construction, but also coarse aggregate for concrete and filters.

No suitable natural sand deposits were identified in the vicinity of the Project site for potential use as fine aggregate for concrete during the site investigations. Investigations of terrace deposits along the sides of the river indicated that these materials may be sandy or contain some quantity of sand, but further exploration of these features could not be carried out due to suspension of site investigation activities in December, 2001. Due to the low ground surface elevation of the lower terraces above the river level, excavation of suitable quantities of materials from these terraces, if found to contain suitable materials, would be difficult.

Helicopter reconnaissance of the Caribbean shoreline on either side of the mouth of the Río Coclé del Norte was carried out. The shoreline in both directions can be described as rocky with many outcrops of basalt bedrock. Small sand beaches were identified, and local people have reportedly used the beach sand for construction purposes in the area; however, it is doubtful that these beaches could successfully yield adequate quantities of sand suitable for construction. There may be offshore sources of sand that could be mined and transported to the Project site via the Río Coclé del Norte; but the existence and adequacy of such sources is purely speculative, and could not be confirmed during the site investigations activities.

Given the above observations, the most promising source of fine concrete aggregate may come from quarry operations such as those described for use in producing coarse aggregates.

### 3.3 Geotechnical and Geologic Design Considerations

Generally, the geologic and geotechnical factors that most influence selection of dam type fall into the following categories:

- General foundation bedrock acceptability, including sliding resistance and deformation characteristics of foundation;
- Required excavation depths to achieve acceptable foundation materials;
- Measures required to treat the foundation to improve physical properties and control leakage;
- Long-term performance of the foundation under normal operation conditions and extreme events, especially earthquake; and
- Availability of suitable construction materials.

Such geological and geotechnical factors can have direct influence on the development of comparative construction costs and were taken into consideration during the study of dam type alternatives. However, in the absence of subsurface investigation data, the process had to be based on qualitative evaluations involving engineering judgment and previous experience in similar geological environments.

**Foundation Bedrock Characteristics.** In general, the basaltic foundation bedrock at the site should provide an excellent foundation for all types of structures being considered. This type of foundation material is not expected to present any significant constraints on project development that cannot be taken care of with appropriate design details and construction practices.

- *Bearing Capacity.* The basaltic bedrock units at the site are strong and are expected to present adequate bearing capacity to support any of the structures being considered. Differential settlements should not be a concern with this type of foundation. Data from subsurface investigation and testing will be needed to develop design and construction details for foundation treatment.
- *Resistance to Sliding.* The basalt should provide adequate resistance to sliding along discontinuities and at foundation-structure interfaces, provided excavation depths are sufficient to achieve fresh sound bedrock.

**Excavation Depths**. Based upon observations made at the site and comparison with rock types elsewhere in similar environments, an average overburden thickness of 3 m can be assumed, i.e. depth to top of weathered rock. An average depth to the top of competent rock can be assumed to be about 6 m. These values can be used in the development of preliminary layouts and in the computation of quantity takeoffs for cost estimates. Actual depths and characteristics of weathering need to be properly investigated by drilling and geophysical exploration since these are very sensitive inputs to the cost estimates.

**Foundation Improvement, Treatment, and Long-Term Performance**. No special foundation improvement or treatment measures are expected for the Río Coclé del Norte site that would influence selection of one dam type over another. Similarly, the basalt bedrock is expected to perform satisfactorily over the lifetime of the project without adverse deterioration.

**Natural Slope Stability**. No large mass movements are expected to affect the reservoir, but the effect of saturation, say after intense rainfall, on the stability of residual soils and saprolites needs to be properly evaluated. This could be significant in design of safe spillway cuts.

**Construction Materials**. Basalt from required excavation, provided it is not entirely decomposed, could be used as rockfill material. All grades of rockfill could be satisfactorily developed from one or more quarries in basalt. All aggregates (including coarse and fine aggregates for concrete, filters, drains, and riprap) need to be manufactured from quarried sources located within a 3-4 km distance of the dam site. Economic sources of impervious fill are not available.

Geotechnical design criteria used for developing preliminary layouts and cost estimates for dam type selection are presented in Table 1, following:

**Table 1: Summary of Geotechnical Design Parameters**

| Parameter | Selected Design Criteria |
|---|---|
| Thickness of overburden (top of weathered rock) | 3 m |
| Depth to top of competent rock | 6 m |
| Rock excavation slopes | 1 H:5 V |
| Soil excavation slopes | |
| Permanent | 2 H:1 V<br>3-m-wide benches every 10 m vertically<br>Bench at soil-rock contact |
| Temporary | 1.5 H:1 V<br>3-m-wide benches every 10 m vertically<br>Bench at soil-rock contact |

# 4 ALTERNATIVE DAM TYPE LAYOUTS

This section gives a brief description of both of the alternative dam type development concepts and highlights the pertinent differences between them.

## 4.1 Concrete Face Rockfill Dam

A site plan and profile of the concrete faced rockfill dam (CFRD) is presented in Exhibit 3. The general arrangement shows the dam, cofferdams, and diversion culvert alignment. Exhibit 4 shows the CFRD ungated spillway plan, profile and section.

The centerline of the dam alignment was selected to minimize excavation and fill volume. The alignment will be confirmed during subsequent studies of the selected dam type to include any additional information from planned geotechnical explorations. The upstream and downstream cofferdams were located to provide adequate construction and laydown areas while minimizing the length of diversion culvert. The minimum distance to the upstream cofferdam was established at 30 m. This provides working space for the construction of the required grouting curtain at the toe of the main dam. In addition to consolidation grouting beneath the plinth of the CFRD and the heel of the RCC dam alternatives, a grout curtain cutoff will be constructed to a depth of 40% of the hydraulic head. The minimum distance to the downstream cofferdam is 40 m.

The CFRD will be constructed of selected rockfill obtained from adjacent or nearby rock quarries. For the dam type selection, the slopes of both the upstream and downstream faces are 1.4H:1.0V, reflecting the relatively low seismicity of the location. These slopes will be optimized during subsequent studies when stability analyses are performed. An upstream parapet wall extending 2 m above the fill, and a downstream retaining wall of 1 m, will form the dam crest respectively.

The dam will be constructed with a conventional reinforced concrete upstream facing as an impermeable membrane. It will be designed to have (1) low permeability, (2) sufficient durability against weathering, and (3) sufficient flexibility to tolerate small expected embankment settlement. The concrete facing will be constructed of panels with intermediate vertical waterstops. A zone of fine gravel and sand will be placed beneath the concrete face to provide continuous support for the concrete facing. The gravel prevents movement of the sand bedding material that supports the concrete facing into the main rockfill. The zone will be about 3 m thick. It is expected that this support zone will be placed using an upstream-extruded concrete curb to provide confinement during compaction and protection against erosion during construction.

A reinforced concrete plinth, or toe slab (also used as the grouting platform), will be placed upstream and under the toe of the concrete facing. This plinth will be extended downstream, as needed, to lengthen the seepage path as required by the rock encountered.

The cofferdams will be constructed of random fill that will be obtained from portions of the required excavation for the main dam, saddle dam and spillway. Placement of the main dam fill will include construction of a filter drain. The diversion tunnel will be located in the left abutment. It will be aligned to provide adequate rock cover, to minimize tunnel length, and to facilitate conversion to a low level outlet for emergency drawdown. The alignment permits construction of an access shaft in the left abutment from the dam crest to an outlet control gate chamber in the diversion/low level outlet tunnel. The access shaft has been located just downstream of the dam crest.

Pertinent data is provided in Table 2:

### 4.1.1 Ungated Spillway

The ungated spillway will be located in the right abutment. A crest road access bridge will span the spillway channel over the control structure. The spillway, chute and flip bucket are described in Section 2.6.1 Ungated Spillway for CFRD Alternative.

## Table 2: CRFD Design Parameters and Pertinent Data

| | |
|---|---|
| **Dam Section** | |
| CFRD | |
| Alignment | See Plan |
| Crest elevation | 82.4 m |
| Parapet elevation | 84.4 m |
| Maximum reservoir elevation | 83.4 m |
| Crest width | 8 m |
| Upstream slope | 1.4 H : 1 V |
| Downstream slope | 1.4 H : 1 V |
| Concrete face thickness | 0.3 - 0.5m, 0.4 m, av. |
| Transition fill thickness | 3 m |
| Plinth width | 4 m |
| Foundation | |
| Plinth | Competent rock |
| Embankment | Weathered rock |
| Material Volumes, $m^3$ | |
| Rockfill | 3,487,000 |
| Filter for concrete | 226,000 |
| Concrete | 49,000 |
| Foundation excavation | 477,000 |
| **Cofferdams** | |
| Upstream cofferdam | |
| Alignment | See Plan |
| Crest Elevation | 22 .5 m |
| Distance from dam | 25 m (min) |
| Downstream cofferdam | |
| Alignment | See Plan |
| Crest Elevation | 3 m |
| Distance from dam | 25 m (min) |
| Crest width | 5 m |
| Freeboard | 1 m |
| Upstream slope | 2.5 H : 1 V |
| Downstream slope | 2 H : 1 V |
| Foundation | |
| Impervious Element | 2 m |
| Shells | 2 m |

## 4.2 Roller Compacted Concrete Dam

The site plan and profile for a RCC dam is presented in Exhibit 5, and spillway plans and sections are shown in Exhibit 6. The centerline of the dam is located on the same axis as the CRFD. The cross section has been selected to provide adequate stability under the prevailing site conditions (low-to-moderate seismicity and moderate foundation strength) based on experience. The selected cross section will include a vertical upstream slope, and a downstream slope of 0.75H:1V. The crest will be 8-m-wide at El. 82.4, with a parapet wall to El. 84.4. An upstream cut-off grout curtain and an under-drainage system will be constructed.

The current alternative assumes low-paste RCC, utilizing bedding mixes, as required, particularly at the rock-concrete interface, and at the upstream end of each lift, and an upstream impervious membrane, and drainage system. The impervious membrane and drainage system will be connected to a conventional reinforced concrete gallery situated above tailwater adjacent to the upstream toe. This gallery will be used for construction of the grout curtain and drainage curtain.

Pertinent data is provided in Table 3:

### 4.2.1 Ungated Spillway

The ungated spillway will have the same hydraulic capacity as the CFRD ungated spillway. It will be located on the RCC dam to discharge directly by means of a chute and flip bucket into the existing Río Coclé del Norte channel. A crest access bridge will be provided. The spillway will be constructed of conventional reinforced concrete.

## Table 3: RCC Design Parameters and Pertinent Data

| | | |
|---|---|---|
| **Dam Section** | | |
| | RCC and gravity | |
| | Alignment | See Plan |
| | Crest elevation | 82.4 m |
| | Parapet Elevation | 2 m |
| | Maximum reservoir elevation | 83.4 m |
| | Crest width | 8 m |
| | Upstream slope | 0 H : 1 V |
| | Downstream slope | 0.75 H : 1 V |
| | RCC uncompacted section downstream | 0.5 m |
| | Foundation | Competent rock |
| | Material Volumes, $m^3$ | |
| | RCC | 1,020,000 |
| | Conventional concrete | 63,000 |
| | Foundation excavation | 245,000 |
| **Cofferdams** | | |
| | Upstream cofferdam | |
| | Alignment | See Plan |
| | Crest Elevation | 22.5 m |
| | Distance from dam | 25 m (min) |
| | Downstream cofferdam | |
| | Alignment | See Plan |
| | Crest Elevation | 3 m |
| | Distance from dam | 25 m (min) |
| | Crest width | 5 m |
| | Freeboard | 1 m |
| | Upstream slope | 2.5 H : 1 V |
| | Downstream slope | 2 H : 1 V |
| | Foundation | |
| | Impervious Element | 2 m |
| | Shells | 2 m |

# 5 EVALUATION OF THE ALTERNATIVE DAM TYPES

The objective of the dam type evaluation is to select the dam type to be included in the project arrangement. The evaluation process will also be used to identify specific aspects of the selected dam type that require additional study.

## 5.1 Factors Considered in Dam Type Selection

The evaluation of the alternative dam types is based on the following factors:

1. Construction cost;
2. Construction considerations;
3. Foundation considerations, and;
4. Operation and Maintenance considerations.

Both dam types have been developed to provide the same level of performance. The dam types have been developed to:

- Minimize the initial construction cost of the project by minimizing the dam size for the selected design parameters;
- Minimize technical difficulties that might be encountered in project construction through project configuration;
- Account for potential foundation related difficulties that might become apparent during future investigation programs, and;
- Minimize project operation and maintenance costs, or the possibility of encountering unique and difficult to solve remedial costs.

The alternative that best satisfies the stated objectives, and any other specific owner requirements, will be the recommended alternative.

### 5.1.1 Initial Construction Costs

To develop the initial construction costs for each alternative, preliminary quantities and costs have been prepared. Only quantities and costs that are judged to vary by alternative have been estimated. The following common costs are not included in the cost estimates:

1. Access Roads;
2. Construction Facilities;
3. Trans-basin diversion tunnel;
4. Reservoir clearing;
5. Environmental and socio-economical costs, and;
6. Contingencies.

Unit costs have been estimated for use at this preliminary cost comparison level. Attachment 3, Comparative Cost Estimate presents the costs for diversion and care of water, the dam, the spillway and the low level outlet for selected quantities and unit costs together with the basis for the unit costs.

Tables 4 below summarizes the resulting cost estimates for the alternatives considered, including ungated and gated spillway alternatives.

**Table 4: Summary of Comparative Costs**

| Component | CFRD Ungated | RCC Ungated |
|---|---|---|
| | US$ x million, 2002 | |
| Diversion and Care of Water | 10.6 | 8.3 |
| Dam | 55.5 | 70.7 |
| Spillway | 6.5 | 1.9 |
| Low Level Outlet | 4.2 | 3.9 |
| Total | 76.8 | 84.8 |

The comparative cost estimate shows the RCC alternative to be $8 million higher in cost, 10% higher that the CFRD alternative. The RCC dam type alternative is primarily dependent on the unit cost of RCC. Historic RCC unit costs for a dam of this volume range from $\$45/m^3$ to $\$75/m^3$. A sensitivity analysis showed that the unit cost of RCC would need to be decreased by 15% (from $\$54/m^3$ to $\$46/m^3$) for the construction cost of the RCC alternative to be equal to the construction costs of the CFRD alternative. In addition, the cost of the RCC dam is more sensitive to changes in its estimated volume than the CFRD dam as it is a larger percentage of the project cost. The volume could vary as a result of foundation conditions, and result in significantly lower or higher cost for the RCC dam alternative.

Construction scheduling could show that the RCC alternative is at lower risk to flooding than the CFRD alternative because of its shorter construction time. Flood routing studies have shown that the proposed cofferdam and diversion tunnel arrangements significantly attenuate the flood peak, and therefore, selection of a more frequent flood with a lower flood peak does not significantly reduce the cofferdam height. The estimated cost of the cofferdams for the RCC alternative is $4 million. Therefore, selection of a smaller diversion flood will not result in the RCC dam type being the low cost alternative.

While the CFRD alternative is lower in cost than the RCC dam, addition of a hydropower facility will be more costly. The principal difference in additional cost is for an intake structure and power tunnel. The RCC alternative would have a lower cost intake structure on its upstream face, and an integral power tunnel. Preliminary estimates for the cost difference of an intake structure and a tunnel similar in size to the diversion tunnel are $4-5 million. Therefore, the overall cost of the CFRD alternative with hydropower facilities is lower than the RCC alternative with hydropower facilities.

The CFRD cost is less sensitive to unit cost or volume changes; for example, a 15% change in rockfill unit cost or quantity results in a 9% change in alternative cost. Rockfill unit cost of quantity would need to increase by 20% for the construction cost of the CFRD alternative to be more that the RCC alternative.

The difference in initial construction cost between the RCC alternative and the CFRD alternative favor the CFRD alternative. Contingencies have not been included on either quantities or unit costs. For the feasibility level estimate, contingency allowances will be included for the following:

1. Uncertainties attributable to unforeseeable adverse geological conditions;
2. Variations in the cost of permanent equipment and resources for construction due to changing market conditions;
3. Modifications in design resulting in an increase in construction cost;
4. Minor items not detailed at this time, and;
5. Overlooked and unforeseen items that may not be included in the present pre-feasibility level quantity estimates.

The application of contingencies to provide reasonable coverage for the first two items will further favor the CFRD alternative over the RCC alternative.

### 5.1.2 Construction Considerations

Construction considerations have been evaluated on the basis of the following objectives:

- Minimize the need for off-site materials;
- Minimize the duration of the construction activities;
- Minimize the consequences of flooding due to streamflow in excess of the diversion dam floods, and;
- Maximize the use of available construction technology, specifically in Panama.

Construction considerations do not clearly favor either of the dam alternatives, as discussed below.

The CFRD alternative takes more advantage of local materials. Basically all materials used for construction of the dam are found at relatively close distance to the site of construction. Construction of the RCC dam requires importation of the substantially larger quantities of cement from an offsite factory, or even from outside of the country, and its transportation to the site. This could strain the highway system between the factory or the port, and the site, and is more susceptible to the potential for delay.

In terms of construction planning, the most significant difference between the two types of dam (CFRD and RCC) is the duration of the construction period. The overall construction of the RCC dam is anticipated to take approximately 32 months with 14 months for preparation, including, the diversion tunnel, cofferdams, quarrying aggregate, foundation preparation, etc., 10 months for construction of the dam, and main components, and 8 months for finishing works. The construction of the CFRD will require the excavation of nearly 3,900,000 $m^3$ of rock. This is anticipated to take approximately 40 months at 100,000 $m^3$/month. Preparatory and finishing works of 6 to 9 months will result in an overall construction period of approximately 48 months. However, if the Río Coclé del Norte Water Supply Project includes the trans-basin diversion tunnel to Río Indio, tunnel construction will determine the overall construction period, making dam type selection independent of construction time.

The effect of flooding during construction does not clearly favor either of the alternatives. The RCC dam is resistant to damage by overtopping but its vital placement equipment, processing plant and material stockpiles may be damaged during the flood, if they are not adequately protected or located. The CFRD can be designed and constructed to withstand overtopping almost as effectively as an RCC dam. Interruption in placement of the CFRD would have less impact.

The CFRD alternative has a definite advantage when previous local experience is considered. Fortuna dam is a 100-m-high CFRD, and was commissioned a few years ago, and the Barrigon dam, a 60-m-high CFRD, part of the Esti Hydroelectric Project, is currently under construction. No RCC dams have been constructed in Panama.

### 5.1.3 Foundation Considerations

Foundation considerations have been evaluated on the basis of the following objectives:

- Minimize impact of potential adverse foundation conditions resulting from future investigations;
- Minimize concerns relating to the foundation strength characteristics;
- Minimize potential for differential deformation, and;
- Minimize potential for seepage through the foundation.

The foundation is an integral part of any dam, as it provides support to the dam body, and continuity to the water-tightness element of the dam. To perform these functions, the foundation material should have certain minimal attributes:

- The foundation should have a strength comparable or superior to the strength of the material being placed on top, and
- The foundation should be of low permeability, or else, it should be possible to treat it by grouting or other means to reach a low permeability.

The known characteristics of the site equally favor the selection of either dam alternative. The rock formation found in outcrop, and assumed to extend throughout the site is basalt, which is suitable for both dam types. The competency and frequency of observed outcrops indicate relatively shallow foundation levels. However, should foundation conditions be less favorable than anticipated, the CFRD would be less impacted. This is because a CFRD does not need to be completely founded on competent rock; only the plinth (toe slab) and the upstream end of the fill need to be founded on competent rock. Recently, appropriately designed CFRD dams have been founded on weathered rock and low compressibility saprolites. Additionally, in designing fill dams, such as a CFRD, it is easier to accommodate differential deformations associated with less competent foundations. Therefore, while it is not anticipated this inherent capability of CFRD will offer a significant advantage at this damsite, if the proposed site exploration program reveals poorer rock foundations than currently anticipated, the CFRD dam would be less impacted.

In conclusion, the lack of subsurface information at this time tends to favor selection of a CFRD. Any unexpected subsurface conditions can be handled more easily, and with less impact on the overall construction, during construction of a CFRD. The competent rock footprint required for the RCC dam is larger than the competent footprint required for a CFRD. Thus if excavation to obtain a competent foundation is greater than estimated, then costs would increase more for the RCC scheme than for the CFRD scheme. However, dam type selection should be revisited at the conclusion of the site investigation program if the subsurface conditions are as anticipated, and remain favorable for an RCC.

### 5.1.4 Operation and Maintenance Considerations

The operation and maintenance considerations of the project have been evaluated on the basis of the following:

- Minimize the potential for overtopping and resulting damage due to improper spillway operation;
- Minimize uncontrolled leakage through the dam or its foundation;
- Minimize the need for maintenance of the dam and the potential for difficult remedial measures, and;
- Minimize the need for maintenance of the spillway and the potential for difficult remedial measures.

Minimizing the potential for improper spillway operation, or failure to operate the spillway (due to gate inoperability or power failure) led to the selection of ungated spillways for both alternatives. Similarly, operation and maintenance requirements should be marginally lower for a (large) ungated spillway than a (more complicated) gated spillway.

Operation and maintenance considerations tend to favor selection of an RCC dam alternative, although owner's preferences usually override any reasoning on this issue. CFRDs and RCC dams are usually both safe and reliable but the upstream grouting and drainage gallery built-in in the RCC dams allow execution of remedial grouting and foundation drainage, if required.

Leakage through either type of dam should be negligible. Although some early RCC dams experienced leakage problems, more recent designs and construction techniques have virtually eliminated this problem. CFRD may be subject to cracking of the concrete facing if poor quality control of concrete placement occurs, or subsidence causes cracking. The general experience is that appropriate design and specification requirements coupled with construction inspection has resulted in CFRD that do not leak any more than other types of dam.

### 5.2 Recommendation

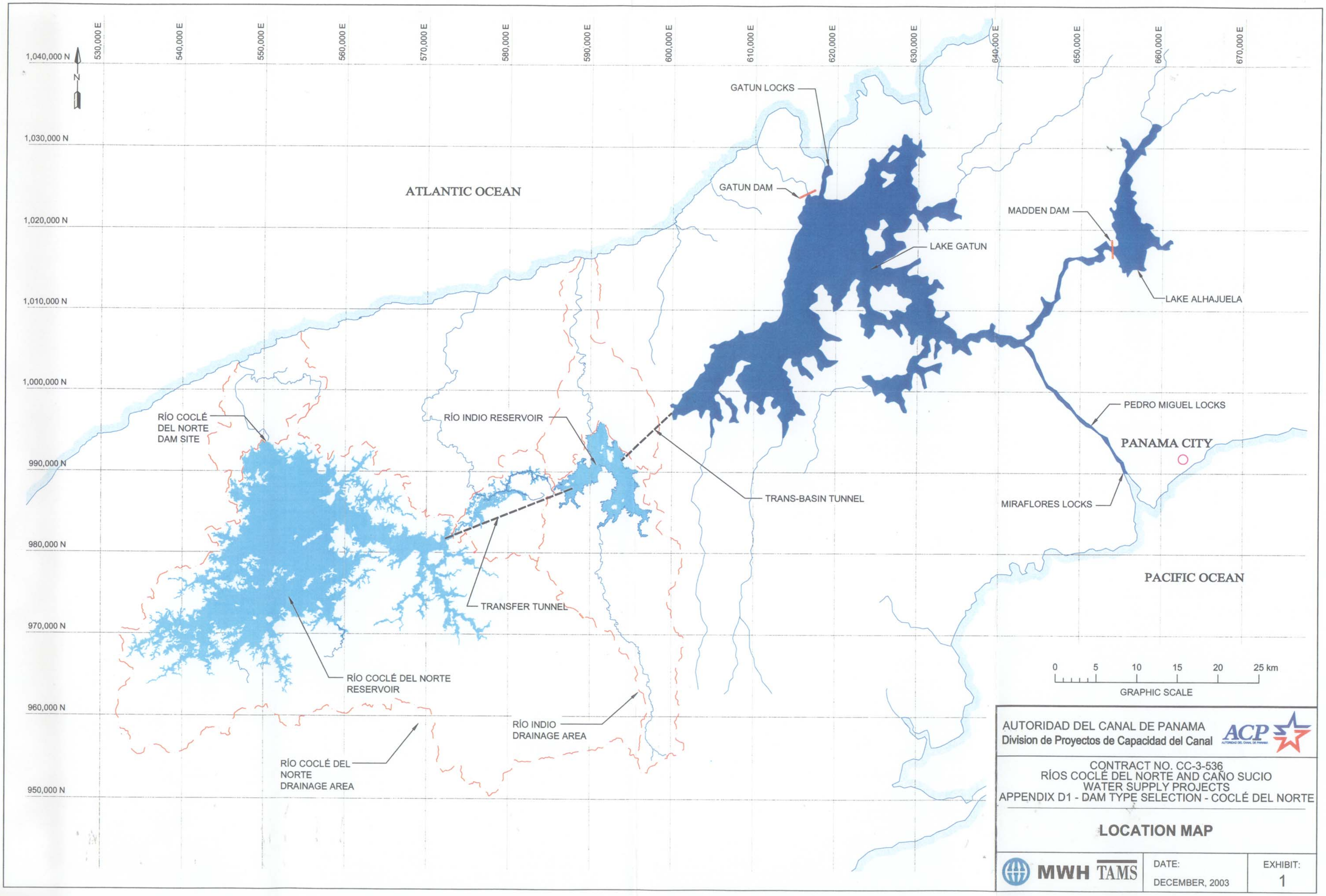
CFRD and RCC dam types are both technically feasible at this site. The comparative cost evaluation favors the CFRD alternative over the RCC alternative and, the RCC alternative cost estimate is more sensitive to a cost increase as a result of higher unit cost for RCC, or changed foundation conditions leading to increased volume.

Based on the available information, the dam type recommended for the Río Coclé del Norte Water Supply Feasibility Studies is the CFRD alternative for the following reasons:

1. Changes to the current available foundation information would have less impact on this dam type and cost;
2. There is more experience with this type of dam in Panama;
3. There is no advantage to the shorter construction time for RCC;
4. The CFRD cost estimate is less sensitive to variation in unit cost, and;
5. The total cost of the CFRD alternative with the addition of hydropower facilities is projected to be lower than the total cost of the RCC alternative with hydropower.

The selection of the CFRD alternative should be confirmed following the completion of site investigation programs if the investigations show foundation conditions that are highly favorable for RCC dams.

# EXHIBITS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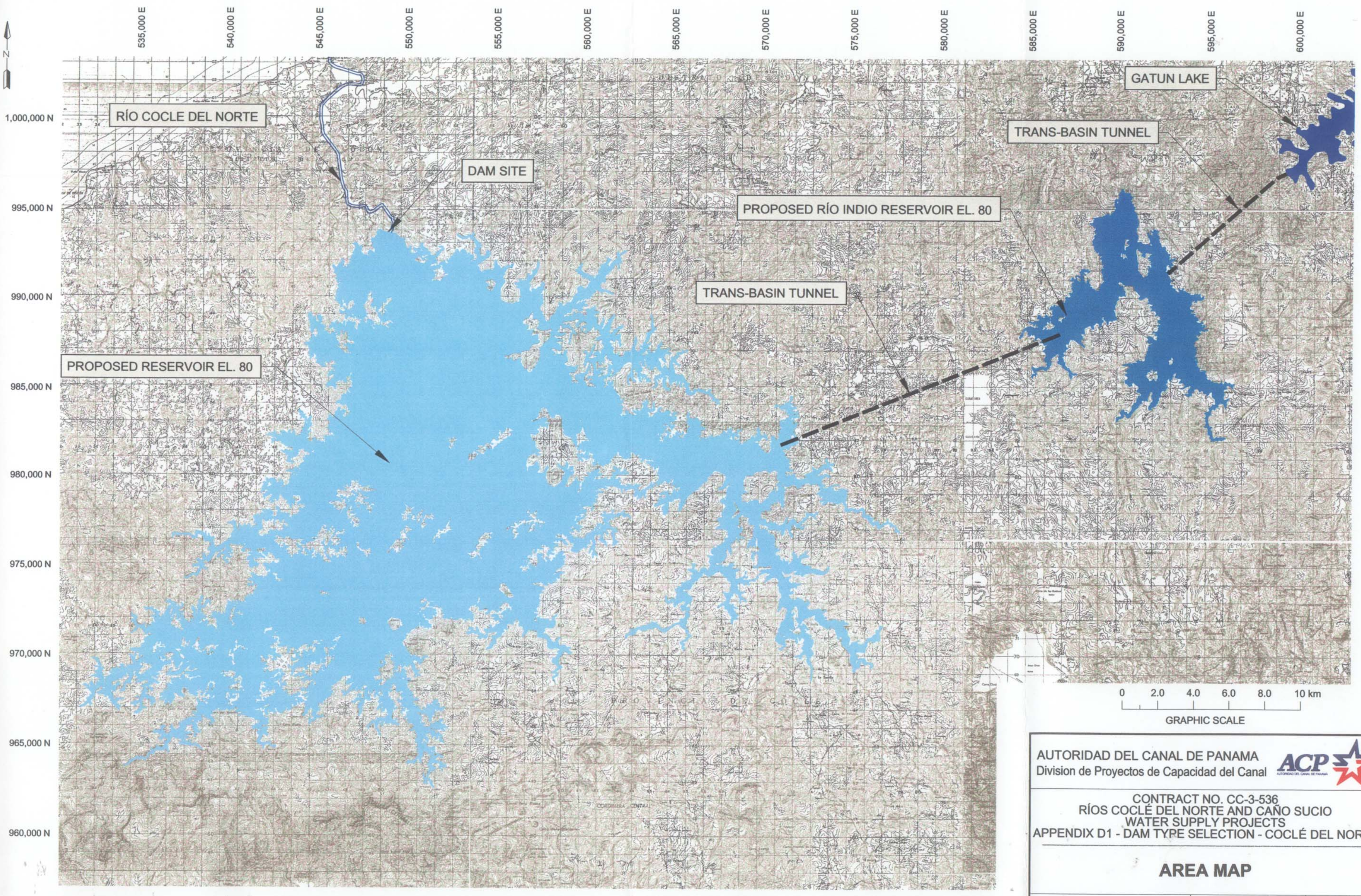
N
ATLANTIC OCEAN
GATUN LOCKS
GATUN DAM
LAKE GATUN
MADDEN DAM
LAKE ALHAJUELA
PEDRO MIGUEL LOCKS
PANAMA CITY
MIRAFLORES LOCKS
PACIFIC OCEAN
RÍO COCLÉ DEL NORTE DAM SITE
RÍO INDIO RESERVOIR
TRANS-BASIN TUNNEL
TRANSFER TUNNEL
RÍO COCLÉ DEL NORTE RESERVOIR
RÍO INDIO DRAINAGE AREA
RÍO COCLÉ DEL NORTE DRAINAGE AREA
0 5 10 15 20 25 km
GRAPHIC SCALE
AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal
ACP
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D1 - DAM TYPE SELECTION - COCLÉ DEL NORTE
LOCATION MAP
MWH TAMS
DATE:
DECEMBER, 2003
EXHIBIT:
1

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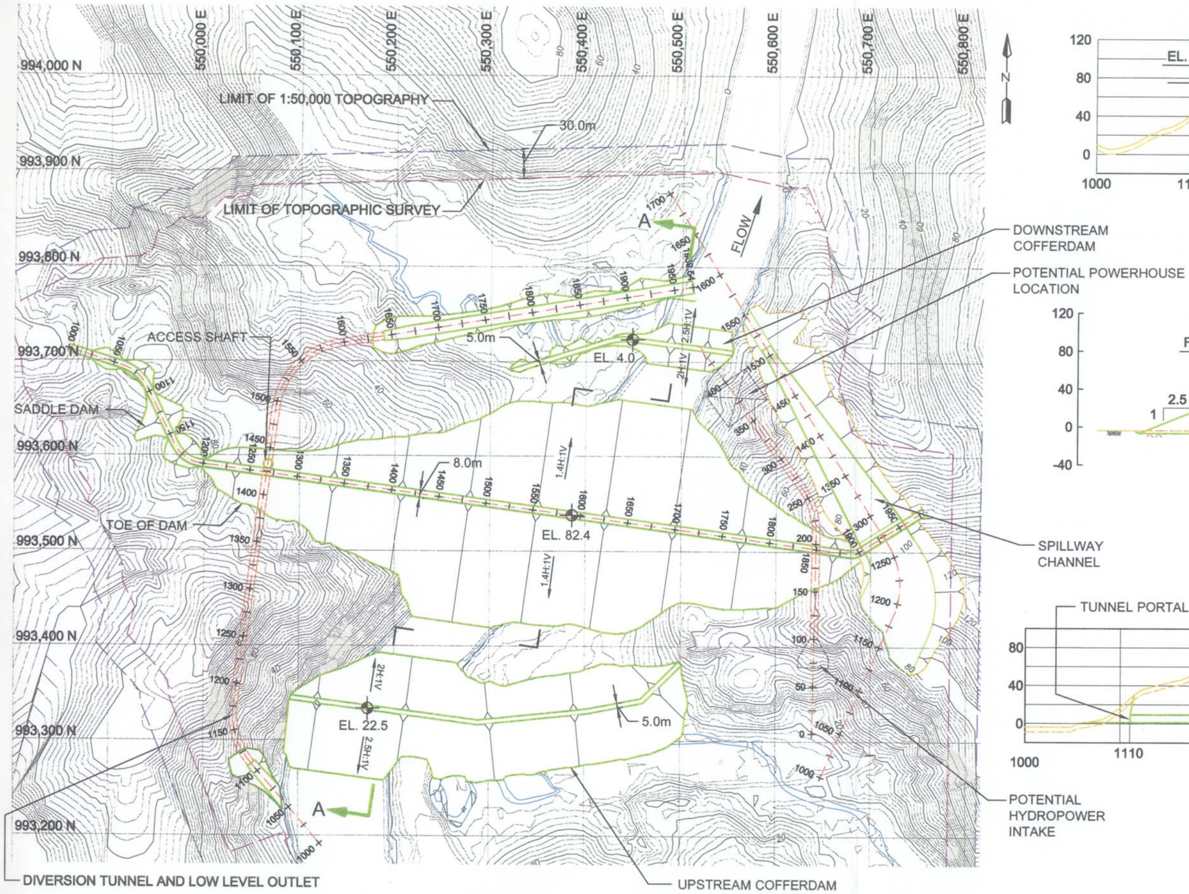
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D1 - DAM TYPE SELECTION - COCLÉ DEL NORTE

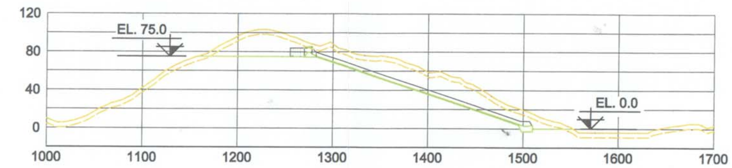
## AREA MAP

MWH TAMS

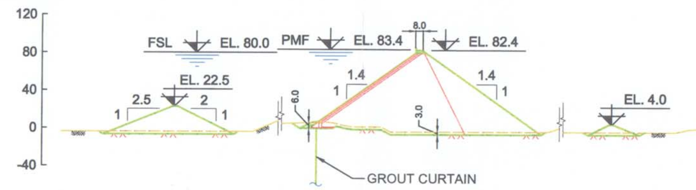
| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 2 |



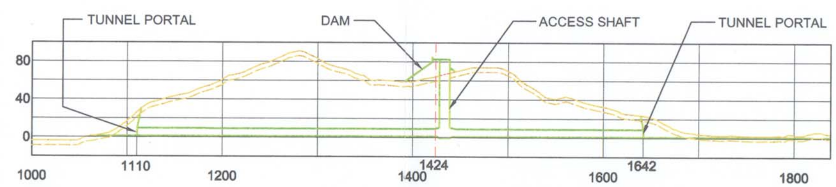

SITE PLAN



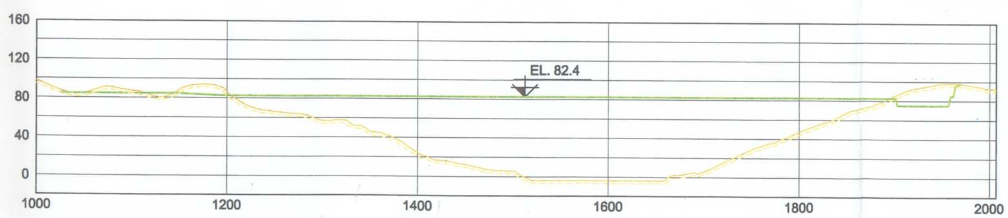

PROFILE OF SPILLWAY ALIGNMENT



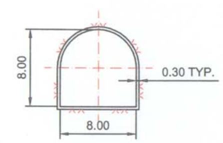

CFRD - TYPICAL CROSS SECTION A - A




DIVERSION TUNNEL AND LOW LEVEL OUTLET




DAM SECTION




TYPICAL TUNNEL SECTION

0 5 m
GRAPHIC SCALE

0 50 100 150 200 250 m
GRAPHIC SCALE

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WATER SUPPLY PROJECTS
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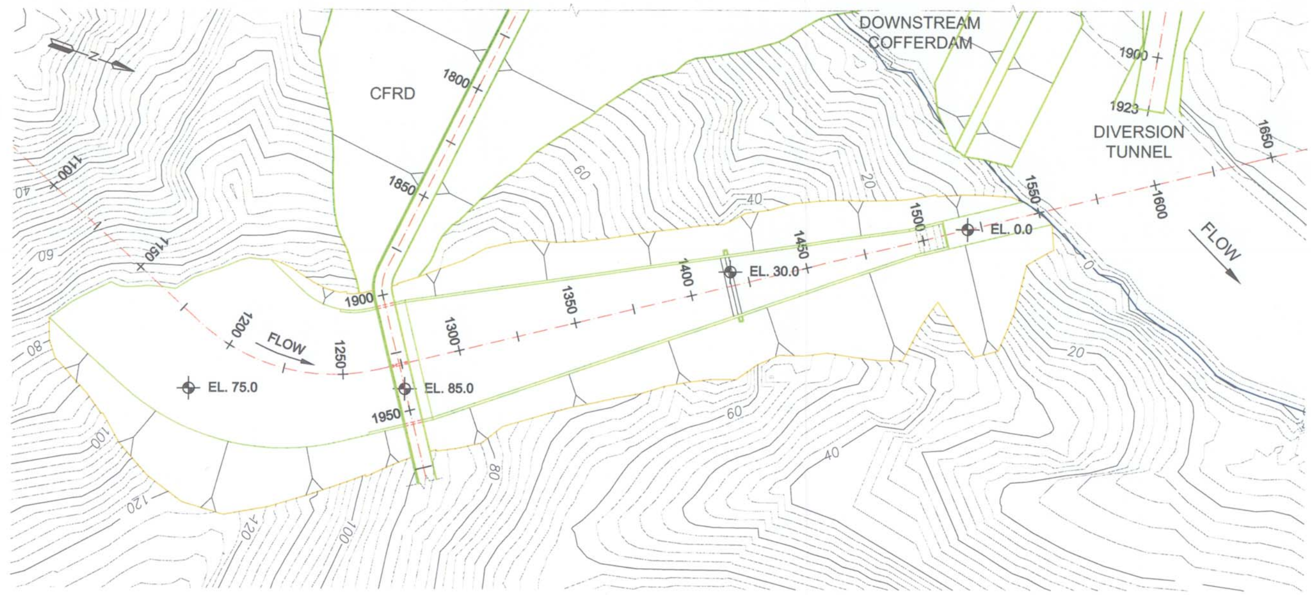
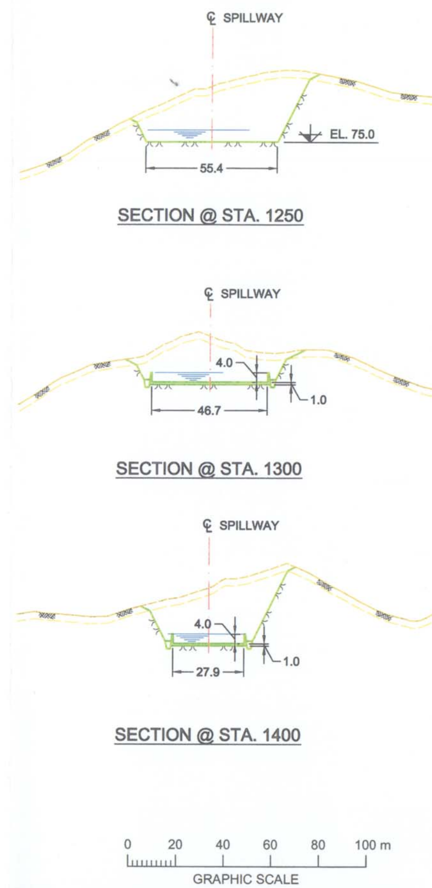
**CFRD**
**PLAN, PROFILE AND SECTIONS**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 3 |

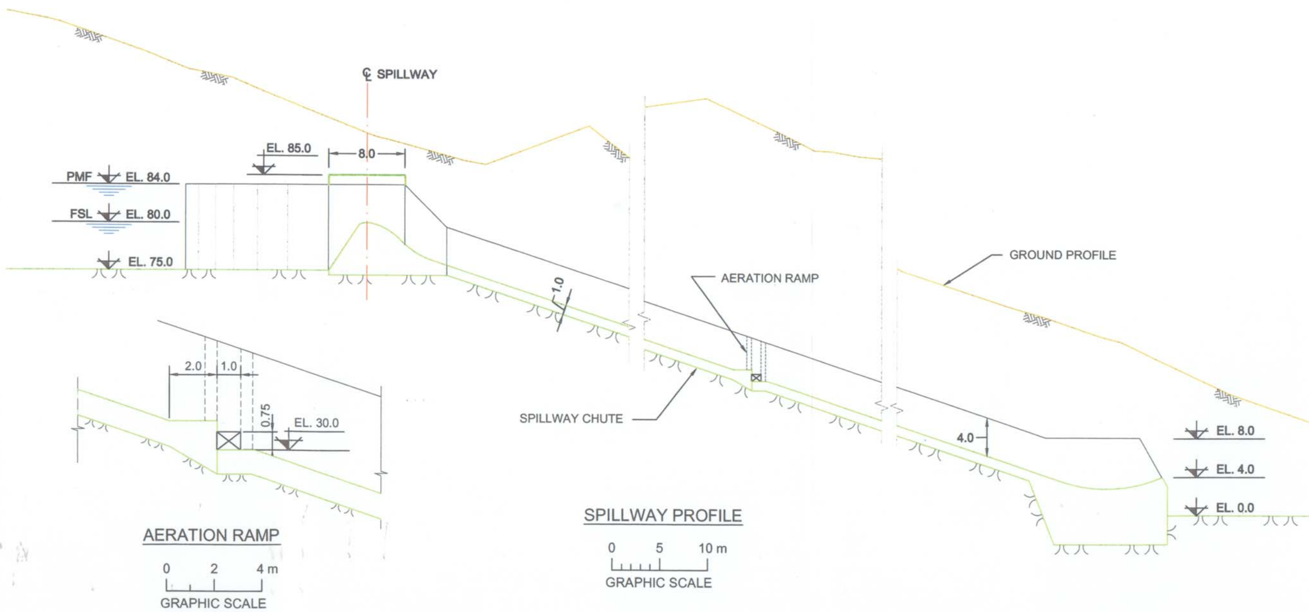



SECTION @ STA. 1250

SECTION @ STA. 1300

SECTION @ STA. 1400




AERATION RAMP

SPILLWAY PROFILE

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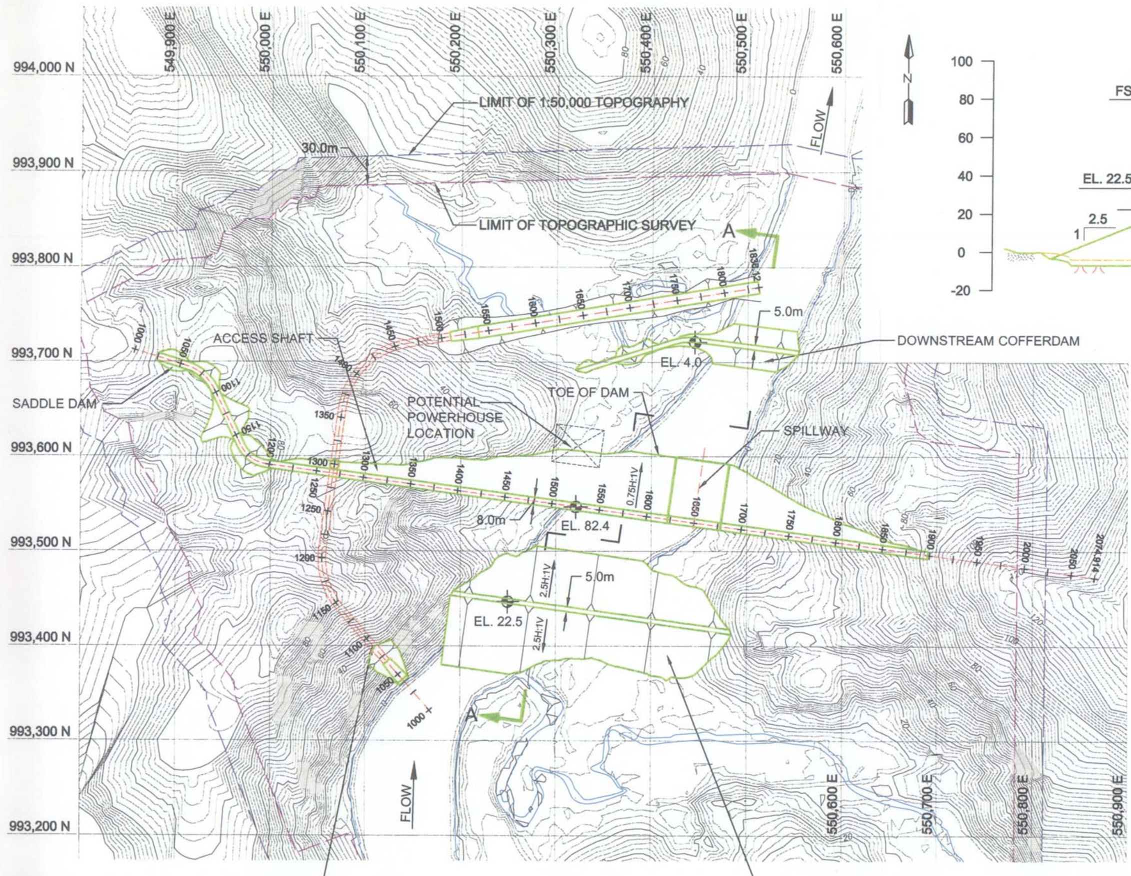
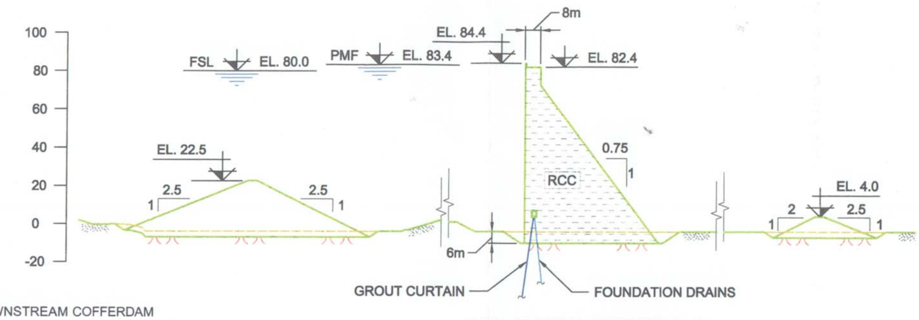
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D1 - DAM TYPE SELECTION - COCLÉ DEL NORTE

## CFRD SPILLWAY
## PLAN, PROFILE, SECTIONS

| MWH TAMS | DATE: DECEMBER, 2003 | EXHIBIT: 4 |
|---|---|---|




SITE PLAN




RCC - TYPICAL SECTION A - A

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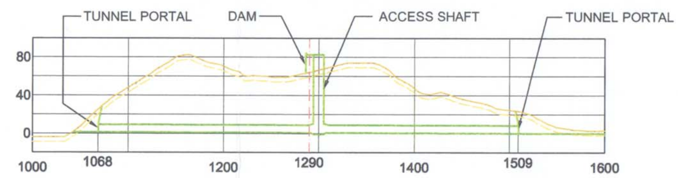
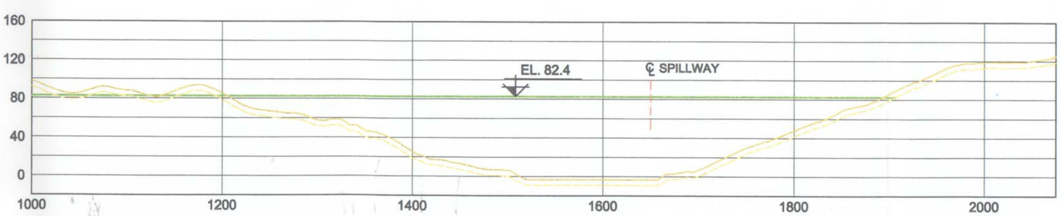
GRAPHIC SCALE

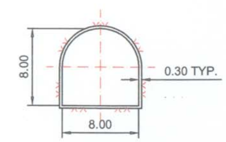



DIVERSION TUNNEL

0 50 100 150 200 250 m
GRAPHIC SCALE




DAM SECTION




TYPICAL TUNNEL SECTION

0 5 m
GRAPHIC SCALE

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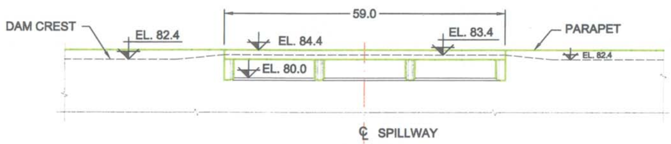
WATER SUPPLY PROJECTS
APPENDIX D1 - DAM TYPE SELECTION - COCLÉ DEL NORTE

**RCC DAM**
**PLAN, PROFILE AND SECTIONS**

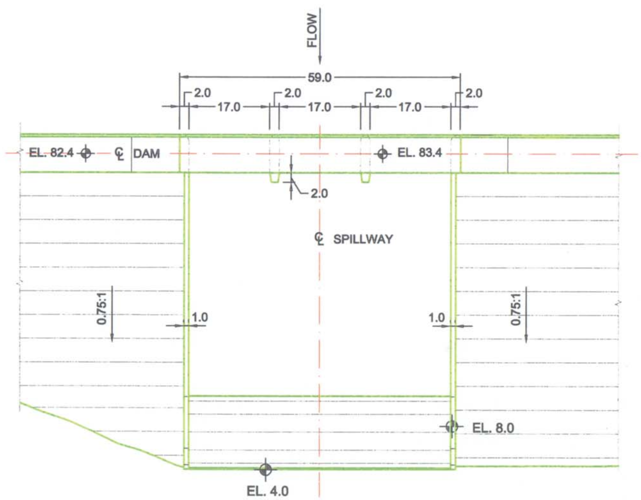
MWH TAMS

DATE: DECEMBER, 2003

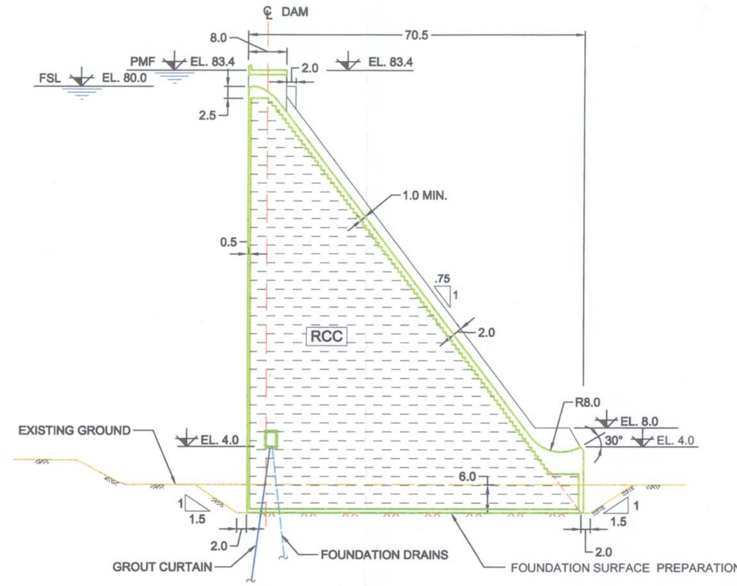
EXHIBIT: 5




UPSTREAM ELEVATION




PLAN




UNGATED SPILLWAY - TYPICAL CROSS SECTION

0 5 10 15 20 25 m
GRAPHIC SCALE

AUTORIDAD DEL CANAL DE PANAMA
División de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D1 - DAM TYPE SELECTION - COCLÉ DEL NORTE

**RCC SPILLWAY**
**PLAN, SECTIONS AND ELEVATION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 6 |

# ATTACHMENTS

# Attachment 1 - Hydraulic Analysis for Design of Diversion Tunnel and Cofferdam

MWH
MONTGOMERY WATSON HARZA

MWH ENERGY & INFRASTRUCTURE, INC.
PRIVATIZATION AND PROJECT DEVELOPMENT

**Location** Chicago Office **Date** September 11, 2002

**To** Michael Newbery

**From** Paul M. Kanellopoulos

**Subject** Cocle del Norte Water Supply Feasibility Study
Hydraulic Analysis for Design of Cofferdam, Closure Dikes, Diversion Tunnel and Transfer Tunnel

## Introduction

This memorandum summarizes the procedures and results of the hydraulic analysis performed for the design of cofferdam, closure dikes, diversion tunnel, and transfer tunnel for the Cocle del Norte Project. The analysis included:

- Development of tailwater rating curve.
- Estimation of cofferdam height upstream and downstream of the proposed dam. The diameters of the modified horseshoe (D-shaped) tunnels considered were 6, 8, and 10 m with a length of 550.0 m.
- Estimation of closure dike height for low flows (25, 50, 75 $m^3/s$).
- Design of 18 km transfer tunnel.
- Drawdown time to 75, 50, and 25% of full supply level.

Basic data used in the analysis is discussed. Results are provided as tables.

## Computer Model

The Full-Equations (FEQ) modeling system of one-dimensional, unsteady, open-channel flow was used for the hydraulic analysis of the Cocle del Norte Project. FEQ is based on the full Saint-Venant equations. This modeling system, developed by Delbert Franz of Linsley, Kraeger Associates, Ltd., Mountain View, CA is widely used by engineers and hydrologists in county and state agencies and consulting firms, and has been accepted by the Federal Emergency Management Agency (FEMA) for use in floodplain studies. It is used in a variety of applications such as flood studies, design studies for dam spillways, dam break analyses, and legal cases. The program supports a wide variety of structures including bridges, culverts, dams, level-pool reservoirs, spillways, weirs, sluice gates, pumps, side weirs, expansions, contractions, drop structures, and flow over roadways. The hydraulic features of the stream system, such as channel cross-sectional properties, are incorporated into the model. FEQ is capable of simulating flow conditions in a network of open channels and storm sewers. The flow conditions are simulated in terms of water-surface elevation, water velocity, and discharge at any point in the system.

**Tailwater Analysis**

The objective of this analysis was to develop a tailwater-rating curve for the proposed Cocle del Norte site. Ten cross-sections, located between 200 and 13,000 m downstream of the dam, were used. The station-elevation data for the first nine cross-sections were obtained from a topographic map of 1:50,000 scale and 10 m contour interval. An echo sounder was used to determine the thalweg of Section 1. Section 10, located 13,000 m downstream of the dam, is a wide section representing the estuary. The average channel slope of the 12,800 m channel reach is 0.004%. The Manning's roughness coefficients for the study reach are 0.035 for the channel flow and 0.050 for over-bank flow. The cross-section data are listed in Exhibit 1.

The resulting tailwater rating curve at the first cross-section is tabulated in Table 1 and plotted in Figure 1. The boundary condition at the estuary was fixed at 0.0 m. Typical tidal data for the area was also simulated, but the model runs show that the tide has no significant effect at the dam, especially at higher flows. This is consistent with field observations.

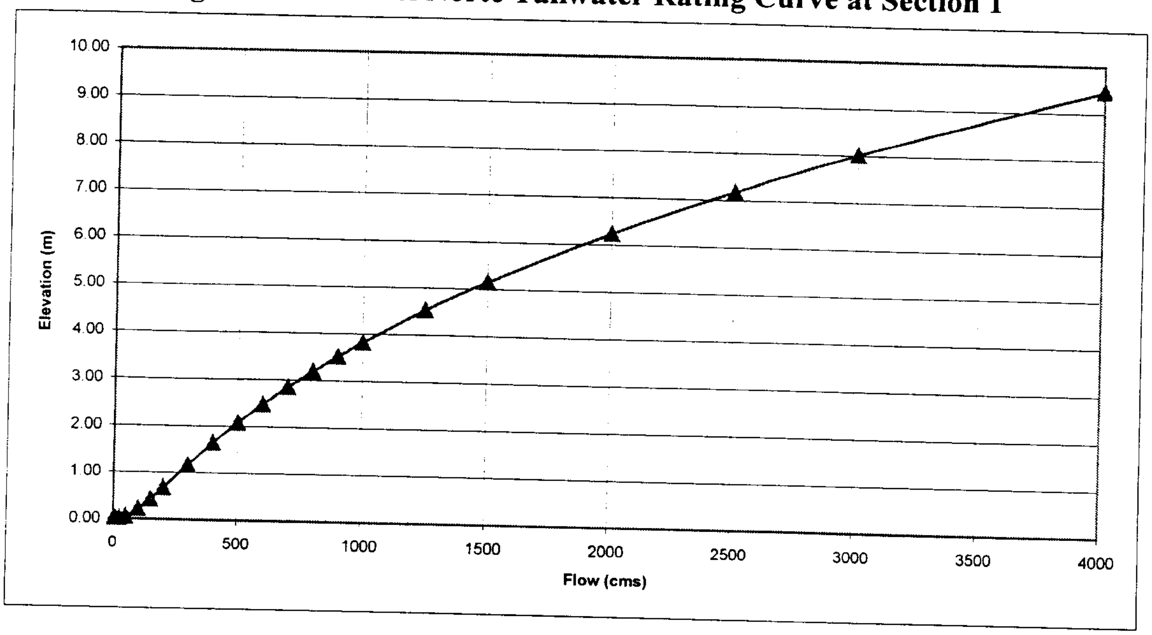
**Table 1. Tailwater Rating Curve**

| Flow ($m^3/s$) | Tailwater Elevation (m) |
|---|---|
| 1.0 | 0.000 |
| 2.0 | 0.000 |
| 5.0 | 0.001 |
| 10.0 | 0.002 |
| 25.0 | 0.015 |
| 50.0 | 0.058 |
| 100.0 | 0.21 |
| 150.0 | 0.43 |
| 200.0 | 0.67 |
| 300.0 | 1.17 |
| 400.0 | 1.64 |
| 500.0 | 2.07 |
| 600.0 | 2.47 |
| 700.0 | 2.84 |
| 800.0 | 3.19 |

**Table 1. Tailwater Rating Curve (continued)**

| Flow<br><br>($m^3/s$) | Tailwater Elevation (m) |
|---|---|
| 900.0 | 3.51 |
| 1000.0 | 3.82 |
| 1250.0 | 4.52 |
| 1500.0 | 5.15 |
| 2000.0 | 6.24 |
| 2500.0 | 7.18 |
| 3000.0 | 8.01 |
| 4000.0 | 9.46 |

**Figure 1. Cocle del Norte Tailwater Rating Curve at Section 1**




## Evaluation of Diversion Tunnel Size

Three diversion tunnel sizes were modeled in order to determine the cofferdam height upstream and downstream of the proposed dam. Tunnel sizes considered are D-shaped with diameters 6, 8, and 10 m and a length of 550 m. The tunnel invert elevation is 0.0 m at both ends and the discharge point is at Section 1, 200 m downstream of the dam. A Manning's coefficient of 0.013 was used for the concrete-lined tunnel. Entrance and exit loss coefficients are 0.5 and 1.0, respectively. Bend losses were assumed to be negligible. The inflow hydrograph routed through the reservoir is the 50-year flow tabulated in Table 2. The storage-elevation data for the reservoir is presented in Table 3.

**Table 2. 50-Year Flood Hydrograph at Cocle del Norte**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Time (hrs)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow ($m^3/s$)** | 128 | 128 | 135 | 244 | 396 | 532 | 742 | 900 |
| **Time (hrs)** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow ($m^3/s$)** | 1500 | 2000 | 2600 | 3200 | 3860 | 3700 | 3400 | 3100 |
| **Time (hrs)** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow ($m^3/s$)** | 2800 | 2600 | 2500 | 2400 | 2300 | 2200 | 2100 | 2000 |
| **Time (hrs)** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| **Flow ($m^3/s$)** | 1900 | 1800 | 1700 | 1600 | 1500 | 1450 | 1400 | 1350 |
| **Time (hrs)** | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| **Flow ($m^3/s$)** | 1300 | 1250 | 1200 | 1150 | 1100 | 1070 | 1040 | 1010 |
| **Time (hrs)** | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| **Flow ($m^3/s$)** | 980 | 950 | 920 | 890 | 860 | 830 | 800 | 770 |
| **Time (hrs)** | 48 | | | | | | | |
| **Flow ($m^3/s$)** | 740 | | | | | | | |

**Table 3. Reservoir Capacity Curve at Cocle del Norte**

| **Elevation (m)** | **Area ($km^2$)** | **Volume (Million $m^3$)** |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 5.0 | 3.60 | 4.58 |
| 10.0 | 8.14 | 28.83 |
| 15.0 | 13.71 | 72.87 |
| 20.0 | 20.52 | 136.80 |
| 25.0 | 28.90 | 265.98 |
| 30.0 | 38.94 | 438.60 |
| 35.0 | 50.86 | 661.80 |
| 40.0 | 65.27 | 952.72 |
| 45.0 | 83.69 | 1,339.89 |
| 50.0 | 105.97 | 1,830.35 |
| 55.0 | 132.07 | 2,426.08 |
| 60.0 | 160.59 | 3,140.95 |
| 65.0 | 190.21 | 4,011.29 |
| 70.0 | 220.44 | 5,039.91 |
| 75.0 | 251.14 | 6,208.50 |
| 80.0 | 282.41 | 7,513.97 |
| 85.0 | 314.43 | 8,986.75 |
| 90.0 | 347.03 | 10,598.11 |
| 95.0 | 380.83 | 12,347.23 |
| 100.0 | 413.90 | 14,435.34 |

The cofferdam heights and peak discharge for the different tunnel sizes are shown in Table 4. Simulations include both a fixed water surface elevation of 0.0 at the estuary and a tide which fluctuates between –0.22 and + 0.27 m. Cofferdam heights turn out to be the same in both cases. This information will be used to select the most cost-effective alternative.

**Table 4. Diversion Tunnel Analysis for Cocle del Norte**

| Tunnel Diameter (m) | Tunnel Length (m) | Peak Discharge ($m^3/s$) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|---|---|
| 6 | 550.0 | 377.2 | 23.9 | 1.6 |
| 8 | 550.0 | 650.2 | 22.0 | 2.7 |
| 10 | 550.0 | 951.1 | 20.5 | 3.7 |

## Analysis of Low Flows

Additional runs were made with constant flows of 25, 50, and 75 $m^3/s$ in order to determine the height of the temporary closure dikes used during the construction of the cofferdams. Tables 5a-c summarize the peak water surface elevations for the 3 tunnel sizes during low flow conditions.

**Table 5a. Low Flow Analysis (25 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 2.3 | 0.02 |
| 8 | 1.9 | 0.02 |
| 10 | 1.7 | 0.02 |

**Table 5b. Low Flow Analysis (50 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 3.6 | 0.06 |
| 8 | 2.9 | 0.06 |
| 10 | 2.5 | 0.06 |

**Table 5c. Low Flow Analysis (75 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 4.6 | 0.13 |
| 8 | 3.8 | 0.13 |
| 10 | 3.2 | 0.13 |

## Design of Transfer Tunnel

The transfer tunnel is an 18000 m long D-Shaped tunnel with an 8 m diameter. It is concrete-lined with a Manning roughness coefficient of 0.013. The entrance loss coefficient is 0.5 and includes minor losses due to bends. At the exit, the water surface elevation is above tailwater and the depth is critical. Intake and outlet invert elevations are 47.0 and 42.0 m, respectively. Figure 2 shows the transfer tunnel rating curve.

**Figure 2. Rating Curve of 8 m Transfer Tunnel**

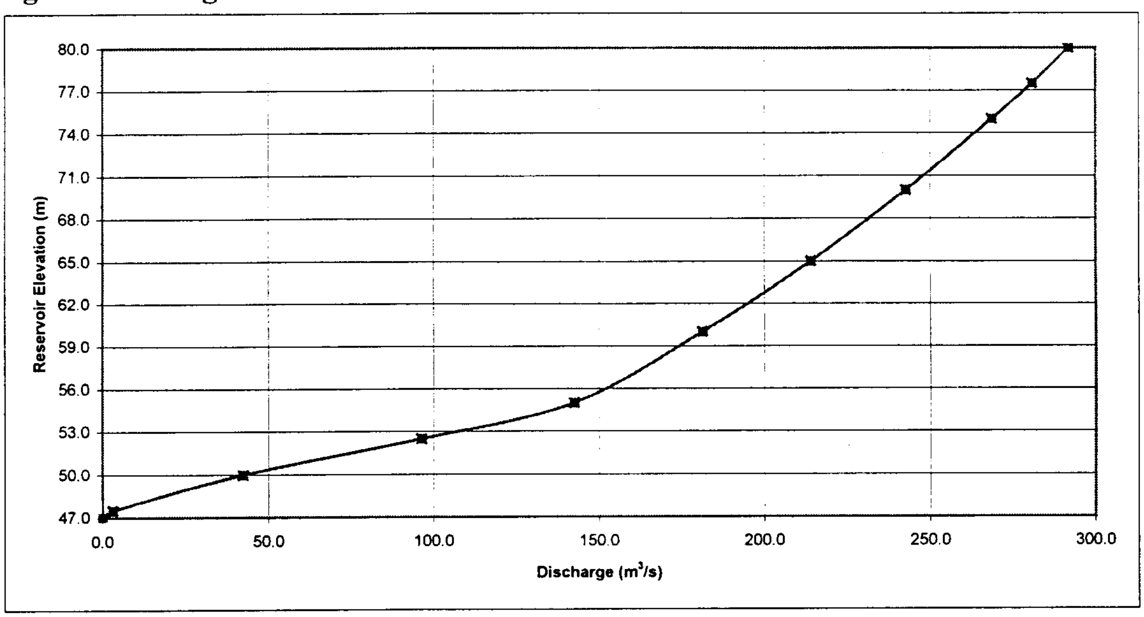
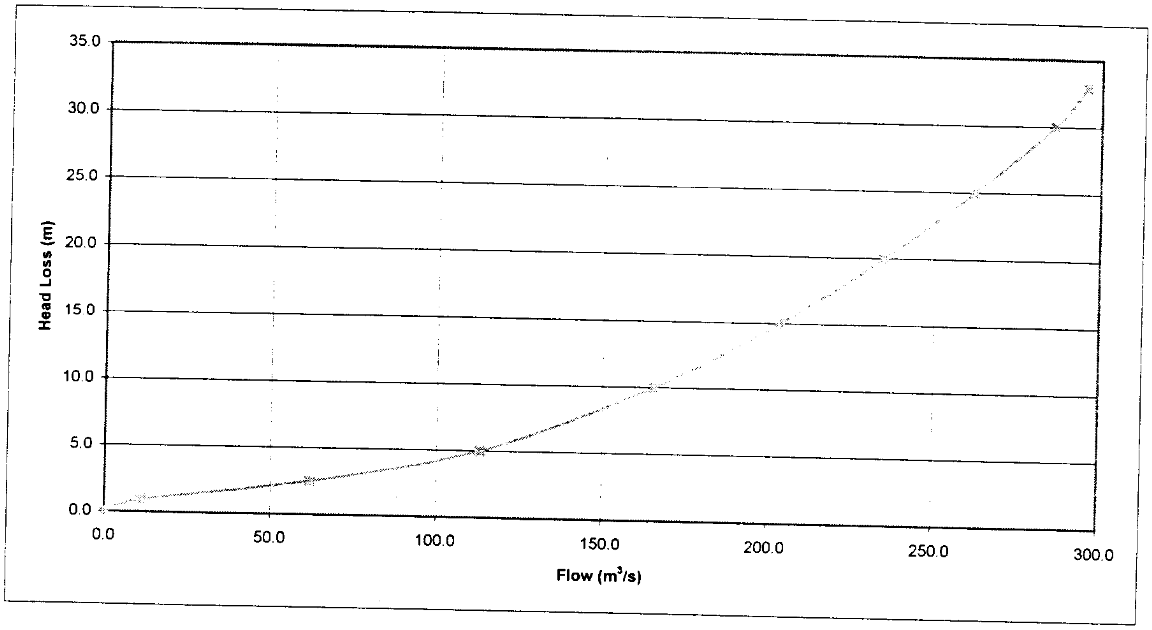


Figure 3 shows head loss as a function of flow for the Cocle transfer tunnel.

**Figure 3. Rating Curve of 8 m Cocle Transfer Tunnel (Head Loss as a Function of Flow Rate)**




## Reservoir Drawdown Analysis

The reservoir drawdown will be designed for a significant hazard, significant risk project as classified by the U.S. Bureau of Reclamation (USBR) in the ACER Technical Memo No. 3 dated 1982. This provides the following guidelines to be met.

| Drawdown El. | Time (days) |
|---|---|
| 75% | 30-40 |
| 50% | 50-60 |
| 25% | 80-100 |

Tables 6a-c show the time to empty out the reservoir to 25, 50, and 75 % of the starting full supply level of 80.0 m with three different tunnel configurations and a constant inflow of 107.5 $m^3/s$. As noted, the 8m transfer tunnel with 6 m diversion tunnel configuration does not meet the USBR guidelines.

**Table 6a. Time Required to Empty Reservoir with 8 m Transfer Tunnel and 6 m Diversion Tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 60.8 |
| 80.0 | 40.0 | 50 | 107.8 |
| 80.0 | 20.0 | 25 | 136.4 |

**Table 6b. Time Required to Empty Reservoir with 8 m Transfer Tunnel and 8 m Diversion Tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 35.0 |
| 80.0 | 40.0 | 50 | 59.2 |
| 80.0 | 20.0 | 25 | 72.7 |

**Table 6c. Time Required to Empty Reservoir with 8 m Diversion Tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 42.2 |
| 80.0 | 40.0 | 50 | 68.0 |
| 80.0 | 20.0 | 25 | 81.5 |

# Attachment 2 - Evaluation of Spillway Sizes and Estimation of Freeboard

**MWH**
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MWH ENERGY & INFRASTRUCTURE, INC.
PRIVATIZATION AND PROJECT DEVELOPMENT

**Location** Chicago Office **Date** January 30, 2002

**To** Michael Newbery

**From** Khalid Jawed

**Subject** Cocle del Norte Water Supply Feasibility Study
Evaluation of Spillway Sizes and Estimation of Freeboard for Rio Cocle Del Norte Project

## Introduction

This memorandum summarizes the procedures and results of hydrologic analyses performed to determine flood surcharge over the normal reservoir pool elevation during the routing of probable maximum flood (PMF), and to estimate magnitudes of wave run-up and wind setup. The analyses included:

- Estimation of flood surcharges for an ungated Ogee spillway with crest elevation at 80 meters. Eight widths of spillway from 25 meters to 346 meters (selected by the USACE in their Reconnaissance Study) were considered.
- Analysis of wave run-up and wind setup.

Basic data used in the analyses are discussed. The results are provided as tables.

## Ungated Spillway

The objective of this analysis was to determine the maximum surcharge over the normal reservoir pool elevation of 80 and 100 meters, during the routing of the PMF. The HEC-1 computer program developed by the United States Army, Corps of Engineers (USACE), was used to route the PMF with a starting elevation at 80 or 100 meters. The elevation-volume data and spillway rating curves used are given in Table 1. The spillway discharges were computed using the following relationship.

$$Q = C L (H^{1.5})$$

where Q is spillway discharge in cubic feet per second, L is width of spillway in feet, H is head over spillway crest in feet and C is coefficient. A constant value of 3.5 was used. The spillway width of 346, 300, 250, 200, 150, 100, 50 and 25 meters were used. The results are summarized in Table 2.

**Table 1**

**ELEVATION-VOLUME AND SPILLWAY DISCHARGE DATA**
**RIO COCLE DEL NORTE RESERVOIR**

| Elevation (m) | Volume (cms) | Elevation (m) | Discharge (cms) L=300m | Discharge (cms) L=250m | Discharge (cms) L=200m | Discharge (cms) L=150m | Discharge (cms) L=100m | Discharge (cms) L=50m | Discharge (cms) L=25m |
|---|---|---|---|---|---|---|---|---|---|
| 80 | 7158 | 80.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 81 | 7383 | 80.5 | 205 | 171 | 137 | 102 | 68 | 34 | 17 |
| 82 | 7653 | 81.0 | 579 | 483 | 386 | 290 | 193 | 97 | 48 |
| 83 | 7930 | 81.5 | 1064 | 887 | 710 | 532 | 355 | 177 | 89 |
| 84 | 8213 | 82.0 | 1639 | 1366 | 1093 | 819 | 546 | 273 | 137 |
| 85 | 8503 | 82.5 | 2290 | 1909 | 1527 | 1145 | 763 | 382 | 191 |
| 86 | 8799 | 83.0 | 3011 | 2509 | 2007 | 1505 | 1004 | 502 | 251 |
| 87 | 9103 | 83.5 | 3794 | 3162 | 2529 | 1897 | 1265 | 632 | 316 |
| 88 | 9412 | 84.0 | 4635 | 3863 | 3090 | 2318 | 1545 | 773 | 386 |
| 90 | 10052 | 84.5 | 5531 | 4609 | 3687 | 2765 | 1844 | 922 | 461 |
| | | 85.0 | 6478 | 5398 | 4319 | 3239 | 2159 | 1080 | 540 |
| 100 | 13669 | 85.5 | 7473 | 6228 | 4982 | 3737 | 2491 | 1246 | 623 |
| 101 | 14084 | 86.0 | 8515 | 7096 | 5677 | 4258 | 2838 | 1420 | 710 |
| 102 | 14495 | 86.5 | 9602 | 8001 | 6401 | 4801 | 3201 | 1600 | 800 |
| 103 | 14915 | 87.0 | 10730 | 8942 | 7154 | 5365 | 3577 | 1788 | 894 |
| 104 | 15342 | 87.5 | | | | 5950 | 3967 | 1983 | 992 |
| 105 | 15777 | 88.0 | | | | 6555 | 4370 | 2185 | 1093 |
| 106 | 16220 | 88.5 | | | | | 4786 | 2393 | 1197 |
| | | 89.0 | | | | | 5215 | 2607 | 1304 |

**Table 2**

**MAXIMUM SURCHARGE DURING PMF**
**RIO COCLE DEL NORTE RESERVOIR**

| PMF Peak (cms) | Initial Pool Elevation (m) | Width of Spillway (m) | Maximum Outflow (cms) | Max. Surcharge Elevation (m) |
|---|---|---|---|---|
| 10459 | 80 | 346 | 2828 | 82.6 |
| 10459 | 80 | 300 | 2566 | 82.7 |
| 10459 | 80 | 250 | 2255 | 82.8 |
| 10459 | 80 | 200 | 1911 | 82.9 |
| 10459 | 80 | 150 | 1528 | 83.0 |
| 10459 | 80 | 100 | 1099 | 83.2 |
| 10459 | 80 | 50 | 602 | 83.4 |
| 10459 | 80 | 25 | 319 | 83.5 |

| MAXIMUM SURCHARGE DURING PMF<br>RIO COCLE DEL NORTE RESERVOIR<br>(Table 2 continued) | | | | |
|---|---|---|---|---|
| PMF Peak | Initial Pool Elevation | Width of Spillway | Maximum Outflow | Max. Surcharge Elevation |
| 10550 | 100 | 346 | 1755 | 101.9 |
| 10550 | 100 | 300 | 1569 | 101.9 |
| 10550 | 100 | 250 | 1356 | 102.0 |
| 10550 | 100 | 200 | 1132 | 102.0 |
| 10550 | 100 | 150 | 890 | 102.1 |
| 10550 | 100 | 100 | 625 | 102.2 |
| 10550 | 100 | 50 | 333 | 102.3 |
| 10550 | 100 | 25 | 174 | 102.4 |

**Analysis of Wind Wave**

**Definitions**

The purpose of this analysis was to determine the freeboard for Indio dam. The freeboard is defined as the difference in elevation between the crest of a dam and normal pool elevation of the reservoir. A term minimum freeboard is also used which is defined as the difference in elevation between the crest of the dam and the maximum water surface elevation reached during the routing of the PMF (or design flood if different from the PMF) with the spillway and other outlets, if any, functioning as planned.

Freeboard computations generally include the determination of wind setup and wave run-up on sloping or vertical embankments. A number of empirical relationships are available. Most of these involve use of wind velocity and fetch length as basic parameters. While the various relationships yield different results, the variation between the results is not so great compared to the variation that could be possible in the results due to assumptions of wind velocity and fetch length. The freeboard estimate is significantly affected by the magnitude of wind velocity and direction, and fetch length.

**Basic Data**

Site-specific data for wind velocity and direction were not available. Also, a reasonable configuration of the reservoir area at normal pool level could not be obtained. The reservoir shape was approximated from 1:50,000-scale map with 20-meter contour interval. In the absence of dominant wind direction data, the fetch length was assumed to be the maximum length of the reservoir for conservative estimates of wave run-up and wind setup. ACP provided monthly average wind speed and wind gust data for Gatun station. Wind speed was assumed after the review of this data.

**Methodology**

The procedures given in the United States Corps of Engineers publication ETL 1110-2-221 dated November 29, 1976 entitled, "Wave Run-up and Wind Setup on Reservoir Embankment by Bruce L. McCartney, Department of Army, Office of the Chief of Engineers, Washington D.C.," were used. The steps necessary for the computations of wind setup and wave run-up included:

- Estimate maximum wind speed
- Plot a wind velocity-duration curve for the site
- Compute reservoir effective fetch length
- Plot a wind velocity-duration curve for the reservoir effective fetch
- Determine magnitude of design wind
- Estimate design wind duration
- Estimate wave run-up
- Estimate wind setup

The step-by-step computations are shown below:

- Embankment slope 1:1.5, impervious, smooth
- Reservoir normal pool elevation = 80 meters
- Depth at toe of embankment = 70 meters (230 feet)
- Maximum fetch length = 30 km (18.6 miles)
- Effective fetch length = 0.25 * 30 = 22.5 km (18.6 miles), there is a procedure as per manual ETL 1110-2-211, to compute effective fetch; because reservoir plan is not available, this procedure could not be applied; an alternative is to assume effective fetch as 25 percent of maximum fetch length.
- Ratios between wind velocity over water and on land (manual ETL 1110-2-211)

| Effective Fetch (mi) | Ratio |
|---|---|
| 0.5 | 1.08 |
| 1.0 | 1.13 |
| 2.0 | 1.21 |
| 3.0 | 1.26 |
| 4.0 | 1.28 |
| 5.0 & above | 1.30 |

- Assumed wind velocity and duration over land and computed velocity over water

| Duration (min) | Wind Velocity over Land (mph) | Wind Velocity over Water (mph) |
|---|---|---|
| 1 | 55 | 72 |
| 60 | 30 | 39 |
| 120 | 28 | 36 |

- Wind velocity for an effective fetch of 4.3 miles from Figure 11 of ETL 1110-2-221.

| Duration (min) | Wind Velocity over Water (mph) |
|---|---|
| 40 | 80 |
| 60 | 36 |
| 90 | 14 |

- Plotted the above two sets of wind data, the intersection of the two curves provided a design velocity of 40 mph and a duration of 57 minutes.
- From Figure 11 of ETL 1110-2-221, the significant wave height (Hs) was about 3.6 feet and wave period (Ts) was about 3.8 seconds.
- The following wave run-up relationship (ETL 1110-2-221) was used:

$$Rs/Hs = 1/(0.4 + ((Hs/Lo)^{0.5}) * \text{Cot } A))$$

Rs = wave run-up, feet
Hs = significant wave height, feet
Cot A = 1.5 (slope)
Lo = wave length in feet
= 5.12 ($Ts^2$), Ts is wave period in seconds

- Based on the above relationship, Rs = 4.9 feet
- As per recommendation in ETL 1110-2-221, Rmax = 4.9 * 1.5 = 7.4 feet
- For wind setup, the following relationship given in ETL 1110-2-221 was used.

$$S = ((U^2) * F)/(1400 D)$$

S = setup in feet
U = average wind velocity in feet, mph, a velocity of 40 mph was used.
D = average depth along the fetch, a depth of 130 feet was used.
F = fetch distance, twice the effective fetch, a value of 8.6 miles was used.

- Based on the above data, the wind setup was about 0.1 feet.

**Summary**

The above computations give the following data:

Design wind velocity = 40 mph
Wind duration = 57 minutes
Wave run-up = 7.4 feet (2.3 m)
Wind setup = 0.1 feet (0.1 m)
Allowance for wave action over normal pool = 2.3 + 0.1 = 2.4 meters

The above allowance may appear to be conservatively on the high side. However, USBR publication "Design of Small Dams," provide recommendation for selection of normal and minimum freeboard (Table 6.4, page 258, third edition, 1987). For an effective fetch length of 4.7 miles, the recommended freeboards are about 7.8 and 5.9 feet (about 2.4 and 1.8 meters), respectively. Based on this, the computed value of 2.4 meters is in line with the USBR's recommendations.

# Attachment 3 – Comparative Cost Estimate

## Cost Estimates

Unit cost for major items of dam construction were developed. These items include: excavation (common and rock), fill placement, quarrying, concrete fabrication and placement, formwork, steel reinforcement and Roller Compacted Concrete. Other unit costs were estimated from experience on other project of similar nature. The major unit costs were developed using cost of labor, equipment and material.

The cost of local labor was estimated based on the "Convención Colectiva de Trabajo de Panamá" dated July 1998. This document indicates the minimum applicable wages to be paid to workers in the construction industry by profession and region, for every years from July 1998 to June 2002. These rate were increased by 30% to reflect the fact they are mandatory minimum wages. An average across the professions was taken to derived four main categories: unskilled labor, skilled labor, equipment operator and truck driver. The wages were also increased to reflect the expected 60-hour work week: an overtime premium of 16.7% was assumed. The costs of salary were then calculated by adding 50% for social cost. This resulted in the following hourly cost of salary:

| | |
|---|---|
| Unskilled labor: | $5.50/hr |
| Skilled labor: | $6.60/hr |
| Equipment operator: | $7.90/hr |
| Truck driver: | $6.20/hr |

In addition to the local labor a crew leader was generally included at the rate of $10.00/hr. For specialized activities, an engineer was included at the rate of $60.00 per hour.

Equipment rate were obtained from the publication of the US Army Corps of Engineers entitled "Construction Equipment Ownership and Operating Expense" (EP 1110-1-8), dated August 31, 2001. Equipment requirements and production rates were developed based on experience in similar type of project in tropical countries.

Materials including explosives, cement, reinforcement steel are anticipated to be imported for the most part. International unit prices were used.

The build-up of the unit rates include also a margin of 30% to reflect the following items:

| | |
|---|---|
| Contractor home office charges | 5% |
| Project management and engineering | 7% |
| Maintenance crew | 3% |
| Field office and accommodation | 2% |
| Electric power | 1% |
| Equipment mobilization and demobilization | 2% |
| Margin for risk | 2% |
| Margin for profit | 8% |

The resulting unit prices were compared with those obtained through the bidding process on other international water resources projects in Central and South America and appear to be reasonable estimate for this type of construction.

The principal unit cost used for the dam comparison study at the Cocle del Norte dam site are as follows:

| | |
|---|---|
| Overburden Excavation | \$3.20 per $m^3$ |
| Rock Excavation | \$8.75 per $m^3$ |
| Concrete | \$115.00 per $m^3$ |
| Formwork | \$46.20 per $m^2$ |
| Steel Reinforcement | \$1,360 per metric ton |
| Roller Compacted Concrete | \$54.00 per $m^3$ |
| Rock fill | \$11.10 per $m^3$ |
| Filters/ Drains | \$16.20 per $m^3$ |

These unit costs are based on estimated production rate adjusted for site-specific conditions. In particular frequent and heavy precipitation at the dam site will significantly affect the RCC placement, as moisture must be closely controlled: an average production rate of 200 $m^3$ per hour is estimated to be a reasonable rate under these conditions. Similarly the unit cost for rockfill takes into account the geological conditions as it is anticipated that only 17% of the rock will be obtained from required excavation (mainly spillway) and the rest will have to be quarried between 2 to 4 kilometers from the dam site.

**Construction schedule**

The rainfall at the dam site limits the construction season for RCC. The total quantity of RCC to be placed is estimated at 1,060,000 $m^3$ at an average weekly production of 24,000 $m^3$, it corresponds to slightly over 10 months of construction. It is anticipated that construction of the RCC dam cannot be completed in one season; the contractor will have to avoid the worst months in terms of rainfall, November and December with close to 550 mm on average per month. The overall construction of the RCC dam is anticipated to take approximately 32 months with 14 months for preparation, including, the diversion tunnel, cofferdams, quarrying aggregate, foundation preparation, etc., 10 months for construction of the dam, and main components, and 8 months for finishing works.

The construction of the CFRD will require the excavation of nearly 3,900,000 $m^3$ of rock. This is anticipated to take approximately 40 months at 100,000 $m^{3/}$month. Preparatory and finishing works of 6 to 9 months will result in an overall construction period of approximately 48 months.

**Panama Canal Authority**
**Contract CC-3-536**
**Task Order 5, Norte Water Supply Feasibility Study**
**Dam Type Alternative Study**

**CFRD Ungated** $ 76,779,961

**Quantity Take-Offs**

| Item | Description | Unit | Quantity | Unit Cost | Cost |
|---|---|---|---|---|---|
| **DIVERSION** | | | | | |
| 1 | Site Preparation | $m^2$ | 90,000 | $ 0.50 | $ 45,000 |
| 2 | Approach/Discharge Channels | | | | |
| 2.1 | Overburden | $m^3$ | 17,855 | $ 3.20 | $ 57,136 |
| 3 | Diversion Tunnel Intake and Outlet Portals | | | | |
| 3.1 | Rock | $m^3$ | 30,400 | $ 8.75 | $ 266,000 |
| 3.2 | Shotcrete | $m^2$ | 3,608 | $ 43.00 | $ 155,123 |
| 3.3 | Rockbolts | l.m. | 1,804 | $ 67.00 | $ 120,851 |
| 3.4 | Concrete | $m^3$ | 237 | $ 115.00 | $ 27,198 |
| 3.5 | Formwork | $m^2$ | 547 | $ 46.20 | $ 25,274 |
| 3.6 | Reinforcement | kg | 9,271 | $ 1.36 | $ 12,609 |
| 4 | Diversion Tunnel | | | | |
| 4.1 | Tunnel Ex. | $m^3$ | 35,125 | $ 80.00 | $ 2,809,982 |
| 4.2 | Shotcrete | $m^2$ | 8,813 | $ 43.00 | $ 378,972 |
| 4.3 | Rockbolts | l.m. | 1,929 | $ 67.00 | $ 129,210 |
| 5 | Cofferdams | | | | |
| 5.1 | Overburden Excavation | $m^3$ | 97,600 | $ 3.20 | $ 312,320 |
| 5.2 | Fill | $m^3$ | 497,420 | $ 11.10 | $ 5,811,960 |
| 5.3 | Filter/Drain | $m^3$ | 26,180 | $ 16.20 | $ 424,116 |
| | Subtotal | | | | $ 10,575,751 |
| **DAM** | | | | | |
| 1 | Site Preparation | $m^2$ | 160,000 | $ 0.50 | $ 80,000 |
| 2 | Excavation | | | | |
| 2.1 | Overburden | $m^3$ | 317,768 | $ 3.20 | $ 1,016,857 |
| 2.2 | Rock | $m^3$ | 158,884 | $ 8.75 | $ 1,390,234 |
| 3 | Grouting | | | | |
| 3.1 | Cut-off | $m^2$ | 25,630 | $ 88.00 | $ 2,255,440 |
| 3.1 | Consolidation | m | 1,850 | $ 25.00 | $ 46,250 |
| 4 | Rockfill | | | | |
| 4.1 | Mass | $m^3$ | 3,486,744 | $ 11.10 | $ 38,702,856 |
| 4.2 | Filter | $m^3$ | 203,258 | $ 16.20 | $ 3,292,779 |
| 4.3 | Drain | $m^3$ | 22,344 | $ 16.20 | $ 361,969 |
| 5 | Concrete | | | | |
| 5.1 | Plinth | $m^3$ | 13,280 | $ 115.00 | $ 1,527,200 |
| 5.2 | Facing | $m^2$ | 67,753 | $ 80.00 | $ 5,420,212 |
| 5.3 | Parapet -US | $m^3$ | 3,218 | $ 250.00 | $ 804,375 |
| 5.4 | Parapet -DS | $m^3$ | 608 | $ 250.00 | $ 151,938 |
| 5.5 | Crest | $m^3$ | 4,290 | $ 115.00 | $ 493,350 |
| Subtotal | | | | | $ 55,543,458 |
| **SPILLWAY** | | | | | |
| 1 | Site Preparation | $m^2$ | 50,000 | $ 0.50 | $ 25,000 |
| 2 | Excavation | | | | |
| 2.1 | Overburden | $m^3$ | 82,939 | $ 3.20 | $ 265,405 |
| 2.2 | Rock | $m^3$ | 388,990 | $ 8.75 | $ 3,403,659 |
| 3 | Headworks | | | | |
| 3.1 | Concrete | $m^3$ | 3,283 | $ 115.00 | $ 377,581 |
| 3.2 | Formwork | $m^2$ | 1,961 | $ 46.20 | $ 90,609 |
| 3.3 | Reinforcement | kg | 155,288 | $ 1.36 | $ 211,191 |
| 4 | Chute and Flip Bucket | | | | |
| 4.1 | Concrete | $m^3$ | 10,015 | $ 115.00 | $ 1,151,717 |
| 4.2 | Formwork | $m^2$ | 4,659 | $ 46.20 | $ 215,247 |
| 4.3 | Reinforcement | kg | 431,533 | $ 1.36 | $ 586,885 |
| 4.4 | Drains | l.m. | 2,750 | | $ - |
| 4.5 | Anchors | l.m. | 5,120 | | $ - |
| 5 | Bridge | | | | |
| 5.1 | Concrete | $m^3$ | 432 | $ 115.00 | $ 49,680 |
| 5.2 | Formwork | $m^2$ | 540 | $ 46.20 | $ 24,948 |
| 5.3 | Reinforcement | kg | 67,738 | $ 1.36 | $ 92,123 |
| Subtotal | | | | | $ 6,494,044 |
| **LOW LEVEL OUTLET** | | | | | |
| 1 | Shaft and Gate Structure | | | | |
| 1.1 | Excavation, Rock | $m^3$ | 5,417 | $ 150.00 | $ 812,534 |
| 1.2 | Shotcrete | $m^2$ | 1,970 | $ 43.00 | $ 84,700 |
| 1.3 | Rockbolts | l.m. | 1,938 | $ 67.00 | $ 129,846 |
| 1.4 | Concrete | $m^3$ | 3,818 | $ 173.00 | $ 660,429 |
| 1.5 | Formwork | $m^2$ | 4,738 | $ 46.20 | $ 218,874 |
| 1.6 | Reinforcement | kg | 149,646 | $ 1.36 | $ 203,519 |
| 2 | Intake Stucture | | | | |
| 2.1 | Concrete | $m^3$ | 2,304 | $ 115.00 | $ 264,960 |
| 2.2 | Formwork | $m^2$ | 2,016 | $ 46.20 | $ 93,139 |
| 2.3 | Reinforcement | kg | 90,240 | $ 1.36 | $ 122,726 |
| 3 | Tunnel Lining | | | | |
| 3.1 | Concrete | $m^3$ | 4,730 | $ 173.00 | $ 818,318 |
| 3.2 | Formwork | $m^2$ | 10,941 | $ 46.20 | $ 505,488 |
| 3.3 | Reinforcement | kg | 185,422 | $ 1.36 | $ 252,174 |
| Subtotal | | | | | $ 4,166,708 |
| Total | | | | | $ 76,779,961 |

## Panama Canal Authority
### Contract CC-3-536
### Task Order 5, Norte Water Supply Feasibility Study
#### Dam Type Alternative Study

**RCC** **Ungated** **$ 84,809,143**

**Quantity Take-Offs**

| Item | Description | Unit | Quantity | Unit Cost | Cost |
|---|---|---|---|---|---|
| **DIVERSION** | | | | | |
| 1 | Site Preparation | $m^2$ | 70,000 | $ 0.50 | $ 35,000 |
| 2 | Approach/Discharge Channels | | | | |
| 2.1 | Overburden | $m^3$ | 17,855 | $ 3.20 | $ 57,136 |
| 3 | Diversion Tunnel Intake and Outlet Portals | | | | |
| 3.1 | Rock | $m^3$ | 28,300 | $ 8.75 | $ 247,625 |
| 3.2 | Shotcrete | $m^2$ | 3,338 | $ 43.00 | $ 143,513 |
| 3.3 | Rockbolts | l.m. | 1,669 | $ 67.00 | $ 111,806 |
| 3.4 | Concrete | $m^3$ | 237 | $ 115.00 | $ 27,198 |
| 3.5 | Formwork | $m^2$ | 547 | $ 46.20 | $ 25,274 |
| 3.6 | Reinforcement | kg | 9,271 | $ 1.36 | $ 12,609 |
| 4 | Diversion Tunnel | | | | |
| 4.1 | Tunnel Ex. | $m^3$ | 29,117 | $ 80.00 | $ 2,329,328 |
| 4.2 | Shotcrete | $m^2$ | 7,306 | $ 43.00 | $ 314,148 |
| 4.3 | Rockbolts | l.m. | 1,599 | $ 67.00 | $ 107,108 |
| 5 | Cofferdams | | | | |
| 5.1 | Overburden Excavation | $m^3$ | 103,550 | $ 3.20 | $ 331,360 |
| 5.2 | Fill | $m^3$ | 384,275 | $ 11.10 | $ 4,265,453 |
| 5.3 | Filter/Drain | $m^3$ | 20,225 | $ 16.20 | $ 327,645 |
| Subtotal | | | | | $ 8,335,202 |
| **DAM** | | | | | |
| 1 | Site Preparation | $m^2$ | 40,000 | $ 0.50 | $ 20,000 |
| 2 | Foundation Excavation | | | | |
| 2.1 | Overburden | $m^3$ | 123,000 | $ 3.20 | $ 393,600 |
| 2.2 | Rock | $m^3$ | 122,412 | $ 8.75 | $ 1,071,105 |
| 3 | Grouting | | | | |
| 3.1 | Cut-off | $m^2$ | 25,630 | $ 88.00 | $ 2,255,440 |
| 3.2 | Consolidation | m | 6,800 | $ 25.00 | $ 170,000 |
| 4 | RCC | | | | |
| 4.1 | Mass | $m^3$ | 1,013,000 | $ 54.00 | $ 54,702,000 |
| 4.2 | Uncompacted | $m^3$ | 11,798 | $ 54.00 | $ 637,065 |
| 4.3 | US/DS Facing | $m^3$ | 24,880 | $ 282.00 | $ 7,016,040 |
| 4.4 | Foundation | $m^3$ | 34,320 | $ 115.00 | $ 3,946,800 |
| 4.5 | Gallery | $m^3$ | 4,200 | $ 115.00 | $ 483,000 |
| Subtotal | | | | | $ 70,675,050 |
| **SPILLWAY** | | | | | |
| 1 | Headworks | | | | |
| 1.1 | Concrete | $m^3$ | 881 | $ 115.00 | $ 101,264 |
| 1.2 | Formwork | $m^2$ | 629 | $ 46.20 | $ 29,051 |
| 1.3 | Reinforcement | kg | 35,614 | $ 1.36 | $ 48,435 |
| 2 | Chute and Flip Bucket | | | | |
| 2.1 | Concrete | $m^3$ | 9,068 | $ 115.00 | $ 1,042,774 |
| 2.2 | Formwork | $m^2$ | 1,603 | $ 46.20 | $ 74,049 |
| 2.3 | Reinforcement | kg | 314,031 | $ 1.36 | $ 427,082 |
| 3 | Bridge | | | | |
| 3.1 | Concrete | $m^3$ | 464 | $ 115.00 | $ 53,360 |
| 3.2 | Formwork | $m^2$ | 580 | $ 46.20 | $ 26,796 |
| 3.3 | Reinforcement | kg | 72,755 | $ 1.36 | $ 98,947 |
| Subtotal | | | | | $ 1,901,759 |
| **LOW LEVEL OUTLET** | | | | | |
| 1 | Shaft and Gate Structure | | | | |
| 1.1 | Excavation, Rock | $m^3$ | 5,417 | $ 150.00 | $ 812,534 |
| 1.2 | Shotcrete | $m^2$ | 1,970 | $ 43.00 | $ 84,700 |
| 1.3 | Rockbolts | l.m. | 1,938 | $ 67.00 | $ 129,846 |
| 1.4 | Concrete | $m^3$ | 3,818 | $ 173.00 | $ 660,429 |
| 1.5 | Formwork | $m^2$ | 4,738 | $ 46.20 | $ 218,874 |
| 1.6 | Reinforcement | kg | 149,646 | $ 1.36 | $ 203,519 |
| 2 | Intake Stucture | | | | |
| 2.1 | Concrete | $m^3$ | 2,304 | $ 115.00 | $ 264,960 |
| 2.2 | Formwork | $m^2$ | 2,016 | $ 46.20 | $ 93,139 |
| 2.3 | Reinforcement | kg | 90,240 | $ 1.36 | $ 122,726 |
| 3 | Tunnel Lining | | | | |
| 3.1 | Concrete | $m^3$ | 3,921 | $ 173.00 | $ 678,343 |
| 3.2 | Formwork | $m^2$ | 9,070 | $ 46.20 | $ 419,023 |
| 3.3 | Reinforcement | kg | 153,705 | $ 1.36 | $ 209,039 |
| Subtotal | | | | | $ 3,897,132 |
| Total | | | | | $ 84,809,143 |

Part 2
Sucio Dam Type Selection

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND RÍO CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX D
PART 2

DAM TYPE SELECTION
RÍO CAÑO SUCIO

Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D2 – DAM TYPE SELECTION, CAÑO SUCIO

### TABLE OF CONTENTS

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# ATTACHMENTS

# FOREWORD

The studies described in this appendix have been performed in accordance with the scope of services for Contract CC3-5-536 - Work Order 005, Feasibility Design and Related Services for the Coclé del Norte and Caño Sucio Water Supply Projects entered into on June, 2000. This appendix covers the selection of the type of dam to be further evaluated in the feasibility studies.

These studies have been performed using the following basic information:

- Panama Canal Reconnaissance Study: Identification, Definition, and Evaluation of Water Supply Projects, prepared by the U.S. Army Corps of Engineers, Mobile District, dated August 1999;
- Topographic mapping of areas of the proposed dam site prepared by Ingenieria Avanzada, S.A. under subcontract to MWH;
- Additional topographic mapping of the dam site developed by digitizing 1:50,000 scale maps obtained from Instituto Geografico Nacional (Tommy Guardia);
- The results of hydrology and meteorology studies presented in Appendix A, and;
- Geological and geotechnical information obtained from one dam site exploration and mapping field program, and a construction materials investigation program, including both test pit sampling and laboratory testing, presented in Appendix B.

# 1 INTRODUCTION

The dam site selected in the reconnaissance study is located about 25 km inland from the Atlantic Ocean on the north-flowing Río Caño Sucio. A location map is shown on Exhibit 1. The location was selected by the Corps to maximize impoundment and to be upstream of a waterfall. It is limited by topography to a reservoir elevation of between 100 m above mean sea level (El. 100) and El. 105.

The dam type adopted in the reconnaissance study was a center core rockfill dam with its crest at El. 105. For this configuration, the full supply level was at El. 100.0, and the maximum reservoir flood level at El. 104. An ungated spillway was located on the left abutment. The spillway would have a crest width of 74 m and a capacity of 1,141 $m^3/s$. The spillway chute was proposed as a sloped and/or stepped natural rock cut channel.

The project also included a transfer tunnel, associated power facilities, an outlet works with a capacity of 0.74 $m^3/s$.

# 2 DAM TYPES AND DEVELOPMENT CRITERIA

This section contains a description of the types of dams that have been considered and the criteria used in sizing the facilities and appurtenant features. Features common to all dam types are identified, but not included in subsequent comparison.

## 2.1 General Criteria

General design criteria have been established for the dam type selection as follows:

- The dam will be located at the site identified in the reconnaissance study;
- The reservoir full supply level will be at El. 100;
- The reservoir minimum supply level will be at El. 90;
- A 25 m wide ungated spillway has been selected to limit flood surcharge to El. 104.3, and;
- The dam crest or upstream parapet wall will be E. 105.3.

As a result of these criteria, the gross storage at full supply level will be 72.8 million cubic meters (MCM). The live storage between El. 100 and El. 90 is estimated to be 68.5 MCM.

### 2.2 Alternative Dam Types

The dam types considered for this study are the following:

| Alternative | Dam Types | Abbreviation |
|---|---|---|
| 1 | Concrete Faced Rockfill Dam | CFRD |
| 2 | Earthfill Dam | ED |
| 3 | Gravity Dam | GD |
| 4 | Roller Compacted Concrete Dam | RCC |

### 2.3 Dam Site Location

Based on a site visit and map studies, we concur with the site selection proposed by the Corps. The dam site is located on the Río Caño Sucio, about 2 km downstream of the village of Las Maravillas. The axis used for this study was selected primarily for topographical considerations. It is located just upstream of a waterfall and series of rapids, takes advantage of a relatively narrow section of river valley to reduce the volume of the dam types, provides adequate space for cofferdam and diversion facilities, and does not present any access difficulties. The final location of the dam will be confirmed following the site investigation program for final design.

### 2.4 Spillway Design Flood

The spillway will be designed for the probable maximum flood (PMF). For a project whose failure would result in loss of human life and economic endeavor, it is customary to design the project for the worst conditions that could reasonably be postulated, i.e. the probable maximum precipitation (PMP) resulting in the PMF. The maximum peak inflow of the PMF is estimated to be 1,690 $m^3/s$. The PMF has a 3-day volume of about

79.9 MCM. The studies to determine the PMF are presented in Appendix A, Hydrology and Meteorology.

### 2.5 Diversion Flood and Diversion Works

For the dam type studies the following approach was taken:

1. Select the diversion flood based on construction at risk period;
2. Determine cofferdam height;
3. Optimize diversion facilities and cofferdam height if required, and;
4. Select diversion works.

Hydraulic analyses for several alternative diversion flood cases and diversion facilities have been prepared. They are presented in Attachment 1, Hydraulic Analysis for Design of Diversion Works and Cofferdam. The 25-year and the 50-year return period floods were used to bracket the flood return period that will likely be selected for the CFRD and Earthfill dam alternatives. The analysis includes development of a tailwater rating curve, diversion culvert analysis and reservoir routing of the selected floods for several diversion culvert sizes.

The length of time at risk and cost of repair to components of the project that could be impacted by a flood during construction is different for the RCC alternative compared with the CFRD, Earthfill and conventional concrete dam alternatives. The Earthfill, conventional concrete and CFRD-type dams will be constructed in one-two years after the diversion facilities are completed. Therefore, the diversion flood for the three alternative dam types for this study will be the same. There is less than a 10% probability that a flood greater in magnitude than the 25-year return period flood will occur in two years. However, applying a 95% confidence limit to the 25-year return period flood peak results in a flood peak larger than the 50-year event. Therefore, a 50-year return period flood is selected for design of the diversion works.

The RCC dam alternative can be constructed to elevations above the cofferdam required for the 25 or 50-year return period in one dry season. Therefore, the diversion culvert and cofferdam will be sized to pass the 50-year dry season flood.

The diversion structure cost difference for the alternative dam types is a function of optimizing the cost of the cofferdam by inversely varying its height (and size) against diversion tunnel or culvert capacity (or size). As the cofferdam is lowered, the diversion tunnel must be increased in size. Preliminary layouts have been prepared for a diversion culvert. The dam site has a slightly wider terrace on the left abutment that can be utilized to construct a culvert. The culvert will be constructed in the rock foundation.

The design flood and diversion facilities selected for the CFRD and Earthfill dam alternatives are:

1. The design flood is selected as the 50-year event with a peak inflow of 417 $m^3/s$;
2. The diversion conduit for all alternative dam types will consist of a 3 x 3 m culvert located to the left of the river channel. The conduit will be founded on competent rock. It varies in length from approximately 130 m (Earthfill) to 140 m (CFRD);
3. The crest of the upstream cofferdam will be at El. 91.
4. Maximum outflow through the conduit is 75 $m^3/s$.
5. There is no requirement for a downstream cofferdam.

The design flood and diversion facilities selected for the RCC alternative is:

1. The design flood is selected as the 50-year dry season event with a peak inflow of 90 $m^3/s$;
2. The diversion conduit for the RCC dam will consist of a 3 x 3 m culvert located to the left of the river channel. The conduit will be founded on competent rock. It will have a length of 40 m;
3. The crest of the upstream cofferdam will be at El. 87;
4. Maximum outflow through the conduit is 47 $m^3/s$, and;
5. There is no requirement for a downstream cofferdam.

There is no requirement for a downstream cofferdam for any of the alternatives, discharge from the diversion culverts will be directed through a channel to the waterfall. The culvert size and cofferdam height will be optimized for the selected dam type.

For this dam type selection study, the following criteria and assumptions were adopted for the emergency drawdown:

1. The drawdown period from full supply level at El. 100 to one-third of the reservoir storage elevation, E. 96, shall be 30 days or less (MWH precedent, U.S.B.R. ACER Technical Memorandum No. 3, 1982); and
2. The average annual inflow is assumed to be 7.6 $m^3/s$.

Emergency drawdown will be effected through control at either the Río Toabré or Río Coclé del Norte dams and no facilities are specifically included for this purpose at Río Caño Sucio.

## 2.6 Spillways

In the reconnaissance study, the USACE selected an ungated spillway located on the left abutment. It was proposed with crest width of 120 m and a capacity of 920 $m^3/s$. The spillway chute was proposed as a stepped, natural rock-cut channel about 1,100 m long. Review of the supporting cost information showed this to be a relatively costly solution. In addition, the foundation rock is not suited to use as a service spillway without lining.

ACP has indicated a preference for an ungated spillway because of its lower operation and maintenance costs. For the dam type selection, an ungated spillway has been considered for all dam type alternatives. The crest of the ungated spillway was set at El.100, and flood routing was performed for several widths from 100 m to 25 m. The results of these routings are presented in Attachment 2, Evaluation of Spillway Sizes and Estimation of Freeboard for Río Caño Sucio Project. For the dam type selection study, the smallest ungated crest width with an acceptable unit flow value was selected. The adopted configuration has a crest width of 25 m, with a corresponding maximum water surface at El.104.3.

### 2.6.1 Ungated Spillway for CFRD and Earthfill Alternatives

Layouts for an ungated spillway adjacent to the CFRD showed the right abutment to have preferable topographical characteristics. A conventional spillway was selected consisting of an approach channel, an ogee-shaped control structure, a tapering channel chute, a flip bucket, and a channel to direct the discharge back to the river. A spillway located on the left abutment would result in a longer spillway chute.

The approach channel would be excavated to El. 96. The crest of the control structure would be at El. 100, the reservoir full supply level. The control structure will have two bays, each 12.5 m wide. The maximum discharge under PMF conditions will be 434 $m^3/s$. A spillway bridge, requiring one pier, will span the chute from the crest to the right abutment. The spillway chute will taper from 26 m at its crest to 12 m at the flip bucket. The chute will have an overall length of about 70 m, and a drop of approximately 15 m. A smooth concrete chute will be provided with training walls about 4 m high. The flip bucket will have its lip at El. 84, which is above the expected maximum tailwater elevation under PMF conditions. All spillway structures will be constructed of conventional mass or reinforced concrete founded on rock. The spillway will discharge directly back into the Río Caño Sucio.

### 2.6.2 Ungated Spillway for RCC Alternative

The ungated spillway for the RCC alternative will be located on the dam and aligned to discharge directly into the Río Caño Sucio. It will include a control structure with its crest at EL. 100.0 and effective hydraulic width of 25 m. A smooth chute of conventional concrete will be provided with training walls. The spillway chute will terminate at a concrete apron and end sill at El. 85.

## 2.7 Other Features

In addition to the dam and spillway, there are a number of other features that comprise or are required for construction of the Río Caño Sucio Project, including:

- Cofferdams;
- Multi-level Intake Structure;
- Access, and;
- Construction Area (laydown and around dam).

These are described below together with how they are addressed in the dam type selection study.

### 2.7.1 Cofferdams

A cofferdam will be constructed upstream of the project works and will be of sufficient height to protect the working area against flooding during the selected diversion flood. The cofferdam will be constructed along an alignment parallel to the main dam at a location far enough upstream to avoid conflicts between construction of the main dam and the cofferdam. For the dam type selection study, a minimum distance of 15 m will be provided between the toe of the cofferdam and the foundation excavation limits for the CFRD and RCC alternatives. For the ED alternative, the cofferdam will be incorporated into the embankment. The upstream and downstream slopes of the cofferdams will be 2.5H:1V. The cofferdams will be constructed of compacted and dumped random fill on the in-situ alluvium. Less pervious material will be placed on the water retaining face. The crest width will be 5 m. Crest elevations, which are the same for all dam types, are given in Section 2.5 Diversion Flood.

### 2.7.2 Multi-level Intake Structure

If a multi-level intake structure is required to provide water quality control for downstream releases, the intake structure will be sized to provide 10% of the mean annual release at each intake level.

The relatively small multi-level intake structure will be connected to a low-level outlet, which will consist of a 0.8-m pipe installed in the existing diversion conduit. For the GD or RCC dam alternatives, an intake control gate will be located at the upstream face of the dam. For the CFRD and ED, the control gate will be located on the upstream side of the dam. Slide gates or valves will be housed in the intake tower structure. Operation of valves at selected elevations will provide withdrawal at the required level. If required, increasing the penstock diameter to 1.0 m will double capacity. The penstock will terminate at control valve and flume for measurement and validation of the required minimum releases. Differences in complexity and cost are too small to be captured in this dam type comparison study. Therefore, the multi-level intake structure is not included in the dam selection cost comparison.

### 2.7.3 Access

New access roads to the dam site and to quarries will be required. Access roads are not specifically included in the dam type selection study as cost differences are small and have not been defined.

### 2.7.4 Construction

Construction camps and facilities will be required prior to commencement of the main Río Caño Sucio dam and facilities construction contract. For the dam type selection study, they have been estimated to be similar and have not been included in comparative cost estimates. The RCC dam will require specific installations for material storage and handling and the costs of these installations are included in the general costs of the RCC.

# 3 GEOLOGIC AND GEOTECHNICAL CHARACTERISTICS

Geologic and geotechnical information used as the basis for input to the dam type selection process were obtained during two visits to the proposed Caño Sucio dam site, one in September 1999 and another in December 2001. Investigations were limited to general reconnaissance of the project area, and descriptions of site geology provided here are taken from observations made during the reconnaissance site visits and literature studies conducted by the USACE for development of the August 1999 Reconnaissance Report. Although further geologic mapping activities and investigations to evaluate subsurface conditions by geophysical surveys have been planned, the results of these additional investigations were not available for use in the dam type selection study.

Only those geologic and geotechnical characteristics pertinent to the dam selection studies are addressed in this section, i.e. bedrock type, excavation depths, excavation slopes, and construction materials. A more detailed description of the local geology and geotechnical characteristics is contained in Appendix B, Geology and Seismicity, of the main report.

## 3.1 Site Geology

The Caño Sucio dam site has been well-selected from a topographic viewpoint and it appears to be the most suitable site in the area. The dam site is located at the top of an approximately 250 m long waterfalls section in the river. The main drop at the falls is about 7-m-high, but several smaller falls and cataracts exist downstream over a horizontal distance of about 200 m. At the proposed dam site, the river is at about El. 85 m. Upstream of the upper section of the falls, the river flows very gently with a low gradient.

Bedrock units in the Caño Sucio project area consist of Tertiary sedimentary rocks. A medium to coarse-grained sandstone occurs at the proposed dam site, cropping out at the waterfalls and in the riverbed. Abutments at the damsite are covered by residual soils and weathered sandstone float. In outcrop, the sandstone is locally strong, moderately hard, and erosionally resistant, as evidenced by the formation of the waterfalls. At the top of the falls, strata strike about N32°E and dip about 10° to the southeast. Examination of outcrops on the left abutment indicates that the units are thin to medium-bedded (5 - 80 cm) and are intersected by joints. The sandstone is locally calcareous and probably tuffaceous. Interbeds of shaley (or tuffaceous) materials are also present. A similar rock sequence exists on the right side as observed on the left.

The waterfall itself is presumably formed by the offsetting of bedding layers along nearly vertical joints perpendicular to the bedding planes. The steep, stair-stepped pattern of the waterfall suggests that these joints, at least in the vicinity of the waterfall, have a predominate spacing of 1 to more than 2 m. Thus, the combination of bedding layers and perpendicular joints break the rock mass into blocks or slabs at this location. Investigation of bedrock conditions away from the riverbed and waterfall was not performed in either of the two reconnaissance visits to the site.

At the damsite, the Caño Sucio flows to the northwest, cutting into a relatively flat lying flood plain that is about 50 m in width at the dam site, but considerably widens upstream. The sides of the river valley at the dam site rise up at a slope of approximately 3H:1V on either side of the river, creating a trapezoidal shape to the valley. There is approximately 60 m of vertical relief between the valley floor and the tops of the abutments on either side of the river.

Although bedrock is well exposed in the river bottom at the dam site and at the waterfall, few other bedrock exposures were observed in the vicinity of the dam site. The shape of the river valley and absence of rock exposure above the valley floor suggest that the slopes forming either side of the river valley consist of residual overburden to some depth. It assumed that the wider flood plain upstream of the dam site is covered by alluvial deposits; however, their extent and composition is not known at this time. Further investigation of these areas is required in the near future.

### 3.2 Materials Available for Construction

Various construction material sources were examined during field reconnaissance and study of topographic maps and later tested in a local laboratory. These are discussed below and their locations are indicated on Exhibit 2.

### 3.2.1 Construction Material Sources

**Alluvial deposits**. Deposits of alluvial materials that could be used for construction are not found in the project area. The nearest significant sources of natural sands and gravel materials are located outside of the drainage basin.

**Residual soils**. It is assumed that most of the bedrock along the sides of the river valley in the project area is covered by well-developed horizons of residual soils. No test pits or close inspection of these soils were conducted in either of the two reconnaissance visits. However, the sedimentary bedrock found in this area is similar to the tuffaceous sandstone and siltstone bedrock found at the Río Indio dam site. The overlying residual soils are also thought to bear strong similarities. Residual soils in a test pit excavated at the Río Indio dam site were found to consist of clayey silt. It is interpreted that most of the overburden in the project area is clay-rich due to the calcareous and tuffaceous nature of the bedrock. Samples of this material from the Río Indio investigations were tested in the laboratory and found to be suitable for use as impervious fill. Sufficient quantities of residual soil are available at or near the dam site for use as impervious fill material for the earthfill dam types being considered for the Caño Sucio site.

**Sandstone.** Tuffaceous sandstones and siltstones form the uppermost bedrock units at the site and are thought to be widespread throughout the project area. As stated earlier, bedrock is covered by overburden to some thickness throughout the project area, except where it is exposed at the river channel and the waterfall. Sandstone and siltstone can be obtained from required excavations in rock at the dam site; however, no other potential quarry sites containing significant quantities of these materials were confirmed during the reconnaissance visits. Furthermore, the results of laboratory testing conducted on tuffaceous sandstones and siltstones for the Río Indio project indicate that the material may be of sufficient strength to be used as random rockfill; however, its durability is such that it most likely would not be suitable for use as concrete aggregate or for select processed fills (i.e. filters, drains, riprap).

**Andesite and basalt.** Andesite and basalt rock units suitable for development as construction material sources are found in the area around Cerro Miguel. A potential quarry site for obtaining these materials was identified near Cerro Loma Alta, located approximately 5-6 km to the southeast of the site. Samples from this site were compared with samples collected and tested for Río Indio and were found to be petrologically similar. Results indicate that the material would be suitable for use as rockfill, processed select fills, and concrete aggregate.

### 3.2.2 Recommended Sources of Available Construction Materials.

**Impervious Fill.** Residual soils, located at or near the damsite can be used for impervious fill.

**Course and Fine Aggregate, Filters, Drain Material, and Riprap.** All aggregates (including coarse and fine aggregates for concrete, filters, drains, and riprap) need to be manufactured from quarried sources of andesite and basalt located about six kilometers away from the damsite. To decrease the cement requirements for RCC, some mixing with imported sands and silts will be necessary, impacting the cost of production.

**Sands and Gravel.** The nearest significant sources on natural sands and gravel material are located outside of the drainage basin

**Random Rockfill.** Sandstone from required excavation, provided it is not entirely decomposed, could be used as random rockfill material in shells of fill dam types. It is expected, however, that handling, placement, and compaction of the relatively weak sandstone will result in production of fines. This can be handled through appropriate design of the zoning of the dam and construction specifications for material handling.

Residual soils and weathered sandstone bedrock can be used for random fill with relatively impervious characteristics for cofferdams and earthfill dam types and for backfill.

**Random Fill.** Required excavation can be used for random fill in, for example, the cofferdams.

### 3.3 Geotechnical and Geologic Design Considerations

Generally, the geologic and geotechnical factors that most influence selection of dam type fall into the following categories:

- General foundation bedrock acceptability, including sliding resistance and deformation characteristics of foundation;
- Required excavation depths to achieve acceptable foundation materials;
- Measures required to treat the foundation to improve physical properties and control leakage;
- Long-term performance of the foundation under normal operation conditions and extreme events, especially earthquake; and
- Availability of suitable construction materials.

Such geological and geotechnical factors can have direct influence on the development of comparative construction costs and were taken into consideration during the study of dam type alternatives. In addition to the factors listed above, the proximity of the 7-m-high waterfall downstream of the proposed dam axis must also be considered. In the absence of geologic mapping or subsurface investigation data for the Caño Sucio dam site, assessing the impact of each one of these factors on dam type selection had to be based on qualitative evaluations involving engineering judgment and previous experience in similar geological environments.

- **Proximity of Waterfall to Dam.** The most prominent geologic feature at the Caño Sucio dam site is the waterfall located downstream of the proposed location of the dam. The height of this is estimated to be about 7 m; the exact height has yet to be determined through precise surveying during a low flow period. Because stability at the toe of the dam could be compromised when the waterfall rock ledge is exposed to elevated seepage pressures from the Caño Sucio reservoir, studies were performed to examine the stability of foundation rock blocks and their influence on stability at the toe of the dam. Basic assumptions were made for the geometry and joint strengths for potentially unstable rock blocks, and a simplified stability analysis was conducted. The results of this analysis indicate that for Earthfill or CFRD dam types the waterfall ledge can be buried within the downstream fill of the dam. However, the downstream extent of drain and filter zones for an Earthfill dam type should be located at least 15 m upstream from the edge of the waterfall. For concrete gravity dam types, the downstream toe of the dam should be located approximately 15 m upstream from the edge of the waterfall as well.

- **Foundation Bedrock Characteristics**. In general, the foundation bedrock at the site is not expected to present any significant constraints on project development. This is in contrast to some sedimentary rock units and geotechnical conditions known from the Canal Zone (e.g. Cucaracha Formation), where sliding and foundation failures have been common and presented serious problems.

    - *Bearing Capacity*. The tuffaceous siltstones and sandstones are relatively soft rocks (say in comparison to basalt) but are expected to present adequate bearing capacity to support any of the structures being considered.

    - *Resistance to Sliding*. The sandstone should provide adequate resistance to sliding along bedding planes or other planes of weakness provided excavation depths are sufficient to achieve fresh sound bedrock.

- **Excavation Depths**. Based upon the general observations made at the site, the excavation depth to sound bedrock is assumed to vary from approximately 2 m at the bottom of the river to approximately 6 m under the dam crest on each abutment. These assumptions were used in the development of preliminary layouts and in the computation of quantity takeoffs for cost estimates. Actual depths and characteristics of weathering need to be properly investigated by drilling and geophysical exploration.

    - No test pits have been conducted at the site to date, but a fully developed weathering profile several meters thick is expected under the slopes on either side of the river valley.

- Variations in foundation quality over short distances could have a more serious impact for rigid structures (gravity dam alternatives) than for fill dam alternatives. For example, the foundation excavation footprint for the RCC alternative is larger than for the CFRD plinth excavation. If excavation to obtain a competent foundation were greater than assumed, then costs would increase more for the RCC scheme than for the CFRD scheme.

- **Foundation Improvement, Treatment, and Long-Term Performance.** No special foundation improvement or treatment measures are expected for the Caño Sucio site that would influence selection of one dam type over another. Similarly, the sandstone bedrock is expected to perform satisfactorily over the lifetime of the project without adverse deterioration. During subsequent investigations, the potential for internal erosion of the sandstone under high seepage pressures and flows should be studied to determine appropriate design and construction details.

  No large mass movements are expected to affect the reservoir, but the effect of saturation, say after intense rainfall, on the stability of residual soils and saprolites needs to be properly evaluated during the design stage.

Geotechnical design criteria used for developing preliminary layouts and cost estimates for dam type selection are presented in Table 1 below:

**Table 1: Summary of Geotechnical Design Parameters**

| Geotechnical Design Parameters | | |
|---|---|---|
| **Parameter** | **Selected Design Criteria** | |
| Location of Dam | Earthfill Dam | Min. 15m between downstream toe of filter and drain zones and edge of waterfall.<br>Add Stability berm if downstream face of Earthfill intersects face of waterfall. |
| | CFRD | Min. 15m between dam axis and edge of waterfall.<br>Add Stability berm if downstream face of rockfill intersects face of waterfall. |
| | RCC Dam | Min. 15m between downstream toe of dam and edge of waterfall. |
| Excavation Depths | Overburden Thickness | Varies from valley floor to dam crest at abutments. |
| | Depth to Competent Rock | Varies from 2 meters at valley floor to 6 meters at abutments under dam crest. |
| Excavation Slopes | Rock | 1H:5V |
| | Permanent in Overburden | 2H:1V, 3m wide benches every 10m vertically. Bench at soil-rock contact |
| | Temporary in Overburden | 1.5H:1V, 3m wide benches every 10m vertically. Bench at soil-rock contact |

# 4 ALTERNATIVE DAM TYPE LAYOUTS AND COSTS

This section gives a brief description of both of the alternative dam type development concepts and describes the pertinent differences between them.

## 4.1 Concrete Faced Rockfill Dam

A site plan, profiles, and sections of the concrete faced rockfill dam (CFRD) are presented in Exhibit 3. The general arrangement shows the dam, cofferdams, and diversion culvert alignment. The centerline of the alignment was selected to minimize dam volume while providing sufficient distance from the waterfalls for toe stability and construction access. The alignment will be confirmed during subsequent studies of the selected dam type to include any additional information from planned geotechnical explorations. The cofferdam was located to provide adequate construction and laydown areas while minimizing the length of diversion culvert. The minimum distance to the upstream cofferdam was established at 15 m. This provides working space for the construction of the required grout curtain at the toe of the main dam. A grout curtain cutoff will be constructed to a depth of 40% of the hydraulic head, 10 m, or to a depth that eliminates any adverse impacts from or to the waterfall.

The CFRD will be constructed of selected rockfill obtained from nearby rock quarries developed in the same sandstone unit found at the dam axis. Material for concrete aggregate, filters and drains will be obtained from a quarry in basalt near Cerro Miguel. For the dam type selection, the slopes of both the upstream and downstream faces are 1.4H:1.0V, reflecting the relatively low seismicity of the location. These slopes will be optimized during subsequent studies when stability analyses are performed. The dam crest will be formed by an upstream parapet wall and a downstream retaining wall to reduce dam volume. The upstream parapet wall will extend an additional 2 m above the crest of the fill to provide freeboard.

The dam will be constructed with a reinforced concrete upstream facing as an impermeable membrane. It will be designed to have (1) low permeability, (2) sufficient durability against weathering, and (3) sufficient flexibility to tolerate small expected

Earthfill settlement. The concrete facing will be constructed with (vertically placed) slabs with intermediate waterstops. A zone of fine gravel and sand will be placed beneath the concrete face to provide continuous support for the concrete facing. It will prevent movement of material into the main rockfill and will be about 3 m thick. It is expected that this support zone will be placed using an upstream extruded concrete curb to provide confinement during compaction and protection against erosion during construction.

A reinforced concrete plinth, or toe slab, also used as a grouting platform, will be placed along the upstream toe. This plinth will be extended downstream, as needed, to lengthen the seepage path as required by the rock encountered. The plinth will be founded on unweathered rock that is assumed to be 2 m below ground level at the river channel, increasing to 4 m below ground level in the abutments.

The cofferdams will be constructed of random fill that will be obtained from portions of the required excavations for the main dam and spillway. The construction sequence of the main fill will include construction of a preferential fill or internal cofferdam, which will help protect the dam construction during flood events of unexpected scale. The diversion culvert will be located to the left of the river channel.

Pertinent data is provided in Table 2.

### 4.1.1 Ungated Spillway

The ungated spillway plan and sections are presented in Exhibit 4. The spillway will be an ogee spillway located on the right abutment. A crest road access bridge will span the spillway channel over the ogee. The spillway, chute and flip bucket are described in Section 2.6.1 Ungated Spillway for CFRD and Earthfill Alternative.

## 4.2 Earthfill Dam

The site plan, profile and section for an earthfill dam is presented in Exhibit 5. The Earthfill dam centerline is located just upstream of the CFRD centerline. This location provides adequate access for construction on both sides of the dam. The earthfill dam

## Table 2: CFRD Design Parameters and Pertinent Data

| | | | |
|---|---|---|---|
| **Dam Section** | | | |
| | CFRD | | |
| | | Alignment | See Plan |
| | | Crest elevation | 103.3 m |
| | | Parapet elevation | 105.3 m |
| | | Maximum reservoir elevation | 104.3 m |
| | | Crest width | 8 m |
| | | Upstream slope | 1.4 H : 1 V |
| | | Downstream slope | 1.4 H : 1 V |
| | | Concrete face thickness | 0.3 - 0.5m, 0.4 m, av. |
| | | Transition fill thickness | 3 m |
| | | Plinth width | 4 m |
| | Foundation | | |
| | | Plinth | Competent rock |
| | | Embankment | Weathered rock |
| | Material Volumes, $m^3$ | | |
| | | Rockfill | 73,500 |
| | | Filter and drain | 14,600 |
| | | Concrete | 8,000 |
| | | Foundation excavation | 28,500 |
| **Spillway** | | | |
| | Material Volumes, m3 | | |
| | | Excavation | 65,000 |
| | | Concrete | 3,800 |
| **Cofferdam** | | | |
| | Alignment | | See Plan |
| | Distance from dam | | 15 m (min) |
| | Crest Elevation | | 91.0 m |
| | Crest width | | 5 m |
| | Freeboard | | 1 m |
| | Upstream slope | | 2.5 H : 1 V |
| | Downstream slope | | 2.5 H : 1 V |
| | Volume, $m^3$ | | 16,300 |
| | Foundation | | |
| | | Impervious Element | Weathered Rock |
| | | Shells | Stripped Overburden |

crest will be at El. 105.3 providing one meter of freeboard for the selected design flood. The crest will be 8 m wide. Slopes of the Earthfill will be 2.5H:1V. The upstream slope will be protected with riprap down to El. 88.0, 2 m below the minimum reservoir level. The cofferdam will be incorporated into the dam. Excavation to a suitable founding grade is assumed at two meters over the entire foundation. Foundation treatment will consist of a grout curtain. A crest road access bridge will span the spillway across the headworks. An ungated spillway, chute and flip bucket are described in Section 2.6.1 Ungated Spillway for CFRD and Earthfill Alternatives.

Pertinent data is provided in Table 3.

### 4.3 Concrete Gravity Dam

The site plan, profile and sections for a conventional concrete or RCC gravity dam is presented in Exhibit 6. The centerline of the dam is located on the same axis as the CRFD to minimize dam volume and provide adequate space for construction. The cross section has been selected to provide adequate stability under the prevailing site conditions (low seismicity and moderate foundation strength) based on experience. The selected cross section will include a vertical upstream slope, and a downstream slope of 0.75H:1V. The 8 m wide crest will be at El. 103.3, with a parapet wall to El. 105.3. A grout curtain and a drainage system will be included.

The current alternative assumes either a low-cement content conventional concrete gravity dam, or a low-paste RCC gravity dam. The RCC dam would utilize bedding mixes, as required, particularly at the rock-concrete interface, at the upstream end of each lift, with an upstream impervious facing and drainage system.

The concrete gravity dam will include an ungated ogee spillway as shown on Exhibit 6. The 26 m-wide spillway will discharge onto a concrete apron with end sill. Access across the spillway will be provided by a 26 m-wide bridge.

Pertinent data is provided in Table 4.

## Table 3: Earthfill Dam Design Parameters and Pertinent Data

| | |
|---|---|
| **Dam Section** | |
| Earthfill | |
| Alignment | See Plan |
| Crest elevation | 105.3 m |
| Maximum reservoir elevation | 104.3 m |
| Crest width | 8 m |
| Upstream slope | 2.5 H : 1 V |
| Downstream slope | 2.5 H : 1 V |
| Riprap Protection | 2 m |
| Filter | 3 m |
| Drain | 3 m |
| Foundation | |
| Excavation | 2 m |
| Seepage | Grout Curtain |
| Material Volumes, $m^3$ | |
| Fill | 167,200 |
| Filter for concrete | 17,300 |
| Concrete | 1,400 |
| Foundation excavation | 42,100 |
| **Spillway** | |
| Material Volumes, $m^3$ | |
| Excavation | 65,000 |
| Concrete | 3,800 |
| **Cofferdam** | |
| Alignment | See Plan |
| Distance from dam | 15 m (min) |
| Crest Elevation | 91.0 m |
| Crest width | 5 m |
| Upstream slope | 2.5 H : 1 V |
| Downstream slope | 2.5 H : 1 V |
| Volume, $m^3$ | 16,300 |
| Foundation | |
| Impervious Element | Weathered Rock |
| Shells | Stripped Overburden |

## Table 4: Gravity Dam Design Parameters and Pertinent Data

| | | |
|---|---|---|
| **Dam Section** | | |
| | Gravity | |
| | Alignment | See Plan |
| | Crest | 103.3 m |
| | Parapet | 2 m |
| | Parapet elevation | 105.3 m |
| | Maximum reservoir elevation | 104.3 m |
| | Crest width | 8 m |
| | Upstream slope | 0 H : 1 V |
| | Downstream slope | 0.75 H : 1 V |
| | (RCC uncompacted section downstream) | 0.5 m |
| | Foundation | Competent rock |
| | Material Volumes, m³ | |
| | Mass Concrete (RCC) | 28,400 |
| | Additional concrete | 5,500 |
| | Total concrete | 33,900 |
| | Foundation excavation | 16,300 |
| **Spillway** | | |
| | Concrete, m³ | 1,900 |
| **Cofferdam** | | |
| | Alignment | See Plan |
| | Distance from dam | 15 m (min) |
| | Crest Elevation | 87.0 m |
| | Crest width | 5 m |
| | Freeboard | 1 m |
| | Upstream slope | 2.5 H : 1 V |
| | Downstream slope | 2.5 H : 1 V |
| | Foundation | |
| | Impervious Element | Weathered Rock |
| | Shells | Stripped Overburden |

# 5 EVALUATION OF THE ALTERNATIVE DAM TYPES

The objective of the dam type evaluation is to select the dam type and corresponding spillway type to be carried forward to the next phase of the study. The evaluation process will also be used to identify specific aspects of the selected dam type that require additional study and to make recommendations for additional data collection.

## 5.1 Factors Considered in Dam Type Selection

The evaluation of the alternative dam types is based on the following factors:

1. Construction cost;
2. Construction considerations and schedule;
3. Foundation considerations, and;
4. Operation and Maintenance considerations.

All of the alternative dam types have been developed to provide the same level of performance. The dam types have been developed to:

- Minimize the initial construction cost of the project by minimizing the dam size for the selected design parameters;
- Minimize technical difficulties that might be encountered in project construction through project configuration;
- Account for potential foundation related difficulties that might become apparent during future investigation programs, and;
- Minimize project operation and maintenance costs, or the possibility of encountering unique and difficult to solve remedial costs.

The alternative that best satisfies the stated objectives, and any other specific owner requirements, is the recommended alternative.

### 5.1.1 Initial Construction Costs

To develop the initial construction costs for each alternative, preliminary quantities and costs have been estimated. Only quantities and costs that are judged to vary by alternative have been included. The following common costs are not included in the cost estimates:

1. Access Roads;
2. Construction Facilities;
3. Trans-basin diversion tunnel;
4. Reservoir clearing;
5. Environmental and socio-economical costs, and;
6. Contingencies.

Unit costs have been estimated for use at this preliminary cost comparison level. Attachment 3, Comparative Cost Estimate presents the costs for diversion and care of water, the dam, the spillway and the low level outlet for selected quantities and unit costs.

Table 5 below summarizes the resulting cost estimates for the alternatives considered.

**Table 5: Summary of Comparative Costs**

| Component | CFRD | Earthfill | RCC | Conventional Concrete |
|---|---|---|---|---|
| | | $US million, 2002 price level | | |
| Diversion and Care of Water | 0.69 | 0.66 | 0.17 | 0.17 |
| Dam | 2.22 | 1.92 | 3.43 | 3.60 |
| Spillway | 1.13 | 1.13 | 0.44 | 0.44 |
| Low Level Outlet | 0.29 | 0.29 | 0.17 | 0.17 |
| Total | 4.3 | 4.0 | 4.2 | 4.4 |

The comparative cost estimate shows the earthfill dam alternative to be the low cost alternative at $4.0 million, more than 5% lower that the RCC or CFRD dam alternatives at $4.2 and $4.3 million respectively. The earthfill dam cost of $1.92 million reflects the use of local available mass fill material at low cost. The cost estimate includes the cost for a freestanding intake control tower for the culvert at the upstream toe of the dam.

The RCC dam alternative is estimated to cost $4.2 million, of which $3.43 million is the cost of the dam itself. The relatively small volume of RCC results in a unit cost at the higher end of the usual experience range. In addition, the high ratio of facing adds substantially to the cost of this alternative. The intake control tower will be located on the upstream face of the dam resulting in a lower cost than for the Earthfill and CFRD alternatives.

The CFRD cost is higher than the Earthfill despite its smaller volume because of the higher unit cost of rockfill, as well as the cost of providing the concrete facing. Other alternative components are essentially the same cost as for the Earthfill dam alternative.

The conventional concrete gravity dam cost estimate is higher than the RCC dam alternative because of the unit cost of concrete. While a lower cementitious mix has been selected, the slower placement rate and additional internal formwork required result in the higher unit cost.

The differences in initial construction cost between the Earthfill, RCC, conventional concrete and the CFRD alternatives are not sufficient to make an evaluation on cost alone. It should be noted that contingencies have not been included on either quantities or unit costs. For the feasibility level estimate, contingency allowances will be included for the following:

1. Uncertainties attributable to unforeseeable adverse geological conditions;
2. Variations in the cost of permanent equipment and resources for construction due to changing market conditions;
3. Modifications in design resulting in an increase in construction;
4. Minor items not detailed at this time, and;

5. Overlooked and unforeseen items that may not be included in the present pre-feasibility level quantity estimates.

The application of contingencies to provide reasonable coverage for the first two items will favor the Earthfill dam over the CFRD, RCC and conventional concrete alternatives. However, the cost difference between the ED and the RCC alternatives, and likely between the ED and all other alternatives considered, will remain within estimating accuracy.

### 5.1.2 Construction Considerations

Construction considerations have been evaluated on the basis of the following objectives:

- Minimize the need for off-site materials;
- Minimize the duration of the construction activities;
- Minimize the consequences of flooding due to streamflow in excess of the diversion dam floods, and;
- Maximize the use of available construction technology, specifically in Panama.

Although each parameter favors a particular dam type, taken as a whole, construction considerations do not clearly favor any of the dam type alternatives, as discussed below.

- The earthfill dam alternative takes most advantage of local materials. Basically all materials used for construction of the dam are found at relatively close distance to the site of construction. Construction of the CFRD requires some transportation of rockfill from the selected quarry. The conventional concrete and RCC dams requires importation of large quantities of cement from an offsite factory, or even from outside of the country, and its transportation to the site.

- In terms of construction planning, the most significant differences between the types of dam are the durations of the construction periods. The RCC dam, excluding preparatory works and construction of ancillary structures, can be built in approximately 3 months. The conventional concrete gravity dam could be constructed in 4 to 8 months plus preparatory and ancillary works, depending on the construction forces mobilized. The CFRD will require the excavation of nearly 75,000 $m^3$ of rock, either for necessary excavation or from quarry. It is anticipated that this volume will take at least 6 months. Completion will take approximately six more months. The Earthfill dam will require at least two dry seasons to place the 167,000 $m^3$ of fill. The overall construction period is estimated at 15-18 months. However, if the schedule for the Coclé del Norte and Caño Sucio Water Supply Projects includes the trans-basin diversion tunnel, tunnel construction will determine the overall construction period, making dam type selection independent of construction time.

- The effect of flooding during construction favors the conventional concrete gravity and RCC dams. Both are resistant to damage by overtopping but vital placement equipment, processing plant and material stockpiles may be damaged during the flood, if not adequately protected or located. The CFRD can be designed and constructed to withstand overtopping almost as effectively as an RCC dam. Interruption in placement of the CFRD would have less impact. The earthfill dam would be most adversely affected by flooding during construction.

- The CFRD alternative has a definite advantage when previous local experience is considered. Fortuna dam is a 100-m-high CFRD, and was commissioned a few years ago, and the Barrigon dam, a 60-m-high CFRD, part of the Esti Hydroelectric Project, is currently under construction. No RCC dams have been constructed in Panama. Small Earthfill dams and conventional concrete dams (Bayano) have been constructed in Panama.

### 5.1.3 Foundation Considerations

Foundation considerations have been evaluated on the basis of the following objectives:

- Minimize impact of potential adverse foundation conditions resulting from future investigations;
- Minimize concerns relating to the foundation strength characteristics;
- Minimize potential for differential deformation, and;

- Minimize potential for seepage through the foundation.

The foundation is an integral part of any dam, as it provides support to the dam body, and continuity to the water-tightness element of the dam. To perform these functions, the foundation material should have certain minimal attributes:

- The material should have a strength comparable or superior to the strength of the material being placed on top, and
- The foundation should be of low permeability, or else, it should be possible to treat it by grouting or other means to reach a low permeability.

The known characteristics of the site tend to favor the selection of an earthfill dam alternative, which does not need to be founded on competent rock. The rock formations found in the river channel and abutment outcrop, and assumed to extend throughout the site (tuffaceous siltstones and sandstones) present a well developed weathering profile and are naturally soft and of relatively low modulus of deformation. Minimal foundation excavation or improvement is required for the earthfill dam. Additionally fill dams are more capable of accommodating the differential deformations associated with a low modulus of deformation.

The lack of subsurface information at this time does not favor selection of any of the alternative dam types considered. Any unexpected subsurface conditions can be handled easily, and with lesser impact on the overall construction, during construction of an Earthfill dam than during construction of a CFRD, conventional concrete or RCC dam. However, the conventional concrete dam or RCC dam type costs have been estimated assuming lower abutment foundation levels than the earthfill dam, and in addition, their footprint on the abutments is much smaller than the earthfill dam. Therefore the risk of unexpected foundation conditions impacting these alternatives more adversely than the earthfill alternative is considered comparable on this relatively small dam.

### 5.1.4 Operating and Maintenance Considerations

The operation and maintenance considerations of the project have been evaluated on the basis of the following:

- Minimize the potential for overtopping and resulting damage due to improper spillway operation;
- Minimize leakage through the dam or its foundation;
- Minimize the need for maintenance of the dam and the potential for difficult remedial measures, and;
- Minimize the need for maintenance of the spillway and the potential for difficult remedial measures.

Operation and maintenance considerations tend to favor selection of a concrete (conventional or RCC) dam alternative.

Leakage through all types of dam should be negligible. There may be marginally greater seepage through the earthfill dam, though it will be less than the anticipated minimum release requirements. Although some early RCC dams experienced leakage problems, more recent designs and construction techniques have virtually eliminated this problem. The concrete face of a CFRD may be subject to cracking if poor quality control of concrete placement occurs, or subsidence causes cracking. The general experience is that appropriate design and specification requirements coupled with construction inspection has resulted in CFRD that minimize leaks.

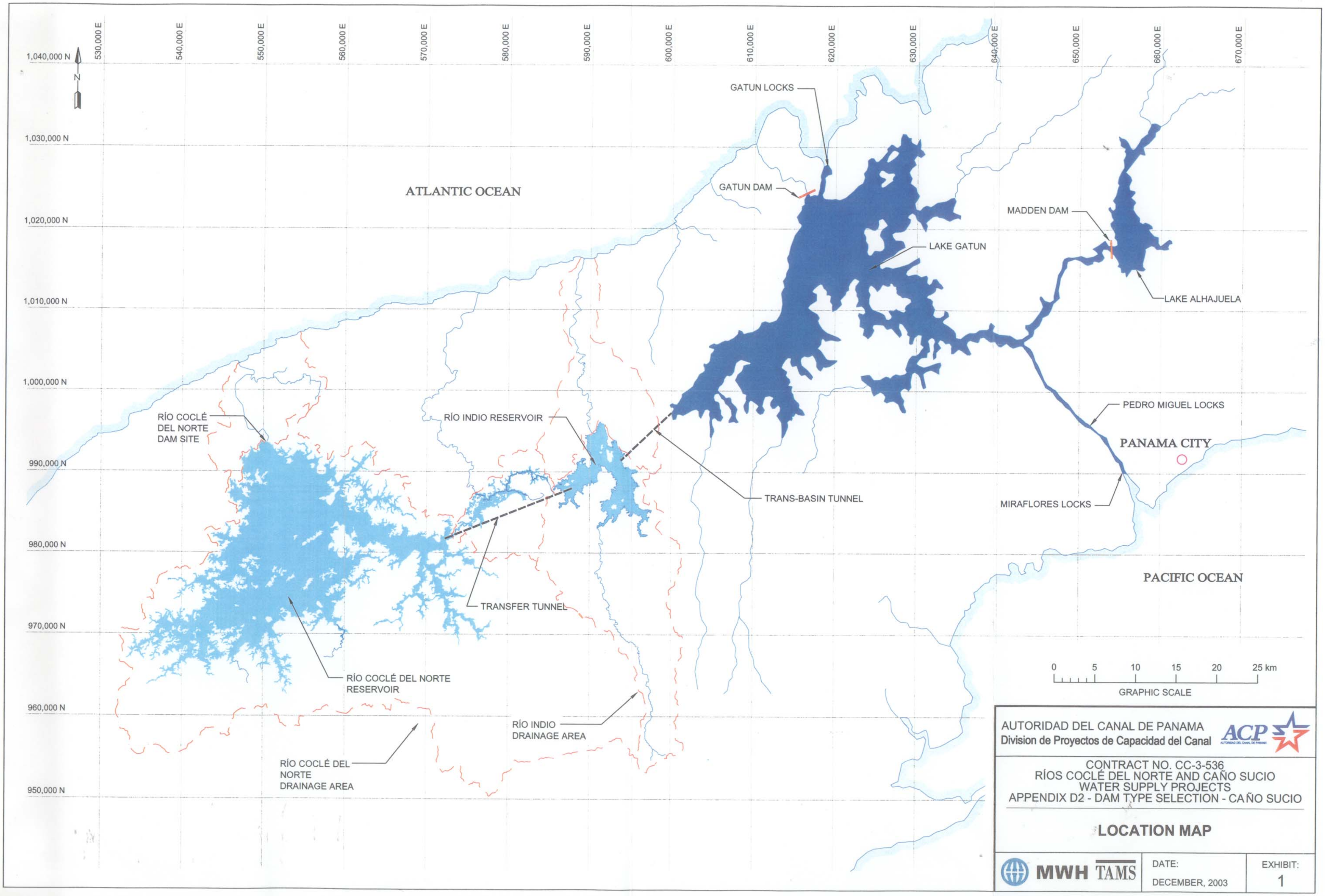
Maintenance requirements will be relatively small for all of the dam types under consideration. However, they will be higher for the earthfill dam than for the other dam alternatives. The dam will require mowing or tree/shrub removal several times a year over the life of the project.

## 5.2 Recommendations

Based on the available information, an RCC dam is recommended for the Río Caño Sucio Water Supply Project.

Earthfill, CFRD, and Concrete Gravity Dam types are all technically feasible at this site. However, while the comparative cost evaluation slightly favors the Earthfill dam alternative, the RCC is, within the accuracy of estimating, about the same cost. The Earthfill dam and the RCC dam have comparable foundation condition risks. On the other hand, the Earthfill dam has a greater flooding risk during its longer construction period, and projected higher maintenance costs. While the selection of the RCC alternative should be confirmed following site investigation studies, it is recommended for Feasibility level study.

# EXHIBITS




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

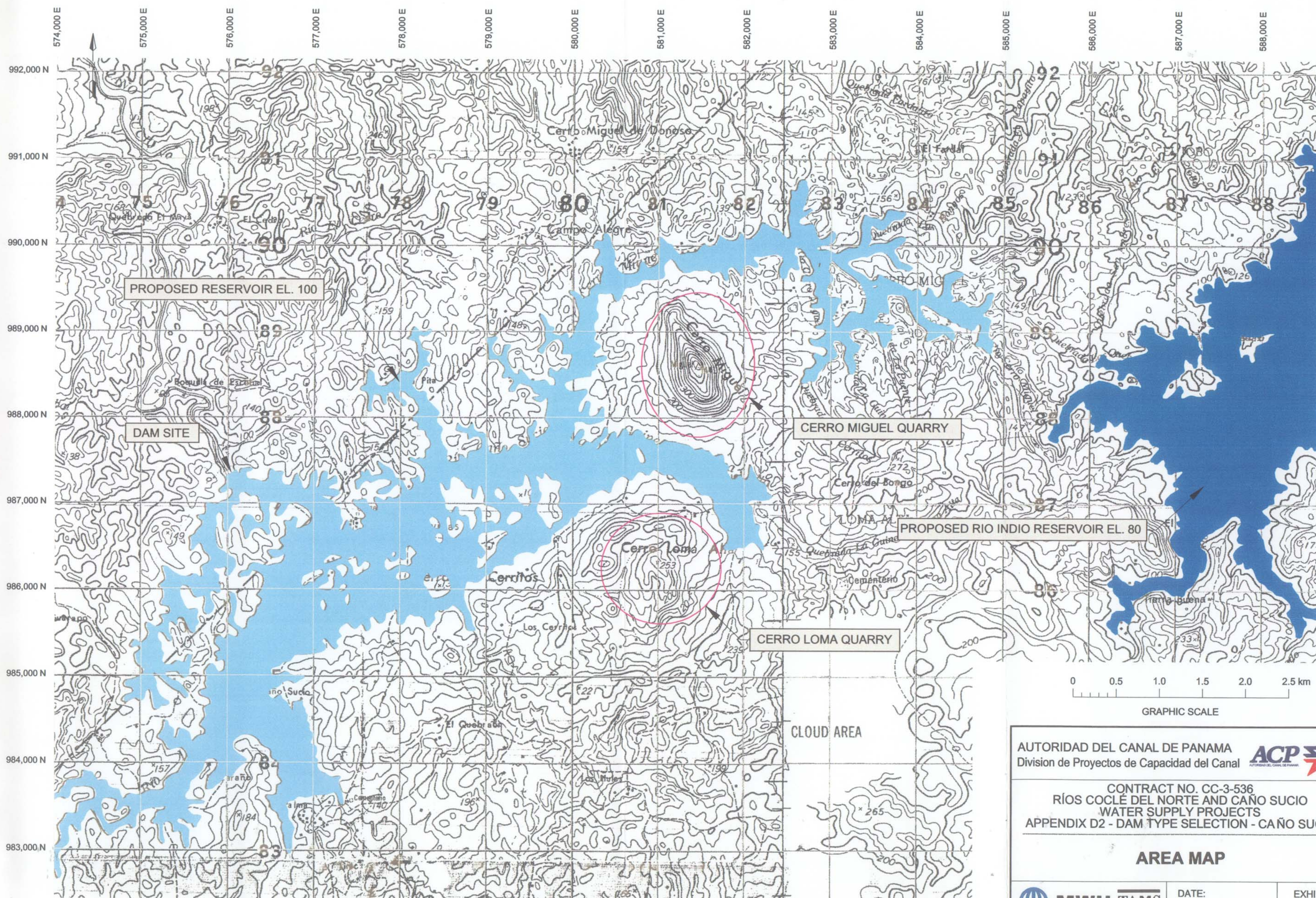
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D2 - DAM TYPE SELECTION - CAÑO SUCIO

**LOCATION MAP**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 1

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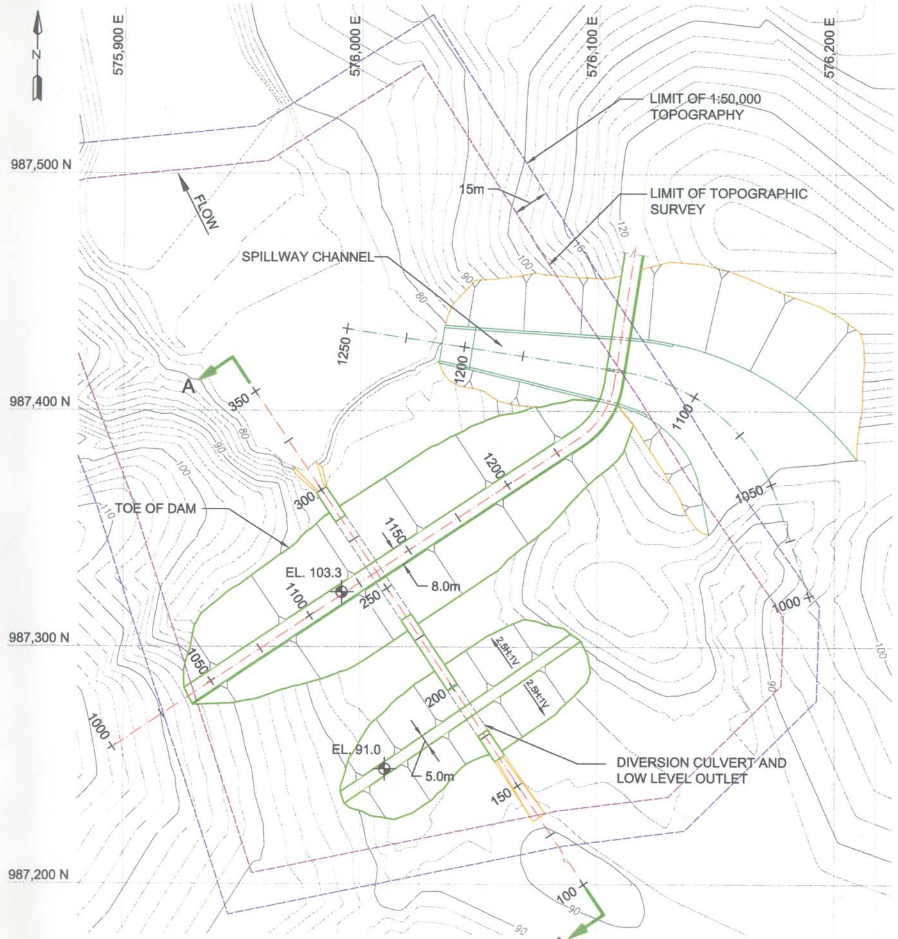
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D2 - DAM TYPE SELECTION - CAÑO SUCIO

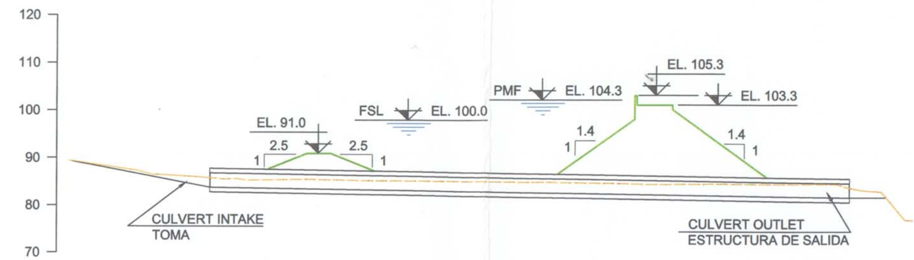
**AREA MAP**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 2 |

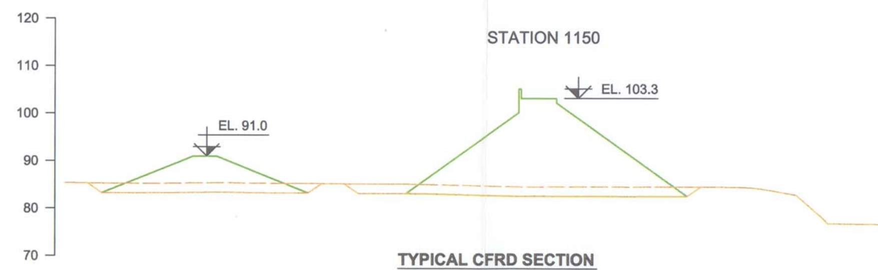



**SITE PLAN**




**PROFILE A - A**
**ALONG DIVERSION CULVERT**

0 10 20 m

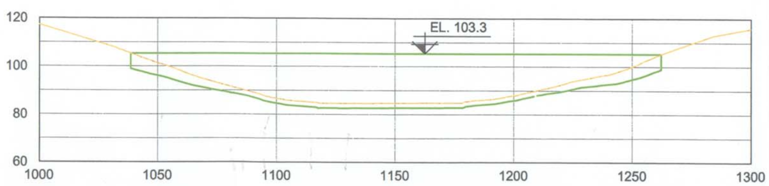



**TYPICAL CFRD SECTION**

0 10 20 m

0 20 40 60 80 100 m

GRAPHIC SCALE




**DAM PROFILE**

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

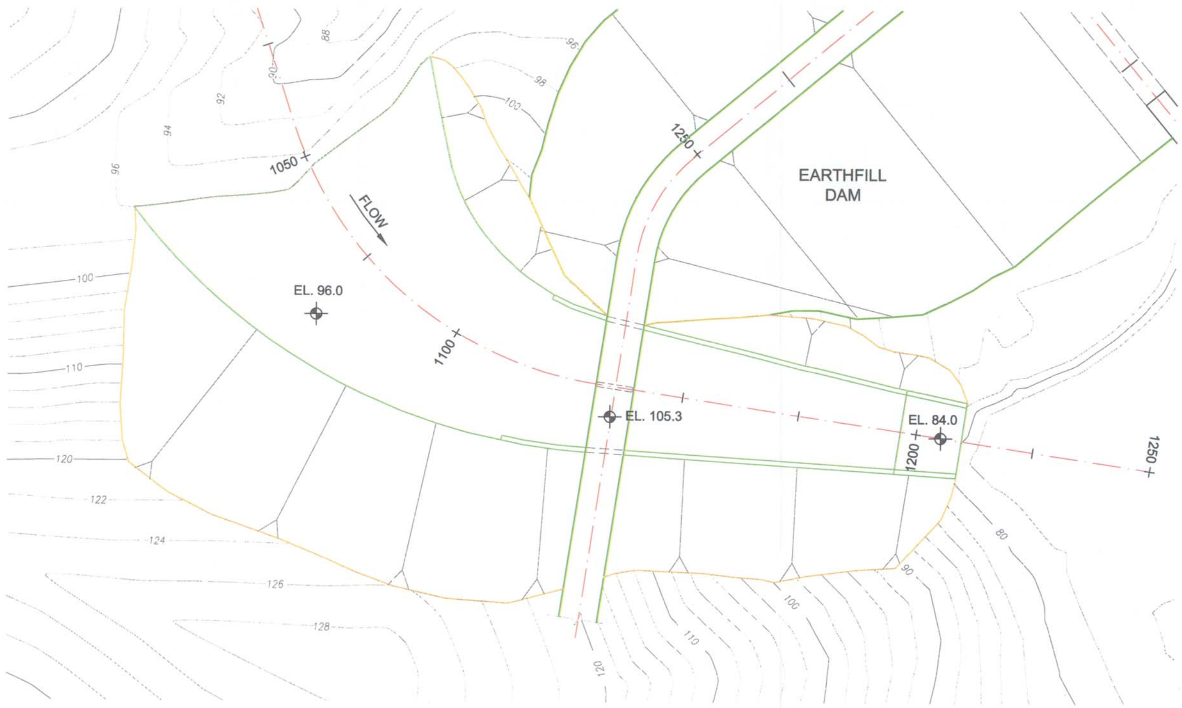
ACP

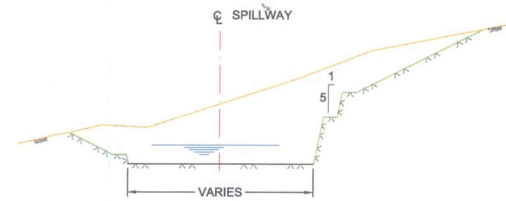
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D2 - DAM TYPE SELECTION - CA ÑO SUCIO

**CFRD**
**PLAN, PROFILE AND SECTIONS**

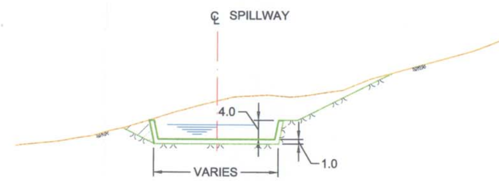
MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 3 |




**APPROACH CHANNEL TYPICAL SECTION**




**SPILLWAY TYPICAL SECTION**


**SPILLWAY PROFILE**

0 5 10 meters

0 10 20 30 40 50 m
GRAPHIC SCALE

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

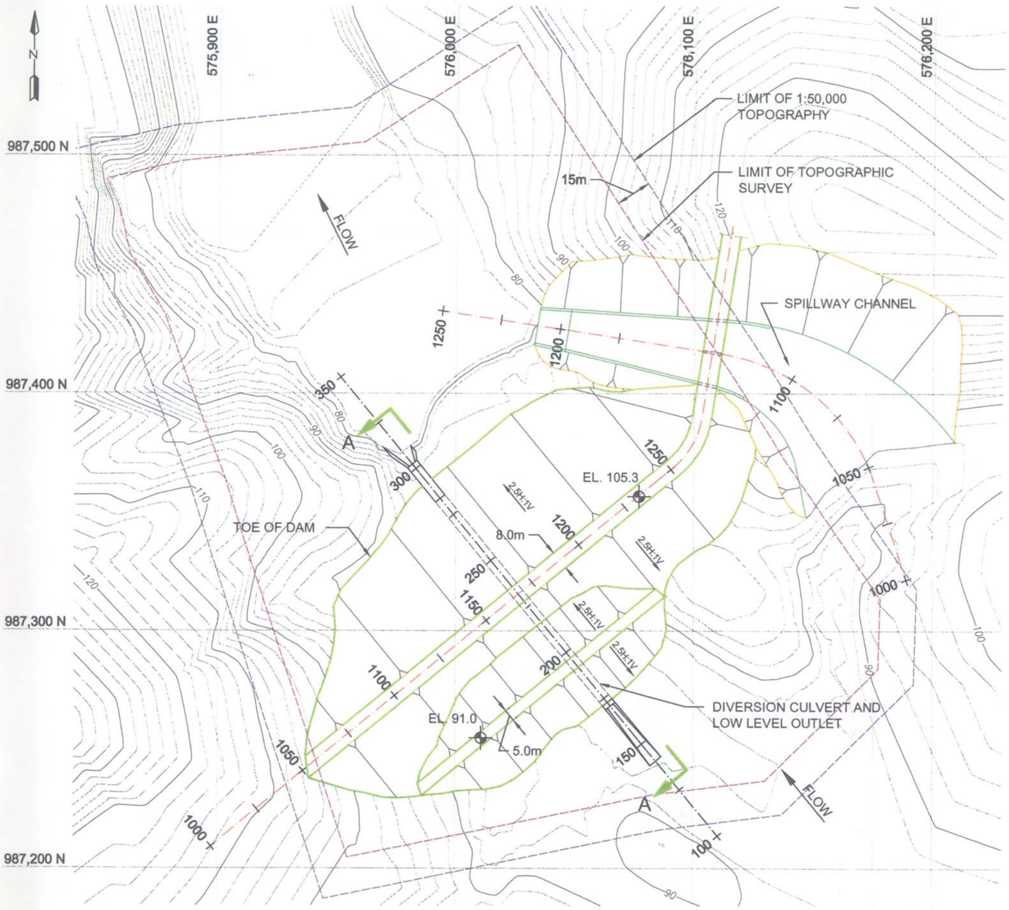
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D2 - DAM TYPE SELECTION - CA ÑO SUCIO

**EARTHFILL DAM AND CFRD SPILLWAY PLAN, PROFILE, SECTIONS**

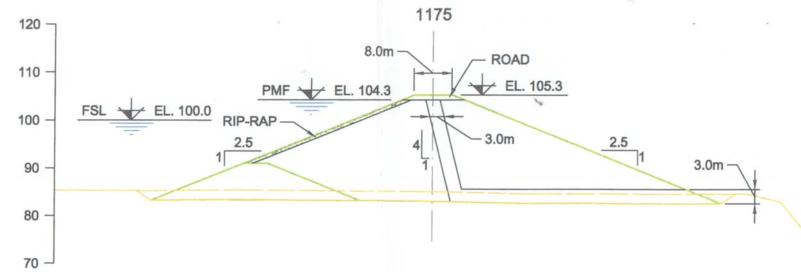
MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 4

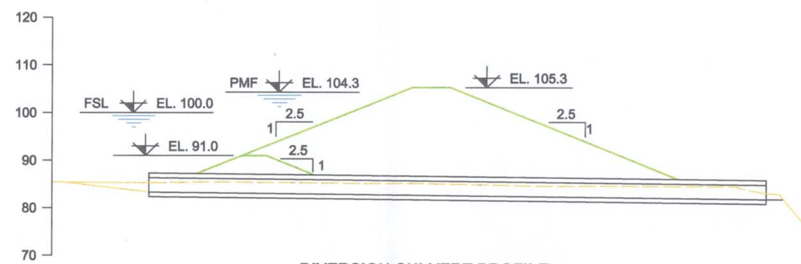



## SITE PLAN




## SECTION A - A

0 10 20 meters

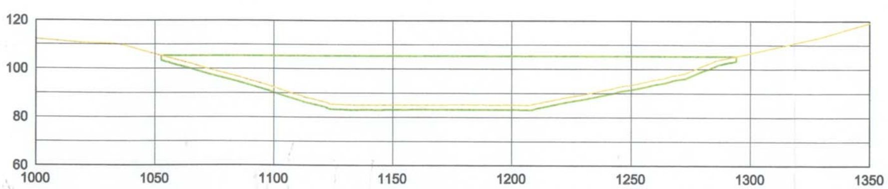



## DIVERSION CULVERT PROFILE

0 10 20 meters

0 20 40 60 80 100 m

GRAPHIC SCALE




## DAM PROFILE

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO
WATER SUPPLY PROJECTS
APPENDIX D2 - DAM TYPE SELECTION - CAÑO SUCIO

**EARTHFILL DAM**
**PLAN, PROFILE AND SECTIONS**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 5 |

# ATTACHMENTS

# Attachment 1 - Hydraulic Analysis for Design of Diversion Tunnel and Cofferdam

MWH
MONTGOMERY WATSON HARZA

MWH ENERGY & INFRASTRUCTURE, INC.
HYDROPOWER

**Location** Chicago Office **Date** March 5, 2002

**To** Michael Newbery

**From** Monica Cheng and Khalid Jawed

**Subject** Hydraulic Analyses for Design of Diversion Works and Cofferdam
Rio Cano Sucio Project

## Introduction

This memo summarizes the procedures and results of the hydraulic analyses performed for design of cofferdam and diversion works of Rio Cano Sucio Project.

The analysis included:

Tailwater analysis
Diversion Works analysis
Reservoir routing

Basic data used in the analysis is discussed. Results are provided as tables and exhibits.

## Tailwater Analysis

The objective of this analysis was to develop a tailwater rating curve for the proposed Rio Cano Sucio Dam site.

### Computer Model

The water surface profiles computer model, HEC-2, developed by the U.S. Army Corps of Engineers, was used in this study to determine the tailwater rating curve. Key input data to the model include flows, river cross-sections and river reach characteristics.

### River Cross Sections

Seven cross sections downstream from the Cano Sucio dam were used. The most upstream and downstream cross sections are located about 100 m and 8,300 m downstream of the dam, respectively. Initially, the seven cross sections were derived from 1:50,000 scale topographic map with 20-m contour interval. Later, the most upstream cross section was replaced by a section derived from 1:2,000 scale topographic map with 1-m contour interval. The cross section data used are listed on Exhibit 1.

### Manning's Roughness Coefficients

The roughness coefficients selected for the study reach are 0.035 for channel flow and 0.050 for over-bank flows.

### Flows

A total of eight flows varying in the range of 5 to 400 cms were used to develop tailwater rating curve.

### Results

Table 1 summarizes the computed tailwater elevations at a distance of 100 meters from the dam site for the selected flows. Exhibit 2 shows the plot of tailwater rating curve.

**Table 1**
**Tailwater Rating Curve**

| **Flow** | cms | 5 | 10 | 20 | 50 | 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|---|---|
| **Tailwater Elevation** | m | 79.2 | 79.4 | 79.5 | 79.9 | 80.3 | 80.8 | 81.1 | 81.4 |

## Diversion Works Analysis

The objective of this analysis was to develop a relationship between headwater and diversion works outflow for routing floods of selected return periods through cofferdam – diversion works scheme. The routing results would be used for determining height of cofferdam.

### Methodology

Flow in diversion works generally is non-uniform with regions of gradually and rapidly varying flows. An exact theoretical analysis of flow in diversion works is very complex which could involve backwater and drawdown calculations, energy and momentum balance, and applications of hydraulic model studies. This exact analysis was not performed in the current study. Instead, a simplified analysis was made and its results were used in the reservoir routing for preliminary design of height of cofferdam.

## Procedures

A Microsoft "EXCEL" spreadsheet was used for the computation. The following components were computed in the spreadsheet.

· Calculate the velocity by dividing the flow rate by the cross sectional area of diversion works. Determine the corresponding velocity head.

· Determine the entrance, exit, friction and any other losses. The entrance and exit loss coefficient was assumed to be 0.3 and 1.0, respectively. The friction loss was computed using Darcy-Weisbach equation. The Darcy-Weisbach friction loss coefficient was computed based on the Manning's coefficient of 0.013 for lined-concrete diversion works.

· Calculate the required headwater elevation by adding the invert elevation at outlet (El. 80) with depth of diversion works and the total loss.

· Select other flow rates and repeat the above computations to develop the relationship of the required headwater elevation and the selected flow rates.

The computation was made for various sizes and lengths of diversion works. The sizes considered are one 3 m x 3 m and 4 m x 4 m square box of length 100, 150, and 200 m. Exhibit 3 shows the headwater elevation versus discharge curves. The computed headwater and the corresponding flow values were applied to the reservoir routing.

## Routing Analysis

The objective of this analysis was to provide information of maximum headwater elevations under various sizes and length of diversion works.

## Methodology

An in-house computer program ROUTE was used for the reservoir routing. The 25-year and 50-year all season floods and 50-year dry season flood were routed for various size and length conditions. The key input to the program included the headwater vs. outflow relationship developed in the diversion works analysis, reservoir capacity curve, and the flood hydrograph. A brief description of these data is given below.

## Reservoir Capacity

The reservoir volume data listed in Table 2 were used for the storage routing. These reservoir volume data was originally provided by the ACP/USACE and adjusted by MWH to reflect a zero volume at El. 85. The volumes at El. 90 and El. 100 were obtained from topographic map of scale 1:50,000. The volume at El. 95 was interpolated graphically.

**Table 2**
**Reservoir Capacity Curve**

| | | | | | |
|---|---|---|---|---|---|
| **Elevation** | m | 85 | 90 | 95 | 100 |
| **Volume** | mcm | 0 | 4.2 | 37.0 | 72.8 |

## Flood Hydrograph

The 25-year and 50-year all season and 50-year dry season flood hydrographs computed for the Cano Sucio dam as shown in Tables 3, 4 and 5 were used as the inflow hydrograph for the reservoir routing.

## Starting Reservoir Elevation

Reservoir routing was made using a starting reservoir elevation at initial flow of the flood. The starting elevation was estimated based on the relationship of headwater vs. outflow computed in the diversion works analysis.

**Table 3**
**25-Year All Season Flood Hydrograph**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Time** | **hr** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow** | **cms** | 15 | 20 | 31 | 71 | 102 | 153 | 204 | 255 |
| **Time** | **hr** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow** | **cms** | 305 | 361 | 392 | 372 | 326 | 285 | 244 | 204 |
| **Time** | **hr** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow** | **cms** | 173 | 143 | 122 | 102 | 92 | 81 | 71 | 61 |
| **Time** | **hr** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
| **Flow** | **cms** | 56 | 51 | 46 | 41 | 36 | 31 | 25 | |

**Table 4**
**50-Year All Season Flood Hydrograph**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Time** | **hr** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow** | **cms** | 16 | 21 | 33 | 76 | 109 | 163 | 217 | 271 |
| **Time** | **hr** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow** | **cms** | 324 | 384 | 417 | 396 | 347 | 303 | 260 | 217 |
| **Time** | **hr** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow** | **cms** | 184 | 152 | 130 | 109 | 98 | 86 | 76 | 65 |
| **Time** | **hr** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
| **Flow** | **cms** | 60 | 54 | 49 | 44 | 38 | 33 | 27 | |

**Table 5**
**50-Year Dry Season Flood Hydrograph**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Time** | **hr** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow** | **cms** | 3 | 5 | 7 | 16 | 23 | 35 | 47 | 59 |
| **Time** | **hr** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow** | **cms** | 70 | 83 | 90 | 85 | 75 | 65 | 56 | 47 |
| **Time** | **hr** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow** | **cms** | 40 | 33 | 28 | 23 | 21 | 19 | 16 | 14 |
| **Time** | **hr** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
| **Flow** | **cms** | 13 | 12 | 11 | 9 | 8 | 7 | 6 | |

## Results

Table 6 summarizes the maximum water surface elevation reached for various size and length conditions routed. These results will be used for the design of height of cofferdam.

**Table 6**
**Maximum Headwater Surface Elevation**

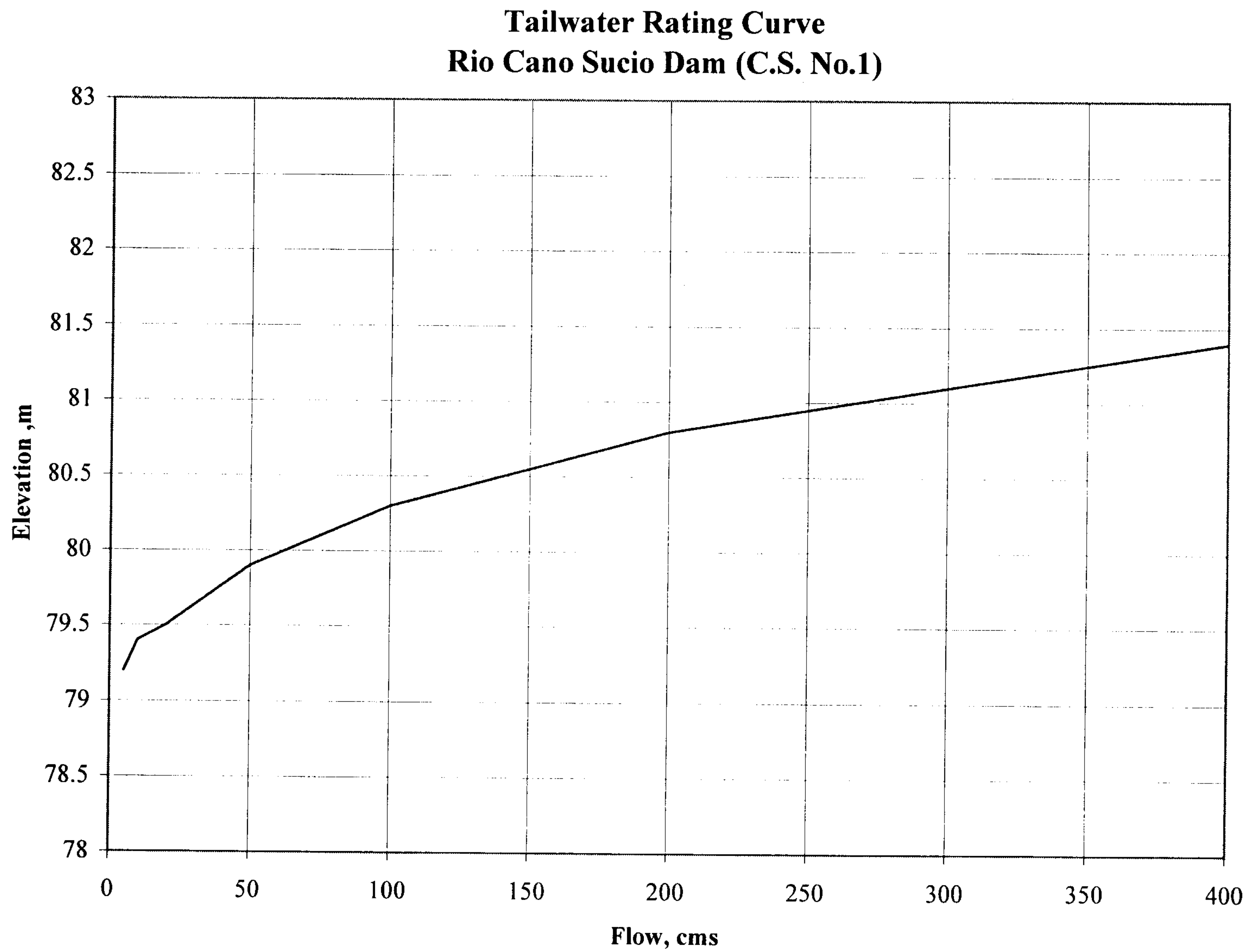
| **Maximum Headwater Surface Elevation, m** | | 25-year All Season Flood | 50-year All Season Flood | 50-year Dry Season Flood |
|---|---|---|---|---|
| Diversion Works | One 3 m x 3 m square-100 m | 90.9 | 91.0 | 86.1 |
| | One 3 m x 3 m square-150 m | 90.9 | 91.0 | -- |
| | One 3 m x 3 m square-200 m | 90.9 | 91.1 | -- |
| | One 4 m x 4 m square-100 m | 90.5 | 90.6 | -- |
| | One 4 m x 4 m square-150 m | 90.5 | 90.6 | -- |
| | One 4 m x 4 m square-200 m | 90.5 | 90.7 | -- |

## Exhibit 1

### River Cross Sections Downstream from Rio Cano Sucio Dam

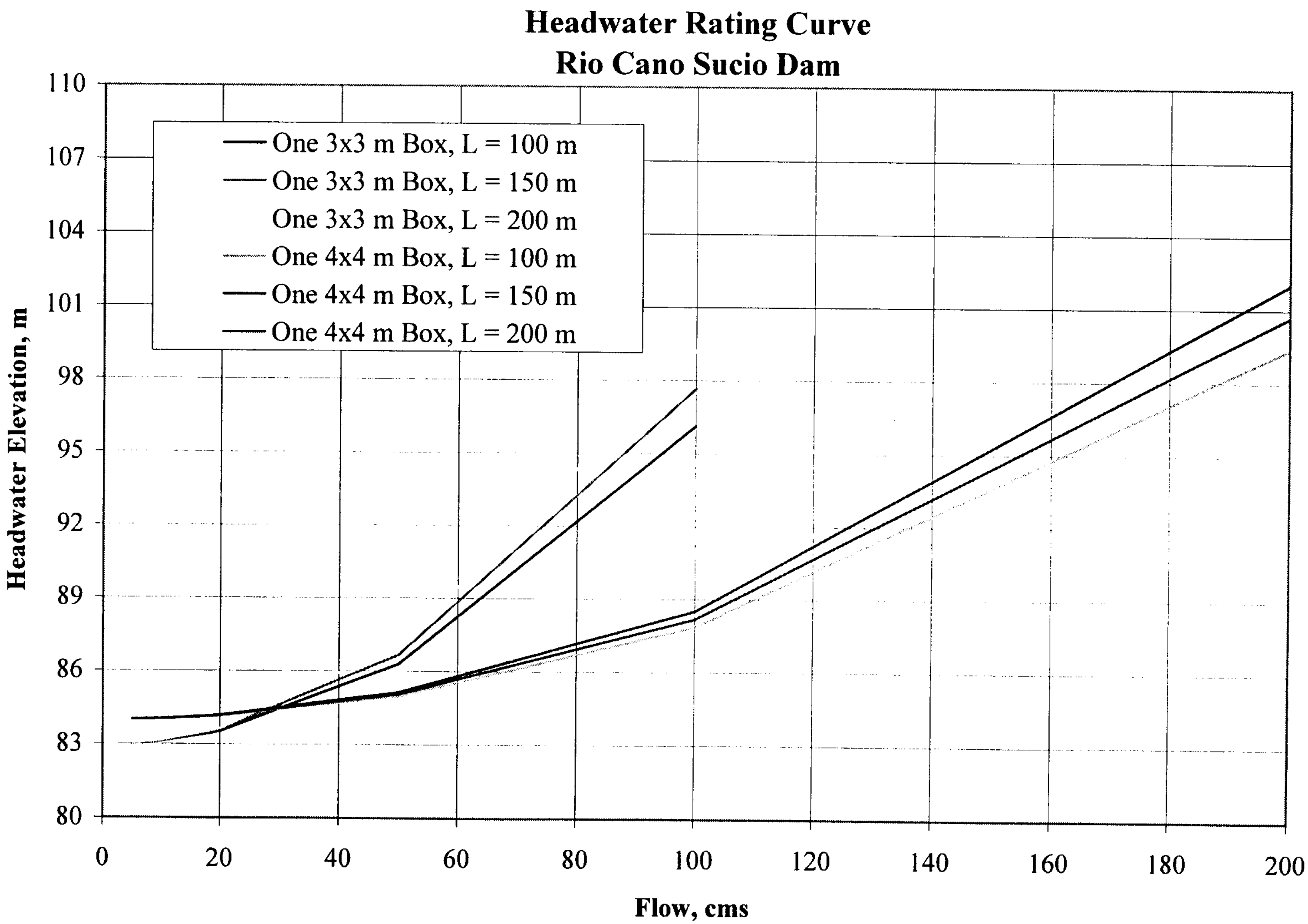
| C.S. No. in HEC-2 | 7 | | 6 | | 5 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | Dist, m | Elev, m | Dist, m | Elev, m | Dist, m | Elev, m | Dist, m | Elev, m |
| | 0 | 120 | 0 | 120 | 0 | 120 | 0 | 120 |
| | 120 | 100 | 50 | 100 | 250 | 100 | 100 | 100 |
| | 150 | 90 | 550 | 80 | 500 | 80 | 550 | 80 |
| | 161 | 85 | 590 | 72.3 | 590 | 68.8 | 690 | 67.3 |
| | 169 | 80 | 610 | 72.3 | 610 | 68.8 | 710 | 67.3 |
| | 176 | 75 | 650 | 80 | 700 | 80 | 850 | 80 |
| | 179 | 74 | 1150 | 100 | 950 | 100 | 1300 | 100 |
| | 192 | 73 | 1200 | 120 | 1200 | 120 | 1400 | 120 |
| | 254 | 74 | | | | | | |
| | 260 | 75 | | | | | | |
| | 269 | 76 | | | | | | |
| | 289 | 80 | | | | | | |
| | 299 | 81 | | | | | | |
| | 306 | 83 | | | | | | |
| | 315 | 85 | | | | | | |
| | 338 | 90 | | | | | | |
| | 380 | 100 | | | | | | |
| | 500 | 120 | | | | | | |

| C.S. No. in HEC-2 | 3 | | 2 | | 1 | |
|---|---|---|---|---|---|---|
| | Dist, m | Elev, m | Dist, m | Elev, m | Dist, m | Elev, m |
| | 0 | 120 | 0 | 120 | 0 | 120 |
| | 75 | 100 | 80 | 100 | 50 | 100 |
| | 235 | 80 | 520 | 80 | 110 | 80 |
| | 315 | 64.9 | 560 | 61.7 | 135 | 60 |
| | 335 | 64.9 | 580 | 61.7 | 205 | 60 |
| | 415 | 80 | 620 | 80 | 230 | 80 |
| | 575 | 100 | 1060 | 100 | 300 | 100 |
| | 650 | 120 | 1150 | 120 | 350 | 120 |



Tailwater Rating Curve
Rio Cano Sucio Dam (C.S. No.1)
83
82.5
82
81.5
81
80.5
80
79.5
79
78.5
78
Elevation ,m
0
50
100
150
200
250
300
350
400
Flow, cms


Exhibit 2



Headwater Rating Curve
Rio Cano Sucio Dam
One 3x3 m Box, L = 100 m
One 3x3 m Box, L = 150 m
One 3x3 m Box, L = 200 m
One 4x4 m Box, L = 100 m
One 4x4 m Box, L = 150 m
One 4x4 m Box, L = 200 m
Headwater Elevation, m
110
107
104
101
98
95
92
89
86
83
80
0
20
40
60
80
100
120
140
160
180
200
Flow, cms


Exhibit 3

# Attachment 2 - Evaluation of Spillway Sizes and Estimation of Freeboard

**Date: January** 30, 2002

**To:** Michael J. Newbery

**From:** Khalid Jawed

**Subject:** Evaluation of Spillway Sizes and Estimation of Freeboard for Rio Cano Sucio Project

## Introduction

This memorandum summarizes the procedures and results of hydrologic analyses performed to determine flood surcharge over the normal reservoir pool elevation during the routing of probable maximum flood (PMF), and to estimate magnitudes of wave run-up and wind setup. The analyses included:

- Estimation of flood surcharges for an ungated Ogee spillway with crest elevation at 100 meters. Four lengths of spillway, 25, 50, 75, and 100 meters were considered.

- Analysis of wave run-up and wind setup.

Basic data used in the analyses are discussed. The results are provided as tables.

## Ungated Spillway

The objective of this analysis was to determine the maximum surcharge over the normal reservoir pool elevation of 100 meters, during the routing of the PMF. The HEC-1 computer program developed by the United States Army, Corps of Engineers, was used to route the PMF with a starting elevation at 100 meters. The elevation-volume data and spillway rating curves used are given in Table 1. The spillway discharges were computed using the following relationship.

$$Q = C\ L\ (H^{1.5})$$

where Q is spillway discharge in cubic feet per second, L is length of spillway in feet, H is head over spillway crest in feet and C is coefficient. A constant value of 3.5 was used. A spillway length of 150 meters was originally used by ACP. Spillway lengths of 100, 75, 50 and 25 were investigated. The results are summarized in Table 2.

**Table 1**

**ELEVATION-VOLUME AND SPILLWAY DISCHARGE DATA**
**RIO SUCIO RESERVOIR**

| Elevation (m) | Volume (mcm) | Elevation (m) | Discharge (cms) L=100m | Discharge (cms) L=75m | Discharge (cms) L=50m | Discharge (cms) L=25m |
|---|---|---|---|---|---|---|
| 80 | 0.0 | 100 | 0 | 0 | 0 | 0 |
| 85 | 4.07 | 100.5 | 68 | 51 | 34 | 17 |
| 90 | 8.14 | 101.0 | 193 | 144 | 96 | 48 |
| 95 | 36.35 | 101.5 | 354 | 266 | 177 | 89 |
| 100 | 80.62 | 102.0 | 546 | 409 | 273 | 136 |
| 101 | 91.39 | 102.5 | 762 | 572 | 381 | 191 |
| 102 | 102.81 | 103.0 | 1002 | 752 | 501 | 251 |
| 103 | 114.88 | 103.5 | 1263 | 947 | 631 | 316 |
| 104 | 127.58 | 104.0 | 1543 | 1157 | 771 | 386 |
| 105 | 140.93 | 104.5 | 1841 | 1381 | 921 | 460 |
| 107 | 169.43 | 105.0 | 2156 | 1617 | 1078 | 539 |
| | | 105.5 | 2488 | 1866 | 1244 | 622 |

**Table 2**

**MAXIMUM SURCHARGE DURING PMF**
**RIO SUCIO RESERVOIR**

| PMF Peak Inflow | Initial Pool Elevation | Width of Spillway | Maximum Outflow | Maximum Surcharge Elevation |
|---|---|---|---|---|
| (cms) | (meters) | (meters) | (cms) | (meters) |
| 1687 | 100 | 100 | 921 | 102.8 |
| 1687 | 100 | 75 | 812 | 103.2 |
| 1687 | 100 | 50 | 661 | 103.6 |
| 1687 | 100 | 25 | 434 | 104.3 |

**Analysis of Wind Wave**

**Definitions**

The purpose of this analysis was to determine the freeboard for Indio dam. The freeboard is defined as the difference in elevation between the crest of a dam and normal pool elevation of the reservoir. A term minimum freeboard is also used which is defined as the difference in elevation between the crest of the dam and the maximum water surface elevation reached during the routing of the PMF (or design flood if different from the PMF) with the spillway and other outlets, if any, functioning as planned.

Freeboard computations generally include the determination of wind setup and wave run-up on sloping or vertical embankments. A number of empirical relationships are available. Most of these involve use of wind velocity and fetch length as basic parameters. While the various relationships yield different results, the variation between the results is not so great compared to the variation that could be possible in the results due to assumptions of wind velocity and fetch length. The freeboard estimate is significantly affected by the magnitude of wind velocity and direction, and fetch length.

**Basic Data**

Site-specific data for wind velocity and direction were not available. Also, a reasonable configuration of the reservoir area at normal pool level could not be obtained. The reservoir shape was approximated from 1:50,000-scale map with 20-meter contour interval. In the absence of dominant wind direction data, the fetch length was assumed to be the maximum length of the reservoir for conservative estimates of wave run-up and wind setup. ACP provided monthly average wind speed and wind gust data for Gatun station. Wind speed was assumed after the review of this data.

**Methodology**

The procedures given in the United States Corps of Engineers publication ETL 1110-2-221 dated November 29, 1976 entitled, "Wave Run-up and Wind Setup on Reservoir Embankment by Bruce L. McCartney, Department of Army, Office of the Chief of Engineers, Washington D.C.," were used. The steps necessary for the computations of wind setup and wave run-up included:

- Estimate maximum wind speed
- Plot a wind velocity-duration curve for the site
- Compute reservoir effective fetch length
- Plot a wind velocity-duration curve for the reservoir effective fetch
- Determine magnitude of design wind
- Estimate design wind duration
- Estimate wave run-up
- Estimate wind setup

The step-by-step computations are shown below:

- Embankment slope 1:1.5, impervious, smooth
- Reservoir normal pool elevation = 100 meters
- Depth at toe of embankment = 70 meters (230 feet)
- Maximum fetch length = 7 km (4.5 miles)

- Effective fetch length = 0.25 * 7 = 1.8 km (1.2 miles), there is a procedure as per manual ETL 1110-2-211, to compute effective fetch; because reservoir plan is not available, this procedure could not be applied; an alternative is to assume effective fetch as 25 percent of maximum fetch length.
- Ratios between wind velocity over water and on land (manual ETL 1110-2-211)

| Effective Fetch (mi) | Ratio |
|---|---|
| 0.5 | 1.08 |
| 1.0 | 1.13 |
| 2.0 | 1.21 |
| 3.0 | 1.26 |
| 4.0 | 1.28 |
| 5.0 & above | 1.30 |

- Assumed wind velocity and duration over land and computed velocity over water

| Duration (min) | Wind Velocity over Land (mph) | Wind Velocity over Water (mph) |
|---|---|---|
| 1 | 55 | 62 |
| 60 | 30 | 34 |
| 120 | 28 | 32 |

- Wind velocity for an effective fetch of 1.2 miles from Figure 11 of ETL 1110-2-221.

| Duration (min) | Wind Velocity over Water (mph) |
|---|---|
| 15 | 82 |
| 25 | 28 |
| 30 | 19 |

- Plotted the above two sets of wind data, the intersection of the two curves provided a design velocity of 53 mph and a duration of 20 minutes.
- From Figure 11 of ETL 1110-2-221, the significant wave height (Hs) was about 2.5 feet and wave period (Ts) was about 2.9 seconds.
- The following wave run-up relationship (ETL 1110-2-221) was used:

Rs/Hs = 1/(0.4 + ((Hs/Lo)^0.5) * Cot A))

Rs = wave run-up, feet
Hs = significant wave height, feet
Cot A = 1.5 (slope)
Lo = wave length in feet
= 5.12 (Ts ^ 2), Ts is wave period in seconds

- Based on the above relationship, Rs = 3.3 feet
- As per recommendation in ETL 1110-2-221, Rmax = 3.3 * 1.5 = 4.9 feet

- For wind setup, the following relationship given in ETL 1110-2-221 was used.

S = ((U ^ 2) * F)/ (1400 D)

S = setup in feet
U = average wind velocity in feet, mph, a velocity of 53 mph was used.
D = average depth along the fetch, a depth of 130 feet was used.
F = fetch distance, twice the effective fetch, a value of 2.4 miles was used.

- Based on the above data, the wind setup was about 0.1 feet.

**Summary**

The above computations give the following data:

Design wind velocity = 53 mph
Wind duration = 20 minutes
Wave run-up = 4.9 feet (1.5 m)
Wind setup = 0.1 feet (0.1 m)
Allowance for wave action over normal pool = 1.5 + 0.1 = 1.6 meters

The above allowance may appear to be conservatively on a high side. However, USBR publication "Design of Small Dams," provide recommendation for selection of normal and minimum freeboard (Table 6.4, page 258, third edition, 1987). For an effective fetch length of 1.2 miles, the recommended freeboards are about 5.0 and 4.0 feet (about 1.5 and 1.2 meters), respectively. Based on this, the computed value of 1.6 meters is in line with the USBR's recommendations.

## Attachment 3 – Comparative Cost Estimate

TAMS

**MEMORANDUM**

| | | | | | |
|---|---|---|---|---|---|
| To | Michael Saunders | Company | MWH | Date | March 25, 2002 |
| From | Jean-Pierre Minois | | | Job No. | 6298 |
| Subject | Unit Construction Cost Estimate for Water Supply Projects - Panama Canal | | | | |


**TAMS Consultants, Inc.**

The TAMS Building 655 Third Avenue New York, NY 10017
(212) 867-1777 Fax (212) 697-6354

Cost Estimates

Unit cost for major items of dam construction were developed. These items include: excavation (common and rock), fill placement, quarrying, concrete fabrication and placement, formwork, steel reinforcement and Roller Compacted Concrete. Other unit cost were estimated from experience on other project of similar nature. The major unit costs were developed using cost of labor, equipment and material.

The cost of local labor was estimated based on the "Convención Colectiva de Trabajo de Panamá" dated July 1998. This document indicates the minimum applicable wages to be paid to workers in the construction industry by profession and region, for every years from July 1998 to June 2002. These rate were increased by 30% to reflect the fact they are mandatory minimum wages. An average across the professions was taken to derived four main categories: unskilled labor, skilled labor, equipment operator and truck driver. The wages were also increased to reflect the expected 60-hour work week: an overtime premium of 16.7% was assumed. The costs of salary were then calculated by adding 50% for social cost. This resulted in the following hourly cost of salary:

| | |
|---|---|
| Unskilled labor: | $5.50/hr |
| Skilled labor: | $6.60/hr |
| Equipment operator: | $7.90/hr |
| Truck driver: | $6.20/hr |

In addition to the local labor a crew leader was generally included at the rate of $10.00/hr. For specialized activities, an engineer was included at the rate of $60.00 per hour.

Equipment rate were obtained from the publication of the US Army Corps of Engineers entitled "Construction Equipment Ownership and Operating Expense" (EP 1110-1-8), dated August 31, 2001. Equipment requirements and production rates were developed based on experience in similar type of project in tropical countries.

Materials including explosives, cement, reinforcement steel are anticipated to be imported for the most part. International unit prices were used.

The build-up of the unit rates include also a margin of 30% to reflect the following items:

| | |
|---|---|
| Contractor home office charges | 5% |
| Project management and engineering | 7% |
| Maintenance crew | 3% |
| Field office and accommodation | 2% |
| Electric power | 1% |
| Equipment mobilization and demobilization | 2% |
| Margin for risk | 2% |
| Margin for profit | 8% |

The resulting unit prices were compared with those obtained through the bidding process on other international water resources projects in Central and South America and appear to be reasonable estimate for this type of construction.

## Panama Canal Authority
### Contract CC-3-536
### Task Order 5, Cocle del Norte and Cano Sucio Water Supply Feasibility Study
#### Dam Type Alternative Study - Cano Sucio

**CFRD** **Ungated** **$ 4,328,670**

**Quantity Take-Offs**

| Item | Description | Unit | Quantity | | Unit Price | | Price |
|---|---|---|---|---|---|---|---|
| **DIVERSION, LOW LEVEL OUTLET** | | | | | | | |
| 1 | Site Preparation | $m^2$ | 10,000 | $ | 0.50 | $ | 5,000 |
| 2 | Diversion | | | | | | |
| 2.1 | Overburden | $m^3$ | - | $ | 3.20 | $ | - |
| 2.2 | Rock | $m^3$ | 3,400 | $ | 8.75 | $ | 29,750 |
| 2.3 | Cofferdams | $m^2$ | 16,300 | $ | 6.40 | $ | 104,320 |
| 2.4 | Concrete | $m^3$ | 2,500 | $ | 115.00 | $ | 287,500 |
| 2.5 | Formwork | $m^2$ | 2,900 | $ | 46.20 | $ | 133,980 |
| 2.6 | Reinforcement | kg | 96,589 | $ | 1.36 | $ | 131,361 |
| | Subtotal | | | | | $ | 691,911 |
| **DAM** | | | | | | | |
| 1 | Excavation | | | | | | |
| 1.1 | Overburden | $m^3$ | 22,762 | $ | 3.20 | $ | 72,837 |
| 1.2 | Rock* | $m^3$ | 5,690 | $ | 8.75 | $ | 49,791 |
| 2 | Grouting | | | | | | |
| 2.1 | Cutoff | L.S. | 1 | $ | 150,000.00 | $ | 150,000 |
| 3 | Rockfill | | | | | | |
| 3.1 | Mass* | $m^3$ | 73,490 | $ | 10.70 | $ | 786,338 |
| 3.2 | Filter | $m^3$ | 13,300 | $ | 16.20 | $ | 215,460 |
| 3.3 | Drain | $m^3$ | 1,330 | $ | 16.20 | $ | 21,546 |
| 4 | Concrete | | | | | | |
| 4.1 | Plinth | $m^3$ | 1,150 | $ | 115.00 | $ | 132,250 |
| 4.2 | Facing | $m^2$ | 4,400 | $ | 80.00 | $ | 352,000 |
| 4.3 | Parapet -US | $m^3$ | 1,000 | $ | 250.00 | $ | 250,000 |
| 4.4 | Parapet -DS | $m^3$ | 200 | $ | 250.00 | $ | 50,000 |
| 4.5 | Crest | $m^3$ | 1,200 | $ | 115.00 | $ | 138,000 |
| Subtotal | | | | | | $ | 2,218,222 |
| **SPILLWAY** | | | | | | | |
| 1 | Site Preparation | $m^2$ | 30,500 | $ | 0.50 | $ | 15,250 |
| 2 | Excavation | | | | | | |
| 2.1 | Overburden | $m^3$ | 44,632 | $ | 3.20 | $ | 142,821 |
| 2.2 | Rock* | $m^3$ | 20,347 | $ | 8.75 | $ | 178,036 |
| 3 | Headworks | | | | | | |
| 3.1 | Concrete | $m^3$ | 1,580 | $ | 115.00 | $ | 181,700 |
| 3.2 | Formwork | $m^2$ | 1,105 | $ | 46.20 | $ | 51,056 |
| 3.3 | Reinforcement | kg | 65,425 | $ | 1.36 | $ | 88,978 |
| 4 | Chute and Flip Bucket | | | | | | |
| 4.1 | Concrete | $m^3$ | 1,997 | $ | 115.00 | $ | 229,658 |
| 4.2 | Formwork | $m^2$ | 822 | $ | 46.20 | $ | 37,967 |
| 4.3 | Reinforcement | kg | 86,428 | $ | 1.36 | $ | 117,543 |
| 5 | Bridge | | | | | | |
| 5.1 | Concrete | $m^3$ | 224 | $ | 115.00 | $ | 25,760 |
| 5.2 | Formwork | $m^2$ | 280 | $ | 46.20 | $ | 12,936 |
| 5.3 | Reinforcement | kg | 35,123 | $ | 1.36 | $ | 47,768 |
| 6 | Tailrace Channel | | | | | | |
| 6.1 | Overburden | $m^3$ | - | $ | 3.20 | $ | - |
| 6.2 | Rock* | $m^3$ | - | $ | 8.75 | $ | - |
| Subtotal | | | | | | $ | 1,129,472 |
| **LOW LEVEL INTAKE TOWER** | | | | | | | |
| 1 | Tower | | | | | | |
| 1.1 | Concrete | $m^3$ | 1,075 | $ | 115.00 | $ | 123,625 |
| 1.2 | Formwork | $m^2$ | 1,100 | $ | 46.20 | $ | 50,820 |
| 1.3 | Reinforcement | kg | 84,280 | $ | 1.36 | $ | 114,621 |
| Subtotal | | | | | | $ | 289,066 |

# Panama Canal Authority
## Contract CC-3-536
## Task Order 5, Cocle del Norte and Cano Sucio Water Supply Feasibility Study
### Dam Type Alternative Study - Cano Sucio

**Earthfill** **Ungated** **$ 4,000,595**

**Quantity Take-Offs**

| Item | Description | Unit | Quantity | | Unit Price | | Price |
|---|---|---|---|---|---|---|---|
| **DIVERSION, LOW LEVEL OUTLET** | | | | | | | |
| 1 | Site Preparation | $m^2$ | 32,000 | $ | 0.50 | $ | 16,000 |
| 2 | Diversion | | | | | | |
| 2.1 | Overburden | $m^3$ | - | $ | 3.20 | $ | - |
| 2.2 | Rock | $m^3$ | 3,200 | $ | 8.75 | $ | 28,000 |
| 2.3 | Cofferdams | $m^2$ | 16,300 | $ | 6.40 | $ | 104,320 |
| 2.4 | Concrete | $m^3$ | 2,300 | $ | 115.00 | $ | 264,500 |
| 2.5 | Formwork | $m^2$ | 2,700 | $ | 46.20 | $ | 124,740 |
| 2.6 | Reinforcement | kg | 89,690 | $ | 1.36 | $ | 121,978 |
| | Subtotal | | | | | $ | 659,538 |
| **DAM** | | | | | | | |
| 1 | Excavation | | | | | | |
| 1.1 | Overburden | $m^3$ | 37,890 | $ | 3.20 | $ | 121,248 |
| 1.2 | Rock | $m^3$ | 4,210 | $ | 8.75 | $ | 36,838 |
| 2 | Grouting | | | | | | |
| 2.1 | Cutoff | L.S. | 1 | $ | 150,000.00 | $ | 150,000 |
| 3 | Fill | | | | | | |
| 3.1 | Random | $m^3$ | 157,220 | $ | 6.40 | $ | 1,006,208 |
| 3.2 | Filter | $m^3$ | 8,650 | $ | 16.20 | $ | 140,130 |
| 3.3 | Drain | $m^3$ | 8,650 | $ | 16.20 | $ | 140,130 |
| 3.4 | Riprap | $m^3$ | 9,980 | $ | 16.20 | $ | 161,676 |
| 4 | Concrete | | | | | | |
| 4.1 | Crest Road | $m^3$ | 1,446 | $ | 115.00 | $ | 166,290 |
| Subtotal | | | | | | $ | 1,922,520 |
| **SPILLWAY** | | | | | | | |
| 1 | Site Preparation | $m^2$ | 30,500 | $ | 0.50 | $ | 15,250 |
| 2 | Excavation | | | | | | |
| 2.1 | Overburden | $m^3$ | 44,632 | $ | 3.20 | $ | 142,821 |
| 2.2 | Rock | $m^3$ | 20,347 | $ | 8.75 | $ | 178,036 |
| 3 | Headworks | | | | | | |
| 3.1 | Concrete | $m^3$ | 1,580 | $ | 115.00 | $ | 181,700 |
| 3.2 | Formwork | $m^2$ | 1,105 | $ | 46.20 | $ | 51,056 |
| 3.3 | Reinforcement | kg | 65,425 | $ | 1.36 | $ | 88,978 |
| 4 | Chute and Flip Bucket | | | | | | |
| 4.1 | Concrete | $m^3$ | 1,997 | $ | 115.00 | $ | 229,658 |
| 4.2 | Formwork | $m^2$ | 822 | $ | 46.20 | $ | 37,967 |
| 4.3 | Reinforcement | kg | 86,428 | $ | 1.36 | $ | 117,543 |
| 5 | Bridge | | | | | | |
| 5.1 | Concrete | $m^3$ | 224 | $ | 115.00 | $ | 25,760 |
| 5.2 | Formwork | $m^2$ | 280 | $ | 46.20 | $ | 12,936 |
| 5.3 | Reinforcement | kg | 35,123 | $ | 1.36 | $ | 47,768 |
| 6 | Tailrace Channel | | | | | | |
| 6.1 | Overburden | $m^3$ | - | $ | 3.20 | $ | - |
| 6.2 | Rock | $m^3$ | - | $ | 8.75 | $ | - |
| Subtotal | | | | | | $ | 1,129,472 |
| **LOW LEVEL INTAKE TOWER** | | | | | | | |
| 1 | Tower | | | | | | |
| 1.1 | Concrete | $m^3$ | 1,075 | $ | 115.00 | $ | 123,625 |
| 1.2 | Formwork | $m^2$ | 1,100 | $ | 46.20 | $ | 50,820 |
| 1.3 | Reinforcement | kg | 84,280 | $ | 1.36 | $ | 114,621 |
| Subtotal | | | | | | $ | 289,066 |

## Panama Canal Authority
### Contract CC-3-536
### Task Order 5, Cocle del Norte and Cano Sucio Water Supply Feasibility Study
#### Dam Type Alternative Study - Cano Sucio

**RCC** **Ungated** **$ 4,198,252**

**Quantity Take-Offs**

| Item | Description | Unit | Quantity | | Unit Price | | Price |
|---|---|---|---|---|---|---|---|
| **DIVERSION, LOW LEVEL OUTLET** | | | | | | | |
| 1 | Site Preparation | $m^2$ | 5,000 | $ | 0.50 | $ | 2,500 |
| 2 | Diversion | | | | | | |
| 2.1 | Overburden | $m^3$ | - | $ | 3.20 | $ | - |
| 2.2 | Rock | $m^3$ | 1,300 | $ | 8.75 | $ | 11,375 |
| 2.3 | Cofferdams | $m^2$ | - | $ | 6.40 | $ | - |
| 2.4 | Concrete | $m^3$ | 700 | $ | 115.00 | $ | 80,500 |
| 2.5 | Formwork | $m^2$ | 800 | $ | 46.20 | $ | 36,960 |
| 2.6 | Reinforcement | kg | 27,597 | $ | 1.36 | $ | 37,532 |
| Subtotal | | | | | | $ | 168,867 |
| **DAM** | | | | | | | |
| 3 | Foundation Excavation | | | | | | |
| 3.1 | Overburden | $m^3$ | 8,150 | $ | 3.20 | $ | 26,080 |
| 3.2 | Rock | $m^3$ | 8,150 | $ | 8.75 | $ | 71,313 |
| 4 | Grouting | | | | | | |
| 4.1 | Cutoff | L.S. | 1 | $ | 150,000.00 | $ | 150,000 |
| 5 | RCC | | | | | | |
| 5.1 | Mass | $m^3$ | 27,900 | $ | 72.00 | $ | 2,008,800 |
| 5.2 | Uncompacted | $m^3$ | 500 | $ | 72.00 | $ | 36,000 |
| 5.3 | US/DS Facing | $m^3$ | 3,000 | $ | 282.00 | $ | 846,000 |
| 5.4 | Foundation | $m^3$ | 1,600 | $ | 115.00 | $ | 184,000 |
| 5.5 | Gallery | $m^3$ | 900 | $ | 115.00 | $ | 103,500 |
| Subtotal | | | | | | $ | 3,425,693 |
| **SPILLWAY** | | | | | | | |
| 1 | Headworks | | | | | | |
| 1.1 | Concrete | $m^3$ | 47 | $ | 115.00 | $ | 5,405 |
| 1.2 | Formwork | $m^2$ | 94 | $ | 46.20 | $ | 4,343 |
| 1.3 | Reinforcement | kg | 3,685 | $ | 1.36 | $ | 5,011 |
| 2 | Chute and Flip Bucket | | | | | | |
| 2.1 | Concrete | $m^3$ | 1,581 | $ | 115.00 | $ | 181,838 |
| 2.2 | Formwork | $m^2$ | 1,234 | $ | 46.20 | $ | 57,011 |
| 2.3 | Reinforcement | kg | 71,940 | $ | 1.36 | $ | 97,838 |
| 3 | Bridge | | | | | | |
| 3.1 | Concrete | $m^3$ | 224 | $ | 115.00 | $ | 25,760 |
| 3.2 | Formwork | $m^2$ | 280 | $ | 46.20 | $ | 12,936 |
| 3.3 | Reinforcement | kg | 35,123 | $ | 1.36 | $ | 47,768 |
| Subtotal | | | | | | $ | 437,910 |
| **LOW LEVEL INTAKE TOWER** | | | | | | | |
| 1 | Tower | | | | | | |
| 1.1 | Concrete | $m^3$ | 550 | $ | 115.00 | $ | 63,250 |
| 1.2 | Formwork | $m^2$ | 950 | $ | 46.20 | $ | 43,890 |
| 1.3 | Reinforcement | kg | 43,120 | $ | 1.36 | $ | 58,643 |
| Subtotal | | | | | | $ | 165,783 |

Part 3
Dam Height Selection

## Attachment 6 – Río Coclé del Norte CFRD Deformation Analysis

MWH **CHICAGO**

| | | | | | |
|---|---|---|---|---|---|
| SUBJECT | Cocle del NorteEarthquake Severity Index | | | PROJECT NAME | Cocle del Norte |
| COMPUTED | R. Green | DATE | 20-Oct-03 | PROJECT NUMBER | 1001217 |
| CHECKED | MW | DATE | Oct-03 | | |
| BACKCHECKED | | DATE | | Page 1 of 1 | |

O:\ProjectNumber\15000-15999\15593\Task Order 5 Norte_Sucio Water Supply\Geology-Geotech\[Norte CFRD Seismic deformation_Oct03.xls]Sheet1

**PURPOSE** Estimate the deformation of the rockfill due to the Maximum Design Earthquake (MDE)

**REFERENCES** Bureau G. et. al. 1985. Seismic Analysis of Concrete Face Rockfill Dams, in Cooke, J.B. and Sherard, J.L. Concrete Face Rockfill Dams - Design, construction and performance. ASCE New York.

**RESULTS**

Calculations of the Earthquake Severity Index (ESI) and resulting deformation calculated following the procedure presented by Bureau et al 1985, indicate that the estimated vertical deformation of the proposed CFRD at the Rio Cocle del Norte site is about 0.2 m The freeboard prvided in the design is larger than this value, so the current dam design would allow safe operation after occurrence of the MDE.

**CALCULATIONS**

pga = 0.27 peak ground acceleration

Mag = 7.5 magnitude of earthquake for the MDE

ESI = $pga\ (Mag-4.5)^3$

ESI = 7.29

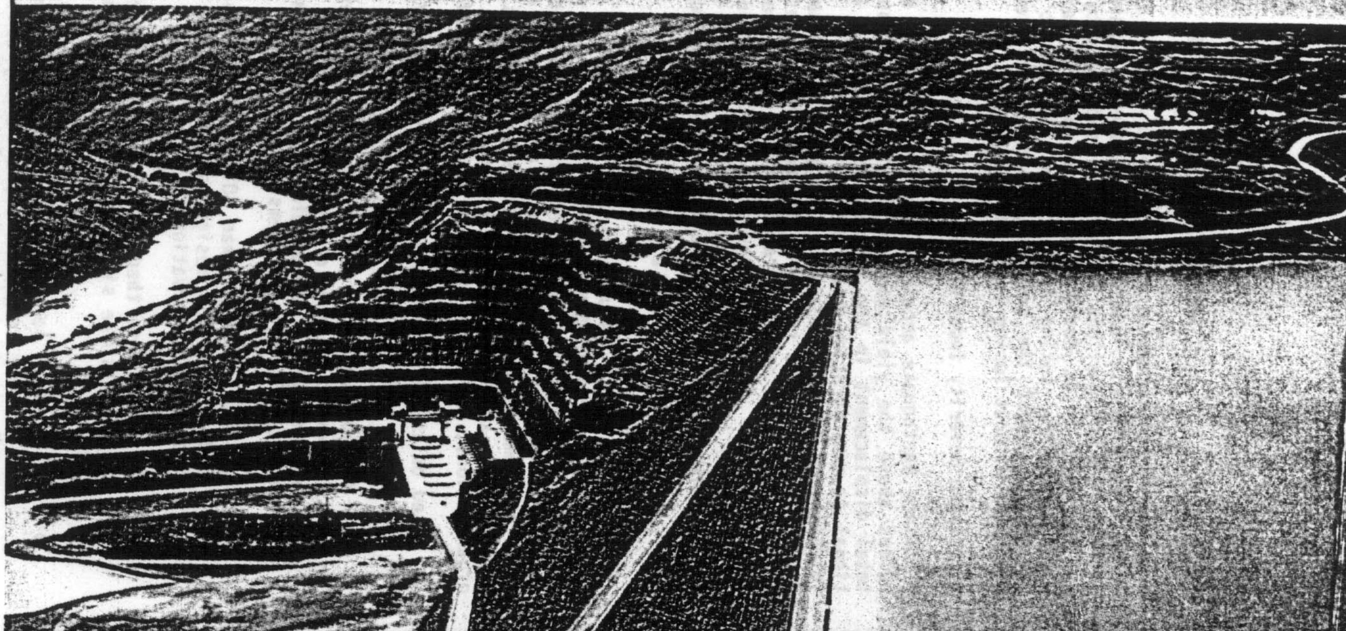
relative vertical deformation (Figure 1 of Bureau et al 1985)

Vdef = 0.0015

Vdef = Hdam * Vdam

| **For Cocle del Norte FSL 100** | | **For Cocle del Norte FSL 71** | |
|---|---|---|---|
| Hdam = | 111 m | Hdam = | 84 m |
| Vdef = | 0.17 m | Vdef = | 0.13 m |

# Concrete Face Rockfill Dams–



# Design, Construction, and Performance

Edited by J. Barry Cooke and James L. Sherard

finite-element model of the dam. The earthquake forces that induce the permanent deformations are, therefore, represented by equivalent increases in the static stresses; the dam deforms in response to this new load.

The above procedures decouple the estimation of dam response and deformations. Additional simplifying assumptions are frequently used: (a) treat the dam foundation as a rigid base (rather than an energy-absorbing boundary); (b) consider horizontal earthquake loading only; (c) disregard hydrodynamic effects of the reservoir water upon the concrete face. Assumption (a) seems reasonable, considering that most concrete face rockfill dams are founded on hard erosion-resistant foundation. Assumptions (b) and (c) (generally acceptable for earthfill dams) need to be substantiated for concrete face rockfill dams, because of their steep slopes, and because water pressures apply directly to the concrete facing, concentrating the loads in that area.

Variances of the above evaluation procedures are possible. For dams which are narrow relative to their height, two-dimensional analyses may overestimate the fundamental period of these structures. The shear modulus can be adjusted so that the two-dimensional model duplicates the response expected from the three-dimensional dam more closely (Vrymoed, 1981). Three-dimensional and probabilistic finite element equivalent-linear response analyses of rockfill dams have also been used (Yanagisawa, Fukui, 1980; Kagawa et al., 1981).

Overall, the Newmark method, combined with detailed dynamic response analyses, applies reasonably well to the seismic evaluation of rockfill dams. The Lee and Serff methods are more difficult to implement because they were originally intended for earthfill dams, where the stress-strain relationships can be established through the dynamic testing of the embankment materials. Cyclic tests on rockfill materials are impractical. Furthermore, the "deformed" embankment shapes determined in the decoupled analyses using the Lee or Serff methods are sometimes questionable.

It should be noted that because of their stiffness characteristics, rockfill dams respond to earthquake motion at shorter periods than earthfill dams: first mode frequencies between 2 and 5 Hertz were derived from measured response to earthquake- and vibrator-induced motions for ten Japanese rockfill dams with heights ranging from 213 to 445 ft (65 to 135 m) (Takahashi et al., 1977). Although fundamental frequencies would decrease under severe earthquake loading, one can expect that relatively high frequency components would contribute to a significant part of the dam response, which emphasizes the need for determining the acceleration response of the dam accurately.

Since maintenance of gross stability and sufficient freeboard remain the primary requirements in evaluating the seismic performance of rockfill dams, limited emphasis has presently been placed on the analysis of the concrete slab itself, especially since cracking of the slab is not expected to result in excessive leakage problems. The simplifying assumptions and limitations of the dam analysis procedures normally



preclude direct inclusion of the concrete face in the dam finite element model. The concrete face is either analyzed separately by applying the computed dam deformations as boundary conditions to a mathematical model of the slab, or is designed based on previous experience and professional judgment, taking into account the amount of shear and moment deformations that the concrete, joints, and steel reinforcement can withstand without losing their effectiveness.

Earthquake Severity Index (ESI)

Since earthquake accelerations are random in nature, the number of pulses above the yield acceleration that contribute to the cumulative total displacement in the Newmark method can be assumed to be proportional to the duration D of the strong phase of shaking (for a given intensity of motion, measured by the peak ground acceleration A in g's). Hence, we propose to relate estimated deformations and the product $AD^2$ (as accelerations are integrated twice with respect to time to obtain displacements). Based on a review of earthquake durations as a function of magnitude (Chang, Krinitzsky, 1977), we have formulated an average relationship between earthquake duration D in seconds and magnitude M:

$$D = 7\ (M - 4.5)^{1.5} \qquad (1)$$

Using the above assumption and relationship between D and M, we introduce the product $A(M - 4.5)^3$, which we call Earthquake Severity Index (ESI), and attempt to correlate ESI with earthquake-induced deformations in rockfill dams. Table 2 and Figure 1 compare relative vertical settlements and ESI's for the seven examples of Table 1 where the magnitude is known, and for eight rockfill dams analyzed by various organizations, including the example discussed further.

Based on the data presented on Figure 1, the following observations can be made:

- A wide range of sites, material properties, conditions of placement, methods of design and analysis and ground motions is represented. Nevertheless, a relationship between ESI and relative settlement seems apparent.
- For ESI's greater than 10 (large magnitudes), the settlements predicted by dam designers agree well with those extrapolated from actual observations.
- For ESI's less than 5 (low to moderate magnitudes), predicted settlements are significantly larger than the average observed trend.
- For a given location and dam height, Figure 1 provides a convenient way to obtain a preliminary estimate of crest settlements, or to compare the relative damage potential of several design earthquakes.

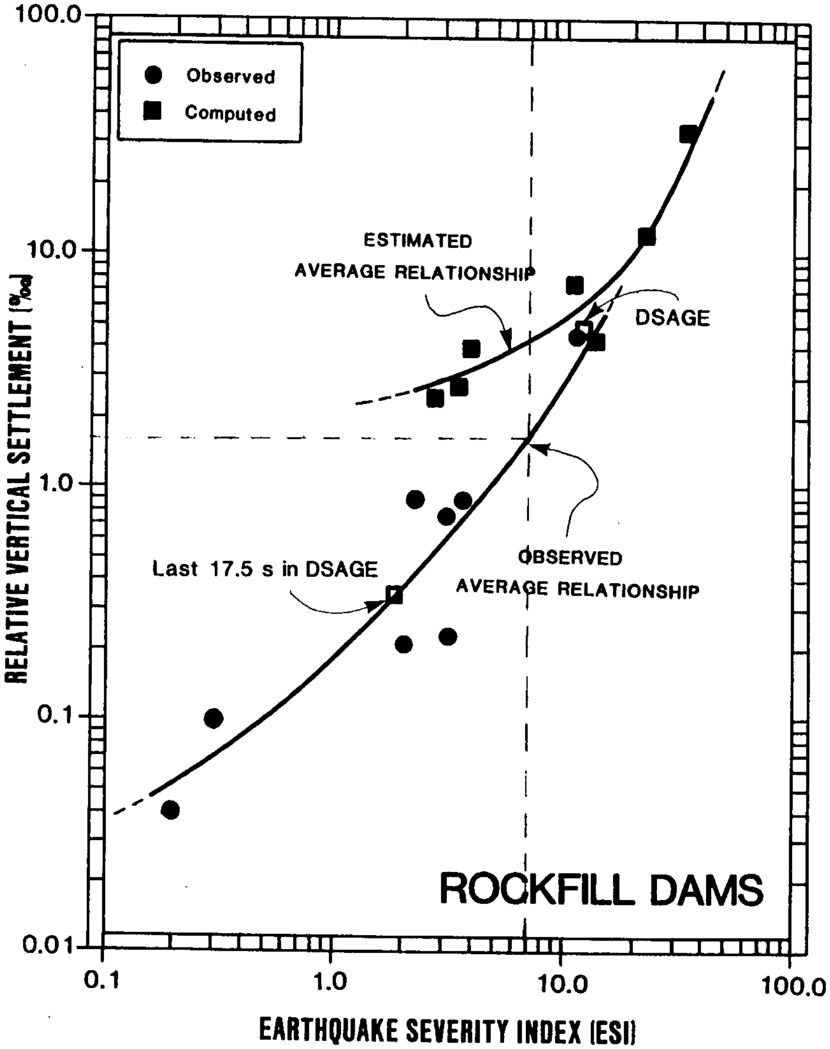



Figure 1. Relationship Between Crest Settlement and ESI

Coclé del Norte Mag 7.5
Pga = 0.27



**Table 2. Relative Settlement and ESI Data**

| DAM NAME (location) | H (m) | ΔH (mm) | RELATIVE SETTLEMENT (°/oo) | PGA (g) | M | ESI | REFERENCE |
|---|---|---|---|---|---|---|---|
| COGOTI (Chile) | 84 | 381(o) | 4.54 | 0.20 | 8.3 | 11.0 | (41) |
| MIBORO (Japan) | 131 | 30(o) | 0.23 | 0.20 | 7.0 | 3.1 | (29),(41) |
| MINASE (Japan) | 67 | 7(e)<br>61(o) | 0.10<br>0.91 | 0.02<br>0.08 | 6.9<br>7.5 | 0.3<br>2.2 | (27) |
| OROVILLE (Calif.) | 235 | 9(o) | 0.04 | 0.10 | 5.7 | 0.2 | (46) |
| EL INFIERNILLO (Mex.) | 148 | 130(o) | 0.88 | 0.12 | 7.6 | 3.6 | (35) |
| LA VILLITA (Mex.) | 60 | 45(o) | 0.75 | 0.10 | 7.6 | 3.0 | (35) |
| LEROY ANDERSON (Calif.) | 72 | 15(o) | 0.21 | 0.41 | 6.2 | 2.0 | (44) |
| TERROR LAKE (AK) | 50 | 600(e) | 12.00 | 0.35 | 8.5 | 22.4 | (18) |
| TERROR LAKE (AK) | 50 | 300(e) | 4.00 | 0.50 | 6.5 | 4.0 | (18) |
| CIRRATA (Indonesia) | 125 | 300(e) | 2.40 | 0.35 | 6.5 | 2.8 | (18) |
| PUEBLO VIEJO (Guatemala) | 133.5 | 4450(e) | 33.33 | 0.65 | 8.25 | 34.3 | (4) |
| CHICOASEN (Mexico) | 240 | 1000(e) | 4.17 | 0.85 | 7.0 | 13.3 | (13) |
| FORTUNA (Panama) (raised) | 104 | 800(e) | 7.69 | 0.40 | 7.5 | 10.8 | (16) |
| USBR (Example Dam) | 213 | 700(e) | 2.72 | 0.43 | 6.5 | 3.5 | (45) |
| Dames & Moore (Example Dam) | 100 | 487(e) | 4.87 | 0.70 | 7.1 | 12.3 | DSAGE (This paper) |

(o) observed
(e) estimated

## Advanced Seismic Evaluation Procedures

The main uncertainties in conventional simplified or detailed analyses of concrete face rockfill dam are primarily related, by increasing order of significance, to: (1) neglecting vertical motion, (2) neglecting hydrodynamic effects of the reservoir water and (3) computing non-recoverable plastic deformations by approximate procedures based on the results of an elastic analysis. Advanced analysis procedures are available to avoid making use of these simplifying assumptions. These improvements of the analysis methodology for concrete face rockfill dams are discussed below:

12. Newmark, N. M., "Effect of Earthquakes on Dams and Embankments," Geotechnique, Vol. 15, No. 2, London, England, June, 1965.

13. Seed, H. Bolton, "Considerations in the Earthquake-Resistant Design of Earth and Rockfill Dams," Geotechnique, Vol. 29, No. 3, 1979.

14. Seed, H. Bolton and Goodman, Robert E., "Earthquake Stability of Slopes of Cohesionless Soils," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 90, No. SM6, November, 1964, pp. 43-73.

15. Seed, H. B. and Idriss, I. M., "Influence of Soil Conditions on Ground Motions During Earthquakes," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 95, No. SM1, January, 1969.

16. State of California, Department of Water Resources, "The August 1, 1975 Oroville Earthquake Investigations," Bulletin 203-78, Department of Water Resources, State of California, The Resources Agency, February, 1978.

17. Vrymoed, J., "Dynamic FEM Model of Oroville Dam," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT8, August, 1981.

# SEISMIC ANALYSIS OF CONCRETE FACE ROCKFILL DAMS

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## Abstract

In this article, the observed behavior of existing rockfill dams during earthquakes is compared with published data regarding the estimated seismic performance of several recently designed embankments. An empirical factor related to peak ground acceleration and magnitude of the causative earthquake, the Earthquake Severity Index (ESI), is proposed to estimate earthquake-induced crest settlements for concrete face and other types of rockfill dams. New methods are proposed to include the effects of the reservoir-embankment interaction in the computed response and obtain the non-recoverable earthquake-induced deformations of the dam directly. These new procedures are illustrated by evaluating the response of a 328 ft (100 m) high example concrete face rockfill dam, subjected to strong earthquake shaking. The results of these analyses confirm the acceptability of the empirical relationship established between crest settlement and ESI.

## Introduction

Many engineers assume that well-compacted concrete face rockfill dams have a high resistance to seismic loading. Justifications for this assumption are based on several factors, including acceptable past performance of similar dams, a recognition that the entire embankment is unsaturated, and the fact that compacted rockfill develops high frictional resistance. Because of these observations, little emphasis has been placed to-date on the seismic design of such dams. Simplified analysis procedures are frequently used, and only recently more elaborate techniques, such as the finite element method of analysis, have been introduced to evaluate the dynamic performance of such dams. Even when detailed analyses are contemplated, these often include many simplifying assumptions, such as the separate evaluation of dam response and earthquake-induced deformations. This article reviews the state-of-the art and proposes new advanced numerical analysis techniques for the seismic design of concrete face rockfill dams.

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# Attachment 7 – Río Coclé del Norte FSL 71 Hydraulic Analyses

**MWH**
MONTGOMERY WATSON HARZA

MWH AMERICAS, INC.
HYDROPOWER

**Location** Chicago Office **Date** October 22, 2003

**To** Michael Newbery

**From** Wade P. Moore

**Subject** Cocle del Norte Water Supply Feasibility Study
Hydraulic Analysis for Design of Cofferdam and Drawdown Times
Reservoir FSL 71.0m

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This memorandum summarizes the procedures and results of the hydraulic analysis performed for the design of cofferdam, closure dikes, and diversion tunnel for the Cocle del Norte Project. The analysis included:

- Estimation of cofferdam height upstream and downstream of the proposed dam. The diameters of the modified horseshoe (D-shaped) tunnels considered were 6, 8, and 10 m with a length of 550.0 m.
- Estimation of closure dike height for low flows (25, 50 and 75 $m^3/s$)
- Drawdown time to 75, 50, and 25% of full supply level.

Basic data used in the analysis is discussed. Results are provided as tables.

## Computer Model

The Full-Equations (FEQ) modeling system of one-dimensional, unsteady, open-channel flow was used for the hydraulic analysis of the Cocle del Norte project. FEQ is based on the full Saint-Venant equations, and was developed by Delbert Franz of Linsley, Kraeger Associates, Ltd., Mountain View, CA. It is widely used by engineers and hydrologists in county and state agencies and consulting firms, and has been accepted by the Federal Emergency Management Agency (FEMA) for use in floodplain studies. The program is used in a variety of applications such as flood studies, design studies for dam spillways, and dam break analyses. The program supports a wide variety of control structures including bridges, culverts, spillways, weirs, sluice gates, pumps, side weirs, expansions, contractions, and drop structures. FEQ is capable of simulating flow conditions in complicated networks of open channels and closed conduits.

## Introduction

The main purpose of this study is to determine the size of the diversion tunnel to pass the 50-yr flow as well as the resulting cofferdam heights upstream and downstream of the dam. The main components of the model include the 50-yr hydrograph, the reservoir capacity curve, and the cross sectional data, shown in Tables 1 and 2, and Appendix I, respectively.

**Table 1. 50-year flood hydrograph at Cocle del Norte**

| Time (hours) | Flow ($m^3/s$) | Time (hours) | Flow ($m^3/s$) | Time (hours) | Flow ($m^3/s$) |
|---|---|---|---|---|---|
| 1 | 128 | 18 | 2500 | 35 | 1150 |
| 2 | 135 | 19 | 2400 | 36 | 1100 |
| 3 | 244 | 20 | 2300 | 37 | 1070 |
| 4 | 396 | 21 | 2200 | 38 | 1040 |
| 5 | 532 | 22 | 2100 | 39 | 1010 |
| 6 | 742 | 23 | 2000 | 40 | 980 |
| 7 | 900 | 24 | 1900 | 41 | 950 |
| 8 | 1500 | 25 | 1800 | 42 | 920 |
| 9 | 2000 | 26 | 1700 | 43 | 890 |
| 10 | 2600 | 27 | 1600 | 44 | 860 |
| 11 | 3200 | 28 | 1500 | 45 | 830 |
| 12 | 3860 | 29 | 1450 | 46 | 800 |
| 13 | 3700 | 30 | 1400 | 47 | 770 |
| 14 | 3400 | 31 | 1350 | 48 | 740 |
| 15 | 3100 | 32 | 1300 | 68 | 140 |
| 16 | 2800 | 33 | 1250 | 72 | 128 |
| 17 | 2600 | 34 | 1200 | | |

**Table 2. Reservoir capacity curve at Cocle del Norte**

| Elevation (m) | Area ($km^2$) | Volume (Million $m^3$) |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 5.0 | 3.60 | 4.58 |
| 10.0 | 8.14 | 28.83 |
| 15.0 | 13.71 | 72.87 |
| 20.0 | 20.52 | 136.80 |
| 25.0 | 28.90 | 265.98 |
| 30.0 | 38.94 | 438.60 |
| 35.0 | 50.86 | 661.80 |
| 40.0 | 65.27 | 952.72 |
| 45.0 | 83.69 | 1,339.89 |
| 50.0 | 105.97 | 1,830.35 |
| 55.0 | 132.07 | 2,426.08 |
| 60.0 | 160.59 | 3,140.95 |
| 65.0 | 190.21 | 4,011.29 |
| 70.0 | 220.44 | 5,039.91 |
| 75.0 | 251.14 | 6,208.50 |
| 80.0 | 282.41 | 7,513.97 |
| 85.0 | 314.43 | 8,986.75 |
| 90.0 | 347.03 | 10,598.11 |
| 95.0 | 380.83 | 12,347.23 |
| 100.0 | 413.90 | 14,435.34 |
| 105.0 | 448.12 | 16,948.64 |
| 110.0 | 482.34 | 19,461.94 |

## Tailwater Analysis

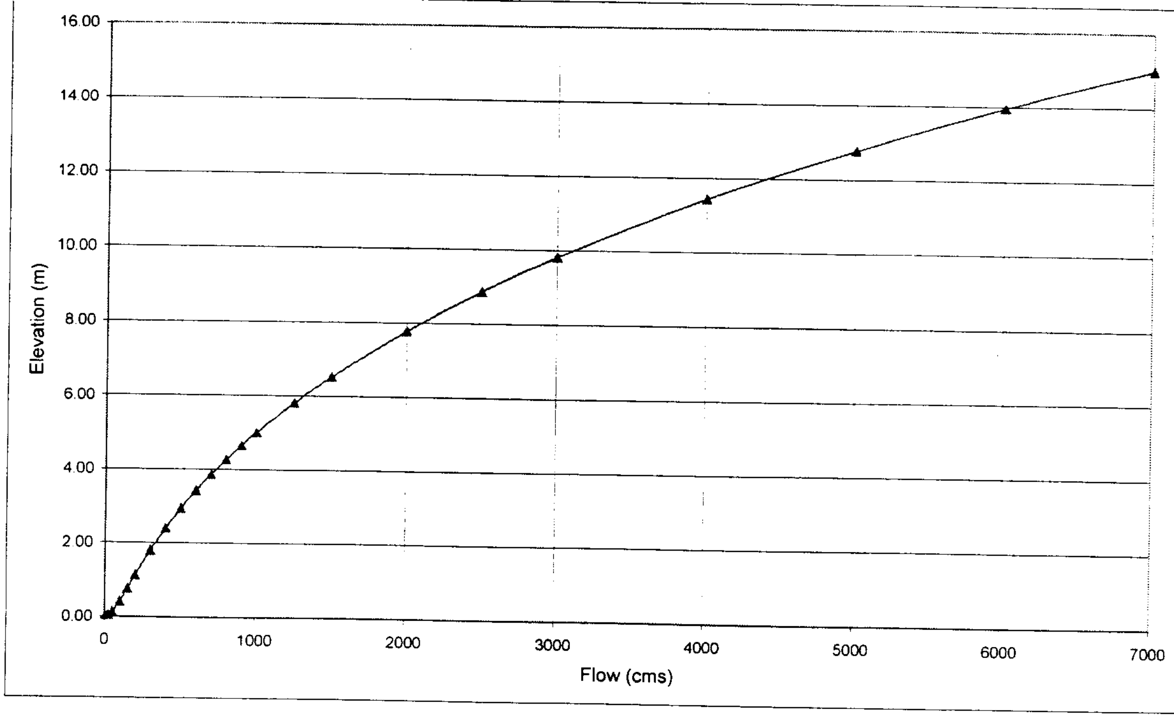
The objective of the tailwater analysis was to develop a tailwater-rating curve for the proposed Cocle del Norte site. Ten cross-sections, located between 200 and 13,000 m downstream of the dam, were used. The station-elevation data for the first nine cross-sections were obtained from a topographic map of 1:50,000-scale and 10 m contour interval. An echo sounder was used to determine the thalweg for Section 1. Section 10, located 13,000 m downstream of the dam, is a wide section representing the estuary. The average channel slope of the 12,800 m channel reach is 0.004%. The Manning's roughness coefficients for the study reach are 0.035 for the channel flow and 0.050 for over-bank flow. As mentioned earlier, the cross-section data are listed in Appendix I.

The resulting tailwater rating curve at the first cross-section is tabulated in Table 3 and plotted in Figure 1. The boundary condition at the estuary was fixed at 0.0 m. Typical tidal data for the area was also simulated, but the model runs show that the tide has no significant effect at the dam, especially at higher flows. This is consistent with field observations.

**Table 3. Tailwater rating curve (200 m d/s of dam)**

| Flow ($m^3/s$) | Tailwater Elevation(m) |
|---|---|
| 1 | 0.00 |
| 2 | 0.00 |
| 5 | 0.00 |
| 10 | 0.01 |
| 25 | 0.03 |
| 50 | 0.12 |
| 100 | 0.40 |
| 150 | 0.75 |
| 200 | 1.11 |
| 300 | 1.79 |
| 400 | 2.39 |
| 500 | 2.93 |
| 600 | 3.41 |
| 700 | 3.85 |
| 800 | 4.26 |
| 900 | 4.64 |
| 1000 | 5.00 |
| 1250 | 5.81 |
| 1500 | 6.53 |
| 2000 | 7.78 |
| 2500 | 8.86 |
| 3000 | 9.81 |
| 4000 | 11.44 |
| 5000 | 12.78 |
| 6000 | 13.95 |
| 7000 | 15.00 |

**Figure 1. Cocle del Norte tailwater rating curve at Section 1**




## Evaluation of Diversion Tunnel Size

Three diversion tunnel sizes were modeled in order to determine the cofferdam height upstream and downstream of the proposed dam. Tunnel sizes considered are D-shaped with diameters 6, 8, and 10 m and a length of 550 m. The tunnel invert elevation is 0.0 m at both ends and the discharge point is at Section 1, 200 m downstream of the dam. A Manning's coefficient of 0.014 was used for the concrete-lined tunnel. Entrance and exit loss coefficients are 0.5 and 1.0, respectively. Bend losses were assumed to be negligible. The inflow routed through the reservoir is the 50-yr hydrograph.

The cofferdam heights and peak discharge for the different tunnel sizes are shown in Table 4a. Simulations include both a fixed water surface elevation of 0.0 m at the estuary and a tide which fluctuates between –0.22 and + 0.27 m. Cofferdam heights turn out to be the same in both cases. This information was used to select the most cost-effective alternative.

**Table 4a. Diversion tunnel analysis for Cocle del Norte (D-shaped, 50-yr flow)**

| Tunnel Diameter (m) | Tunnel Length (m) | Peak Outflow ($m^3/s$) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|---|---|
| 6 | 550.0 | 367 | 24.0 | 2.2 |
| 8 | 550.0 | 636 | 22.1 | 3.5 |
| 10 | 550.0 | 933 | 20.6 | 4.8 |

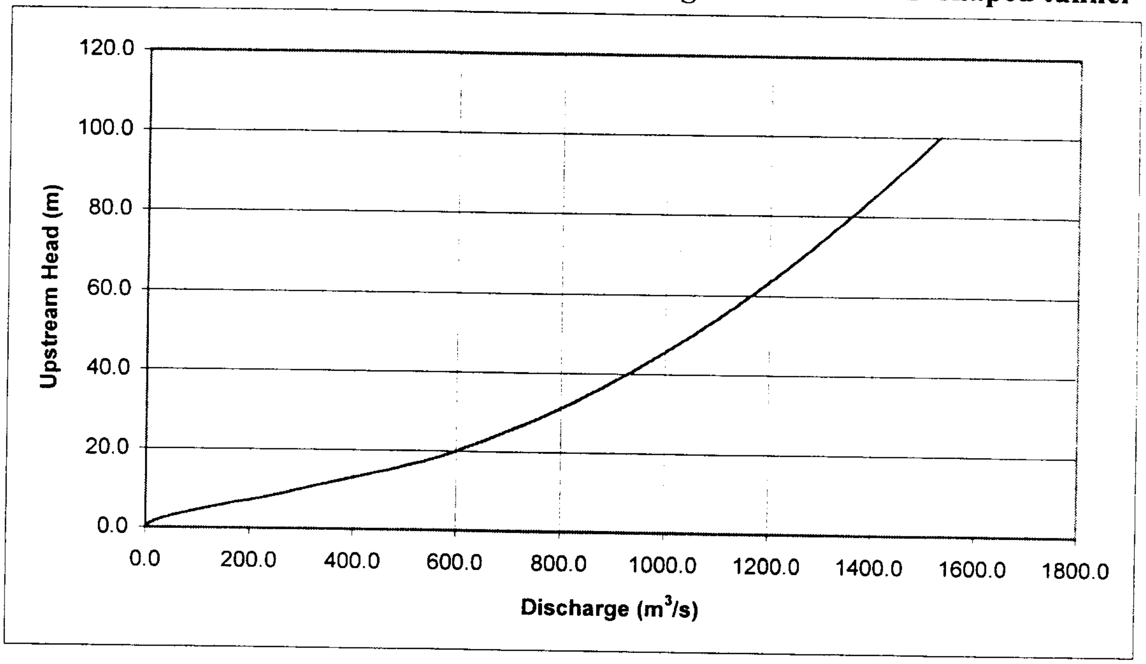
Another set of runs involved the routing of hydrographs with peaks of 300, 500, 1000, and 2000 $m^3/s$ through the reservoir with the 8 m tunnel configuration. These hydrographs were obtained by scaling down the ordinates of the 50-yr hydrograph by the ratio of peaks. The results of this analysis are summarized in Table 4b.

**Table 4b. Diversion tunnel analysis (D-shaped, varied flow)**

| Peak Inflow ($m^3/s$) | Tunnel Configuration Diameter-Length (m-m) | Peak Outflow ($m^3/s$) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|---|---|
| 300 | 8-550 | 137 | 5.6 | 0.7 |
| 500 | 8-550 | 192 | 7.0 | 1.1 |
| 1000 | 8-550 | 315 | 10.5 | 1.9 |
| 2000 | 8-550 | 484 | 15.6 | 2.8 |

An analysis of the results shows that it is more economical to use a single concrete-lined, 8 m diameter, 550 m long diversion tunnel. The rating curve for this tunnel, which applies to free flow conditions, is shown in Figure 2.

**Figure 2. Rating curve for 8m diameter, 550m long concrete-lined D-shaped tunnel**




## Analysis of Low Flows

Additional runs were made with constant flows of 25, 50, and 75 $m^3/s$ in order to determine the height of the temporary closure dikes used during the construction of the cofferdams. Tables 5a-c summarize the peak water surface elevations for the 3 tunnel sizes during low flow conditions.

**Table 5a. Low flow analysis (25 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 2.3 | 0.03 |
| 8 | 1.9 | 0.03 |
| 10 | 1.7 | 0.03 |

**Table 5b. Low flow analysis (50 m³/s)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 3.6 | 0.12 |
| 8 | 2.9 | 0.12 |
| 10 | 2.5 | 0.12 |

**Table 5c. Low flow analysis (75 m³/s)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 4.6 | 0.3 |
| 8 | 3.8 | 0.3 |
| 10 | 3.2 | 0.3 |

## Reservoir Drawdown Analysis

The reservoir drawdown is designed for a significant hazard, significant risk project as classified by the U.S. Bureau of Reclamation (USBR) in the ACER Technical Memo No. 3 dated 1982. This provides the following guidelines to be met.

| Drawdown El. | Time (days) |
|---|---|
| 75% | 30-40 |
| 50% | 50-60 |
| 25% | 80-100 |

Table 6 shows the time to empty out the reservoir to 25, 50, and 75 % of the starting full supply level of 71 m with a constant inflow of 107.5 $m^3/s$.

**Table 6. Time required to empty reservoir with 8 m diversion tunnel**

| Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Discharge ($m^3/s$) | Velocity (m/s) | Time to Empty (Days) |
|---|---|---|---|---|
| 71.0 | 100 | 1139 | 20.0 | - |
| 53.3 | 75 | 1113 | 19.6 | 34.2 |
| 35.5 | 50 | 862 | 15.2 | 53.8 |
| 17.8 | 25 | 509 | 9.0 | 64.6 |

O:\ProjectNumber\15000-15999\15593\Task Order 5 Norte_Sucio Water Supply\Hydraulics\Cocle\Cocle Cofferdam Memo FSL 71.doc

## Attachment 8 – Río Caño Sucio Stability Analyses

MWH
MONTGOMERY WATSON HARZA

Intra-Company Correspondence

MWH AMERICAS, INC.
HYDROPOWER

**Location:** Chicago

October 17, 2003

**To:** Michael Newbery

**From:** Rori Green

**Subject:** Caño Sucio RCC Dam Stability and Bearing Capacity Analysis

Preliminary sliding stability and bearing capacity analyses were performed for the proposed RCC gravity dam on the Río Caño Sucio. The results indicate that the dam is stable based on the assumed loading and foundation conditions.

## I. SLIDING STABILITY ANALYSIS

### Section Description and Loading Conditions

The dam section selected for analysis is the highest section through the river channel.

*Dam Section Description:*

| | |
|---|---|
| Crest El.: | 105 m |
| Upstream Slope: | Vertical |
| Downstream Slope: | 0.75H:1V |
| Foundation El.: | 84 m |

*Loading Assumptions:*

| | |
|---|---|
| Reservoir FSL: | 100 m |
| PMF El.: | 103.6 m |
| Normal Tailwater El.: | 84 m |
| PMF Tailwater El.: | 84 m |
| Drainage Efficiency: | 67% |
| Silt El.: | 88 m |
| Seismic Acceleration: | 0.14 g (use 2/3 of MDE acceleration, 0.21 g, for pseudo-static analysis) |

The loading cases considered in the analysis together with the required factors of safety are listed in the table below. The loading cases and factors of safety are based on a combination of recommendations taken from the U.S. Army Corps of Engineers Engineering and Design Manual for Gravity Dam Design (USACE, 1995), and the FERC *Engineering Guidelines for the*

*Evaluation of Hydropower Projects* (FERC, 2002). The required factors of safety are based on the FERC guidelines for an analysis performed assuming the foundation material has no cohesion (i.e. friction only).

| Loading Case | Reservoir El. (m) | Tailwater El. (m) | Silt El. (m) | Seismic Acceleration (g) | Required Factor of Safety |
|---|---|---|---|---|---|
| Usual | 100 | 84 | 88 | 0 | 1.5 |
| Unusual | 103.6 | 84 | 88 | 0 | 1.3 |
| Extreme | 100 | 84 | 88 | 0.14 | 1.3 |

**Foundation Material Strength Parameters**

The foundation at the dam site is composed of sandstone. No material testing has been performed on the sandstones found at the dam site, therefore material parameters had to be estimated from published literature and from previous experience with similar materials. The upper layers of sandstone are assumed to be weathered and somewhat weaker than the fresher sandstone that is expected to be encountered at depth. The rock mass strength parameters estimated for the Caño Sucio dam site are listed in the table below.

| Rock Type | Friction Angle (deg) | Cohesion (MPa) |
|---|---|---|
| Sandstone, fresh | 45 | 0 |
| Sandstone, weathered | 30 | 0 |

It is anticipated that the upper layers of weathered sandstone will be removed during foundation excavation for the dam, and therefore the dam will be founded on the unweathered, or fresh, sandstone. Based on this assumption, the material strength parameters used in the stability analysis are those listed for the fresh sandstone.

**Method of Analysis**

Factors of safety against sliding were computed using the following expression:

$$Factor\ of\ Safety = \frac{F_{ver} \cdot \tan\phi}{F_{hor}}$$

Vertical forces considered in the analysis are due to the weight of the dam and to hydrostatic uplift at the base of the dam. Horizontal forces considered are due to the reservoir, tailwater, silt load, and where applicable, seismic acceleration.

**Results of Stability Analysis**

The computed factors of safety for each of the three loading conditions are listed in the table below. The results of the preliminary stability analysis indicate that the dam meets the required factors of safety and will be stable under the assumed loading conditions.

| Case | Computed Factor of Safety | Required Factor of Safety | Criteria Satisfied? |
|---|---|---|---|
| Usual – Normal Pool | 3.0 | 1.5 | Yes |
| Unusual – Flood Pool | 1.9 | 1.3 | Yes |
| Extreme – Earthquake | 1.8 | 1.3 | Yes |

## II. BEARING CAPACITY ANALYSIS

The foundation bearing capacity was analyzed using the method described in Goodman (1989) for estimating the bearing capacity of rock foundations. The equation for estimating the bearing capacity are given by the following:

$$q_f = q_u(N_\phi + 1)$$

where

$$N_\phi = \tan^2\left(45 + \frac{\phi}{2}\right)$$

$q_u$ = uniaxial compressive strength
$q_f$ = ultimate bearing capacity
$\phi$ = friction angle

The allowable bearing capacity is computed using a factor of safety of 5, such that:

$$q_{allowable} = \frac{q_f}{5}$$

Bearing capacities estimated for the sandstone at the damsite are presented in the table below.

| Rock Type | Friction Angle (deg) | Unconfined Compressive Strength (MPa) | Allowable Bearing Capacity (MPa) |
|---|---|---|---|
| Sandstone, fresh | 45 | 100 | 137 |
| Sandstone, weathered | 30 | 20 | 16 |

Stresses, or bearing pressures, at the foundation were computed as part of the sliding stability analyses described in Section I. The maximum bearing pressures for each of the three cases are listed in the table below. The minimum allowable bearing capacity is taken as that computed for the weathered sandstone. It is anticipated, however, that the weathered sandstone will be removed during foundation excavation and that the dam will be founded in fresh sandstone, which has a higher allowable bearing capacity.

| Case | Maximum Bearing Pressure (MPa) | Minimum Allowable Bearing Capacity (MPa) | Criteria Satisfied? |
|---|---|---|---|
| Usual – Normal Pool | 0.32 | 16 | Yes |
| Unusual – Flood Pool | 0.33 | 16 | Yes |
| Extreme – Earthquake | 0.35 | 16 | Yes |

The results indicate that the foundation has sufficient bearing capacity for the proposed dam on the Río Caño Sucio.

**References**

Federal Energy Regulatory Commission. (2002). *Engineering Guidelines for the Evaluation of Hydropower Projects – Chapter III Gravity Dams.*

Goodman, R.E. (1989). *Introduction to Rock Mechanics, Second Edition.* John Wiley and Sons.

U.S. Army Corps of Engineers. (1995). *Gravity Dam Design.* EM 1110-2-2200.

# Sample Stability Calculations

# STABILITY ANALYSIS

Rios Cocle del Norte and Cano Sucio Water Supply Projects
Cano Sucio RCC Dam Stability Analysis

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## PROGRAM DESCRIPTION SECTION

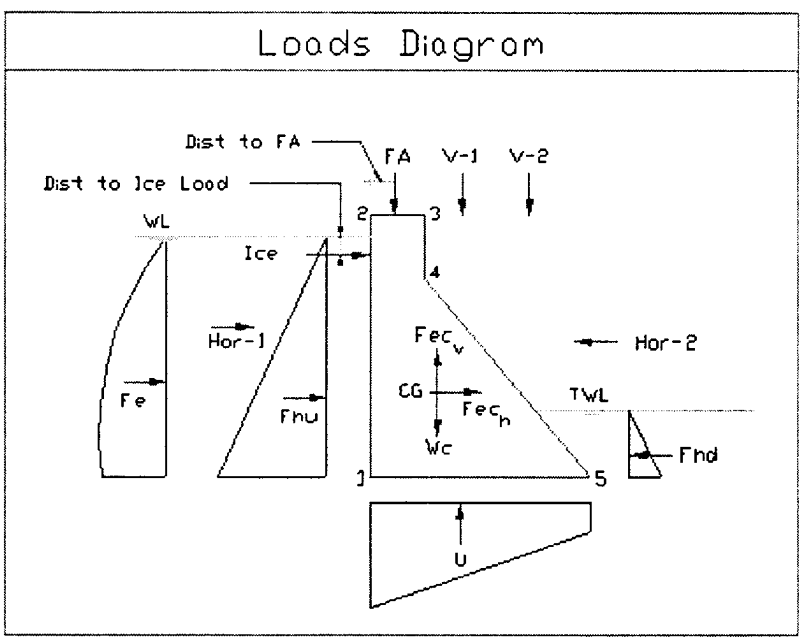
Stabil-1.mcd is a Mathcad file which calculates factors of safety against sliding and overturning for any shaped structure.

Features

- metric or imperial units
- ice, anchor, hydrostatic and gravity loads
- crack analysis (with modified uplift for load cases other than seismic)
- calculates percentage of effective base
- bearing pressures
- volume and position of center of gravity of structure (including voids)
- summary of forces and moments (including resultant and eccentricity)
- additional point loads (eg. backfill, vertical hydrostatic, etc.)
- hydrodynamic forces by Westergaard
- equivalent horizontal and vertical inertia forces on structure during earthquake
- results in any units (including user defined)

Assumptions and Limitations

- 2-dimensional
- horizontal base only
- vertical hydrostatic and backfill loads must be input as point loads
- lowest point on structure is level of base
- all vertical point loads are referenced to most upstream point of structure



**INPUT SECTION**

**Unit System**

1 - metric
2 - imperial

**Select unit system**

$\Psi$ units := 1 <... select unit system

unL := if(units = 1, 1·m, 1·ft)

unM := if(units = 1, 1·kN, 1·lb)

**Geometry of Structure defined by perimeter coordinates**

**There is no need to "close" the perimeter ,i.e, so that last point equal to first point**

$$\Psi \quad X := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0.5 \\ 0.5 \\ 8 \\ 8 \\ 15.2 \end{pmatrix} unL \qquad Y := \begin{pmatrix} 84 \\ 103.3 \\ 105.3 \\ 105.3 \\ 103.3 \\ 103.3 \\ 93.6 \\ 84 \end{pmatrix} unL$$

<... input X & Y coordinaytes

$\Psi$ Length_Base := 15.2 <... length of the base of the structure

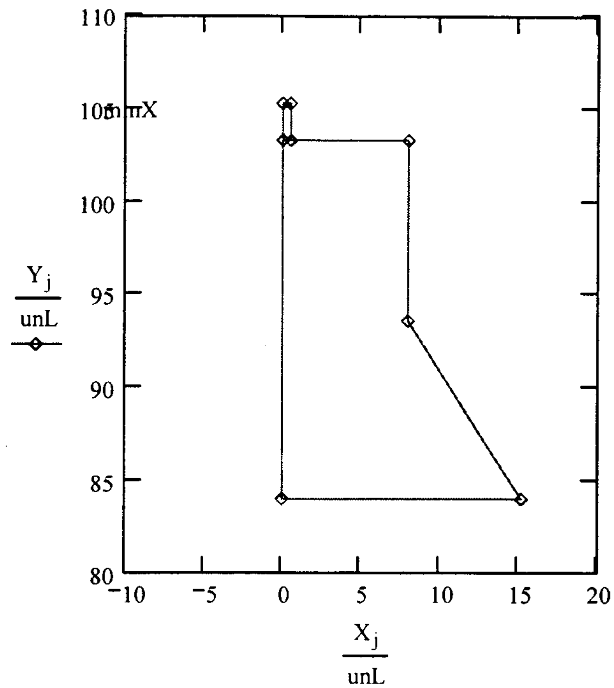
$\Psi$ Structure_Width := 1 <... width of structure

$$maxY := \frac{max(Y)}{unL} + 10 \qquad minY := \frac{min(Y)}{unL} - 10 \qquad i := 1..\,length(X)$$

$$maxX := \frac{max(X)}{unL} + 10 \qquad minX := \frac{min(X)}{unL} - 10 \qquad j := 1..\,length(X) + 1$$

$$X_{length(X)+1} := X_1 \qquad Y_{length(Y)+1} := Y_1$$

Graphical Representation of Structure defined by X & Y Coordinates




## Densities of Water and Concrete, Water Level, Width of Structure, of Structure defined by perimeter coordinates

Ψ $\gamma w := \text{if}\left(\text{units} = 1, 9.81 \cdot \frac{kN}{m^3}, 62.4 \cdot \frac{lb}{ft^3}\right)$ <... water density

Ψ $\gamma c := \text{if}\left(\text{units} = 1, 23 \cdot \frac{kN}{m^3}, 150 \cdot \frac{lb}{ft^3}\right)$ <... concrete density

Ψ US_Water_Level := 100.0 <... upstream water level

Ψ Tailwater_Level := 84 <... tailwater level

Ψ $\phi := 45 \cdot deg$ <... angle of internal friction for foundation material

## EHorizontal & Vertical Components of the Earth Quake Intensity and Coefficient of Hydrodynamic Pressure Distribution

Ψ $\lambda_{hor} := 0.14$ <... **horizontal** component of earth quake intensity = ratio of earth quake acceleration to accelaration due to gravity

Ψ $\lambda_{vert} := 0.0$ <... **vertical** component of earth quake intensity

Ψ $C_m := 0.74$ <... from fig 8-6, page 325 of "Design of Small Dams", for a structure with **vertical face**

## Uplift, Ice load & Point of Application, Anchor Force & Point of Application, & Other Vertical and Horizontal Forces

Ψ Uplift := 46

<... percent of uplift pressure acting at the upstream point of the structure foundation

If imperial units selected, **Ice Load** will be in **lb/ft** of Structure. Otherwise, i.e., metric units, **Ice Load** will be in **kN/m**

Ψ Ice_Load := 0

<... ice load acting per unit width of the structure

Ψ Dist_WL_to_Ice_Load := 0.0

<... distance from water level to point of application of Ice load

If imperial units selected, **Anchor Force** will be in **lb.** Otherwise, i.e., metric units, Anchor Force will be in **kN**

Ψ Anchor_Force := 0

<... anchor force acting per unit width of the structure

Ψ Dist_to_Anc_Force := 0

<... distance from most upstream point of structure to point of application of anchor force

## Additional Horizontal Forces Acting in the Downstream and Upstream Directions

Ψ US_Hor_Force := 27

<... Horizontal Force acting in the Downstream Direction. For instance, this force can be used to input effect of soil pressure on the upstream side of Structure

Ψ EL_US_Hor_F := 85.3

<...Elevation at which the Upstream Horizontal Force is applied to the Structure

Ψ DS_Hor_Force := 0

<... Horizontal Force acting in the Upstream Direction. For instance, this force can be used to input effect of soil pressure on the downstream side of Structure

Ψ EL_DS_Hor_F := 0

<...Elevation at which the Downstream Horizontal Force is applied to the Structure

## Additional Vertical Forces (Stabilizing Forces)

If imperial units selected, **Vertical Forces** will be in **lb.** Otherwise, i.e., metric units, **Vertical Forces** will be in **kN**

Ψ Vert_Force_1 := 0

<... Vertical Force acting on the Downward Direction. It is a stabilizing force

Ψ Dist_to_F1 := 0

<... distance from most upstream point of structure to point of application of vertical force

Ψ Vert_Force_2 := 0

<... Vertical Force acting on the Downward Direction. It is a stabilizing force

Ψ Dist_to_F2 := 0

<... distance from most upstream point of structure to point of application of vertical force

OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO

FINAL RESULTS

**initial point of inflection**

PI = 0 m

**initial point of inflection as % of the base**

$$\frac{PI}{L} = 0\,\%$$

**CALCULATED CRACK LENGTH**

Cr = 0 m

**% OF EFFECTIVE BASE**
(portion not cracked)

EFF_BASE = 100 %

**STRESSES AT FOUNDATION**

fmin = 151.14031 kPa

fmax = 351.53704 kPa

**SAFETY FACTOR AGAINST SLIDING**

FSS = 1.8338

**SAFETY FACTOR AGAINST OVERTURNING**

FSO = 2.3423

# Summary of Forces and Moments

## 1) Vertical Forces

$Wc = 4369.08\ kN$ <... weight of concrete in structure

$Fa = 0\ kN$ <... anchor Force

$V1 = 0\ kN$ <... Vertical Force 1 acting on the Downward Direction.

$V2 = 0\ kN$ <... Vertical Force 2 acting on the Downward Direction.

$Fec_V = 0\ kN$ <... Equivalent Vertical Inertia Force on Structure due to earth quake

$U = 548.73\ kN$ <... uplift force acting upwards

$F_{ver\_U} = 4369.08\ kN$ <... resultant of the vertical forceswithout uplift

$F_{ver} = 3820.35\ kN$ <... resultant of the vertical forceswith uplift

## 2) Horizontal Forces

$Fhu = 1255.68\ kN$ <... upstream hydrostatic force

$Fhd = 0\ kN$ <... downstream hydrostatic force

$Fi = 0\ kN$ <... Ice Force

$Fe = 188.89\ kN$ <...hydrodynamic force

$Fec_h = 611.67\ kN$ <... Equivalent Horizontal Inertia Force on Structure due to earth quake

$USHF = 27\ kN$ <...horizontal force acting in the Downstream Direction

$DSHF = 0\ kN$ <...horizontal force acting in the Upstream Direction

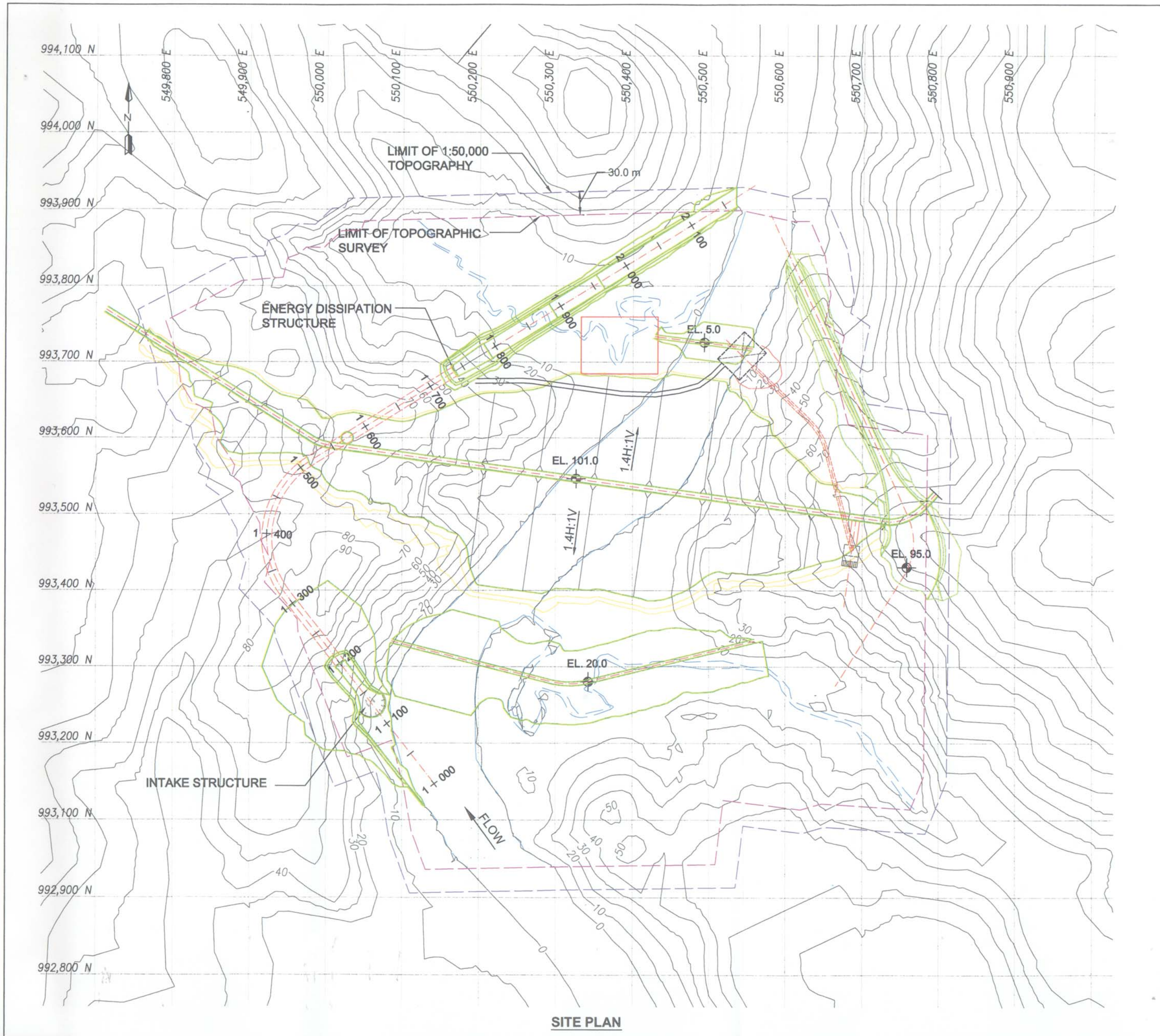
$F_{hor} = 2.083 \times 10^3\ kN$ <... resultant of the horizontal forces

## 3) Stabilizing, Overturning, and Resultant Moments

$Ms = 43932.71\ kN \cdot m$ <... stabilizing moment

$Mo_T = 18756.38\ kN \cdot m$ <... overturning moment

$Mr = 25176.34\ kN \cdot m$ <... resultant moment




SITE PLAN

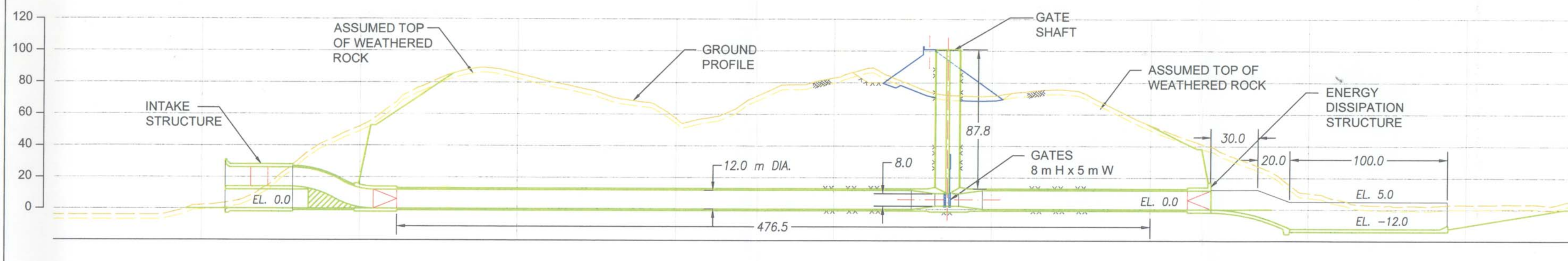
AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

ACP

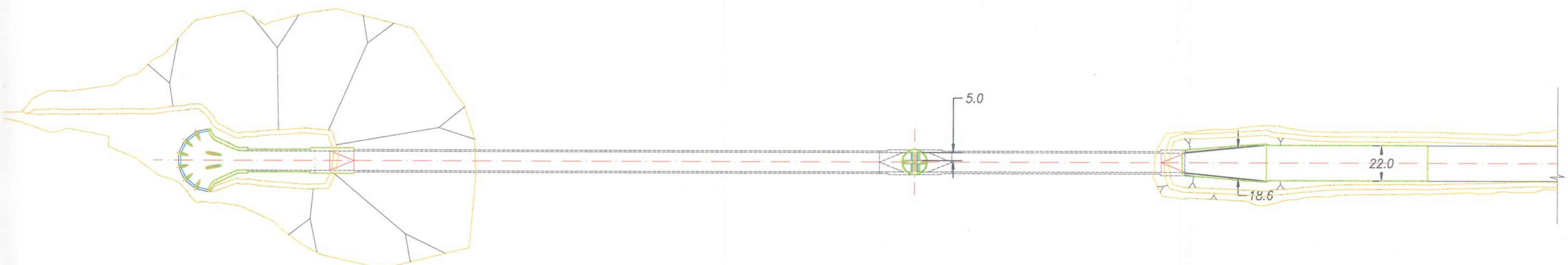
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D4 - PROJECT COMPONENT CONFIGURATION

**RÍO COCLÉ DEL NORTE**
**LOW LEVEL OUTLET WORKS FOR**
**12 m DIA. DIVERSION TUNNEL - SITE PLAN**

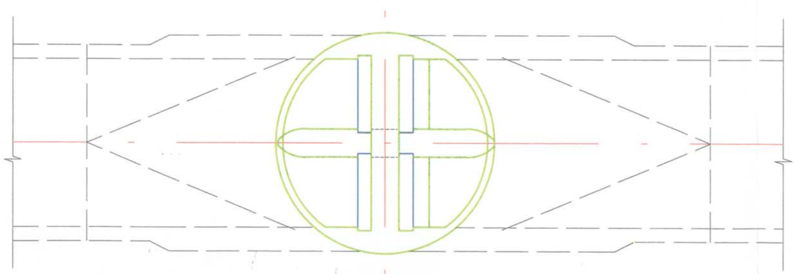
| MWH TAMS | DATE: DECEMBER, 2003 | EXHIBIT: 1 |
|---|---|---|




**SECTION**
**DIVERSION TUNNEL AND LOW LEVEL OUTLET**




**PLAN**
**DIVERSION TUNNEL AND LOW LEVEL OUTLET**



**SECTION**
**GATE SHAFT**

0 25 50 75 100 125 m
GRAPHIC SCALE

AUTORIDAD DEL CANAL DE PANAMA
**División de Proyectos de Capacidad del Canal**
ACP

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D4 - PROJECT COMPONENT CONFIGURATION

**LOW LEVEL OUTLET WORKS FOR 12 m DIA. DIVERSION TUNNEL PLAN AND SECTION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 2 |

Part 4
Component Configuration

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX D
PART 4

PROJECT COMPONENT CONFIGURATION

Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D - PART 4
## PROJECT COMPONENT CONFIGURATION

### TABLE OF CONTENTS

# LIST OF TABLES

# ATTACHMENTS

# 1 INTRODUCTION

Appendix D4, Project Component Configuration, presents supporting design studies performed to develop the proposed project configuration for the selected projects. The appendix covers the following studies:

- Río Coclé del Norte Dam Axis Optimization
- Río Coclé del Norte and Río Caño Sucio Spillway Arrangements
- Río Coclé del Norte Diversion and Emergency Drawdown Facilities
- Río Coclé del Norte Stability Analyses
- Río Caño Sucio Stability Analyses

Studies documenting the Río Coclé del Norte and the Río Caño Sucio dam type selection are presented in Appendix D1 and D2 respectively, dam height studies are presented in Appendix D3, and water transfer facility studies are presented in Appendix D5.

# 2 RÍO COCLÉ DEL NORTE DAM AXIS OPTIMIZATION

A dam axis optimization study was performed for the Río Coclé del Norte dam, FSL 100 m, by shifting the dam axis upstream and downstream up to 50 meters from the location selected for the dam type selection study. Gross fill quantities were computed for the new axes using the using templates (Autodesk LDD) projected to the top of weathered rock surface. The results of the study are summarized in Table 1 below:

**Table 1 Río Coclé del Norte Dam Volumes**

| Distance Moved | Dam Fill Volume ($m^3$) | Original Volume ($m^3$) | Difference from Original Volume |
|---|---|---|---|
| 25 m upstream | 6,247,200 | 6,033,200 | + 3.4 % |
| 15 m downstream | 5,968,700 | 6,033,200 | - 1.1 % |
| 20 m downstream | 5,958,700 | 6,033,200 | - 1.3 % |
| 25 m downstream | 5,959,200 | 6,033,200 | - 1.2 % |
| 50 m downstream | 6,159,100 | 6,033,200 | + 2.0 % |

The results indicate that a minor reduction in the quantities of up to about 1% could be realized by moving the dam axis about 20 m downstream of its present location. However, the selected dam axis for the 100-m FSL is that chosen during the dam type study. While this is not the minimum dam volume, this selection has been made for the following reasons:

1. The impact of moving the dam alignment downstream on the spillway is to make it more difficult to position the spillway adjacent to the dam so that the headworks will be founded on rock (based on the assumption of 6 m to competent rock); the ground surface slopes down just north of where the dam axis ends at the right abutment.

On the left abutment, a portion of the dam is located on a relatively narrow ridge; this is the part of the dam that is located west of the bend in the dam axis. From a geotechnical perspective, it has been recommended that the section of dam located on this ridge should be placed toward the upstream side of the ridge rather than on the downstream side to limit the potential for founding the dam on a weathered ridge that could require deeper foundation excavation and/or improvement.

Final selection of the dam axis should be revisited after a site investigation program has been completed and foundation conditions can be better characterized.

# 3 SPILLWAY ARRANGEMENTS

## 3.1 Río Coclé del Norte Project FSL 100

ACP has expressed a preference for an ungated spillway for the Río Coclé del Norte Project. Hydraulic flood routing studies confirmed that the large reservoir, formed by a dam at the selected Río Coclé del Norte damsite would substantially attenuate the inflow flood caused by the PMP, the selected design event for spillway design. As part of the dam type selection studies, ungated spillways of various widths from 25 m to 250 m were evaluated and shown to pass the flood with small reservoir surcharges. Estimated construction costs for various combinations of dam crest elevation and spillway widths showed that the lowest cost project would be to store the flood and eliminate the spillway. The hydropower facilities and water transfer facilities could be used to lower the reservoir under normal operation, and the emergency drawdown facilities would provide more capacity than the spillway if required to lower the reservoir under unusual circumstances. As there is no precedent for not providing a spillway on a project of this size, this option was not considered further.

The cost of a project with a 25 m or 50 m wide spillway was, within the accuracy of the estimate, the same. Therefore, a spillway with a hydraulic crest width of 50 m was selected.

The dam type selection studies were performed for a reservoir with a normal full supply level at El. 80. For a full supply level at El. 100, the reservoir attenuation is larger, and an ungated spillway with crest hydraulic width of 50 m limits reservoir surcharge to only 1.8 m. A nominal 1 m of freeboard is provided above this elevation for potential wave overtopping. The resulting freeboard elevation of El. 102.8 of was then rounded to El. 103 for the selected dam and spillway layout. This also provides the required 2.4 m of freeboard for wave run-up above the reservoir full supply level of El. 100. The upstream parapet wall will project 2-m above the dam crest, which is set at El. 101. Supporting hydraulic analyses for flood routing and spillway sizing are presented in Attachment 1.

The selected spillway arrangement has potential for cost reduction. The location selected for the spillway is on the right abutment, with the entire spillway located on rock. This location was adopted as part of the spillway layout studies for the dam type study (FSL at El. 80), and also appears preferable for the higher full supply level at El. 100 project. Three discharge chute and flip bucket alignments were considered. Initial layouts considered constant slopes on the discharge chute, and linear tapering of the chute from the crest to the flip bucket. The shorter Alignment 1 resulted in large excavations, an unfavorable alignment for the trajectory of spillway discharge from the flip bucket, and limited space for a possible hydropower station. The longer Alignment 3 has less excavation and a more favorable discharge direction, but the longer chute will result in higher cost. Alignment 2 is a compromise location, providing adequate for a potential hydropower station, and an acceptable discharge trajectory. However, the topography was not favorable for a linearly sloping chute without deep excavations.

Therefore, additional hydraulic analyses were performed to optimize the headworks and spillway chute layouts. Introducing a curved ogee crest structure, and, taking advantage of the relatively small discharges, tapering more acutely into the chute, improved the headworks. Simultaneously, the slope of the chute was reduced at higher elevations before sloping more steeply to follow the adopted top of rock at about mid-length. This necessitated higher spillway walls to funnel flows immediately downstream of the ogee crest to the steeper section of the chute, but reduced excavation, and, in combination with the narrower chute, resulted in less concrete.

The Main Report (Volume 2) Exhibits 5-2 and 5-3 show the final arrangement. The maximum discharge is 250 $m^3/s$. The maximum flow depth in the spillway chute is less than 3 m. Four meter high spillway walls are provided to contain the flow. The spillway tapers from 50 m at the ogee crest to 10 m in the chute over 100 m. An access bridge from the right abutment to the dam crest is provided above the ogee crest structure. The chute is 250 m long, and terminates in a flip bucket set at El. 4, approximately 2 m above tailwater elevation during the PMF. The chute includes an aeration ramp at El. 50 and, as shown in profile in Exhibit 5-2, has a varying slope.

### 3.2 Río Coclé del Norte Project FSL 71

Cost comparisons of the Río Coclé del Norte Project with a full supply level at El. 71 and spillways varying from 25 m to 150 m again confirmed that eliminating the spillway and storing the probable maximum flood would result in the lowest cost project. As for the Río Coclé del Norte Project FSL 100, this would be unprecedented and was not considered an acceptable option. A 50 m wide spillway was selected.

The topography favors a spillway on the right abutment. Within some constraints, several alignments were investigated to minimize the spillway excavation and length, which will result in the lowest cost. The constraints included that the spillway that the headworks should be aligned with the crest, the spillway should be founded on sound rock, the converging chute section should be relatively flat to limit velocities, and that the maximum discharge trajectory should form a plunge pool within the existing river channel. The selected spillway alignment is shown on Exhibit 5-2 in Volume 1 of the Main Report.

The maximum discharge is 800 $m^3/s$. The maximum flow depth in the spillway chute is less than 5 m. Six-meter high spillway walls are provided to contain the flow. The spillway tapers from 50 m at the ogee crest to 10 m in the chute over 100 m. An access bridge from the right abutment to the dam crest is provided above the ogee crest structure. The chute is 250 m long, and terminates in a flip bucket set at El. 6, approximately 1 m above tailwater elevation during the PMF. The chute includes an aeration ramp at El. 30 and has a varying slope, as shown in profile in Exhibit 5-3 of the Main Report (Volume 1).

### 3.3 Río Caño Sucio Project

Hydraulic analyses of the Río Caño Sucio spillway were updated from the dam type selection study (Appendix D-2) following refinement in the area-volume data. Changes in flood levels were minimal, and the spillway configuration was not modified. The hydraulic analysis is presented in Attachment 2.

# 4 RÍO COCLÉ DEL NORTE DIVERSION AND EMERGENCY DRAWDOWN FACILITIES

The Río Coclé del Norte diversion and emergency drawdown facilities were originally developed for the dam type selection study that considered a full supply level of El. 80. These original studies considered a cofferdam separate from the main dam and a diversion tunnel. Additional studies were performed to evaluate alternative diversion and emergency drawdown arrangements that would provide the same level of flood protection during construction and the required drawdown capacity, but at lower cost. These additional studies considered an arrangement with the cofferdam incorporated into the main dam as well as a conventional arrangement that combined a longer tunnel with a lower-cost cofferdam location. These studies are presented in Attachment 3 (hydraulic analysis) and Attachment 4 (layouts and costs) and are summarized below.

## 4.1 Initial Arrangement Selection

The three alternative arrangements considered are as follows:

**Table 2 Diversion Alternatives for FSL El. 80**

| | |
|---|---|
| Alternative 1: | One 8-m diameter, 530-m long diversion tunnel in left abutment; cofferdam crest El. 22.5, located 25 m upstream of dam toe (dam-type study arrangement). |
| Alternative 2: | One 8-m diameter, 530-m long diversion tunnel in left abutment; cofferdam crest El. 23.5, incorporated in main dam and constructed with plinth and concrete facing; Pre-cofferdam crest El. 10, located 25 m upstream of dam toe |
| Alternative 3: | One 8-m diameter, 780-m long diversion tunnel in left abutment; cofferdam crest El 22.5, located 250 m upstream of dam toe |

Preliminary plans and sections were developed for these alternatives, and are also presented in Attachment 1. The study included development of cost estimates, an estimate of construction schedule, and a risk analysis for the three alternative diversion arrangements. The costs are as follows:

**Table 3 Cost Comparison of Diversion Alternatives**

| Feature | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| Diversion Tunnel | $ 7,800,000 | $ 7,800,000 | $ 11,400,000 |
| Cofferdam | $ 4,900,000 | $ 8,100,000 | $ 2,400,000 |
| Pre-cofferdam | | $ 1,300,000 | |
| Main Dam | | ($ 6,500,000) | |
| **Total** | **$ 12,700,000** | **$ 10,600,000** | **$ 13,800,000** |

As a result of the study, the location and general alignment associated with Alternative 1 (shorter tunnel – larger cofferdam) was adopted. Alternative 2 was rejected because of the risk associated with potential construction problems and the impact these problems would have on cost and performance during construction. Alternative 3 (longer tunnel – smaller cofferdam) was rejected as more costly.

It is suggested that Alternative 2 be re-evaluated following the design-level foundation investigation program because of the potential for cost savings.

### 4.2 Diversion and Emergency Drawdown Facilities for FSL El. 100

The original studies demonstrated that meeting the selected drawdown requirements governed the minimum size of diversion tunnel that would subsequently be used as the low-level outlet facility. The adopted drawdown requirements were taken from the USBR guidelines (ACER Technical Memorandum No. 3 dated January 1982 entitled Criteria and Guidelines for Evacuating Storage Reservoirs and Sizing Low-level Outlet Works).

A series of hydraulic analyses were performed to determine the diameter for several lengths of tunnel that could accommodate the alternative cofferdam locations. It was soon apparent that the tunnel diameter would be large to meet the drawdown criteria, and that the cost of the tunnel would be significantly greater than a cofferdam, clearly favoring a shorter tunnel. This conclusion would confirm the recommendation for a shorter tunnel – larger cofferdam arrangement described in Section 4.1.

Preliminary hydraulic analysis showed that a 10.5 m D shaped tunnel would meet draw down the reservoir to El. 75 in 34 days, less than the 40-days recommended in the USBR guidelines. However, the peak flow of 3,100 $m^3/s$ results in peak velocities in the tunnel of over 30 m/s, which is not acceptable. The adopted limiting peak velocities are 20 m/s in the tunnel and 30 m/s through the outlet gates (which would have steel-lined transition sections). For these velocities, the required tunnel diameter to draw down the reservoir by 25% elevation of the hydraulic head (*i.e.* from E. 100 to El. 75) is 12 m. The peak discharge would be 2,500 $m^3/s$.

At the higher discharge rates, the flow depth will exceed El. 8 at very high velocities, which will inundate and possibly cause damage to the powerhouse, flip bucket and downstream infrastructure. It was decided that energy dissipation would be required to eliminate or reduce damage, as the tailwater elevations are insufficient to reduce flow velocities to sub-critical.

Initially, it was assumed that a stilling basin would be used for energy dissipation. Preliminary computations indicated that the critical discharge for design of the stilling basin is less than the maximum discharge, and a flow of 1,000 $m^3/s$ was selected for design. The adopted arrangement consisted of a sloping apron to a recessed stilling basin. The resulting structure would be 100 m long, 12 m deep, and 22 m wide. Exhibits 1 and 2 in Attachment 5 show the plan layout and a section through this low-level outlet works and diversion tunnel. In addition to the required energy dissipation structure, the large flows dictate a large intake structure to limit flow velocities and the potential for vorticity. A fan shaped structure is proposed that would be constructed over the diversion intake during a subsequent dry season. The cost of this tunnel, intake, shaft and control gates, steel lining, strengthened concrete, energy dissipation structure and cofferdams is estimated as follows:

**Table 4 Comparative Cost for Reservoir Drawdown Facilities with 8 and 12 m Diversion Tunnels**

| Diversion Tunnel | Estimated Cost US$ x million |
|---|---|
| 8-m Diameter | 21.6 |
| 12-m Diameter | 41.0 |
| **Difference** | **19.3** |

Because of the cost and the fact that the emergency drawdown facility will be used rarely, if ever, the viability of the arrangement was called into question and further study was performed.

The adopted guidelines were carried over from the studies of the Río Indio and Upper Chagres Water Supply Projects. These smaller reservoirs could be drawn down through diversion facilities sized to pass the selected diversion floods (50 and 25 year return periods, respectively). For the very large reservoir that would be impounded by the Río Coclé del Norte Dam with a FSL at El. 100, meeting the drawdown criteria will result in significant additional diversion and low level outlet cost.

The USBR guidelines state that relaxation of criteria and guidelines because of site-specific conditions should be considered on a case-by-case basis after the consequences and costs of different alternatives have been evaluated and quantified. The guidelines also suggest other criteria including:

- Large reservoirs requiring 5 years to fill might require outlets sized to pass a 25-year flood in addition to mean inflow at specified filling rates. The diversion tunnel will be sized to pass the 50-year flood, so this criterion is met.
- Low level outlet works should be located and sized to provide discharge capacity sufficient to maintain reservoir filling rates specified by initial filling criteria and to hold reservoir levels reasonably constant for elevations above 50% of the hydraulic height of the dam.

The second criterion was evaluated at the 50 % hydraulic height. Diversion studies had shown that an 8 m diameter tunnel would result in an acceptable cofferdam size and height and pass the selected 50-year return period construction flood. Emergency drawdown hydraulic analyses showed that the diversion tunnel could discharge 1,080 $m^3/s$ at El. 50. This increases to 1,140 $m^3/s$ at El. 100 (limiting velocities to 20 m/s). The 50-year return period flood was routed through the reservoir at El. 50 and the low level outlet used to control filling with a maximum discharge of 20 m/s. The resulting rise in reservoir elevation was 0.9 m. This is judged to be reasonably constant. With a likelihood of exceedance of 8% in the 4-year filling period (over El. 50), this is considered an acceptable risk, and the emergency drawdown capacity resulting from an 8-m diameter tunnel was accepted.

Maximum discharge downstream would be 1,100 $m^3/s$, which would result in a maximum tailwater to El. 5.5. This discharge is less than the pre-project average annual flood, and would inundate the powerhouse (above El. 4) unless limited to 700 $m^3/s$. As a result, the powerhouse entrance has been raised to El. 6, which will eliminate the potential for inundation for the maximum discharge. However, there is the potential for some damage downstream unless a stilling basin is provided.

Drawdown times with this 8-m diameter tunnel are:

**Table 5 Drawdown Time for 8 m Diversion Tunnel**

| Drawdown Elevation (and % of hydraulic head) | Time, days |
|---|---|
| El 75 (75%) | 91 |
| El. 50 (50%) | 141 |
| El. 25 (25%) | 163 |

The drawdown estimates do not include using the Río Caño Sucio to Río Indio tunnel for reservoir evacuation, which would decrease the drawdown time from El. 100 to El. 90.

With the adoption of an 8-m diameter tunnel, the recommendation of a shorter tunnel and larger cofferdam presented in Section 4.1 remains valid. Two additional alternative tunnel alignments and cofferdam locations were considered. The resulting surcharge during construction flood diversion for these two alternatives are:

| Alternative | Description | U/S Flood El. | D/S Flood El. | Max. Flow, $m^3/s$ |
|---|---|---|---|---|
| 1 | 550 m tunnel | 22.1 | 3.5 | 636 |
| 2 | 700 m tunnel | 22.2 | 3.4 | 612 |

As the upstream flood elevation is effectively the same, the shorter tunnel, Alternative 1, is selected for diversion and to serve as the low level outlet.

### 4.3 Diversion and Emergency Drawdown Facilities for FSL El. 71

The limiting criteria for minimizing the diversion cost for a FSL El. 71 project was, again, determined to be the required minimum tunnel size to meet the emergency drawdown criteria. An analysis of a 7 m tunnel showed that it does not meet the criteria, so the diversion tunnel size was established at 8 m. The arrangement developed for the diversion tunnel and emergency drawdown for the FSL El. 100 project was also selected for this FSL El. 71 project. The smaller dam allowed the cofferdam to be located downstream, slightly reducing the length of tunnel required. The resulting drawdown times are presented below in Table 6.

**Table 6 Drawdown Time for 8 m Diversion Tunnel**

| Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Discharge ($m^3/s$) | Velocity (m/s) | Time to Empty (Days) |
|---|---|---|---|---|
| 71.0 | 100 | 1139 | 20.0 | - |
| 53.3 | 75 | 1113 | 19.6 | 34.2 |
| 35.5 | 50 | 862 | 15.2 | 53.8 |
| 17.8 | 25 | 509 | 9.0 | 64.6 |

# 5 RÍO COCLÉ DEL NORTE STABILITY ANALYSES

Stability analyses is presented for:

1. Río Coclé del Norte with a full supply level at El. 100
2. Río Coclé del Norte with a full supply level at El. 71

The feasibility level design of the Río Coclé del Norte CFRD has been performed in accordance with guidelines presented in Cooke, J. B. 1998, Empirical Design of the CFRD, Hydropower and Dams, Issue Six. The governing design for the dam is deformation during an earthquake event. Maintenance of gross stability and sufficient freeboard remain the primary requirements in evaluating seismic performance of rockfill dams.

Limited emphasis is placed on the analysis of the concrete slab, since cracking of the slab is unlikely and is not expected to result in excessive leakage. The internal zoning of the dam is designed to control the amount of water that can enter any potential crack, and then direct this leakage out of the fill maintaining it dry. Design of the slab is usually based on previous experience and professional judgment. The thickness of the slab and its reinforcement have been reduced through the years of development of the CFRD, reaching the current recommendations, for a dam of this height, of 0.25 m to 0.4 m constant thickness and 0.3% to 0.35% reinforcement each way, which provide an economical and reliable watertight element.

The method of analysis to estimate the seismic deformation of the rockfill and to evaluate the adequacy of freeboard follows the recommendation of Bureau et al. 1985 Seismic analysis of concrete face rockfill dams, published in Cooke, J. B. and Sherard, J. L. Concrete Face Rockfill Dams - Design, Construction and Performance, ASCE, New York. Conventional limit state stability analyses are not performed for CFRD dams. Rockfill slopes on competent foundation and no pore pressure, using slopes up to 1.3H:1V have been found stable without the need for stability analyses, as discussed in Cooke 1998.

### 5.1 Río Coclé del Norte FSL at El. 100

Attachment 6 provides the deformation computation for the maximum design earthquake (MDE). Estimated deformation for the CFRD is less than 0.2 m as a result of the MDE. The dam is provided with 3 m of freeboard from the full supply level of El. 100.0 to the crest (top of parapet) at El.103.0. The dam has adequate freeboard to prevent overtopping as a result of deformation during the MDE.

### 5.2 Río Coclé del Norte FSL at El. 71

Attachment 6 also provides the deformation computation for the maximum design earthquake (MDE). Estimated deformation for the CFRD is less than 0.2 m as a result of the MDE. The dam is provided with 3 m of freeboard from the full supply level of El. 71.0 to the crest (top of parapet) at El.76.0. The dam has adequate freeboard to prevent overtopping as a result of deformation during the MDE.

# 6 RÍO CAÑO SUCIO STABILITY ANALYSES

Río Caño Sucio stability analyses comprise:

- Foundation stability analyses to evaluate sliding stability of the dam foundation upstream of the Caño Sucio waterfalls, and
- Stability analyses for the RCC dam

Additional detailed of the analyses is included in Attachment 8.

## 6.1 Foundation Stability Analyses

Foundation stability analyses were performed to evaluate how close the dam could be located to the waterfalls. The analyses considered the three dam types under consideration for this site. The conclusion is that a gravity dam must be constructed a minimum distance of 15 m from the upstream edge of the waterfalls. The selected dam location for the Caño Sucio project is 40 m upstream at its closest point.

## 6.2 Stability Analysis

### 6.2.1 Sliding Stability

A preliminary sliding stability analysis and a foundation bearing capacity analysis were performed for the proposed RCC gravity dam on the Río Caño Sucio. The dam section selected for analysis is the highest section through the river channel. The loading assumptions used in the analysis are listed below.

| | |
|---|---|
| Reservoir FSL: | 100 m |
| PMF El.: | 103.6 m |
| Normal Tailwater El.: | 84 m |
| PMF Tailwater El.: | 84 m |
| Drainage Efficiency: | 67 % |
| Silt El.: | 88 m |
| Seismic Acceleration: | 0.14 g (use 2/3 of MDE acceleration, 0.21 g, for pseudo-static analysis) |

The loading cases considered in the analysis together with the required factors of safety are listed in the table below. The loading cases and factors of safety are based on a combination of recommendations taken from the U.S. Army Corps of Engineers Engineering and Design Manual for Gravity Dam Design (USACE, 1995), and the FERC *Engineering Guidelines for the Evaluation of Hydropower Projects* (FERC, 2002). The required factors of safety are based on the FERC guidelines for an analysis performed assuming the foundation material has no cohesion (i.e. friction only).

**Table 7 Loading Conditions for Dam Stability Analysis**

| Loading Case | Reservoir El. (m) | Tailwater El. (m) | Silt El. (m) | Seismic Acceleration (g) | Required Factor of Safety |
|---|---|---|---|---|---|
| Usual | 100 | 84 | 88 | 0 | 1.5 |
| Unusual | 103.6 | 84 | 88 | 0 | 1.3 |
| Extreme | 100 | 84 | 88 | 0.14 | 1.3 |

The foundation at the dam site is composed of sandstone. No material testing has been performed on the sandstones found at the dam site, therefore material parameters had to be estimated from published literature and from previous experience with similar materials. The upper layers of sandstone are assumed to be weathered and somewhat weaker than the fresher sandstone that is expected to be encountered at depth. The rock mass strength parameters estimated for the Caño Sucio dam site are listed in Table 7 below.

**Table 8 Selected Material Strength Parameters**

| Rock Type | Friction Angle (deg) | Cohesion (MPa) |
|---|---|---|
| Sandstone, fresh | 45 | 0 |
| Sandstone, weathered | 30 | 0 |

It is anticipated that the upper layers of weathered sandstone will be removed during foundation excavation for the dam, and therefore the dam will be founded on the unweathered, or fresh, sandstone. Based on this assumption, the material strength parameters used in the stability analysis are those listed for the fresh sandstone.

Factors of safety against sliding were computed using the following expression:

$$Factor\ of\ Safety = \frac{F_{ver} \cdot \tan\phi}{F_{hor}}$$

Vertical forces considered in the analysis are due to the weight of the dam and to hydrostatic uplift at the base of the dam. Horizontal forces considered are due to the reservoir, tailwater, silt load, and for the Extreme loading case, seismic acceleration.

The computed factors of safety for each of the three loading conditions are listed in the table below. The results of the preliminary stability analysis indicate that the dam meets the required factors of safety and will be stable under the assumed loading conditions.

**Table 9 Stability Analysis Results**

| Case | Computed Factor of Safety | Required Factor of Safety | Criteria Satisfied? |
|---|---|---|---|
| Usual – Normal Pool | 3.0 | 1.5 | Yes |
| Unusual – Flood Pool | 1.9 | 1.3 | Yes |
| Extreme – Earthquake | 1.8 | 1.3 | Yes |

### 6.2.2 Bearing Capacity Analysis

A preliminary foundation bearing capacity analysis was performed using a procedure recommended by Goodman (1989) for rock foundations. The range of bearing capacities estimated for the rock at the dam site are listed in the table below.

**Table 10 Allowable Bearing Capacity**

| Rock Type | Friction Angle (deg) | Allowable Bearing Capacity (MPa) |
|---|---|---|
| Sandstone, fresh | 45 | 137 |
| Sandstone, weathered | 30 | 16 |

The maximum foundation loads due to the three dam loading conditions are given in the table below. The minimum allowable bearing capacity is taken as that computed for the weathered sandstone. It is anticipated, however, that the weathered sandstone will be removed during foundation excavation and that the dam will be founded in fresh sandstone, which has a higher allowable bearing capacity.

**Table 11 Bearing Capacity Analysis Results**

| Case | Maximum Bearing Pressure (MPa) | Minimum Allowable Bearing Capacity (MPa) | Criteria Satisfied? |
|---|---|---|---|
| Usual – Normal Pool | 0.32 | 16 | Yes |
| Unusual – Flood Pool | 0.33 | 16 | Yes |
| Extreme – Earthquake | 0.35 | 16 | Yes |

# ATTACHMENTS

# Attachment 1 – Río Coclé del Norte Spillway Hydraulic Analysis

**MWH**
MONTGOMERY WATSON HARZA

MWH AMERICAS, INC.
HYDROPOWER

**Location** Chicago Office **Date** July 3, 2003

**To** Michael Newbery

**From** Paul M. Kanellopoulos

**Subject** Hydraulic Analysis of the Spillway at Cocle del Norte Dam

---

This memorandum summarizes the procedures and results performed for the Cocle del Norte Dam spillway design. The analysis includes:

- Estimation of flood surcharges for an ungated ogee spillway with a 50m length and a crest elevation ranging from 70.0 to 105.0 m.

Basic data used in the analysis is discussed. Results are provided as tables.

## Computer Model

The Full-Equations (FEQ) modeling system of one-dimensional, unsteady, open-channel flow was used for the hydraulic analysis of the Cocle del Norte Dam. FEQ is based on the full Saint-Venant equations. This modeling system, developed by Delbert Franz of Linsley, Kraeger Associates, Ltd., Mountain View, CA is widely used by engineers and hydrologists in county and state agencies and consulting firms, and has been accepted by the Federal Emergency Management Agency (FEMA) for use in floodplain studies. It is used in a variety of applications such as flood studies, design studies for dam spillways, dam break analyses, and legal cases. The program supports a wide variety of structures including bridges, culverts, dams, level-pool reservoirs, spillways, weirs, sluice gates, pumps, side weirs, expansions, contractions, drop structures, and flow over roadways. The hydraulic features of the stream system, such as channel cross-sectional properties, are incorporated into the model. FEQ is capable of simulating flow conditions in a network of open channels and storm sewers. The flow conditions are simulated in terms of water-surface elevation, water velocity, and discharge at any point in the system.

## Evaluation of Spillway Size

The probable maximum flood (PMF) was routed through the reservoir with starting pool elevations of 70.0, 80.0, 90.0, 100.0, and 105.0 m and an ogee spillway width of 50m. The PMF and reservoir stage-volume data are listed in Tables 1 and 2, respectively. The ogee spillway coefficients vary with surcharge and range between 1.5 and 2.28, as shown in Table 3. A design head of 3 m was used to determine these coefficients. Table 4 shows the results for each starting pool elevation (spillway crest) including, maximum water surface elevation at the reservoir and dam tailwater, peak flow through spillway, and top of dam, which corresponds to the maximum water surface elevation at the reservoir plus one meter. Table 5 shows the results for a starting pool El. 71 for 25 m, 50 m, 75 m width.

**Table 1. Probable maximum flood at Cocle del Norte**

| Time (hrs) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Flow (cms) | 110 | 114 | 124 | 138 | 158 | 188 | 227 | 278 |
| Time (hrs) | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Flow (cms) | 339 | 407 | 480 | 555 | 631 | 707 | 783 | 858 |
| Time (hrs) | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Flow (cms) | 932 | 1004 | 1081 | 1167 | 1259 | 1358 | 1471 | 1601 |
| Time (hrs) | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Flow (cms) | 1747 | 1918 | 2130 | 2383 | 2756 | 3330 | 4021 | 4771 |
| Time (hrs) | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| Flow (cms) | 5634 | 6626 | 7671 | 8671 | 9515 | 10103 | 10402 | 10459 |
| Time (hrs) | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Flow (cms) | 10352 | 10134 | 9814 | 9395 | 8917 | 8423 | 7935 | 7460 |
| Time (hrs) | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 |
| Flow (cms) | 7000 | 6556 | 6128 | 5720 | 5332 | 4958 | 4597 | 4247 |
| Time (hrs) | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| Flow (cms) | 3911 | 3591 | 3291 | 3011 | 2753 | 2516 | 2297 | 2098 |
| Time (hrs) | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| Flow (cms) | 1917 | 1753 | 1604 | 1469 | 1345 | 1232 | 1132 | 1040 |
| Time (hrs) | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 |
| Flow (cms) | 958 | 882 | 813 | 750 | 691 | 632 | 580 | 535 |
| Time (hrs) | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 |
| Flow (cms) | 497 | 462 | 431 | 403 | 378 | 355 | 334 | 315 |
| Time (hrs) | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 |
| Flow (cms) | 297 | 281 | 267 | 253 | 241 | 229 | 219 | 209 |
| Time (hrs) | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 |
| Flow (cms) | 200 | 192 | 184 | 177 | 170 | 162 | 151 | 141 |
| Time (hrs) | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 |
| Flow (cms) | 134 | 130 | 127 | 124 | 122 | 120 | 118 | 117 |
| Time (hrs) | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 |
| Flow (cms) | 116 | 115 | 114 | 113 | 112 | 112 | 111 | 111 |

**Table 2. Reservoir capacity curve at Cocle del Norte**

| Elevation (m) | Area ($km^2$) | Volume (MCM) |
|---|---|---|
| 0 | 0 | 0 |
| 5 | 3.60 | 4.58 |
| 10 | 8.14 | 28.83 |
| 15 | 13.71 | 72.87 |
| 20 | 20.52 | 136.80 |
| 25 | 28.90 | 265.98 |
| 30 | 38.94 | 438.60 |
| 35 | 50.86 | 661.80 |
| 40 | 65.27 | 952.72 |
| 45 | 83.69 | 1339.89 |
| 50 | 105.97 | 1830.35 |
| 55 | 132.07 | 2426.08 |
| 60 | 160.59 | 3140.95 |
| 65 | 190.21 | 4011.29 |
| 70 | 220.44 | 5039.91 |
| 75 | 251.14 | 6208.50 |
| 80 | 282.41 | 7513.97 |
| 85 | 314.43 | 8986.75 |
| 90 | 347.03 | 10598.11 |
| 95 | 380.83 | 12347.23 |
| 100 | 413.90 | 14435.34 |
| 105 | 448.12 | 16948.64 |
| 110 | 482.34 | 19461.94 |

**Table 3. Ogee spillway coefficients for a design head of 3m**

| Surcharge (m) | Coefficient |
|---|---|
| 0.0 | 1.50 |
| 0.36 | 1.66 |
| 0.6 | 1.74 |
| 0.9 | 1.85 |
| 1.2 | 1.93 |
| 1.5 | 2.00 |
| 1.8 | 2.06 |
| 2.1 | 2.10 |
| 2.4 | 2.15 |
| 2.7 | 2.20 |
| 3.0 | 2.23 |
| 3.3 | 2.25 |
| 3.6 | 2.27 |
| 3.9 | 2.28 |
| 4.2 | 2.28 |
| 5.0 | 2.28 |
| 10.0 | 2.28 |

**Table 4. Surcharge over the 50m spillway for the PMF at Cocle del Norte Dam**

| Starting Full Supply Level (m) | Maximum Reservoir Water Surface Elevation (m) | Peak Flow Through Spillway ($m^3/s$) | Maximum Tailwater Water Surface Elevation (m) | Top of Dam (m) |
|---|---|---|---|---|
| 70.0 | 73.7 | 794 | 3.2 | 74.7 |
| 80.0 | 83.0 | 574 | 2.4 | 84.0 |
| 90.0 | 92.6 | 444 | 1.9 | 93.6 |
| 100.0 | 101.8 | 253 | 1.0 | 102.8 |
| 105.0 | 106.8 | 253 | 1.0 | 107.8 |

**Table 5. Surcharge from El.71 FSL for the PMF at Cocle del Norte Dam**

| Spillway Width (m) | Maximum Reservoir Water Surface Elevation (m) | Peak Flow Through Spillway ($m^3/s$) | Maximum Tailwater Water Surface Elevation (m) | Top of Parapet (m) |
|---|---|---|---|---|
| 25.0 | 74.9 | 431 | 2.5 | 75.9 |
| 50.0 | 74.7 | 798 | 4.3 | 75.7 |
| 75.0 | 74.5 | 1122 | 5.4 | 75.5 |

# Attachment 2 – Río Caño Sucio Spillway Hydraulic Analysis

MWH
MONTGOMERY WATSON HARZA

MWH AMERICAS, INC.
HYDROPOWER

**Location** Chicago Office **Date** July 10, 2003

**To** Michael Newbery

**From** Paul M. Kanellopoulos

**Subject** Hydraulic Analysis of Río Caño Sucio Dam

---

This memorandum summarizes the procedures and results performed for the Río Caño Sucio Dam spillway and outlet culvert design. The analysis includes:

- Estimation of flood surcharges for an ungated ogee spillway with length ranging from 25-100 m and a crest of 100.0 m;

- Estimation of water surface elevation in the reservoir for 3 different box culvert configurations.

Basic data used in the analysis is discussed. Results are provided as tables.

## Computer Model

The Full-Equations (FEQ) modeling system of one-dimensional, unsteady, open-channel flow was used for the hydraulic analysis of the Río Caño Sucio Dam. FEQ is based on the full Saint-Venant equations. This modeling system, developed by Delbert Franz of Linsley, Kraeger Associates, Ltd., Mountain View, CA is widely used by engineers and hydrologists in county and state agencies and consulting firms, and has been accepted by the Federal Emergency Management Agency (FEMA) for use in floodplain studies. It is used in a variety of applications such as flood studies, design studies for dam spillways, dam break analyses, and legal cases. The program supports a wide variety of structures including bridges, culverts, dams, level-pool reservoirs, spillways, weirs, sluice gates, pumps, side weirs, expansions, contractions, drop structures, and flow over roadways. The hydraulic features of the stream system, such as channel cross-sectional properties, are incorporated into the model. FEQ is capable of simulating flow conditions in a network of open channels and storm sewers. The flow conditions are simulated in terms of water-surface elevation, water velocity, and discharge at any point in the system.

## Introduction

The main components of the Río Caño Sucio unsteady flow model are the cross-sectional data, the flow data, the storage-elevation data, and the downstream boundary condition. One cross-section was used for the flat, 27m long channel reach downstream of the dam. This cross section, which was obtained from the topographic map provided by Ingeniería Avanzada S.A., is shown in Table 1. The Manning's roughness coefficient used is 0.04. Critical depth is set at the downstream boundary where a waterfall is present. Flow and storage information will be presented in the subsequent sections of this memo.

**Table 1. Cross Section Downstream of Río Caño Sucio Dam**

| Offset (m) | Elevation (m) |
|---|---|
| 0.0 | 94.0 |
| 7.5 | 92.0 |
| 12.5 | 90.0 |
| 16.0 | 88.0 |
| 19.5 | 86.0 |
| 25.5 | 84.0 |
| 30.5 | 82.7 |
| 34.0 | 84.0 |
| 101.0 | 86.0 |
| 111.5 | 88.0 |
| 122.5 | 90.0 |

## Evaluation of Spillway Size

The probable maximum flood (PMF) was routed through the reservoir with starting pool elevation of 100.0 m, which corresponds to the spillway crest elevation. Ogee spillway widths of 25, 50, 75, and 100 m were modeled. The PMF and reservoir stage-volume data are listed in Tables 2 and 3, respectively. The ogee spillway coefficients vary with surcharge and range between 1.5 and 2.28, as shown in Table 4. A design head of 3 m was used to determine these coefficients. Table 5 shows the water surface elevation at the reservoir, surcharge, dam height, and peak flow through the spillway for each of the 4 spillway widths. The top of the dam is obtained by adding one meter to the peak water surface elevation.

**Table 2. Probable maximum flood at Río Caño Sucio**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Time (hrs)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow ($m^3$/s)** | 10 | 13 | 22 | 35 | 51 | 66 | 79 | 91 |
| **Time (hrs)** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow ($m^3$/s)** | 100 | 108 | 114 | 118 | 122 | 126 | 132 | 140 |
| **Time (hrs)** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow ($m^3$/s)** | 148 | 156 | 166 | 183 | 204 | 227 | 252 | 279 |
| **Time (hrs)** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| **Flow ($m^3$/s)** | 308 | 346 | 403 | 481 | 652 | 969 | 1330 | 1600 |
| **Time (hrs)** | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| **Flow ($m^3$/s)** | 1687 | 1587 | 1387 | 1174 | 985 | 823 | 689 | 584 |
| **Time (hrs)** | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| **Flow ($m^3$/s)** | 505 | 442 | 389 | 342 | 299 | 262 | 233 | 207 |
| **Time (hrs)** | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 |
| **Flow ($m^3$/s)** | 185 | 166 | 143 | 117 | 91 | 68 | 51 | 39 |
| **Time (hrs)** | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| **Flow ($m^3$/s)** | 30 | 24 | 20 | 17 | 15 | 13 | 12 | 11 |
| **Time (hrs)** | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| **Flow ($m^3$/s)** | 11 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

**Table 3. Reservoir capacity curve at Río Caño Sucio**

| Elevation (m) | Area ($km^2$) | Volume (MCM) |
|---|---|---|
| 85 | 0.00 | 0.00 |
| 86 | 0.33 | 0.50 |
| 87 | 0.82 | 1.20 |
| 88 | 1.34 | 2.30 |
| 89 | 1.90 | 3.70 |
| 90 | 2.54 | 5.20 |
| 91 | 3.18 | 8.00 |
| 92 | 3.90 | 11.20 |
| 93 | 4.68 | 15.40 |
| 94 | 5.55 | 20.20 |
| 95 | 6.50 | 27.20 |
| 96 | 7.50 | 34.30 |
| 97 | 8.58 | 42.40 |
| 98 | 9.71 | 51.60 |
| 99 | 11.00 | 62.00 |
| 100 | 12.41 | 73.80 |
| 101 | 13.74 | 86.60 |
| 102 | 15.17 | 100.70 |
| 103 | 16.67 | 116.70 |
| 104 | 18.24 | 133.50 |
| 105 | 20.00 | 154.00 |

**Table 4. Ogee spillway coefficients for a design head of 3m**

| Surcharge (m) | Coefficient |
|---|---|
| 0.0 | 1.50 |
| 0.36 | 1.66 |
| 0.6 | 1.74 |
| 0.9 | 1.85 |
| 1.2 | 1.93 |
| 1.5 | 2.00 |
| 1.8 | 2.06 |
| 2.1 | 2.10 |
| 2.4 | 2.15 |
| 2.7 | 2.20 |
| 3.0 | 2.23 |
| 3.3 | 2.25 |
| 3.6 | 2.27 |
| 3.9 | 2.28 |
| 4.2 | 2.28 |
| 5.0 | 2.28 |
| 10.0 | 2.28 |

**Table 5. Surcharge over the spillway at Río Caño Sucio Dam during PMF**

| Spillway Width (m) | Maximum Reservoir Water Surface Elevation (m) | Surcharge (m) | Peak Flow Through Spillway ($m^3/s$) | Top of Dam (m) |
|---|---|---|---|---|
| 25 | 103.6 | 3.6 | 393 | 104.6 |
| 50 | 103.1 | 3.1 | 611 | 104.1 |
| 75 | 102.8 | 2.8 | 761 | 103.8 |
| 100 | 102.5 | 2.5 | 870 | 103.5 |

## Evaluation of Outlet Size

The outlet design was based on the 50-yr dry season flood hydrograph, which is shown in Table 6. Three concrete-lined box culvert sizes were modeled separately. These cases include a 1-by-1 m, a 2-by-2 m, and a 3-by-3 m culvert. These box culverts have a Manning's number of 0.014, a length of 46 m, and invert elevations of 83.0 m at the entrance and 82.7 m at the exit. Figure 1 shows the water surface elevation at the reservoir as a function of culvert cross-sectional area.

**Table 2. Reservoir capacity curve at Cocle del Norte**

| Elevation (m) | Area ($km^2$) | Volume (Million $m^3$) |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 5.0 | 3.60 | 4.58 |
| 10.0 | 8.14 | 28.83 |
| 15.0 | 13.71 | 72.87 |
| 20.0 | 20.52 | 136.80 |
| 25.0 | 28.90 | 265.98 |
| 30.0 | 38.94 | 438.60 |
| 35.0 | 50.86 | 661.80 |
| 40.0 | 65.27 | 952.72 |
| 45.0 | 83.69 | 1,339.89 |
| 50.0 | 105.97 | 1,830.35 |
| 55.0 | 132.07 | 2,426.08 |
| 60.0 | 160.59 | 3,140.95 |
| 65.0 | 190.21 | 4,011.29 |
| 70.0 | 220.44 | 5,039.91 |
| 75.0 | 251.14 | 6,208.50 |
| 80.0 | 282.41 | 7,513.97 |
| 85.0 | 314.43 | 8,986.75 |
| 90.0 | 347.03 | 10,598.11 |
| 95.0 | 380.83 | 12,347.23 |
| 100.0 | 413.90 | 14,435.34 |
| 105.0 | 448.12 | 16,948.64 |
| 110.0 | 482.34 | 19,461.94 |

## Tailwater Analysis

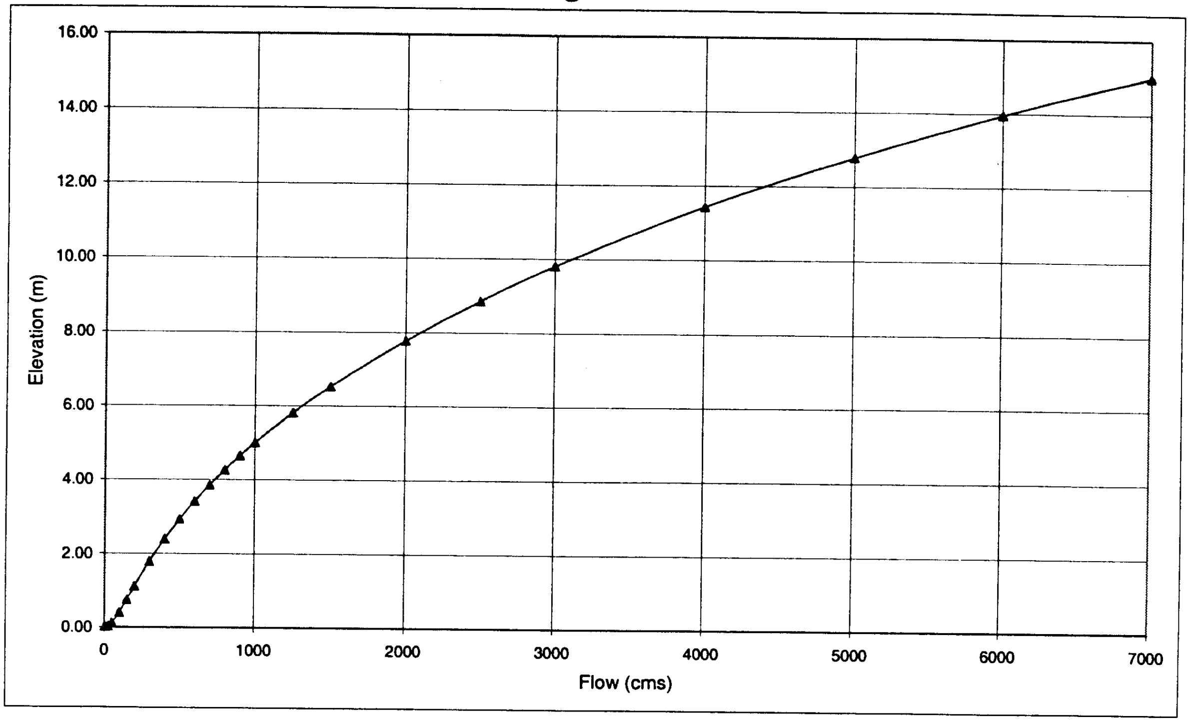
The objective of the tailwater analysis was to develop a tailwater-rating curve for the proposed Cocle del Norte site. Ten cross-sections, located between 200 and 13,000 m downstream of the dam, were used. The station-elevation data for the first nine cross-sections were obtained from a topographic map of 1:50,000-scale and 10 m contour interval. An echo sounder was used to determine the thalweg for Section 1. Section 10, located 13,000 m downstream of the dam, is a wide section representing the estuary. The average channel slope of the 12,800 m channel reach is 0.004%. The Manning's roughness coefficients for the study reach are 0.035 for the channel flow and 0.050 for over-bank flow. As mentioned earlier, the cross-section data are listed in Appendix I.

The resulting tailwater rating curve at the first cross-section is tabulated in Table 3 and plotted in Figure 1. The boundary condition at the estuary was fixed at 0.0 m. Typical tidal data for the area was also simulated, but the model runs show that the tide has no significant effect at the dam, especially at higher flows. This is consistent with field observations.

**Table 3. Tailwater rating curve (200 m d/s of dam)**

| Flow ($m^3/s$) | Tailwater Elevation (m) |
|---|---|
| 1 | 0.00 |
| 2 | 0.00 |
| 5 | 0.00 |
| 10 | 0.01 |
| 25 | 0.03 |
| 50 | 0.12 |
| 100 | 0.40 |
| 150 | 0.75 |
| 200 | 1.11 |
| 300 | 1.79 |
| 400 | 2.39 |
| 500 | 2.93 |
| 600 | 3.41 |
| 700 | 3.85 |
| 800 | 4.26 |
| 900 | 4.64 |
| 1000 | 5.00 |
| 1250 | 5.81 |
| 1500 | 6.53 |
| 2000 | 7.78 |
| 2500 | 8.86 |
| 3000 | 9.81 |
| 4000 | 11.44 |
| 5000 | 12.78 |
| 6000 | 13.95 |
| 7000 | 15.00 |

**Figure 1. Cocle del Norte tailwater rating curve at Section 1**




## Evaluation of Diversion Tunnel Size

Three diversion tunnel sizes were modeled in order to determine the cofferdam height upstream and downstream of the proposed dam. Tunnel sizes considered are D-shaped with diameters 6, 8, and 10 m and a length of 550 m. The tunnel invert elevation is 0.0 m at both ends and the discharge point is at Section 1, 200 m downstream of the dam. A Manning's coefficient of 0.014 was used for the concrete-lined tunnel. Entrance and exit loss coefficients are 0.5 and 1.0, respectively. Bend losses were assumed to be negligible. The inflow routed through the reservoir is the 50-yr hydrograph.

The cofferdam heights and peak discharge for the different tunnel sizes are shown in Table 4a. Simulations include both a fixed water surface elevation of 0.0 m at the estuary and a tide which fluctuates between –0.22 and + 0.27 m. Cofferdam heights turn out to be the same in both cases. This information was used to select the most cost-effective alternative.

**MWH**
MONTGOMERY WATSON HARZA

MWH AMERICAS, INC.
HYDROPOWER

**Location** Chicago Office

**Date** August 6, 2003

**To** Michael Newbery

**From** Paul M. Kanellopoulos

**Subject** Cocle del Norte Water Supply Feasibility Study
Hydraulic Analysis for Design of Cofferdam, Diversion Tunnel and Transfer Tunnel

---

This memorandum summarizes the procedures and results of the hydraulic analysis performed for the design of cofferdam, closure dikes, diversion tunnel, and transfer tunnel for the Cocle del Norte Project. The analysis included:

- Development of tailwater rating curve.
- Estimation of cofferdam height upstream and downstream of the proposed dam. The diameters of the modified horseshoe (D-shaped) tunnels considered were 6, 8, and 10 m with a length of 550.0 m.
- Estimation of closure dike height for low flows (25, 50, 75 $m^3/s$).
- Design of 18 km transfer tunnel.
- Drawdown time to 75, 50, and 25% of full supply level.

Basic data used in the analysis is discussed. Results are provided as tables.

## Computer Model

The Full-Equations (FEQ) modeling system of one-dimensional, unsteady, open-channel flow was used for the hydraulic analysis of the Cocle del Norte project. FEQ is based on the full Saint-Venant equations. This modeling system, developed by Delbert Franz of Linsley, Kraeger Associates, Ltd., Mountain View, CA is widely used by engineers and hydrologists in county and state agencies and consulting firms, and has been accepted by the Federal Emergency Management Agency (FEMA) for use in floodplain studies. It is used in a variety of applications such as flood studies, design studies for dam spillways, dam break analyses, and legal cases. The program supports a wide variety of structures including bridges, culverts, dams, level-pool reservoirs, spillways, weirs, sluice gates, pumps, side weirs, expansions, contractions, drop structures, and flow over roadways. The hydraulic features of the stream system, such as channel cross-sectional properties, are incorporated into the model. FEQ is capable of simulating flow conditions in a network of open channels and storm sewers. The flow conditions are simulated in terms of water-surface elevation, water velocity, and discharge at any point in the system.

## Introduction

The main purpose of this study is to determine the size of the diversion tunnel to pass the 50-yr flow as well as the resulting cofferdam heights upstream and downstream of the dam. The main components of the model include the 50-yr hydrograph, the reservoir capacity curve, and the cross sectional data, shown in Tables 1 and 2, and Appendix I, respectively.

**Table 1. 50-year flood hydrograph at Cocle del Norte**

| Time (hrs) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Flow ($m^3/s$) | 128 | 128 | 135 | 244 | 396 | 532 | 742 | 900 |
| Time (hrs) | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Flow ($m^3/s$) | 1500 | 2000 | 2600 | 3200 | 3860 | 3700 | 3400 | 3100 |
| Time (hrs) | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Flow ($m^3/s$) | 2800 | 2600 | 2500 | 2400 | 2300 | 2200 | 2100 | 2000 |
| Time (hrs) | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Flow ($m^3/s$) | 1900 | 1800 | 1700 | 1600 | 1500 | 1450 | 1400 | 1350 |
| Time (hrs) | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| Flow ($m^3/s$) | 1300 | 1250 | 1200 | 1150 | 1100 | 1070 | 1040 | 1010 |
| Time (hrs) | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Flow ($m^3/s$) | 980 | 950 | 920 | 890 | 860 | 830 | 800 | 770 |
| Time (hrs) | 48 | 68 | 72 | | | | | |
| Flow ($m^3/s$) | 740 | 140 | 128 | | | | | |

## Attachment 3 – Río Coclé del Norte FSL El. 80 Diversion Hydraulic Analysis

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX D
PART 3

DAM HEIGHT SELECTION

Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D – PART 3
## DAM HEIGHT SELECTION

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# 1 INTRODUCTION

The scope of services for the Ríos Coclé del Norte and Caño Sucio Water Supply Projects requires selecting the reservoir operation range and dam height for two separate developments:

1. The Río Coclé del Norte reservoir acting in full regulation with the Río Indio reservoir;
2. The Río Coclé del Norte reservoir acting in full regulation with the Río Caño Sucio and Río Indio reservoirs.

This appendix describes the approach and studies adopted to select the dam heights for these two project developments. Studies to confirm the reservoir area and volume as a function of elevation, which are a key input to the operation model are also described in this appendix. The original requirement of optimization of the two projects cannot be performed as project economics now encompass scheduling and construction of new locks and associated revenue, and the results of these studies are not available. Therefore, dam height selection has been based on fully developing the water supply yield of the Coclé del Norte and the Coclé del Norte and Caño Sucio basins at the lowest cost and impact.

For this study, the cost and impact have been assessed based on the following major cost components of developing a water resource project:

1. Dam and appurtenant features, including reservoir clearing
2. Water conveyance systems, and
3. Relocations and compensation.

Cost estimates also include common development costs, contingencies and engineering and administration.

The Panama Canal water supply system yields were estimated based on extensive operation simulations studies performed using a HEC-5 computer model.

# 2 RESERVOIR AREA AND VOLUME DATA

This section presents the development of the area and volume versus elevation relationships for the Ríos Coclé del Norte and Caño Sucio Water Supply Projects.

## 2.1 Río Coclé del Norte Reservoir

Topography for the Coclé del Norte reservoir was taken from digital 1:50,000-scale contour maps provided by the USACE Mobile District in *.dxf* format; the contour interval on these maps is 20 meters. The contour data matches published 1:50,000 topography maps. The reservoir is located on the following map sheets:

1. Petaquilla (4042-I)
2. Cerro Miguel (4142-IV)
3. Tulu (4142-III)
4. Coclecito (4042-II)

Land survey data obtained by Ingenieria Avanzada (under a separate task order of this contract) were used to determine the base elevations for estimating volume. The area bounded by the 20, 40, 60, 80 and 100-m contours was computed using the AutoCAD *area* command. The area of numerous 'islands', present within the reservoir for various elevations, were computed separately and subtracted from the overall area; the remaining area composed of numerous small islands was estimated base on visual inspection.

The equation used for volume estimates is:

$$Volume = \frac{1}{3}(H_1 - H_2)(A_1 + A_2 + \sqrt{A_1 A_2})$$

where $H$ is elevation, $A$ is area.

MWH volume estimates were made with MWH area estimates using the above equation and a smooth curve was drawn through the data. The same equation was used by MWH for estimating volumes for the Río Indio, Río Caño Sucio and Upper Chagres reservoirs.

**Table 1 Recommended Río Coclé del Norte Reservoir Area-Volume Data**

| Elevation (m) | Area ($km^2$) | Cumulative Volume (MCM) |
|---|---|---|
| **0** | **0** | **0** |
| 5 | 3.60 | 4.58 |
| 10 | 8.14 | 28.83 |
| 15 | 13.71 | 72.87 |
| **20** | **20.52** | **136.80** |
| 25 | 28.90 | 265.98 |
| 30 | 38.94 | 438.60 |
| 35 | 50.86 | 661.80 |
| **40** | **65.27** | **952.72** |
| 45 | 83.69 | 1,339.89 |
| 50 | 105.97 | 1,830.35 |
| 55 | 132.07 | 2,426.08 |
| **60** | **160.59** | **3,140.95** |
| 65 | 190.21 | 4,011.29 |
| 70 | 220.44 | 5,039.91 |
| 75 | 251.14 | 6,208.50 |
| **80** | **282.41** | **7,513.97** |
| 85 | 314.43 | 8,986.75 |
| 90 | 347.03 | 10,598.11 |
| 95 | 380.83 | 12,347.23 |
| **100** | **413.90** | **14,435.34** |
| *105* | *448.12* | *16,948.64* |
| *110* | *482.34* | *19,461.94* |

Values in **BOLD** indicate measured contour data; all other values interpolated from curve.
Values in *Italics* extrapolated linearly from El. 100

The level of precision presented in this and following area-volume data tables is not intended to represent the accuracy of the estimates.

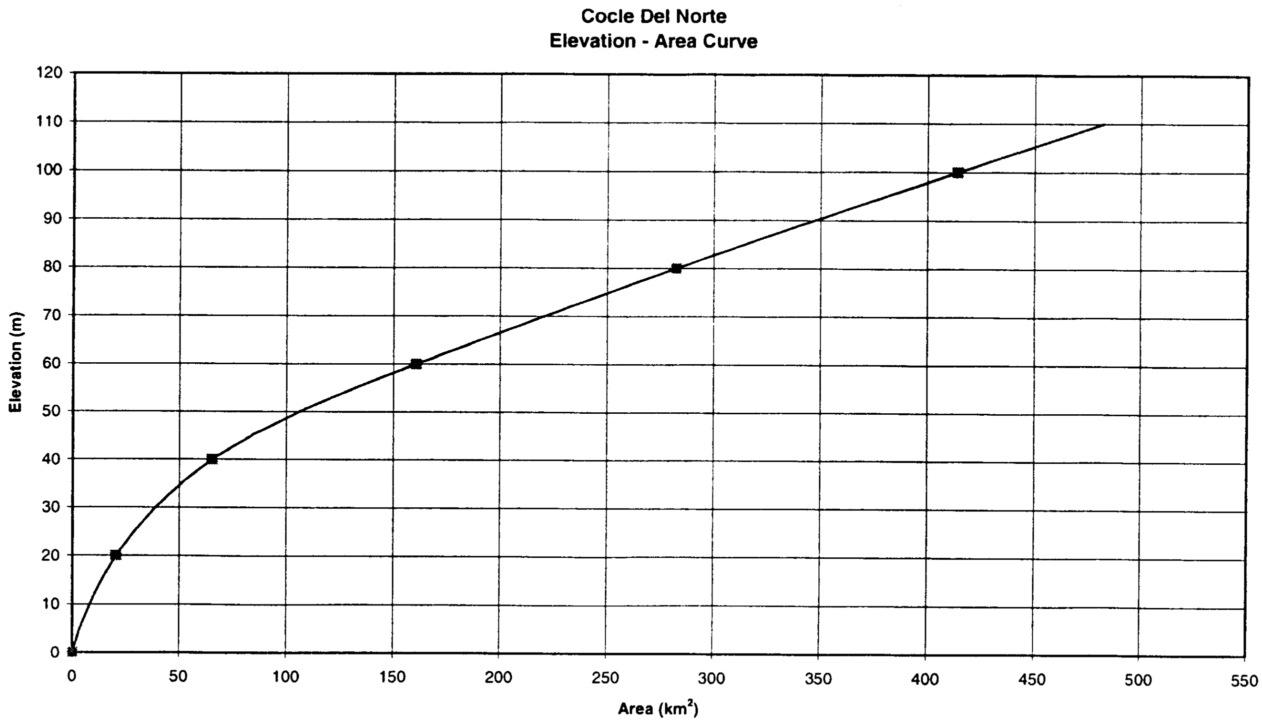



**Figure 1. Recommended Río Coclé del Norte Elevation-Area Curve**

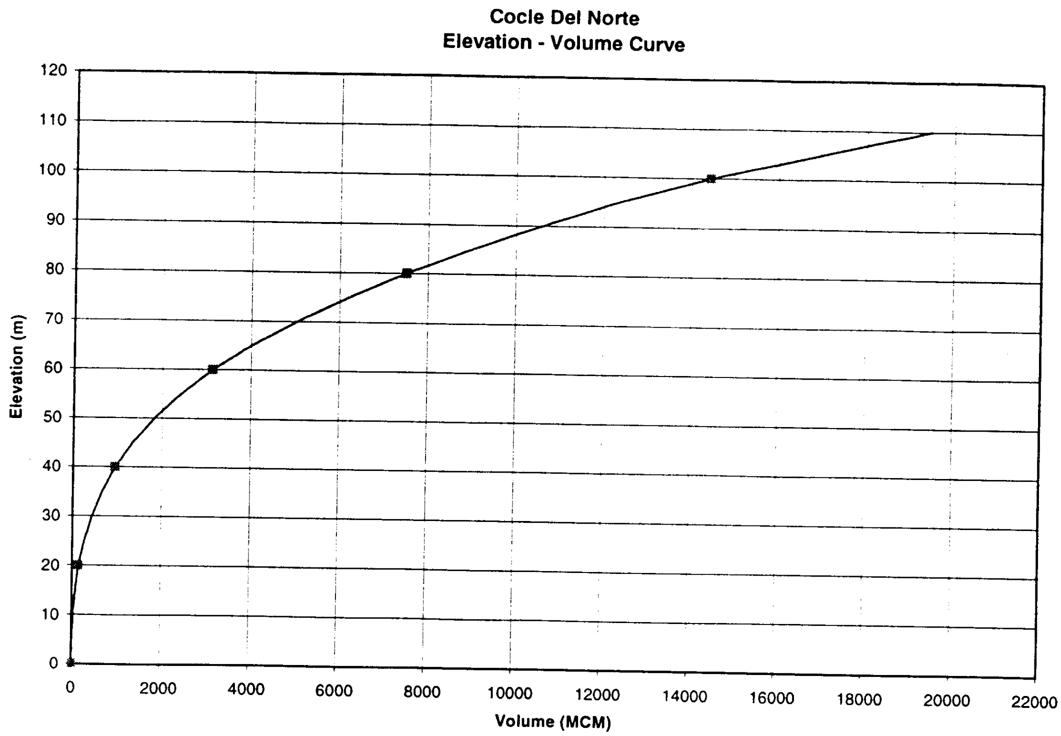



**Figure 2. Recommended Río Coclé del Norte Elevation-Volume Curve**

## 2.2 Río Caño Sucio Reservoir

A similar process was performed for the development of the areas of the Río Caño Sucio Reservoir. A limitation on the process was the topographical data available in the elevation range of interest, namely from about El. 80 to El. 105. In addition to damsite survey data that was used to establish the minimum elevation of the reservoir at EL. 85, there is a partial contour at El. 90, and a full (continuous) contour at El. 100. Areas and volumes for the reservoir have been generated from this information only. Should the Caño Sucio Water Transfer Project be developed, additional survey data should be obtained to better define the reservoir.

**Table 2 Recommended Río Caño Sucio Reservoir Area-Volume Data**

| Elevation (m) | Area ($km^2$) | Cumulative Volume (MCM) |
|---|---|---|
| **85** | **0.00** | **0.00** |
| 86 | 0.33 | 0.50 |
| 87 | 0.82 | 1.20 |
| 88 | 1.34 | 2.30 |
| 89 | 1.90 | 3.70 |
| **90** | **2.54** | **5.20** |
| 91 | 3.18 | 8.00 |
| 92 | 3.90 | 11.20 |
| 93 | 4.68 | 15.40 |
| 94 | 5.55 | 20.20 |
| 95 | 6.50 | 27.20 |
| 96 | 7.50 | 34.30 |
| 97 | 8.58 | 42.40 |
| 98 | 9.71 | 51.60 |
| 99 | 11.00 | 62.00 |
| **100** | **12.41** | **73.80** |
| 101 | 13.74 | 86.60 |
| 102 | 15.17 | 100.70 |
| 103 | 16.67 | 116.70 |
| 104 | 18.24 | 133.50 |
| 105 | 20.00 | 154.00 |

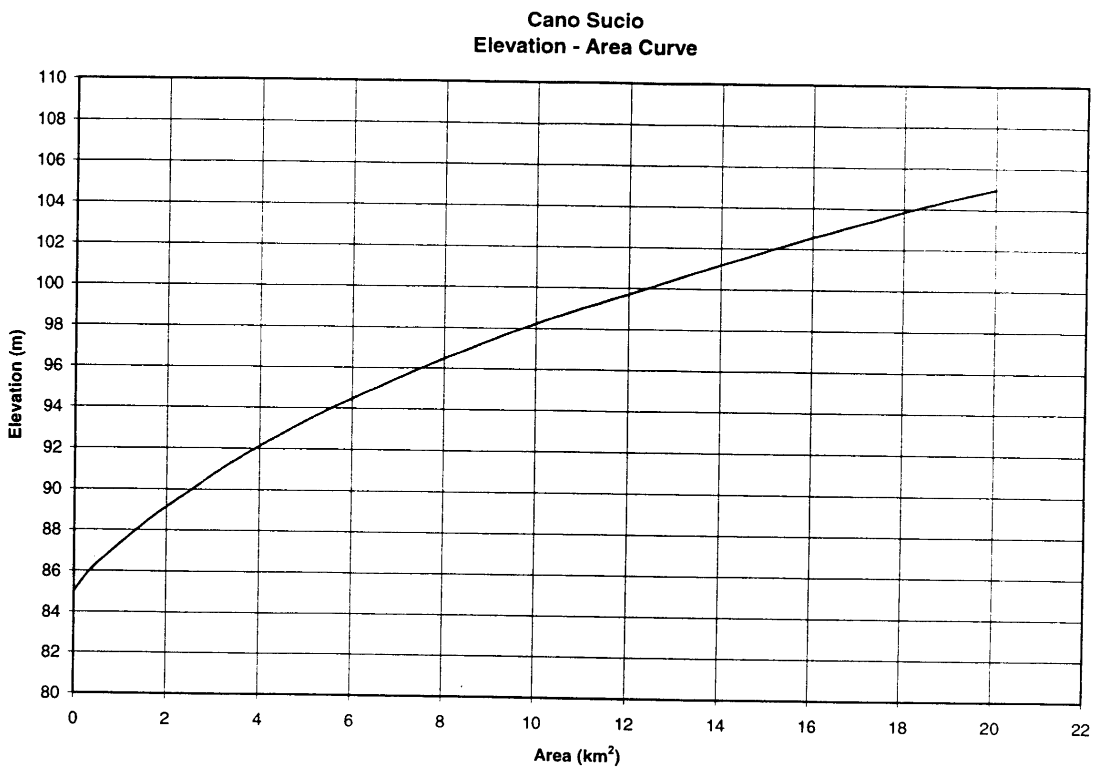



**Figure 3. Recommended Río Caño Sucio Elevation-Area Curve**

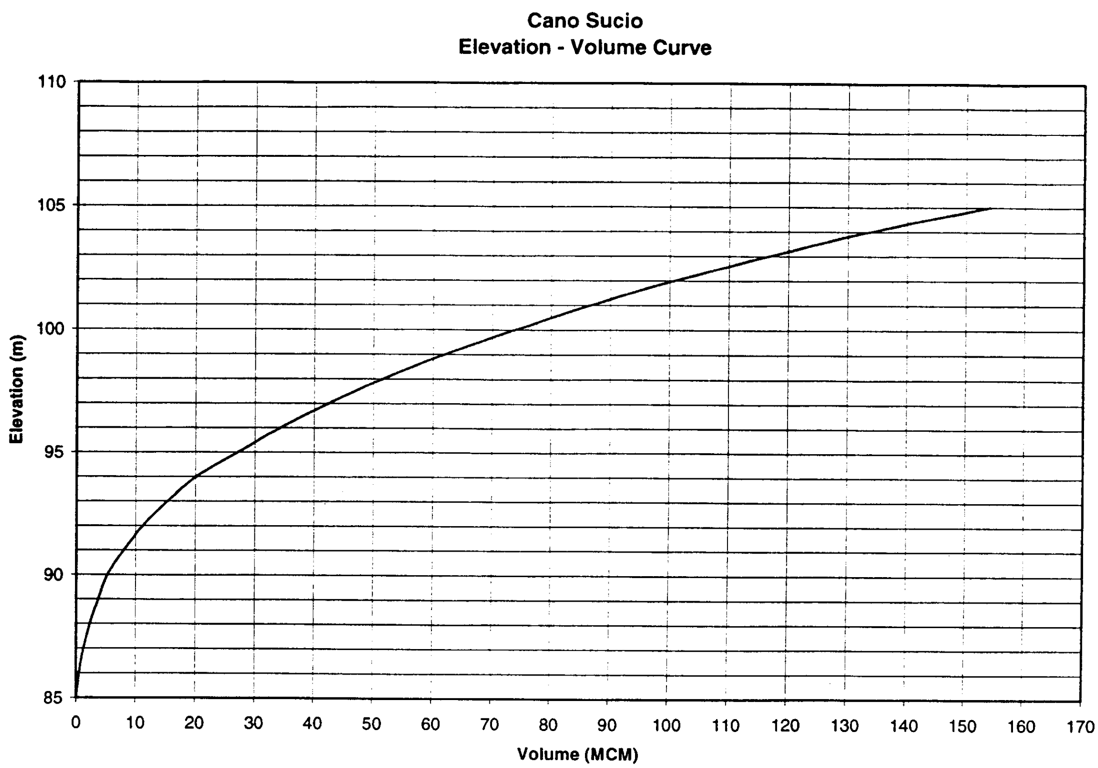



**Figure 4. Recommended Río Caño Sucio Elevation-Volume Curve**

# 3 OPERATION (YIELD) STUDIES

A series of HEC-5 runs have been made to estimate the yield of the Coclé del Norte and the Coclé del Norte and Río Caño Sucio basins acting in regulation with the Río Indio Water Supply Project. These are described in more detail in Appendix C and also the Main Report. A summary figure of the yield as a function of active storage is presented below in Figure 5:

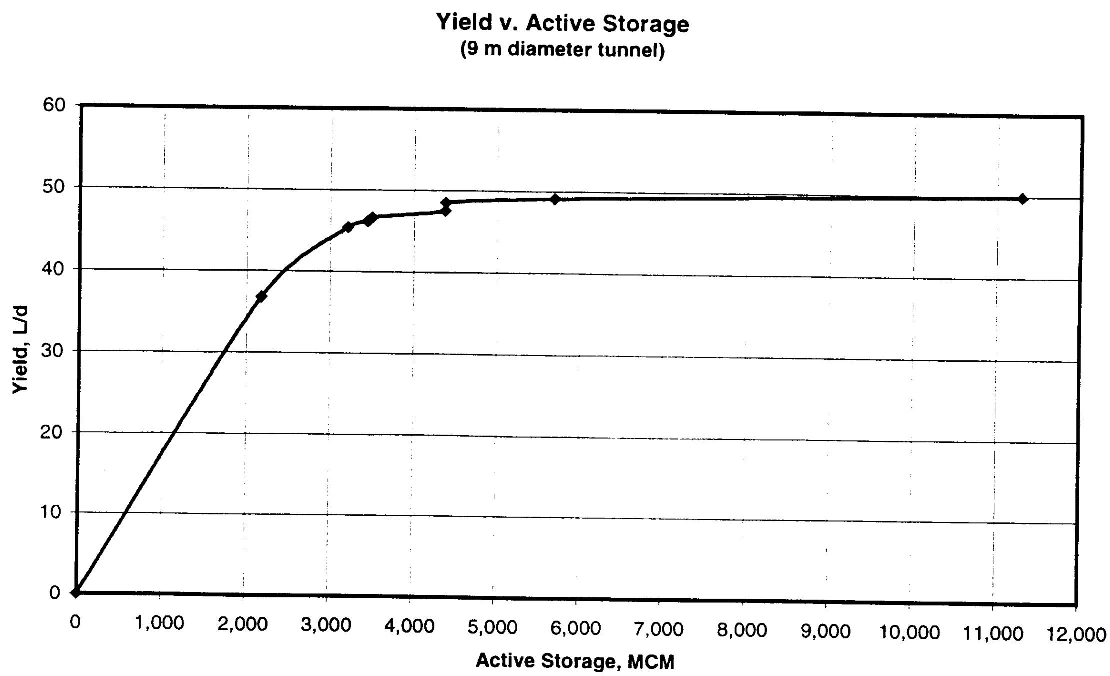



**Figure 5 Yield of Río Coclé del Norte and Río Caño Sucio with Active Storage**

Experience on other water supply development projects has shown that "optimum development" usually occurs in the vicinity of the point of maximum curvature of the storage-yield curve. In the case of the date presented in Figure 5, this would be between active storages of 3,200 MCM and 4,400 MCM. These results are largely independent of reservoir operating elevation because the selected water transfer facility capacities do not appear to be a constraint on yield. Additional operation studies for the selected projects should be performed to confirm this.

It should be noted that the operation and yield studies performed do not follow any rule curves for operation of the Río Coclé del Norte, Río Caño Sucio (if included) and Río Indio Water Supply Projects. At the time of these operation studies an updated HEC-5 model, including improved modeling of lock water usage, was being calibrated for use with the existing system, Lakes Madden and Gatun. Additional operation studies should be performed with the updated HEC-5 model for all of the selected additional water supply projects, including development of operation rule curves as used for Lakes Madden and Gatun to optimize yield.

As a result of the operation studies, selection of dam heights for the two Ríos Coclé del Norte and Río Caño Sucio Water Supply Projects will be to provide active storages of 3,200 MCM to 4,400 MCM.

### 3.1 Río Coclé del Norte- Río Caño Sucio- Río Indio Water Supply Project

The Río Coclé del Norte- Río Caño Sucio- Río Indio Water Supply Project operation range is limited by topography. To take advantage of the Río Caño Sucio basin to transfer water from Río Coclé del Norte to Río Indio, the minimum operating level is about El. 90. Even at this elevation, a canal will be required to provide adequate flow capacity at low Río Coclé del Norte reservoir levels. Establishing this as a minimum operating level, the maximum operating levels to provide an active storage of 3,200 MCM and 4,400 MCM are El 99 and El. 101.

An operating range of El. 100-90 was selected for the operating range of the Río Coclé del Norte-Río Caño Sucio- Río Indio Water Supply Project, providing an active operating range of 3,900 MCM (including Río Caño Sucio reservoir) and an incremental yield of about 3,600 MCM/year (47 lockages/day). Optimization of this water supply project operating range is not warranted unless the project is selected for further consideration as part of the Panama Canal water supply system and until the operation model (HEC-5) is updated, the operation criteria are selected, and the economic value of water can be determined. Subsequent studies to develop this project are described in Appendix D-4, Project Component Configuration.

## 3.2 Río Coclé del Norte- Río Indio Water Supply Project

Figure 5 shows that the yield of the reservoir increases significantly with active storage up to 3,200-4,400 MCM, and is then nearly constant indicating the basin yield is fully developed. The point of optimum yield was judged to be about 3,500 MCM where the system yield is increased by 46.5 lockages per day, for a total system yield of about 107 lockages per day (at 99.6% reliability). As stated previously, selection of the optimum yield requires an economic analysis that cannot be performed as this time. Therefore, for this study additional HEC-5 operation studies have been made for active storage volumes of about 3,500 MCM. Project optimization considered various operation ranges providing this active storage, as well as transfer tunnel sized. A summary of the project operation studies for varying operation ranges and tunnel sizes connecting the Río Coclé del Norte and Río Indio Water Supply Projects are presented in Figure 6 below:

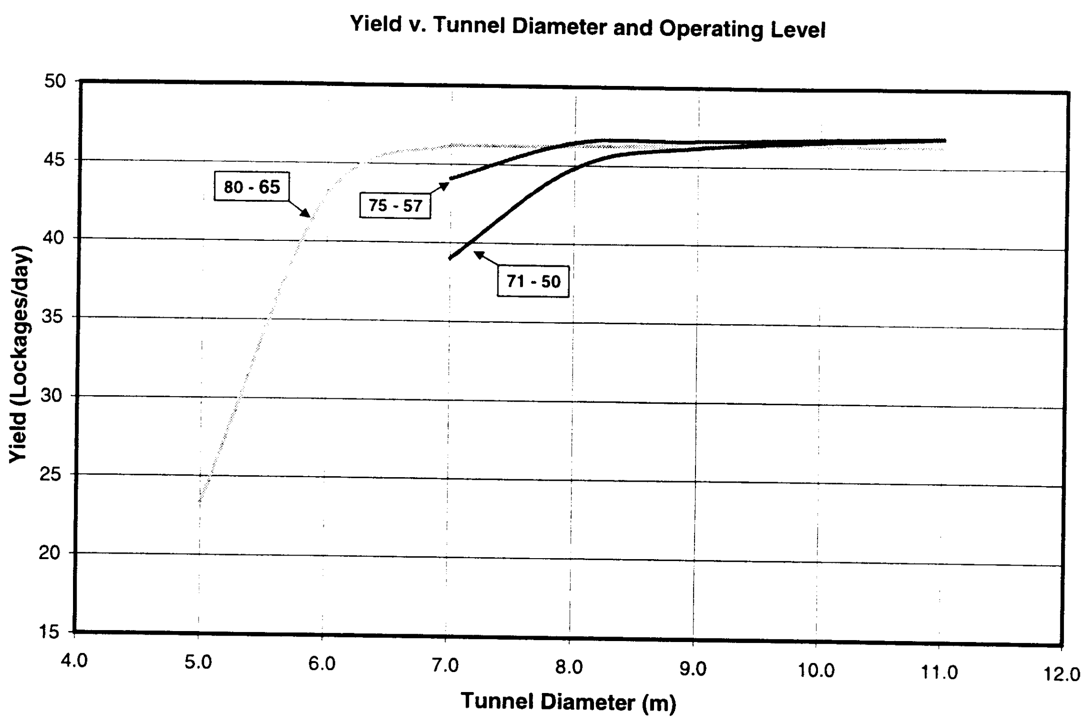



**Figure 6 Yield v. Tunnel Diameter**

Figure 6 is used to determine the size of transfer tunnel required to provide a yield of 46.5 l/d at various operation ranges. From the figure, the following tunnel sizes have been selected:

**Table 3 Water Conveyance Tunnel Diameter Required for Selected Operating Range**

| Operating Range (for Active Storage of 3,500 MCM) | Tunnel Diameter, m |
|---|---|
| 100-90 (Active Storage 3,840 MCM) | Use Río Caño Sucio |
| 80-65 | 7 |
| 75-57 | 8 |
| 71-50 | 9 |

Comparison of the development cost for the dam and conveyance these three operating ranges will determine the least cost development for the Río Coclé del Norte/ Río Indio Water Supply Project to supply 47.5 lockages of water per day.

# 4 COMPARATIVE COST ESTIMATES FOR THE RÍO COCLÉ DEL NORTE – RÍO INDIO PROJECT

To select the dam height for the Río Coclé del Norte- Río Indio Water Supply Project that provides the least cost project development, comparative costs have been developed for the following major project components:

1. Dam
2. Water Conveyance
3. Resettlement (and Compensation)

These cost estimates are intended for comparison between the alternative dam heights, water conveyance sizes, and resettlement mitigation for the alternative projects only. More detailed cost estimates will be prepared for the selected project for all of the project components.

## 4.1 Dam and Appurtenant Works Costs

Dam costs have been prepared using the unit costs and quantity take-offs for several alternative dam heights. Costs include:

- Common project costs (access roads, mob./demob.)
- Diversion and care of water
- Main dam and saddle dams
- Spillway
- Low level outlet
- Reservoir clearing
- Contingency (25%), and
- Engineering and Administration (15%)

The contingency and engineering and administration percentages are the same as used for all feasibility level project cost estimates. Figure 7 presents a graph of dam cost against dam elevation.

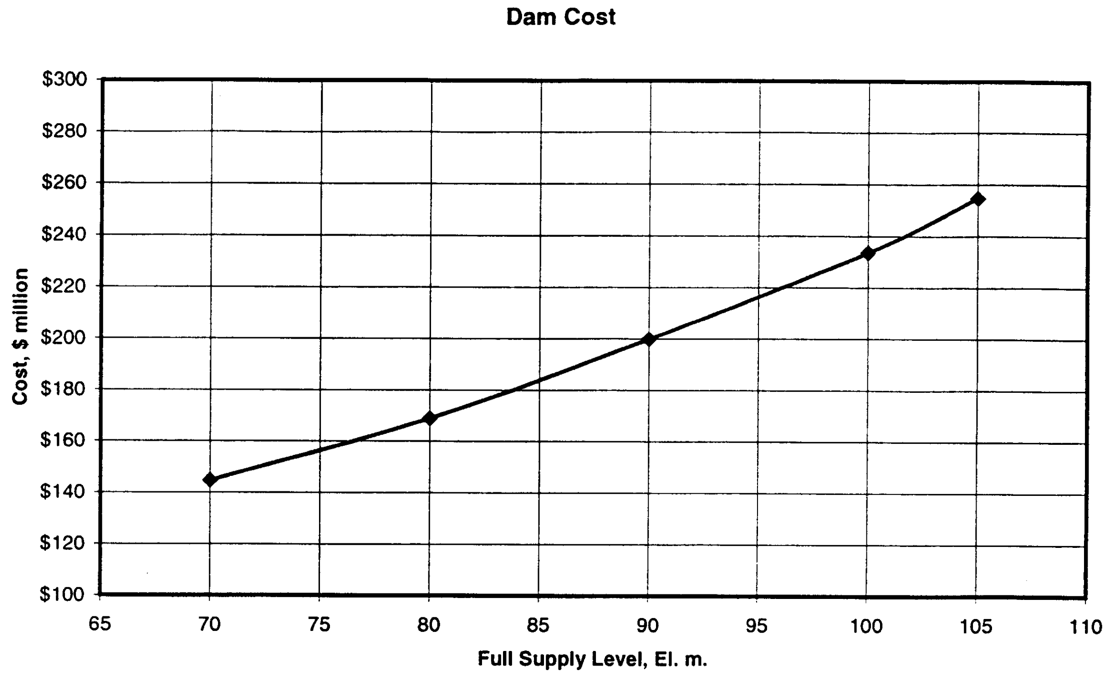



**Figure 7 Dam Height Costs**

It should be noted that the estimated reservoir clearing cost (based on land inundated) represents approximately 40% of the dam and appurtenant works estimated cost before contingency (at El. 80). This estimate should be confirmed.

### 4.2 Water Conveyance Costs

The lower operating elevations selected for the second Río Coclé del Norte project preclude the use of a canal to convey water to the Río Indio project and into Lake Gatun. The lowest topography between the two watersheds is through the Río Caño Sucio project, and is generally at or above El. 90. For the Río Coclé del Norte Project to operate below El. 80 as all three alternatives are considering, the canal would need to convey water between El. 65 as a maximum, to El. 50 as a minimum. By inspection, a canal may not be technically viable, and would not be cost effective. Therefore, a tunnel water conveyance system is proposed for the lower Río Coclé del Norte operating range alternatives.

Tunnel costs have been developed for a range of tunnel sizes. A number of assumptions have been made as follows:

- A tunnel boring machine- (TBM) will be used rather than drill and blast to construct most of the tunnel from Río Coclé del Norte to Río Indio. The long distance and generally high ground cover that would require long intermediate adits favor the TBM.
- A TBM will be used for about 16 km tunnel from the Río Coclé del Norte intake to an access shaft located adjacent to the proposed Río Indio reservoir. Drill and blast will be used for the tunnel under the Río Indio reservoir.
- The tunnel passes through highly variable geology, and will require lining during construction. The selected lining system is segmental lining constructed behind the TBM shield.
- To limit the impact on water supply from the Río Indio reservoir, a lake tap will be used for the tunnel connection.

A cost curve for various tunnel diameters is presented in Figure 8 below:

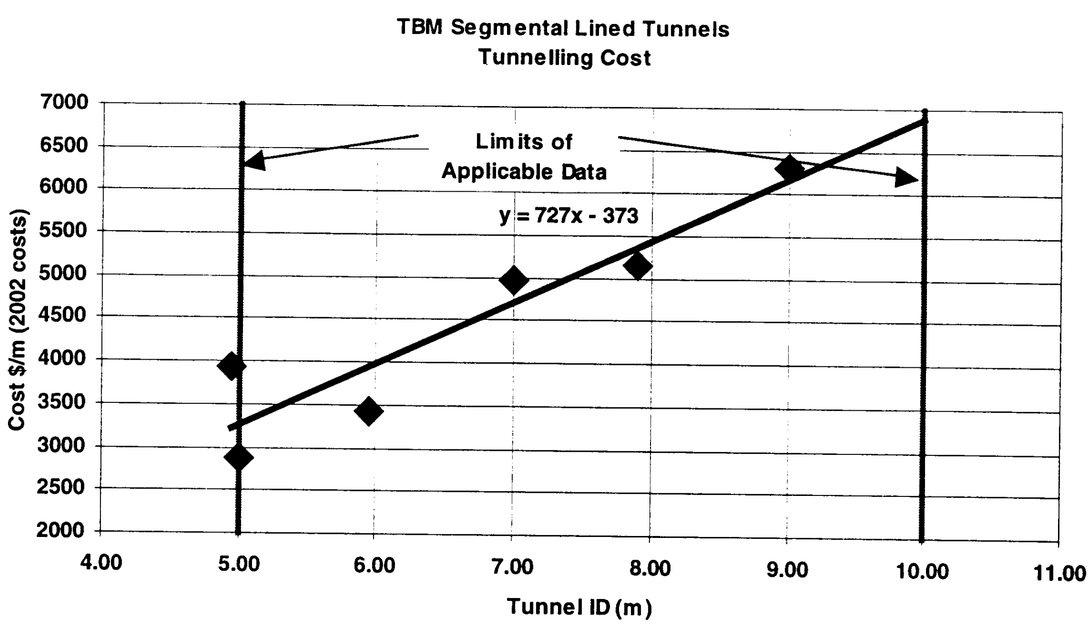



**Figure 8 TBM Tunnel Costs**

As noted the costs do not include a number of costs required for construction of the tunnel, including the segmental lining. The tunnel will be constructed after the Río Indio Water Supply Project is in place. Therefore, it has been assumed that an access shaft and lake tap will be required for the connection. For more information on the tunnel design and construction, see Appendix D5. Total water conveyance system costs for the Río Coclé to Indio connection have been developed for the following components:

1. Site preparation
2. TBM mobilization and assembly
3. Construction shaft (at tunnel intersection with Río Indio reservoir)
4. Tunnel intake portal
5. TBM tunnel with segmental lining
6. Muck disposal
7. Intake structure
8. Intake gate access shaft
9. Outlet control structure
10. Drill and blast tunnel connection to Río Indio lake tap
11. Lake tap
12. Hydro-mechanical equipment
13. Contingency, and
14. Engineering and administration.

Figure 9 presents the resulting cost curve for tunnel diameters ranging from 4 m to 10 m, the anticipated range required for water transfer from Río Coclé del Norte to Río Indio.

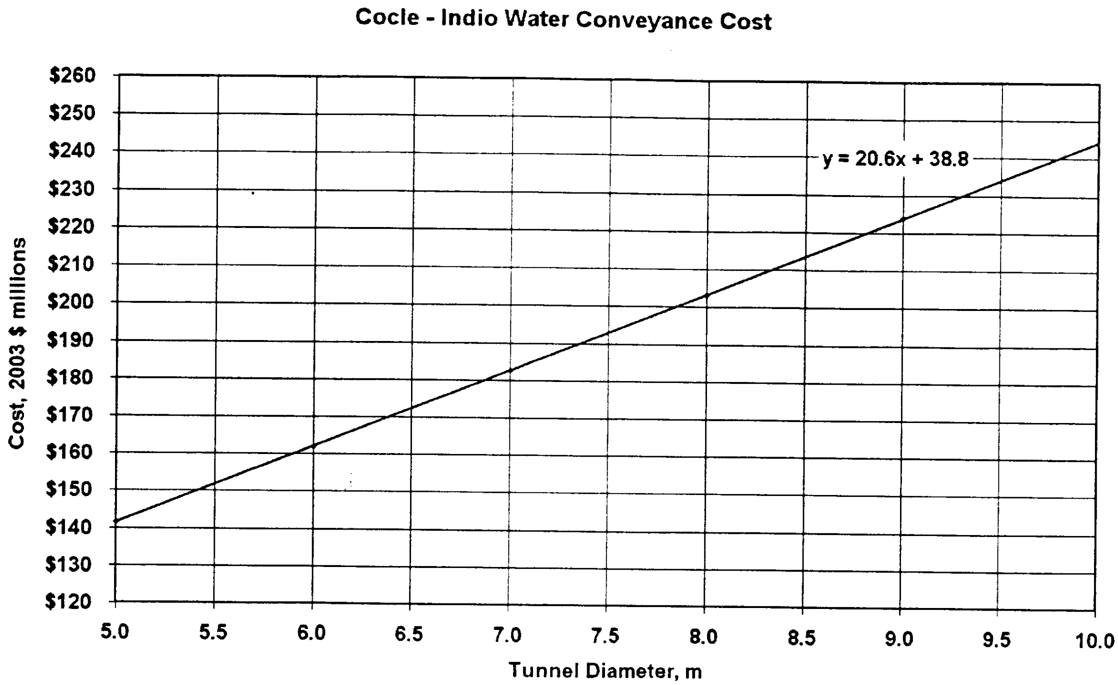



**Figure 9 Water Conveyance Costs**

The major cost component of the overall water conveyance costs is the estimated cost of excavation and lining of the tunnel (over 80%). A contingency of 25% is included in the cost, together with 15% for engineering and administration. It should be noted that the second Río Indio – Lake Gatun tunnel costs are not included in this comparison as they are common. The second tunnel is anticipated to cost of the order of $85 million before contingency, engineering and administration.

## 4.3 Resettlement (and Compensation) Costs

Resettlement and compensation costs have been provided by ACP's ESM division. Two values are given for the proposed El. 80 and El. 100 full supply level developments for Río Coclé del Norte as follows:

| | |
|---|---|
| FSL 80 | $164.4 million |
| FSL 100 | $230.5 million |
| Río Caño Sucio | $7.4 million |

The separate and combined costs are presented in below in Figure 10 against area inundated:

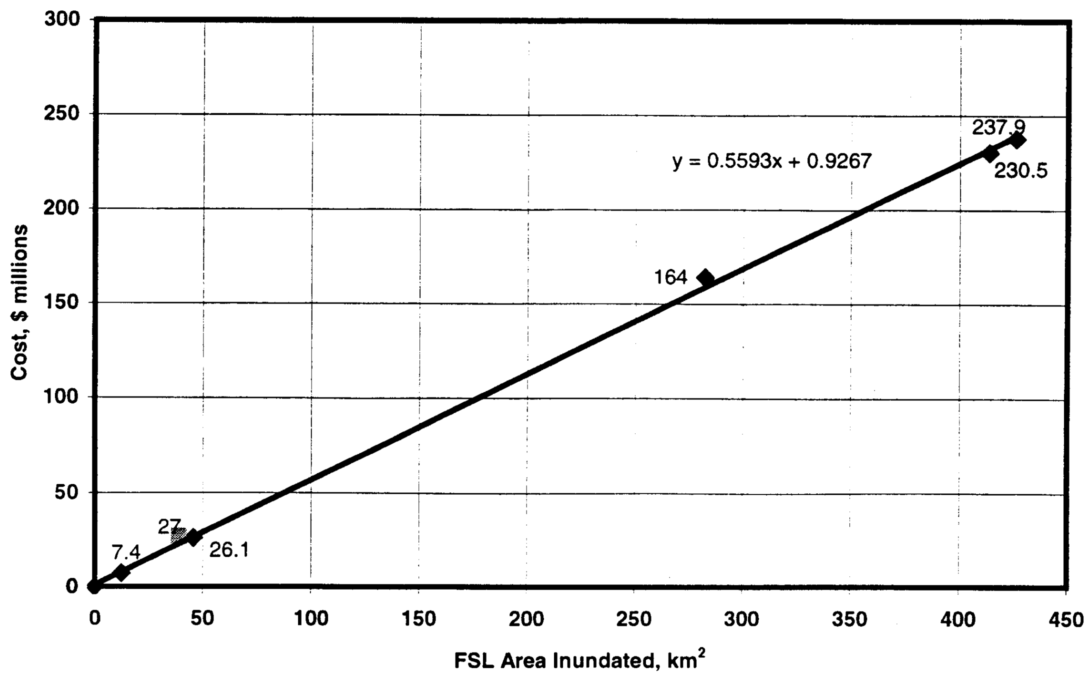



**Figure 10 Relocation Costs**

After comparing relocation costs against area and elevation, the costs were presented against area inundated. For this alternatives analysis, a linear relationship is adopted.

## 4.4 Project Development Costs for Río Coclé del Norte

Figure 11 below presents the total comparative development cost for the Río Coclé del Norte and Río Caño Sucio Water Supply Projects at various levels of operation but for the same active storage.

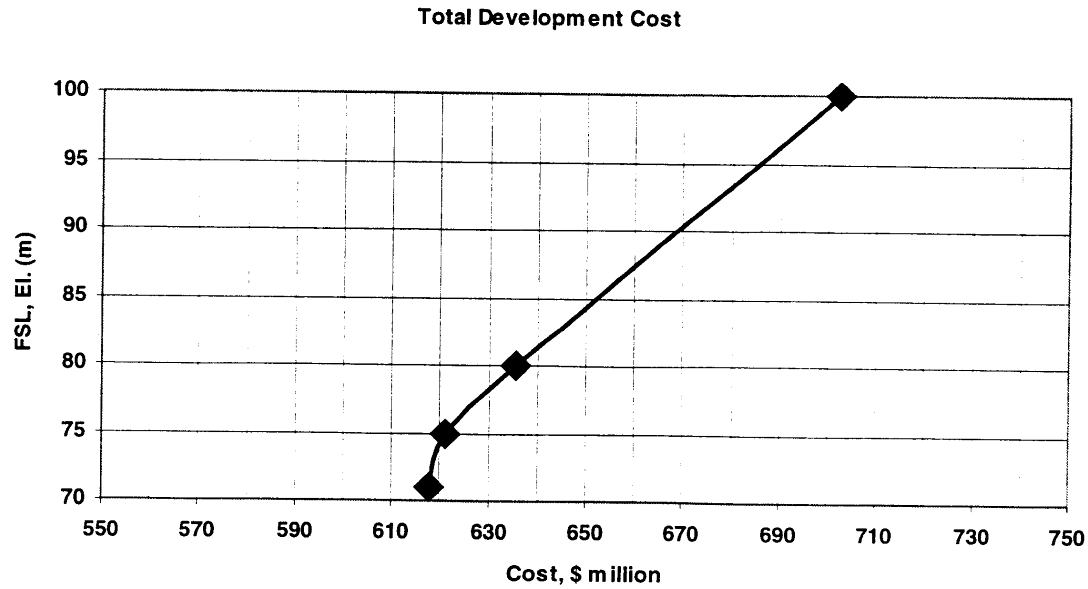



**Figure 11 Development Cost**

Development costs presented in Figure 11 include the second Río Indio – Lake Gatun tunnel required to deliver the additional water provided by the Río Coclé del Norte and Río Caño Sucio Projects. Development costs do not include some common costs such as access roads and construction camps, nor hydropower facilities. These costs will be established as part of the feasibility level design of the selected project. It can be seen that the lowest cost development is the alternative with an operating range from El. 71-50.

# 5 SELECTION OF THE OPERATING RANGE FOR THE RÍO COCLÉ DEL NORTE – RÍO INDIO PROJECT

Based on project cost and yield for the four alternative project operating ranges, the recommended operating range for the Río Coclé del Norte Water Supply Project is El. 71-50. This is the minimum elevation project that fully develops the basin with the minimum socio-economic and environmental impact. Figure 12 shows the cost to yield in L/d as a function of full supply level. It should be noted that the higher projects obviously have the capability to be operated over a wider operation range that additional operation studies using operation rule curves could show result in higher yields.

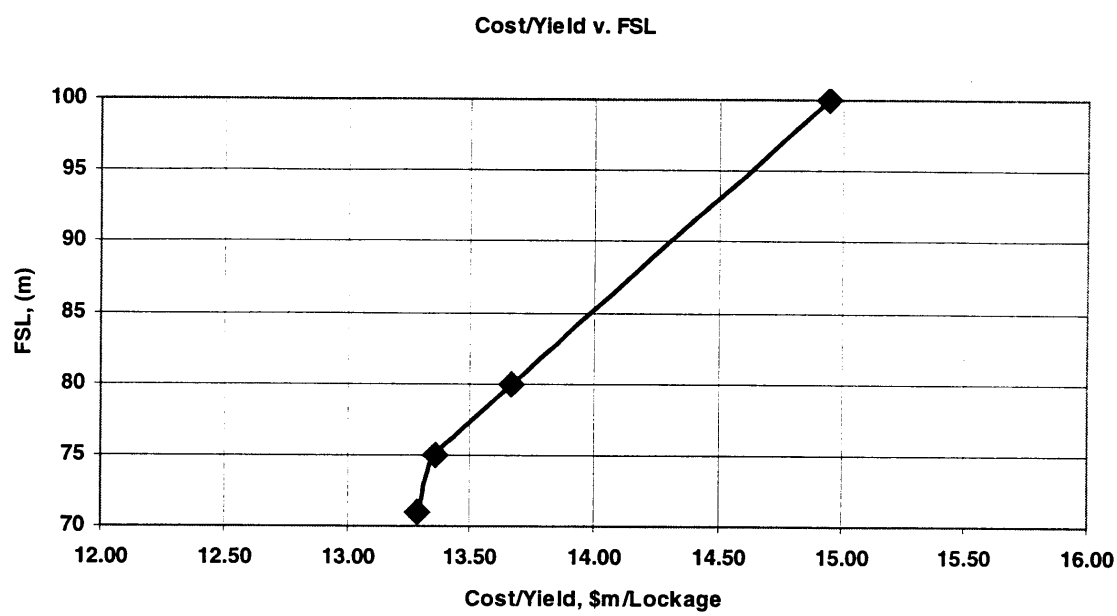



**Figure 12 Cost/lockage**

**Table 6. 50-yr dry-season flood hydrograph**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Time (hrs)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Flow ($m^3/s$)** | 3 | 5 | 7 | 16 | 23 | 35 | 47 | 59 |
| **Time (hrs)** | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| **Flow ($m^3/s$)** | 70 | 83 | 90 | 85 | 75 | 65 | 56 | 47 |
| **Time (hrs)** | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Flow ($m^3/s$)** | 40 | 33 | 28 | 23 | 21 | 19 | 16 | 14 |
| **Time (hrs)** | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
| **Flow ($m^3/s$)** | 13 | 12 | 11 | 9 | 8 | 7 | 6 | |

**Figure 1. Surcharge in Río Caño Sucio Reservoir**

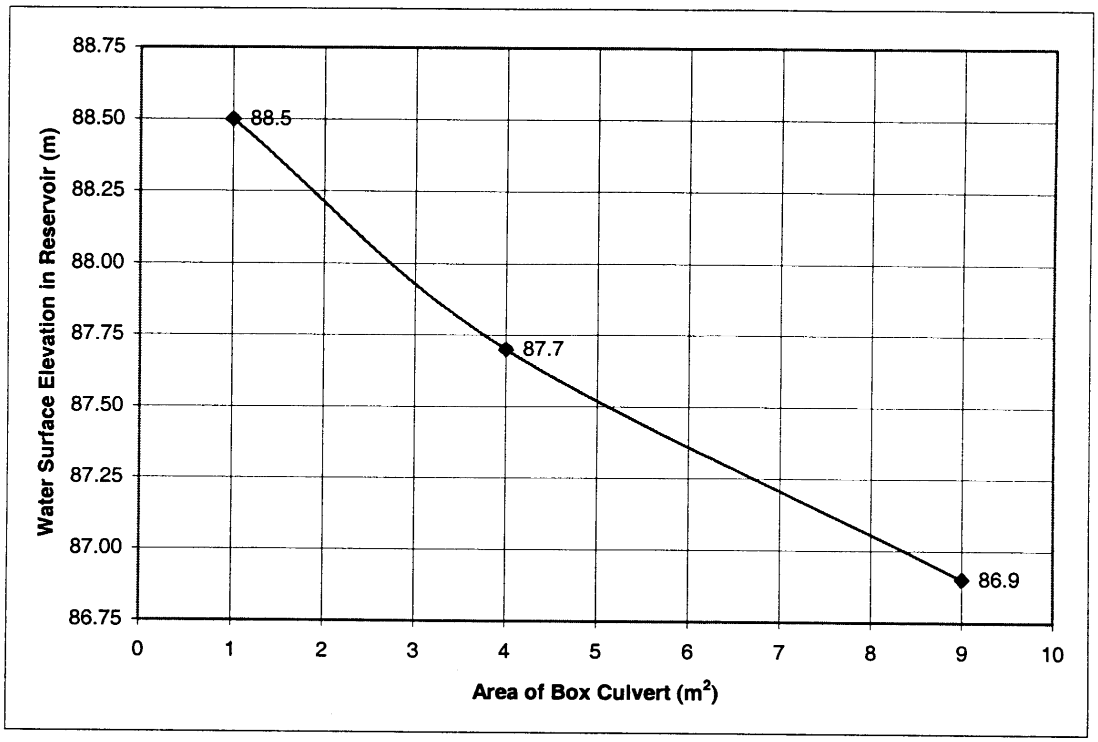
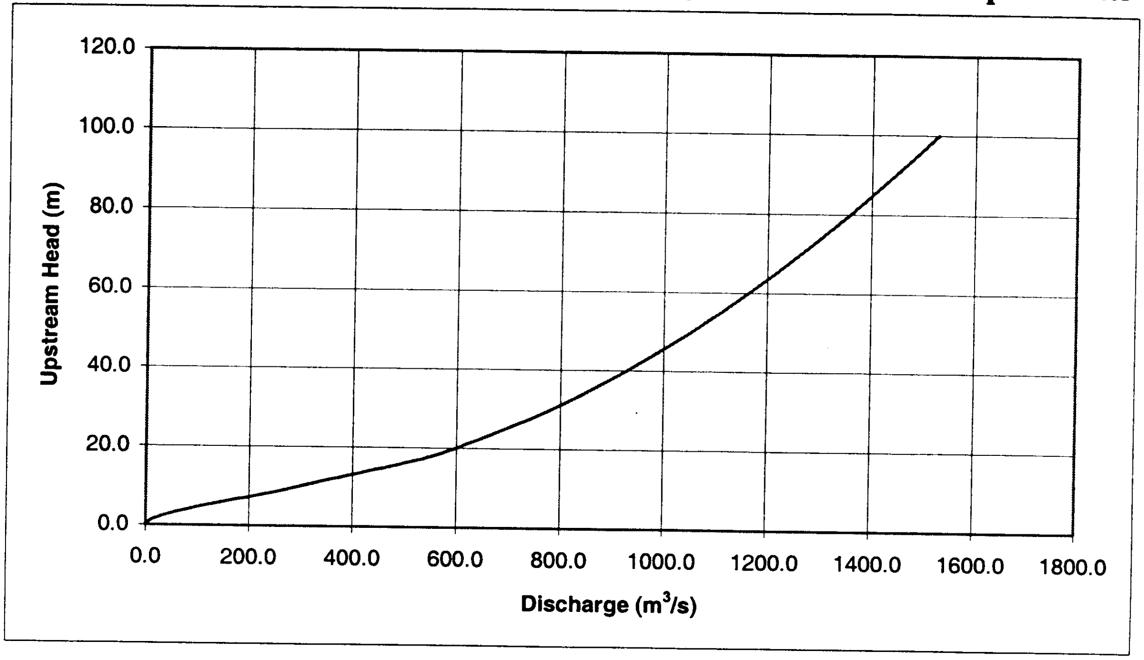


**Figure 2. Rating curve for 8m diameter, 550m long concrete-lined D-shaped tunnel**




## Analysis of Low Flows

Additional runs were made with constant flows of 25, 50, and 75 $m^3/s$ in order to determine the height of the temporary closure dikes used during the construction of the cofferdams. Tables 5a-c summarize the peak water surface elevations for the 3 tunnel sizes during low flow conditions.

**Table 5a. Low flow analysis (25 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 2.3 | 0.03 |
| 8 | 1.9 | 0.03 |
| 10 | 1.7 | 0.03 |

**Table 5b. Low flow analysis (50 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 3.6 | 0.12 |
| 8 | 2.9 | 0.12 |
| 10 | 2.5 | 0.12 |

**Table 5c. Low flow analysis (75 $m^3/s$)**

| Tunnel Diameter (m) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|
| 6 | 4.6 | 0.3 |
| 8 | 3.8 | 0.3 |
| 10 | 3.2 | 0.3 |

## Design of Transfer Tunnel

The transfer tunnel is an 18000 m long D-Shaped tunnel with an 8 m diameter. It is concrete-lined with a Manning roughness coefficient of 0.013. The entrance loss coefficient is 0.5 and includes minor losses due to bends. At the exit, the water surface elevation is above tailwater and the depth is critical. Inlet and outlet invert elevations are 47.0 and 42.0 m, respectively. Figure 3 shows the transfer tunnel rating-curve.

**Figure 3. Rating curve of 8 m transfer tunnel**

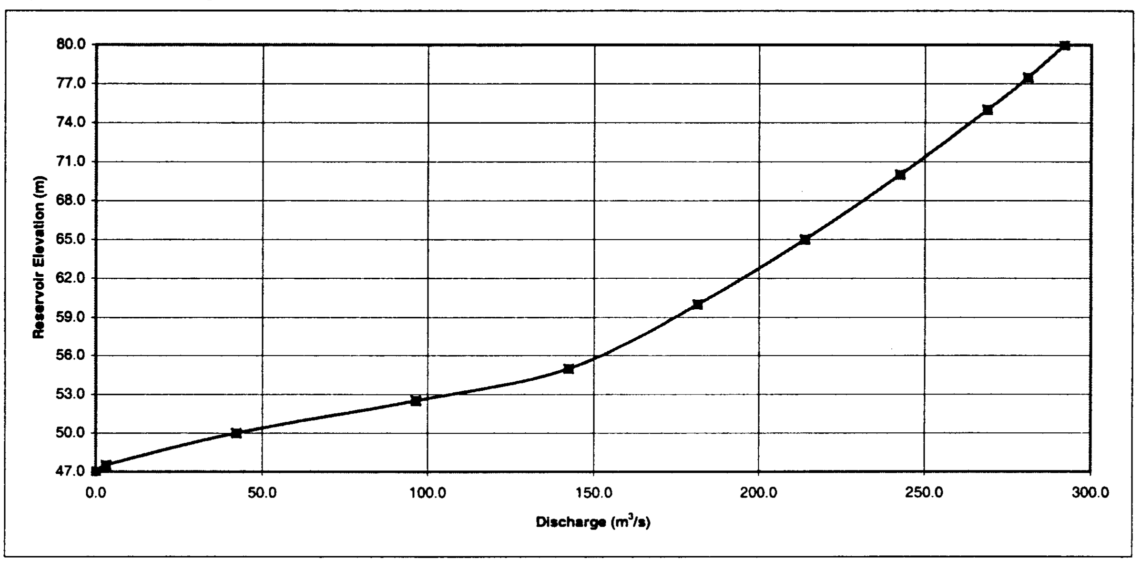
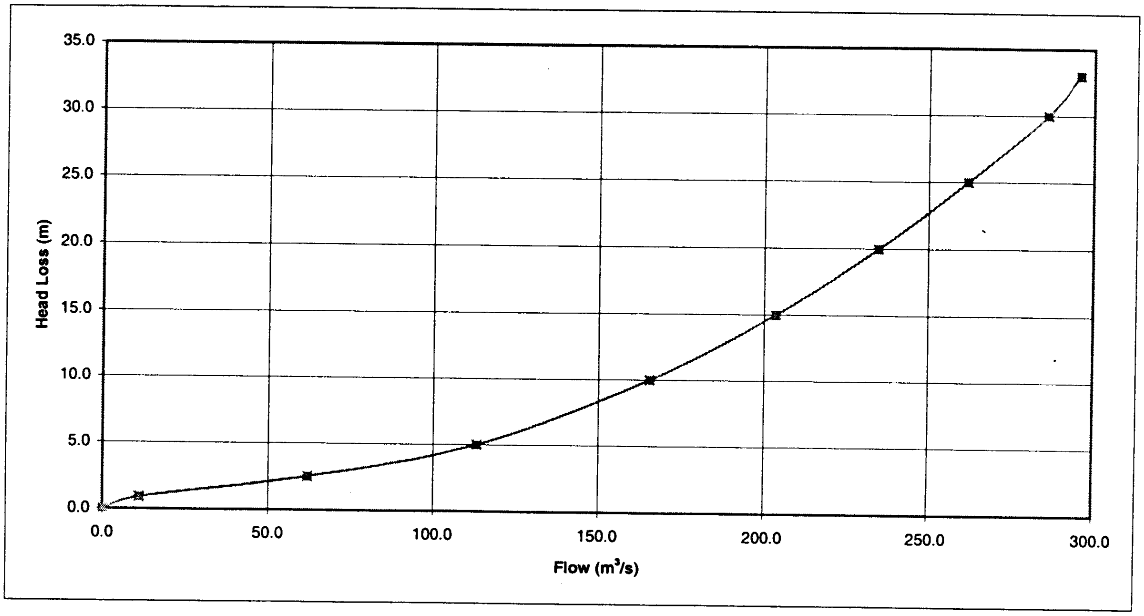


Figure 4 shows head loss as a function of flow for the Cocle transfer tunnel.

**Figure 4. Rating curve for 8 m Cocle transfer tunnel (head loss as a function of flow rate)**




## Reservoir Drawdown Analysis

The reservoir drawdown is designed for a significant hazard, significant risk project as classified by the U.S. Bureau of Reclamation (USBR) in the ACER Technical Memo No. 3 dated 1982. This provides the following guidelines to be met.

| Drawdown El. | Time (days) |
|---|---|
| 75% | 30-40 |
| 50% | 50-60 |
| 25% | 80-100 |

Tables 6a-c show the time to empty out the reservoir to 25, 50, and 75 % of the starting full supply level of 80.0 m with three different tunnel configurations and a constant inflow of 107.5 $m^3/s$. As noted, the 8m transfer tunnel with 6 m diversion tunnel configuration does not meet the USBR guidelines.

**Table 6a. Time required to empty reservoir with 8 m transfer tunnel and 6 m diversion tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 60.8 |
| 80.0 | 40.0 | 50 | 107.8 |
| 80.0 | 20.0 | 25 | 136.4 |

**Table 6b. Time required to empty reservoir with 8 m transfer tunnel and 8 m diversion tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 35.0 |
| 80.0 | 40.0 | 50 | 59.2 |
| 80.0 | 20.0 | 25 | 72.7 |

**Table 6c. Time required to empty reservoir with 8 m diversion tunnel**

| Full Reservoir Elevation (m) | Water Surface Elevation in Reservoir (m) | Elevation / Full Reservoir Elevation (%) | Time to Empty (Days) |
|---|---|---|---|
| 80.0 | 60.0 | 75 | 42.2 |
| 80.0 | 40.0 | 50 | 68.0 |
| 80.0 | 20.0 | 25 | 81.5 |

# Attachment 4 – Río Coclé del Norte FSL El. 80 Diversion Alternatives

**MWH**
MONTGOMERY WATSON HARZA

Intra-Company Correspondence

MWH AMERICAS, INC.
HYDROPOWER

**Location:** Chicago

July 17, 2003

**To:** Michael Newbery

**From:** Rori Green

**Subject:** Coclé del Norte Diversion Alternatives

Diversion alternatives for the Río Coclé del Norte at the damsite are limited by the topography at the site, by the capacity required for the diversion tunnel following conversion to a low level outlet for emergency drawdown, and by the required height of the upstream cofferdam to pass the diversion design flood. The location of the dam axis within the site is limited by the presence of moderately sized creeks located upstream of the dam on the right bank and downstream of the dam on the left bank. As a result of these constrains, the alternatives for diversion are to either have a long upstream cofferdam and a shorter diversion tunnel, or to have a shorter cofferdam located farther upstream with a longer diversion tunnel. An additional alternative, identified in an effort to reduce costs, would be to incorporate the cofferdam into the body of the main dam, which would reduce the total volume of fill to be placed. This alternative would, however, require construction of the plinth and concrete facing to El 22.5, as well as construction of an upstream pre-cofferdam.

These three different alternatives for the diversion arrangements were considered for the Coclé del Norte damsite in terms of their cost, their risk due to overtopping during construction, and their effect on the completed project behavior. These alternatives are described below. Sketches of the layouts for each of the alternatives are attached.

Alternative 1: One 8-m diameter, 550-m long diversion tunnel in left abutment; cofferdam crest El. 22.5, located 25 m upstream of dam toe.

Alternative 2: One 8-m diameter, 550-m long diversion tunnel in left abutment; cofferdam crest El. 23.5, incorporated in main dam and constructed with plinth and concrete facing; Pre-cofferdam crest El. 10, located 25 m upstream of dam toe

Alternative 3: One 8-m diameter, 800-m long diversion tunnel in left abutment; cofferdam crest El 22.5, located 250 m upstream of dam toe

A fourth alternative that would involve construction of two 8-m diameter diversion tunnels: one 550-m long tunnel in left abutment and one 500-m long tunnel in right abutment was also considered. The tunnel through the right abutment could be converted to a power tunnel if studies indicated the addition of power at the damsite to be feasible. This alternative was no longer pursued when initial calculations showed that the addition of a second diversion tunnel resulted in only a 3 m reduction in the upstream cofferdam crest elevation. This small reduction in cofferdam height is not sufficient to offset the cost of a second diversion tunnel.

**Quantities and Cost Estimate**

The major quantities for each of the alternatives is provided in the table below:

**Table 1: Estimated Quantities for Diversion Alternatives**

| Feature | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| Diversion Tunnel, length (m) | 550 | 550 | 80 |
| Cofferdam, volume ($m^3$) | 592,000 | 329,000 | 291,000 |
| Pre-cofferdam, volume ($m^3$) | -- | 120,000 | -- |
| Plinth, length (m) | -- | 330 | -- |
| Concrete Facing, area ($m^2$) | -- | 13,000 | -- |

Cost estimates developed for each of the alternatives is provided in the table below.

**Table 2: Cost Comparison of Diversion Alternatives**

| Feature | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| Diversion Tunnel | $ 7,800,000 | $ 7,800,000 | $ 11,400,000 |
| Cofferdam | $ 4,900,000 | $ 8,100,000 | $ 2,400,000 |
| Pre-cofferdam | | $ 1,300,000 | |
| Main Dam | | ($ 6,500,000) | |
| **Total** | **$ 12,700,000** | **$ 10,600,000** | **$ 13,800,000** |

The estimated cost for each diversion tunnel includes costs for excavation of the intake and outlet portals, construction of inlet and outlet structures, excavation of approach and discharge channels, excavation, support, and concrete lining of the tunnel. For estimating purposes, the portal excavation costs are assumed to be the same for each alternative; the discharge channel cost was doubled for Alternative 3 to account for the approach channel. The cofferdam and pre-cofferdam costs include foundation excavation and preparation, fill, and filters and drains supply, placement and compaction. For Alternative 2, the costs for the cofferdam and pre-cofferdam are based on the unit costs used for the construction of the dam, but increased by 20% to reflect an increased rate of construction that would be required to complete construction of the cofferdam in a shorter time period so as to reduce the risk of overtopping. (The construction risks and time of construction are discussed in further detail in the following sections.) The negative cost for the main dam is the equivalent cost of the cofferdam, if it were constructed as part of the dam and at the construction rates needed to construct the dam.

**Construction Time and Risk**

In addition to cost, it is also necessary to consider the risk involved for each of the diversion alternatives. For the purposes of this evaluation, the risk is considered to be the probability that the cofferdam would be overtopped during its construction.

The dry season at Coclé del Norte site usually lasts two months, February and March. According to Appendix A (Hydrology) low flows occur from February to April. The rainy season is generally from October to December, but quite often high flows can occur during January or September. Some of the highest floods of record have occurred in January. Initial river diversion would need to be performed at the end of January, or early February to take advantage of the dry season.

The time to construct the upstream cofferdam has been estimated for each of the alternatives based on construction rates used to develop the construction schedule for the Río Indio project. The estimated construction times are presented below.

**Table 3: Estimated Construction Time for Upstream Cofferdam**

| | **Alternative 1** | **Alternative 2*** | **Alternative 3** |
|---|---|---|---|
| Wet Season, prior | 10 | 10 | 0 |
| Dry Season | 9 | 9 | 9 |
| Wet Season, post | 7 | 8 | 5 |
| **Total Time (weeks)** | **26** | **27** | **14** |

*assumes accelerated rates of construction compared with those assumed for the dam body.

For Alternatives 1 and 2, a significant portion of the cofferdam is located outside of the river channel on the right bank. In order to complete construction of the entire cofferdam to reasonable elevation in the dry season, it would be necessary to begin construction of the cofferdam prior to the start of the dry season. Construction of the cofferdam section in the river channel would begin in the dry season when flows are lowest and risk of overtopping the pre-cofferdam are lower. For Alternative 3, a relatively smaller portion of the cofferdam lies outside of the river channel; and although construction could begin prior to the start of the dry season, for the purposes of this evaluation, no construction is assumed to take place prior to the start of the wet season.

The risk of overtopping increases after the dry season ends and is related to the time to finish construction of the cofferdam. The risk is determined using the following expression:

$$R = 1 - \left(1 - \frac{1}{T}\right)^n$$

where $R$ is the risk (probability that an event occurs), $T$ is the flood return period, and $n$ is the number of years. Stated verbally, the expression defines the risk, $R$, that a flow with a return period, $T$, will occur once in a period of length $n$.

As discussed above, based on the assumed construction rates, it is not possible to complete construction of the upstream cofferdam during the 2-month dry season for any of the three alternatives. As a result, the risk of overtopping the cofferdam increases based on the length of time it takes to complete construction of the cofferdam after the end of the dry season. The length of cofferdam construction prior to the start of the dry season is not considered in the risk calculation because it does not involve closure of the river channel.

Dry Season and All Season flood peaks for the Coclé del Norte damsite are listed below. For reference, the design flood selected for diversion is the 50-year All Season event with a peak inflow of 3,860 cms. Using the above expression, the risk that a flood greater than the 50-year return period flood will occur in two years is 5 %.

**Table 4: Flood Peaks at the Coclé del Norte Damsite**

| Return Period (years) | Dry Season Flood Peak (cms) | All Season Flood Peak (cms) |
|---|---|---|
| 2 | 130 | 1,295 |
| 5 | 288 | 1,925 |
| 10 | 458 | 2,430 |
| 20 | 697 | 2,995 |
| 50 | 1,171 | 3,860 |
| 100 | 1,705 | 4,610 |

The computed risks associated with the cofferdam construction time after the end of the dry season are presented below. The column showing the upstream water elevation plus freeboard will be the nominal cofferdam height required to store the flood event for the assumed 8-m diameter diversion tunnel; the values for the 2, 5, 10 and 20-year events are estimated from scaled hydrographs based on the 50-year all season flood hydrograph.

**Table 5: Risk During Construction Following Dry Season**

| Return Period (years) | All Season Flood Peak (cms) | U/S Water Elevation (m) | Risk | | |
|---|---|---|---|---|---|
| | | | 1 month | 2 months | 4 months |
| 2 | 1,295 | 12 | 5.6 % | 10.9 % | 20.6 % |
| 5 | 1,925 | 16 | 1.8 % | 3.7 % | 7.2 % |
| 10 | 2,430 | 17 | 0.9 % | 1.7 % | 3.5 % |
| 20 | 2,995 | 19 | 0.4 % | 0.9 % | 1.7 % |
| 50 | 3,860 | 22.1 | 0.2 % | 0.3 % | 0.7 % |
| 100 | 4,610 | -- | 0.1 % | 0.2 % | 0.3 % |

Based on the information in Table 5, in order to achieve a level of risk similar to that established for the diversion (about 5 percent, based on a 50-year all-season flood), the upstream cofferdam would have to be constructed to an elevation of about 12 m within one month following the end of the dry season, and to an elevation of about 16 m within three months following the end of the dry season.

**Discussion of Alternatives**

The final selection of the diversion arrangement will be based on the cost and the risk involved, but other factors will also be considered. These other factors include, uncertainties with respect to the foundation conditions, effect of accelerated construction on long-term performance, and uncertainty in the estimates of cost and schedule for the alternatives.

On the basis of cost, Alternative 2 is the most attractive, followed by Alternatives 1 and 3, which are $2.1 million and $3.2 million costlier, respectively. In terms of risk, each of the alternatives has a risk of overtopping the cofferdam on the order of 5 %. This risk is highest in the months following the end of the dry season. Alternative 2 has some additional risks that are difficult to quantify, such as poor workmanship during construction of the plinth, perimeter joint and concrete face due to the accelerated construction schedule, and the potential disturbance (or damage) to the plinth, filter and/or concrete facing should an overtopping event occur prior to completion of the cofferdam.

A discussion of the advantages and disadvantages of each of the diversion alternatives is presented below:

*Alternative 1*

| | |
|---|---|
| Estimated Cost: | $ 12.7 million |
| Total Construction Time: | 26 weeks (6 months) |

Advantages:
- Foundation conditions are not a significant issue
- A substantial portion of the cofferdam is located on the right bank outside of the river channel and can be constructed prior to the river diversion

Disadvantages:
- Largest cofferdam volume
- Long overall construction period

*Alternative 2*

| | |
|---|---|
| Estimated Cost: | $ 10.6 million |
| Total Construction Time: | 27 weeks (6.2 months) |

Advantages:
- Lowest cost alternative
- A substantial part of construction can take place prior to the river diversion

Disadvantages:
- Since the cofferdam is part of the main dam, any unfavorable (and unanticipated) foundation conditions discovered during excavation could extend the construction period, thus increasing the risk of overtopping prior to completion of the cofferdam.
- Construction would have to take place at faster than normal rate; this could impact the quality of construction for the plinth and concrete facing, which are relatively delicate structures.
- Additional protective measures would have to be undertaken to mitigate the potential for disturbance of or damage to the cofferdam in the event of overtopping; these measures would include protection of the filters and construction of a temporary spillway over the top of the dam.
- There is a potential for differential settlement of the concrete facing since the upper section of the concrete facing would be placed several years following construction of the cofferdam and lower section of concrete facing
- Any problems related to construction of the cofferdam, whether a result of construction quality or overtopping, could result in additional future costs should these problems result in the need for repair or maintenance.

- Equipment required for high volume concrete production (crushers, batch plant, etc.) would be required on site at an earlier stage during construction. This would result in additional capital costs at the beginning of the project.

*Alternative 3*

| | |
|---|---|
| Estimated Cost: | $ 13.8 million |
| Total Construction Time: | 14 weeks (3.2 months) |

Advantages:

- Shortest construction time

Disadvantages:

- Highest cost
- Longer diversion tunnel
- Water from drainage located on right bank between cofferdam and main dam would have to be controlled

**Conclusions and Recommendations**

Alternative 1 is recommended as the diversion alternative for the Coclé del Norte damsite for a reservoir FSL of 80 m. It is about $1.1 million less than Alternative 3, and it has fewer disadvantages than Alternative 2. Alternative 3 is also considered a feasible alternative.

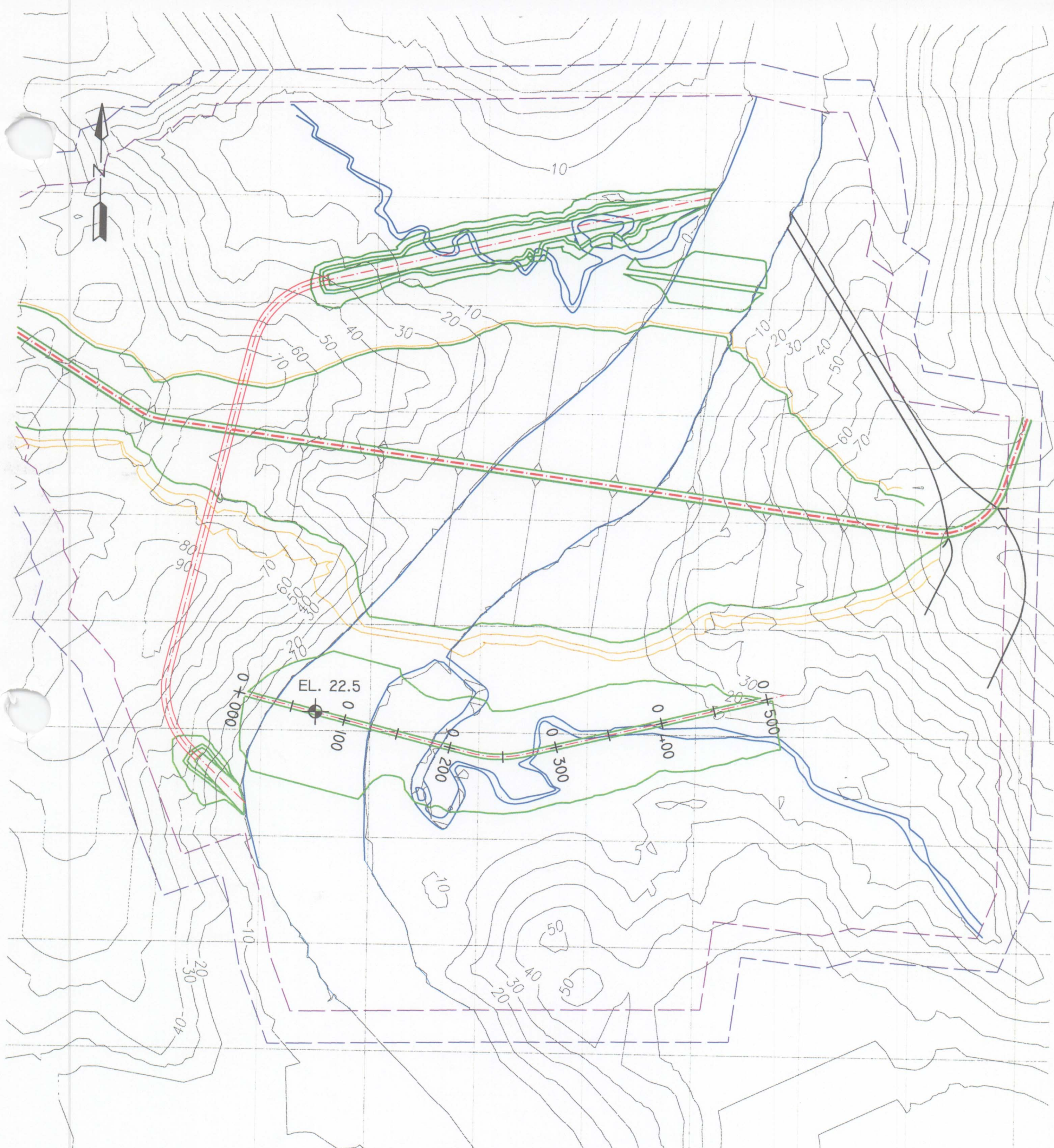
Alternative 2, although the least costly of the three alternatives, has considerably more risk involved in the sense that any problems that might occur during construction could have a fairly significant impact on the cofferdam cost, total project cost, and future project performance. The $2.1 million cost savings is not believed to be significant enough to offset potential additional costs should problems be encountered during construction of the cofferdam. At the feasibility level of design, Alternative 2 is not recommended. However, Alternative 2 is recommended for additional evaluation following a foundation investigation program or during detailed design.

**Additional Comments**

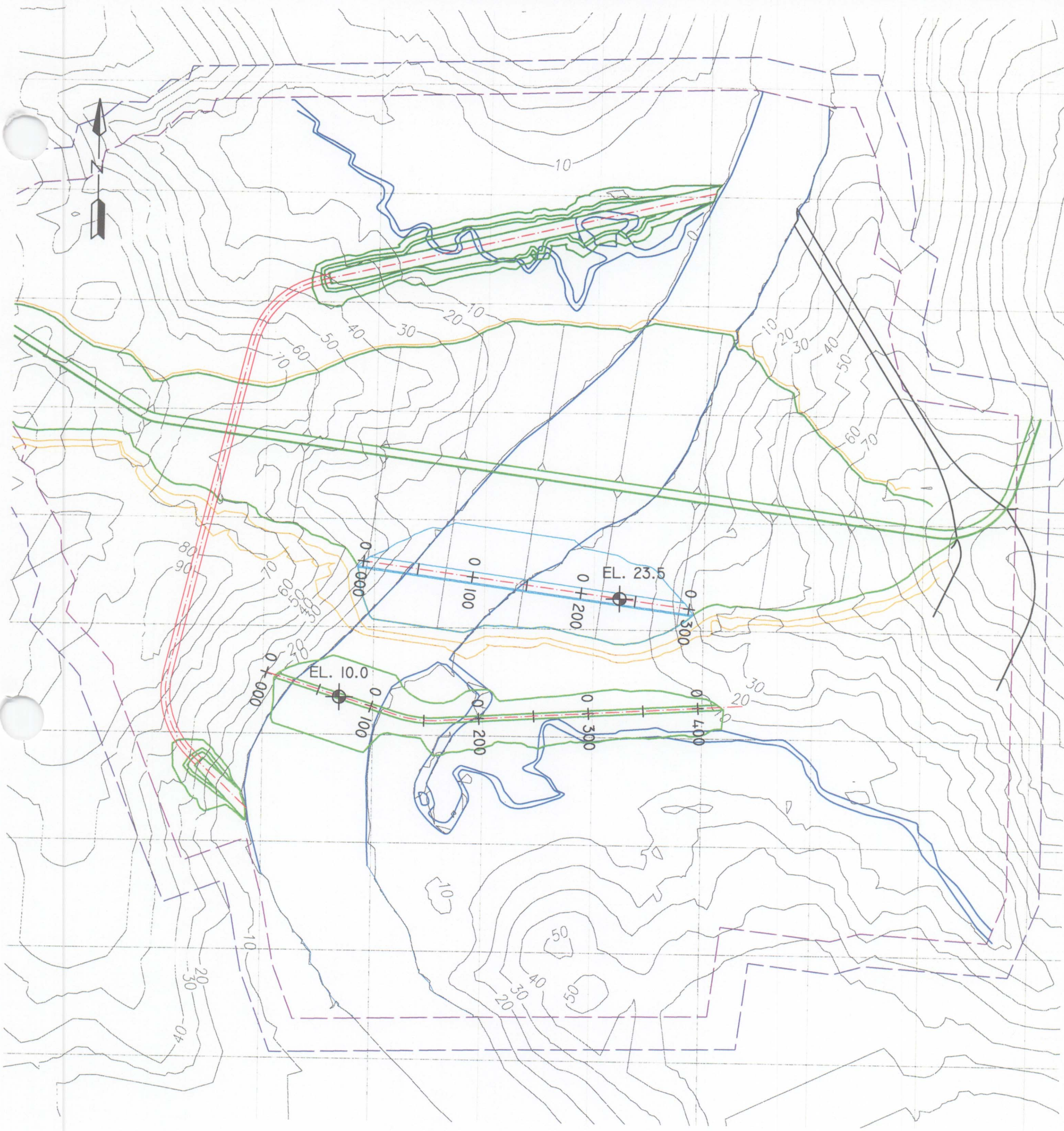
The Coclé del Norte project diversion arrangement should be re-evaluated for the selected full supply level. Drawdown requirements will vary which may result in minimum diversion tunnel sizes and therefore different costs for the two recommended diversion arrangement.

Another potentially viable alternative would be to construct a cofferdam of RCC, which would become the plinth and would be incorporated into the main dam. This alternative has been used in other projects, but, as for Alternative 2, was not considered at this time due to the lack of information about the foundation conditions at the site.

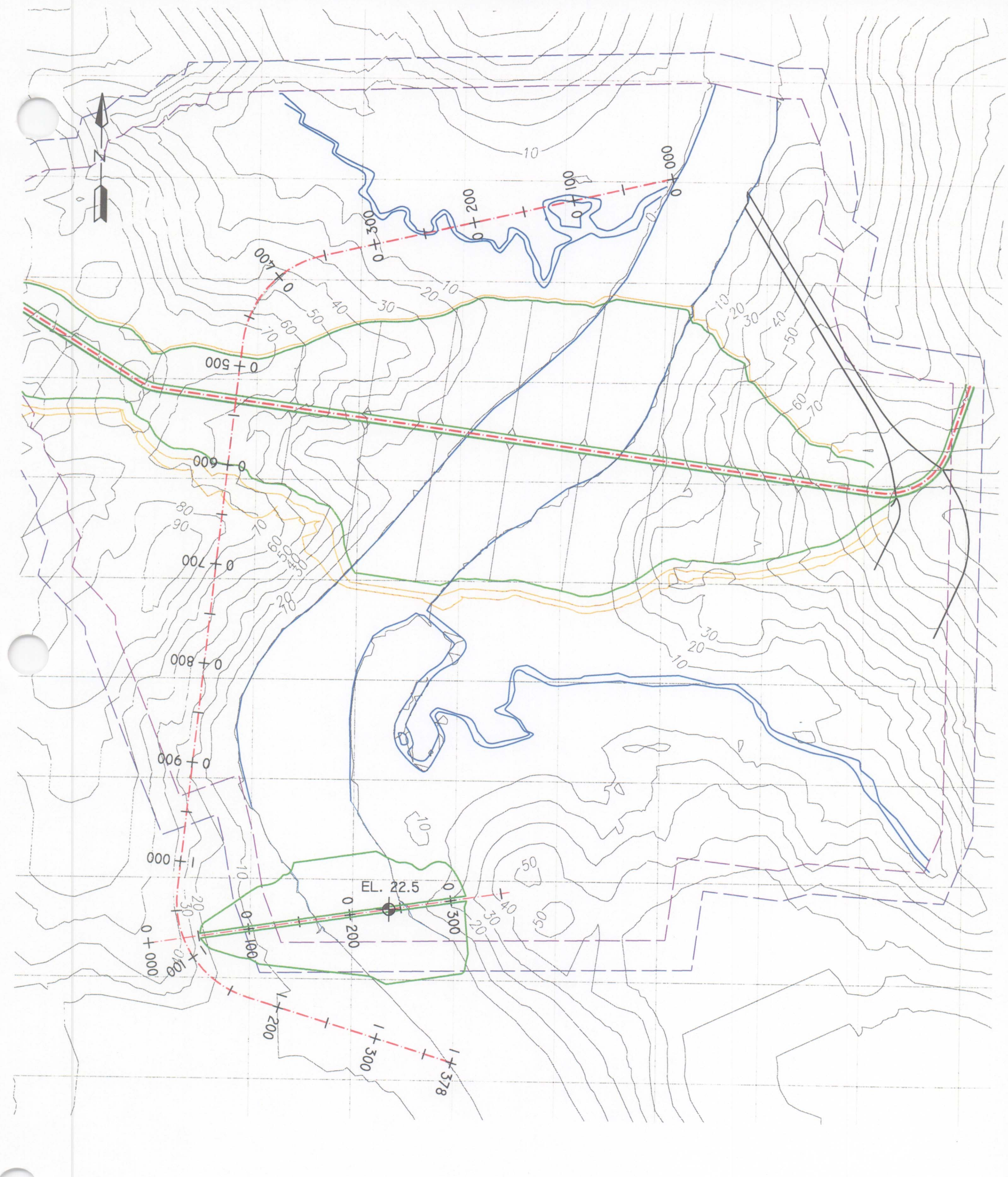
*NOTE – December 2003*
*At the time this study was made, an operating range had not been selected for the Río Coclé del Norte projects. This study was revisited upon selection of the operating ranges for the two projects (El. 71-50 and El. 100-90). Projects at each of these operating ranges would result in slightly different upstream cofferdam elevations and diversion tunnel lengths. The conclusions reached as a result of this study are considered to be valid for either operating range.*




**Coclé del Norte Diversion Alternatives**
**Option 1**




**Coclé del Norte Diversion Alternatives**
**Option 2**




**Coclé del Norte Diversion Alternatives**
**Option 3**

# Attachment 5 – Río Coclé del Norte FSL El. 100 Diversion Alternative

**Table 4a. Diversion tunnel analysis for Cocle del Norte (D-shaped, 50-yr flow)**

| Tunnel Diameter (m) | Tunnel Length (m) | Peak Outflow ($m^3/s$) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|---|---|
| 6 | 550.0 | 367 | 24.0 | 2.2 |
| 8 | 550.0 | 636 | 22.1 | 3.5 |
| 10 | 550.0 | 933 | 20.6 | 4.8 |

Another set of runs involved the routing of hydrographs with peaks of 300, 500, 1000, and 2000 $m^3/s$ through the reservoir with the 8 m tunnel configuration. These hydrographs were obtained by scaling down the ordinates of the 50-yr hydrograph by the ratio of peaks. The results of this analysis are summarized in Table 4b.

**Table 4b. Diversion tunnel analysis for Cocle del Norte (D-shaped, varied flow)**

| Peak Inflow ($m^3/s$) | Tunnel Configuration Diameter-Length (m-m) | Peak Outflow ($m^3/s$) | Upstream Water Surface Elevation (m) | Downstream Water Surface Elevation (m) |
|---|---|---|---|---|
| 300 | 8-550 | 137 | 5.6 | 0.7 |
| 500 | 8-550 | 192 | 7.0 | 1.1 |
| 1000 | 8-550 | 315 | 10.5 | 1.9 |
| 2000 | 8-550 | 484 | 15.6 | 2.8 |

An analysis of the results shows that it is more economical to use a single concrete-lined, 8 m diameter, 550 m long diversion tunnel. The rating curve for this tunnel, which applies to free flow conditions, is shown in Figure 2.

Part 5
Water Transfer Facilities

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX D
PART 5

WATER TRANSFER FACILITIES

Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX D5 – WATER TRANSFER FACILITIES

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CHAPTER PAGE

# LIST OF EXHIBITS

## ATTACHMENTS

# 1 INTRODUCTION

This appendix presents the results of studies carried out in support of the design of water transfer facilities for the Río Coclé del Norte and Río Caño Sucio Water Supply Projects.

## 1.1 Background Information

The ACP is undertaking studies that include the evaluation of additional sources of water to augment Canal capacity. During preliminary reconnaissance study of potential water supply projects, several projects in the Río Coclé del Norte basin were identified as having significant potential to augment the existing water supply to the Canal. Two projects were selected for development to the feasibility level. These are:

- The Río Coclé del Norte Reservoir acting in full regulation with the Río Indio Reservoir (Coclé del Norte – Río Indio Project), and
- The Río Coclé del Norte Reservoir acting in full regulation with the Río Caño Sucio and Río Indio Reservoirs (Coclé del Norte – Caño Sucio – Río Indio Project).

According to the present concept, the Río Indio Project will have been constructed about 20 to 30 years prior to any Río Coclé del Norte Project configuration. Therefore, the discussion of the water transfer systems presented in this appendix presumes that the Río Indio project has been constructed and is operational. The Río Indio project is described in the report *Feasibility Design of the Río Indio Water Supply Project* (MWH, April 2003). This appendix describes the selection and design of two water transfer facilities for the two proposed projects in the Río Coclé del Norte basin and the required modification to the presumed existing Río Indio Project water transfer facilities.

## 1.2 Project Descriptions

The two projects are located in the middle of the Republic of Panama, in three contiguous watersheds immediately to the west of the Panama Canal Watershed.

### 1.2.1 Coclé del Norte - Río Indio Project

The Norte/Indio Water Supply Project consists of a storage facility in the Río Coclé del Norte basin, a tunnel between the storage facility in the Río Coclé del Norte basin and the presumed existing Río Indio Reservoir, and a second tunnel between the Río Indio Reservoir and Lake Gatun. The project has been sized to maximize development of the yield from the Río Coclé del Norte Basin. Operation studies demonstrated that this could be achieved by a project configured as follows:

- A reservoir operation range that provides an active storage of about 3,500 MCM. This results in an increase in the existing system yield of approximately 3,500 MCM, or 45 lockages/day.
- For the Río Indio Project operating at its minimum level of El. 40.0, the minimum level of the Río Coclé del Norte Project is set at El. 50.0. This results in a maximum supply level (or full supply level - FSL) of El. 71.0.
- Transfer of water from the Río Coclé del Norte project to Río Indio and on to Lake Gatun can be accomplished by drawing down the Río Indio Reservoir by discharging it into Lake Gatun. Once the Río Indio Reservoir is at or below approximately El. 70, the Río Coclé del Norte project can be discharged into the Río Indio Reservoir. The Río Indio Reservoir is then maintained at or about 5-10 m below the elevation of the Coclé del Norte Reservoir over the operating range from El. 71.0 to 50.0.

Water transfer facility studies presented in Section 2 of this appendix have been performed to size and design the required project features for these operation parameters.

Additional information on the operation studies is presented in Appendix C, and on project configuration in Appendix D-3.

### 1.2.2 Coclé del Norte - Caño Sucio - Río Indio Project

The Norte/Sucio/Indio Water Supply Project consists of a storage facility in the Río Coclé del Norte basin, a storage facility in the Río Caño Sucio basin, water transfer facilities between the Río Coclé del Norte and Río Caño Sucio basins, a tunnel between the Río Caño Sucio basin and the presumed existing Río Indio Reservoir, and a tunnel between the presumed existing Río Indio Reservoir and Lake Gatun.

An objective of evaluating a project in the Coclé del Norte basin acting in full regulation with a project in the adjacent Río Caño Sucio basin and the presumed existing Río Indio Reservoir is to utilize surface water transfer facilities (i.e. canal and reservoir) and to minimize tunneling. The Coclé del Norte and Caño Sucio basins are separated at their closest points by a relatively low divide below El. 100. Excavation of a canal through this divide and across the Caño Sucio basin to its eastern boundary adjacent to the Río Indio project would result in full regulation of the Río Coclé del Norte and Caño Sucio Projects. A relatively short 2.5 km tunnel is then required to transfer the water from these basins to the presumed existing Río Indio Reservoir. A second tunnel would also be required to transfer the increased volume of water from the presumed existing Río Indio Reservoir to Lake Gatun.

Operation studies presented in Appendix C, and project configuration studies presented in Appendix D3 were performed to determine the project arrangement that would maximize basin yield. These showed the following:

- Existing system yield is increased by a maximum of 3,570 MCM, or 47 lockages/day.
- The active storage required for this yield increase is about 3,800 MCM.
- An operating range for Coclé del Norte and Caño Sucio between El. 100.0 and El. 90.0 provides this active storage.

Water transfer facility studies presented in Section 3 of this appendix have been performed to size and design the required project features for these operation parameters.

### 1.3 Supporting Information

Additional information regarding studies made in support of the water transfer facilities is included in the following Appendices:

- Appendix B, Geology, Geotechnical and Seismological Studies,
- Appendix C, Operation Studies (HEC-5),
- Appendix D3, Dam Height Selection, and
- Appendix D4, Project Component Configuration.

For completeness, some information from these appendices is repeated in this appendix as it is used in the selection and design of the two water transfer facilities.

# 2 RÍO COCLÉ DEL NORTE TO RÍO INDIO TRANSFER TUNNEL

## 2.1 Description

A general plan of development for the Río Coclé del Norte Basin operating between El. 71.0 and 50.0 is presented on Exhibit 1. Operating at its minimum level, El. 50, the Coclé del Norte reservoir is approximately 16 km from the Río Indio reservoir at its closest point. Intervening topography reaches over 200m, and is predominantly over 100 m in elevation. Water transfer facility studies focused on the principal cost component, namely a water transfer tunnel. The studies and designs also defined the related project features such as intake and outlet works, approach channels, and water transfer control facilities.

Water transfer facility studies performed this development included the following:

- Geological assessment of tunneling conditions,
- Topographical assessment of alternative tunnel alignments,
- Selection of a recommended alignment,
- Operational assessment of water transfer facility sizes,
- Development of water transfer facility components, and
- Development of a construction plan for the selected water transfer facilities

The resulting water transfer facilities from the Río Coclé del Norte reservoir to the Río Indio basin comprise:

- A 1,500-m long approach channel in the reservoir to convey water to the tunnel intake,
- A 190-m long, 9.0-m diameter drill-and-blast tunnel at the intake
- A 15,830-m long, 9.0-m diameter TBM tunnel to the downstream access shaft,
- A 760-m long, 9.0-m diameter drill-and-blast tunnel from the downstream access shaft to an outlet into the Río Indio Reservoir,
- Intake and outlet portal structures, and
- Upstream and downstream access and gate shafts.

A plan and profile showing the tunnel alignment and associated features are presented on Exhibits 1 and 2. Additional exhibits showing the project facilities are presented in Volume 2.

## 2.2 Geology

It is probable that tunnel construction for the inter-basin transfer will encounter a wide range of rock types and tunneling conditions. The range and relative persistence of various conditions will depend on final alignment selection. Rock types could include sandstone and softer epiclastics of the Caimito Formation as well as hard, strong lavas (andesites, dacites, and basalts), limestones, and agglomerates. Based on interpretation of air-photos and the results of map and limited field studies, there is a strong probability of encountering karstic limestone conditions within the first third of the tunnel length – as evidenced by enclosed surface depressions and doline-like features. Associated with such karstic conditions would be the potential for significant water inflows and poor tunneling conditions. There will also be transition over short distances from very hard strong rock (such as andesite or basalt) to soft, weak almost clay-like materials. Such aspects would need to be examined in more detail to establish their impact on construction method as well as cost parameters, including support and lining requirements.

In April 2003, geologic reconnaissance was carried out at the proposed intake and outlet portal locations for the proposed water transfer tunnel route. Observations indicated that the outlet works into the Río Indio reservoir would be constructed in rolling subdued topography with possibly little cover over tunnel grade and in deeply weathered sedimentary units (sandstones and shales). Recommendations were made to locate the proposed outlet works sufficiently far back to ensure adequate rock cover and to attain relatively sound bedrock.

At the intake end, reconnaissance revealed that the topography in the portal area is complicated with deeply incised drainages. Nevertheless, it was considered that a favorable portal location could be found with a range of options for detailed design, i.e. flexibility in vertical and horizontal location. The bedrock geology in this area (possibly

Cañazas Formation) consists of a variable sedimentary sequence of thick-bedded calcareous pebbly sandstone units (conglomerates), calcareous sandstone and siltstone (calcilutes), sandy tuffaceous limestone, and hard cherty limestone (calcarenite). Based on the presence of abundant basalt float in the area, an igneous unit could also occur in the area, possibly a local dike, sill, or isolated lava flow, but its exact location with respect to the portal is not known.

## 2.3 Tunnel Alignment

An assessment of potential tunnel alignments was made by inspection of topographic maps. Until geologic conditions are known in the area, there are no factors that influence selection of one alignment over another. As a result, the optimal tunnel alignment is the one with the shortest length. Therefore the selected alignment is the one that results in the shortest length of tunnel between the Río Coclé del Norte and Río Indio reservoirs. When more information regarding geologic and tunneling conditions becomes available, a tunnel alignment study should be performed.

ACP proposed upstream and downstream portal locations for the tunnel. These portal locations were adjusted once intake and outlet elevations and a tunnel diameter were selected. The upstream tunnel portal location recommended by ACP was moved about 200 m to the south in order to provide more rock cover along the upstream end of the tunnel and also to allow a more favorable orientation for the upstream portal with respect to the topography. The downstream portal location was moved slightly to the north to provide a more favorable location for the downstream access shaft and a more favorable alignment for the tunnel and outlet into the Río Indio reservoir.

## 2.4 Operation Studies

As a part of the operation studies, it was determined that the operating range will be between El. 50 and El. 71 and that the system yield would be about 45 L/d. The HEC-5 runs were performed assuming a 9.0-m diameter tunnel from Coclé del Norte to Río Indio Reservoir. Additional HEC-5 runs were performed for other diameter tunnels to determine the minimum diameter required to provide the yield. It was concluded that a

9.0-m diameter is the appropriate diameter. The minimum operating level at Río Coclé del Norte was selected to provide for acceptable hydraulic conditions in the operation of the transfer tunnel. El. 50 was adopted as a suitable minimum level.

The dimensions of the facilities are controlled by the requirement to pass about 185 $m^3/s$ when the Río Coclé del Norte reservoir is at its minimum level (El. 50).

Details of the operation studies and selection of tunnel diameter are presented in Appendix D3.

### 2.5 Construction Methodology

Two alternative methods of excavation were considered for the water transfer tunnel:

- conventional drill-and-blast, and
- mechanical excavation by tunnel boring machine (TBM).

These methods entail different excavation and finished tunnel profiles, as well as differing construction schedules and associated risks and costs. Selection of a preferred method involves consideration of various factors, including geologic conditions, construction schedule, risk, and cost.

For costing and scheduling purposes, it was assumed that tunnel construction would utilize TBM for the bulk of excavation with drill-and-blast techniques in limited lengths at the main portals.

The most compelling reason for selection of the TBM method of excavation is the total length of the tunnel and the necessity for intermediate access locations with a drill-and-blast approach. For a drill-and-blast operation, it is estimated that at least three intermediate construction access points would be needed to meet ventilation and construction logistics requirements. Because of the relatively subdued topography, access adits would have to be very long. Construction shafts could be used as an alternative to access adits but they would be relatively deep. It is considered that, using a TBM approach, it would be possible to eliminate the need for intermediate access, though small diameter utility shafts might be needed and are in fact included in the estimated costs. If a segmental lining system is also assumed, as discussed in the following paragraphs, the TBM construction approach also has advantages with respect to providing immediate support and ground control in weathered zones, including karstic conditions.

### 2.5.1 Tunnel Lining

For this study, it is assumed that the tunnel will be fully lined from portal to portal. The lining will be required mostly for hydraulic reasons, but will also be to control water loss in low cover zones and areas of severely fractured rock and to prevent erosion and deterioration of the rock in areas of soft or highly fractured rock.

A pre-cast concrete, segmental lining has been assumed for the TBM portion of the tunnel. The thickness of the liner is expected to be between 0.3 and 0.5 m. A thickness of 0.4 m has been assumed for estimating purposes.

The segmental lining will be designed for various loading conditions, including construction (grouting and rock wedge loads), operation (external and internal hydrostatic pressures, rock relaxation loads), and inspection/de-watering condition (external water and rock pressures). The design will take into account areas of low cover (inadequate confinement) or poor ground. A simple expanded liner would be used in good ground, while a stronger reinforced liner will be provided for lining in poor ground. In areas where the rock cover is low and there is inadequate confinement (estimated to be where the hydraulic grade line exceeds 40 m of total cover), a more heavily reinforced liner will be designed to accept internal tunnel pressures with some interaction with the surrounding rock.

The hydraulic roughness of a segmental lining system is usually greater than a cast-in-place concrete lining. This has been taken into consideration in the present analysis. A segmental lining system, however, can offer significant scheduling and production advantages in that rock support and tunnel lining are installed in one pass. With a cast-in-place concrete lining, the lining operation could not begin until mining has been completed. Although schedule and cost differences penalties have been evaluated, detailed comparisons have not been carried out.

A cast-in-place concrete lining (reinforced as required) will be included in the drill-and-blast sections of the tunnel.

Final design of the tunnel lining will require information on geologic and groundwater conditions obtained from appropriate investigations.

The potential for substituting steel-fiber reinforced shotcrete lining for segmental or cast-in-place concrete should be investigated in a later phase. For cost estimating purposes, it was assumed in this study that shotcrete with rock bolts would constitute the primary method of support for drill-and-blast sections and for those areas of the TBM tunnel where such support can be used. Based on results of future investigations, it might be possible to optimize use of shotcrete as permanent lining for drill-and-blast sections and for parts of the TBM tunnel.

### 2.5.2 Excavation Advance Rates

The anticipated geologic and tunneling conditions strongly influenced the estimate of excavation advance rate and construction cost.

A detailed estimate of the advance rate including lining that could be achieved by a TBM-mined alternative has not been made at this stage of design. In general, it is estimated that the mining advance rate could be in the range of 12-15 m per day (net penetration rate of about 1.75 m/h and 42% utilization). For scheduling purposes, an advance rate of 13 m/day, six days per week was used. Provisions would need to be made for adjustments in the cutter system to account for changes in rock type (hardness and abrasivity) along the length of the tunnel. Design of a TBM system for the Río Coclé del Norte project would probably be able to address most, if not all the rock mass parameters that influence TBM excavation advance rate. Nevertheless, there can remain important risk elements associated with certain geologic conditions, such as potential for water inflow or squeezing conditions, though for this project squeezing ground is considered to be only a remote possibility because of relatively low cover.

The estimated daily advance rate estimates per excavation face for drill-and-blast excavation sections of the tunnel range from about 1 m/day in the worst ground to about 5 m/day in the best ground. The average is assumed to be 3 m/day under the Río Indio Reservoir consistent with average tunneling conditions. Limiting factors on the production rates will probably not be geologic but rather other aspects, such as resource availability and intermediate access.

## 2.6 Associated Features

### 2.6.1 TBM Adit

A separate upstream portal entrance for the TBM for construction access is included on the drawings and in the cost estimate. This will allow work on the intake structure and upstream access shaft to proceed without affecting TBM mining and mucking operations. The adit could be eliminated if scheduling studies indicate that it is not on the critical path, which would result in some cost savings.

### 2.6.2 Intake Structure

The intake structure has been designed as a bell mouth structure about 15 m wide by 10 m high. Trashracks will be installed on the front of the intake structure, which will be accessible for cleaning by a trash rake located on a platform that is situated above the PMF elevation. The cross-sectional area of the intake opening was designed to have a maximum flow velocity across the trashracks of 1.5 m/s.

The location of the intake portal was selected on the basis of having 2D rock cover above the tunnel crown. Hydraulic calculations indicate that for the design flows (220 m3/s, maximum pool; 185 m3/s at minimum pool), minimal submergence is required at the intake structure. Based on topographic conditions at the upstream end of the tunnel, it is advantageous to set the intake elevation as high as possible thus limiting the required length of approach channel to the intake structure. Therefore, the invert of the intake structure has been set at El. 40, which is 10 m below the minimum reservoir operating level.

An approach channel excavated to El. 40 will convey water to the intake structure. The approach channel will be about 1,500 m long in order to reach a ground elevation of 40 m in the reservoir. The channel is assumed to be excavated in overburden and will have a trapezoidal cross-section with a base width of 5 m and side slopes of 2H:1V.

### 2.6.3 Access and Gate Shafts

A 10-m diameter gate and access shaft has been selected for the upstream end of the transfer tunnel. Two 4m wide by 8m high wheel gates will be located in the shaft to allow for closure and dewatering of the tunnel from the upstream side.

An 11-m diameter shaft is required at the downstream end of the tunnel. The shaft will be utilized for removal of the TBM at the end of mining and will also be used as a gate shaft and for access to the downstream end of the tunnel. The shaft will house two sets of 4m wide by 7m high bonneted gates (operating and guard) that will be used to regulate flows through the tunnel and will also serve to allow closure of the tunnel from the downstream end. A 2-m diameter access shaft and sump for a pump is located upstream of the gates and will allow for dewatering of the tunnel between the upstream and downstream shafts.

A temporary excavation made on one side of the downstream access shaft will allow for removal of tunnel spoil and mining equipment prior to making the final connection to the Río Indio Reservoir.

## 2.7 Tunnel Outlet to the Río Indio Reservoir

The Río Indio reservoir will be operational at the time when the transfer tunnel from Coclé del Norte is being constructed. The outlet elevation of the transfer tunnel into the Río Indio reservoir has been set at El 35. Because the minimum operating level of the

Río Indio reservoir is El. 40, special consideration must be given to the method utilized for making the connection.

### 2.7.1 Potential Alternatives

Several alternatives were examined for making the outlet into the Río Indio reservoir, giving consideration to construction method, risk, and cost. The alternatives are summarized below; a discussion of the alternatives follows. A more in-depth discussion of the alternatives is included in Attachment 1.

| Alternative | Estimated Construction Cost | Comments |
|---|---|---|
| 1 Pre-construct outlet works prior to filling the Río Indio reservoir | $1,000,000 | High future equivalent cost; would not be needed for about 20 years |
| 2 Excavate of the outlet works in the dry behind a cofferdam | $1,000,000 to $2,000,000 | Feasible; requires maximum drawdown of Río Indio reservoir |
| 3 Lake tap | $1,500,000 to $2,500,000 | Feasible; higher geotechnical risk; does not require full drawdown of Río Indio reservoir |
| 4 Outfall shafts | $30,000,000 | Not feasible; too costly |

Alternative 1 would be the easiest and would involve the least risk from a geotechnical standpoint. A portal structure, a short tunnel extension, and a temporary bulkhead would be constructed prior to filling the Río Indio reservoir and would be left submerged until construction of the Coclé del Norte Project. Completion of the transfer tunnel would not affect operation of the Río Indio reservoir. The main disadvantage to this alternative is that it involves construction of the outlet works for a project that would be constructed approximately 20 years in the future, or possibly would not even be constructed at all. Although the present value of the construction is the least costly of the four alternatives, the equivalent future cost is potentially much higher. Due to the economic risk associated with this alternative, it is not considered feasible.

Alternative 2 would involve temporary drawdown of the Río Indio Reservoir and construction of a cofferdam around the outlet works, behind which construction would take place in the dry. The main disadvantage is related to the temporary drawdown of the Río Indio reservoir, which could potentially impact operation of the Canal, thus representing a potentially significant cost increase. This alternative is viable, however, due to the potential impact on Canal operations, it was not selected.

Alternative 3 would involve construction of a tunnel beneath the Río Indio reservoir, leaving a short rock plug in place until the final connection is made by removal of the rock plug. This is a relatively low cost alternative that would not require full drawdown of the Río Indio reservoir when the "lake tap" connection is made. The main disadvantage of this method is related to the geotechnical risk associated with tunneling beneath the Río Indio reservoir under relatively low rock cover, especially in the area where the lake tap will be made. This alternative is feasible and has been selected as the design alternative. The lake tap method is described in more detail in the following section.

Alternative 4 would involve drilling of several large diameter shafts to a depth of about 25 m below the lakebed, which would be temporarily plugged until a connection is made through a tunnel extended below the reservoir. The main disadvantage of alternative is the costly, specialty construction equipment that would be required for drilling the shafts. This alternative was not selected due to high construction costs.

### 2.7.2 Selected Alternative

The selected method of connecting to the Río Indio reservoir will be made by construction of a lake tap, as shown on Exhibit 3. This method, which has been used successfully on many projects, would involve the following:

- At the outlet location, excavate in-the-wet (below water) all overburden to top of firm rock using a clamshell excavator and a barge on the Río Indio reservoir;

- Using drill and blast methods, excavate a 9-m diameter, D-shaped tunnel that extends from the downstream access shaft to a point below the Río Indio reservoir where the ground is at El. 35;
- Excavate a 30-m long by 5 m deep rock trap at the downstream end of the tunnel to collect rock excavated when the final blast is made for the lake tap;
- Intensely grout the rock where the outlet shaft will be excavated to reduce rock mass permeability and water inflows, and also to improve rock mass strength;
- Partially excavate an inclined 10-m diameter shaft to intersect the Río Indio reservoir floor at El 35, leaving in place a rock plug, approximately 10-m long, until the final connection is made; and
- Remove all mining equipment from the tunnel and make the final blast at the rock plug.

In the area of the tunnel outlet and lake tap, the depths to the top of weathered rock and to the top of competent rock are assumed to be 5 m and 10 m, respectively. Extensive geologic and geotechnical investigations would have to be made at the proposed lake tap site in order to confirm ground conditions. Consideration should be given to making at least preliminary investigations prior to filling the Río Indio reservoir, as once the reservoir is filled, direct access to the proposed tunnel outlet would be lost. Should the rock conditions be worse than anticipated or be unfavorable for making a lake tap connection, then certain adjustments could be made to the procedure. For example, if the depth to competent rock is deeper than anticipated, the tunnel invert could be lowered and a deeper excavation made from the surface.

If geologic conditions are found to be such that a lake tap method cannot be used, then it would be necessary to resort to a different method for constructing the tunnel outlet. In this case, Alternative 2 involving temporary drawdown of the reservoir and construction of a cofferdam, is recommended as a viable alternative. The tunnel outlet could be constructed in the dry thus reducing the risk to personnel and equipment.

# 3 CAÑO SUCIO CANAL AND TUNNEL

## 3.1 Description

A general plan of development for the Río Coclé del Norte and Río Caño Sucio basins operating between El. 100.0 and 90.0 is presented in Exhibit 4. At their minimum operating levels of El. 90, the Coclé del Norte reservoir is approximately 2.5 km from the Río Caño Sucio reservoir at its closest point. The intervening topography is predominantly less than 100 m elevation, which favors a surface water transfer facility. At its minimum operating level of El. 90, the Río Caño Sucio reservoir is approximately 8 to 10 km from the Río Indio reservoir. Over most of this distance, the intervening topography is generally about El. 90 to 95, which favors a surface water transfer system (canal and reservoir). In the most downstream section, the topography reaches over 150 m, and is predominantly over 120 m in elevation, which precludes a surface water transfer facility. Therefore, a 2.5 km-long tunnel was selected as the final segment for transferring water between the Río Caño Sucio and Río Indio reservoirs.

The studies and designs also defined the related project features such as intake and outlet works, approach channels, and water transfer control facilities.

Water transfer facility studies performed this development included the following:

- Geological assessment of conditions along the canal and tunnel alignment
- Topographical assessment of alternative alignments
- Selection of a recommended alignment
- Operational assessment of water transfer facility sizes
- Development of water transfer facility components
- Development of a construction plan for the selected water transfer facilities

The resulting water transfer facilities from the Río Coclé del Norte reservoir to the Río Indio basin comprise:

- A 6,500-m long west branch of canal through the divide between the Río de U and the Río Limon to the Río Caño Sucio,
- An 8,650-m long canal east branch along the Río Caño Sucio and Río Cerro Miguel to the headrace of a tunnel to the Río Indio basin,
- A 2,550-m long, 5.5-m diameter tunnel,
- Intake and outlet portal structures, and
- An upstream access shaft.

A plan showing the canal and tunnel alignment is presented on Exhibit 4. A profile through the tunnel is shown on Exhibit 5.

### 3.2 Topographic Information

The topographic model used initially during this study was based on the published 1:50,000-scale topographic map (20-m contour interval) of the project area. Later in the studies, the topographic model for the Río Caño Sucio area (including the Caño Sucio canal and tunnel and the Coclé del Norte to Río Indio tunnel) was updated using new information provided by ACP and Ingenieria Avanzada, S.A. (IASA). The new information consists of the following:

1. Contour data generated from 1:20,000-scale aerial photographs using photogrammetric methods (re-restitution of existing photographs). The contours are at 1-m intervals and cover two areas representing the upstream and downstream ends of the Cocle-Sucio-Indio and Cocle-Indio water transfer systems. The data were prepared for ACP by Geocart-Grafos under a separate contract.

2. Survey points from a ground survey conducted by IASA approximately along the Caño Sucio canal route and at the proposed Sucio-Indio tunnel intake portal. Data along the canal route consist of cross-sections taken approximately every 75 m along a survey route provided to IASA by ACP. There are three areas along the route where cross-sections were not surveyed due to problems with gaining permission for access. The survey at the Sucio-Indio tunnel intake portal is based

on more comprehensive survey with survey points taken approximately every 10 m in a square grid pattern. IASA performed these surveys under subcontract to MWH.

Topographic information used to develop the final tunnel and canal alignments was combined from the three sources. Where topographic information overlapped, only one source was utilized. Priority was given first to the ground survey, second to the aerial photographs, and finally to the published topographic maps.

A comparison was made between the IASA survey points and the aerial photo-derived contours where they overlap at the upstream end of the water transfer systems. The agreement between the two sources is variable: in some areas the elevations are within 1 m, in other areas there is a discrepancy of as much as 15 m.

### 3.3 Geology

The first part of the water transfer facilities consists of a canal from the Río Coclé drainage to the Río Caño Sucio drainage. This part of the canal will require excavation through the saddle area at Quebrada Encantada. The excavation will be through varied sedimentary rock units belonging to the upper Cañazas Formation and lower Caimito Formation, ranging from marls, limestones, siltstones, coarse-grained sandstones, to conglomerates. Based on the presence of abundant basalt float in the area, igneous units could also occur in the area, possibly local dikes, sills, or isolated lava flows.

The bulk of the proposed canal alignment through the Río Caño Sucio Reservoir would encounter various soil or overburden units rather than rock formations. The nature and origin of these are unknown at this time but are thought to include fine-grained alluvium (silty sand), possibly lacustrine sand and silt deposits, and severely weathered to decomposed sedimentary bedrock. The groundwater table can be expected to be close to the surface or at shallow depths along about one third to half of this reach. Locally in the canal reach leading up to the Río Indio tunnel, excavation might encounter bouldery basalt talus originating from basalt outcrops on the flanks of Cerro Miguel.

It is probable that excavation of the 2,550-m long tunnel from the Río Caño Sucio Reservoir to the Río Indio drainage will encounter a wide range of rock types and tunneling conditions. Rock types could include sandstone and softer epiclastics of the Caimito Formation as well as hard, strong lavas (andesites, dacites, and basalts) and agglomerates. Because of the relatively low cover, various degrees of weathering of the rock formations should be expected over much of the tunnel length.

Bedrock outcrops in the tunnel outlet area consist of a sequence of interbedded tuffs, epiclastics, sandstone, and dark andesitic lava. The commonest lithology appears be the sandstone, which in many outcrops is seen to be thick-bedded and relatively strong. The volcanic units form many of the steep hills and high plateaus that are readily apparent on topographic maps and aerial photographs, while the sedimentary units tend to occur in the lower ground. Some of the volcanic formations might represent older units cropping out as erosional inliers.

## 3.4 Canal and Tunnel Alignment Studies

The alignment of the water transfer facilities was determined from an inspection of topographic maps, field visits, and preliminary cost studies. It was determined that the water transfer facilities will consist of a canal and a tunnel. The west branch of the canal will convey Río Coclé del Norte water from the Quebrada La Encantada, which flows into the Río de U, along the Río Limon in the Río Caño Sucio basin. The east branch of canal conveys water from the Río Caño Sucio Reservoir along the Río Cerro Miguel to a tunnel headrace. The tunnel will convey water through the divide between the Río Caño Sucio basin and the Río Indio basin to a small tributary of the Río Uracillo in the Río Indio basin.

### 3.4.1 Alignment Alternatives

Preliminary studies identified two basic alignments for the water transfer facilities: a northern alignment that follows the Río Cerro Miguel around the north side of Cerro Miguel, and a southern alignment that follows the Quebrada La Guinea de Loma Alta for about 2 to 3 km and then passes below Cerro del Bongo. The alignment to the north of

Cerro Miguel is the longer of the two, with a total length of about 9.0 km, while the southern alignment has a length of about 6.8 km. (The lengths are measured from about 1 km downstream of the confluence of the Río Cerro Miguel and the Quebrada La Guinea de Loma Alta.)

Three alternatives were identified from these two alignments and were considered in more detail:

1. Northern alignment. A 7,700-m long canal through the Río Caño Sucio reservoir and a 1,300-m long canal between the Caño Sucio and Río Indio reservoirs.
2. Northern Alignment. A 7,700-m long canal through the Caño Sucio reservoir and a 1,300-m long tunnel between the Caño Sucio and Río Indio reservoirs.
3. Southern Alignment. A 3,500-m long canal through the Caño Sucio reservoir and a 3,300-m long tunnel between the Caño Sucio and Río Indio reservoirs.

A preliminary cost comparison made between Alternatives 1 and 2 showed the canal to be the more expensive option, and therefore Alternative 1 was eliminated on the basis of cost. Alternatives 2 and 3 resulted in costs that differed by only about $1 million, which is less than 5 percent of the total cost of the water transfer facilities and is within the accuracy of the estimate. Alternative 2 was selected on the basis that it resulted in a slightly lower cost and because it has a shorter transfer tunnel than Alternative 3. The rational for selecting the alternative with the shorter transfer tunnel is due to the limited geologic information available for the project area; there is significantly more uncertainty associated with the tunnel excavation than with the canal excavation, and it is believed that potential cost impacts due to unforeseen geologic conditions would be greater for the longer tunnel.

### 3.4.2 Recommended Future Alignment Studies

It is recommended that further study of alternative alignments be included in future work. In particular, it is suggested that closer examination be made of potential merits of the southern alignment (Alignment Alternative 3 in the previous paragraphs) that only started to become apparent upon receipt of information late during the course of the present study. This information includes:

- New topographic information showed that ground elevations at the downstream end of the canal were 10 to 15 m higher than what is shown on the 1:50,000-scale topographic maps. This resulted in ACP recommending that the upstream tunnel portal be moved upstream in order to reduce canal excavation quantities. The transfer tunnel for the northern alignments (1 and 2) increased in length from 1,300 m to 2,550 m as a result of this relocation of the upstream portal.
- Flows from the Río Coclé del Norte to Río Indio reservoir were increased, resulting in deepening of the canal to keep flow velocities at 1.5 m/s. The canal cost thus increased from about $2.2 million/km to about $3.5 million/km as a result of the increased excavation.

As a result of these two changes to the water transfer facilities, it appears that significant cost reductions might be achieved by selecting the southern alignment with the shorter canal section and longer transfer tunnel. Before undertaking these studies, further data would have to be obtained in order to confirm ground elevations and geologic conditions along the southern alignment.

### 3.5 Operation Studies

The dimensions of the water transfer facilities are based on flow data computed as a part of the operation studies performed by the ACP. The maximum flow from Sucio Reservoir to the Río Indio Reservoir is estimated to be 180 $m^3/s$ when the Río Coclé del Norte Project is at El. 100 and the minimum is estimated to be 160 $m^3/s$ at El. 90. The water transfer facilities are designed to pass the water from the Río de U to the Río Caño Sucio Reservoir, to the Río Indio Reservoir, and on to Lake Gatun.

Hydraulic studies, supported by preliminary estimates, were performed to determine the canal dimensions and the tunnel diameter required to provide the required maximum and minimum transfer capacity. The lengths of the water transfer facilities is shown below:

| Water Transfer Facility Reach | Length (m) |
|---|---|
| West Branch of the Río Caño Sucio Canal | 6,500 |
| East Branch of the Río Caño Sucio Canal | 8,650 |
| Río Caño Sucio Tunnel | 2,550 |
| Río Indio Second Tunnel | 8,250 |
| **Total Length of Water Transfer Facilities** | **25,950** |

The diameter of the tunnel from the Río Caño Sucio basin to the Río Indio Reservoir was determined to be 5.5 m based on HEC-5 model studies of system operation performed by the ACP. The tunnel will have a modified horseshoe shape and the invert will vary from El. 82.0 at the intake to El. 70.0 at the outlet. The tunnel will be lined throughout its length with concrete.

During more detailed design phases, additional optimization of the tunnel and canal sizes should be performed in conjunction with reservoir operation studies.

### 3.6 Construction Methodology

The water transfer facilities will consist of a combination of canal and tunnel. The canal will be excavated, for the most part, in overburden. In some of the deeper cuts, excavation will likely be in rock

Canal slopes in soil and soil-like decomposed materials would be 2H:1V. A 3-m wide bench will be excavated for every 10 m of vertical cut. Slopes in deeper sections in fresh rock could be steeper. The canal will have a base width of 5 m. It is assumed that the canal would be unlined and that water velocities would be low and less than 1.5 m/s.

Alternative methods of excavation can be considered for the water transfer tunnel, involving either conventional drill-and-blast or mechanical excavation by tunnel boring machine (TBM). For estimating costs, it was assumed that tunnel construction would utilize drill-and-blast techniques from both portals. Intermediate access locations will probably not be used due to the short distance of the tunnel.

It is assumed that the tunnel will be fully lined from portal to portal. The lining will be required to control water loss in low cover zones and areas of severely fractured rock and to prevent erosion and deterioration of the rock in areas of soft or highly fractured rock. A cast-in-place concrete lining has been assumed in all rock conditions with an average lining thickness of 25 cm.

The anticipated geologic and tunneling conditions strongly influenced the estimate of excavation advance rate and of course construction cost. The daily advance rate assumed for estimating costs was 4 m/day, which is considered realistic. Limiting factors on the production rates will probably not be geologic but rather other aspects such as resource availability.

## 3.7 Associated Features

### 3.7.1 Intake

The intake to the tunnel consists of a transition from the end of the canal that widens out to accommodate the intake structure. The intake is a reinforced concrete structure with be a 6-bay entrance, each bay dimensioned at 5.5-m high by 4.9-m wide to limit the velocity through the trashracks to 1.5 m/s. The 6-bay entrance transitions over a distance of 24.5 m to the entrance of the tunnel, which will house a 5.5 m square bulkhead. The section then transitions from a square opening to the modified horseshoe shape over a distance of 8.1 m.

### 3.7.2 Gate Shaft

A gate shaft and gate will be provided at the upstream end of the tunnel for dewatering. It is located 70 m from the intake structure housing two gates, each 3.4 m wide by 6.0 m high. The gate will be raised and lowered by means of a hydraulic cylinder hoist that will be powered and operated from a surface control structure.

### 3.7.3 Outlet to Río Indio Reservoir

The outlet will discharge at El. 70, slightly below the full supply water surface elevation for the Río Indio Reservoir. The tunnel outlet structure will house a gate chamber containing two 2.5 m by 5.5 m bulkheads and two 2.5 m by 5.5 m slide gates. The water will discharge from the gate chamber on to a concrete sill, which will be about 20 m long. The sill ends at El. 64. The sill widens from 7 m wide at the outlet structure to 12 m wide at the downstream channel. The outlet structure will be founded on sound rock. Power and control equipment will be housed in a small structure adjacent to the gates. A road will be provided for a mobile crane to access the gates when maintenance is required.

Because the outlet structure extends to El. 64 and the Río Indio reservoir maximum operating level is El. 80, either a cofferdam will be required in order to construct the outlet works, or the Río Indio reservoir would have to be drawn down. A cellular cofferdam has been assumed for this study and has been included in the cost estimate. The reservoir drawdown alternative should be evaluated and its impact on Canal operation determined during final design.

# 4 RÍO INDIO TO LAKE GATUN SECOND TRANSFER TUNNEL

## 4.1 Description

According to the present concept, the Río Indio Project will have been constructed about 20 to 30 years before any work starts on the Río Coclé del Norte Project. As described in the Río Indio Water Supply Project Report, a 4.5-m diameter tunnel is required to convey Río Indio water to Lake Gatun. With the connection of the Río Coclé del Norte Project to the system, a second tunnel will be required to augment the water transfer capacity. The same tunnel would be used for either of the two Río Coclé del Norte projects.

To transfer the additional water from the Río Indio basin to Lake Gatun, it is necessary to construct:

- A 8,250-m long, 6.5-m diameter tunnel,
- Intake and outlet portal structures, and
- An upstream access shaft

A plan and profile of the water transfer tunnel is shown on Exhibit 6.

## 4.2 Studies for the First Indio to Gatun Transfer Tunnel

Tunnel alignment studies were carried as part of the feasibility study for the Río Indio Water Supply Project. The final alignment was selected on the basis of tunnel length and rock cover conditions. Details of the tunnel alignment study are included in the Río Indio Feasibility Design Report

## 4.3 Geology

Existing geologic maps of the region show bedrock in the region as belonging to 'undifferentiated Tertiary volcanics' or alternatively as belonging to the Tertiary age Caimito Formation (tuffaceous sandstone, tuffaceous siltstone, tuffs, dacitic agglomerate, conglomerate, sandstone, and limestone). It is probable that tunnel construction for the inter-basin transfer will encounter a wide range of rock types and tunneling conditions. Rock types could include sandstone and softer epiclastics of the Caimito Formation as well as hard, strong lavas (andesites, dacites, and basalts) and agglomerates. There is potential for transition over short distances from very hard strong rock (such as andesite or basalt) to soft, weak almost clay-like materials.

Two reconnaissance visits were made to the area of the proposed tunnel intake and outlet portals in 1999 and 2002 as part of the studies for the Río Indio Project. Outcrops of a very hard and strong andesite and basalt were found in the vicinity a potential location for the tunnel outlet works was visited close to Isla Pablon on Lake Gatun. These materials are quarried locally and would provide useful sources of construction material for the project. Sedimentary rocks, possibly tuffaceous and foraminiferal sandstone belonging to the marine phase of the Caimito Formation, were found nearby. It was confirmed that the Gatun outlet works could be founded on sound igneous bedrock, however, design details, such as the extent of tailrace channel excavation and the extent of tunnel steel lining would depend on final arrangements with respect to local topography.

At the intake end, reconnaissance revealed that the topography in the portal area is favorable and provides a range of options for detailed design, i.e. flexibility in vertical and horizontal location. The bedrock geology consists of thick-bedded sandstone units, such as found at the dam site, which crop out or are mantled with a thin layer of cobbly/bouldery colluvium. Based on the presence of basalt float in the area, an igneous unit also occurs in the area, probably a local sill or dike, but its exact location with respect to the portal is not known.

### 4.4 Operation Studies

The finished diameter of the tunnel is 6.5 m and the capacity is 277 $m^3/s$ and 137 $m^3/s$ at full supply level, El. 80 and minimum pool level, El. 40, respectively. The tunnel diameter was selected based on the results of HEC-5 analyses made by ACP.

### 4.5 Tunnel Alignment

Only one tunnel alignment was examined for the second transfer tunnel; it is located about 120 m to the south of the first tunnel in an approximately parallel alignment. The alignment was selected with the idea that facilities developed for the Río Indio project, such as access roads, power facilities and intermediate tunnel access adits, would be utilized for construction of the second transfer tunnel. Additionally, experience gained during construction of the first transfer tunnel, especially knowledge of ground conditions, would be directly applicable to the second tunnel. The selected tunnel alignment for the second transfer tunnel is about 8,250 m long.

### 4.6 Construction Methodology

It was assumed that the tunnel construction would utilize drill-and-blast techniques from multiple headings. Intermediate access would be through adits originally developed for the first transfer tunnel; the adits would have to be rehabilitated before they could be used again. Alternatively, a TBM-excavated option could be considered, but selection would depend on experience learnt from the first tunnel.

It is assumed that the tunnel will be fully lined. The lining is included to prevent erosion and deterioration of the rock in areas of soft or highly fractured rock. The lining will be cast-in-place concrete with a thickness of either 0.25 m or 0.50 m, depending on the rock cover. Reinforcement, thicker concrete, and steel lining will be installed where required.

### 4.7 Associated Features

The water transfer tunnel consists of an approach channel, an intake structure, the tunnel, an outlet structure, a gate structure, and a discharge channel.

#### 4.7.1 Intake Structure

The approach channel will be 220 m long and has its invert at El. 30. The channel is excavated as a trapezoidal section with a bottom width of 14 m and side slopes averaging

1H:2V. The intake structure is a reinforced concrete structure with an opening of 12 m by 15 m. Trash racks protect the openings. Intake flow velocities at maximum discharge are limited to 1.5 m/s. The invert of the intake is at El. 32 to allow for proper hydraulic conditions at minimum pool operation. The intake structure extends up to El. 85, 1 m above the design flood elevation to provide access to the trash racks. A trash rake is provided to clean the trash racks.

### 4.7.2 Outlet Structure

At the downstream end of the tunnel, an outlet structure will house two 3.5 m wide by 5.4 m high, bonneted guard gates and bonneted control gates in series. This will provide redundancy for reliable operation and maintenance, and additional flow control. The outlet structure will be founded on sound rock. Power and control equipment will be housed in a small structure adjacent to the gates. A road is provided for a mobile crane to access the gates when maintenance is required.

The outlet will discharge at El. 27, slightly above the maximum water surface elevation for Lake Gatun, onto a concrete sill about 35 m long. The sill ends at El. 20, slightly below the minimum level of Lake Gatun. The sill widens from 11 m wide at the outlet structure to 21 m wide at the downstream channel.

The outlet structure discharges into a 400 m long channel, which discharges into the presumed existing discharge channel for the first tunnel. The channel is excavated as a trapezoidal section with a bottom width of 22 m and side slopes of 2H:1V. It directs the flow from the Río Indio transfer tunnel into Lake Gatun adjacent to Isla Pablon.

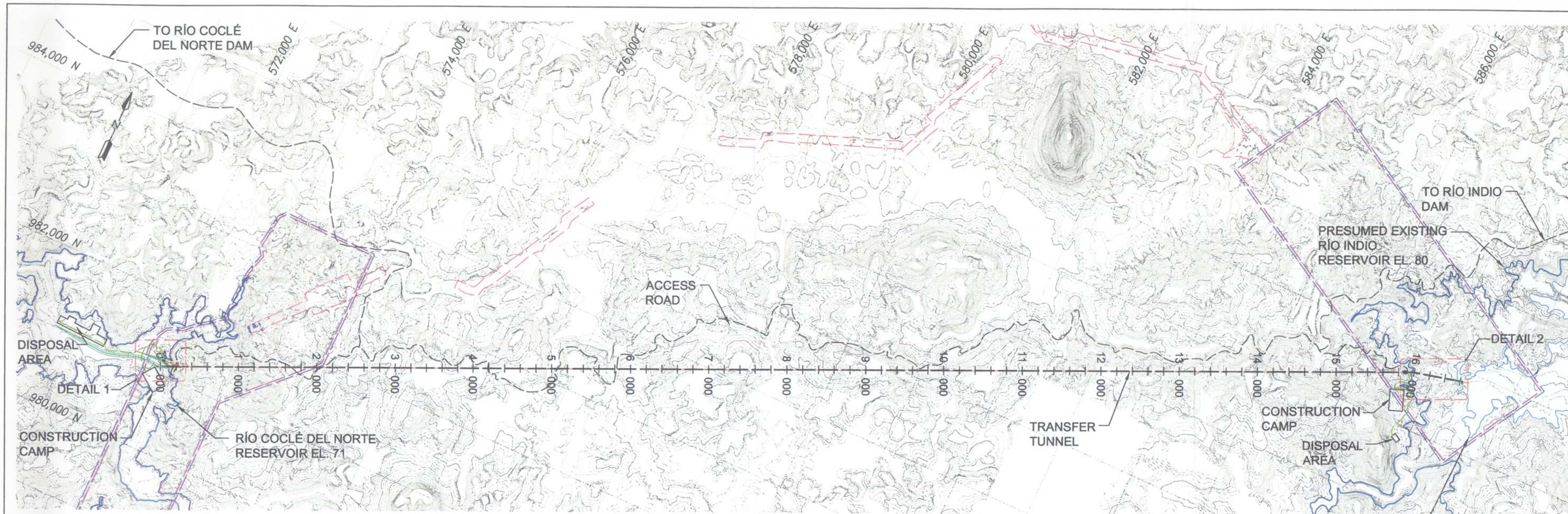
### 4.7.3 Gate Structure

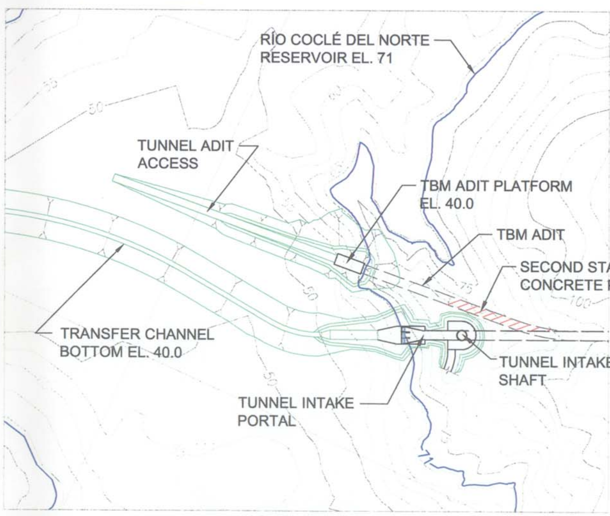
A gate shaft and gate will be provided at the upstream end of the tunnel for dewatering. It is located 70 m from the intake structure housing two gates, each 3.4 m wide by 6.0 m high. The gate will be raised and lowered by means of a hydraulic cylinder hoist that will be powered and operated from a surface control structure.

# 5 REFERENCES

MWH, Work Order No. 3, Feasibility Design for the Río Indio Water Supply Project, Volume I: Main Report, April 2003

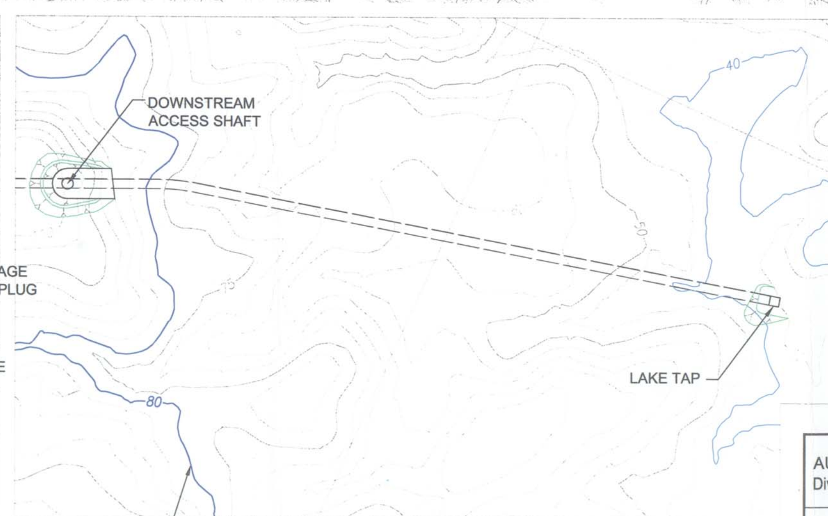
# EXHIBITS




**DETAIL 1**
**TRANSFER TUNNEL INTAKE AND TBM ADIT**

0 50 100 m
GRAPHIC SCALE




PRESUMED EXISTING RÍO INDIO RESERVOIR EL. 80

**DETAIL 2**
**TRANSFER TUNNEL OUTLET**

0 50 100 m
GRAPHIC SCALE

**NOTE:**

TOPOGRAPHY COMPILED FROM THE FOLLOWING SOURCES:

1. GROUND SURVEY (IASA, 2003)
2. AERIAL PHOTOGRAPHY (GEOCART - GRAFOS, 2002)
3. PUBLISHED 1:50,000 TOPOGRAPHIC MAPS (TOMMY GUARDIA)

0 0.5 1.0 1.5 2.0 2.5 km
GRAPHIC SCALE

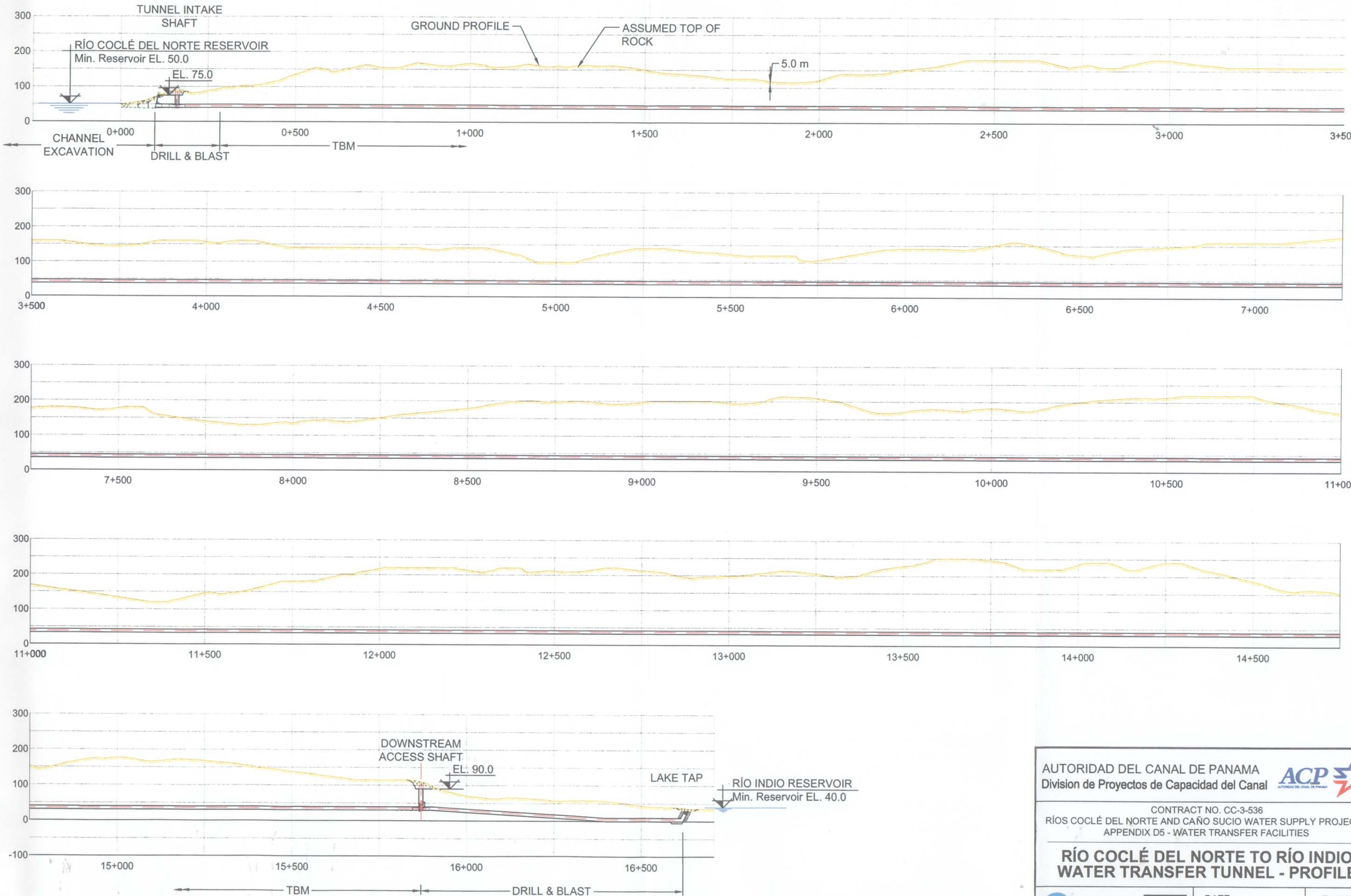
AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

# RÍO COCLÉ DEL NORTE TO RÍO INDIO WATER TRANSFER TUNNEL - PLAN

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 1 |



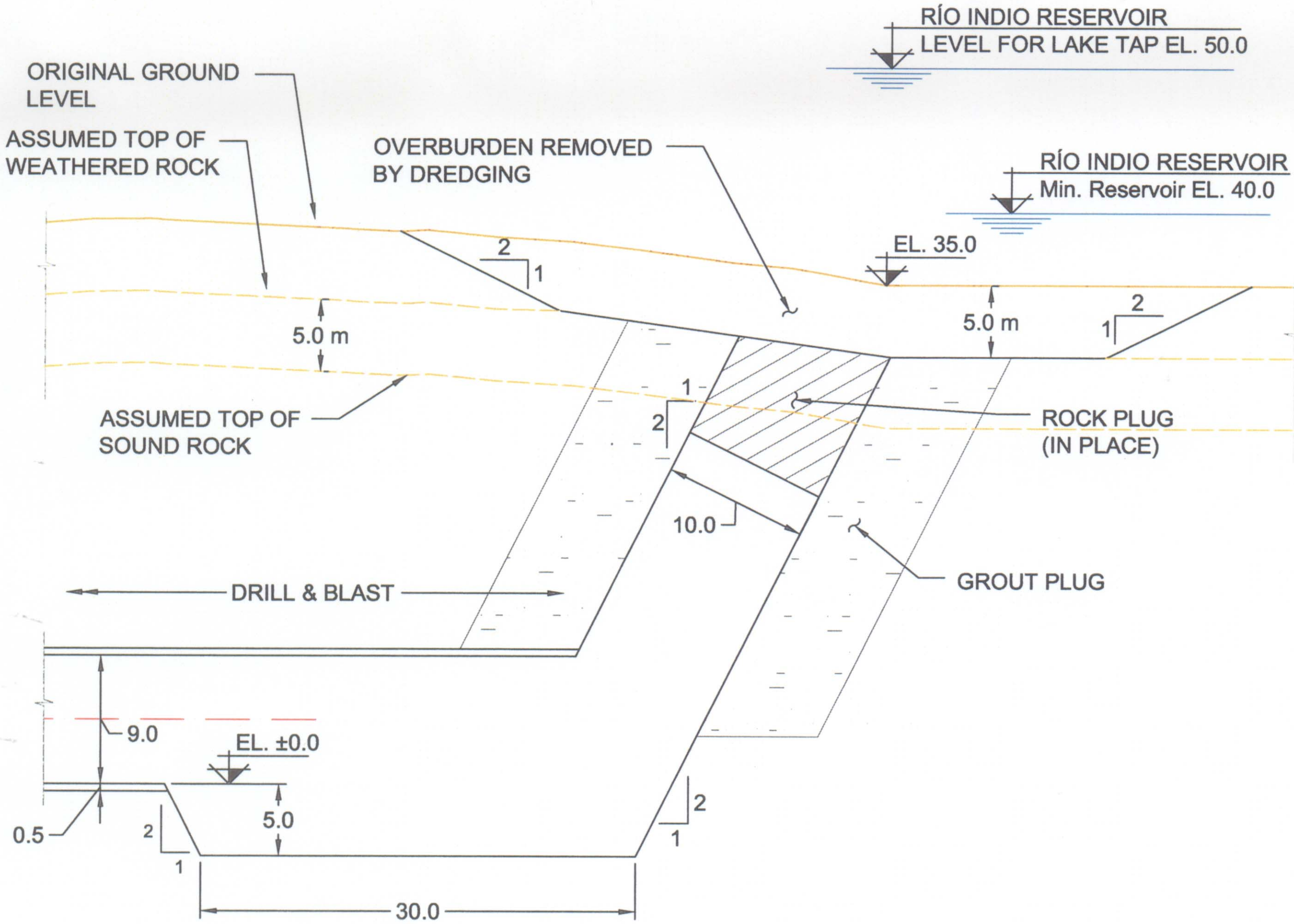

AUTORIDAD DEL CANAL DE PANAMA
**Division de Proyectos de Capacidad del Canal**

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

## RÍO COCLÉ DEL NORTE TO RÍO INDIO WATER TRANSFER TUNNEL - PROFILE

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 2 |




## LAKE TAP

0 5 10 15 20 25 m
GRAPHIC SCALE

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

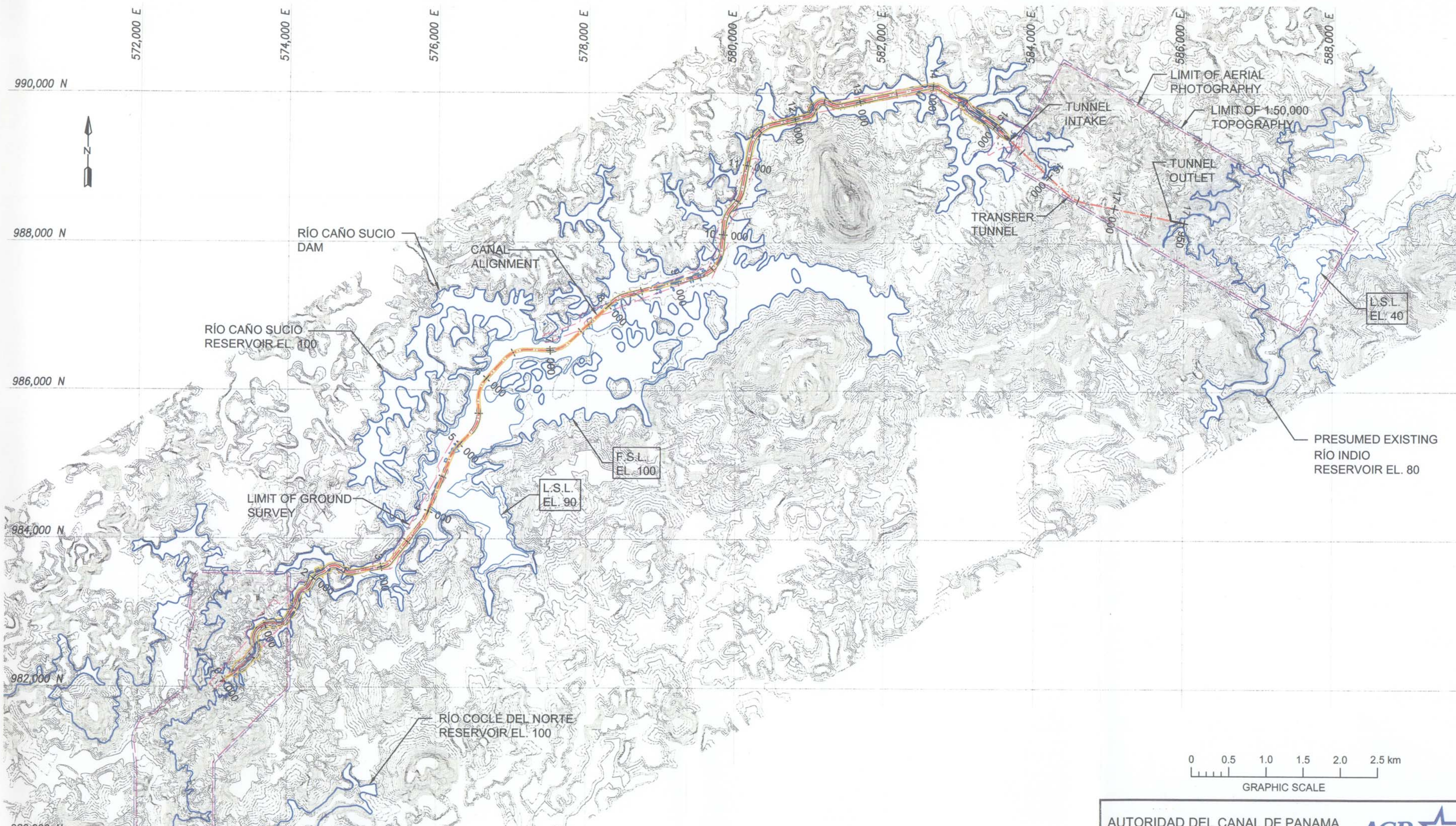
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

**RÍO COCLÉ DEL NORTE TO RÍO INDIO WATER TRANSFER TUNNEL - LAKE TAP**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 3




**NOTE:**

TOPOGRAPHY COMPILED FROM THE FOLLOWING SOURCES:

1. GROUND SURVEY (IASA, 2003)
2. AERIAL PHOTOGRAPHY (GEOCART - GRAFOS, 2002)
3. PUBLISHED 1:50,000 TOPOGRAPHIC MAPS (TOMMY GUARDIA)

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

**COCLÉ DEL NORTE - CAÑO SUCIO - INDIO CANAL AND TUNNEL - PLAN**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 4 |


AUTORIDAD DEL CANAL DE PANAMA
División de Proyectos de Capacidad del Canal

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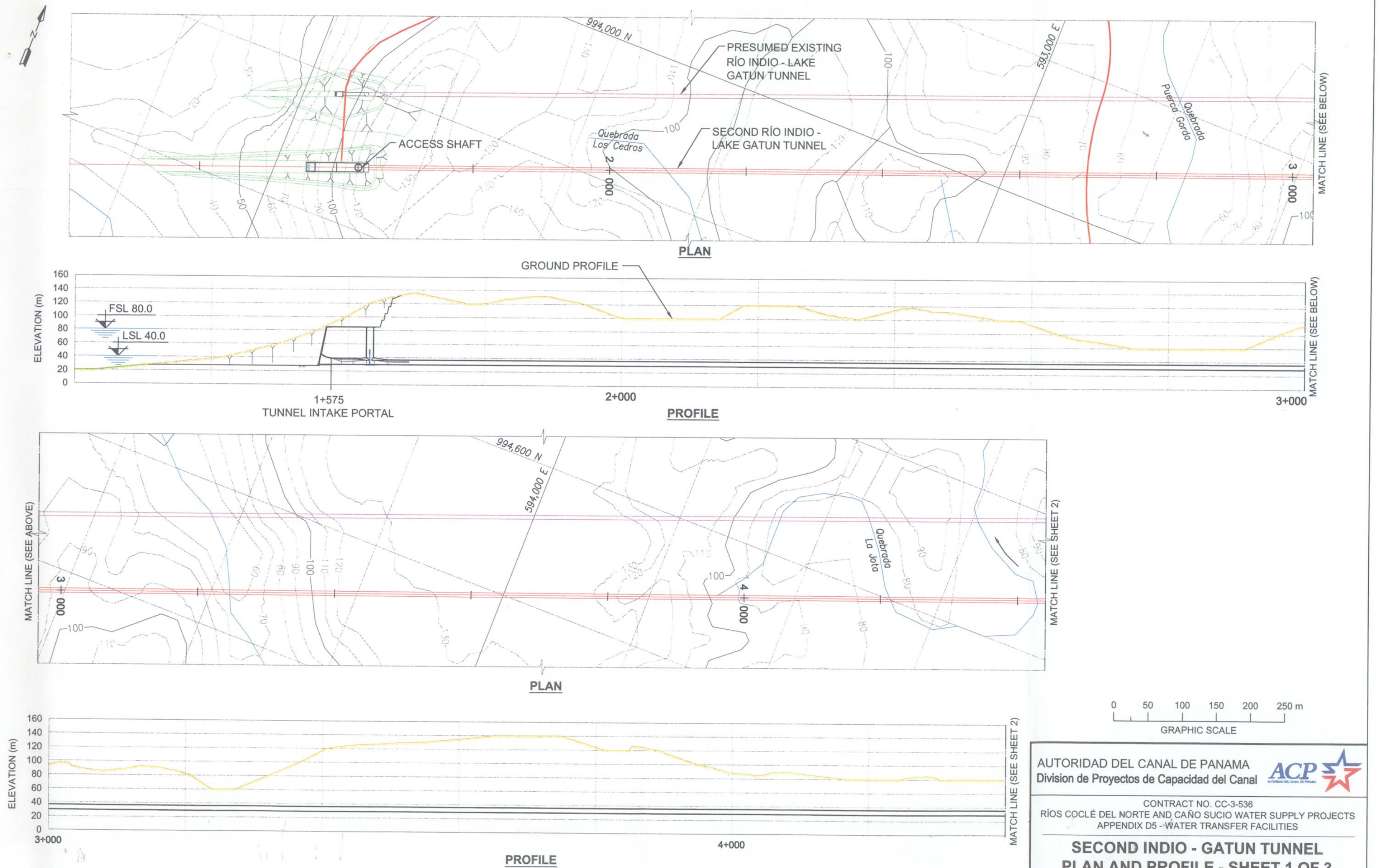
APPENDIX D5 - WATER TRANSFER FACILITIES

**CAÑO SUCIO - INDIO TUNNEL PROFILE**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 5 |




0 50 100 150 200 250 m

GRAPHIC SCALE

AUTORIDAD DEL CANAL DE PANAMA
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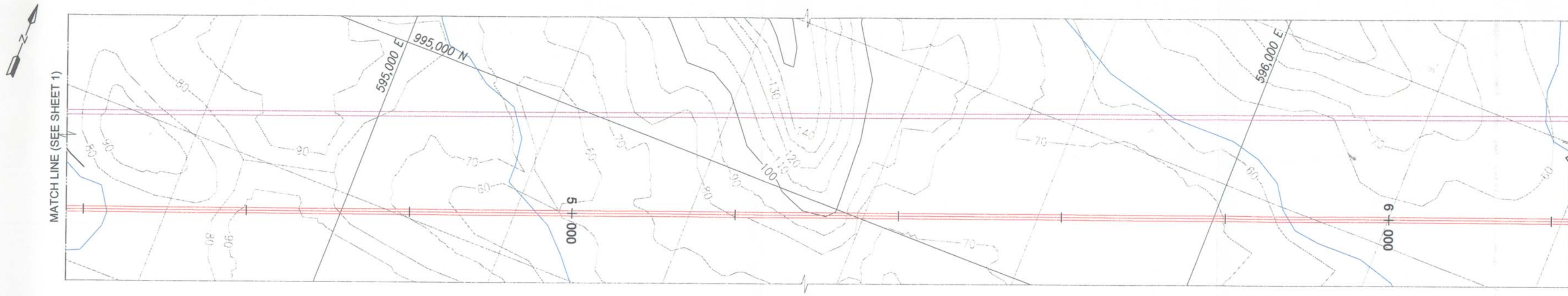
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

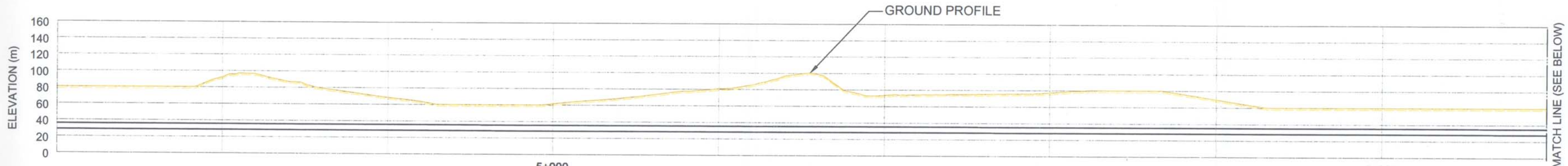
## SECOND INDIO - GATUN TUNNEL PLAN AND PROFILE - SHEET 1 OF 3

MWH TAMS

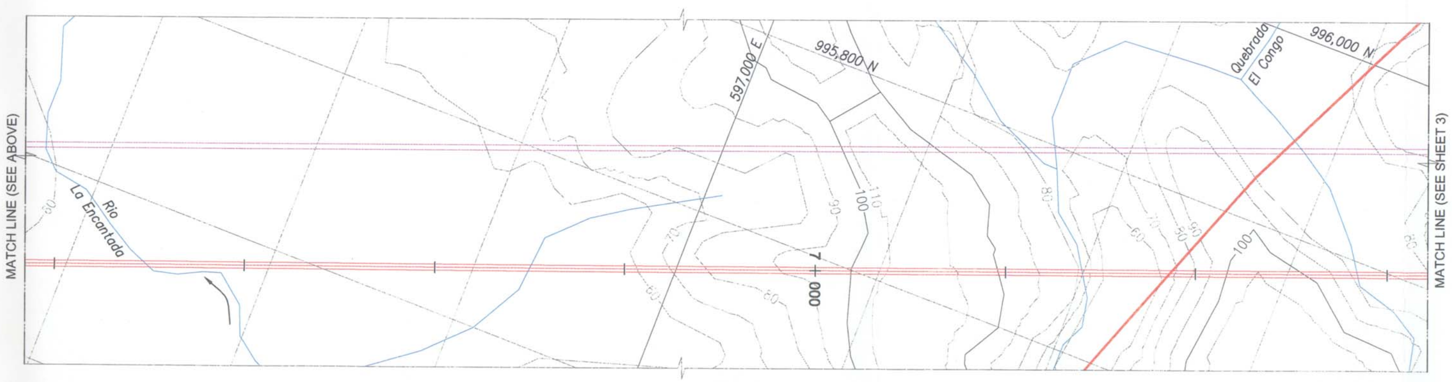
| DATE: | EXHIBIT: |
| --- | --- |
| DECEMBER, 2003 | 6 |



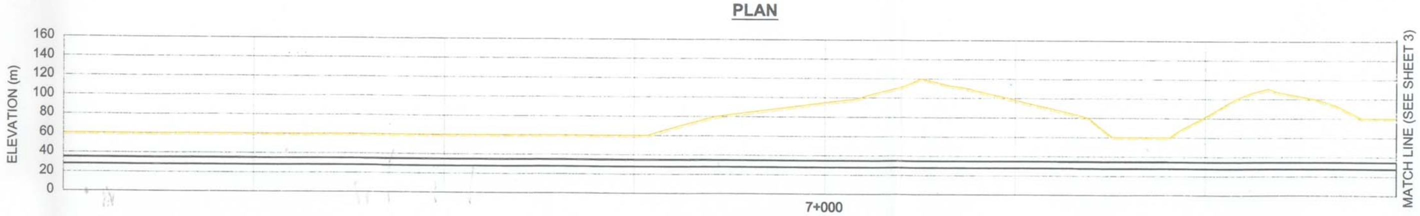

PLAN




PROFILE




PLAN




PROFILE

0 50 100 150 200 250 m
GRAPHIC SCALE

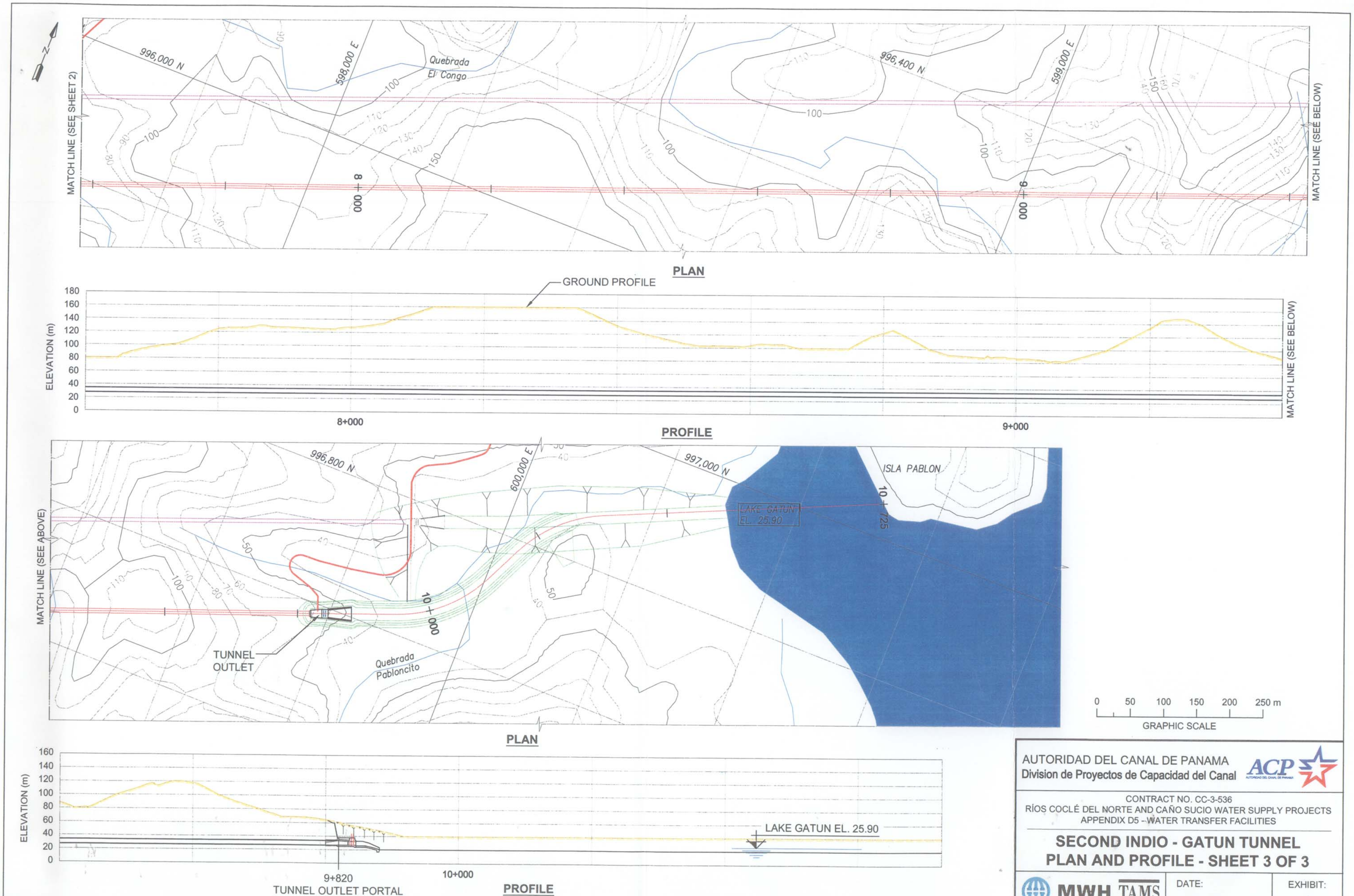
AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

**SECOND INDIO - GATUN TUNNEL**
**PLAN AND PROFILE - SHEET 2 OF 3**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 6 |




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX D5 - WATER TRANSFER FACILITIES

**SECOND INDIO - GATUN TUNNEL**
**PLAN AND PROFILE - SHEET 3 OF 3**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 6

# ATTACHMENTS

# Attachment 1 – Coclé del Norte – Río Indio Transfer Tunnel Outlet Works

**Location:** Chicago

August 04, 2003

**To:** M. Newbery

**From:** C. Ottsen

**Subject:** Cocle del Norte – Rio Indio transfer tunnel outlet works (FINAL)

The following memo presents some preliminary concepts for construction of outlet works for the transfer tunnel between Cocle del Norte and Rio Indio reservoirs. For relative comparison, rough cost estimates are given for each of the various outlet options. Detailed costs estimates will need to be prepared for the selected option in order to provide more accurate costs.

Based on our previous discussions, I have assumed that the tunnel alignment and outlet location are as shown on the existing layout drawings. No alternative alignments or outlet locations were considered. Due to the limited topographical and geological information, I have assumed a general geologic profile where sound bedrock is located approximately 5-m to 10-m below ground surface.

I have also assumed that the transfer tunnel will be approximately 10-m diameter and will outlet at an invert elevation of approximately El. 35-m. It is understood that the Rio Indio reservoir will operate between El. 80-m and El.40-m, and there is preference to construct the outlet works without drawing down the reservoir. The following options for the transfer tunnel outlet have been developed considering these assumptions.

**Option #1 – Pre-construction of Outlet Works**

This option would involve construction of the outlet works for the transfer tunnel prior to filling Rio Indio reservoir. The outlet works would include: a portal structure; a short outlet tunnel extension for future connection; and a temporary bulkhead. Upon filling the Rio Indio reservoir, the outlet works would be flooded and left submerged until such time that the remainder of the transfer tunnel system is constructed. At that time, an access/gate shaft would be excavated along the transfer tunnel alignment, outside of the Rio Indio reservoir. A section of the transfer tunnel would then be excavated between the access/gate shaft and the outlet tunnel extension, leaving the temporary bulkhead in place (Figure 1). After completion of the entire transfer tunnel system, the temporary bulkhead, which isolates the transfer tunnel from the outlet, would be removed.

**Advantages:**

- construction of the entire transfer tunnel system (including tunnels, shafts and outlet structures) by conventional methods
- no underwater construction
- no cofferdams or diversion works
- construction would not affect operation of Rio Indio reservoir

- less geotechnical risk compared to other options
- relatively low present cost

**Disadvantages:**
- outlet works would require construction before the rest of the transfer tunnel system, thus limiting future changes or modifications
- costs associated with a transfer tunnel system which may not be developed in the future
- relatively high future cost

The estimated cost for this option is on the order of $1 million (present value). In comparison with other options which would be constructed approximately twenty years in the future, the equivalent future cost would be $10 million, assuming an interest on capital of 12%.

**Option #2 – Outlet Construction - Dry Excavation (Cofferdam)**
This option would involve construction of the entire transfer tunnel system after the Rio Indio reservoir is filled. An access/gate shaft would be excavated along the transfer tunnel alignment, outside of the Rio Indio reservoir, and the entire transfer tunnel would be excavated between Cocle del Norte and the access/gate shaft.

A section of transfer tunnel would then be extended toward the Rio Indio reservoir, leaving a short rock plug between the reservoir and tunnel. The final connection to Rio Indio reservoir would be made by constructing a cofferdam around the tunnel outlet and excavating a short tunnel or shaft from within the cofferdam to connect with the transfer tunnel extension (Figure 2). The entire outlet works and tunnel connection would be performed in the dry. In order to minimize the size of the cofferdam, the Rio Indio reservoir would need to be drawn down to the minimum elevation for the duration of the outlet construction.

**Advantages:**
- entire transfer tunnel system can be constructed after completion of Rio Indio reservoir as a future project phase
- less geotechnical risk compared to other options

**Disadvantages:**
- maximum draw down of Rio Indio reservoir required
- cofferdams or diversion works required
- underwater excavation required

The estimated cost for this option is on the order of $2 million. Other costs associated with drawing the reservoir down to minimum elevation for the duration of the outlet construction have not been factored into the cost and could represent a significant additional cost.

**Option #3 – Lake Tap**
This option would involve construction of the entire transfer tunnel system after the Rio Indio reservoir is filled. Similar to Option #2, an access/gate shaft would be excavated along the transfer tunnel alignment, outside of the Rio Indio reservoir, and the entire transfer tunnel would be excavated between Cocle del Norte and the access/gate shaft.

A section of transfer tunnel would then be extended toward the Rio Indio reservoir, leaving a short rock plug (e.g., one to two tunnel diameters length) in place. The final connection to Rio Indio reservoir would be made by removing the rock plug by "lake tap" methods (Figure 3).

**Advantages:**
- entire transfer tunnel system can be constructed after completion of Rio Indio reservoir as a future project phase
- limited underwater excavation
- no cofferdams or diversion works
- relatively low cost

**Disadvantages:**
- limited draw down of Rio Indio reservoir may be required for "lake tap"
- greatest geotechnical risk compared with other options

The cost of this option is estimated to be on the order of $1 million to $2 million.

**Option #4 – Outfall Shafts**
Similar to Options #2 and #3, this option would involve construction of the entire transfer tunnel system after the Rio Indio reservoir is filled. An access/gate shaft would be excavated along the transfer tunnel alignment, outside of the Rio Indio reservoir, and the entire transfer tunnel would be excavated between Cocle del Norte and the access/gate shaft at Rio Indio. Simultaneously, several large-diameter outfall shafts (max. 4-m dia. each), would be constructed in Rio Indio reservoir at the lake bed elevation of approximately El. 30-m. The outfall shafts would extend approximately 25-m below the lakebed. A temporary plug would be installed in the bottom of each shaft to be removed after connection with the transfer tunnel.

A section of transfer tunnel would then be extended from the access/gate shaft to intersect the bottom of the outfall shafts. The final connection to Rio Indio reservoir would be made by flooding the transfer tunnel system and removing the plugs from the outfall shafts under balanced pressures.

**Advantages:**
- entire transfer tunnel system can be constructed after completion of Rio Indio reservoir as a future project phase
- no cofferdams or diversion works

**Disadvantages:**

- limited draw down of Rio Indio reservoir may be required for construction of outfall shafts
- overwater drilling and underwater construction required for outfall shafts
- specialty construction methods and equipment
- moderate geotechnical risk compared to other options
- significantly higher cost compared to other options

The cost for construction of each outfall shaft is estimated to be approximately $5 million. For the 10-m diameter transfer tunnel, a total of six 4-m diameter outfall shafts would be required. The total cost for this option would therefore be on the order of $30 million.

**Summary and Recommendations**

The most appropriate alternative for construction of the tunnel outlet will likely depend on the planning and sequencing of other phases of the project. Considering only the actual costs and geotechnical risks, Option #1 represents the best approach to construction of the tunnel outlet. However, the equivalent future cost of this option is significantly higher than other options.

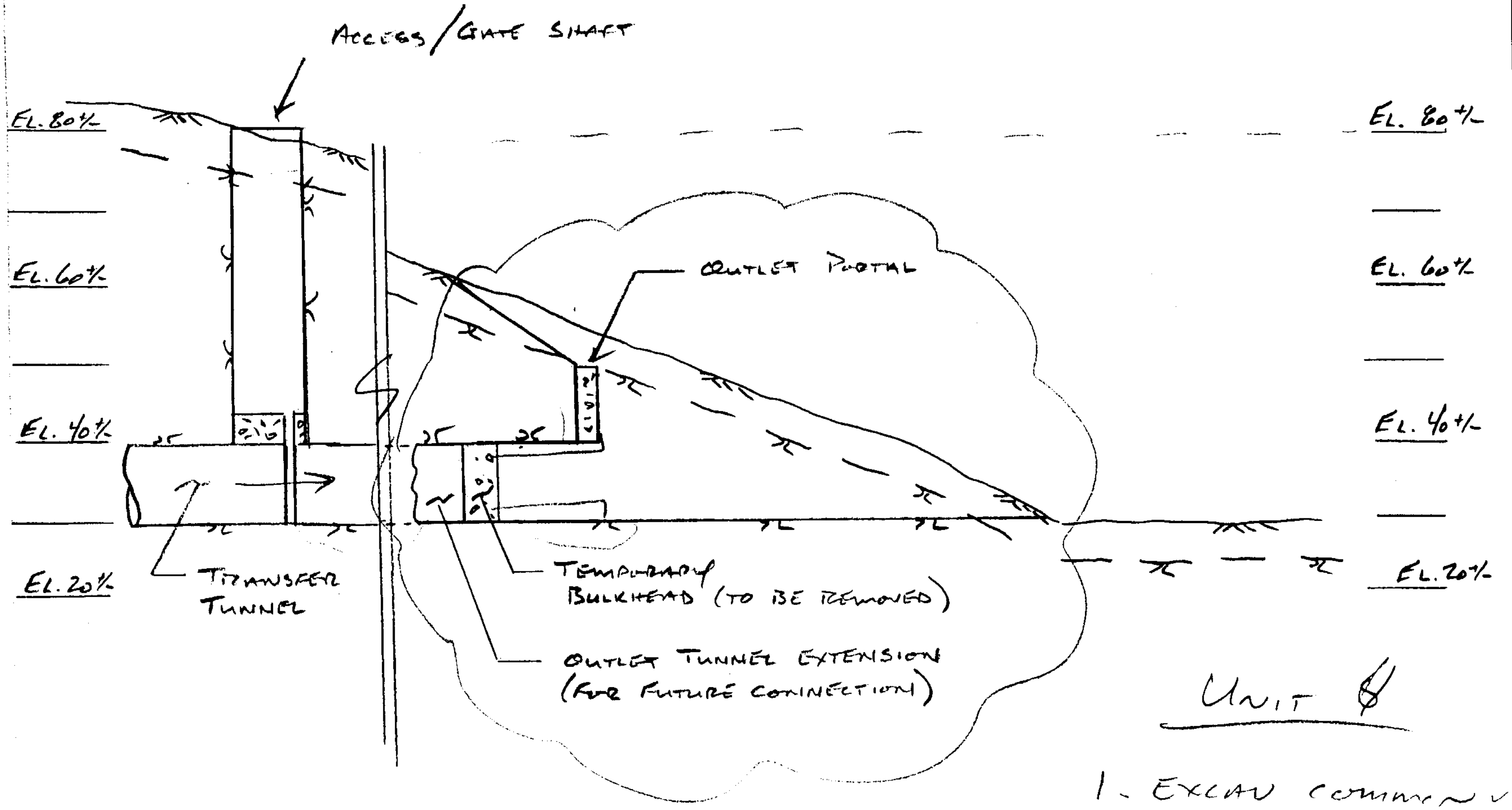
Of the options involving construction after Rio Indio reservoir is filled, Option #3 (lake tap) appears to be the best alternative. Although there is generally a higher geotechnical risk associated with tunnel excavation under low rock cover and in close proximity to the reservoir, the risks can be minimized by ground improvement (i.e., consolidation grouting, rock support, etc.) and careful construction practice. The most significant advantage of this option is that it does not incur the costs associated with drawing down the reservoir (unknown value), construction of temporary cofferdams, or the difficult and costly construction of several underwater drilled shafts.

For all of the tunnel outlet options, a significant portion of the site investigation and site preparation work could be performed prior to filling the Rio Indio reservoir. Such work may include geotechnical investigations, detailed surveying, clearing and grading, and even excavation to sound rock. For the lake tap option, consolidation grouting and installation of initial rock supports could also be performed. In general, the more investigation and site preparation work that can be completed in advance of reservoir filling could reduce the amount of more costly overwater, underwater and underground work in the future.

COCLE DEL NORTE - RIO INDIO
INTER-BASIN TRANSFER TUNNEL OUTLET OPTIONS
PRELIMINARY COST ESTIMATES

| Description | Unit | Unit Cost[1] | Quantity | Amount |
|---|---|---|---|---|
| **OPTION 1 - PRE-CONSTRUCTION OF OUTLET** | | | | |
| ***1.1 Mobilization/Demobilization*** | L.S. | $200,000.00 | 1 | $200,000 |
| ***1.2 Portal Structure*** | | | | |
| 1.2.1 Overburden Excavation (common) | $m^3$ | *$3.20* | 11,375 | $36,400 |
| 1.2.2 Rock Excavation (conventional drill and blast) | $m^3$ | *$8.75* | 7,500 | $65,625 |
| 1.2.3 Shotcrete | $m^2$ | *$45.90* | 285 | $13,082 |
| 1.2.4 Rockbolts | l.m. | *$60.50* | 95 | $5,748 |
| 1.2.5 Concrete | $m^3$ | *$115.00* | 150 | $17,250 |
| 1.2.6 Formwork | $m^2$ | *$46.20* | 285 | $13,167 |
| 1.2.7 Reinforcement | kg | *$1.36* | 7,500 | $10,200 |
| ***1.3 Tunnel Extension*** | | | | |
| 1.3.1 Rock Excavation (tunnel drill and blast) | $m^3$ | *$105.00* | 2,700 | $283,500 |
| 1.3.2 Shotcrete | $m^2$ | *$45.90* | 1,000 | $45,900 |
| 1.3.3 Rockbolts | l.m. | *$60.50* | 320 | $19,360 |
| 1.3.4 Steel Ribs | kg | *$2.90* | 40,000 | $116,000 |
| 1.3.5 Concrete Lining (reinforced) | $m^3$ | $250.00 | 550 | $137,500 |
| 1.3.6 Concrete Plug (unreinforced) | $m^3$ | *$115.00* | 750 | $86,250 |
| 1.3.7 Formwork | $m^2$ | *$46.20* | 150 | $6,930 |
| **Subtotal Option 1** | | | | **$1,056,911** |
| | | | | |
| **OPTION 2 - DRY EXCAVATION - COFFERDAM** | | | | |
| ***2.1 Mobilization/Demobilization*** | L.S. | $200,000.00 | 1 | $200,000 |
| ***2.2 Portal Structure*** | | | | |
| 2.2.1 Overburden Excavation (common) | $m^3$ | $6.40 | 6,825 | $43,680 |
| 2.2.2 Rock Excavation (conventional drill and blast) | $m^3$ | $17.50 | 4,500 | $78,750 |
| 2.2.3 Shotcrete | $m^2$ | *$45.90* | 285 | $13,082 |
| 2.2.4 Rockbolts | l.m. | *$60.50* | 95 | $5,748 |
| 2.2.5 Concrete | $m^3$ | *$115.00* | 150 | $17,250 |
| 2.2.6 Formwork | $m^2$ | *$46.20* | 285 | $13,167 |
| 2.2.7 Reinforcement | kg | *$1.36* | 7,500 | $10,200 |
| ***2.3 Cofferdam*** | | | | |
| 2.3.1 Overburden Excavation (underwater/dredge) | $m^3$ | $30.00 | 4,550 | $136,500 |
| 2.3.2 Rock Excavation (underwater - drill/blast/dredge) | $m^3$ | $300.00 | 3,000 | $900,000 |
| 2.3.3 Pre-grouting | L.S. | $150,000.00 | 1 | $150,000 |
| ***2.3 Tunnel Extension*** | | | | |
| 2.3.1 Rock Excavation (tunnel drill and blast) | $m^3$ | *$105.00* | 2,700 | $283,500 |
| 2.3.2 Shotcrete | $m^2$ | *$45.90* | 1,000 | $45,900 |
| 2.3.3 Rockbolts | l.m. | *$60.50* | 320 | $19,360 |
| 2.3.4 Steel Ribs | kg | *$2.90* | 40,000 | $116,000 |
| 2.3.5 Concrete Lining (reinforced) | $m^3$ | $250.00 | 550 | $137,500 |
| **Subtotal Option 2** | | | | **$2,170,636** |
| | | | | |
| **OPTION 3 - LAKE TAP** | | | | |
| ***3.1 Mobilization/Demobilization*** | L.S. | $200,000.00 | 1 | $200,000 |
| ***3.2 Lake Tap Outlet*** | | | | |
| 3.2.1 Overburden Excavation (underwater/dredge) | $m^3$ | $30.00 | 3,125 | $93,750 |
| 3.2.2 Rock Plug Excavation (controlled drill and blast) | $m^3$ | $210.00 | 1,000 | $210,000 |
| 3.2.3 Pre-support | L.S. | $150,000.00 | 1 | $150,000 |
| 3.2.4 Pre-grouting | L.S. | $150,000.00 | 1 | $150,000 |
| ***3.3 Tunnel Extension*** | | | | |
| 3.3.1 Rock Excavation (tunnel drill and blast) | $m^3$ | *$105.00* | 4,450 | $467,250 |
| 3.3.2 Shotcrete | $m^2$ | *$45.90* | 1,000 | $45,900 |
| 3.3.3 Rockbolts | l.m. | *$60.50* | 320 | $19,360 |
| 3.3.4 Steel Ribs | kg | *$2.90* | 40,000 | $116,000 |
| 3.3.5 Concrete Lining (reinforced) | $m^3$ | $250.00 | 550 | $137,500 |
| **Subtotal Option 3** | | | | **$1,389,760** |

[1] Unit costs indicated in italics are taken from Rio Indio-Gatun Transfer Tunnel cost estimate




Unit 8

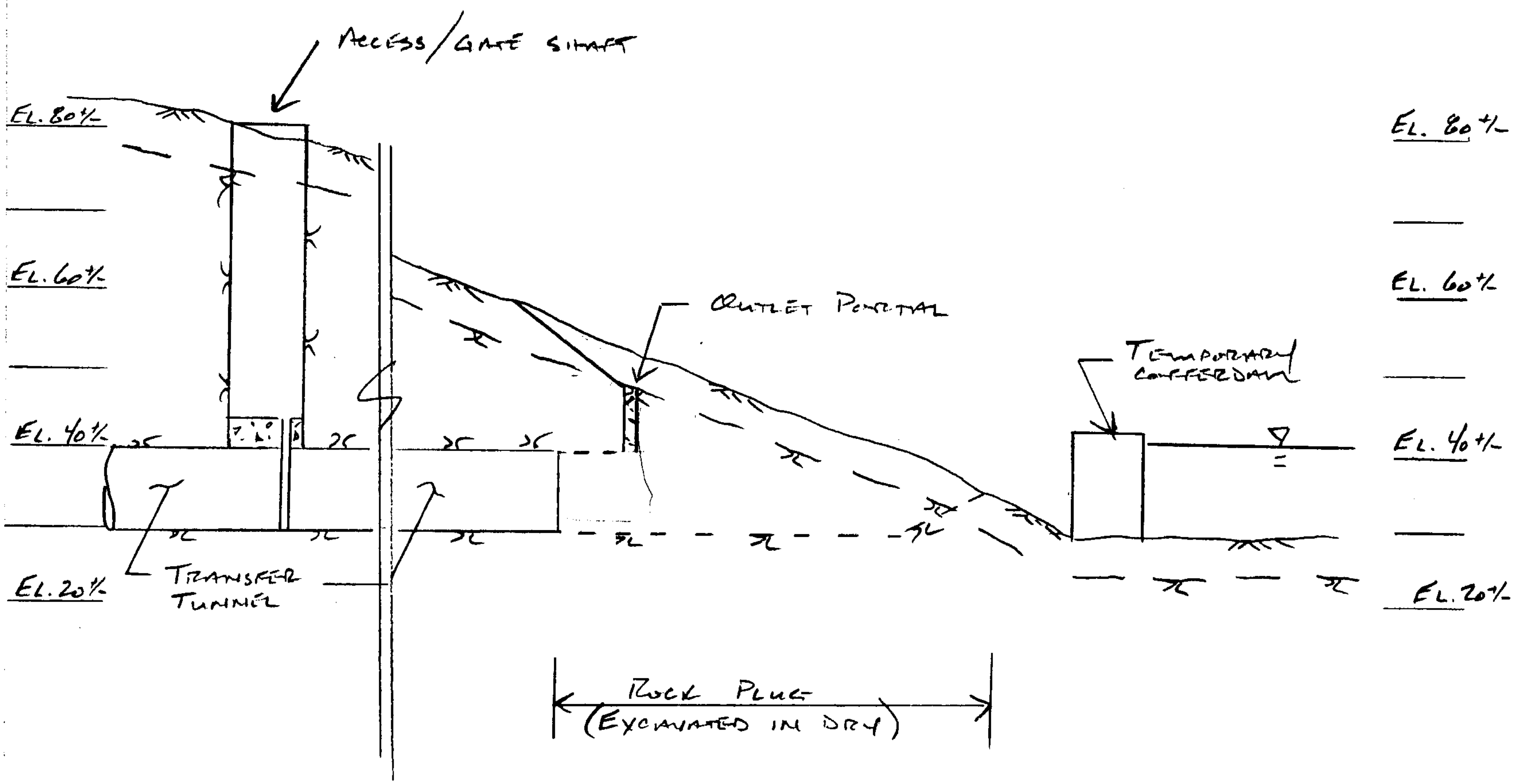
1. Excav common
2. Portal
3. Tunnel Ex
4. Tunnel Conc
5. Plug Conc.

Figure 1.

MWH

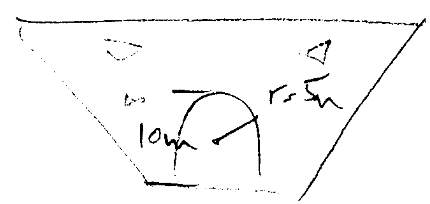
By ______ Date ______ Client ______ Sheet ______ of ______

Chkd. By ______ Description Option #2 - Outlet Construction in Cofferdam ______ Job No. ______




1. Exav
2. Portal Conc
3. Tunnel Ex

FIGURE 2.



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By ______ Date ______ Client ______ Sheet ______ of ______

Chkd. By ______ Description Option #3 - Lake Tap ______ Job No. ______

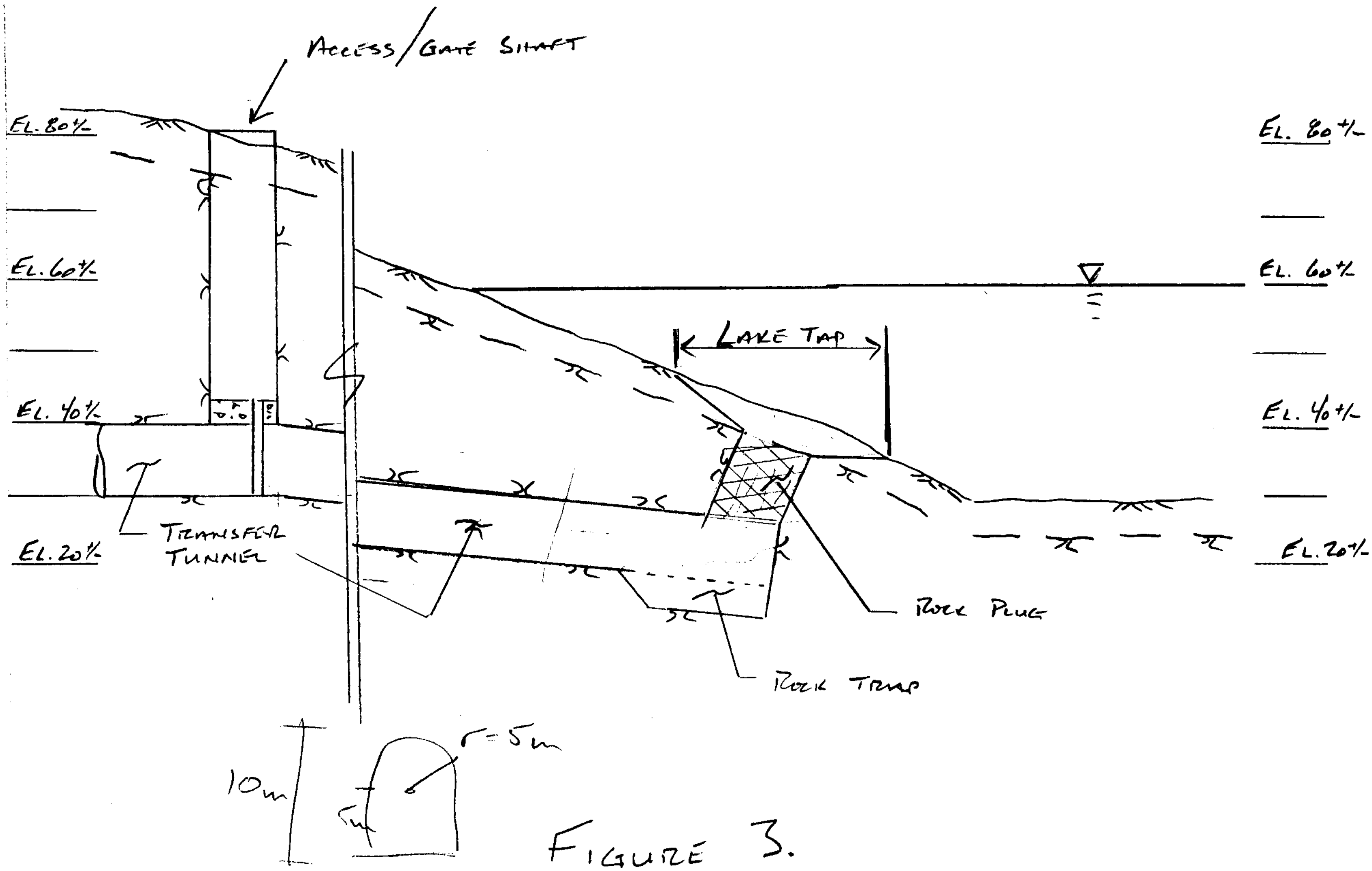



FIGURE 3.

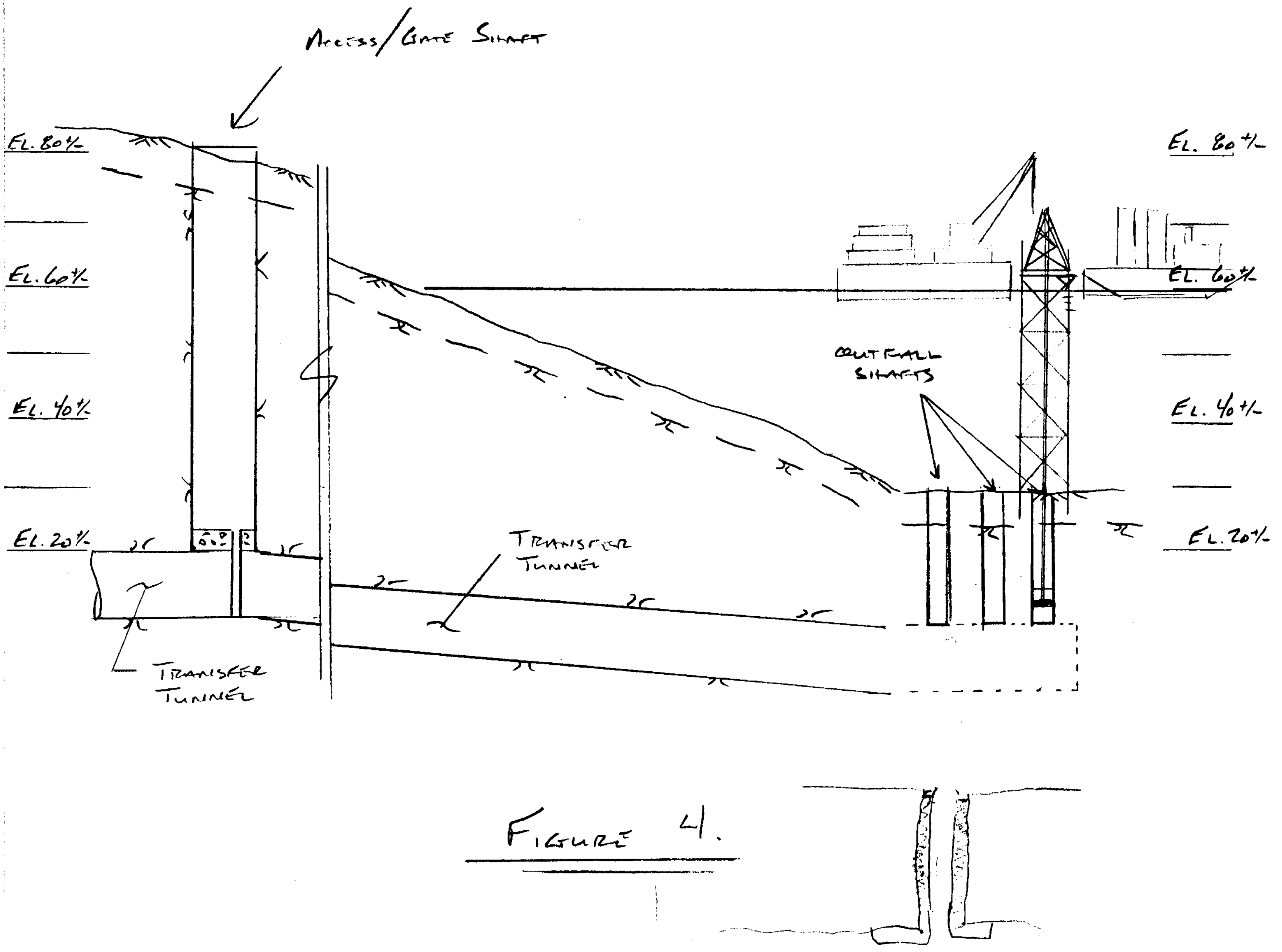



FIGURE 4.

MWH

By ____ Date ____ Client ____ Sheet ____ of ____

Chkd. By ____ Description OPTION #4 - OUTFALL SHAFTS Job No. ____

Appendix E
Power and Energy

Part 1
Power Market Study

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX E
PART 1

POWER MARKET STUDY



Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX E, PART 1 – POWER MARKET STUDY

### TABLE OF CONTENTS

# LIST OF TABLES

# 1 INTRODUCTION

The Canal Capacity Projects Office of the Panama Canal Authority plans to construct a project in the Río Coclé del Norte Watershed to augment sources of water supply for meeting the growing municipal and industrial water uses of the Canal Zone, and increased lock operation. Two projects have been identified: the Río Coclé del Norte Reservoir acting in full regulation with the Río Indio Reservoir, and the Río Coclé del Norte Reservoir acting in full regulation with the Río Caño Sucio and Río Indio Reservoirs

Either project will result in the formation of a reservoir to regulate water in the middle part of the Río Coclé del Norte for eventual delivery to Lake Gatun. A powerplant, with a capacity of up to 75 MW, will be a part of the appurtenant works of the project,

A power market survey of Panama was conducted to determine the future power needs of the Panama national electric system. The results of this survey were used in evaluation of the economic attractiveness of the hydroelectric power plants.

A draft report, prepared in November, 2000, contained information received from the Electricity Department and taken from the following two reports:

(1) *Revision del Plan de Expansion Indicativo del Sistema de* Generation, ETESA, August 1998
(2) *Plan de Expansion del Sistema de Generacion 1999-2015,* ETESA, 1999

Due to a delay in the development studies, the Power Market Report was not finalized until September 2002. In the interim, four additional reports were made available:

(3) *Informe Indicativo de Demanda 2001-2010*, ETESA, November 2000
(4) *Informe de Indisponibilidad Unidades de Generacion, Noviembre 1999-Octubre 2000*, ETESA
(5) *Planiamiento Operativo del Sistema Integrado Nacional,* ETESA, July 2002
(6) *Plan de Expansion de Transmission*, ETESA, 2002

In addition, current information is available from the ETESA web site.

Some of the information from the four sources is conflicting, especially with respect to the generation companies and the installed capacities of the individual units. However to present a better picture of the situation, information was taken from all sources. It is recognized that some of the information presented herein is outdated or even incorrect. This information is considered to be adequately representative to present the power market picture in Panama.

We also are aware of a newer expansion plan report, however, we have not been able to obtain a copy either through the APC or our own contacts.

# 2 ECONOMIC SETTING

The economy of the Panama has experienced continued growth over recent years. Annual Gross Domestic Product (GDP) has grown at an average annual rate of 6.7 percent during the period of 1989-1994, and the annual rate of growth of GDP was reduced to 3.3 percent for the 5-year period of 1994 through 1999. The GDP reached U. S. $ 9,130.3 million in 1999 at the 1995 price level.

Total population of Panama has slightly increased from 2.35 million in 1989 to 2.58 million in 1994 and 2.81 million in 1999. Average annual rates of growth in total population for the periods of 1989-1994 and 1994-1999 were at 1.9 percent and 1.7 percent, respectively.

The GDP values per capita, at the 1995 price level, were U.S. $ 2,383 for year 1989, $ 3,009 for year 1994, and $ 3,249 for year 1999. Average annual growth rate of the GDP per capita was at 4.8 percent for the period of 1989 through 1994, and the rate was reduced to 1.5 percent during the subsequent period of 1994 through 1999.

The annual GDP values, per capita GDP values, and annual growth rates of these values of Panama for the period of 1980 through 1999 are shown in Table 1.

The main changes in the structure of the Panama economy over the recent years occurred in the shares of Agriculture, Industry, Commerce, and Governmental Service sectors in the total GDP. The Agriculture Sector includes farming and fishery, and the Industry Sector consists of mining, manufacturing, electricity generation and supply, water supply, gas and construction. The Commerce Sector includes imports and exports, hotels and restaurants, transportation and communications, financial and banking services, and housing and rentals.

The shares of the Agriculture sector in the GDP of Panama shrank from 10.2% in 1989 to 8.1% in 1994 and 7.6% in 1999, and shares of the Governmental Services decreased from 15.2% in 1989 to 10.4% in 1994 and 10.1% in 1999. The shares of Industry and Commerce sectors increased. The shares of the Industry sector increased from 15.5% in 1989 to 18.5% in 1994, and remained unchanged at 18.5% in 1999, and shares of the Commerce sector increased from 50.2% in 1989 to 53.4% in 1994 and 53.9% in 1999.

**Table 1 GDP and Per Capita GDP Values and Annual Growth Rates of Panama for Period of 1980-1999**

**(Values are in U.S. Dollars at the 1995 Price Level)**

| Year | GDP Values | | Per Capita GDP Values | |
|---|---|---|---|---|
| | GDP in $ million | Growth Rate in Percent | GDP/Capita in Dollars | Growth Rate in Percent |
| 1980 | 5,282.9 | - | 2,709 | - |
| 1981 | 5,769.2 | 9.2 | 2,897 | 6.9 |
| 1982 | 6,077.8 | 5.3 | 2,989 | 3.2 |
| 1983 | 5,804.8 | -4.5 | 2,794 | -6.5 |
| 1984 | 5,962.1 | 2.7 | 2,810 | 0.6 |
| 1985 | 6,256.8 | 4.9 | 2,887 | 2.7 |
| 1986 | 6,480.0 | 3.6 | 2,930 | 1.5 |
| 1987 | 6,362.8 | -1.8 | 2,819 | -3.8 |
| 1988 | 5,511.4 | -13.4 | 2,393 | -15.1 |
| 1989 | 5,597.5 | 1.6 | 2,383 | -0.4 |
| 1990 | 6,050.9 | 8.1 | 2,524 | 5.9 |
| 1991 | 6,620.8 | 9.4 | 2,711 | 7.4 |
| 1992 | 7,163.8 | 8.2 | 2,879 | 6.2 |
| 1993 | 7,554.7 | 5.5 | 2,980 | 3.5 |
| 1994 | 7,770.0 | 2.9 | 3,009 | 1.0 |
| 1995 | 7,906.1 | 1.8 | 3,005 | -0.1 |
| 1996 | 8,128.3 | 2.8 | 3,040 | 1.1 |
| 1997 | 8,492.2 | 4.5 | 3,124 | 3.0 |
| 1998 | 8,843.5 | 4.1 | 3,200 | 2.2 |
| 1999 | 9,130.3 | 3.2 | 3,249 | 1.5 |

# 3 THE EXISTING ELECTRIC SYSTEM IN PANAMA

Until 1998, electric energy was produced by the *Instituto de Recursos Hidraulicos y Electrificacion* (IRHE), and some small private industries generate electricity for their own uses. The IRHE was also responsible for the operation and maintenance of the transmission and distribution systems, and sales to electricity consumers in Panama. NIS). With the restructuring of electricity sector in 1998, the IRHE was abolished and the generation and distribution facilities were privatized. Transmission was assigned to a new government agency, the *Empresa de Transmision Electrica, S.A.* (ETESA), which was also responsible for load forecasts, planning of generation and transmission facilities to meet forecasted electrical needs of Panama, and operation of the National Dispatch Center (CND) of the Panama National Integrated System (PNIS).

## 3.1 System in 1998

With the abolition of IHRE, 10 generation companies and 3 distribution firms were formed to produce and sale electricity to consumers.

The generation companies of the PNIS as of early year 2000 included:

- EGE-Bayano: *Empresa de Generacion Electrica Bayano, S.A.*
- EGE-Fortuna: *Empresa de Generacion Electrica Fortuna, S.A.*
- EGE-Bahia Las Minas: *Empresa de Generacion Electrica Bahia Las Minas, S.A.*
- EGE-Chiriqui: *Empresa de Generacion Electrica Chiriqui, S.A.*
- COPESA: *Corporacion Panamena de Energia, S.A.*
- PanAm: IGC/ERI Pan Am Thermal Generating Ltd.
- Pana Energy
- Hidro Panama
- Petroelectrica de Panama, S.A.
- Petroterminales de Panama, S.A.

The three distribution companies were:

- EDE-Metro Oeste (EDEMET): *Empresa de Distribucion Electrica Metro Oeste, S.A.*

- EDE-Chiriqui (EDECHI): *Empresa de Distribucion Electrica Chiriqui, S.A.*
- EDE-Elektra Noreste (ELEKTRA): *Empresa de Distribucion Electrica Elektra Noreste, S.A.*

The newly formed distribution companies forecast electricity needs of their individual distribution systems, and submit these forecasts to ETESA.

It is the responsibility of ETESA to develop generation and transmission system expansion plans for the PNIS on the basis of the electricity forecasts by the distribution companies, and to operate and maintain the transmission system and dispatch center.

A map of Panama with locations of existing major generating and transmission facilities are shown in Exhibit 1.

### 3.1.1 The Generation System

As reported in ETESA's *Plan de Expansion del Sistema de Generacion, 1999* (1), the installed capacity of the generation companies was 998.8 MW. This capacity, based on anticipated additions and plant retirements, is now (November 2000) estimated to be 1,184.3 MW as shown in Table 2.

**Table 2 Generation Company Power Facilities**

| Company and Power Plant | Number of Units and Unit Capacity, MW | Type of Power Plant | Type of Fuel | Installed Capacity, MW |
|---|---|---|---|---|
| **EGE- Las Minas** | | | | |
| BLM #1- #4 | 1x20, 3x40 | Steam | Bunker C | 140.0 |
| Catepillar | 7 | I.C. | Diesel | 30.0 |
| Monte Esperanze | 1x 20 | G.T. | Diesel | 20.0 |
| San Francisco | 3 | Steam | Bunker C | 10.0 |
| TG-CCBLM | 4 | I.C | Bunker C | 34.8 |
| Ciclo-Comb. BLM[1] | | GT/Steam | M. Diesel<br>Bunker C | 160.0 |
| *Subtotal* | *1* | | | *394.8* |
| **EGE-Bayano** | | | | |
| Sub Estacion Panama | 2x 20 | G.T. | Diesel | 40.0 |
| Bayano | 2x75 | H | - | 150.0 |
| *Subtotal* | | | | *190.0* |

| Company and Power Plant | Number of Units and Unit Capacity, MW | Type of Power Plant | Type of Fuel | Installed Capacity, MW |
|---|---|---|---|---|
| **EGE-Chiriqui** | | | | |
| La Estrella | 2x21 | H | - | 42.0 |
| Los Valles | 2x24 | H | - | 48.0 |
| *Subtotal* | | | | *90.0* |
| **EGE-Fortuna** | | | | |
| Fortuna | 3x100 | H | - | 300.0 |
| **Petroelectrica** | 12 | I.C. | Diesel | 55.0 |
| **Petroterminales** | 7 | I.C. | Diesel | 15.0 |
| **COPESA** | 1x42 | I.C. | Diesel | 42.0 |
| **Pan Am** | 6x16.0 | I.C. | Bunker C | 96.0 |
| **Hidro Panama** | | | | |
| Anton 1 | 1 | H | - | 1.5 |
| | | | | |
| **TOTAL** | | | | **1,184.3** |

(1) Replaces John Brown 1 and 2 and includes 35 MW of new gas turbine generation and 60 MW of steam generation

I.C. = Internal Combustion Units, G.T. = Gas Turbines Units, H = Hydroelectric Units.

About 45 percent of the total installed capacity of the generation companies is from hydropower.

Two of the three distribution companies also own and operate a number of hydro and thermal power plants. Of the 49 MW in this category, about 35 MW are connected to the PNIS system and 14 MW are not. A tabulation of these plants are presented in Table 3.

**Table 3 Distribution Company Power Facilities**

| Company and Power Plant | Number of Units and Unit Capacity, MW | Type of Power Plant | Type of Fuel | Installed Capacity MW |
|---|---|---|---|---|
| **Connected to the PNIS** | | | | |
| **EDE-Metro Oeste** | | | | |
| La Yeguada | 2x3.0, 1x1.0 | H | - | 7.0 |
| Chitre | 1x2.0, 5x2.5 | I.C. | Diesel | 14.5 |
| Capira | 2x0.55, 1x1.0, 3x2.5 | I.C. | Diesel | 9.6 |
| Macho Monte | 1x0.77 | H | - | 0.77 |
| Dolega | 2x1.12, 2x0.4 | H | - | 3.04 |
| **Total connected to the PNIS** | | | | **34.9** |

| Company and Power Plant | Number of Units and Unit Capacity, MW | Type of Power Plant | Type of Fuel | Installed Capacity MW |
|---|---|---|---|---|
| **Not Connected to the PNIS** | | | | |
| **EDE-Elektra Noreste** | | | | |
| Taboga | 2x0.365, 1x0.545 | I.C. | Diesel | 1.275 |
| Chepillo | 1x0.060, 1x0.075 | I.C. | Diesel | 0.135 |
| Otoque | 1x0.150, 1x0.125 | I.C. | Diesel | 0.275 |
| San Miguel | 1x0.090,1x0.160 | I.C. | Diesel | 0.250 |
| Condadora | 1x1.200,1x0.650, 1x0.850,1x.545, 1x0.912 | I.C. | Diesel | 4.157 |
| Garachine | 1x0.150,1x0.155,1x0.175 | I.C. | Diesel | 0.480 |
| Jaque | 1x0.160, 1x0.125 | I.C. | Diesel | 0.285 |
| Yaviza | 2x0.160, 1x0.250 | I.C. | Diesel | 0.570 |
| La Palma | 1x0.425,1x0.600,1x0.525 | I.C. | Diesel | 1.550 |
| Tucuti | 2x 0.035 | I.C. | Diesel | 0.070 |
| Boca de Cupe | 2x0.035 | I.C. | Diesel | 0.070 |
| Sante Fe | 1x0.160, 1x0.225, 1x0.250,1x0.600 | I.C. | Diesel | 1.235 |
| Nargana | 1x0.055, 1x0.100 | I.C. | Diesel | 0.155 |
| Río Azucar | 2x0.035 | I.C. | Diesel | 0.070 |
| *Subtotal* | | | | *10.8* |
| | | | | |
| **EDE-Metro Oeste** | | | | |
| Bocas del Toro | 2x0.545, x1.000, 1x0.600 | I.C. | Diesel | 2.690 |
| Chiriqui Grande | 1x0.272,1x0.250,1x0.400 | I.C. | Diesel | 0.922 |
| *Subtotal* | | | | *3.4* |
| **Total Not Connected to the PNIS** | | | | **14.2** |

I.C. = Internal Combustion Units

The total energy production amounted to 4,191.6 million kWh in 1998 including energy produced at the plants owned by the distribution companies. Hydroelectric power plants produced 2,140.3 million kWh of energy, about 51.1 % of the system total energy production.

### 3.1.2 The Panama Canal Authority Power Plants

The Panama Canal Authority (ACP) owns and operates three power plants, the Gatun and Madden Hydroelectric Plants, and Miraflores Thermal Plant. The three plants have a total combined installed capacity of 175 MW. Total number of generating units, unit capacity, and fuel type for each of the three plants are shown in Table 4.

**Table 4 Panama Canal Authority Power Plants**

| Power Plant | Number of Units and Unit Capacity, MW | Type of Power Plant | Type of Fuel | Installed Capacity, MW |
|---|---|---|---|---|
| Gatun | 3x3.0, 3x5.0 | H | - | 24.0 |
| Madden | 3x12.0 | H | - | 36.0 |
| Miraflores | 2x10.0, 1x18.0<br>1x22.0, 1x37.0, 1x18.0 | G.T.<br>Steam | Diesel<br>Bunker C | 38.0<br>77.0 |
| **Total** | | | | **175.0** |

The Gatun hydroelectric plant is located adjacent to the Gatun Spillway on the Atlantic side of the Panama Canal. Water surplus to canal operational requirements is used for power generation. The Madden hydroelectric plant is located at the downstream toe of the Madden Dam. The Madden Dam was constructed to form a reservoir for providing an adequate water supply to the Gatun Lake to maintain the minimum draft essential to passing ships through the Canal. The water released from the Madden reservoir to the Gatun Lake is used to generate power.

Historically, the power generated at the Gatun and Madden power plants was used for canal operations, supplied to U.S. government agencies operating in the Canal area, and sold in the spot market. Currently, generation is used to meet the electricity needs of the canal operation and any surplus can be sold into the Panama national electrical system. The Miraflores plant serves as backup for the hydroelectric plants in times of high water, and supplies electricity in times of low water, if needed.

### 3.1.3 Transmission Company and System

The *Empresa de Transmision Electrica* (ETESA) has the responsibility for the operation and maintenance of the PNIS transmission system and the National Dispatch Center, and the development of generation and transmission expansion plans for the PNIS.

The existing transmission system consists of 578 km of 230 kV line, 134 km of 115 kV line, and ten 230-kV substations with a total capacity of 885 MVA (6).

For the six-month period of July-December 1998, ETESA's revenues, received from the generation and distribution companies for use of the transmission system, amounted to $17.0 million.

Transmission energy losses of the PNIS for the period of July-December 1998 were estimated at 72,1 GWh, or about 3.4 percent of total energy supply. This corresponds to a loss of $ 4.12 million with a unit cost of energy at $ 0.057/kWh. The transmission energy losses for year 1999 were reported at 150.8 GWh, or about 3.4 percent of the total energy production of 4,455 GWh, and for year 2002 at 186.8 GWh or about 3.7% of the total energy production of 4,999GWh.

### 3.2 System in Year 2002

After the restructuring, there were ten generation companies as described in Section 3.1. Currently, there are six companies generating a total of 1,060 MW that are providing the bulk of the electricity to Panama.

Two of the original ten companies, EGE Bayano and EGE Chiriqui were bought by the AES Corporation and merged into AES Panama. As reported in a 1999 plan of expansion (12), two additional generation companies, Petroterminales and Hidro Panama operated 15 MW and 1.5 MW respectively. It is not known whether these units were retired or just not considered as major producers for the 2002 operation plan (5).

In the 1999 expansion plan, it was also reported that the distribution companies operated a series of thermal plants. EDE Metro Oeste operated five plants totaling 35 MW that were connected to the Panama National Integrated System (PNIS) and 3.4 MW that were not connected. EDE Elektra Noreste operated 14 plants with a total capacity of 10.8 MW that were not connected to the grid.

The 2002 Operation Plan indicates that an additional installed capacity of 344 MW will be on line by the end of 2003, consisting of 224 MW of hydro and 120 MW of thermal (although the tabulated expansion plan only shows 206 MW of hydro). Therefore, the major generation companies will have an installed capacity of about 1,404 MW by the end of 2003.

The total installed capacity and distribution between thermal and hydro is presented in Table 5.

**Table 5 Generation Facilities**

| Company | Hydro Capacity (MW) | Thermal Capacity (MW) | Total Capacity (MW) | Connected to PNIS |
|---|---|---|---|---|
| **Major Generation Companies** | | | | |
| AES Panama | 240.0 | 40.0 | 280.0 | Yes |
| EGE Fortuna | 300.0 | 0.0 | 300.0 | Yes |
| EGE Bahia Las Minas | 0.0 | 280.0 | 280.0 | Yes |
| Petroelectrica de Panama | 0.0 | 60.0 | 60.0 | Yes |
| COPESA | 0.0 | 44.0 | 44.0 | Yes |
| PanAm | 0.0 | 96.0 | 96.0 | Yes |
| *Subtotal* | *540.0* | *520.0* | *1,060* | |
| **Planned Expansion** | | | | |
| 2002 | 86.0 | 0.0 | 86.0 | Yes |
| 2003 | 120.0 | 120.0 | 240.0 | Yes |
| **Other Generation (may or may not be still available)** | | | | |
| ACP | 60.0 | 93.0 | 153.0 | Yes |
| Petroterminales | 0.0 | 15.0 | 15.0 | Yes |
| Hidro Panama | 1.5 | 0.0 | 1.5 | Yes |
| EDE Metro Oeste | 0.0 | 34.9 | 34.9 | Yes |
| EDE Metro Oeste | 0.0 | 3.4 | 3.4 | No |
| EDE Elektra Noreste | 0.0 | 10.8 | 10.8 | No |

The major generation companies, including their planned expansions, have a total installed capacity of 1,386 MW.

In 1998, 2000, and 2002, the total net energy production, which is defined as gross generation less station use, amounted to about 4,192 GWh, 4,511 GWh, and 4,686 GWh respectively.

### 3.2.1 Energy Consumption

Three distribution companies were formed in 1998 to purchase energy from generation companies and to sell energy to consumers. The total energy consumption, number of consumers, and energy consumption by sector in year 1998 for each of three distribution companies are shown in Table 6.

**Table 6 Energy Consumption and Customers in 1998**

| Company | Metro Oeste | Chiriqui | Elecktra Noreste | Total |
|---|---|---|---|---|
| **Energy Consumption in MWh** | | | | |
| Residential | 491.84 | 90.47 | 422.34 | 1,004.65 |
| Commercial | 809.39 | 91.03 | 441.64 | 1,342.06 |
| Industrial | 170.02 | 45.92 | 271.70 | 487.64 |
| Governmental | 257.87 | 37.86 | 181.52 | 477.25 |
| Public Lighting | 35.04 | 9.76 | 19.63 | 64.43 |
| Own Uses | 8.92 | 2.29 | 5.59 | 16.80 |
| Total | 1,773.08 | 277.33 | 1,342.42 | 3,392.83 |
| % Total System | 52% | 8% | 40% | 100% |
| **Number of Customers** | | | | |
| Total | 216,283 | 68,301 | 167,445 | 452,029 |
| % Total System | 47.85% | 15.11% | 37% | 100% |

In 1999, the energy consumption and number of customers for each of the three distribution companies increased as shown in Table 7. The total number of customers for the three distribution companies increased by 5.3% during the 1998-1999 period, and the total energy consumption increased at the relatively low rate of 3.8 percent during the same period.

**Table 7 Comparison of Energy Consumption and Number of Customers of the Three Distribution Companies in 1998 and 1999**

| Company | Metro Oeste | Chiriqui | Elecktra Noreste | Total |
|---|---|---|---|---|
| **Energy Consumption in MWh** | | | | |
| Year 1998 | 1,773.08 | 277.33 | 1,342.42 | 3,392.83 |
| % of Total System | 52 | 8 | 40 | 100.0 |
| Year 1999 | 1,784.99 | 287.64 | 1,448.74 | 3,521.37 |
| % of Total System | 51 | 8 | 41 | 100 |
| Annual Growth Rate | 0.7% | 3.7% | 7.9% | 3.8% |
| **Number of Consumers** | | | | |
| Year 1998 | 216,283 | 68,301 | 167,445 | 452,029 |
| % of Total System | 48 | 15 | 37 | 100 |
| Year 1999 | 228,866 | 72,229 | 174,876 | 475,971 |
| % of Total System | 48 | 15 | 37 | 100 |
| Annual Growth Rate | 5.8% | 5.8% | 4.4% | 5.3% |

Total distribution system energy losses of the three distribution companies for the period of July-December 1998 were estimated at 379 million kWh, about 18% of purchased energy. These losses are shown by distribution company in Table 8.

**Table 8 Distribution System Losses for July-December 1998**

| Company | Metro Oeste | Chiriqui | Elektra Noreste | Total |
|---|---|---|---|---|
| Energy Losses, MWh | 113,768 | 9,218 | 255,978 | 378,964 |
| Percent of Purchased Energy, % | 11 | 5 | 27 | 18 |

Firm capacity contracts among the generation and distribution companies for year 1999 are shown in Table 9.

**Table 9 Firm Capacity Contracts in 1999 in MW**

| Company | Metro Oeste | Chiriqui | Elektra Noreste | Total |
|---|---|---|---|---|
| **Hydro Generation** | | | | |
| Fortuna | 140 | 24 | 120 | 284 |
| Bayano | 51 | - | 31 | 82 |
| EGE-Chiriqui | 19 | 22 | 18 | 59 |
| *Total Hydro Generation* | *210* | *46* | *169* | *425* |
| **Thermal Generation** | | | | |
| Bahia Las Minas | 156.5 | - | 98 | 254.5 |
| IGC/ERI | 30 | - | - | 30 |
| COPESA | - | - | 42 | 42 |
| *Total Thermal Generation* | *186.5* | - | *140* | *326.5* |
| | | | | |
| **Total Hydro/Thermal** | **396.5** | **46** | **309** | **751.5** |

### 3.2.2 Electricity Tariff

Each of the three distribution companies has established a tariff structure including capacity and energy charges for various types of energy consumers. The tariff structure also includes clauses dealing with escalation of the capacity and energy charges on the basis of consumer price indices. The EDE-Metro Oeste and EDE-Chiriqui update their tariff structures every six months, and the existing EDE-Elektra Noreste tariff structure will be valid until June 2003.

Each of the three distribution companies has individual contracts for capacity and energy purchases/sales with the generation companies. The duration of these contracts varies from two to five years.

The average unit energy sale price for the three distribution companies was $0.111/kWh in 1998 and $0.103/kWh in 1999. The average unit energy sale price for each consumer sector in 1998 is given in Table 10.

**Table 10 Average Unit Energy Sales Price by Sector in 1998**

**($/kWh)**

| **Sector** | Residential | Commercial | Industrial | Government | System |
|---|---|---|---|---|---|
| **Sale Prices** | 0.119 | 0.116 | 0.097 | 0.111 | 0.111 |

The unit energy sale prices in Panama have decreased slightly over the last decade. From 1990 through 1999, the price has decreased at a rate of 1.4% p.a. However, in 2002, the average sales price was estimated to be about $0.119/kWh.

# 4 LOAD AND ENERGY DEMANDS OF THE PANAMA ELECTRIC SYSTEM

Energy demand, peak load and the annual growth rates for the PNIS over the last 10 years are shown in Table 11. The average annual growth rate of the energy demand was at 5.5% for the period and the average annual growth rate for the peak load was 5.5%. The annual system load factor averaged about 67.4 percent over the period.

**Table 11 Energy Demand, Peak Load, and Load Factor in the PNIS System**

| Year | Energy Demand, GWh | Annual Growth Rate, % | Peak Load, MW | Annual Growth Rate, % | Load Factor, % |
|---|---|---|---|---|---|
| 1990 | 2,746.1 | - | 464.4 | - | 67.5 |
| 1991 | 2,896.6 | 5.48 | 488.5 | 5.19 | 67.7 |
| 1992 | 3,011.6 | 3.97 | 518.0 | 6.04 | 66.2 |
| 1993 | 3,199.1 | 6.23 | 541.2 | 4.48 | 67.5 |
| 1994 | 3,400.0 | 6.28 | 591.5 | 9.29 | 65.6 |
| 1995 | 3,619.4 | 6.45 | 619.2 | 4.68 | 66.7 |
| 1996 | 3,795.8 | 4.87 | 639.9 | 3.34 | 67.5 |
| 1997 | 4,254.4 | 12.08 | 706.6 | 10.42 | 68.7 |
| 1998 | 4,295.8 | 0.97 | 726.4 | 2.80 | 67.5 |
| 1999 | 4,456.8 | 4.76 | 754.5 | 3.87 | 67.4 |
| 2002[1] | 4,998.5 | 3.90 | 857 | 4.33 | 67 |

[1] ETESA Web site

The total energy demands of the Panama Canal Authority for the period of 1992 through 1999 are shown in Table 12. The total energy demands include energy sales to the PNIS. The energy demand was decreased from 643.6 million kWh in year 1992 to 548.0 million kWh in 1998, and 450.0 million kWh in 1999. Fluctuations in energy demand for the period of 1992 through 1998 were partially dependent on the amount of energy sales to the PNIS. The decrease in energy demand for 1999 was due to the planned transfer of Panama Canal operation from U.S. to Panama. The peak load demand was reduced from 86 MW in 1992 to about 68 MW in year 1999.

**Table 12 Historical Peak Load and Energy Demands of the ACP, 1992-2002**

| | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Energy Demand GWh** | 624 | 599 | 635 | 570 | 522 | 548 | 450 | 444 | 457 | 405 |
| **Annual Rate of Change, %** | | -4.0 | -6.0 | -10.2 | -8.4 | -9.2 | -17.9 | -1.3 | 2.9 | -11.4 |
| **Peak Load, MW** | 86 | 87 | 86 | 79 | 83 | 71 | 68 | 53 | 64 | 58 |
| **Annual Rate of Change, %** | | 1.2 | -1.2 | -8.1 | 5.1 | -14.5 | -4.2 | -22.1 | 20.8 | -9.4 |

## 4.1 Load Demand Characteristics

There are minor variations among monthly peak loads and energy demands of the PNIS as monthly temperatures and rainfall in Panama remain relatively constant throughout the year. The monthly peak loads for 1999, expressed in term of percent of the annual peak load, are shown in Table 13. The monthly energy demands of the PNIS for year 1999 in term of percentage of total annual energy demand are also shown in Table 13.

**Table 13 Monthly Peak Loads and Energy Demands of the PNIS in 1999 and 2000**

| Month | Peak Load in Percent of Annual Peak Load | | Energy Demands in Percent of Total Demand | |
|---|---|---|---|---|
| | **1999** | **2000** | **1999** | **2000** |
| January | 93.5 | 89.8 | 8.0 | 7.9 |
| February | 93.6 | 90.5 | 7.4 | 7.7 |
| March | 97.2 | 94.8 | 8.8 | 8.3 |
| April | 99.7 | 95.9 | 8.7 | 8.2 |
| May | 98.6 | 96.0 | 8.6 | 8.7 |
| June | 98.9 | 94.8 | 8.2 | 8.3 |
| July | 96.4 | 98.1 | 8.2 | 8.5 |
| August | 98.9 | 98.9 | 8.4 | 8.6 |
| September | 97.9 | 95.1 | 8.2 | 8.2 |
| October | 97.8 | 96.6 | 8.6 | 8.5 |
| November | 96.4 | 95.4 | 8.3 | 8.1 |
| December | 100.0 | 100.0 | 8.8 | 8.9 |
| **Total** | - | | **100.0** | **100.0** |

Daily peak loads of the PNIS occur during the period of 11 A.M. through 3 P.M. on weekdays and Saturdays, and at 7 P.M. or 8 P.M. on Sundays. Hourly loads of typical weekdays and Sundays of the PNIS for the months of September 1999 and March 2000, expressed in terms of percent of the daily peaks, are given in Table 14.

**Table 14 Hourly Loads of Typical Weekdays and Sundays**

| Date | Thurs. 9/16/99 | | Sun. 9/19/99 | | Mon. 3/20/00 | | Sun. 3/19/00 | |
|---|---|---|---|---|---|---|---|---|
| Hour | Load, MW | Percent of Peak. % | Load, MW | Percent of Peak, % | Load, MW | Percent of Peak, % | Load, MW | Percent of Peak, % |
| 1 | 413.4 | 57.9 | 413.4 | 77.7 | 408.2 | 55.5 | 435.4 | 79.7 |
| 2 | 396.8 | 55.6 | 389.7 | 73.2 | 383.9 | 52.2 | 407.4 | 74.6 |
| 3 | 388.2 | 54.3 | 376.6 | 70.8 | 380.9 | 51.8 | 390.4 | 71.5 |
| 4 | 382.0 | 53.5 | 368.4 | 69.2 | 373.1 | 50.7 | 380.2 | 69.6 |
| 5 | 385.0 | 53.9 | 354.6 | 66.6 | 378.4 | 51.4 | 376.9 | 69.0 |
| 6 | 415.6 | 58.2 | 353.7 | 66.5 | 412.7 | 56.1 | 372.9 | 68.3 |
| 7 | 435.3 | 60.9 | 340.5 | 64.0 | 431.8 | 58.7 | 358.6 | 65.7 |
| 8 | 519.9 | 72.8 | 357.2 | 67.1 | 505.3 | 68.7 | 352.2 | 64.5 |
| 9 | 627.5 | 87.8 | 378.7 | 71.2 | 628.8 | 85.4 | 365.1 | 66.9 |
| 10 | 676.3 | 94.7 | 403.5 | 75.8 | 693.6 | 94.2 | 398.6 | 73.0 |
| 11 | 702.0 | 98.3 | 420.7 | 79.1 | 723.7 | 98.3 | 425.7 | 78.0 |
| 12 | 710.8 | 99.5 | 433.3 | 81.4 | 729.7 | 99.1 | 428.4 | 78.4 |
| 13 | 699.5 | 97.9 | 432.2 | 81.2 | 714.8 | 97.1 | 440.0 | 80.6 |
| 14 | 714.3 | 100.0 | 433.5 | 81.5 | 731.5 | 99.4 | 444.0 | 81.3 |
| 15 | 713.3 | 99.9 | 437.4 | 82.2 | 736.0 | 100.0 | 445.9 | 81.7 |
| 16 | 704.3 | 98.6 | 436.1 | 82.0 | 718.4 | 97.6 | 440.2 | 80.6 |
| 17 | 669.3 | 93.7 | 434.1 | 81.6 | 673.8 | 91.5 | 446.3 | 81.7 |
| 18 | 612.7 | 85.8 | 440.3 | 82.7 | 599.8 | 81.5 | 440.4 | 80.6 |
| 19 | 640.7 | 89.7 | 493.5 | 92.7 | 607.9 | 82.6 | 493.9 | 90.4 |
| 20 | 630.7 | 88.3 | 531.9 | 100.0 | 638.3 | 86.7 | 546.1 | 100.0 |
| 21 | 607.1 | 85.0 | 532.1 | 100.0 | 622.2 | 84.5 | 538.8 | 98.7 |
| 22 | 574.9 | 80.5 | 505.1 | 94.9 | 570.7 | 77.5 | 522.3 | 95.6 |
| 23 | 519.2 | 72.7 | 474.1 | 89.1 | 502.4 | 68.3 | 479.8 | 87.9 |
| 24 | 467.5 | 65.4 | 429.7 | 80.8 | 447.5 | 60.8 | 435.7 | 79.8 |

# 5 FORECAST OF POWER DEMAND OF THE PANAMA ELECTRIC SYSTEM

Three demand forecasts are available for each of two economic assumptions, moderate growth and high growth. One forecast was developed in 1998 (reference 1), one in 1999 (reference 2) and the third in November 2000 (reference 3). The earlier estimates were developed using a multiple regression analysis to define the relationship between energy consumption and economic parameters for each consumer sector including residential, commercial, industrial, government, and public lighting. A regression equation was defined for each sector. The economic parameters included population, gross domestic product (GDP) per capita, unit energy sale price for each sector, and energy efficiency. The energy efficiency is the unit energy consumption rate for producing the GDP of the industry sector, and is computed by dividing the GDP by total energy consumption of the sector. GDP is a broad measure of the health of the Panamanian economy and is usually defined as the value of goods and services produced by labor and property in Panama. It is a measure of domestic production. The peak load demands were estimated on the basis of the forecasted energy demand and a system load factor at 67.9 %.

The more recent demand estimate was developed using a simplified relation of total energy sales as a function of gross national product (GNP). GNP is a measure of income since it reflects income from domestic production (GDP) plus net income from abroad. The coefficient of determination for the two samples (total energy and GNP) was highest using a polynomial function. The simplified approach was taken due to the difficulty in obtaining accurate economic information.

The estimated energy losses of the transmission and distribution systems, in terms of percentage of the total energy consumption, for the two scenarios was estimated to decrease from about 22% in 1997 to about 14% in 2015. The most recent estimated total energy demands of the PNIS developed in 2000 for the medium and high growth scenarios are shown in Table 15.

**Table 15 Demand Forecast Developed in 2000 for the PNIS**

| Year | Medium Growth Scenario | | High Growth Scenario | |
|---|---|---|---|---|
| | Capacity MW | Energy GWh | Capacity MW | Energy GWh |
| 2000 (Actual) | 790 | 4,732 | | 4,732 |
| 2002 (Actual) | 857 | 4998 | | |
| 2005 | 1,107 | 5,304 | 1,177 | 5,655 |
| 2010 | 1,608 | 7,616 | 1,832 | 8,691 |

For comparison, the energy production estimates for the medium growth scenario are shown for all three estimated in Table 16.

**Table 16 Energy Forecast for Three Recent Estimates**

| Year | Medium Growth Scenario – GWh | | |
|---|---|---|---|
| | 1998 Estimate | 1999 Estimate | 2000 Estimate |
| 2001 | 4,981 | 4,907 | 4,028 |
| 2005 | 6,280 | 6,431 | 5,304 |
| 2010 | 8,154 | 8,435 | 7,616 |

Average annual growth rates of the most recent forecasted energy demands of the PNIS for the period of 2001-2010 were 7.3 % for the medium scenario forecast, and 8.8 % for the high scenario. These compare with the historical average annual growth rate of the energy demand at 5.5 % for the period of 1990-1999 and 5.6% and 7.0% for the corresponding period and scenario of the 1998 estimate. The comparison indicates a reduction in the forecast of about 18% in the early years and about 10% in 2010.

The average annual load factor of the PNIS was at 67.2 % for the period of 1990-1999. In recent years, the system load factor has increased from 65.6 % in 1994 to 68.5 % in 1997, and decreased to 67.4% in 1999. The PNIS has forecasted that the annual system factor will be in the low $50^{th}$ percentile through year 2010.

# 6 ROLE OF HYDROPOWER IN PNIS EXPANSION PLANS

The earliest commissioning date of a project in the Coclé del Norte basin will probably be after 2030 especially if implementation is contingent upon the installation of a third set of locks. No demand estimates have been made for that far into the future. The peak loads in 2010 for the medium forecast will be about 1,600 MW. The ACP demand, which according to the ACP Electricity Department is not included, is another 60 MW.

The generation expansion plan of the PNIS for the period of 1999-2015 was developed and recommended by the EDESA in a 1999 study. Contribution from the ACP facilities was not included. The recommended generation expansion plan with private hydro development is shown in Table 17.

**Table 17 Generation Expansion Plan 2000-2015**

| Operation Date | Type | Name of Plant | Capacity (MW) |
|---|---|---|---|
| 1999 September | Hydro | Anton 1 | 1.5 |
| November | Thermal | Combined Cycle | 160 |
| December | Thermal | Gas Turbine | 96 |
| 2000 | - | - | - |
| 2001 | - | - | - |
| 2002 October | Hydro | Guasquitas | 84 |
| 2003 April | Hydro | Canjilones | 34.8 |
| 2004 | Thermal | Gas turbine | 50 |
| 2005 | Thermal | Combined Cycle | 100 |
| 2006 | Hydro | Gualaca | 27 |
| 2007 | Hydro | Los Aniles | 34 |
| | Hydro | Chiriqui | 56 |
| 2008 | Hydro | Baru | 150 |
| 2009 | Thermal | Gas Turbine | 50 |
| 2010 | Thermal | Combined Cycle | 150 |
| 2011 | Thermal | Combined Cycle | 100 |
| 2012 | Thermal | Gas Turbine | 50 |
| | Hydro | Changuinola 5 | 120 |
| 2013 | Thermal | Combined Cycle | 250 |
| 2014 | Thermal | Combined Cycle | 100 |
| 2015 | Thermal | Combined Cycle | 100 |

In a personal communication with staff of the Electricity Department, it was indicated that the expansion plan is out of date and that they did not expect the new plants to come on line as indicated. However, the important part of the expansion plan is that hydro is expected to be a very important component of future development - the 1999 expansion plan suggests that new capacity will include about 386 MW of hydro capacity during the period of 2002 – 2008. The installed capacities, average annual energy production, and estimated construction costs of these hydroelectric projects and the Coclé del Norte Project are shown in Table 18.

**Table 18 Pertinent Data of the Coclé del Norte and Candidate Expansion Plan Hydro Project for the Period 2002 through 2008**

| Project | Type of Plant | Installed Capacity, MW | Average Annual Energy, GWh | Estimated Construction Cost, $/kW |
|---|---|---|---|---|
| Coclé del Norte | Storage | 75 | 410 | 1000 |
| Guasquitas | Storage | 84 | 449 | 1618 |
| Canjilones | Run of River | 35 | 178 | 1816 |
| Gualaca | Run of River | 27 | 138 | 1656 |
| Los Aniles | Run of River | 34 | 172 | 1938 |
| Chiriqui | Run of River | 56 | 290 | 1635 |
| Baru | Storage | 150 | 800 | 1989 |

The cost of a 75-MW installation at Coclé del Norte dam was estimated at about $ 1,000 per kW of installed capacity. This would be lower than the estimated costs of the six candidate hydroelectric plants to be added to the PNIS for the period of 2002 – 2008.

### 6.1 Marginal Costs

The marginal costs for each calendar month of the PNIS for the period of 1999 – 2015 were estimated on the basis of the recommended generation expansion program and 1999 oil prices. These estimates indicated that the marginal costs will decrease over the period from $45/MWh in 1999 to about $42/MWh in 2015 and average about $43/MWh. This value could be used to represent the energy benefit of the Coclé del Norte Project hydropower. The actual marginal costs for the period from 1998-2002 were as follows:

| Year | Marginal Cost ($/MWh) |
|---|---|
| 1998 | 57 |
| 1999 | 45 |
| 2000 | 53 |
| 2001 | 52 |
| 2002 | 50 |

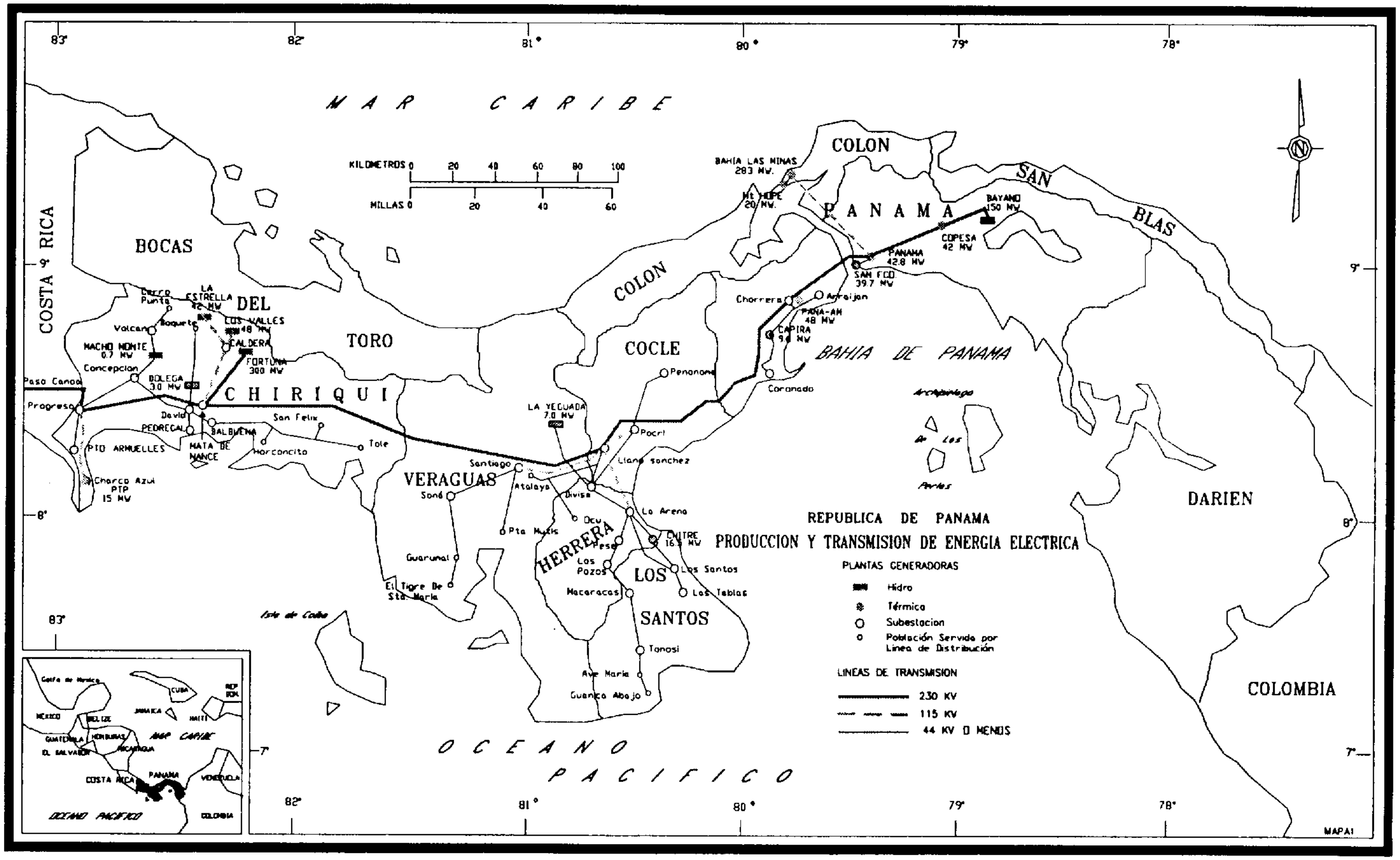
As the marginal costs are running higher than forecasted, the energy benefit may be understated.

# 7 CONCLUSIONS

As a result of this analysis, it can be concluded that:

- The existing system recognizes the importance of hydro to the extent that it provides about one-half of the available capacity.
- The current expansion plans for the period through 2015 include hydro as a major component.
- Demand for power is expected to grow at a rate of more than 4% per year.
- Based on the available information, the Coclé del Norte power and energy will be competitive in the national power system.
- The capcity and energy from an installation of the size appropriate for the Coclé del Norte project will be easily absorbed into the system and will provide a very cost-effective addition – replacing any of the projects identified in the 1999 expansion plan

SISTEMA DE TRANSMISION ACTUAL
AÑO 1999



Part 2
Power Development

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

APPENDIX E
PART 2

POTENTIAL FOR POWER DEVELOPMENT

Prepared by

MWH

In association with

TAMS
AN EARTH TECH COMPANY

# FEASIBILITY DESIGN FOR THE RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS

## APPENDIX E – POWER AND ENERGY STUDIES
## PART 2 – POTENTIAL FOR POWER DEVELOPMENT

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## APPENDIX E – POTENTIAL FOR POWER DEVELOPMENT

# ATTACHMENTS

# 1 INTRODUCTION

It was concluded in the power market study, presented as Part 1 of this Appendix E – Power and Energy Studies, that the demand for power in the Panama National Integrated System (PNIS) is expected to grow at a rate of more than 5% per year. It is also stated that the PNIS recognizes the importance of hydropower, as the current expansion plan for the period through 2015 includes six new hydroelectric power plants (excluding any power plants associated with the expansion of the Panama Canal System).

The Reconnaissance Study, performed by the US Army Corps of Engineers, Mobil District, in December 1999 evaluated, among other alternatives, three projects in the Coclé del Norte basin. Hydropower was considered to be viable at various locations for all of the projects.

For this feasibility study, two alternative arrangements have been evaluated:
:

- A project on the Río Coclé del Norte with a full supply level at El. 71 acting in full regulation with the Río Indio Reservoir, and

- A project on the Río Coclé del Norte with a full supply level at El. 100 acting in full regulation with the Río Caño Sucio and Río Indio Reservoirs.

In the following sections, the evaluation of the potential for hydroelectric development is described.

Reservoir operation studies performed in conjunction with Río Indio Project feasibility design have indicated that the system of reservoirs Gatun-Madden-Indio has a yield of 60.33 lockages per day (L/d) at 99.6% reliability. Based on the projection for unconstrained water demand for Navigation presented in the Reconnaissance Study and the M&I and tourism water demand presented in the report entitled "Long Term Forecast for M&I Demand" prepared by MWH, January 2001, this yield will be reached in 2028. The present study, therefore, considered that the Coclé del Norte Project would be built to be operational at that time.

The feasibility design for the Río Indio project, dated April 2003, indicates that the hydropower development associated with that project is not economically viable. Only a small 2.5MW power plant is considered and would be limited to supply electricity to areas in the vicinity of the proposed dam. No hydroelectric development is recommended at the end of the 4.50-meter diameter transfer tunnel from Indio reservoir to Isla Pablon in Lake Gatun. The proposed power plant would not be connected to the national grid and therefore no transmission line would connect the project to the substation near La Chorrera.

The first arrangement consists of a 75-meter high dam, with a reservoir operating between El. 50 and El. 71. A 16-km long tunnel would be used to transfer water from the Coclé reservoir to the Indio reservoir. The transfer of water to the Lake Gatun would require the construction of a second 8.4-km long Indio-Gatun tunnel to accommodate the larger discharges.

The second arrangement consists of a 100-meter high dam in conjunction with a 30-meter high dam at the Caño Sucio site, located approximately 26 kilometers East of Coclé. The reservoirs formed behind the two dams would operate between El. 90 and El. 100, and would be connected by a 3-km long canal. Regulated flows from the combined reservoirs would be transferred to the Indio reservoir via a 2.7-km long tunnel. As for the first scheme, a second tunnel 8.4-km long would be required to transfer water from the Indio reservoir to Lake Gatun.

Sections 2 and 3 of this Appendix evaluate the hydroelectric potential of these arrangements.

The present power and energy studies for the Río Coclé del Norte Water Supply Project were performed by TAMS Consultants, Inc., an Earth Tech company, under the Sub-consultant Services Agreement No.15593 S-1 for MWH.

# 2 COCLÉ DEL NORTE RESERVOIR ACTING IN FULL REGULATION WITH RÍO INDIO RESERVOIR

## 2.1 Selected Coclé Reservoir

The Coclé del Norte reservoir has been sized without consideration for hydroelectric power and is anticipated to increase the water yield of the Panama Canal reservoir system from 60.3 L/d to 106.1 L/d at a reliability of 99.6%. The projection for unconstrained water demand for Navigation presented in the Reconnaissance Study and the M&I and tourism water demand presented in the report entitled "Long Term Forecast for M&I Demand" prepared by MWH, January 2001, indicates that the demand on the system is expected to reach 85.0 L/d by 2060. This corresponds to an average annual growth of 1.075% over the period 2030 to 2060. For the purpose of estimating hydropower benefit, it has been assumed that the rate of growth will remain constant over the following 30 years, i.e., to year 2090. On the basis of that assumption, the water demand will reach the yield of the reservoir system, including Gatun, Madden, Indio and Coclé del Norte, in 2081 approximately.

The initial configuration of the Panama Canal water supply system considered for this study consists of the deepened Lake Gatun operating between El. 23.93 (78.5 ft) and El. 26.75 (87.75 ft), the Madden reservoir, operating between El. 57.91 (190 ft) and El. 76.81 (252 ft) and the Río Indio reservoir operating between El. 40 and El. 80. It is assumed that the deepening of Lake Gatun will be completed and will allow draw down of the Lake three feet lower than it is currently allowed for normal operation. The reservoir operation studies conducted by the ACP with the HEC-5 simulation program have demonstrated that the yield of this system of reservoirs at the required reliability is 60.3 L/d (145.3 $m^3/s$). The Indio reservoir active storage provided is 1,294 million cubic meters (MCM).

Additional HEC-5 simulations undertaken by the ACP, have demonstrated that when the Coclé del Norte reservoir, operating between El. 50 and El. 71 is added to the system, the yield would increase to 106.1 L/d (255.6 $m^3/s$). The reservoir would have an active storage of 3,443 MCM. On average, the transfer tunnel between Coclé and the Indio reservoir would convey 71.2 $m^3/s$. The average transferred discharge from Indio to Lake Gatun would be 93.7 $m^3/s$. The simulation considered minimum releases of 10.9 $m^3/s$ at the Coclé del Norte dam and 2.6 $m^3/s$ at the Río Indio dam. The results of the Coclé del Norte – Río Indio reservoir simulations under these conditions are shown in graphical form in Attachment 2.

Figures 1 and 2 below show plots of the Coclé del Norte reservoir levels against the weekly transferred discharges into Indio reservoir and of the Indio reservoir levels against the weekly transferred discharges into Lake Gatun, respectively.

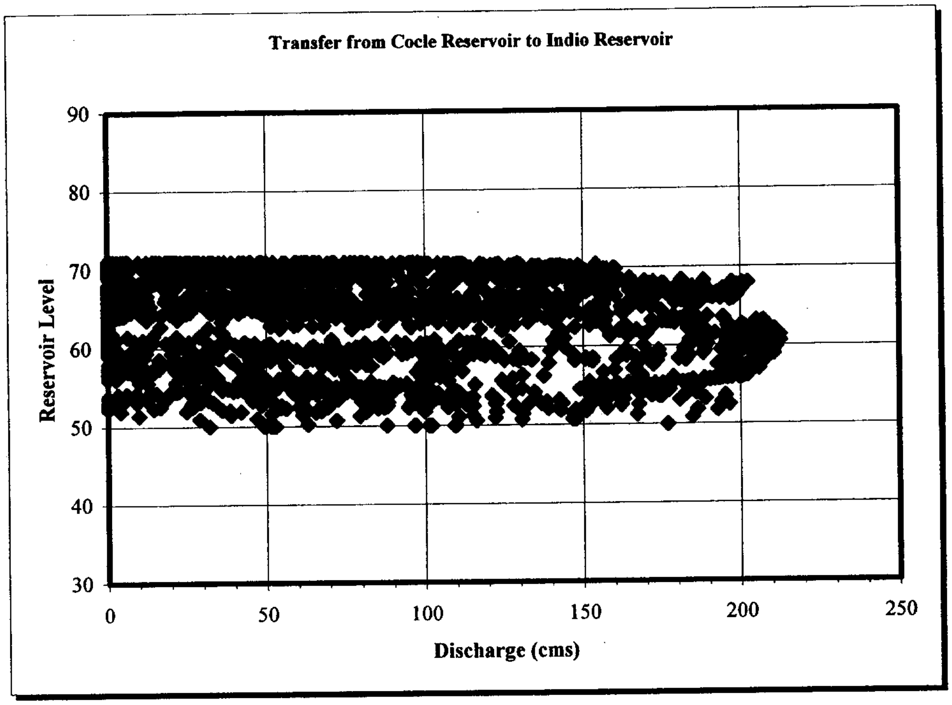



**Figure 1 – Coclé del Norte Reservoir Operation El. 50 – El. 71**

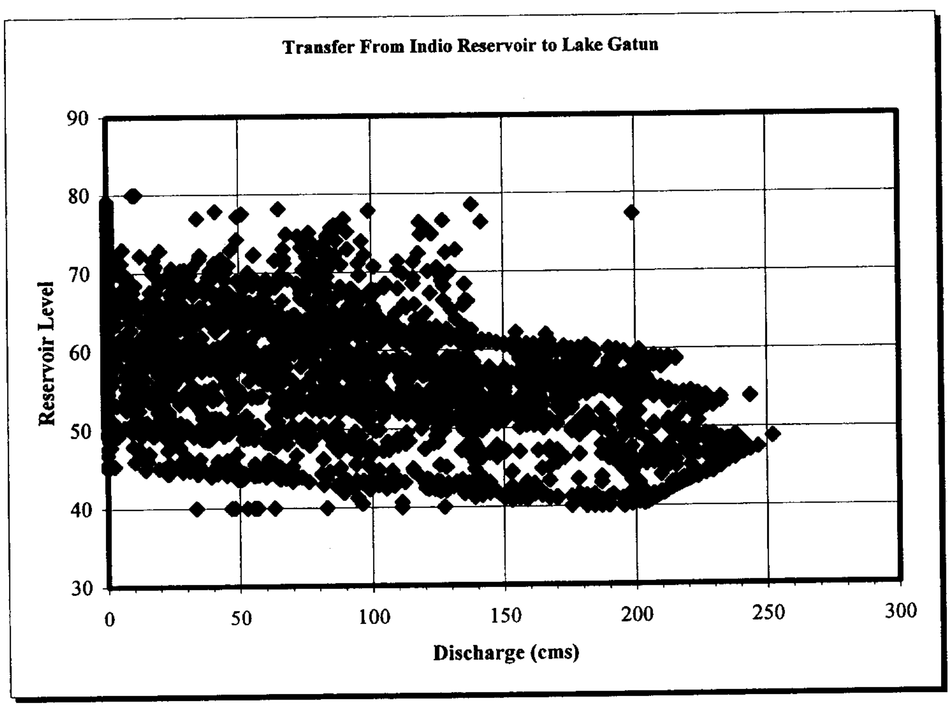



**Figure 2 – Indio Reservoir Operation (with Coclé 50-71)**

Figures 3 and 4 below show the Coclé and Indio reservoir elevation frequency curves derived from the HEC-5 simulation. These curves are used to select the best turbine operating range.

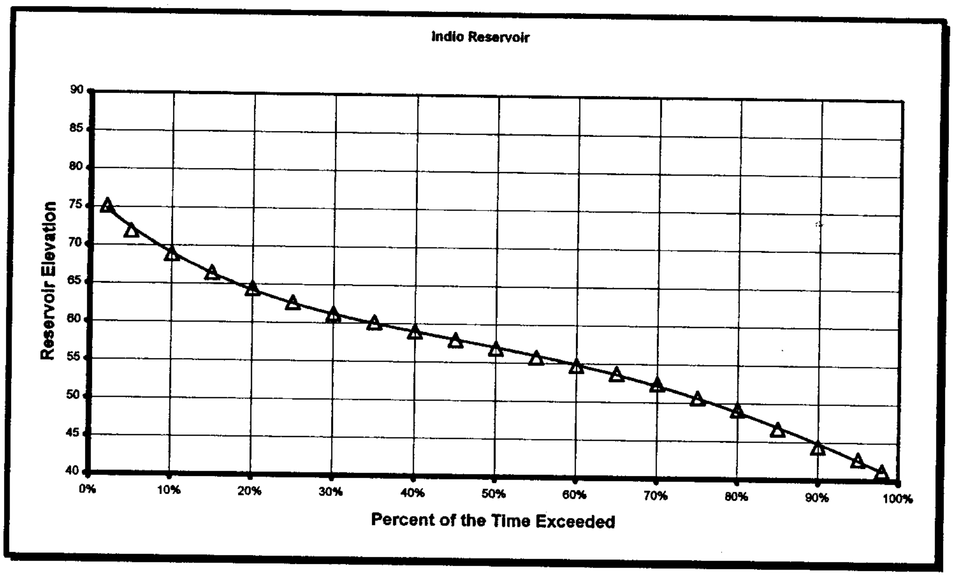



**Figure 3 – Indio Reservoir Elevation Duration Curve (with Coclé 50-71)**

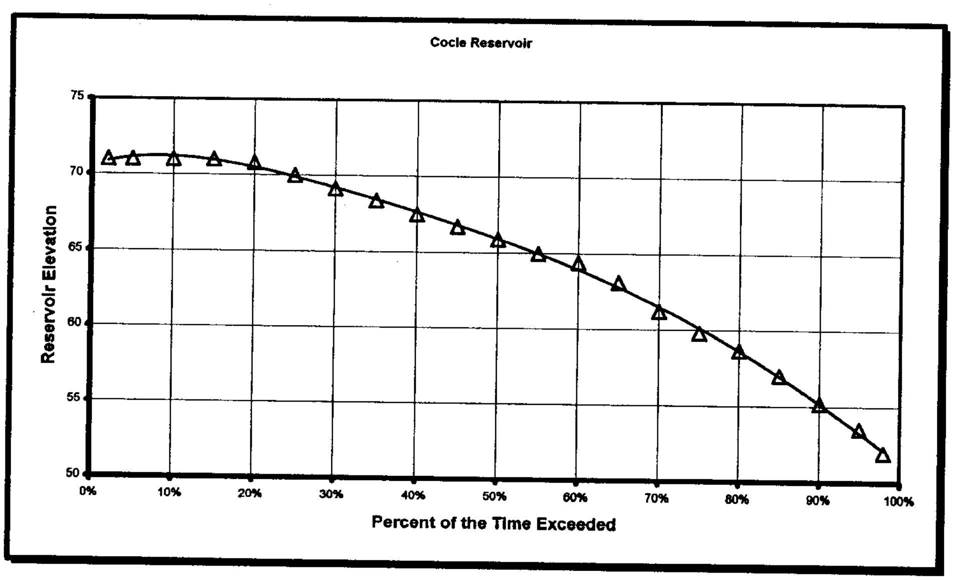



**Figure 4 – Coclé Reservoir (El. 50- El. 71) Elevation Duration Curve**

The transfer tunnels, one between Coclé and Indio, and two between Indio and Lake Gatun have been sized for the purpose of delivering water into Lake Gatun and not necessarily for hydroelectric power generation. The present study considered that the Río Indio project has been developed and includes a 4.50-meter diameter D-shaped transfer tunnel, 8.4 kilometers long. The discharge capacity of the tunnel varies between 43 $m^3/s$ with Indio reservoir at El.40 and 94 $m^3/s$ with the reservoir at El. 80.

The required transfer capacity at full reservoir, between Indio and Lake Gatun for operation with the Coclé reservoir is approximately 391 $m^3/s$: for that purpose a second tunnel 6.50-meter diameter D-shaped will be built parallel to the existing one. The capacity of this second tunnel varies between 156 $m^3/s$ with Indio reservoir at El.40 and 297 $m^3/s$ with the reservoir at El. 80. The transfer tunnel from the Coclé reservoir to Indio is a 9.0-meter diameter tunnel 16 km long with a capacity of 248 $m^3/s$ with the Coclé reservoir at El 71 and the Indio reservoir at El 50. Figure 5 bel the Coclé del Norte reservoir could be maintained above El. 60 while releasing a constant 60 $m^3/s$ discharge downstream of the dam through a power plant; Indio minimum operating pool would be lowered progressively from El. 60 in 2038, to El. 50 in 2043 and to El. 40 in 2046.ow shows plots of the transferred discharge duration curves.

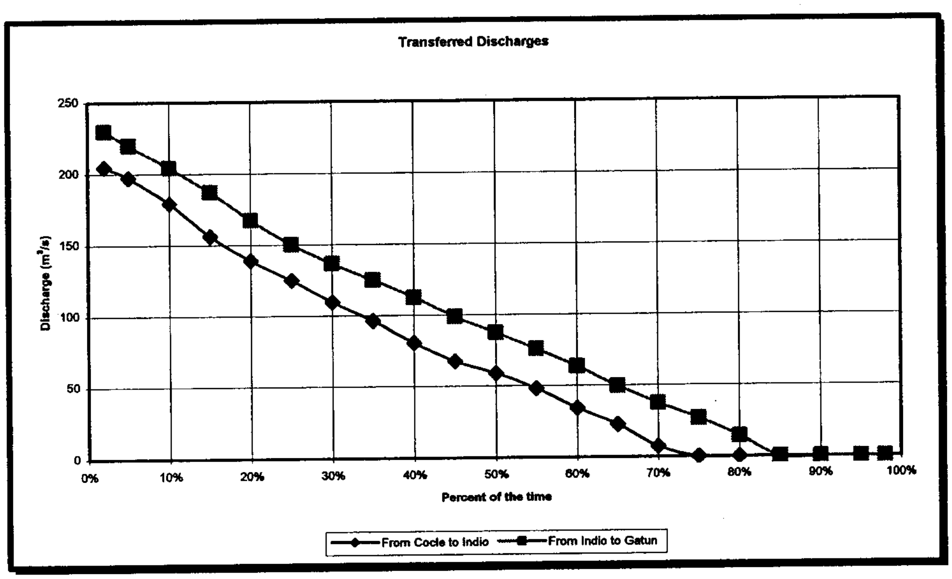



**Figure 5 – Transferred Discharge Duration Curves (with Coclé 50-71)**

## 2.2 Hydropower Scheme Selection for Coclé Reservoir 50-71

### 2.2.1 Reservoir Operations and System Yield

The reservoir operation simulations presented above were performed to assess the water supply yield of the system of reservoirs. Under these conditions, most of the water passes through the transfer tunnels and only the minimum release of 10.9 $m^3/s$ at the Coclé del Norte dam and 2.6 $m^3/s$ at the Indio dam could be developed. Hydropower could also be developed at the downstream end of the transfer tunnel, but generally the conditions may not be the most favorable at these locations as the transfer tunnels are long and the net head is relatively limited.

It is estimated that the system will not be required to supply its full yield until approximately 50 years after the project completion. In this interim period, more favorable hydropower developments could be developed, even if these potential developments had a limited economic life. For the purpose of selecting the best hydropower development associated with the reservoir scheme, a number of reservoir simulations with modified operating rules were performed.

Three different strategies were investigated:

- Strategy 1 would consist in discharging the maximum possible flow into the Río Coclé del Norte to favor hydropower development at that site.
- Strategy 2 would consist in discharging the maximum flow into the Río Indio to favor hydropower development at that site.
- Strategy 3 would consist in discharging the maximum flow through the transfer tunnel between Indio and Lake Gatun to favor the development of a power plant at the Isla Pablon site.

Strategy 3 would also favor energy production at the Gatun 24-MW hydroelectric plant.

The operating rules considered would reduce the overall yield of the system, and therefore they would have a limited life: for each of these strategies, the yield of the system and the estimated year when the water demand will reach that yield are shown on Table 1.

A preliminary review of the reservoir operation simulations indicates that the hydropower potential at the end of the Coclé-Indio transfer tunnel is not a viable option as under the best reservoir operation circumstances the average net head on the power plant would be 5 meters or less. Furthermore development of that option would involve an underground facility of difficult construction and costly. This option was therefore not investigated.

For all three strategies energy production and firm capacity at the three other potential hydropower sites were calculated for a range of hydropower plant capacities. In order to estimate the energy production for any given scheme, it was assumed that operating rules would apply until the water demand reaches the yield achieved under these conditions.

Rules would be progressively modified to increase the yield of the system. Under Strategy 1 several combinations of operating ranges have been investigated.

**Table 1 – Reservoir System Yield (Coclé 50 – 71)**

| | Coclé Constant Release ($m^3/s$) | Coclé Operating Range | Indio Constant Release ($m^3/s$) | Indio Operating Range | Constant Transferred Discharge into Gatun ($m^3/s$) | System Yield (L/d) | Year |
|---|---|---|---|---|---|---|---|
| **Base Case** | 10.9 | 50 - 71 | 2.6 | 40 – 80 | No Rule | 106.1 | 2081 |
| **Strategy 1A** | 20.0 | 50 – 71 | 2.6 | 40 – 80 | No Rule | 102.7 | 2078 |
| | 40.0 | 50 – 71 | 2.6 | 40 – 80 | No Rule | 95.1 | 2070 |
| | 60.0 | 50 – 71 | 2.6 | 40 – 80 | No Rule | 86.8 | 2062 |
| **Strategy 1B** | 10.9 | 50 - 71 | 2.6 | 50 – 80 | No Rule | 99.8 | 2075 |
| | 20.0 | 50–71 | 2.6 | 50 – 80 | No Rule | 97.0 | 2072 |
| | 40.0 | 50 – 71 | 2.6 | 50 – 80 | No Rule | 89.9 | 2065 |
| | 60.0 | 50 – 71 | 2.6 | 50 – 80 | No Rule | 82.0 | 2055 |
| | 80.0 | 50 – 71 | 2.6 | 50 – 80 | No Rule | 74.1 | 2044 |
| **Strategy 1C** | 20.0 | 60 –71 | 2.6 | 40 – 80 | No Rule | 91.1 | 2066 |
| | 40.0 | 60 – 71 | 2.6 | 40 – 80 | No Rule | 83.5 | 2057 |
| | 60.0 | 60 – 71 | 2.6 | 40 – 80 | No Rule | 76.2 | 2046 |
| **Strategy 1D** | 20.0 | 60 –71 | 2.6 | 50 – 80 | No Rule | 89.0 | 2064 |
| | 40.0 | 60 – 71 | 2.6 | 50 – 80 | No Rule | 81.4 | 2054 |
| | 60.0 | 60 – 71 | 2.6 | 50 – 80 | No Rule | 73.9 | 2044 |
| **Strategy 1E** | 10.9 | 60 – 71 | 2.6 | 60 – 80 | No Rule | 87.7 | 2063 |
| | 20.0 | 60 – 71 | 2.6 | 60 – 80 | No Rule | 84.5 | 2059 |
| | 40.0 | 60 –71 | 2.6 | 60 – 80 | No Rule | 77.0 | 2047 |
| | 60.0 | 60 – 71 | 2.6 | 60 – 80 | No Rule | 69.4 | 2038 |
| | 80.0 | 60 – 71 | 2.6 | 60 – 80 | No Rule | 61.5 | 2030 |
| **Strategy 2** | 10.9 | 50 – 71 | 20.0 | 50 – 80 | No Rule | 91.7 | 2067 |
| | 10.9 | 50 – 71 | 40.0 | 50 – 80 | No Rule | 81.6 | 2054 |
| | 10.9 | 50 – 71 | 60.0 | 50 – 80 | No Rule | 71.6 | 2041 |
| | 10.9 | 50 – 71 | 80.0 | 50 – 80 | No Rule | 62.5 | 2031 |
| | 10.9 | 60 – 71 | 60.0 | 60 – 80 | No Rule | 60.5 | 2029 |
| | 10.9 | 60 - 71 | 80.0 | 60 – 80 | No Rule | 52.2 | - |
| **Strategy 3** | 10.9 | 50 – 71 | 2.6 | 50 – 80 | 60.0 | 97.3 | 2073 |
| | 10.9 | 50 – 71 | 2.6 | 50 – 80 | 80.0 | 97.5 | 2073 |
| | 10.9 | 60 – 71 | 2.6 | 60 – 80 | 60.0 | 86.4 | 2061 |
| | 10.9 | 60 - 71 | 2.6 | 60 – 80 | 80.0 | 87.2 | 2061 |

Under Strategy 1, an example of the operation sequence would be as follows:

- From 2029 to 2046, the Coclé del Norte reservoir could be maintained above El. 60 while releasing a constant 60 $m^3/s$ discharge downstream of the dam through a power plant; Indio minimum operating pool would be lowered progressively from El. 60 in 2038, to El. 50 in 2044 and to El. 40 in 2046.

- From 2046 to 2062, the minimum operating pool of the Coclé del Norte reservoir would be lowered to El. 50 while releasing the same constant 60 $m^3/s$ discharge through the power plant; Indio minimum operating pool would be lowered progressively from El. 50 in 2055, to El. 40 in 2062.
- The discharge downstream of Coclé would then be progressively reduced to 40 $m^3/s$ in 2070, and 20 $m^3/s$ in 2078, and so on, until the full yield of the system is reached and only the minimum release is discharged through the Coclé del Norte power plant.

Similarly, Strategy 2 would apply to the Indio power plant.

Under Strategy 3, Indio reservoir would be maintained between El. 60 and El. 80 and a constant 80 $m^3/s$ discharge would be transferred to Gatun, possibly through a power plant at the end of the second transfer tunnel. The minimum releases of 10.9 $m^3/s$ at Coclé and 2.6 $m^3/s$ at Indio would be maintained. This operation could be sustained from 2029 until 2062 (on the assumed water demand growth). The minimum operating level of both Indio and Coclé would then be lowered to El. 50 in 2073. After that period power generation would be reduced during periods of high flow demand.

### 2.2.2 Energy Production

For the purpose of calculating the energy production and firm capacity, a spreadsheet-type model was developed: the model uses the weekly output of the HEC-5 simulation performed by the ACP. The project water released were those determined by the HEC-5 simulation. The tailwater rating curve established under the hydraulics studies was used for the purpose of calculating the gross head on the project at the Río Coclé and Río Indio dam sites.

The energy production at each potential site was calculated for a range of installed capacity depending on the strategy contemplated:

- At Río Coclé del Norte from 20 MW to 75 MW;
- At Río Indio from 2.5 MW to 40 MW;
- At Isla Pablon from 15 MW to 40 MW.

The input parameters of the computation and the results are presented in Attachment 3. Typical sequences of energy generation are shown on tables 2, 3 and 4 below.

**Table 2 – Energy Production (GWh/yr) under Strategy 1 (Coclé 50 – 71)**

| Power Plant | 2029 | 2044 | 2062 | 2070 | 2081 |
|---|---|---|---|---|---|
| Coclé del Norte 60-MW | 423.6 | 398.3 | 300.4 | 226.6 | 117.7 |
| Isla Pablon 20-MW | 28.9 | 54.6 | 51.0 | 56.6 | 59.4 |
| Indio 2.5-MW | 11.4 | 11.4 | 9.4 | 9.2 | 9.3 |
| Madden 36-MW | 180.9 | 170.5 | 161.7 | 157.4 | 152.4 |
| Gatun 24-MW | 39.0 | 16.5 | 7.6 | 5.2 | 2.8 |
| Total | 683.8 | 651.3 | 530.1 | 455 | 341.6 |

**Table 3 – Energy Production (GWh/yr) under Strategy 2 (Coclé 50 – 71)**

| Power Plant | 2029 | 2041 | 2054 | 2067 | 2081 |
|---|---|---|---|---|---|
| Coclé del Norte 20-MW | 86.5 | 86.5 | 90.3 | 90.9 | 72.3 |
| Isla Pablon 20-MW | 41.1 | 41.1 | 61.8 | 83.2 | 66.1 |
| Indio 30-MW | 238.8 | 238.8 | 164.0 | 80.4 | 9.3 |
| Madden 36-MW | 174.4 | 170.9 | 165.3 | 160.3 | 152.4 |
| Gatun 24-MW | 53.3 | 14.3 | 7.8 | 5.0 | 2.8 |
| Total | 594.1 | 551.6 | 489.2 | 419.8 | 296.2 |

**Table 4 – Energy Production (GWh/yr) under Strategy 3 (Coclé 50 – 71)**

| Power Plant | 2029 | 2045 | 2062 | 2073 | 2081 |
|---|---|---|---|---|---|
| Coclé del Norte 20-MW | 85.3 | 85.3 | 85.3 | 75.6 | 72.3 |
| Isla Pablon 25-MW | 216.7 | 216.7 | 216.7 | 186.7 | 75.9 |
| Indio 2.5-MW | 11.7 | 11.7 | 11.7 | 10.5 | 9.3 |
| Madden 36-MW | 178.2 | 173.7 | 169.8 | 167.5 | 152.4 |
| Gatun 24-MW | 123.0 | 78.7 | 41.7 | 27.3 | 2.8 |
| Total | 614.9 | 566.1 | 525.2 | 467.6 | 312.7 |

It should be noted that each hydroelectric project should be economically justified individually on the basis of construction cost, operating cost and revenues to be considered in a strategy. The energy projections indicated in Tables 2, 3 and 4 are the maximum achievable if all projects are economically viable. Also, while Gatun and Madden power plants currently exist, a small 2.5-MW power plant is anticipated to be included in the Indio Project. For the purpose of the present study, the construction of a larger power plant at the Indio dam, if justified, would be concurrent with the construction of the Coclé project.

### 2.2.3 Power Scheme Selection

#### 2.2.3.1 General

As previously indicated each of the potential hydroelectric projects should be economically justified on its internal rate of return. As the primary objective of the project is water supply, the hydropower component will be evaluated on a marginal basis, meaning that the economic viability of a hydroelectric component is evaluated by comparing hydropower revenues to the cost specifically associated with the hydropower component.

The elements of the hydropower component cost generally include:

- Power intake;
- Power tunnel, or necessary enlargement of the transfer tunnel;
- Steel liner;
- Surge tank;
- Powerhouse structure and ancillary equipment;
- Generating equipment;
- Switchyard and transmission lines.

The energy and power benefits for each of these schemes were estimated based on the marginal value of energy presented in the power market studies ($45 per MWh) and the value of firm capacity of $60 per kW-yr. The firm capacity was calculated on the basis of the projected monthly energy production: it is the capacity that could be delivered 8 hours per day, every day of the month with the monthly energy exceeded 95% of the time.

The operation and maintenance cost of the hydropower scheme were estimated as follows:

- 1.0% of the cost of all civil works;
- 2.5% of the cost of all mechanical and electrical equipment;
- 1.5% of the cost of the transmission line.

The following sections evaluate the three potential hydropower developments: Coclé del Norte, Indio and Isla Pablon.

### 2.2.3.2 Coclé del Norte Power Plant

For this site, two project capacities can be considered depending on the followed energy strategy. For Strategy 1, the maximum installed capacity considered could be in the order of 100 MW if the project had power generation for sole purpose. It is however likely that a smaller capacity would be justified, as more and more water will be transferred to the Gatun watershed. Based on the sequence of reservoir operation developed previously for this strategy, the hydropower revenues for the 60-year period (from 2029, the initial year of operation, to 2088) were calculated for a range of installed capacity at the Coclé del Norte power plant. The present values (at the first year of operation) of these revenues were calculated for the purpose of comparing them to the implementation and running costs of the project: they are presented in Table 5 below. A discount rate of 12% was selected for this preliminary evaluation.

For strategies 2 and 3, the water available for power generation at the dam site is the minimum release of 10.8 $m^3/s$ and spillage. This discharge would allow the development of a power plant with an installed capacity of approximately 15 to 25 MW. The present values of these projects revenues are also presented in Table 5.

**Table 5 – Coclé del Norte Revenues (Coclé 50 – 71)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 1** | |
| 20 | $70,500 |
| 25 | $88,400 |
| 30 | $106,400 |
| 40 | $141,400 |
| 50 | $169,300 |
| 60 | $181,000 |
| 75 | $196,700 |
| **Strategy 2** | |
| 20 | $40,900 |
| 25 | $45,400 |
| 30 | $49,600 |
| 40 | $57,300 |
| **Strategy 3** | |
| 20 | $40,900 |
| 25 | $45,000 |
| 30 | $48,900 |
| 40 | $56,100 |
| 50 | $62,400 |
| 60 | $67,900 |

The project would consist of a power intake located near the spillway on the right abutment of the dam. Access to the intake would be gained from the dam crest via a bridge leading to a tower approximately 25 to 30 meter high. Immediately downstream of the trashrack and intake gates, the waterways would converge to a vertical shaft 40 meters deep; a near horizontal, 250-meter long tunnel would follow it. The powerhouse will be located on the right bank of the river between the toe of the dam and the spillway flip bucket. The switchyard will be located across the river approximately 100 meter from the powerhouse at the toe of the dam. For strategy 1, it is anticipated that a transmission line 230-kV will connect the project to the Substation at La Chorrera. For strategies 2 and 3, a 115-kV line will be sufficient to carry the energy from Coclé to La Chorrera, as well as that of any additional power plant such as Indio (Strategy 2) or Isla Pablon.

For the purpose of assessing the viability of the scheme for a given strategy, the preliminary cost estimates of two representative projects have been developed. These were a 3 x 20-MW power plant for Strategy 1 and a 2 x 15-MW power plant for Strategies 2 and 3. These estimates are presented in Table 6 below.

**Table 6 – Coclé del Norte Power Plant (Coclé 50 – 71) – Cost Estimates**

| Description | 3 x 20-MW Power Plant Cost ($,000) | 2 x 15-MW Power Plant Cost ($,000) |
|---|---|---|
| Power Intake Civil Work | $2,200 | $1,300 |
| Power Intake Equipment | $3,200 | $1,000 |
| Shaft, Tunnel and Liner | $5,200 | $3,000 |
| Power Plant Civil Work | $3,100 | $2,200 |
| Power Plant Equipment | $18,500 | $10,200 |
| Transmission System | $21,500 | $4,500 |
| Subtotal | $53,700 | $22,200 |
| Contingencies (25%) | $13,400 | $5,700 |
| Eng. & Admin (15%) | $10,200 | $4,200 |
| **Total** | **$77,300** | **$32,100** |

The cost for transmission line included in the estimate for the 60-MW development includes the cost of 109 kilometer of 230-kV from Coclé del Norte to the substation near La Chorrera, as this project would be the largest beneficiary of such a transmission line. For the 30-MW development only 61 kilometers of 115-kV transmission line, from Coclé del Norte to Isla Pablon are included as it is anticipated that this project would be developed in association with the Isla Pablon power scheme.

The development costs of these projects are lower than the present value of the benefits, and therefore they can be considered in the analysis of the hydropower component.

**2.2.3.3 Río Indio Power Plant**

The Río Indio dam and appurtenant works will have been built, along with the transfer tunnel from Indio to Gatun and a small 2.5-MW power plant at the toe of the dam, several years prior to the construction of the Coclé project. Under the proposed Strategy 2, a larger power plant would be built at the Indio dam on the left bank of the river. The project would include a power intake, a 600-meter long tunnel, a powerhouse, a switchyard and a 58.7-kilometer long, 115-kV transmission line to La Chorrera substation.

The present values of the hydropower benefits of such development have been calculated for a range of installed capacity and the results are presented in Table 7 below.

**Table 7 – Río Indio Hydropower Revenues (Coclé 50-71)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 2** | |
| 15 | $43,600 |
| 20 | $67,000 |
| 25 | $86,600 |
| 30 | $99,700 |
| 35 | $103,400 |

For the purpose of assessing the site for its hydropower potential, the cost estimate of a two 15-MW power plant was developed and is presented in Table 8 below.

**Table 8 – Río Indio Power Plant (Coclé 50–71) - Cost Estimates**

| Description | 2 x 15-MW Power Plant Cost ($,000) |
|---|---|
| Power Intake incl. Cofferdam | $9,500 |
| Tunnel and Liner | $6,100 |
| Power Plant Civil Work | $1,600 |
| Power Plant Equipment | $13,900 |
| Transmission System | $6,200 |
| Subtotal | $37,300 |
| Contingencies (25%) | $9,400 |
| Eng. & Admin (15%) | $7,000 |
| **Total** | **$53,700** |

On the basis of this estimate, it appears that the Río Indio hydroelectric scheme should be considered as it is anticipated that it would have an internal rate return greater than 12%. This development would be competing with a large development at the Río Coclé dam site; only one of the two projects would be developed.

**2.2.3.4 Isla Pablon Power Plant**

The existing Río Indio project incorporates an 8.4-kilometer long, 4.50-meter diameter D-shaped tunnel to transfer water from the Indio reservoir to Lake Gatun. The discharge capacity of the tunnel varies between 43 $m^3/s$ with Indio reservoir at El.40 and 94 $m^3/s$ with the reservoir at El. 80. In conjunction with the development of the Coclé del Norte water supply project, a second tunnel 6.50-meter diameter D-shaped, parallel to the initial tunnel will be built to transfer the additional water to Lake Gatun. This tunnel will increase the transfer capacity to 225 m$^3$/sec with Indio reservoir at El.40 and 390 m$^3$/s with Indio at El. 80.

The Río Indio studies have demonstrated that hydropower development at the end of the first transfer tunnel (Isla Pablon) cannot be economically justified on the basis of the Río Indio project alone. The objective of the present study is to determine whether hydropower development can be justified on the second tunnel when the system of reservoirs includes Indio and Coclé del Norte. For the purpose of this evaluation it is assumed that the hydroelectric power plant would be developed at the same time as the tunnel.

The transfer capacity of the second tunnel must be guaranteed regardless of the ability of the power plant to discharge water. For that reason, the tunnel will include a bifurcation located approximately 50 meters upstream of the proposed outlet works; the power development will be built at the downstream end of a steel-lined branch. Both the outlet works and the power station will discharge in a common tailrace channel separate from the first tunnel tailrace channel.

**Table 9 –Isla Pablon Hydropower Revenues (Coclé 50-71)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 1** | |
| 20 | $15,100 |
| 25 | $16,600 |
| 30 | $17,200 |
| 35 | $17,500 |
| 40 | $17,700 |
| **Strategy 2** | |
| 15 | $13,900 |
| 20 | $16,600 |
| 25 | $18,300 |
| 30 | $19,100 |
| **Strategies 3** | |
| 20 | $75,000 |
| 25 | $93,400 |
| 30 | $99,900 |
| 35 | $102,700 |
| 40 | $105,300 |

Development of the hydropower capability of the second tunnel will require some modification to the proposed tunnel. The intake will be equipped with finer trash-screens; the diameter of the tunnel will be increased so as to limit the head losses during hydropower operation to a maximum of 20% of the net head on turbine; and a surge tank near the downstream end of the tunnel will also be required to limit the starting characteristics of the waterways to a reasonable starting time. The cost of these features must be included in the economic evaluation of the hydropower component to determine the viability of a scheme developed on the second tunnel to Isla Pablon.

It is assumed that, depending of the required transferred discharge, the second tunnel (including hydropower) will first be used to transfer water up to the capacity of the turbines. For larger discharges, the first tunnel will transfer discharge in excess of the turbine capacity, up to its capacity. Only when the required discharge is greater than the sum of the turbine capacity and the first tunnel capacity, the flow transferred through the second tunnel will be greater than the turbine capacity. Under these conditions, hydropower generation will be reduced as the head losses in the second transfer tunnel are increased.

For the purpose of assessing the site for its hydropower potential, the cost estimate of a power plant with two 15-MW units was developed and is presented in Table 10 below.

**Table 10 – Isla Pablon Power Plant (Coclé 50-71) - Cost Estimates**

| Description | 2 x 15-MW Power Plant Cost ($,000) |
|---|---|
| Power Intake Modification | $800 |
| Tunnel (Increasing diameter) | $5,300 |
| Surge Tank | $3,900 |
| Steel Liner | $5,500 |
| Power Plant Civil Work | $2,400 |
| Power Plant Equipment | $14,900 |
| Transmission System | $5,600 |
| Subtotal | $38,400 |
| Contingencies (25%) | $9,600 |
| Eng. & Admin (15%) | $7,200 |
| **Total** | **$55,200** |

Comparison with expected hydropower revenues indicates that such power plant could only be justified under strategy 3; the development could also include a small power plant at the Río Coclé dam site. For all other strategy the return of the development at Isla Pablon would be smaller than 12%. This development would be an alternative to large developments at either the Coclé dam site or at the Indio dam site.

**2.2.3.5 Strategy Selection**

To compare the three strategies the internal rate of return of each development was calculated and is presented in Table 11 below. Detailed calculations are presented in Attachment 5.

**Table 11 – Comparison of Alternatives (Coclé 50-71)**

| Scheme | Const. Cost ($,000) | Annual O&M Cost ($,000) | Period from 2029 to 2088 | | | Internal Rate of Return |
|---|---|---|---|---|---|---|
| | | | Avg Energy (GWh/yr) | Avg. Firm Capacity (MW-yr) | Avg. Revenue ($,000) | |
| **3 x 20 MW at Coclé** | $77,300 | $1,395 | 292.5 | 48.8 | $16,090 | 23% |
| **2 x 15 MW at Coclé** | $32,100 | $595 | 100.3 | 17.2 | $5,546 | 15% |
| **2 x 15 MW at Indio** | $53,700 | $931 | 132.4 | 22.8 | $7,326 | 19% |
| **2 x 15 MW at Pablon** | $55,200 | $914 | 193.6 | 24.3 | $10,168 | 18% |

Table 11 shows that each of the developments is economically viable, and therefore can be integrated in a strategy. In order to compare the strategies, the costs and revenues of the schemes involved in each strategy must be added to determine the best development. In addition, the incremental revenues from the Gatun and Madden projects resulting from the reservoir operation must be accounted for as the projected energy production at these plants vary depending on the adopted strategy, as shown on Tables 2, 3 and 4. For the purpose of comparing the strategies, a rate of return that includes incremental revenue from Gatun and Madden has been calculated and is shown in Table 12 below.

**Table 12 – Comparison of Strategies (Coclé 50-71)**

| | Installed Capacity (MW) | Construction Cost ($1,000) | O&M Cost ($1,000/year) | Annualized PV (12%) of Revenue | Rate of Return |
|---|---|---|---|---|---|
| | | **Strategy 1** | | | |
| Cocle del Norte | 60 | 77,300 | 1,395 | 21,750 | |
| Indio | 2.5 | Assumed Exist | No change | 510 | 23% |
| Gatun | 24 | Existing | No change | 1,260 | |
| Madden | 36 | Existing | No change | 7,900 | |
| Total | | 77,300 | 1,395 | 31,420 | |
| | | **Strategy 2** | | | |
| Rio Indio | 30 | 53,700 | 931 | 12,070 | |
| Cocle del Norte | 30 | 32,100 | 595 | 5,880 | |
| Gatun | 24 | Existing | No change | 1,470 | 17% |
| Madden | 36 | Existing | No change | 7,720 | |
| Total | | 85,800 | 1,526 | 27,140 | |
| | | **Strategy 3** | | | |
| Cocle del Norte | 30 | 32,100 | 595 | 5,880 | |
| Indio | 2.5 | Assumed Exist. | No change | 680 | |
| Isla Pablon | 40 | 55,200 | 914 | 12,000 | 20% |
| Gatun | 24 | Existing | No change | 4,540 | |
| Madden | 36 | Existing | No change | 7,920 | |
| Total | | 87,300 | 1,509 | 31,020 | |

On the basis of the higher return, and higher revenue particularly in the initial years of operation, Strategy 1, which consists of a large development at the Río Coclé del Norte dam site, is recommended. The economic advantage of Strategy 1 over the other schemes is further evidenced with the comparison of the net present value of the three strategies as shown on Table 13 below.

**Table 13 – Comparison of Scheme Net Present Values (Coclé 50-71)**

| | Present Value of Benefits ($,000) | Present Value of O&M Costs ($,000) | Present Value of Construction ($,000) | Net Present Value of the Project ($,000) |
|---|---|---|---|---|
| Strategy No.1 | 261,500 | 11,600 | 95,200 | 154,700 |
| Strategy No.2 | 226,200 | 12,700 | 105,500 | 108,000 |
| Strategy No.3 | 258,200 | 12,600 | 107,400 | 138,200 |

All present values were calculated at a discount rate of 12%, for the first year of operation (estimated to be 2029). Operation and maintenance costs and revenues were estimated for a period of 60 years following the first year of operation. Estimated hydroelectric revenues from the Gatun and Madden power plants were included to facilitate the comparison of strategies, however, it was assumed that O&M for these two existing plants would be the same for each strategy. From Table 15, it can be seen that Strategy No.1 would contribute approximately $46,700,000 and $16,500,000 more to the economic benefits of the Río Coclé del Norte Water Supply Project than strategies No.2 and No.3, respectively.

The preliminary selection of 60 MW as installed capacity for the Río Coclé del Norte power plant was further evaluated. For that purpose, cost estimates of the proposed scheme for three different installed capacities at the dam site were developed and are presented in Table 14 below.

**Table 14 – Coclé del Norte Development Cost Comparison (Coclé 50-71)**

| Description | 3 x 15-MW Power Plant Cost ($,000) | 3 x 20-MW Power Plant Cost ($,000) | 3 x 25-MW Power Plant Cost ($,000) |
|---|---|---|---|
| Power Intake Civil Work | $2,066 | $2,193 | $2,372 |
| Power Intake Equipment | $2,075 | $2,800 | $3,645 |
| Shaft, Tunnel and Liner | $4,611 | $5,242 | $6,712 |
| Power Plant Civil Work | $2,665 | $3,137 | $3,653 |
| Power Plant Equipment | $16,127 | $18,969 | $22,929 |
| Transmission System | $21,381 | $21,731 | $22,081 |
| Subtotal | $48,925 | $54,072 | $61,392 |
| Contingencies | $7,805 | $8,639 | $9,845 |
| Eng. & Admin (15%) | $8,510 | $9,407 | $10,686 |
| **Total** | **$65,240** | **$72,118** | **$81,923** |

The generated energy, firm capacity and the present value of the revenues of each of these developments are presented in Table 15 below.

**Table 15 - Coclé del Norte Development Revenue Comparison (Coclé 50-71)**

| Description | 3 x 15-MW Power Plant | 3 x 20-MW Power Plant | 3 x 25-MW Power Plant |
|---|---|---|---|
| Annual Energy Generated in 2029 | 380.2 | 423.6 | 450.5 |
| Firm Power in 2029 | 45 | 60 | 75 |
| Annual Energy Generated in 2081 | 103.6 | 117.7 | 129.3 |
| Firm Power in 2081 | 14.5 | 14.5 | 14.5 |
| Average Annual Energy Generated over the 50-year period | 299.6 | 326.8 | 343.2 |
| Present Value (at 12%) of Revenue ($,000) | $158,700 | $181,000 | $196,700 |

The internal rate of return for each of the schemes presented above has been calculated using the previously estimated benefits: the IRR of the 45-MW, 60-MW and 75-MW projects are 23.4%, 24.1% and 23.2%, respectively. The computation of the IRR and expected energy production sequences are presented in Attachment 5. On that basis a 60-MW power plant is recommended. Table 16 below shows the results of the economic comparison of the evaluated hydropower development at the Coclé del Norte dam site.

**Table 16 - Installed Capacity Comparisons (Coclé 50-71)**

| | Const. Cost ($,000) | Annual O&M Cost ($,000) | Avg. Annual Revenue ($,000) | Rate of Return |
|---|---|---|---|---|
| **3 x 15 MW Scheme** | $65,240 | $1,160 | $14,300 | 23% |
| **3 x 20 MW Scheme** | $72,120 | $1,300 | $16,100 | 24% |
| **3 x 25 MW Scheme** | $81,920 | $1,490 | $17,400 | 23% |

## 2.3 Recommended Scheme

### 2.3.1 General

The proposed Hydroelectric Development associated with the Coclé del Norte reservoir operating between El.50 and El.71 consists of a 60-MW power plant located at the toe of the dam. Under the recommended strategy, which would consist of maximizing hydropower generation at the Coclé del Norte dam, no other hydropower plant would provide a viable economic return.

The average annual energy generated by the 60-MW power plant will vary from 425 GWh per year for the first years of the project, when most of the water is used to generate electricity at the Coclé del Norte dam site, to 120 GWh per year, after approximately 50 years when the system of reservoirs in the Panama Canal Watershed are dedicated to maximize the water supply yield in Lake Gatun to meet the water supply demand. On average, over the first 50 years of the project, the 60-MW power plant will generate 327 GWh per year.

### 2.3.2 Civil Works

#### 2.3.2.1 Power Intake

The power intake is located on the right abutment of the dam, approximately 40 meters west of the spillway. It consists of a reinforced concrete tower, 35 meters high with foundation at approximately El 35 and the access platform level with the crest of the dam. A 6-meter wide bridge will be built to access the intake tower. The waterways invert is located at El. 43. The trashrack consists of three bays 7 meters wide by 8 meters high, separated by a central pier, and each upstream of a conduit 2.50 meters wide by 3.80 meters high. Each conduit contains a gate, and a short steel liner. The conduits join and transition into the 5.80-meter diameter vertical shaft. The vertical shaft extends in the tower all the way up to the access platform.

#### 2.3.2.2 Shaft, Tunnel and Manifold

At the base of the power intake, a vertical shaft 30 meters deep is to be excavated to El. 5 where it connects with the horizontal tunnel. The 5.80-meter diameter shaft is lined with reinforced concrete, and includes high pressure grouting. A 90° vertical bend transitions the shaft into the 5.80-meter diameter tunnel. The 260-meter long tunnel is steel lined and backfilled with concrete. The conduit diameter is reduced to 5.20 meters at the tunnel portal immediately upstream of the four-branch manifold. The manifold located in the back of the powerhouse consists of three 2.60-meter diameter branches and one 1.70-meter diameter. It is embedded in concrete and underneath the transformers. The manifold invert is at about El. 1.

#### 2.3.2.3 Powerhouse

The powerhouse is a conventional 60-meter long by 17.5-meter wide reinforced concrete structure located on the right banks of the Rio Coclé del Norte, between the toe of the dam and the spillway. It contains three unit bays and one service bay located at the western end of the powerhouse nearest to the access. The foundation excavation, in sound rock, is down to El. -9 approximately 15 to 20 meters below existing ground surface at that location and is approximately 38 meters long. The centerline of the units is located at El. –2.0 below the minimum tailwater level. A 5-meter long shaft connects the generator to the turbine; the generator floor level is at El. 2.

The powerhouse downstream deck, the surrounding ground and access are at El. 6 to protect the area against flooding while a large discharge would be released through the low level outlet. It is estimated that a discharge of 1,100 $m^3/s$ would create a tailwater level above El 5.0. The Probable Maximum Flood, a discharge from the spillway of 800 $m^3/s$, would raise the tailwater level to El 4.3. Above El 6.0, the superstructure is made of structural steel with metal cladding. The powerhouse houses the mechanical and electrical equipment in four bays and three levels below grade. The powerhouse also contains the minimum release pressure relief valve (1.50-meter diameter) to insure the minimum release from the reservoir even during outage due maintenance or repair.

### 2.3.3 Mechanical and Electrical Equipment

#### 2.3.3.1 Power Intake

The power tunnel intake will include a trash screen consisting of three bays, each with twelve 2.0 meters by 2.0 meters removable screen panels and associated supports and guides. At the top of the concrete intake structure two rail mounted trash rakes will be provided. The trash rakes will also serve to install and remove the trash screen panels and stop logs. Nine 2.0 meters by 2 meters stop logs, sufficient to close one bay under balanced head, will be provided.

The intake structure will contain the intake gates consisting of three 2.5 meters x 3.8 meters wheeled gates designed to close the power tunnel under full flow and reservoir pressure condition. The associated guides, hoists and controls will be provided.

To serve the power tunnel intake area equipment, lighting and dam roadway lighting a 480-V line from the powerhouse will be provided. Provision will also be made for a 50kW portable emergency generator for use during power outage in this area. The portable emergency generator can also be used at the Low Level Outlet intake or at the switchyard if needed.

#### 2.3.3.2 Powerhouse

*Inlet Valve*

At the end of three manifold branches, serving the three 20-MW units, 2.3-meter diameter spherical inlet valves will be provided in the powerhouse. Inlet valves will be provided with the required hydraulic power units and control devices, and the various tapings for filling and draining of the associated waterways.

*Turbine/Generator Units*

For this powerhouse we have selected three turbine/generator units rated at 20-MW each. The selected number and size of units takes into consideration the required flexibility of operation under anticipated range of heads and flows at the site.

The turbines are of the vertical shaft Francis type with a steel spiral case and following characteristics:

| | |
|---|---|
| **Turbine** | 20 MW |
| Runner diameter | 1.90 meters |
| Design net head | 68 meters |
| Discharge | 35 $m^3/s$ |
| Rated output | 27,000 hp |
| Setting | 2 meters below minimum tailwater level |
| Speed | 300 RPM |

| | |
|---|---|
| **Generator** | |
| Type | Synchronous / direct coupled |
| Rated output | 22,250 kVA |
| Terminal voltage | 13.8 kV |
| Frequency | 60 Hz |
| Power factor | 0.90 |

*Turbine/Generator Auxiliaries*
Each unit will be provided with the necessary auxiliaries such as bearings, servomotor, hydraulic power unit, digital governor, cooling water system for turbine bearing, shaft seal and generator bearings and coolers, lubricating oil system, excitation system, voltage regulator, automatic synchronizer, brakes, SCADA and protection system.

*Draft Tube Gates*
Each 20-MW unit will have two welded steel sliding gates 3.00-meter wide and 1.90-meter high to allow for unit and tunnel dewatering. The same 75-tonne semi-gantry crane provided for the turbine/generator units will handle draft tube gates.

*Cranes*
A 75-ton semi-gantry crane spanning the powerhouse and the draft tube deck, and running on rails located at elevations 5.0 and 11.0 will be provided to handle turbine and generator components, inlet valves and draft tube gates during erection and maintenance. The lower rail is located at El. 6.0, 1meter above the expected maximum water level.

*Dewatering system*
The dewatering system will consist of two dewatering pumps and two station drainage pumps in each of the two conveniently located station dewatering and sump pits, and associated piping and valves to enable dewatering of each turbine independently or to dewater the whole system including the power tunnel. To prevent powerhouse flooding pumps will be sized to cope with failure of largest penstock tapping in the powerhouse and upstream of main inlet valves.

*Switchgear*

The generating voltage will be 13.8-kV. Generators will have individual main power transformers directly connected to the generators. Generator breakers will be on the 230kV side of the transformers and will be located in the switchyard. Station service power will be provided at 480/277-V thru service power and station service transformers described below. Therefore, no HV or MV switchgear is anticipated in the powerhouse.

A 480/277-V station service power distribution switchboard will be provided to feed the outlaying areas, the station auxiliaries and the three unit auxiliary motor control centers (MCC). Each unit MCC will also be fed from the unit auxiliary transformer providing power for its own auxiliaries when the unit is in operation.

*Transformers*
Three main power transformers for the generating units will be provided. They will be located adjacent to the powerhouse and connected to the switchyard by an underground line in a duct bank. The main power transformers will be three phase, oil filled step-up transformers 13.8kV - 230kV, 60Hz with standard ratings of 25MVA, Class OA *(liquid-immersed air-cooled, self-cooled).*

A Service Power Transformer with standard rating of 5MVA, Class OA located in the switchyard will be used to step down the voltage from 230-kV to 13.8-kV.

A Station Service Transformer, located at the powerhouse, to serve all utilization level power requirements at the site, will be provided. The transformer will be a three phase, oil filled step down transformer from 13.8-kV to 480-V, 60-Hz rated 2 MVA, Class OA. The station service transformer will be fed from the service power transformer by an overhead 15kV line.

Each unit will have a 150kVA dry type transformer directly connected to the generator terminals stepping down the voltage from 13.8-kV to 480/277-V to feed the unit auxiliary MCC.

*Station Auxiliaries*
Other station auxiliaries will include a 500-kW stand-by diesel generator, station battery, lighting system, Heating, Ventilation and Air Conditioning, fire alarm and protection system, communication system, and grounding and lightning protection.
Medium and low voltage power cables, as well as control, instrumentation and communication wires and cables will be provided to serve various needs at the site.

### 2.3.3.3 Switchyard

The switchyard will be located at approximate El. 20 on a leveled area at the toe of the dam about 100 meters east of the powerhouse. The area required is approximately 130 meters by 65 meters. It will be a 230-kV switchyard of conventional open air design utilizing the 'breaker and a half' switching scheme. The switchyard will have three fully equipped bays serving the three generator units, a single circuit 230-kV transmission line and the service power transformer. All galvanized steel gantries and equipment supporting structures, as well as concrete foundations and cable trenches, will be provided. It will be fenced in and served by access and boundary roads. A suitably sized control building will also be provided to house the control, protection, metering and communication equipment.

#### 2.3.3.4 Transmission System

The transmission system is depicted in the simplified one-line diagram included in this report. It includes the step-up main power transformers, one for each turbine-generator unit, connected by overhead lines to the 230-kV switchyard at the project site. From the switchyard a single circuit 230-kV transmission line will carry the station output to ETESA's La Chorrera Substation where it will be connected to the National Grid.

The proposed single circuit line will cross the Río Coclé del Norte near the project site in the eastern direction and proceed in that direction and by passing the Río Indio Dam to the vicinity of Isla Pablon. It will then continue in the east-southeast direction to La Chorrera Substation. The total length of the proposed line is estimated at 109 km. The line route was over flown by helicopter and studied with the help of available geographic and topographic maps at various scales that depict the roads and main features of the land. The western part of line route nearer to the project site is hilly and forested terrain while eastern part nearer to the La Chorrera Substation is of more gentle topography suitable for relatively easy construction.

The transmission line will be designed and built for 230-kV operation utilizing steel towers with one circuit having three 750-kcmil ACAR conductors. The shield wires and conductors will be supported in horizontal configuration by single shaft lattice steel towers with steel arms. Each tower will be provided with four reinforced concrete caissons or spread footing and pier type foundations. The average height of the towers will be 30 meters for a normal span of 250 meters.

One of the two empty 230-kV bays at La Chorrera Substation will be fully equipped to handle the new incoming line from Río Coclé del Norte project.

### 2.4 Project cost estimate

Detailed cost estimate of the hydropower component of the project are presented in Attachment 4 and are summarized below. The costs shown do not include the cost of access, general mobilization and other site preparation costs.

A 20% contingency factor has been used for the civil work component of the hydroelectric scheme. Contingencies on equipments and transmission line have been taken as 15%. An engineering and administration cost of 15% has been added to the overall construction cost.

The development cost of the hydropower component of the Río Coclé del Norte Project, consisting of one power plant, located at the toe of the dam equipped with three 20-MW units would increase the overall cost of the project by an estimated amount of $76,979,000. This amount includes the costs of 109 km of 230-kV transmission line from the project site to the existing La Chorrera substation.

**Estimated Development Cost**

| | | |
|---|---|---|
| **<u>Río Coclé del Norte Power Plant</u>** | | |
| **Civil Works** | | |
| • Power Intake | | $2,193,000 |
| • Power Tunnel and Manifold | | $5,242,000 |
| • Powerhouse | | <u>$3,137,000</u> |
| | **Subtotal** | **$10,572,000** |
| **Electrical & Mechanical Equipment** | | |
| • Power Intake | | $2,800,000 |
| • Generating Equipment | | $15,000,000 |
| • Auxiliary Powerhouse Equipment | | $1,719,000 |
| • Auxiliary Electrical | | <u>$2,250,000</u> |
| | **Subtotal** | **$21,769,000** |
| **<u>Transmission System</u>** | | |
| • Switchyard | | $3,481,000 |
| • 230-kV Transmission Line | | <u>$18,250,000</u> |
| | **Subtotal** | **$21,731,000** |
| **Subtotal** | | **$54,072,000** |
| Contingencies | | <u>$8,639,000</u> |
| Construction Cost of the Hydropower Component | | $62,711,000 |
| Engineering & Administration (15%) | | <u>$9,407,000</u> |
| **Total Estimated Development Cost** | | **$72,118,000** |

## 2.5 Economic Evaluation

The economic analysis presented in the comparison of alternatives shows an internal rate of return of 24.1% for the recommended hydropower scheme, which is well above the requirement for development. The project as presented will generate an estimated annual revenue of $22,660,000 for the initial years of operation. The revenue consists of $19,060,000 for energy (at $45 per MWh) and $3,600,000 for firm capacity (at $60 per kW-year). The revenues will diminish as water demand for Navigation increases until the Coclé del Norte reservoir become fully dedicated to the Canal operation estimated to be in 2081. At that time the revenues will become approximately $6,170,000 per year.

A sensitivity analysis of the rate of return to the costs of development and the value of energy is presented in Table 17 below.

**Table 17 – Sensitivity Analysis (Coclé 50-71)**

| Variables | Internal Rate of Return |
|---|---|
| Base Case | 24.1% |
| General Costs Increased by 20% | 20.6% |
| General Costs Increased by 10% | 22.2% |
| Value of Energy and Power Reduced by 20% | 19.6% |
| Value of Energy and Power Reduced by 10% | 21.0% |
| Value of Energy and Power Increased by 10% | 26.3% |
| Value of Energy and Power Increased by 20% | 28.4% |

# 3 COCLÉ DEL NORTE ACTING IN FULL REGULATION WITH THE RÍO CAÑO SUCIO AND RÍO INDIO RESERVOIRS

## 3.1 Selected Coclé Reservoir

The Caño Sucio and Coclé del Norte reservoirs have been sized without consideration for hydroelectric power and are anticipated to increase the water yield of the Panama Canal reservoir system from 60.3 L/d to 107.2 L/d at a reliability of 99.6%. The projection for unconstrained water demand for Navigation presented in the Reconnaissance Study and the M&I and tourism water demand presented in the report entitled "Long Term Forecast for M&I Demand" prepared by MWH, January 2001, indicates that the demand on the system is expected to reach 85.0 L/d by 2060. This corresponds to an average annual growth of 1.075% over the period 2030 to 2060. For the purpose of estimating hydropower benefit, it has been assumed that the rate of growth will remain constant over the following 30 years, i.e., to year 2090. On the basis of that assumption, the water demand will reach the yield of the reservoir system, including Gatun, Madden, Indio, Caño Sucio and Coclé del Norte, in 2082.

The initial configuration of the Panama Canal water supply system considered for this study consists of the deepened Lake Gatun operating between El. 23.93 (78.5 ft) and El. 26.75 (87.75 ft), the Madden reservoir, operating between El. 57.91 (190 ft) and El. 76.81 (252 ft) and the Río Indio reservoir operating between El. 40 and El. 80. It is assumed that the deepening of Lake Gatun will be completed and will allow draw down of the Lake three feet lower than it is currently allowed for normal operation. The reservoir operation studies conducted by the ACP with the HEC-5 simulation program have demonstrated that the yield of this system of reservoirs at the required reliability is 60.3 L/d (145.3 $m^3/s$). The Indio reservoir active storage provided is 1,294 million cubic meters (MCM).

Additional HEC-5 simulations undertaken by the ACP, have demonstrated that when the Caño Sucio and Coclé del Norte reservoirs are added to the system, the yield would increase to 107.2 L/d (258.3 $m^3/s$). The combined reservoir (Caño Sucio – Coclé del Norte) would operate between El. 90 and El. 100 and would have an active storage of 3,906 MCM. On average, the transfer tunnel between Caño Sucio and the Indio reservoir would convey 87.6 $m^3/s$. The average transferred discharge from Indio to Lake Gatun would be 105.7 $m^3/s$. The simulation considered minimum releases of 11.5 $m^3/s$ at the Coclé del Norte dam and 2.6 $m^3/s$ at the Río Indio dam. The results of the Coclé del Norte – Caño Sucio – Río Indio reservoir simulations under these conditions are shown in graphical form in Attachment 6.

Figures 6 and 7 below show plots of the Coclé del Norte reservoir levels against the weekly transferred discharges into Indio reservoir and of the Indio reservoir levels against the weekly transferred discharges into Lake Gatun, respectively.

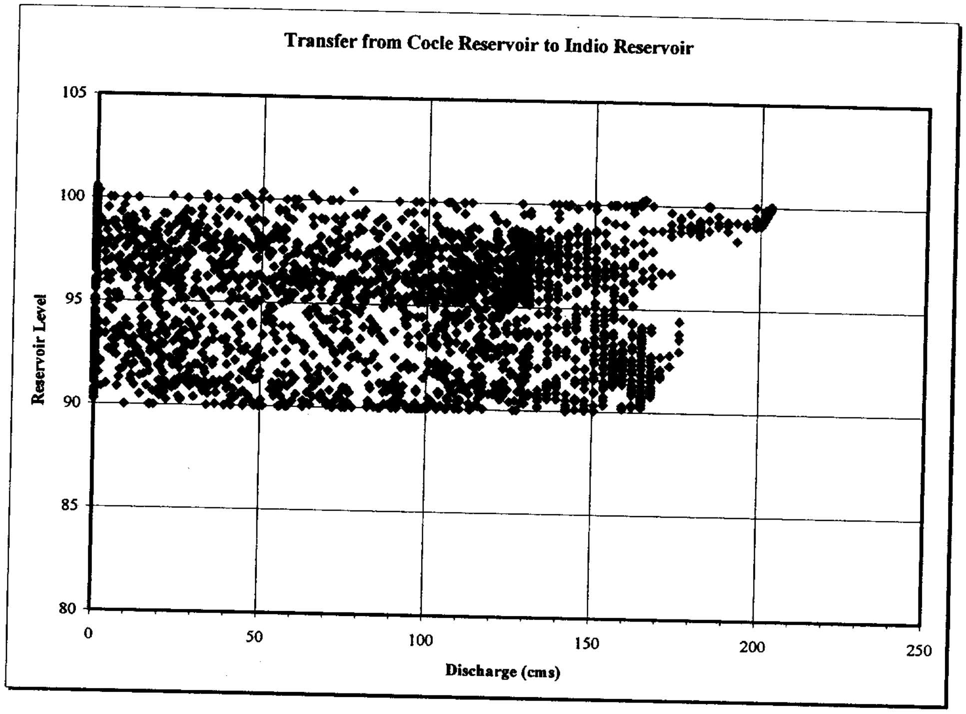



**Figure 6 - Coclé del Norte Reservoir Operation El. 90 – El. 100**

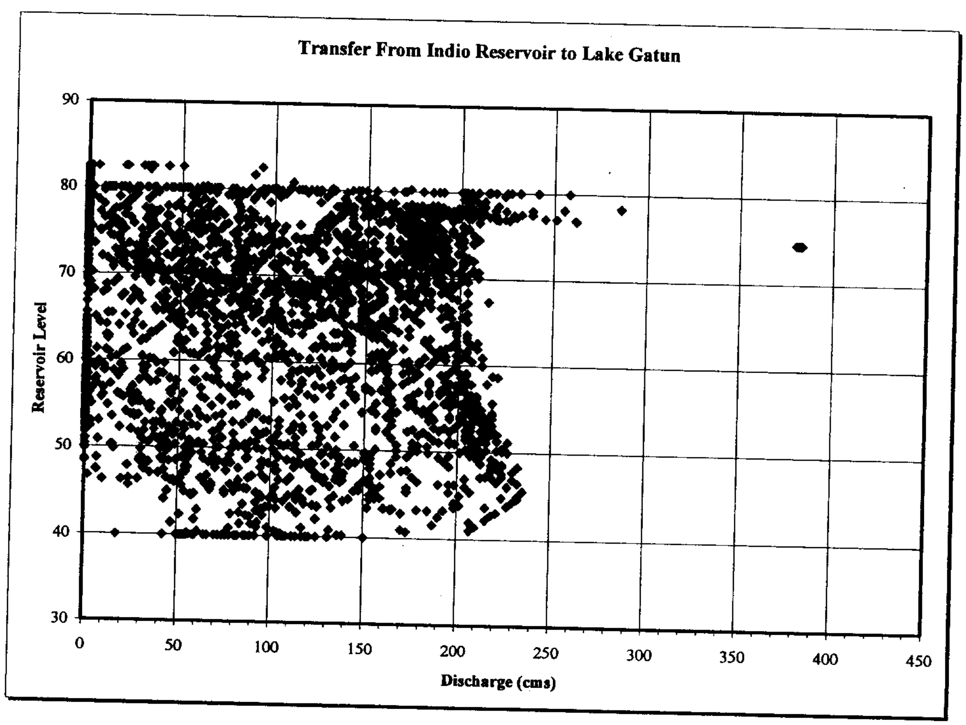



**Figure 7 – Indio Reservoir Operation (Coclé 90-100)**

Figures 8 and 9 below show the Coclé and Indio reservoir elevation frequency curves derived from the HEC-5 simulation. These curves are used to select the best turbine operating range.

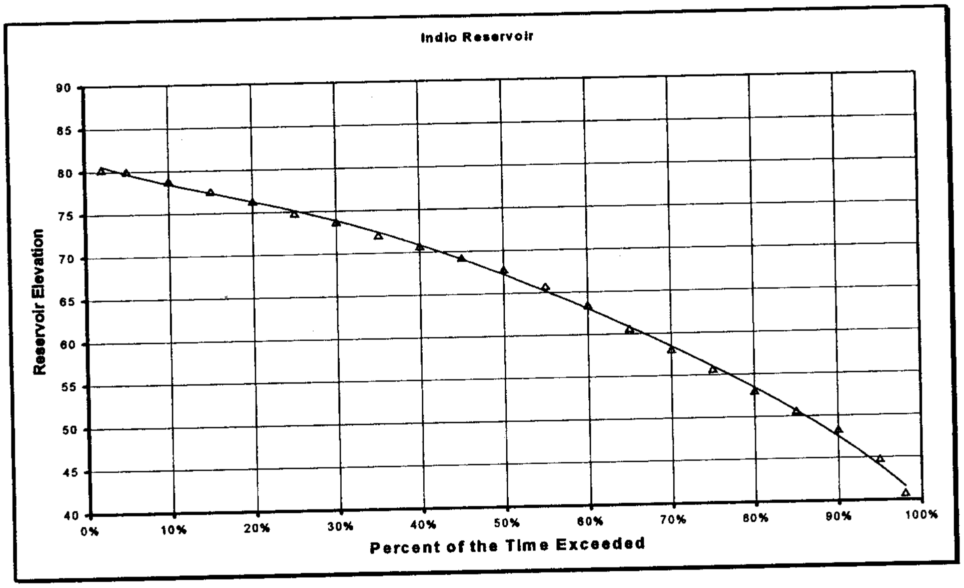



**Figure 8 – Indio Reservoir Elevation Duration Curve (Coclé 90-100)**

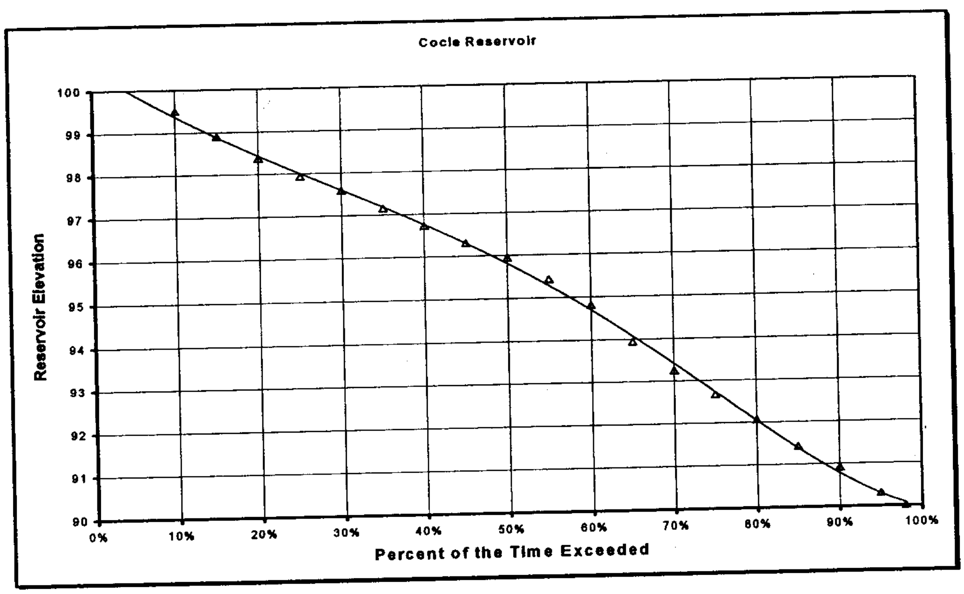



**Figure 9 – Cocle Reservoir Elevation Duration Curve (Coclé 90-100)**

The transfer tunnels, one between Caño Sucio and Indio, and two between Indio and Lake Gatun have been sized for the purpose of delivering water into Lake Gatun and not necessarily for hydroelectric power generation. The present study considered that the Río Indio project has been developed and includes a 4.50-meter diameter D-shaped transfer tunnel, 8.4 kilometers long. The discharge capacity of the tunnel varies between 43 $m^3/s$ with Indio reservoir at El.40 and 94 $m^3/s$ with the reservoir at El. 80.

The required transfer capacity between Indio and Lake Gatun for operation with the Coclé reservoir is approximately 391 $m^3/s$: for that purpose a second tunnel 6.50-meter diameter D-shaped will be built parallel to the existing one. The capacity of this second tunnel varies between 156 $m^3/s$ with Indio reservoir at El.40 and 297 $m^3/s$ with the reservoir at El. 80. The transfer tunnel from the Coclé-Caño reservoir to Indio is a 5.5-meter diameter tunnel 1.2 km long with a capacity of 214 $m^3/s$ with the Coclé reservoir at El 100 and the Indio reservoir at or below El 70. Figure 10 below shows plots of the transferred discharge duration curves.

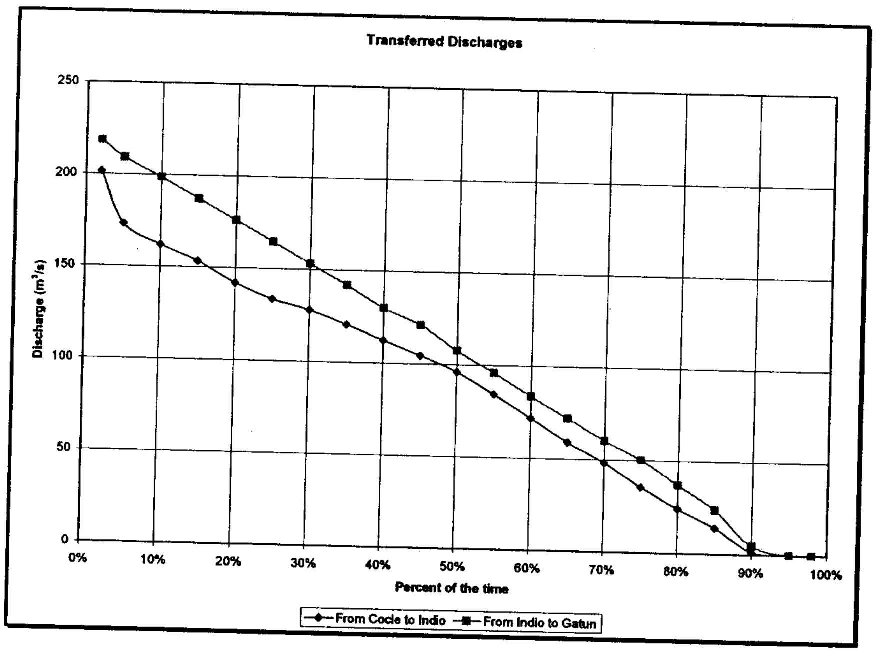



**Figure 10 – Transferred Discharge Duration Curves (Coclé 90-100)**

## 3.2 Hydropower Scheme Selection for Coclé Reservoir 90-100

### 3.2.1 Reservoir Operations and System Yield

The reservoir operation simulations presented above were performed to assess the water supply yield of the system of reservoirs. Under these conditions, most of the water passes through the transfer tunnels and only the minimum release of 10.8 $m^3/s$ at the Coclé del Norte dam and 2.6 $m^3/s$ at the Indio dam could be developed. Hydropower could also be developed at the downstream end of the transfer tunnel, but generally the conditions may not be the most favorable at these locations as the transfer tunnels are long and the net head is relatively limited.

It is estimated that the system will not be required to supply its full yield until approximately 50 years after the project completion. In this interim period, more favorable hydropower developments could be developed, even if these potential developments had a limited economic life. For the purpose of selecting the best hydropower development associated with the reservoir scheme, a number of reservoir simulations with modified operating rules were performed.

Three different strategies were investigated:

- Strategy 1 would consist in discharging the maximum possible flow into the Río Coclé del Norte to favor hydropower development at that site.
- Strategy 2 would consist in discharging the maximum flow into the Río Indio to favor hydropower development at that site.
- Strategy 3 would consist in discharging the maximum flow through the transfer tunnel between Indio and Lake Gatun to favor the development of a power plant at the Isla Pablon site.

Strategy 3 would also favor energy production at the Gatun 24-MW hydroelectric plant.

The operating rules considered would reduce the overall yield of the system, and therefore they would have a limited life: for each of these strategies, the yield of the system and the estimated year when the water demand will reach that yield are shown on Table 18. It should be noted that reducing the active storage of the Indio reservoir has a relatively small impact on the system yield after the Coclé project is built.

For all three strategies energy production and firm capacity at the four potential hydropower sites were calculated for a range of hydropower plant capacities. In order to estimate the energy production for any given scheme, it was assumed that operating rules would apply until the water demand reaches the yield achieved under these conditions. Rules would be progressively relaxed to increase the yield of the system. For example under Strategy 1, the Coclé del Norte reservoir would release a constant 80 $m^3/s$ downstream of the dam through a power plant until 2048; this discharge would be progressively reduced to 60 m³/s in 2062, and 40 m³/s in 2071, and so on, until the full yield of the system is reached and only the minimum release is discharged through the Coclé del Norte power plant. Strategy 1A would consist of the same rules of operation for the Coclé reservoir, but Indio reservoir would be operated between El. 60 and El 80. Similarly, Strategy 2 would apply to the Indio power plant. Under Strategy 3, a continuous, constant discharge would be transferred from Indio to Gatun. It is apparent on Table 18 that this strategy hardly limits the yield of reservoir system, and therefore a power plant at the end of the transfer tunnel, could generate energy from all transferred water for the entire interim period. It is only towards the end of that period that the variation in discharges would become unfavorable to power generation.

**Table 18 – Reservoir System Yield (Coclé 90-100)**

| | Coclé & Caño Constant Release (m³/s) | Indio Constant Release (m³/s) | Indio Operating Range | Constant Transferred Discharge into Gatun (m³/s) | System Yield (L/d) | Year |
|---|---|---|---|---|---|---|
| **Base Case** | 11.5 | 2.6 | 40 – 80 | No Rule | 107.2 | 2082 |
| **Strategy 1** | 20.0 | 2.6 | 40 – 80 | No Rule | 103.7 | 2078 |
| | 40.0 | 2.6 | 40 – 80 | No Rule | 95.2 | 2071 |
| | 60.0 | 2.6 | 40 – 80 | No Rule | 86.5 | 2062 |
| | 80.0 | 2.6 | 40 – 80 | No Rule | 77.6 | 2048 |
| **Strategy 1A** | 20.0 | 2.6 | 60 – 80 | No Rule | 102.5 | 2077 |
| | 40.0 | 2.6 | 60 – 80 | No Rule | 94.0 | 2069 |
| | 60.0 | 2.6 | 60 – 80 | No Rule | 85.2 | 2060 |
| | 80.0 | 2.6 | 60 – 80 | No Rule | 76.4 | 2046 |
| **Strategy 2** | 11.5 | 20.0 | 40 – 80 | No Rule | 99.8 | 2075 |
| | 11.5 | 40.0 | 40 – 80 | No Rule | 91.3 | 2067 |
| | 11.5 | 60.0 | 40 – 80 | No Rule | 82.6 | 2055 |
| | 11.5 | 80.0 | 40 – 80 | No Rule | 73.9 | 2044 |
| **Strategy 3** | 11.5 | 2.6 | 40 – 80 | 20.0 | 106.9 | 2081 |
| | 11.5 | 2.6 | 40 – 80 | 40.0 | 106.8 | 2081 |
| | 11.5 | 2.6 | 40 – 80 | 60.0 | 106.5 | 2081 |
| | 11.5 | 2.6 | 40 – 80 | 80.0 | 105.9 | 2080 |
| **Strategy 3A** | 11.5 | 2.6 | 60 - 80 | 80.0 | 105.2 | 2079 |

Under Strategy 3A, Indio reservoir would be maintained between El. 60 and El. 80 and a constant 80 m³/s discharge would be transferred to Gatun. The minimum releases of 10.8 m³/s at Coclé, 0.7 m³/s at Caño and 2.6 m³/s at Indio would be maintained. This operation could be sustained from 2032 until 2079 (on the assumed water demand growth). After that period power generation would be reduced during periods of high flow demand.

### 3.2.2 Energy Production

For the purpose of calculating the energy production and firm capacity, a spreadsheet-type model was developed: the model uses the weekly output of the HEC-5 simulation performed by the ACP. The project water released were those determined by the HEC-5 simulation. The tailwater rating curve established under the hydraulics studies was used for the purpose of calculating the gross head on the project at the Río Coclé and Río Indio dam sites.

The energy production at each potential site was calculated for a range of installed capacity depending on the strategy contemplated:

- At Río Coclé del Norte from 10 MW to 135 MW;
- At Caño Sucio from 20 MW to 60 MW;
- At Río Indio from 2.5 MW to 60 MW;
- At Isla Pablon from 20 MW to 50 MW.

The input parameters of the computation and the results are presented in Attachment 7. Typical sequences of energy generation are shown on tables 19, 20 and 21 below.

**Table 19 – Energy Production (GWh/yr) under Strategy 1 (Coclé 90-100)**

| Power Plant | 2032 | 2062 | 2071 | 2078 | 2082 |
|---|---|---|---|---|---|
| Coclé del Norte 90-MW | 542.4 | 413.4 | 277.1 | 138.0 | 76.0 |
| Isla Pablon 30-MW | 90.0 | 90.0 | 108.0 | 122.4 | 131.0 |
| Caño Sucio 20-MW | 46.7 | 46.7 | 58.4 | 59.3 | 60.2 |
| Indio 2.5-MW | 10.4 | 10.4 | 10.4 | 10.4 | 10.4 |
| Madden 36-MW | 187.9 | 165.5 | 161.8 | 158.4 | 157.0 |
| Gatun 24-MW | 54.5 | 16.2 | 14.2 | 13.0 | 12.6 |
| Total | 931.7 | 742.2 | 629.9 | 501.5 | 447.2 |

**Table 20 – Energy Production (GWh/yr) under Strategy 2 (Coclé 90-100)**

| Power Plant | 2032 | 2044 | 2055 | 2067 | 2075 | 2082 |
|---|---|---|---|---|---|---|
| Coclé del Norte 16-MW | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 |
| Isla Pablon 30-MW | 62.6 | 62.6 | 84.4 | 102.6 | 118.8 | 131.0 |
| Caño Sucio 20-MW | 88.9 | 88.9 | 79.5 | 73.9 | 69.0 | 60.2 |
| Indio 40-MW | 286.1 | 286.1 | 240.5 | 162.9 | 76.3 | 10.4 |
| Madden 36-MW | 187.9 | 171.4 | 167.2 | 163.4 | 159.9 | 157.0 |
| Gatun 24-MW | 54.5 | 20.1 | 16.9 | 14.5 | 13.5 | 12.6 |
| Total | 755.7 | 704.8 | 664.2 | 593.0 | 513.2 | 446.9 |

**Table 21 – Energy Production (GWh/yr) under Strategy 3A (Coclé 90-100)**

| Power Plant | 2032 | 2039 | 2079 | 2082 |
|---|---|---|---|---|
| Coclé del Norte 16-MW | 75.7 | 75.7 | 75.7 | 75.7 |
| Isla Pablon 40-MW | 285.8 | 285.8 | 220.3 | 155.9 |
| Caño Sucio 20-MW | 66.7 | 66.7 | 65.8 | 60.2 |
| Indio 2.5-MW | 13.6 | 13.6 | 11.9 | 10.4 |
| Madden 36-MW | 188.6 | 184.7 | 160.2 | 157.0 |
| Gatun 24-MW | 138.1 | 98.1 | 23.0 | 12.6 |
| Total | 768.5 | 724.4 | 556.9 | 453.8 |

It should be noted that each hydroelectric project should be economically justified individually on the basis of construction cost, operating cost and revenues to be considered in a strategy. The energy projections indicated in Tables 19, 20 and 21 are the maximum achievable if all projects are economically viable. Also, while Gatun and Madden power plants currently exist, a small 2.5-MW power plant is anticipated to be included in the Indio Project. For the purpose of the present study, the construction of a larger power plant at the Indio dam, if justified, would be concurrent with the construction of the Coclé project.

### 3.2.3 Power Scheme Selection

#### 3.2.3.1 General

As previously indicated each of the potential hydroelectric projects should be economically justified on its internal rate of return. As the primary objective of the project is water supply, the hydropower component will be evaluated on a marginal basis, meaning that the economic viability of a hydroelectric component is evaluated by comparing hydropower revenues to the cost specifically associated with the hydropower component.

The elements of the hydropower component cost generally include:

- Power intake;
- Power tunnel, or necessary enlargement of the transfer tunnel;
- Steel liner;
- Surge tank;
- Powerhouse structure and ancillary equipment;
- Generating equipment;
- Switchyard and transmission lines.

The energy and power benefits for each of these schemes were estimated based on the marginal value of energy presented in the power market studies ($45 per MWh) and the value of firm capacity of $60 per kW-yr. The firm capacity was calculated on the basis of the projected monthly energy production: it is the capacity that could be delivered 8 hours per day, every day of the month with the monthly energy exceeded 95% of the time.

The operation and maintenance cost of the hydropower scheme were estimated as follows:

- 1.0% of the cost of all civil works;
- 2.5% of the cost of all mechanical and electrical equipment;
- 1.5% of the cost of the transmission line.

The following sections evaluate the four potential hydropower developments: Coclé del Norte, Caño Sucio, Indio and Isla Pablon.

### 3.2.3.2 Coclé del Norte Power Plant

For this site, two project capacities can be considered depending on the followed energy strategy. For Strategy 1, the maximum installed capacity considered could be in the order of 140 MW if the project had power generation for sole purpose. It is however likely that a smaller capacity would be justified, as more and more water will be transferred to the Gatun watershed. Based on the sequence of reservoir operation developed previously for this strategy, the hydropower revenues for the 60-year period (from 2032, the initial year of operation, to 2091) were calculated for a range of installed capacity at the Coclé del Norte power plant. The present values (at the first year of operation) of these revenues were calculated for the purpose of comparing them to the implementation and running costs of the project: they are presented in Table 22 below. A discount rate of 12% was selected for this preliminary evaluation.

For strategies 2, 3 and 3A, the only water available for power generation at the dam site is the minimum release of 10.8 $m^3/s$. This discharge would allow the development of a power plant with an installed capacity of approximately 10 to 20 MW. The present values of these projects revenues are also presented in Table 22.

**Table 22 – Coclé del Norte Revenues (Coclé 90-100)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 1** | |
| 25 | $89,600 |
| 35 | $125,300 |
| 50 | $175,300 |
| 70 | $230,900 |
| 90 | $242,100 |
| 110 | $254,200 |
| 135 | $267,300 |
| **Strategies 2, 3 and 3A** | |
| 10 | $33,400 |
| 15 | $35,800 |
| 20 | $38,300 |
| 25 | $40,700 |

The project would consist of a power intake located near the spillway on the right abutment of the dam. Access to the intake would be gained from the dam crest via a bridge leading to a tower approximately 25 to 30 meter high. Immediately downstream of the trashrack and intake gates, the waterways would converge to a vertical shaft 70 to 75 meter deep; a near horizontal, 250-meter long tunnel would follow it. The powerhouse will be located on the right bank of the river between the toe of the dam and the spillway flip bucket. The switchyard will be located across the river approximately 200 meter from the powerhouse. For strategy 1, it is anticipated that a transmission line 230-kV will connect the project to the Substation at La Chorrera. For strategies 2, 3 and 3A a 115-kV line will be sufficient to carry the energy from Coclé to La Chorrera, as well as that of any additional power plant such as Indio (Strategy 2), Caño Sucio or Isla Pablon.

For the purpose of assessing the viability of the scheme for a given strategy, the preliminary cost estimates of two representative projects have been developed. These were a 3 x 30-MW power plant for Strategy 1 and a 2 x 8-MW power plant for Strategies 2, 3 and 3A. These estimates are presented in Table 23 below.

**Table 23 – Coclé del Norte Power Plant (Coclé 90-100) – Cost Estimates**

| Description | 3 x 30-MW Power Plant Cost ($,000) | 2 x 8-MW Power Plant Cost ($,000) |
|---|---|---|
| Power Intake Civil Work | $2,300 | $1,100 |
| Power Intake Equipment | $3,200 | $800 |
| Shaft, Tunnel and Liner | $7,700 | $2,200 |
| Power Plant Civil Work | $3,300 | $900 |
| Power Plant Equipment | $22,300 | $7,100 |
| Transmission System | $21,500 | $4,500 |
| Subtotal | $60,300 | $16,600 |
| Contingencies (25%) | $15,100 | $4,200 |
| Eng. & Admin (15%) | $11,300 | $3,100 |
| **Total** | **$86,700** | **$23,900** |

The cost for transmission line included in the estimate for the 90-MW development includes the cost of 109 kilometer of 230-kV from Coclé del Norte to the substation near La Chorrera, as this project would be the largest beneficiary of such a transmission line. For the 16-MW development only 61 kilometers of 115-kV transmission line, from Coclé del Norte to Isla Pablon are included as it is anticipated that this project would be developed in association with Isla Pablon.

The development costs of these projects are significantly lower than the present value of the benefits, and therefore they can be considered in the analysis of the hydropower component.

### 3.2.3.3 Caño Sucio Power Plant

As for Coclé del Norte development, the present value of the hydropower benefits of a power plant at the end of the transfer tunnel from Caño Sucio to Indio have been calculated for a range of installed capacity and for each strategy. The results are presented in Table 24 below.

To develop this scheme the proposed intake at the entrance of the transfer tunnel would be modified to accommodate trash-screens and a cleaning device located above the maximum water level. It would also require a larger intake as the transferred discharge of up to 210 $m^3/s$ would create excessive velocities and head losses. The 5.50-meter tunnel diameter would not be modified, as hydropower generation would not be contemplated during the period of high flows due to excessive losses. The tunnel outlet considered for the water-only scheme would be built for operation during period of high flows or when the hydropower is inoperable due to maintenance or repair. The power conveyance would consist of a vertical shaft located approximately 50 meters upstream of the proposed outlet structure. A 25-meter diameter surge tank would be built at ground level. The vertical shaft would lead to an underground powerhouse with the turbine centerline at El. 40 approximately. A tailrace tunnel approximately 400 meters long would return the water to Indio reservoir. A transmission line approximately 8-kilometer long would connect the scheme to the proposed Coclé-Indio-Pablon transmission system.

**Table 24 – Caño Sucio Hydropower Revenues (Coclé 90-100)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 1** | |
| 20 | $17,600 |
| 25 | $20,400 |
| 30 | $22,200 |
| 35 | $22,700 |
| **Strategy 2** | |
| 20 | $32,700 |
| 25 | $38,300 |
| 30 | $42,100 |
| 35 | $44,900 |
| **Strategies 3** | |
| 20 | $17,000 |
| 30 | $24,200 |
| 40 | $30,500 |
| 50 | $41,700 |
| 60 | $49,100 |
| **Strategy 3A** | |
| 20 | $24,900 |

For the purpose of assessing the site for its hydropower potential, the cost estimate of a two 10-MW power plant was developed and is presented in Table 25 below.

**Table 25 – Caño Sucio Power Plant (Coclé 90-100) - Cost Estimates**

| Description | 2 x 10-MW Power Plant Cost ($,000) |
|---|---|
| Power Intake Modification | $700 |
| Shaft, Surge Tank and Liner | $2,800 |
| Power Plant Civil Work | $4,200 |
| Tailrace Tunnel & Cofferdam | $7,600 |
| Power Plant Equipment | $8,600 |
| Transmission System | $2,000 |
| Subtotal | $25,900 |
| Contingencies (25%) | $6,500 |
| Eng. & Admin (15%) | $4,900 |
| Total | $37,300 |

The cost of the hydropower development at Caño Sucio exceeds the present value of the revenues for all strategies. It indicates that the project would have internal rate of return lower than 12% and therefore power development should not be contemplated at that location.

### 3.2.3.4 Río Indio Power Plant

The Río Indio dam and appurtenant works will have been built, along with the transfer tunnel from Indio to Gatun and a small 2.5-MW power plant at the toe of the dam, several years prior to the construction of the Coclé and Caño project. Under the proposed Strategy 2, a larger power plant would be built at the Indio dam on the left bank of the river. The project would include a power intake, a 600-meter long tunnel, a powerhouse, a switchyard and a 58.7-kilometer long, 115-kV transmission line to La Chorrera substation.

The present values of the hydropower benefits of such development have been calculated for a range of installed capacity and the results are presented in Table 26 below.

**Table 26 – Río Indio Hydropower Revenues (Coclé 90-100)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| Strategy 2 | |
| 30 | $79,200 |
| 40 | $103,300 |
| 50 | $112,600 |

For the purpose of assessing the site for its hydropower potential, the cost estimate of a two 20-MW power plant was developed and is presented in Table 27 below.

**Table 27 – Río Indio Power Plant (Coclé 90-100) - Cost Estimates**

| Description | 2 x 20-MW Power Plant Cost ($,000) |
|---|---|
| Power Intake incl. Cofferdam | $9,677 |
| Tunnel and Liner | $8,554 |
| Power Plant Civil Work | $1,651 |
| Power Plant Equipment | $15,748 |
| Transmission System | $6,158 |
| Subtotal | $41,788 |
| Contingencies (25%) | $10,447 |
| Eng. & Admin (15%) | $7,835 |
| **Total** | **$60,070** |

On the basis of this estimate, it appears that the Río Indio hydroelectric scheme should be considered as it is anticipated that it would have an internal rate return greater than 12%. This development would be competing with a large development at the Río Coclé dam site; only one of the two projects would be developed.

**3.2.3.5 Isla Pablon Power Plant**

The existing Río Indio project incorporates an 8.4-kilometer long, 4.50-meter diameter D-shaped tunnel to transfer water from the Indio reservoir to Lake Gatun. The discharge capacity of the tunnel varies between 43 $m^3$/s with Indio reservoir at El.40 and 94 $m^3$/s with the reservoir at El. 80. In conjunction with the development of the Coclé del Norte water supply project, a second tunnel 6.50-meter diameter D-shaped, parallel to the initial tunnel will be built to transfer the additional water to Lake Gatun. This tunnel will increase the transfer capacity to 225 $m^3$/sec with Indio reservoir at El.40 and 390 $m^3$/s with Indio at El. 80.

The Río Indio studies have demonstrated that hydropower development at the end of the first transfer tunnel (Isla Pablon) cannot be economically justified on the basis of the Río Indio project alone. The objective of the present study is to determine whether hydropower development can be justified on the second tunnel when the system of reservoirs includes Indio, Caño Sucio and Coclé del Norte. For the purpose of this evaluation it is assumed that the hydroelectric power plant would be developed at the same time as the tunnel.

The transfer capacity of the second tunnel must be guaranteed regardless of the ability of the power plant to discharge water. For that reason, the tunnel will include a bifurcation located approximately 50 meters upstream of the proposed outlet works; the power development will be built at the downstream end of a steel-lined branch. Both the outlet works and the power station will discharge in a common tailrace channel separate from the first tunnel tailrace channel.

**Table 28 –Isla Pablon Hydropower Revenues (Coclé 90-100)**

| Project Installed Capacity (MW) | Present Value of Revenues ($,000) |
|---|---|
| **Strategy 1** | |
| 20 | $26,000 |
| 30 | $33,900 |
| 40 | $39,100 |
| 50 | $41,200 |
| **Strategy 2** | |
| 20 | $19,200 |
| 30 | $24,900 |
| 40 | $27,400 |
| 50 | $28,000 |
| **Strategies 3** | |
| 20 | $35,200 |
| 30 | $49,900 |
| 40 | $52,300 |
| 50 | $52,800 |
| **Strategy 3A** | |
| 20 | $67,800 |
| 30 | $108,700 |
| 40 | $123,000 |
| 50 | $129,300 |

Development of the hydropower capability of the second tunnel will require some modification to the proposed tunnel. The intake will be equipped with finer trash-screens; the diameter of the tunnel will be increased so as to limit the head losses during hydropower operation to a maximum of 20% of the net head on turbine; and a surge tank near the downstream end of the tunnel will also be required to limit the starting characteristics of the waterways to a reasonable starting time. The cost of these features must be included in the economic evaluation of the hydropower component to determine the viability of a scheme developed on the second tunnel to Isla Pablon.

For the purpose of estimating the energy potential, it is assumed that, depending of the required transferred discharge, the second tunnel (including hydropower) will first be used to transfer water up to the capacity of the turbines. For larger discharges, the first tunnel will transfer discharge in excess of the turbine capacity, up to its capacity. Only when the required discharge is greater than the sum of the turbine capacity and the first tunnel capacity, the flow transferred through the second tunnel will be greater than the turbine capacity. Under these conditions, hydropower generation will be reduced as the head losses in the second transfer tunnel are increased.

For the purpose of assessing the site for its hydropower potential, the cost estimate of a power plant with two 20-MW units was developed and is presented in Table 29 below.

**Table 29 – Isla Pablon Power Plant (Coclé 90-100) - Cost Estimates**

| Description | 2 x 20-MW Power Plant Cost ($,000) |
|---|---|
| Power Intake Modification | $800 |
| Tunnel (Increasing diameter) | $7,800 |
| Surge Tank | $3,900 |
| Power Plant Civil Work | $8,500 |
| Power Plant Equipment | $18,100 |
| Transmission System | $5,600 |
| Subtotal | $44,700 |
| Contingencies (25%) | $11,200 |
| Eng. & Admin (15%) | $8,400 |
| **Total** | **$64,300** |

Comparison with expected hydropower revenues indicates that such power plant could only be justified under strategy 3A; the development could also include a small power plant at the Río Coclé dam site. For all other strategy the return of the development at Isla Pablon would be smaller than 12%. This development would be an alternative to large developments at either the Coclé dam site or at the Indio dam site.

**3.2.3.6 Strategy Selection**

To compare the three strategies the internal rate of return of each development was calculated and is presented in Table 30 below. Detailed calculations are presented in Attachment 9.

**Table 30 – Comparison of Alternatives (Coclé 90-100)**

| Scheme | Const. Cost ($,000) | Annual O&M Cost ($,000) | Period from 2032 to 2091 | | | Internal Rate of Return |
|---|---|---|---|---|---|---|
| | | | Avg Energy (GWh/yr) | Avg. Firm Cap. (MW-yr) | Avg. Revenue ($,000) | |
| **3 x 30 MW at Coclé** | $86,911 | $1,575 | 355.8 | 73.4 | $20,410 | 26% |
| **2 x 8 MW at Coclé** | $23,750 | $439 | 75.7 | 16.0 | $4,370 | 15% |
| **2 x 20 MW at Indio** | $60,070 | $1,037 | 170.9 | 0.0 | $7,690 | 17% |
| **2 x 20 MW at Pablon** | $64,070 | $1,070 | 216.5 | 18.7 | $10,860 | 19% |

Table 30 shows that each of the developments is economically viable, and therefore can be integrated in a strategy. In order to compare the strategies, the costs and revenues of the schemes involved in each strategy must be added to determine the best development. In addition, the incremental revenues from the Gatun and Madden projects resulting from the reservoir operation must be accounted for as the projected energy production at these plants vary depending on the adopted strategy, as shown on Tables 19, 20 and 21. For the purpose of comparing the strategies, a rate of return that includes incremental revenue from Gatun and Madden has been calculated and is shown in Table 31 below.

**Table 31 – Comparison of Strategies (Coclé 90-100)**

| | Installed Capacity (MW) | Construction Cost ($1,000) | O&M Cost ($1,000/year) | Annualized PV (12%) of Revenue | Rate of Return |
|---|---|---|---|---|---|
| | | **Strategy 1** | | | |
| Cocle del Norte | 90 | 86,900 | 1,575 | 29,087 | 26% |
| Indio | 2.5 | Assumed Exist | No change | 468 | |
| Gatun | 24 | Existing | No change | 2,004 | |
| Madden | 36 | Existing | No change | 8,114 | |
| Total | | 86,900 | 1,575 | 39,673 | |
| | | **Strategy 2** | | | |
| Rio Indio | 40 | 60,100 | 1,037 | 12,410 | 16% |
| Cocle del Norte | 16 | 23,700 | 439 | 4,367 | |
| Gatun | 24 | Existing | No change | 1,630 | |
| Madden | 36 | Existing | No change | 8,038 | |
| Total | | 83,800 | 1,476 | 26,445 | |
| | | **Strategy 3A** | | | |
| Cocle del Norte | 16 | 23,700 | 439 | 4,367 | 20% |
| Indio | 2.5 | Assumed Exist. | No change | 727 | |
| Isla Pablon | 40 | 64,100 | 1,070 | 14,455 | |
| Gatun | 24 | Existing | No change | 4,736 | |
| Madden | 36 | Existing | No change | 8,276 | |
| Total | | 87,800 | 1,509 | 32,561 | |

On the basis of the higher return, and higher revenue particularly in the initial years of operation, Strategy 1, which consists of a large development at the Río Coclé del Norte dam site, is recommended. The economic advantage of Strategy 1 over the other schemes is further evidenced with the comparison of the net present value of the three strategies as shown on Table 32 below.

**Table 32 – Comparison of Scheme Net Present Values (Coclé 90-100)**

| | Present Value of Benefits ($,000) | Present Value of O&M Costs ($,000) | Present Value of Construction ($,000) | Net Present Value of the Project ($,000) |
|---|---|---|---|---|
| Strategy No.1 | 330,218 | 13,109 | 107,035 | 210,074 |
| Strategy No.2 | 220,124 | 12,286 | 103,231 | 104,607 |
| Strategy No.3A | 273,903 | 12,560 | 108,157 | 153,186 |

All present values were calculated at a discount rate of 12%, for the first year of operation (estimated to be 2032). Operation and maintenance costs and revenues were estimated for a period of 60 years following the first year of operation. Estimated hydroelectric revenues from the Gatun and Madden power plants were included to facilitate the comparison of strategies, however, it was assumed that O&M for these two existing plants would be the same for each strategy. From Table 35, it can be seen that Strategy No.1 would contribute approximately $105,000,000 and $57,000,000 more to the economic benefits of the Río Coclé del Norte Water Supply Project than strategies No.2 and No.3A, respectively.

The preliminary selection of 90 MW as installed capacity for the Río Coclé del Norte power plant was further evaluated. For that purpose, cost estimates of the proposed scheme for three different installed capacities at the dam site were developed and are presented in Table 33 below.

**Table 33 – Coclé del Norte Development Cost Comparison (Coclé 90-100)**

| Description | 3 x 20-MW Power Plant Cost ($,000) | 3 x 25-MW Power Plant Cost ($,000) | 3 x 30-MW Power Plant Cost ($,000) |
|---|---|---|---|
| Power Intake Civil Work | $5,316 | $5,697 | $6,503 |
| Power Intake Equipment | $1,995 | $2,388 | $2,914 |
| Shaft, Tunnel and Liner | $5,726 | $6,893 | $8,323 |
| Power Plant Civil Work | $2,487 | $2,695 | $3,249 |
| Power Plant Equipment | $15,511 | $18,700 | $22,191 |
| Transmission System | $21,169 | $21,169 | $21,169 |
| Subtotal | $52,204 | $57,542 | $64,349 |
| Contingencies | $8,507 | $9,396 | $10,556 |
| Eng. & Admin (15%) | $9,107 | $10,041 | $11,236 |
| **Total** | **$69,818** | **$76,979** | **$86,141** |

The generated energy, firm capacity and the present value of the revenues of each of these developments are presented in Table 34 below.

**Table 34 - Coclé del Norte Development Revenue Comparison (Coclé 90-100)**

| Description | 3 x 20-MW Power Plant | 3 x 25-MW Power Plant | 3 x 30-MW Power Plant |
|---|---|---|---|
| Annual Energy Generated in 2032 | 472 GWh | 538 GWh | 542 GWh |
| Firm Power in 2032 | 60 MW | 75 MW | 90 MW |
| Annual Energy Generated in 2082 | 76 GWh | 76 GWh | 76 GWh |
| Firm Power in 2082 | 24.7 MW | 24.7 MW | 24.7 MW |
| Average Annual Energy Generated over the 50-year period | 379 GWh | 410 GWh | 412 GWh |
| Present Value (at 12%) of Revenue ($,000) | $203,450 | $233,830 | $242,120 |

The internal rate of return for each of the schemes presented above has been calculated using the previously estimated benefits: the IRR of the 60-MW, 75-MW and 90-MW projects are 27.3%, 28.5% and 26.6%, respectively. The computation of the IRR and expected energy production sequences are presented in Attachment 9. On that basis a 75-MW power plant is recommended. Table 35 below shows the results of the economic comparison of the evaluated hydropower development at the Coclé del Norte dam site.

**Table 35 - Installed Capacity Comparisons (Coclé 90-100)**

| | Const. Cost ($,000) | Annual O&M Cost ($,000) | Avg. Annual Revenue ($,000) | Rate of Return |
|---|---|---|---|---|
| **3 x 20 MW Scheme** | $69,818 | $1,186 | $17,879 | 27.3% |
| **3 x 25 MW Scheme** | $76,979 | $1,328 | $19,692 | 28.5% |
| **3 x 30 MW Scheme** | $86,141 | $1,500 | $20,411 | 26.6% |

## 3.3 Recommended Scheme (Coclé 90-100)

### 3.3.1 General

The proposed Hydroelectric Development associated with the Coclé del Norte reservoir operating between El.90 and El.100 consists of a 75-MW power plant located at the toe of the dam. Under the recommended strategy, which would consist of maximizing hydropower generation at the Coclé del Norte dam, no other hydropower plant would provide a viable economic return.

The average annual energy generated by the 75-MW power plant will vary from 538 GWH per year for approximately the first 15 years of the project, when most of the water is used to generate electricity at the Coclé del Norte dam site, to 76 GWh per year, after approximately 50 years when only 10.8 $m^3/s$ are released through the power plant, and most of the water is used to meet the water supply demand. On average, over the first 50 years of the project, the 75-MW power plant will generate 410 GWh per year.

### 3.3.2 Civil Works

#### 3.3.2.1 Power Intake

The power intake is located on the right abutment of the dam, approximately 40 meters west of the spillway. It consists of a reinforced concrete tower, 35 meters high with foundation at approximately El 68 and the access platform level with the crest of the dam. A 6-meter wide bridge will be built to access the intake tower. The waterways invert is located at El.84. The trashrack consists of three bays 7 meters wide by 8 meters high, separated by a central pier, and each upstream of a conduit 2.20 meters wide by 3.30 meters high. Each conduit contains a gate, and a short steel liner. The conduits join and transition into the 5.00-meter diameter vertical shaft. The vertical shaft extends in the tower all the way up to the access platform.

#### 3.3.2.2 Shaft, Tunnel and Manifold

At the base of the power intake, a vertical shaft 50 meters deep is to be excavated to El. 5 where it connects with the horizontal tunnel. The 5.00-meter diameter shaft is lined with reinforced concrete, and includes high pressure grouting. A 90° vertical bend transitions the shaft into the 5.00-meter diameter tunnel. The 260-meter long tunnel is steel lined and backfilled with concrete. The conduit diameter is reduced to 4.60 meters at the tunnel portal immediately upstream of the four-branch manifold. The manifold located in the back of the powerhouse consists of three 2.80-meter diameter branches and one 1.70-

meter diameter. It is embedded in concrete and underneath the transformers. The manifold invert is at about El. 1.

#### 3.3.2.3 Powerhouse

The powerhouse is a conventional 57-meter long by 16.5-meter wide reinforced concrete structure located on the right banks of the Rio Coclé del Norte, between the toe of the dam and the spillway. It contains three unit bays and one service bay located at the western end of the powerhouse nearest to the access. The foundation excavation, in sound rock, is down to El. -10 approximately 15 to 20 meters below existing ground surface at that location and is approximately 40 meters long. The centerline of the units is located at El. –3.0 below the minimum tailwater level. A 5-meter long shaft connects the generator to the turbine; the generator floor level is at El. 1.

The powerhouse downstream deck and surrounding ground and access are at El. 4 to protect the area against flooding during the Probable Maximum Flood (a discharge released from the spillway of 500 $m^3/s$). Above that level, the superstructure is made of structural steel with metal cladding. The powerhouse houses the mechanical and electrical equipment in four bays and three levels below grade. The powerhouse also contains the minimum release pressure relief valve (1.50-meter diameter) to insure the minimum release from the reservoir even during outage due maintenance or repair.

### 3.3.3 Mechanical and Electrical Equipment

#### 3.3.3.1 Power Intake

The power tunnel intake will include a trash screen consisting of three bays, each with twelve 2.0 meters by 2.0 meters removable screen panels and associated supports and guides. At the top of the concrete intake structure two rail mounted trash rakes will be provided. The trash rakes will also serve to install and remove the trash screen panels and stoplogs. Nine 2.0 meters by 2 meters stoplogs, sufficient to close one bay under balanced head, will be provided.

The intake structure will contain the intake gates consisting of three 2.2 meters x 3.3 meters wheeled gates designed to close the power tunnel under full flow and reservoir pressure condition. The associated guides, hoists and controls will be provided.

To serve the power tunnel intake area equipment, lighting and dam roadway lighting a 480-V line from the powerhouse will be provided. Provision will also be made for a 50kW portable emergency generator for use during power outage in this area. The portable emergency generator can also be used at the Low Level Outlet intake or at the switchyard if needed.

### 3.3.3.2 Powerhouse

*Inlet Valve*

At the end of three manifold branches, serving the three 25-MW units, 2.5-meter diameter spherical inlet valves will be provided in the powerhouse. Inlet valves will be provided with the required hydraulic power units and control devices, and the various tapings for filling and draining of the associated waterways.

*Turbine/Generator Units*

For this powerhouse we have selected three turbine/generator units rated at 25-MW each. The selected number and size of units takes into consideration the required flexibility of operation under anticipated range of heads and flows at the site.

The turbines are of the vertical shaft Francis type with a steel spiral case and following characteristics:

| | |
|---|---|
| **Turbine** | 25 MW |
| Runner diameter | 1.78 meters |
| Design net head | 95 meters |
| Discharge | 30 $m^3/s$ |
| Rated output | 34,000 hp |
| Setting | 3 meters below minimum tailwater level |
| Speed | 360 RPM |

| | |
|---|---|
| **Generator** | |
| Type | Synchronous / direct coupled |
| Rated output | 27,800 kVA |
| Terminal voltage | 13.8 kV |
| Frequency | 60 Hz |
| Power factor | 0.90 |

*Turbine/Generator Auxiliaries*

Each unit will be provided with the necessary auxiliaries such as bearings, servomotor, hydraulic power unit, digital governor, cooling water system for turbine bearing, shaft seal and generator bearings and coolers, lubricating oil system, excitation system, voltage regulator, automatic synchronizer, brakes, SCADA and protection system.

*Draft Tube Gates*

Each 25-MW unit will have two welded steel sliding gates 2.80-meter wide and 1.80-meter high to allow for unit and tunnel dewatering. The same 80-tonne semi-gantry crane provided for the turbine/generator units will handle draft tube gates.

*Cranes*

A 80-ton semi-gantry crane spanning the powerhouse and the draft tube deck, and running on rails located at elevations 4.0 and 10.0 will be provided to handle turbine and generator components, inlet valves and draft tube gates during erection and maintenance. Please note that elevation 4.0 the PMF water level.

*Dewatering system*
The dewatering system will consist of two dewatering pumps and two station drainage pumps in each of the two conveniently located station dewatering and sump pits, and associated piping and valves to enable dewatering of each turbine independently or to dewater the whole system including the power tunnel. To prevent powerhouse flooding pumps will be sized to cope with failure of largest penstock tapping in the powerhouse and upstream of main inlet valves.

*Switchgear*
The generating voltage will be 13.8-kV. Generators will have individual main power transformers directly connected to the generators. Generator breakers will be on the 230kV side of the transformers and will be located in the switchyard. Station service power will be provided at 480/277-V thru service power and station service transformers described below. Therefore, no HV or MV switchgear is anticipated in the powerhouse.

A 480/277-V station service power distribution switchboard will be provided to feed the outlaying areas, the station auxiliaries and the three unit auxiliary motor control centers (MCC). Each unit MCC will also be fed from the unit auxiliary transformer providing power for its own auxiliaries when the unit is in operation.

*Transformers*
Three main power transformers for the generating units will be provided. They will be located adjacent to the powerhouse and connected to the switchyard by an underground line in a duct bank. The main power transformers will be three phase, oil filled step-up transformers 13.8kV - 230kV, 60Hz with standard ratings of 30MVA, Class OA *(liquid-immersed air-cooled, self-cooled).*

A Service Power Transformer with standard rating of 5MVA, Class OA located in the switchyard will be used to step down the voltage from 230-kV to 13.8-kV.

A Station Service Transformer, located at the powerhouse, to serve all utilization level power requirements at the site, will be provided. The transformer will be a three phase, oil filled step down transformer from 13.8-kV to 480-V, 60-Hz rated 2 MVA, Class OA. The station service transformer will be fed from the service power transformer by an overhead 15kV line.

Each unit will have a 150kVA dry type transformer directly connected to the generator terminals stepping down the voltage from 13.8-kV to 480/277-V to feed the unit auxiliary MCC.

*Station Auxiliaries*

Other station auxiliaries will include a 500-kW stand-by diesel generator, station battery, lighting system, Heating, Ventilation and Air Conditioning, fire alarm and protection system, communication system, and grounding and lightning protection.
Medium and low voltage power cables, as well as control, instrumentation and communication wires and cables will be provided to serve various needs at the site.

**3.3.3.3 Switchyard**

The switchyard will be located at approximate El. 20 on a leveled area at the toe of the dam about 100 meters east of the powerhouse. The area required is approximately 130 meters by 65 meters. It will be a 230-kV switchyard of conventional open air design utilizing the 'breaker and a half' switching scheme. The switchyard will have three fully equipped bays serving the three generator units, a single circuit 230-kV transmission line and the service power transformer. All galvanized steel gantries and equipment supporting structures, as well as concrete foundations and cable trenches, will be provided. It will be fenced in and served by access and boundary roads. A suitably sized control building will also be provided to house the control, protection, metering and communication equipment.

**3.3.3.4 Transmission System**

The transmission system is depicted in the simplified one-line diagram included in this report. It includes the step-up main power transformers, one for each turbine-generator unit, connected by overhead lines to the 230-kV switchyard at the project site. From the switchyard a single circuit 230-kV transmission line will carry the station output to ETESA's La Chorrera Substation where it will be connected to the National Grid.

The proposed single circuit line will cross the Río Coclé del Norte near the project site in the eastern direction and proceed in that direction and by passing the Río Indio Dam to the vicinity of Isla Pablon. It will then continue in the east-southeast direction to La Chorrera Substation. The total length of the proposed line is estimated at 109 km. The line route was over flown by helicopter and studied with the help of available geographic and topographic maps at various scales that depict the roads and main features of the land. The western part of line route nearer to the project site is hilly and forested terrain while eastern part nearer to the La Chorrera Substation is of more gentle topography suitable for relatively easy construction.

The transmission line will be designed and built for 230-kV operation utilizing steel towers with one circuit having three 750-kcmil ACAR conductors. The shield wires and conductors will be supported in horizontal configuration by single shaft lattice steel towers with steel arms. Each tower will be provided with four reinforced concrete caissons or spread footing and pier type foundations. The average height of the towers will be 30 meters for a normal span of 250 meters.

One of the two empty 230-kV bays at La Chorrera Substation will be fully equipped to handle the new incoming line from Río Coclé del Norte project.

### 3.4 Project cost estimate

Detailed cost estimate of the hydropower component of the project are presented in Attachment 9 and are summarized below. The costs shown do not include the cost of access, general mobilization and other site preparation costs.

A 20% contingency factor has been used for the civil work component of the hydroelectric scheme. Contingencies on equipments and transmission line have been taken as 15%. An engineering and administration cost of 15% has been added to the overall construction cost. Detailed cost estimate are presented in Attachment 9.

The development cost of the hydropower component of the Río Coclé del Norte Project, consisting of one power plant, located at the toe of the dam equipped with three 25-MW units would increase the overall cost of the project by an estimated amount of $76,979,000. This amount includes the costs of 109 km of 230-kV transmission line from the project site to the existing La Chorrera substation.

**Estimated Development Cost**

| | | |
|---|---|---|
| **Río Coclé del Norte Power Plant** | | |
| **Civil Works** | | |
| • Power Intake | | $5,697,000 |
| • Power Tunnel and Manifold | | $6,893,000 |
| • Powerhouse | | $2,695,000 |
| | **Subtotal** | **$15,285,000** |
| **Electrical & Mechanical Equipment** | | |
| • Power Intake | | $2,388,000 |
| • Generating Equipment | | $13,688,000 |
| • Auxiliary Powerhouse Equipment | | $1,331,000 |
| • Auxiliary Electrical | | $3,681,000 |
| | **Subtotal** | **$21,088,000** |
| **Transmission System** | | |
| • Switchyard | | $2,919,000 |
| • 230-kV Transmission Line | | $18,250,000 |
| | **Subtotal** | **$21,169,000** |
| **Subtotal** | | **$57,542,000** |
| Contingencies | | $9,396,000 |
| Construction Cost of the Hydropower Component | | $66,938,000 |
| Engineering & Administration (15%) | | $10,041,000 |
| **Total Estimated Development Cost** | | **$76,979,000** |

### 3.5 Economic Evaluation

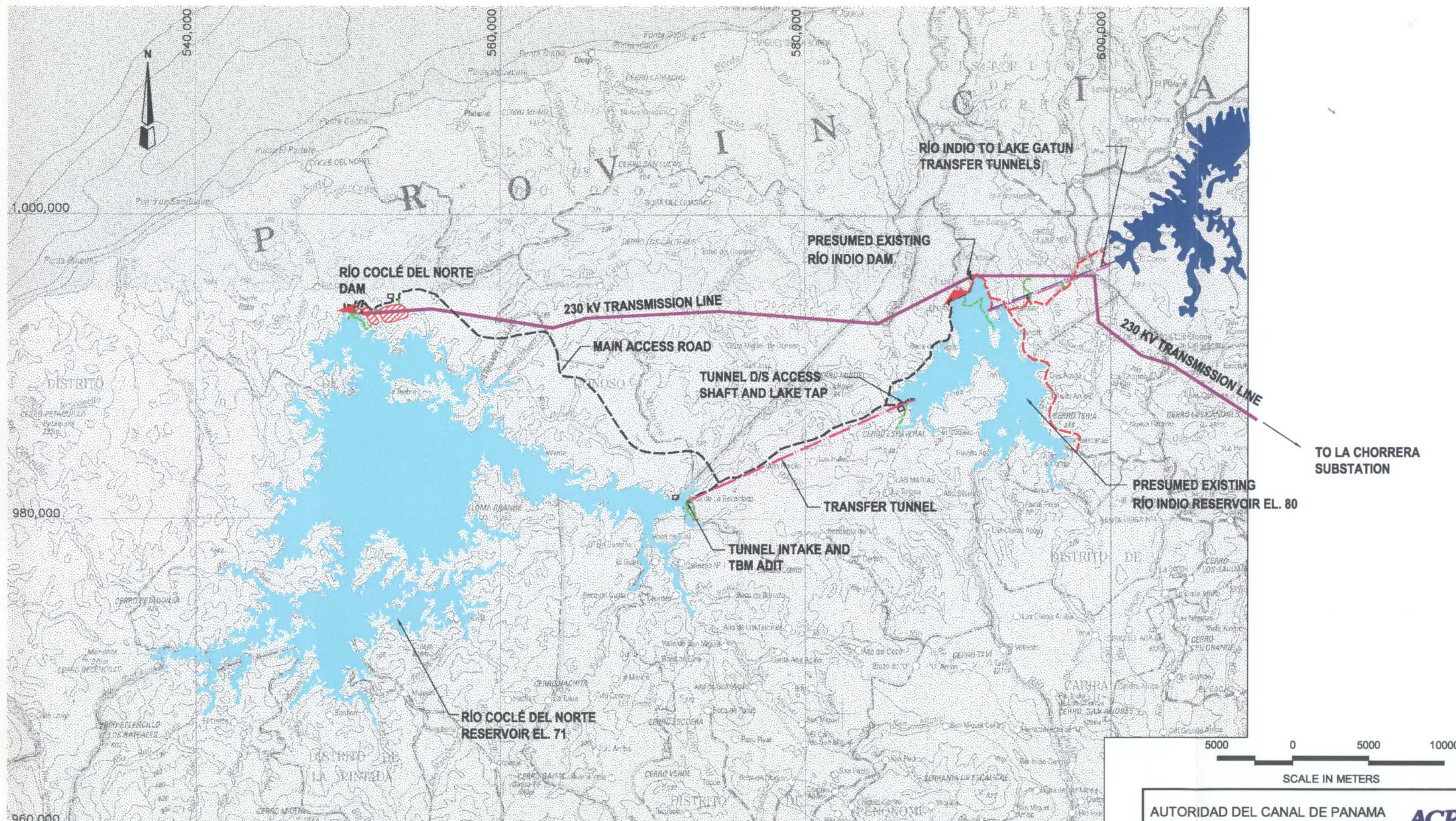
The economic analysis presented in the comparison of alternatives shows an internal rate of return of 28.5% for the recommended hydropower scheme, which is well above the requirement for development. The project as presented will generate an estimated annual revenue of $28,710,000 for the initial years of operation. The revenue consists of $24,210,000 for energy (at $45 per MWh) and $4,500,000 for firm capacity (at $60 per kW-year). The revenues will diminish as water demand for Navigation increases until the Coclé del Norte reservoir become fully dedicated to the Canal operation estimated to be in 2082. At that time the revenues will become approximately $4,900,000 per year.

A sensitivity analysis of the rate of return to the costs of development and the value of energy is presented in Table 36 below.

**Table 36 – Sensitivity Analysis (Coclé 90-100)**

| Variables | Internal Rate of Return |
|---|---|
| Base Case | 28.5% |
| General Costs Increased by 20% | 25.1% |
| General Costs Increased by 10% | 26.7% |
| Value of Energy and Power Reduced by 20% | 20.5% |
| Value of Energy and Power Reduced by 10% | 22.8% |
| Value of Energy and Power Increased by 10% | 29.0% |
| Value of Energy and Power Increased by 20% | 29.5% |

# EXHIBITS




**LEGEND:**

- 230 kV TRANSMISSION LINE
- PRESUMED EXISTING TRANSFER TUNNEL
- PROPOSED TRANSFER TUNNEL
- CONSTRUCTION CAMP
- PRESUMED EXISTING ACCESS ROAD
- PROPOSED PERMANENT ACCESS ROAD
- EXISTING PAVED ROAD
- CONSTRUCTION ACCESS
- QUARRY
- PROPOSED DAM
- PRESUMED EXISTING DAM
- PRESUMED EXISTING LAKE/ RESERVOIR
- PROPOSED RESERVOIR

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

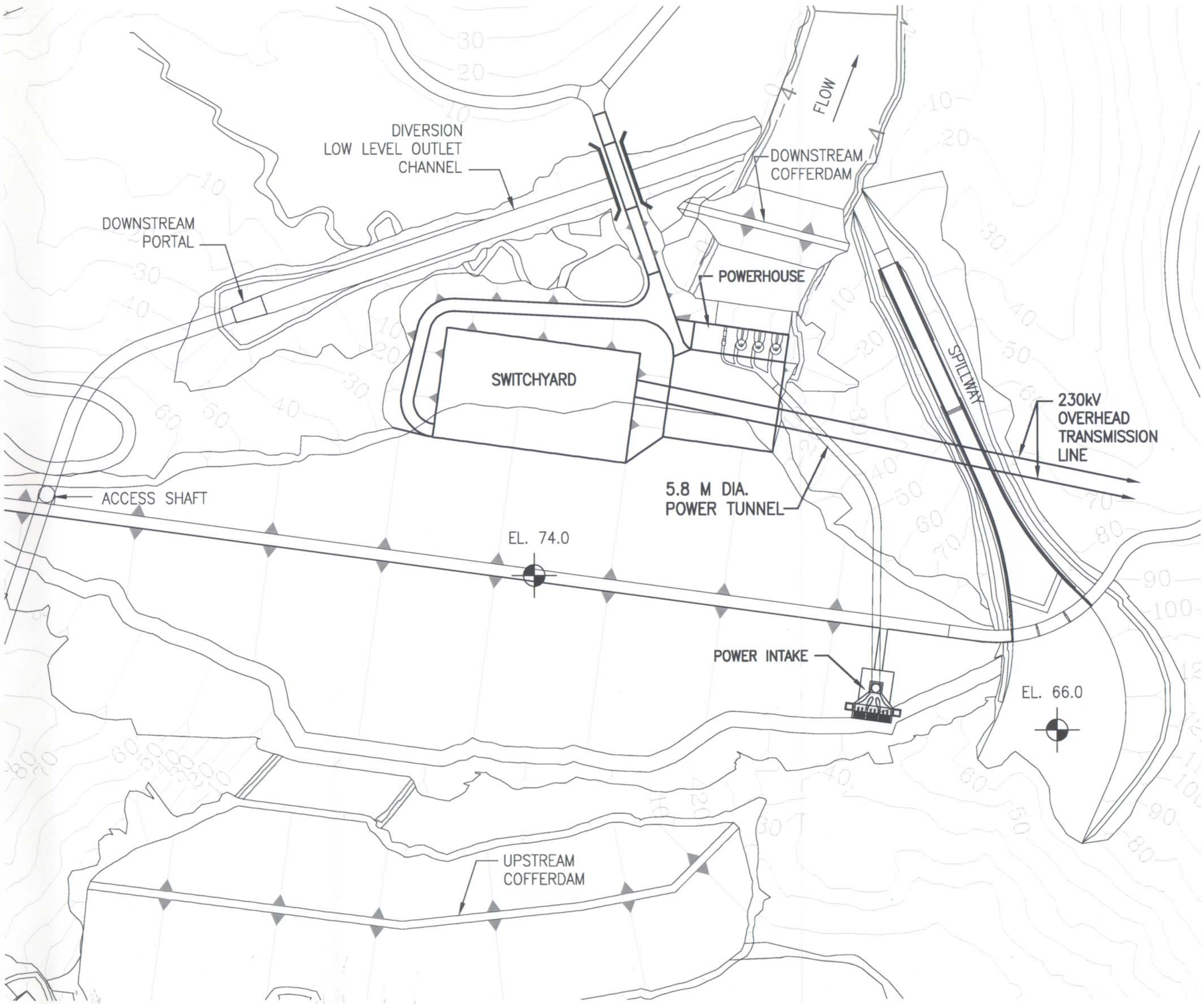
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## LOCATION MAP (COCLÉ 71)

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 1




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - GENERAL ARRANGEMENT**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 2 |

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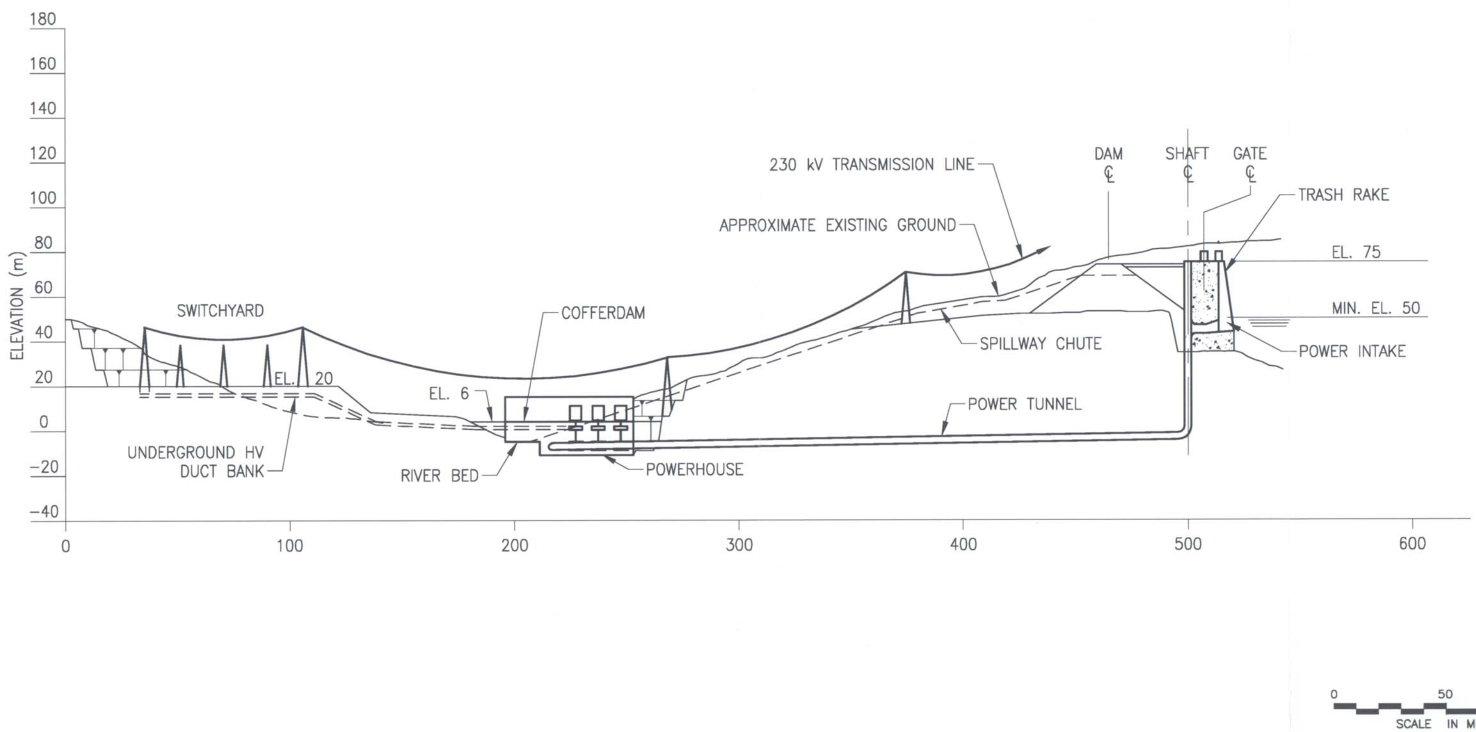



AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

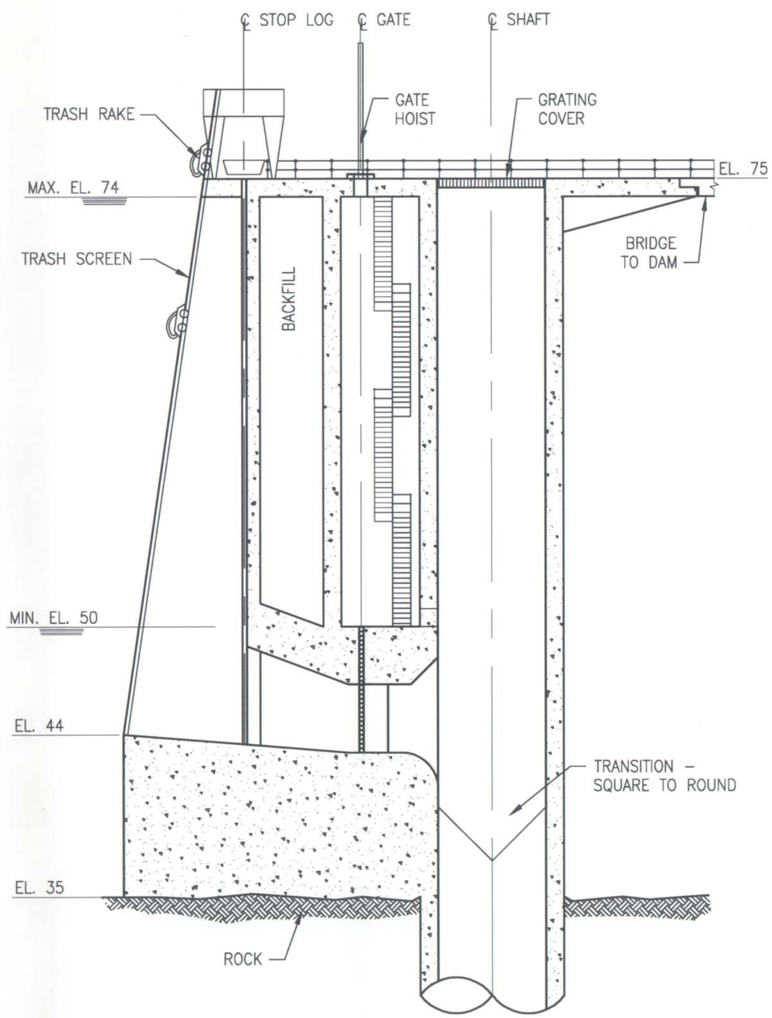
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

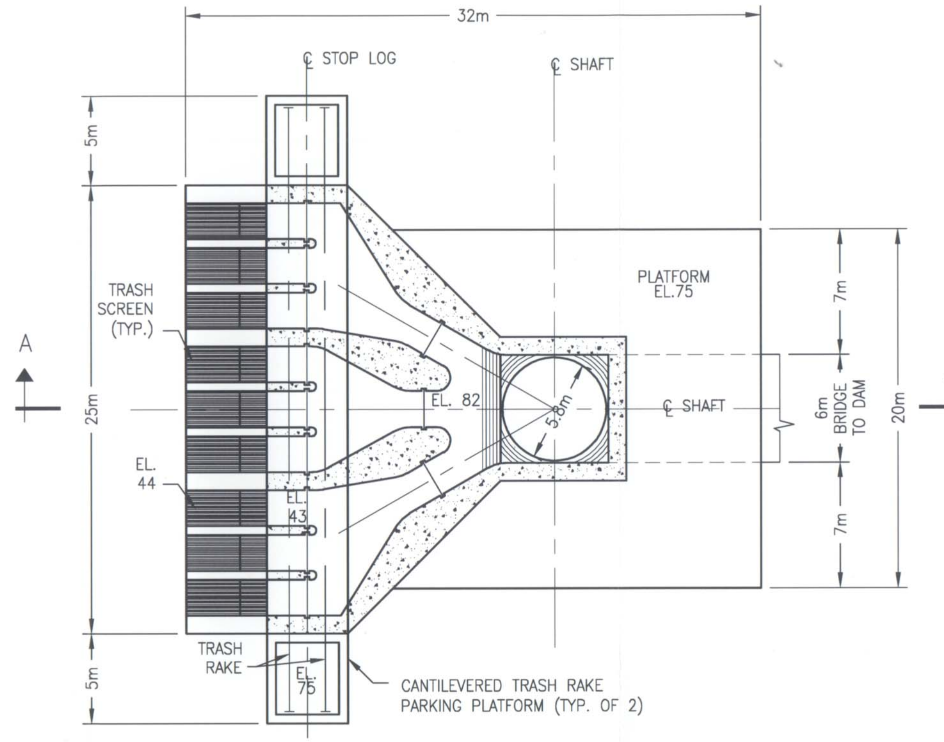
**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - PROFILE**

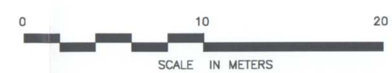
MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 3



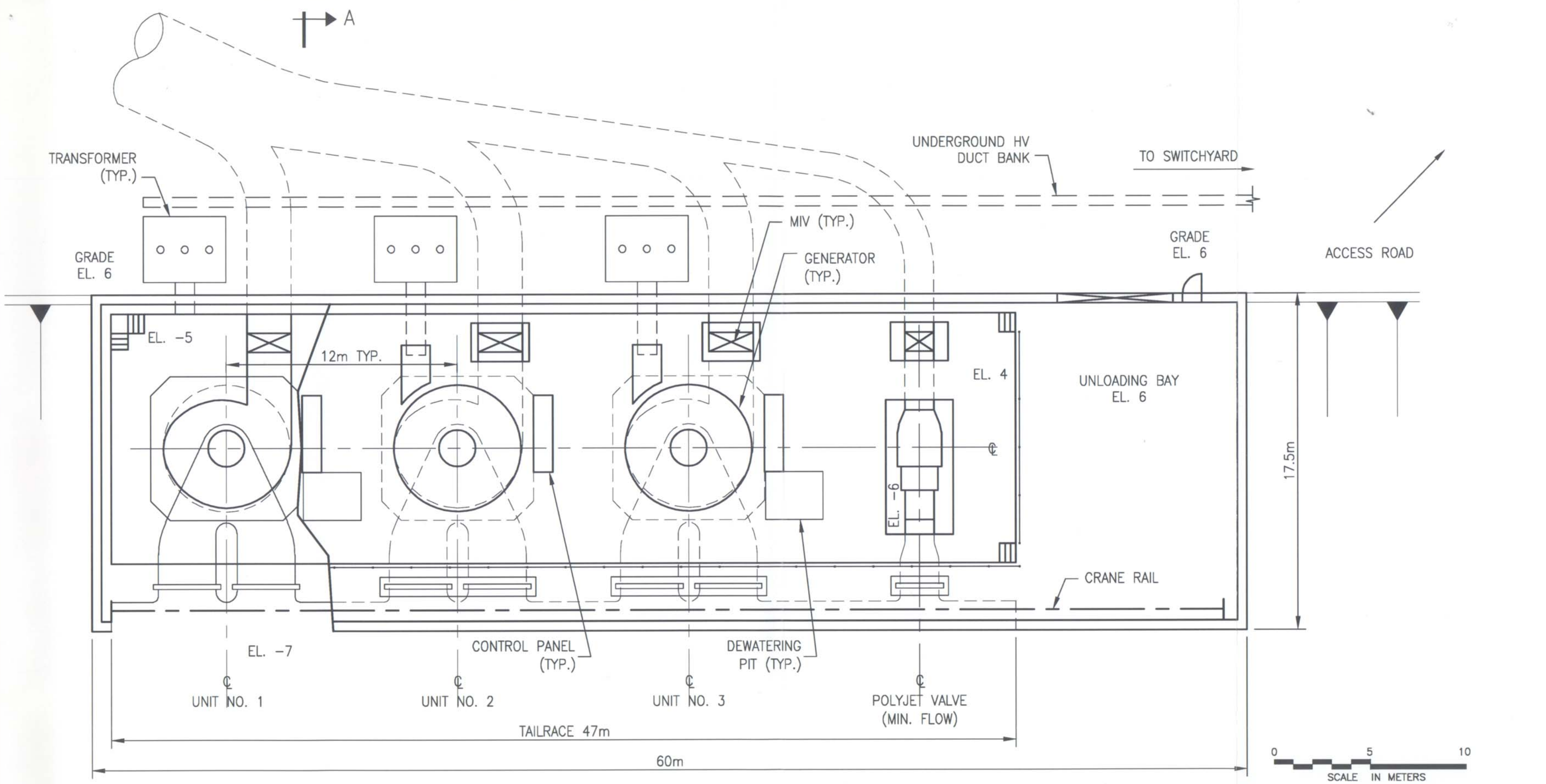

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - POWER INTAKE - PLAN AND SECTION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 4 |



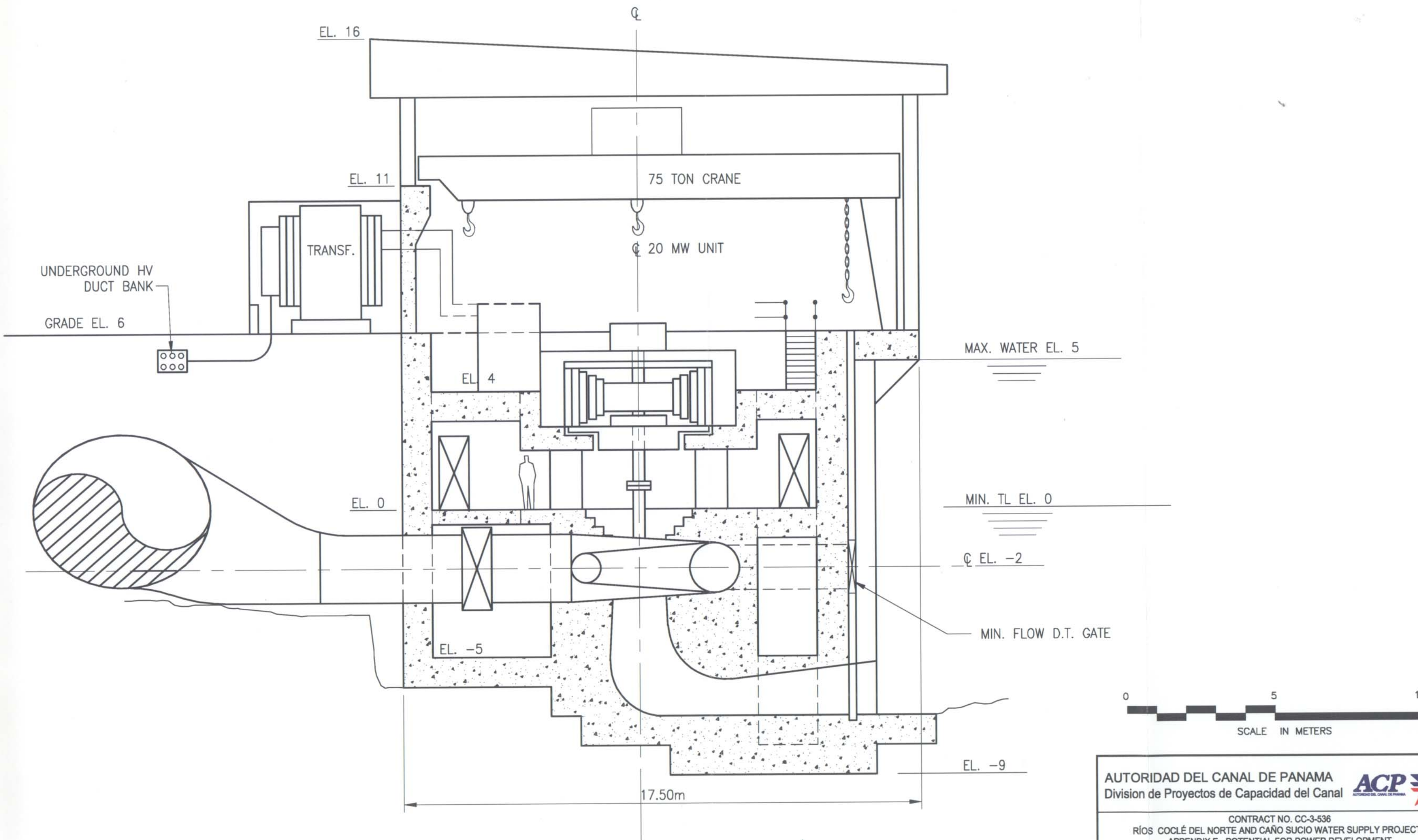

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - POWERHOUSE - PLAN**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 5 |




## SECTION A–A

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - POWERHOUSE - SECTION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 6 |

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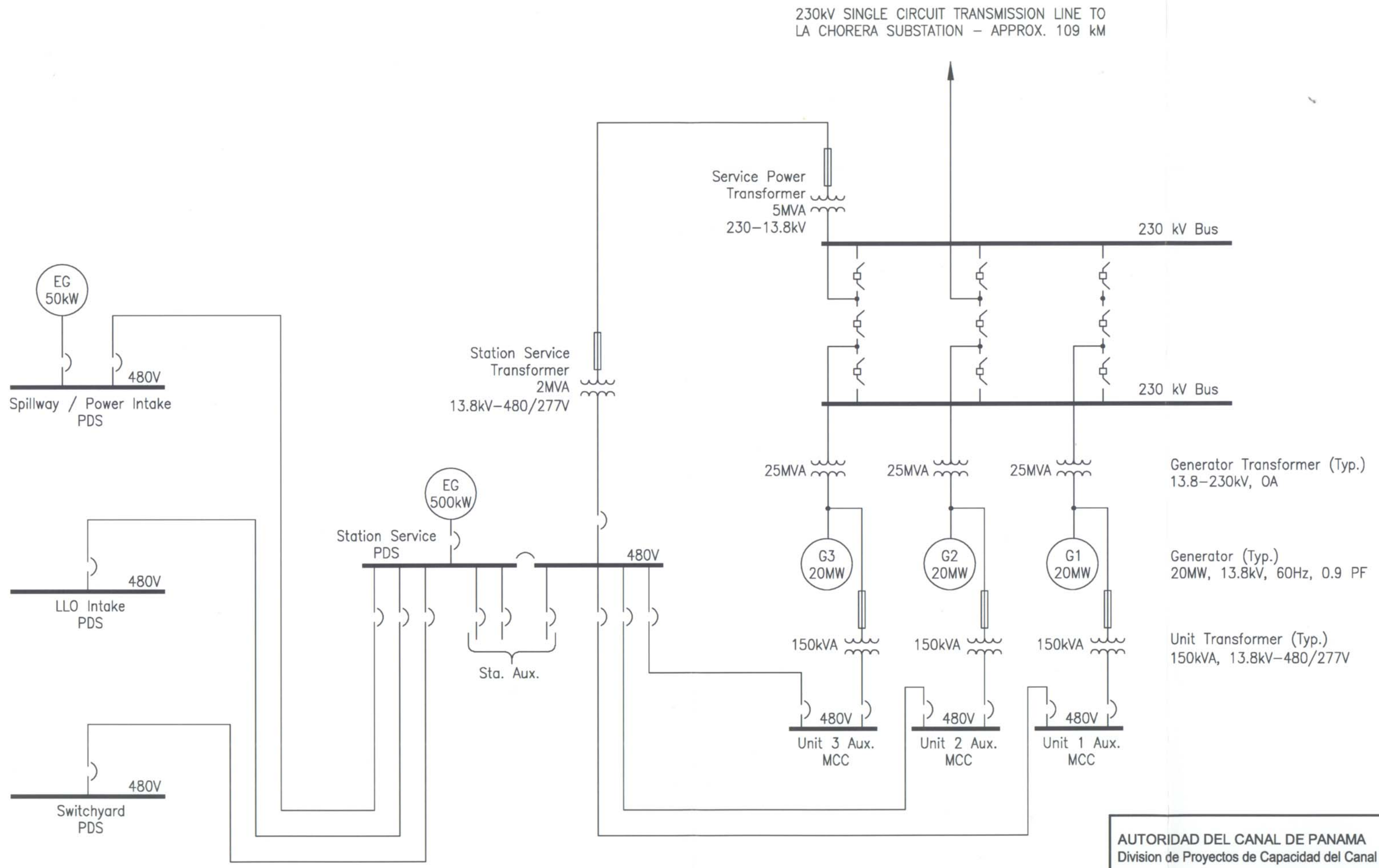



AUTORIDAD DEL CANAL DE PANAMA
División de Proyectos de Capacidad del Canal

ACP

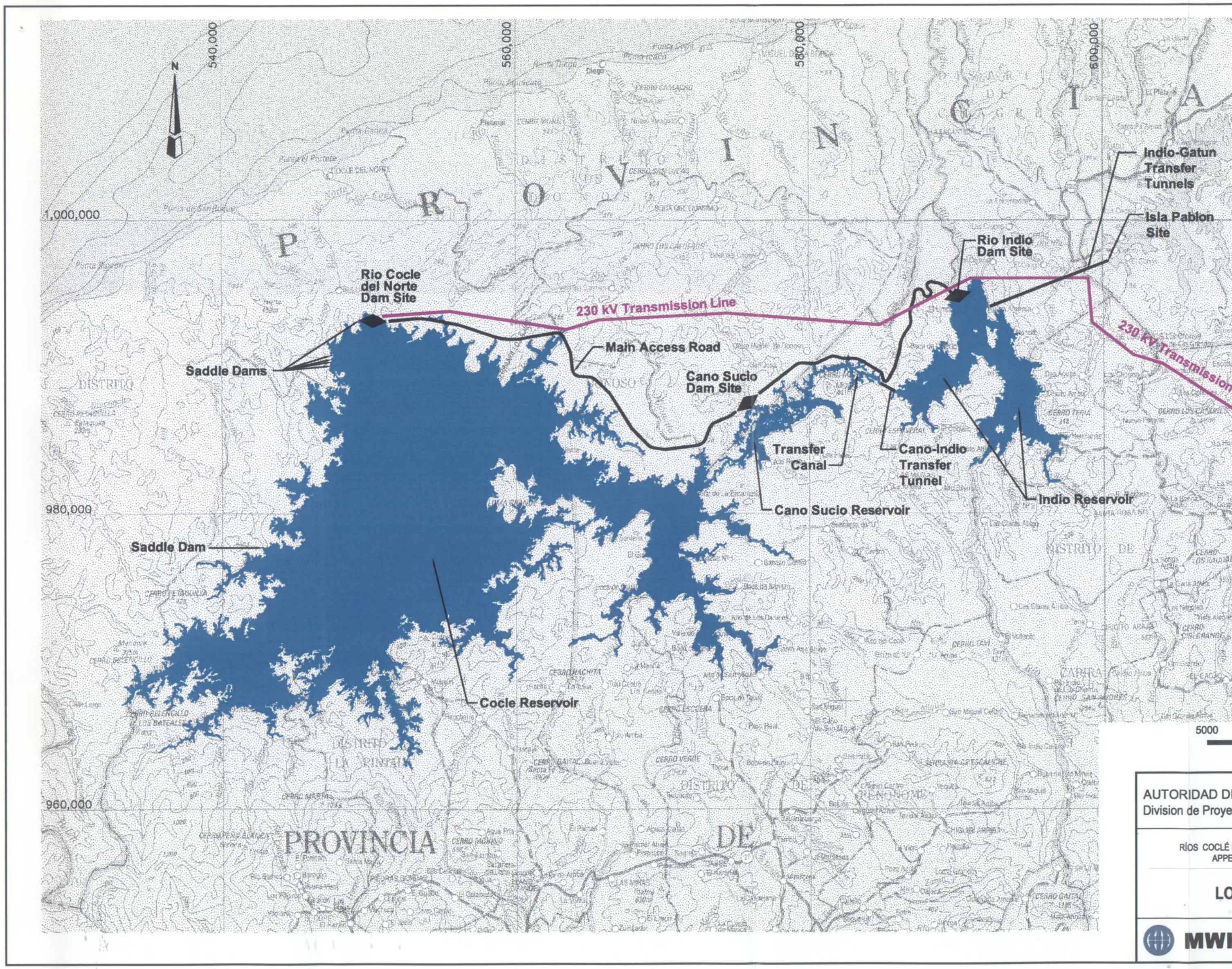
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 71) - ONE-LINE DIAGRAM**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 7




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

ACP

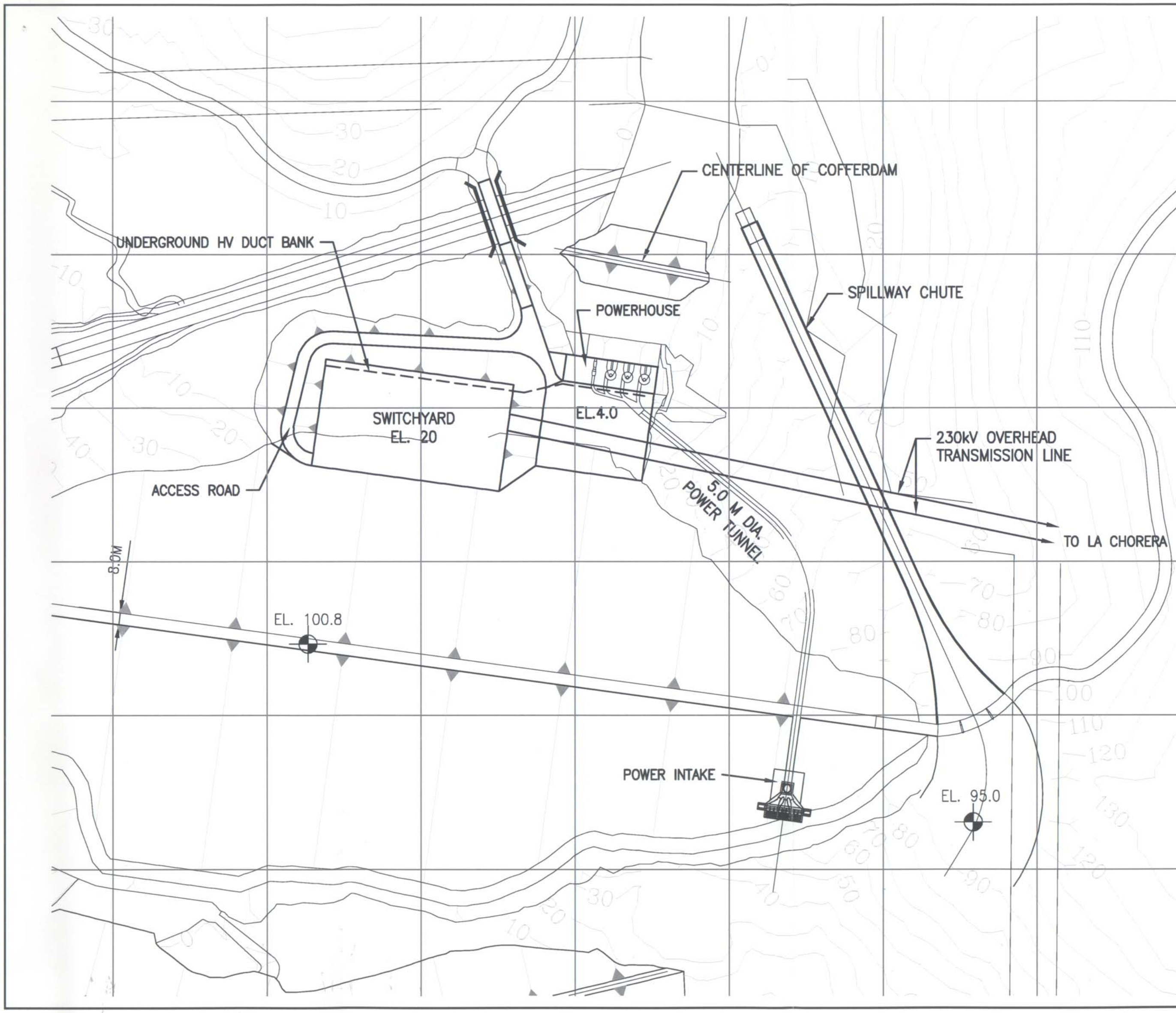
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## LOCATION MAP (COCLÉ 100)

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 8




0 100 200

SCALE IN METERS

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - GENERAL ARRANGEMENT**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
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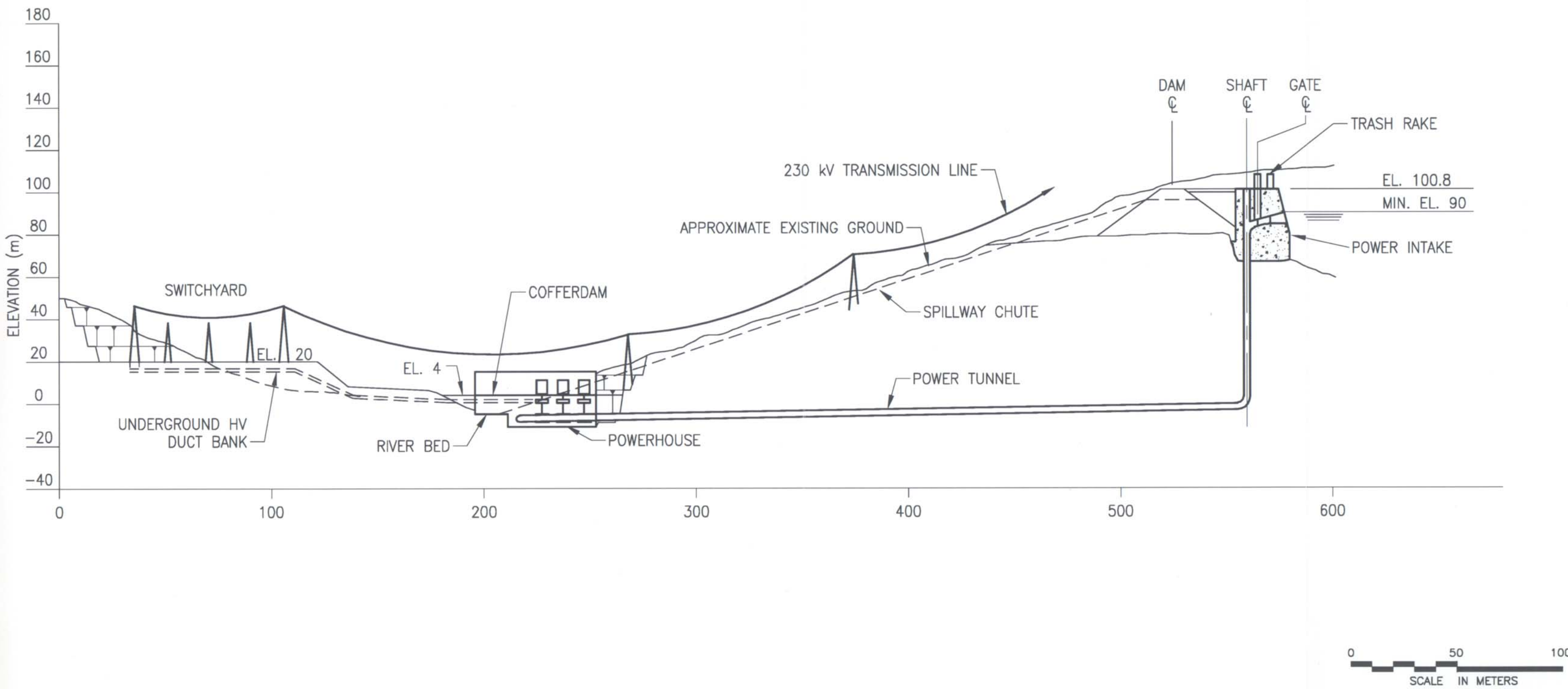


AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - PROFILE**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 10 |

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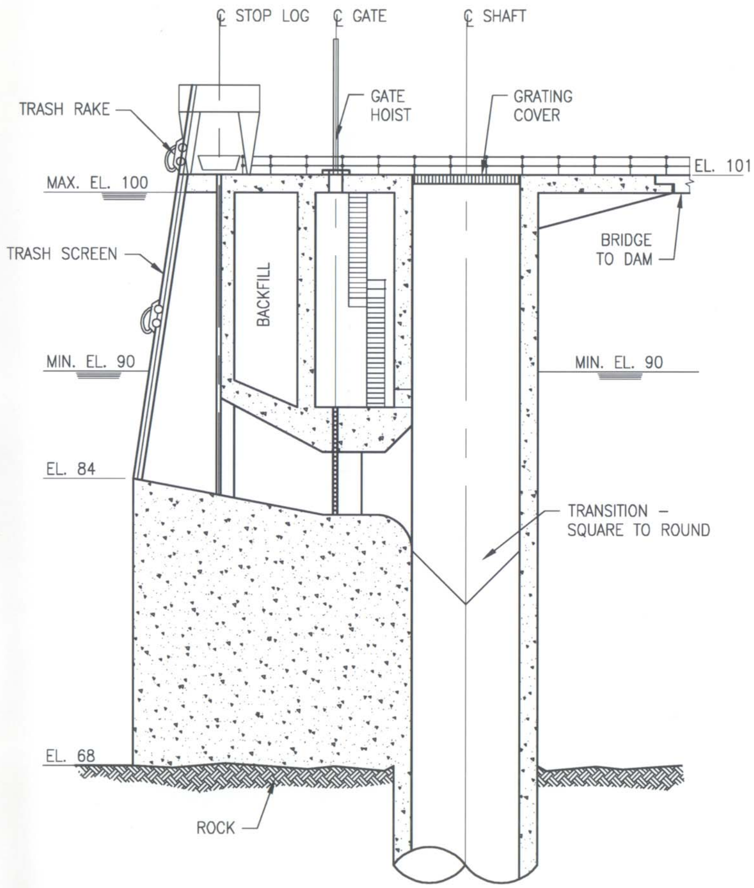
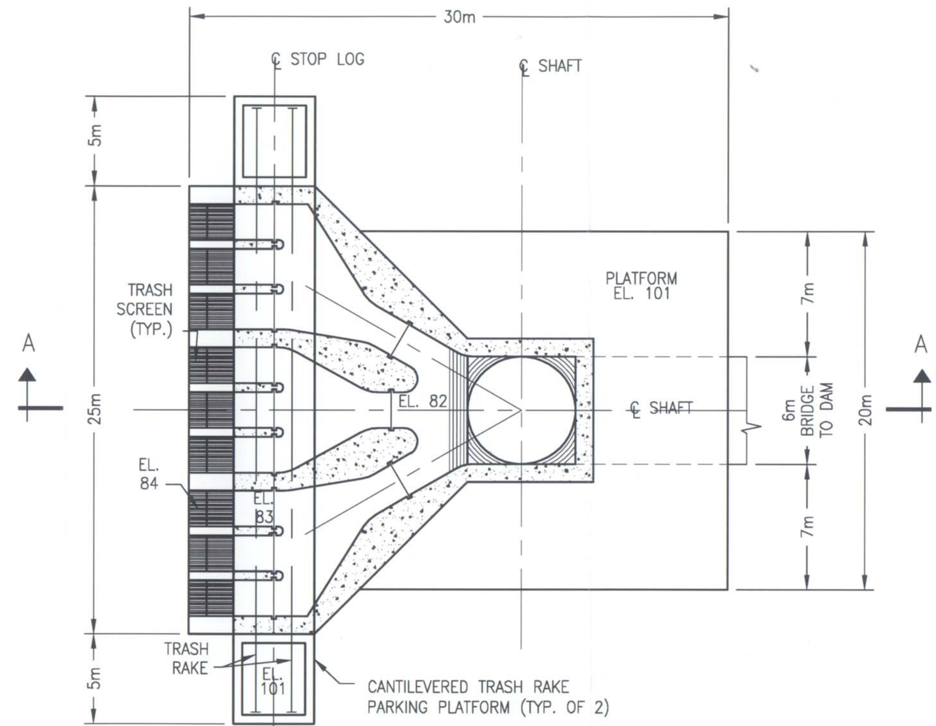
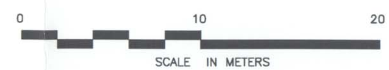


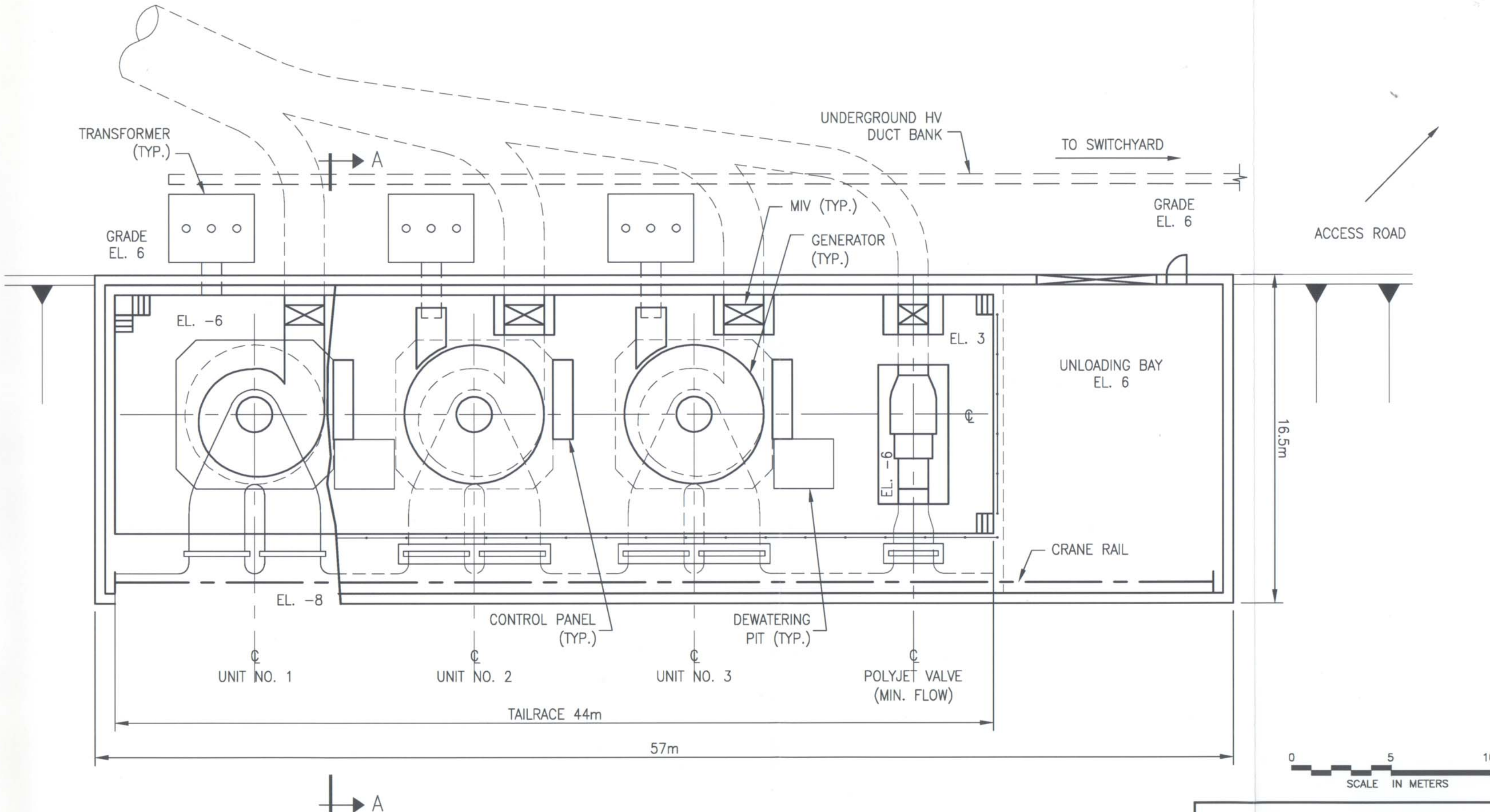

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - POWER INTAKE - PLAN AND SECTION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 11 |



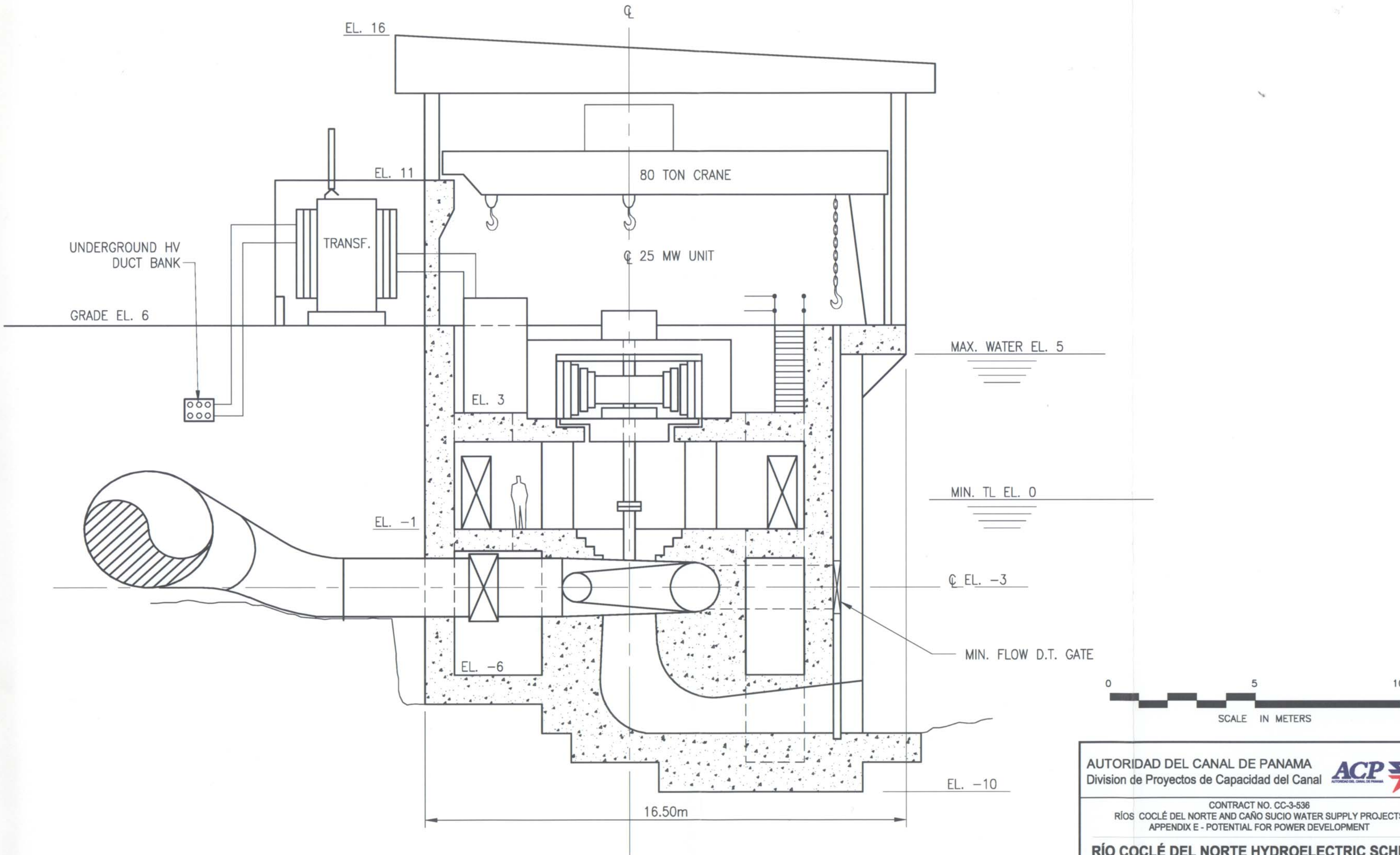

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - POWERHOUSE - PLAN**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 12 |




SECTION A–A

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

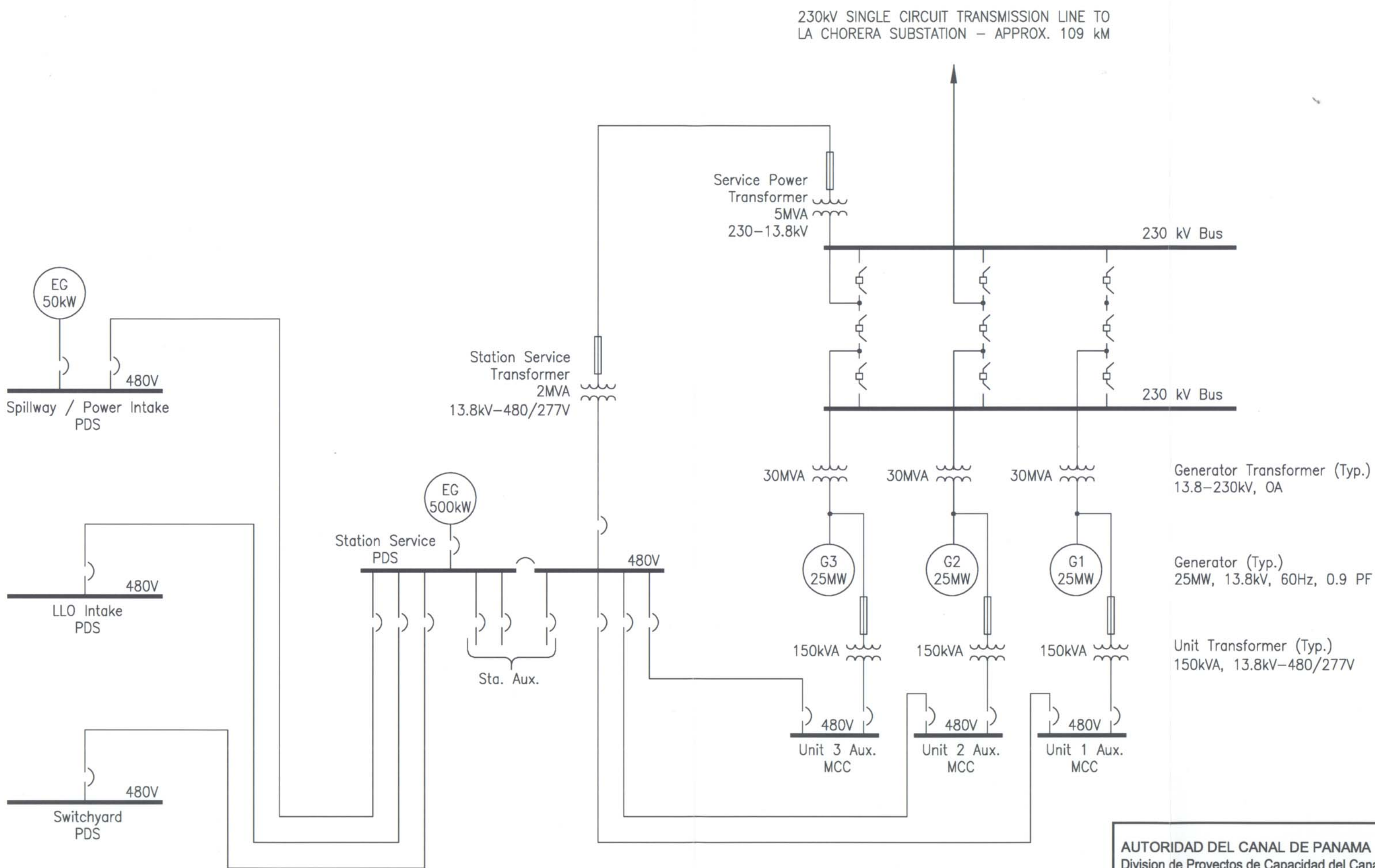
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - POWERHOUSE - SECTION**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 13




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME (COCLÉ 100) - ONE-LINE DIAGRAM**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 14

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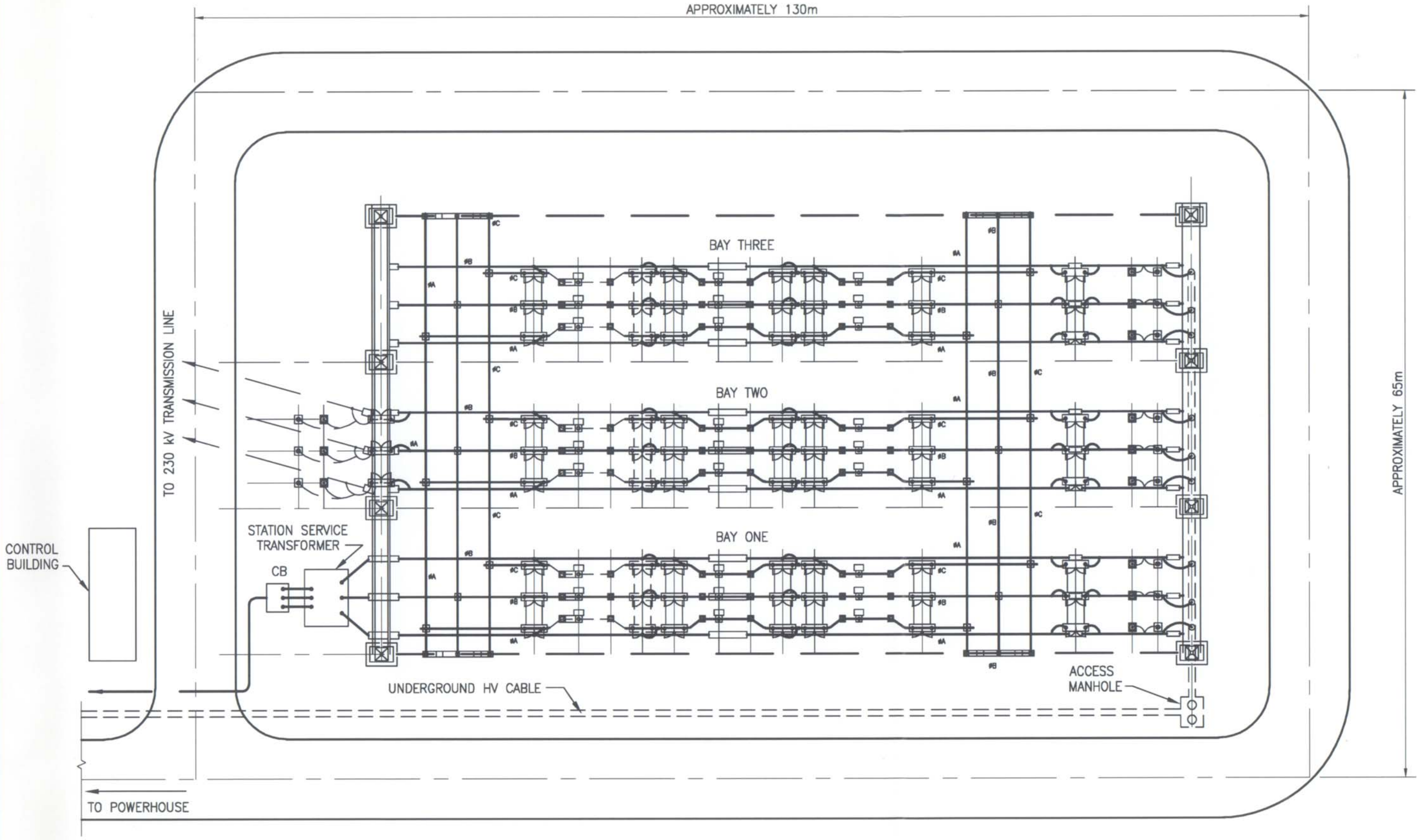



NOT TO SCALE

230 kV YARD AT RIO COCLE DEL NORTE – PLAN VIEW

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

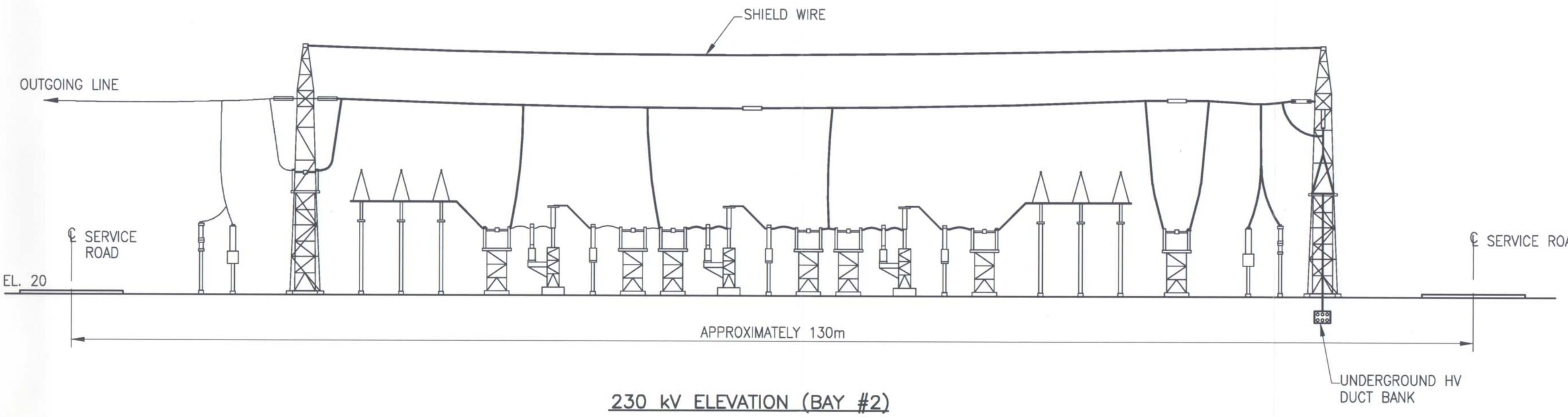
CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME - 230 KV SWITCHYARD - PLAN**

MWH TAMS

DATE: DECEMBER, 2003

EXHIBIT: 15




230 kV ELEVATION (BAY #2)

NOT TO SCALE

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**RÍO COCLÉ DEL NORTE HYDROELECTRIC SCHEME - 230 KV SWITCHYARD - ELEVATION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 16 |

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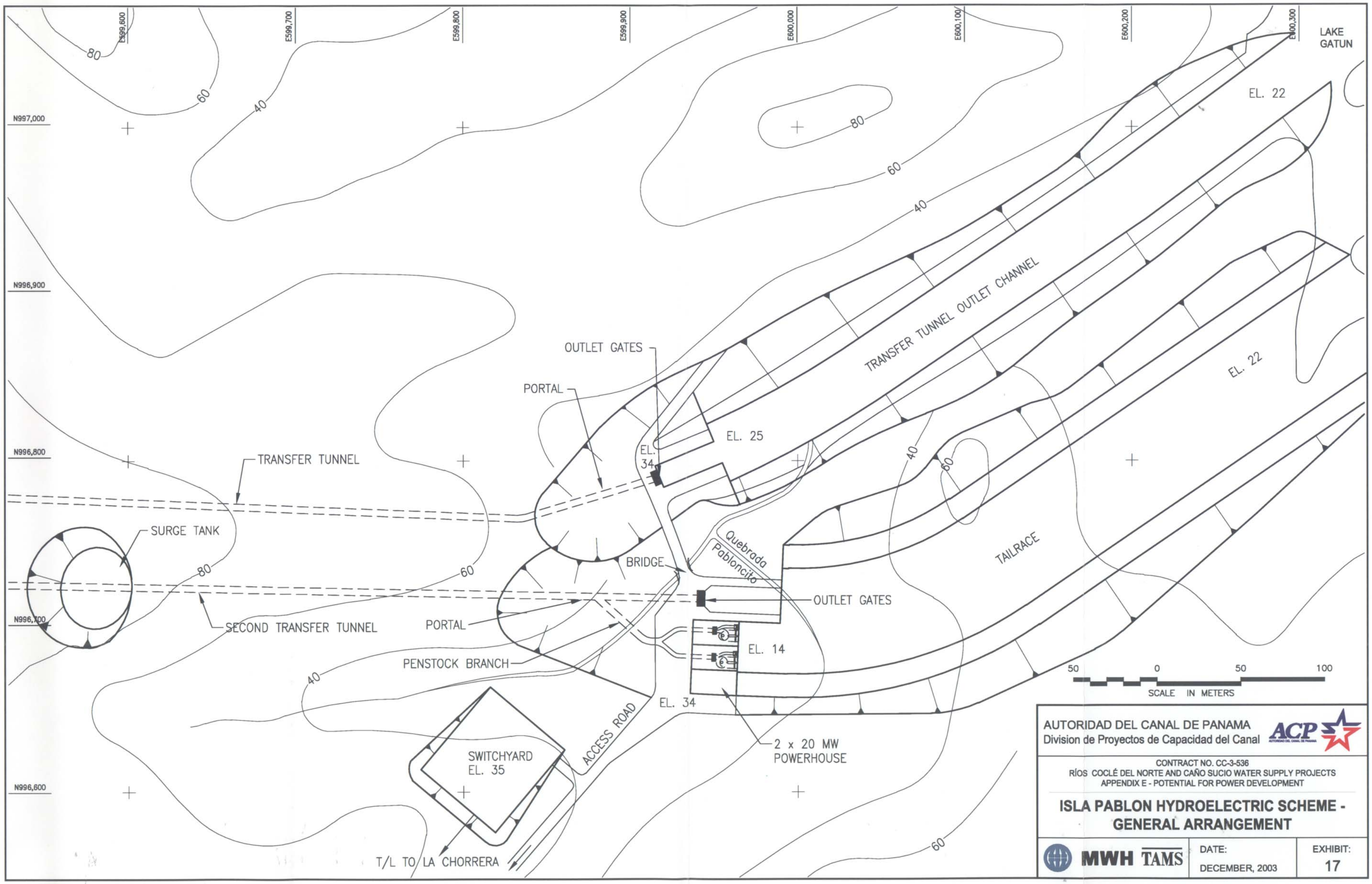


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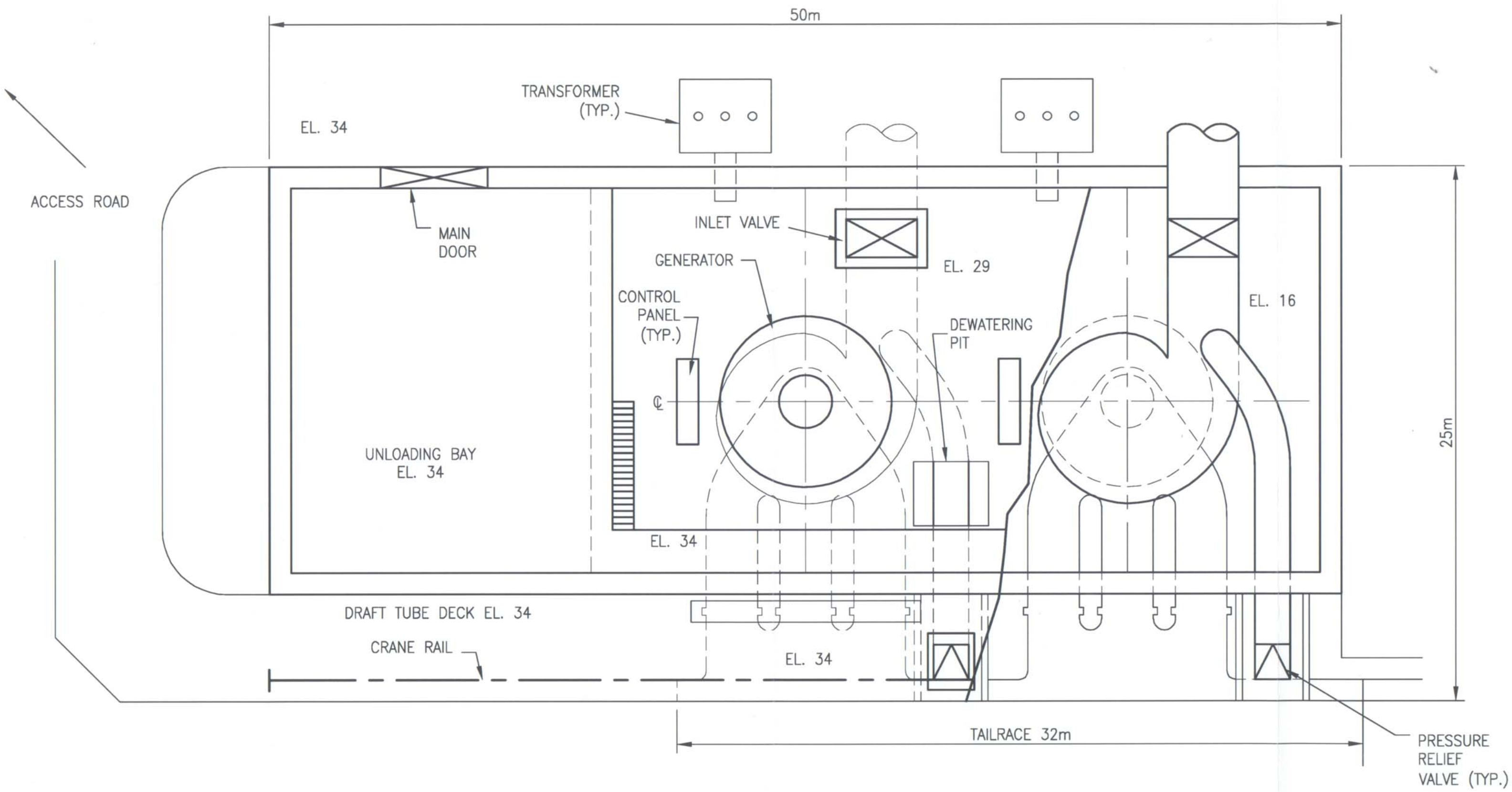


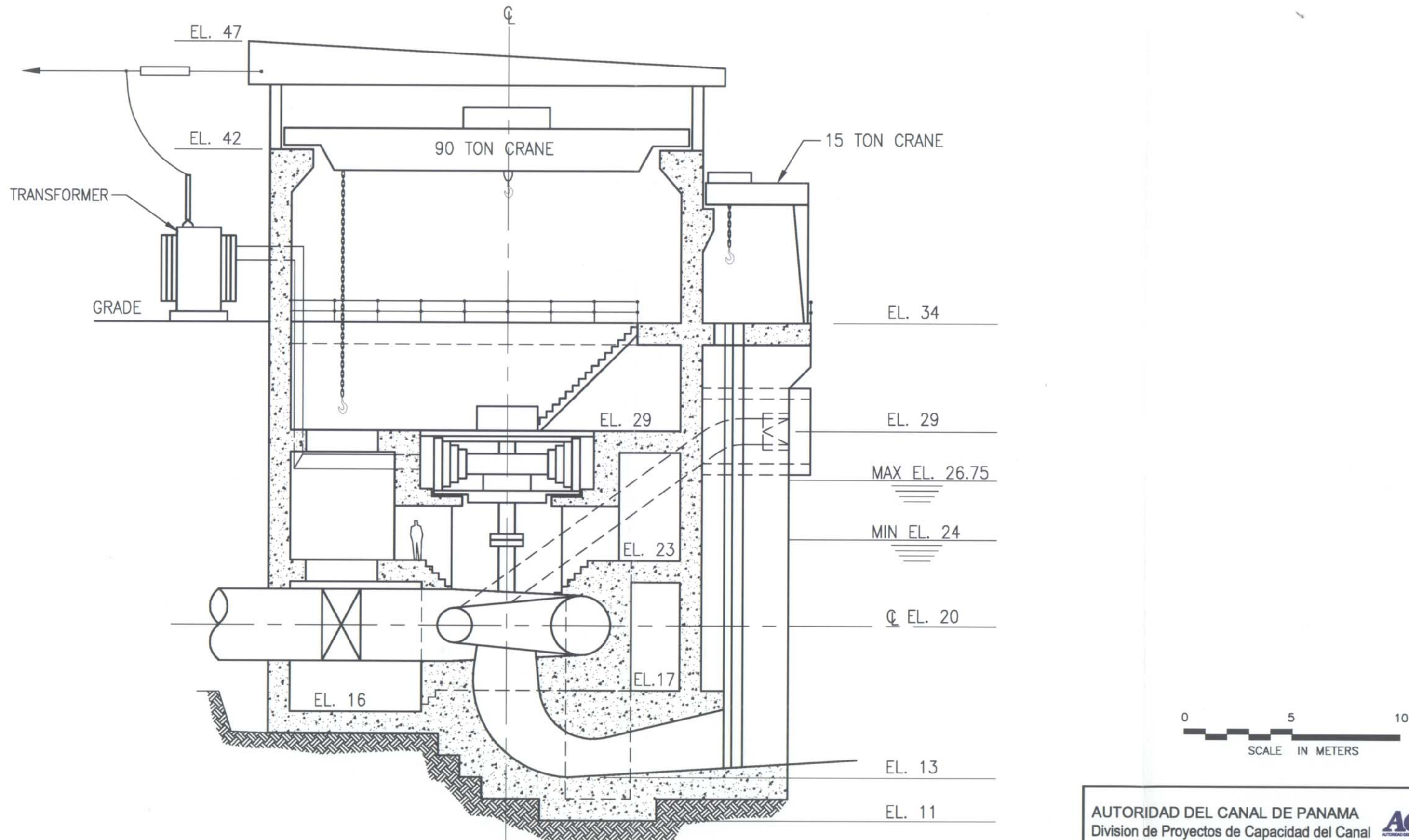

AUTORIDAD DEL CANAL DE PANAMA
División de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**ISLA PABLON HYDROELECTRIC SCHEME - POWERHOUSE - PLAN**

MWH TAMS

| DATE: | EXHIBIT: |
| --- | --- |
| DECEMBER, 2003 | 18 |




AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

**ISLA PABLON HYDROELECTRIC SCHEME - POWERHOUSE - SECTION**

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 19 |

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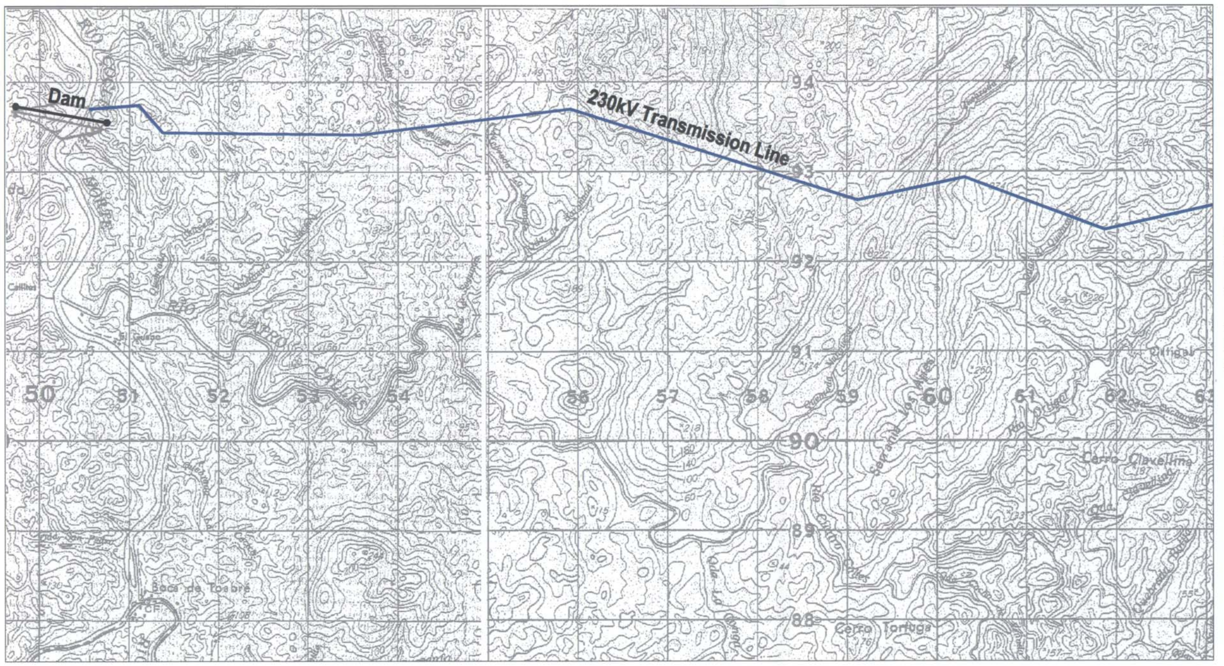


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SCALE IN METERS

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

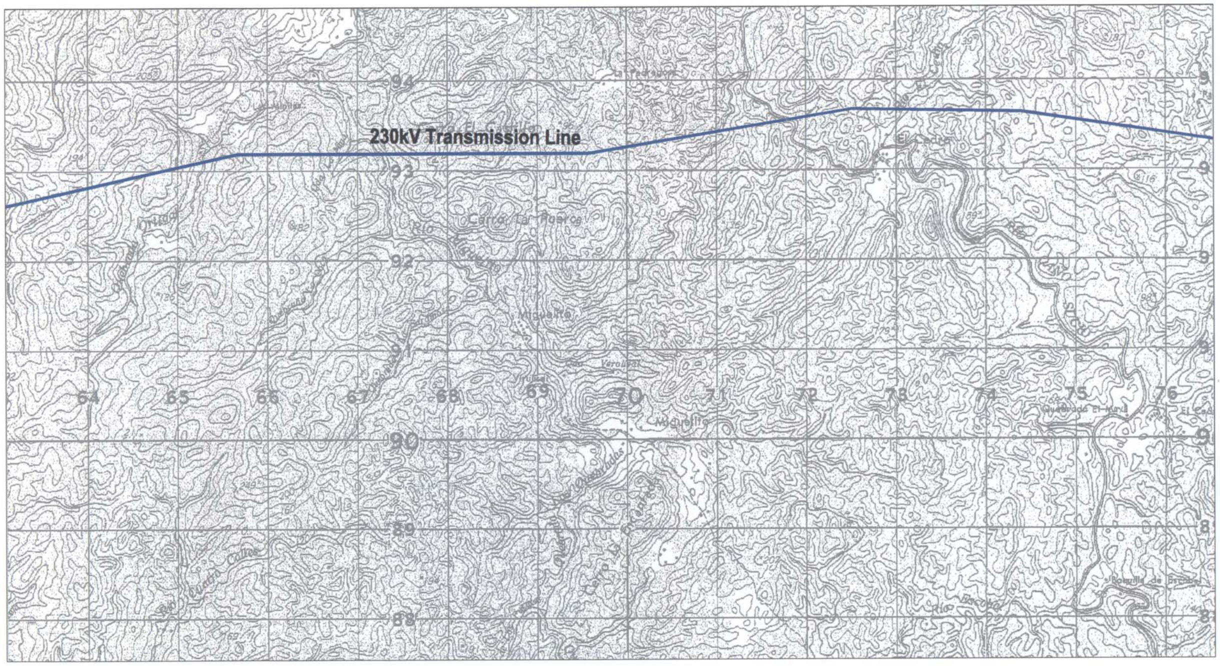
ACP

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## 230 KV TRANSMISSION LINE ROUTE (SHEET 1 OF 6)

| MWH TAMS | DATE: DECEMBER, 2003 | EXHIBIT: 20 |
|---|---|---|

Match Line - See Sheet 1




Match Line - See Sheet 3

1000 0 1000 2000

SCALE IN METERS

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

# 230 KV TRANSMISSION LINE ROUTE
# (SHEET 2 OF 6)

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 21 |

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Match Line - See Sheet 2


Match Line - See Sheet 4

1000 0 1000 2000

SCALE IN METERS

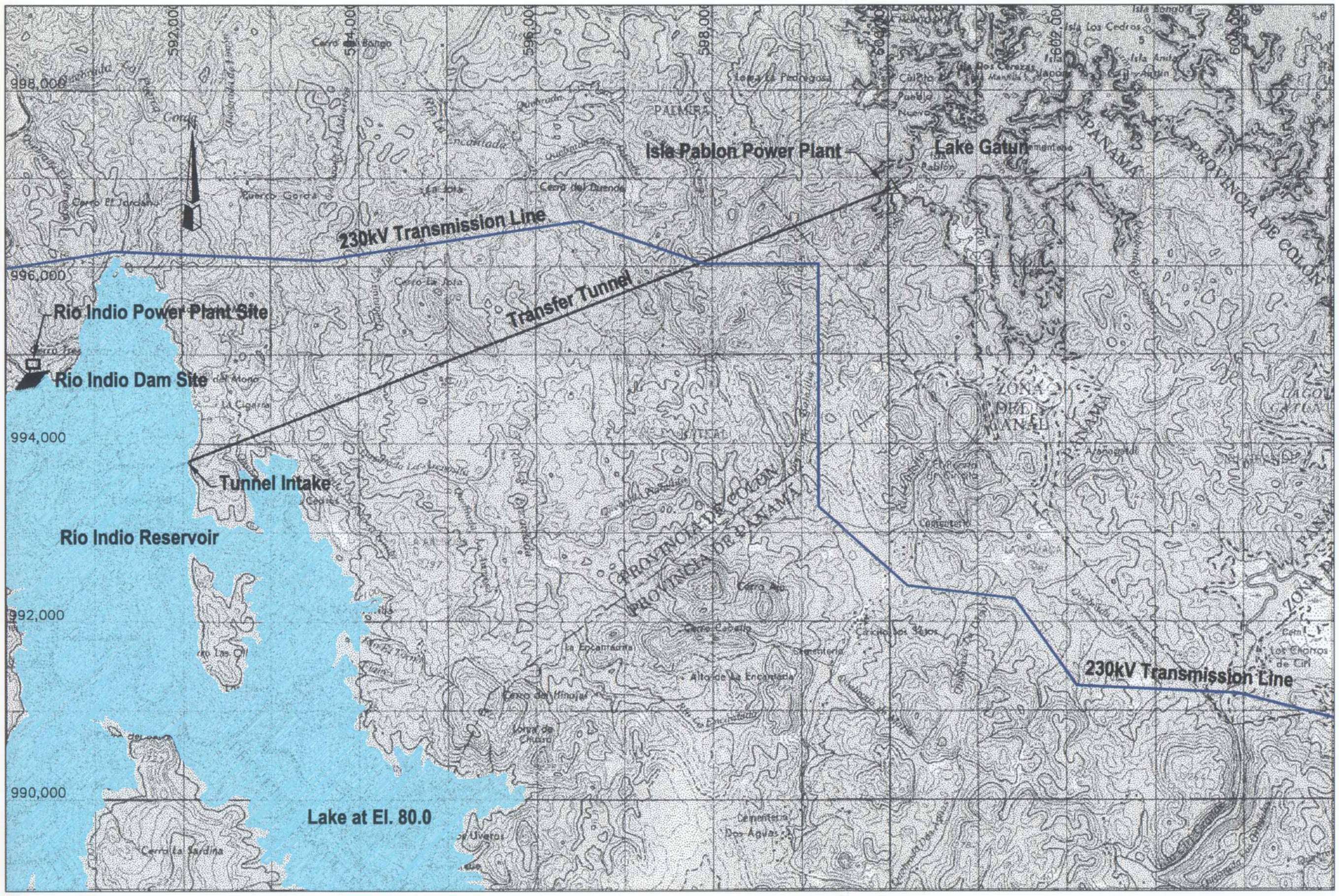
AUTORIDAD DEL CANAL DE PANAMA
División de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## 230 KV TRANSMISSION LINE ROUTE (SHEET 3 OF 6)

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 22 |

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SCALE IN METERS

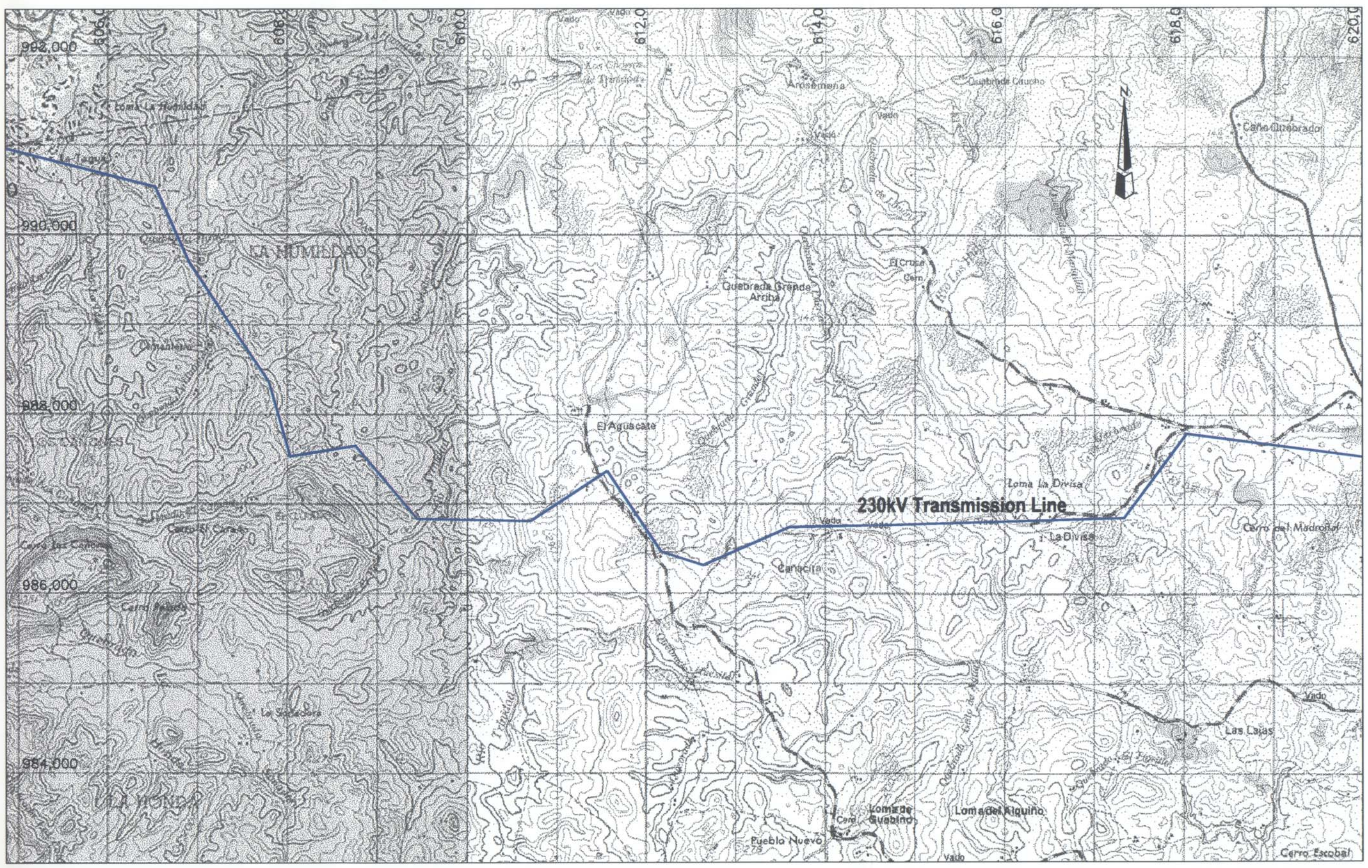
AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## 230 KV TRANSMISSION LINE ROUTE
## (SHEET 4 OF 6)

| MWH TAMS | DATE: DECEMBER, 2003 | EXHIBIT: 23 |
|---|---|---|

Match Line - See Sheet 4




Match Line - See Sheet 6

1000 0 1000 2000

SCALE IN METERS

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## 230 KV TRANSMISSION LINE ROUTE
## (SHEET 5 OF 6)

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 24 |

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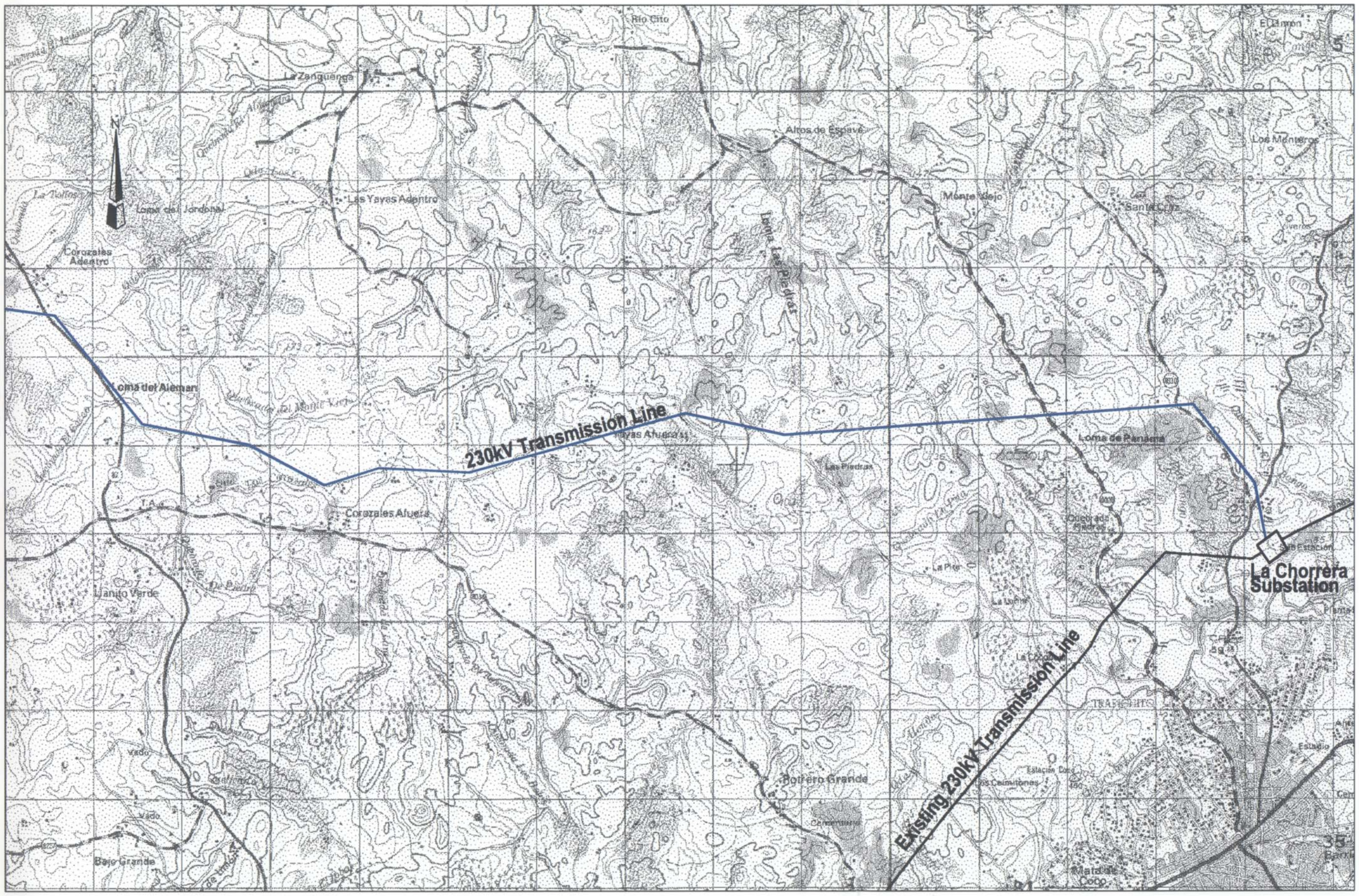



1000 0 1000 2000

SCALE IN METERS

AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
RÍOS COCLÉ DEL NORTE AND CAÑO SUCIO WATER SUPPLY PROJECTS
APPENDIX E - POTENTIAL FOR POWER DEVELOPMENT

## 230 KV TRANSMISSION LINE ROUTE
## (SHEET 6 OF 6)

MWH TAMS

| DATE: | EXHIBIT: |
|---|---|
| DECEMBER, 2003 | 25 |

# ATTACHMENTS

# ATTACHMENT 1

# SITE RECONNAISSANCE REPORT

# Site Reconnaissance Report

## Site Trip From February 17 to February 21, 2002

The writer arrived to Panama City the night of Sunday February 17, 2002. Site visits and interviews were performed during the following week to gather information for the proposed feasibility study, as follows:

### Monday, February 18

1) Met with Mr. Roderick E. Lee of the ACP Canal Capacity Projects office and Ing. Rodrigo Chanis assigned to act as liaison and ACP counterpart for the electrical work associated with the transmission feasibility study.

2) As told by Mr. Lee, the initial plan was to visit ACP's Gatun substation as the possible point of connection for the Rio Indio development and ACP's Madden and Miraflores substations as possible points of connections for the Upper Chagres river development. However, during the meeting with Ing. Enrique Tejera, ACP electrical system operation and maintenance, it was revealed that ACP's 44 kV system would not be capable of receiving 30 MW from Rio Indio neither 35 MW from Upper Chagres. Therefore the initial plan of visits was abandoned and the search for feasible points of connection with 115/230 kV capabilities concentrated in ETESA's La Chorrera substation for Rio Indio and Cocle del Norte projects and Panama II substation for the Upper Chagres project.

3) Visited ETESA's Ing. Jose M.Lopez and Ing. Delano E. James of operation and maintenance to obtain system information and review possibilities for interconnection at both 115 and 230 kV voltages. Copy of an up-to-date ETESA's electrical system map was provided to the writer. The discussion revealed the following:

- La Chorrera substation has at present two empty bays at 230 kV and also two operating 230/115/13.8 kV step down transformers that feed a 13.8 kV distribution switchyard. However, the 115 kV yard has never been developed although land space has been provided for such purpose. ETESA does not have immediate plans to develop the 115 kV yard and is waiting for a private generator or the private distribution companies to generate the need for it. A connection for Rio Indio at 115 kV would entail to build the 115 kV yard as part of the project cost.

- Regarding the connection of the Upper Chagres river project, ETESA's Panama II substation has capabilities and empty bays at 115 kV for that purpose. Another possibility for interconnection would be to intersect and open one of the four (4) 115 kV circuits running between Panama City and Colon and to extend its length with a double circuit line to the Upper Chagres substation to be provided with a breaker and a half scheme which is typical of the ETESA's substation arrangements.

4) ACP provided an array of topographic maps at the 1:25,000 scale for routing the transmission lines for the proposed project sites.

**Tuesday, February 19**

5) The morning was dedicated to make a visit to the Panama II substation together with ETESA's Ing. Jose M. Lopez. There are two (2) empty bays in the 115-kV switchyard one of which could be used for the interconnection to the Upper Chagres project. The crossing of the 115-kV line under the future second 230-kV transmission line from Llano Sanchez substation should be made underground, as ETESA does not allow aerial line crossings inside the substations.

6) A review of ETESA's system map revealed that besides Panama II there are no other 115-kV substations owned by ETESA in the area to connect the Upper Chagres project. However, there are two privately owned 115-kV substations connected to the ETESA system close to Madden, namely, Chilibre (owned by ELECTRA Distribution Company) and Cemento Panama. Chilibre is a tap of two 115-kV circuits and from system reliability is not considered adequate to hook the proposed 35-MW Upper Chagres generation. Cemento Panama substation, instead, is a promising point of interconnection since the ETESA 115-kV line is sectionalized.

7) Both Chilibre and Cemento Panama as well as Madden substations were visited during the same morning with the following results:

- Chilibre is not acceptable since it is a tap to the 115-kV system. Two ETESA line circuits are tapped, one serves a 13.8-kV step down transformer, and the other is used to extend a 115-kV single circuit line to another Cement plant. Additionally, it does not have space availability for expansion.

- Cemento Panama has a spare bay for connection of a 115-kV line circuit with the need of only minor additional switching equipment. This substation is located some 8 km north of the Chagres River and would require extending the length of the transmission line that much to a total of about 18 km.

- Madden substation was looked from the dam top and it is an exclusive 44-kV switchyard located immediately adjacent to the power plant with no room for expansion. Two aerial circuits connect this substation to ACP's 44-kV transmission system.

8) In the afternoon the ETESA's Substation Engineering Division was visited and the writer met Ing. Eduardo N. Brugiatti, Head of Substation Design. The alternative of opening one circuit of the 115-kV Panama-Colon transmission line to connect the Upper Chagres river project appeared acceptable to ETESA as long as the plant substation at Upper Chagres is built following their standards using a breaker and a half switching scheme.

Prints of typical substation plans, elevations and one lines with protection schemes at 115-kV and 230-kV were obtained.

**Wednesday, February 20**

9) The transmission line routes and site locations were flown over by helicopter together with ACP's personnel Ing. Roderick Lee and Rodrigo Chanis.

10) The writer provided the preliminary routes between La Chorrera substation and Rio Indio and Cocle del Norte sites. ACP furnished new tunnel coordinates for the Indio River tunnel and the writer corrected the route in the affected section.

11) The helicopter landed first at La Chorrera substation where ETESA's engineers Jose M. Lopez, O&M, Eduardo N. Brugiatti, Engineering, and Moses Cano, Planning, were awaiting the party. The substation yards were walked and ETESA showed two (2) 230-kV empty bays were the ACP line could be connected. The 115-kV yard was never developed but the space is available. If required to connect at 115-kV ACP should bare the cost for building the 115-kV yard where initially only one breaker would be installed for the ACP line; but the design should have provisions for ultimate breaker and a half scheme. The control room of the substation has ample space to locate the necessary panels for relays, metering and communications.

12) The party continued the flight over the proposed line route to the Rio Indio tunnel and plant sites. The terrain is of gentle topography with low hills showing marked signs of deforestation, traversed by dirt road accesses and few paved roads, where scattered buildings and little agricultural farming (pineapple, vineyards and fruit trees) and some large chicken houses are present. The area is accessible by land and of relatively easy line construction.

13) The foot of the tunnel is now at a new location facing the Pablon Island in the Gatun Lake, about 8 km east of the proposed Rio Indio dam.

14) After circling the location around the Pablon Island and the Rio Indio dam sites the party proceeded almost due west toward Cocle del Norte site. The flight deviated slightly to go over an intermediate site at the Cano Sucio River, which will not be developed for power.

15) As the helicopter moved west the topography became more hilly and the ground were covered by dense and thick where deforestation has been less active in this more remote and un-inhabited region. After circling the Rio Cocle del Norte site the helicopter turned due south toward the locality of Coclecito for refueling.

16) The party left Coclecito in a general northeast direction toward Rio Indio but passing first by the Toabre river site under study by another consultant. The flight headed toward the Rio Chagres crossing the Gatun Lake. ETESA's 115-kV transmission line circuits running from Panama City to Colon were intersected and a convenient space of land was

spotted adjacent to the crossing of the Chagres River at the southern bank where one of the line circuits could be cut in. The ACP double circuit transmission line would be running from this point in and out the plant site following the south margin of the Alahuela Lake in a general SW-NE direction for about 10 km.

17) The helicopter moved around the southern margin of Alahuela Lake where the transmission line route presents a gentle rolling type country with rounded hills, with short vegetation and practically no population, crossed by few scattered dirt roads. At one point some 2-3 km from the proposed site the line route enters a heavily wooded area of high hilly terrain in jurisdiction of the National Parks agency.

18) From the Upper Chagre site the party proceeded to fly south by Southwest to the Panama II substation that provides an option for connection of this power project to the national grid. The flown area is very hilly and steep at times, thickly wooded for most of the area and with no apparent roads, of difficult access. In the last part of the route near the Panama II substation, for about 5 km, the land becomes gentler, of lower elevations and occupied by scattered housing and roads. The Panama II substation was spotted and circled, after that the party returned and finally landed at the local airport.

**Thursday, February 21**

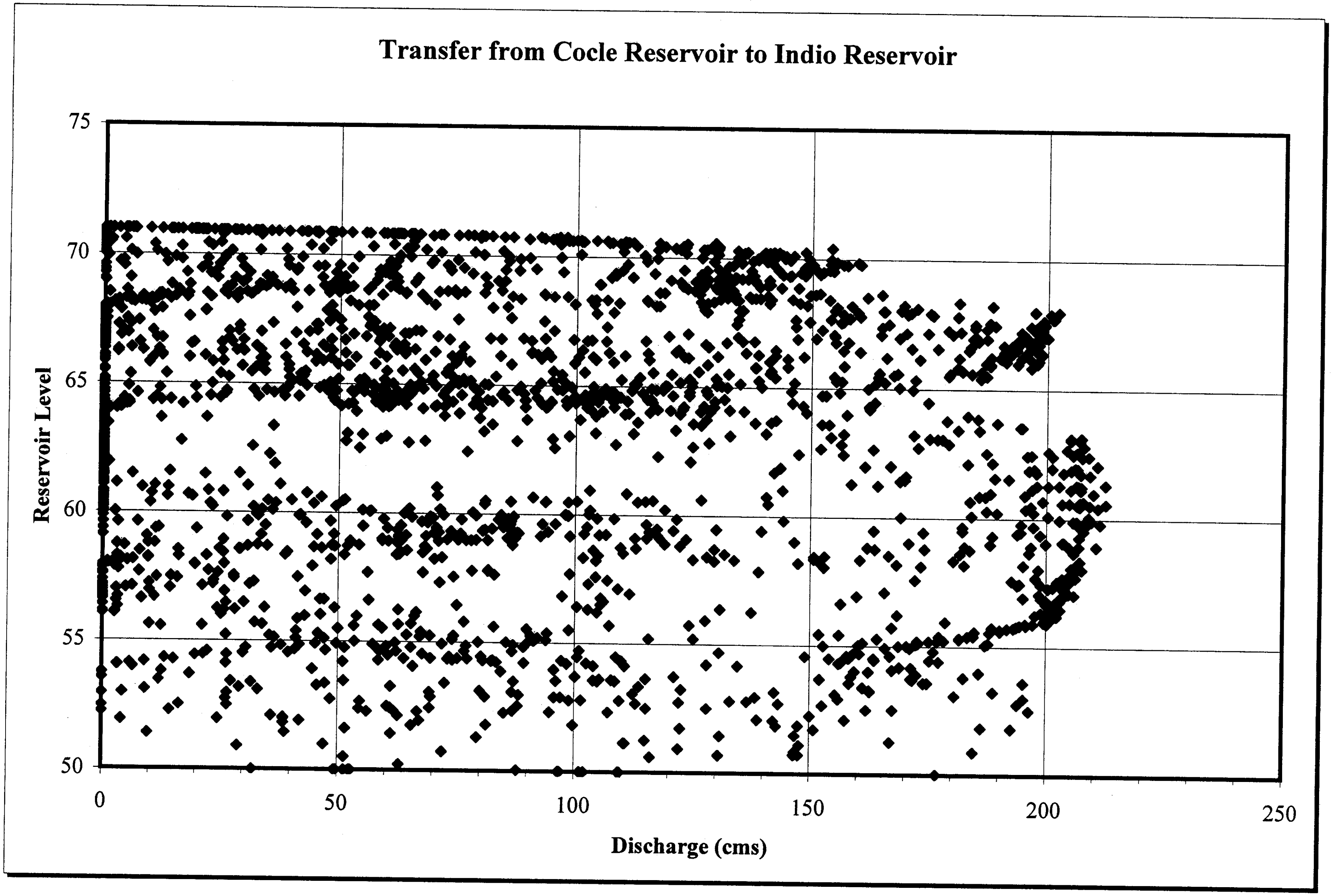
19) A number of documents were obtained from ETESA and ACP as well as pictures that were developed as follows:

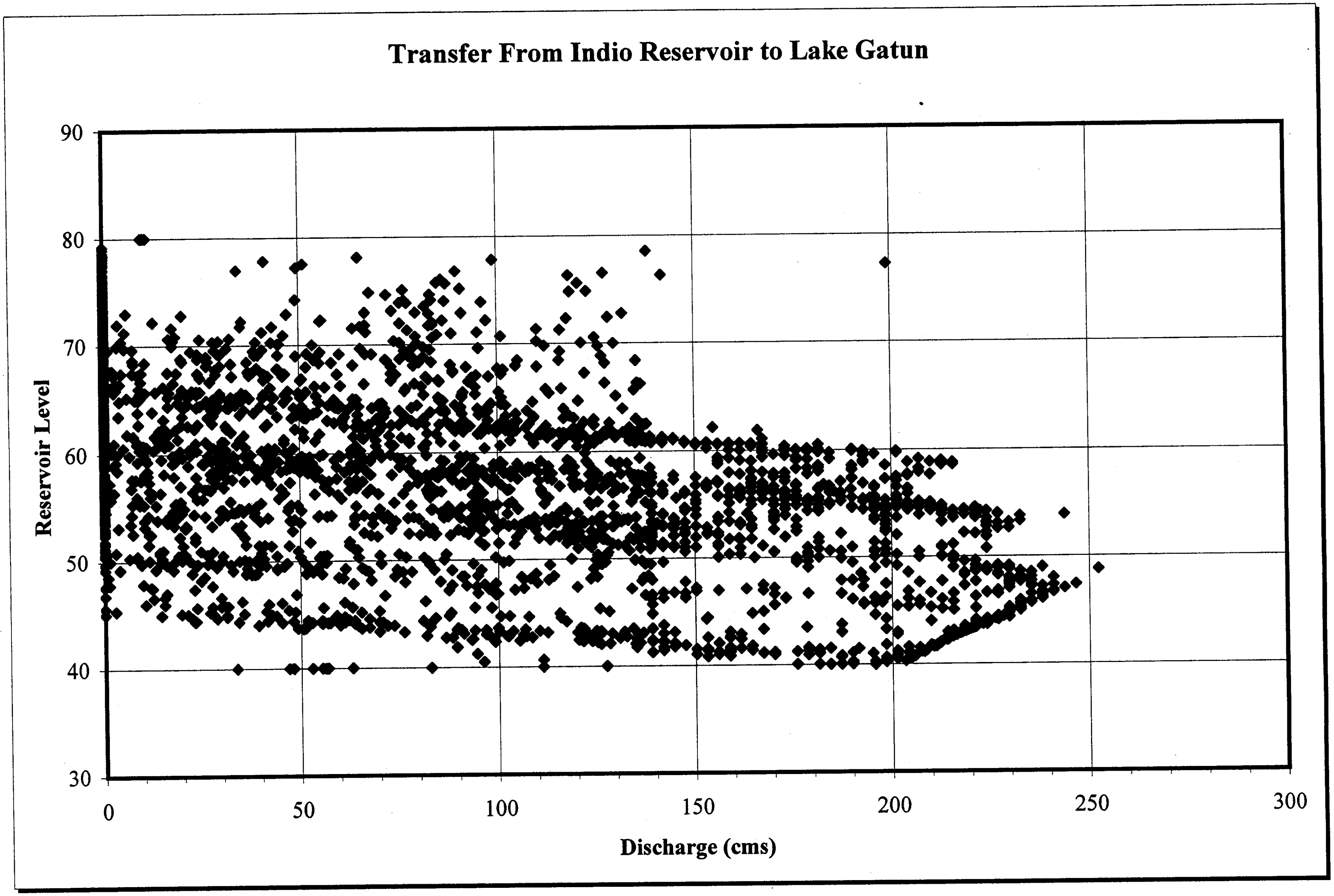
- Typical Plan and Elevation drawings of the Panama II substation from ETESA
- Typical one-line diagrams w/protection schemes for 115-kV and 230-kV substation bays from ETESA.
- Typical 115-kV and 230-kV transmission line and substation costs from ETESA.
- ETESA's one-line electric interconnected system map.
- Physical location maps of the La Chorrera and Panama II substations and 115 kV and 230 kV transmission lines from ETESA.
- Typical 115 kV and 230 kV transmission line structure outlines from ACP
- Maps at 1:25,000 scale from ACP.
- ACP's one-line diagram for their 44 kV system.
- ACP's physical location map of their 44 kV lines and substations.

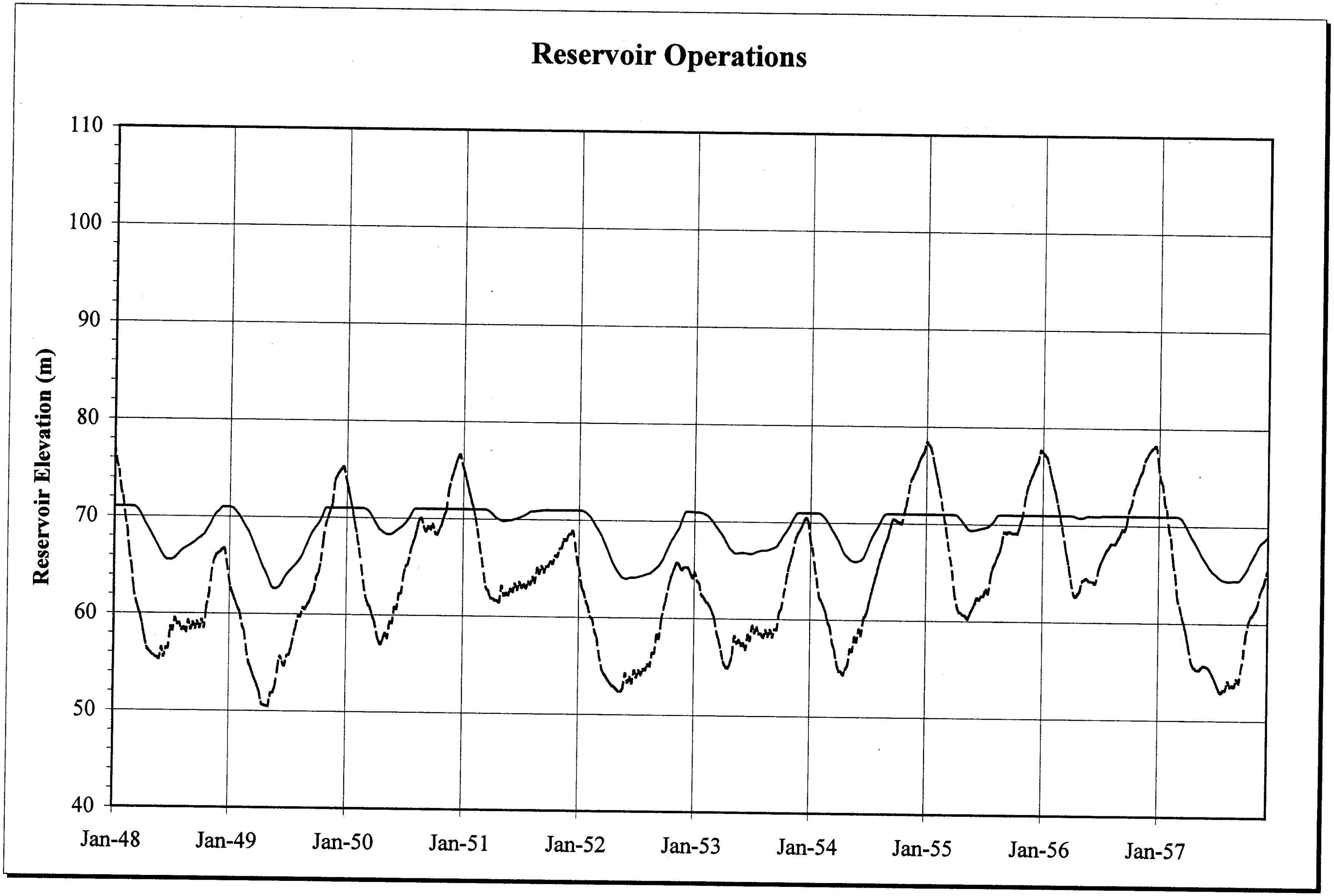
# ATTACHMENT 2

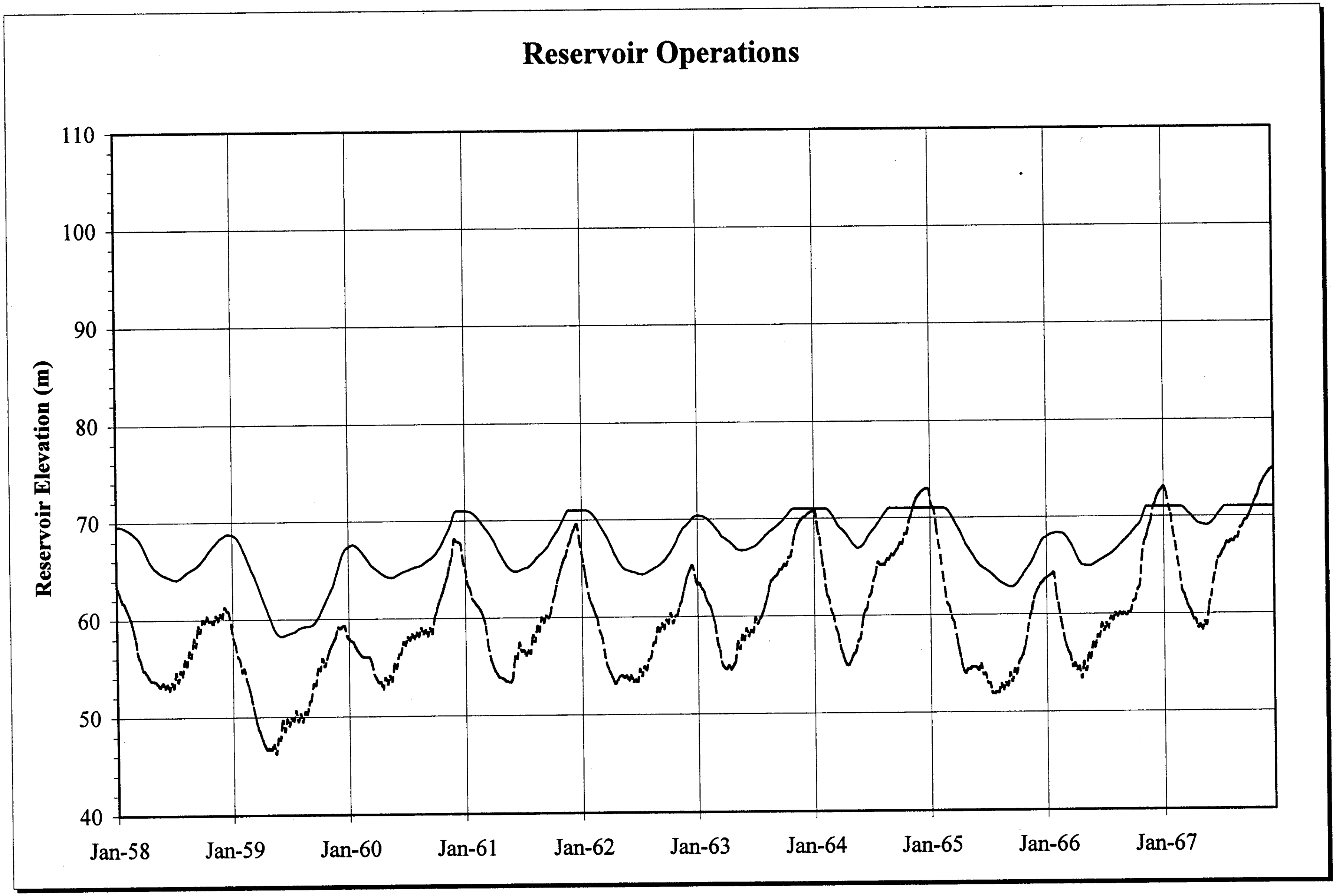
# PROPOSED RÍO INDIO RESERVOIR OPERATIONS

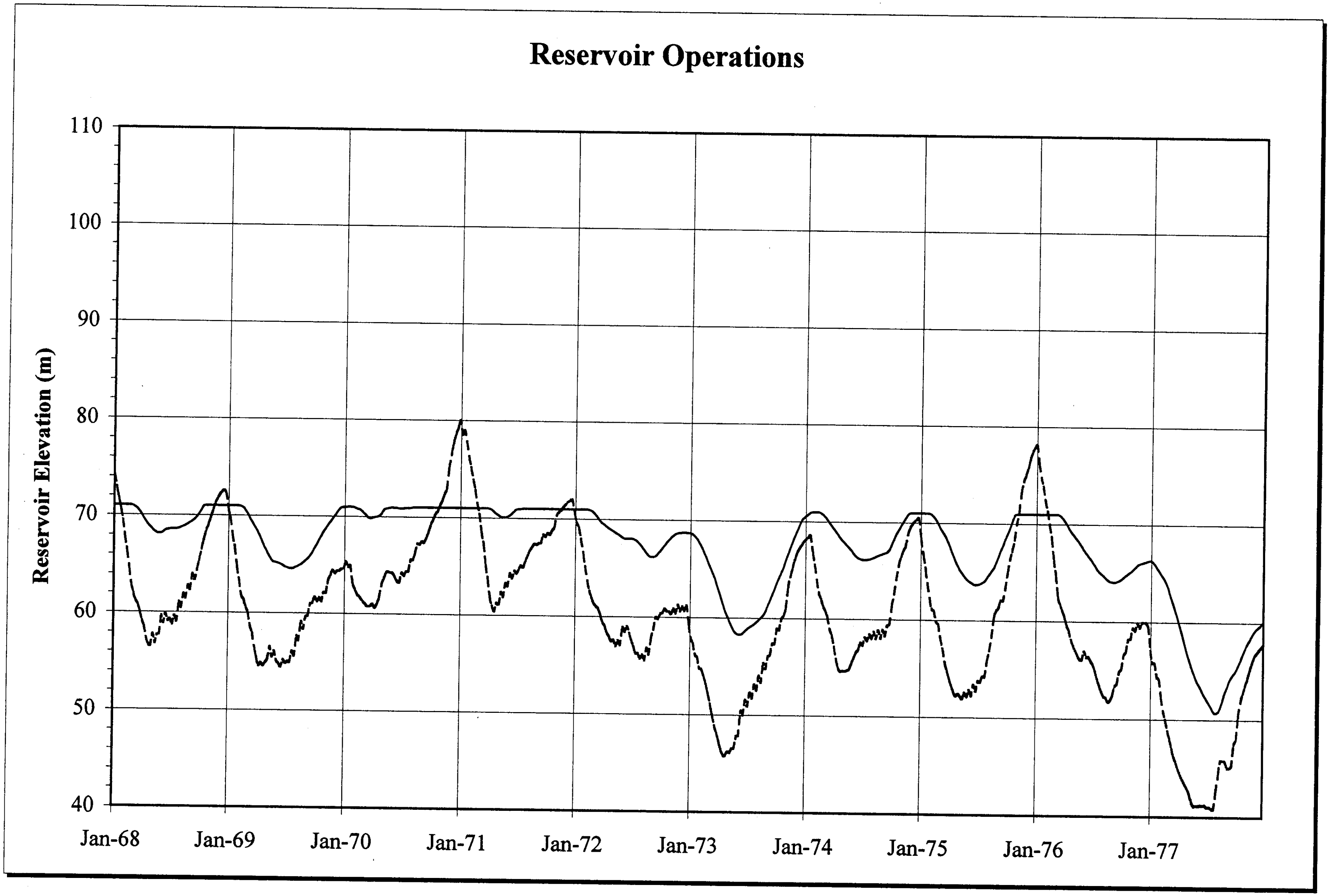
# COCLE 50 –71

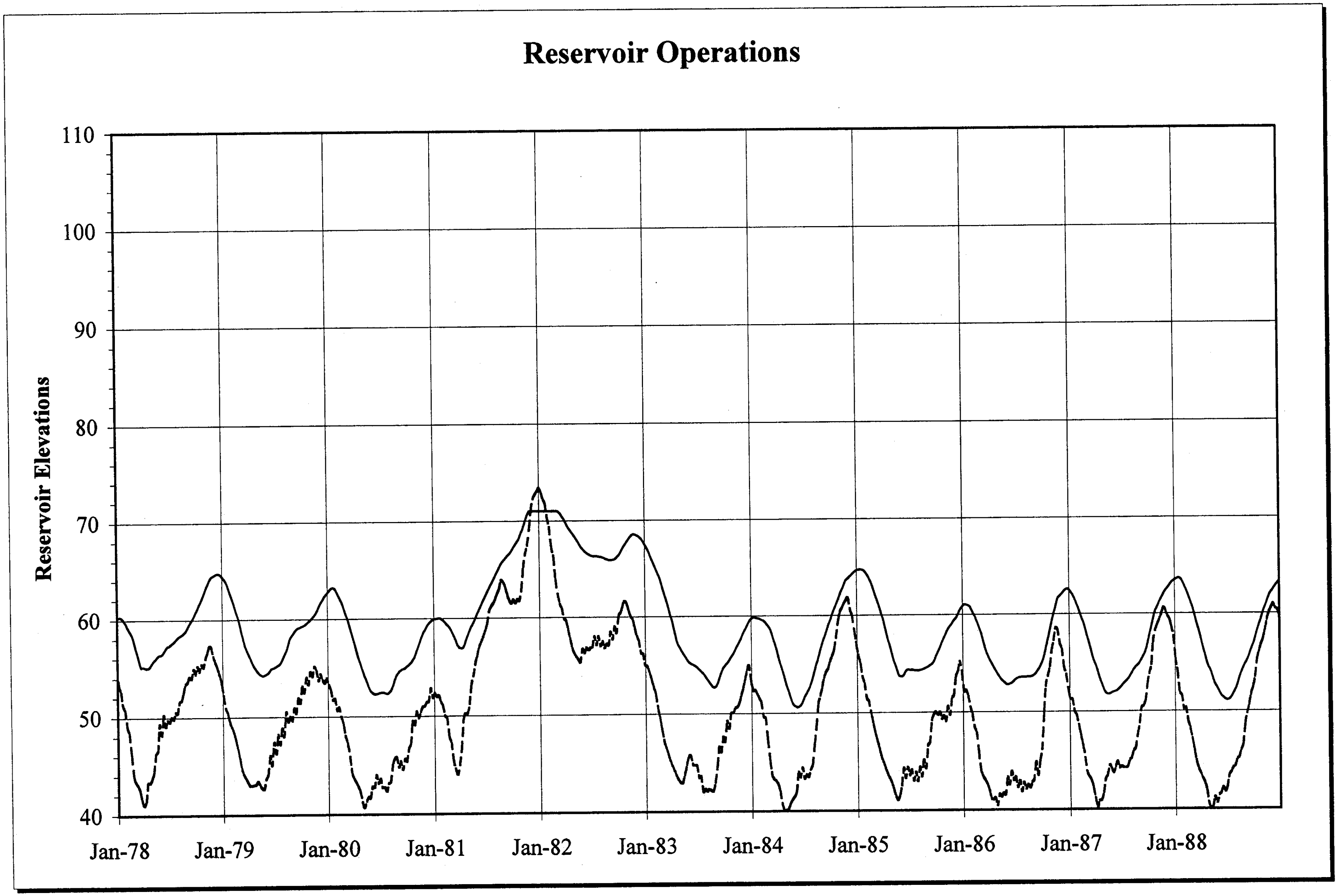

Transfer from Cocle Reservoir to Indio Reservoir
75
70
65
60
55
50
Reservoir Level
0
50
100
150
200
250
Discharge (cms)

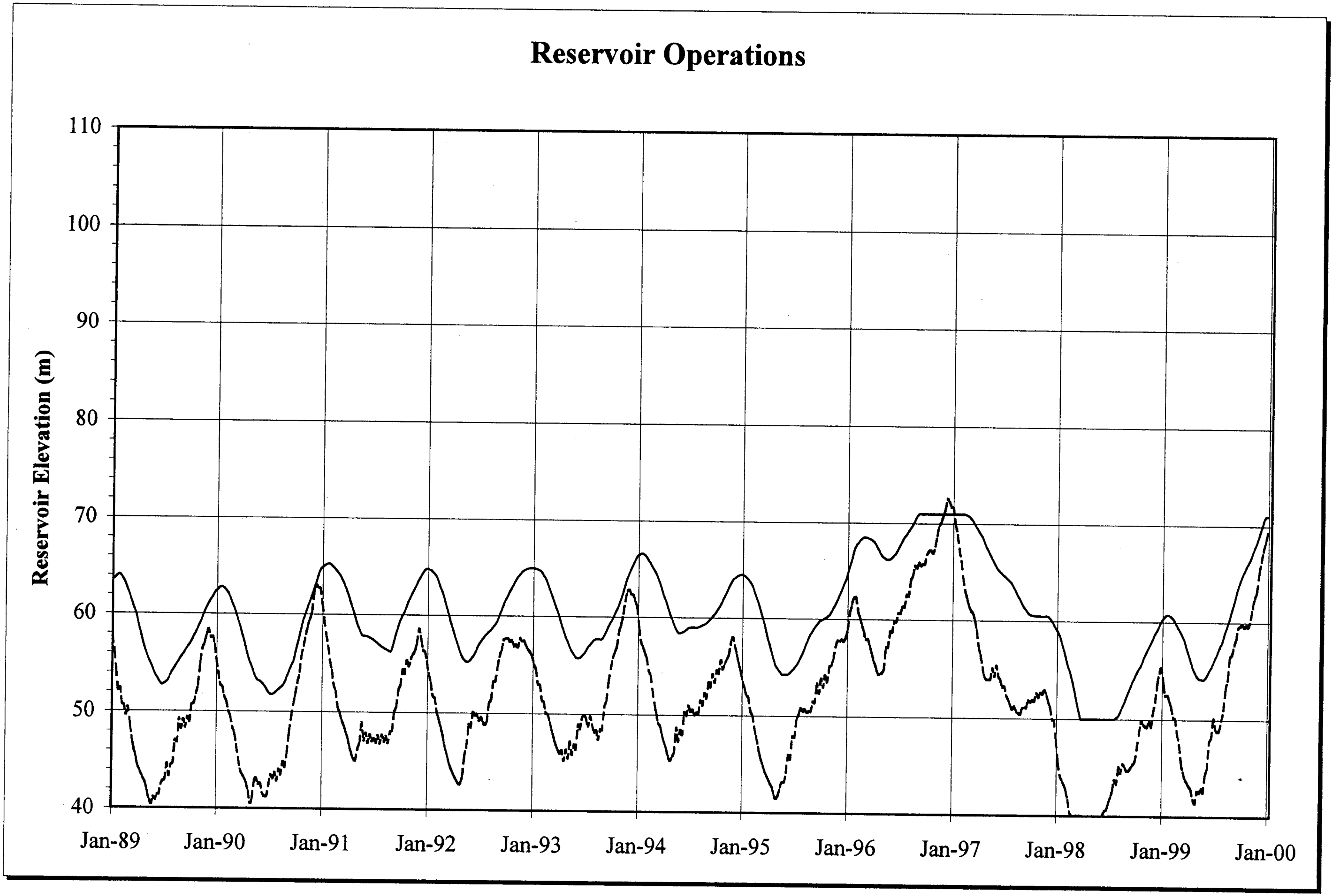

Transfer From Indio Reservoir to Lake Gatun
90
80
70
60
50
40
30
Reservoir Level
0
50
100
150
200
250
300
Discharge (cms)

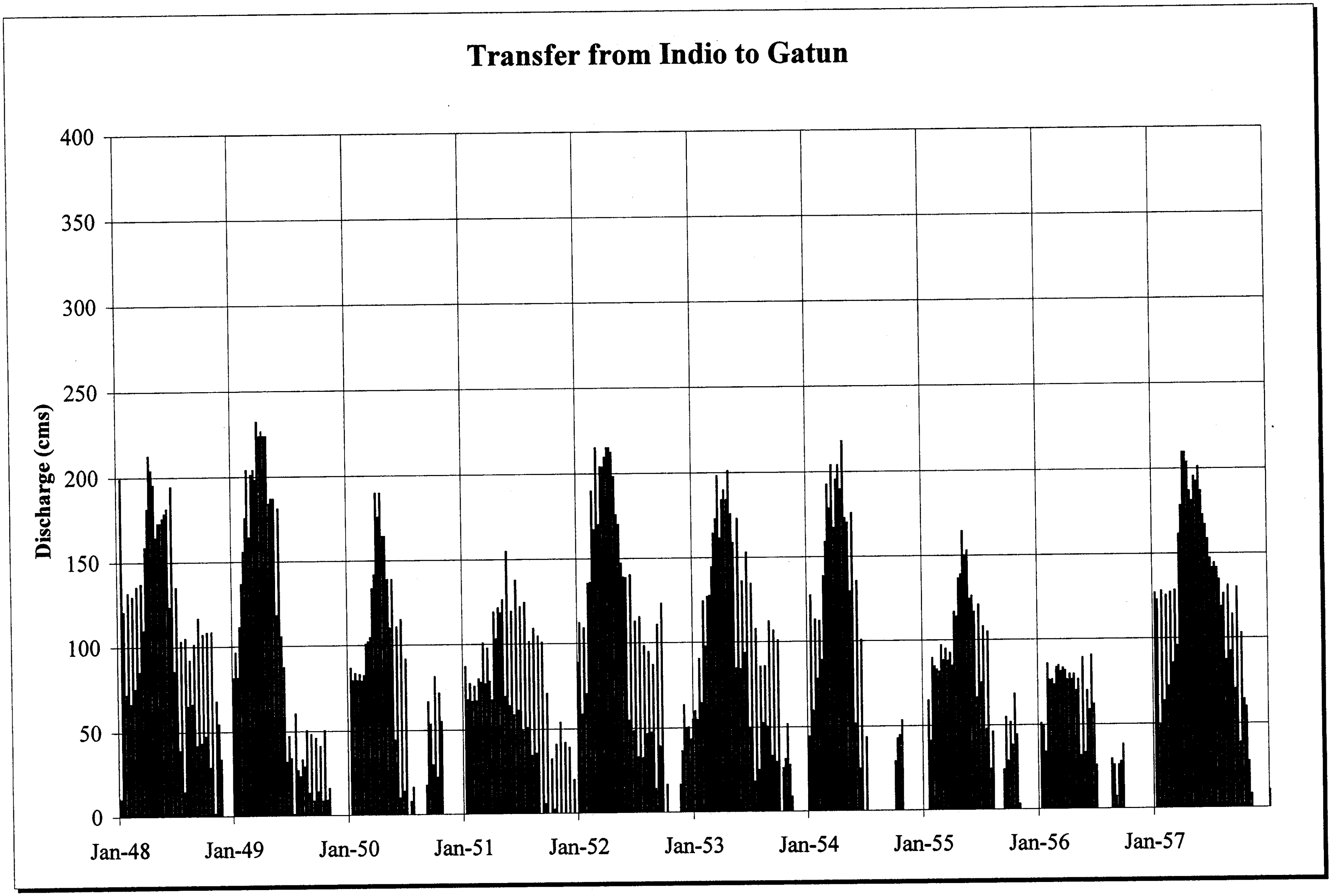

Reservoir Operations
Reservoir Elevation (m)
110
100
90
80
70
60
50
40
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57

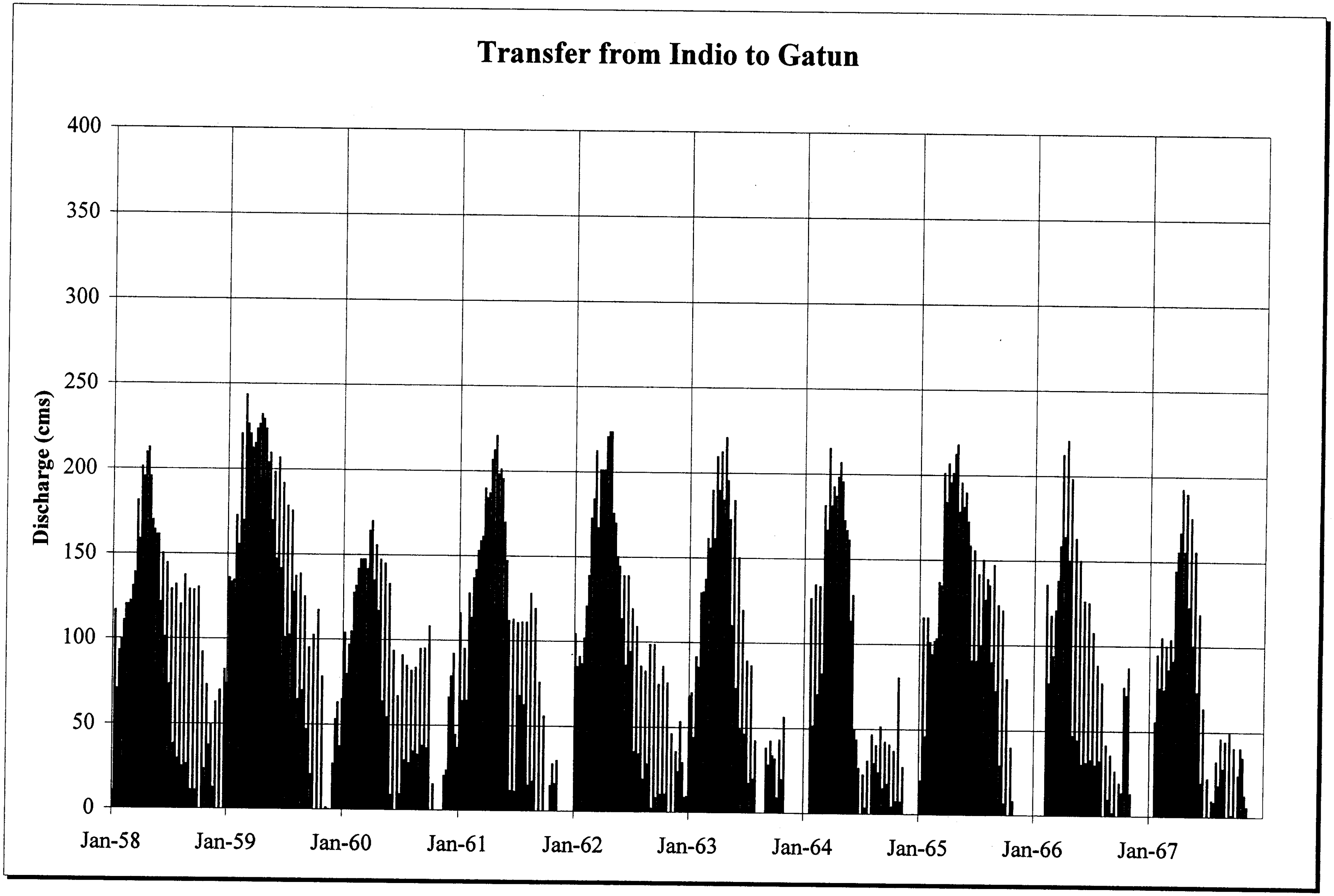

Reservoir Operations
110
100
90
80
70
60
50
40
Reservoir Elevation (m)
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67

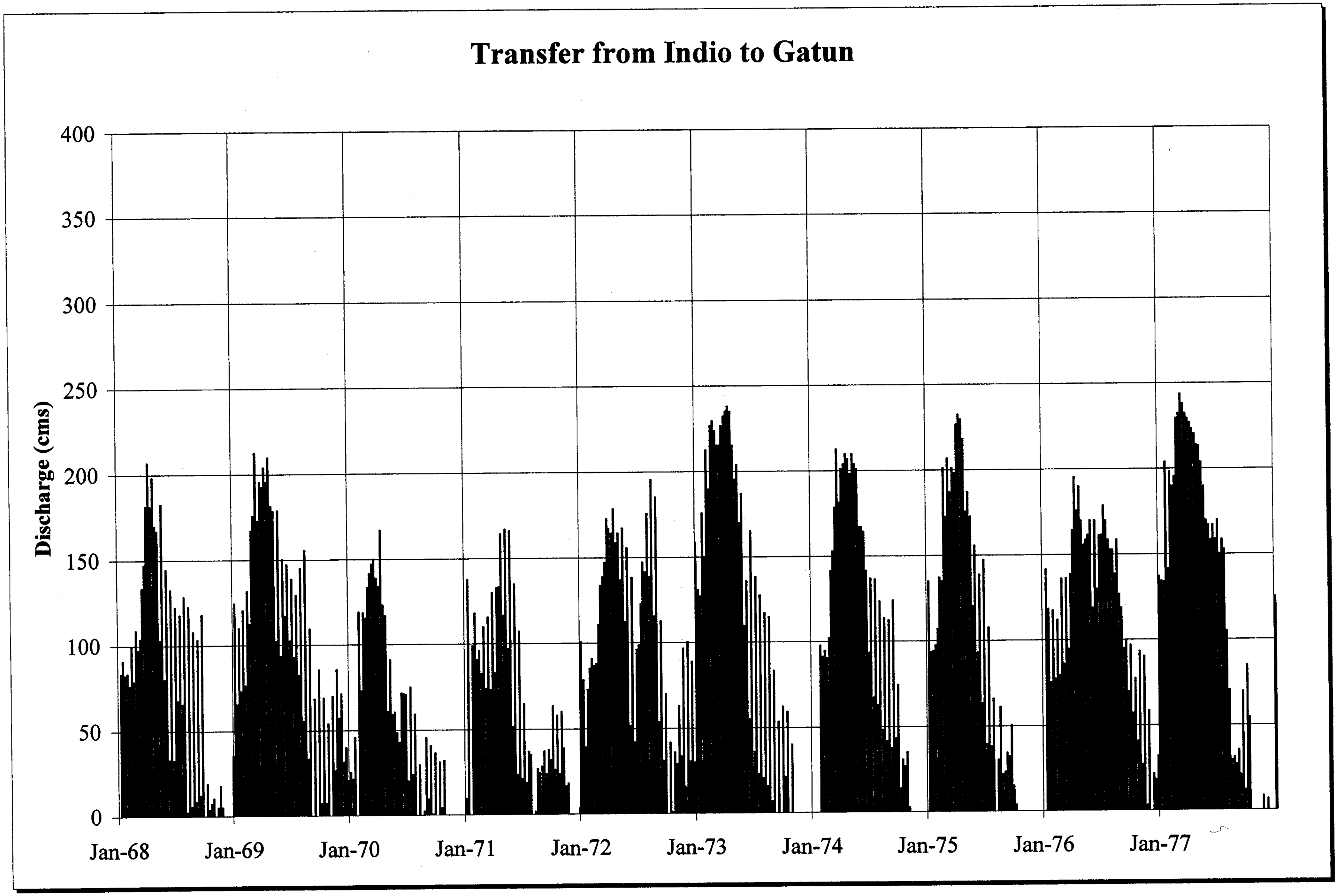

Reservoir Operations
110
100
90
80
70
60
50
40
Reservoir Elevation (m)
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77

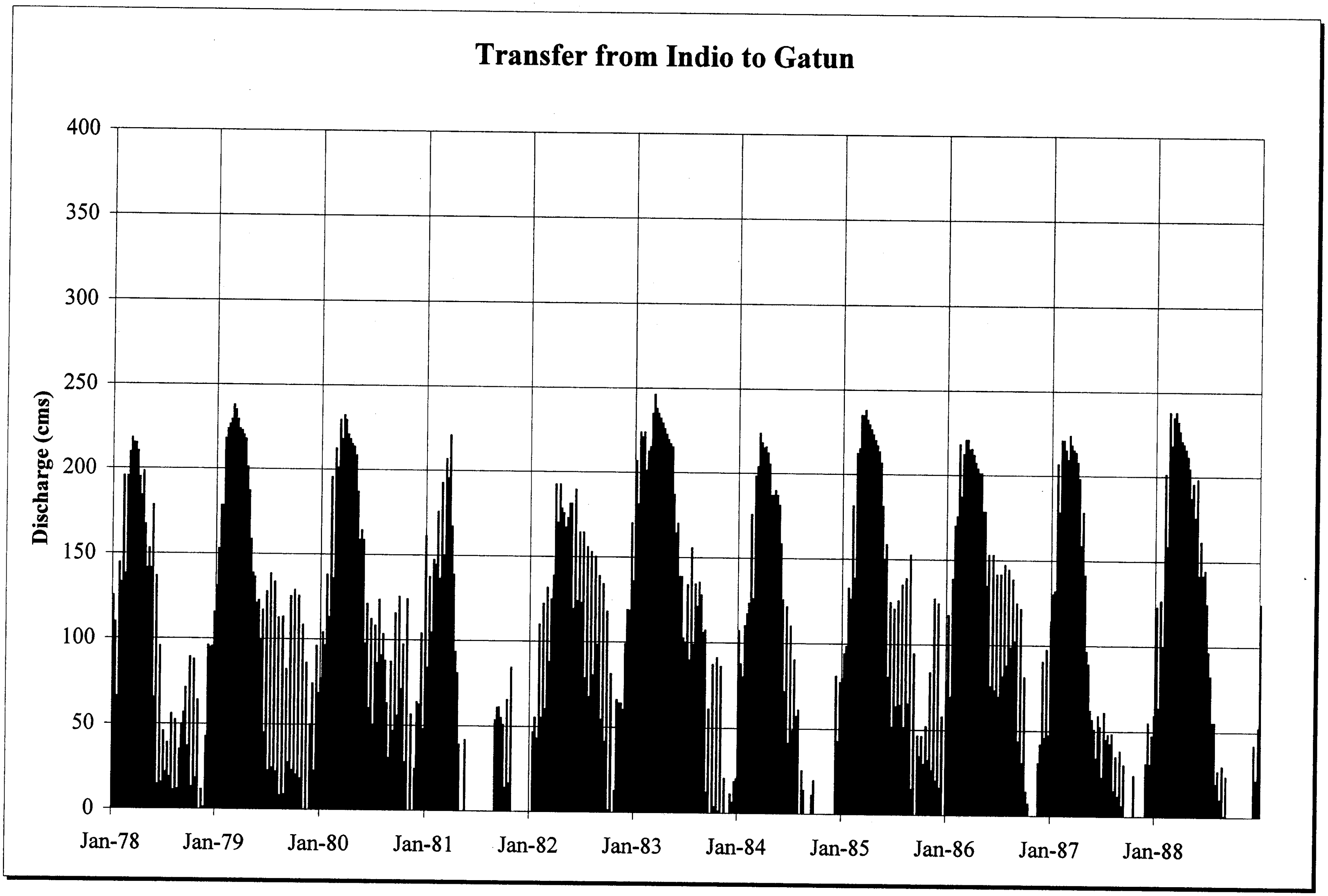

Reservoir Operations
Reservoir Elevations
110
100
90
80
70
60
50
40
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88

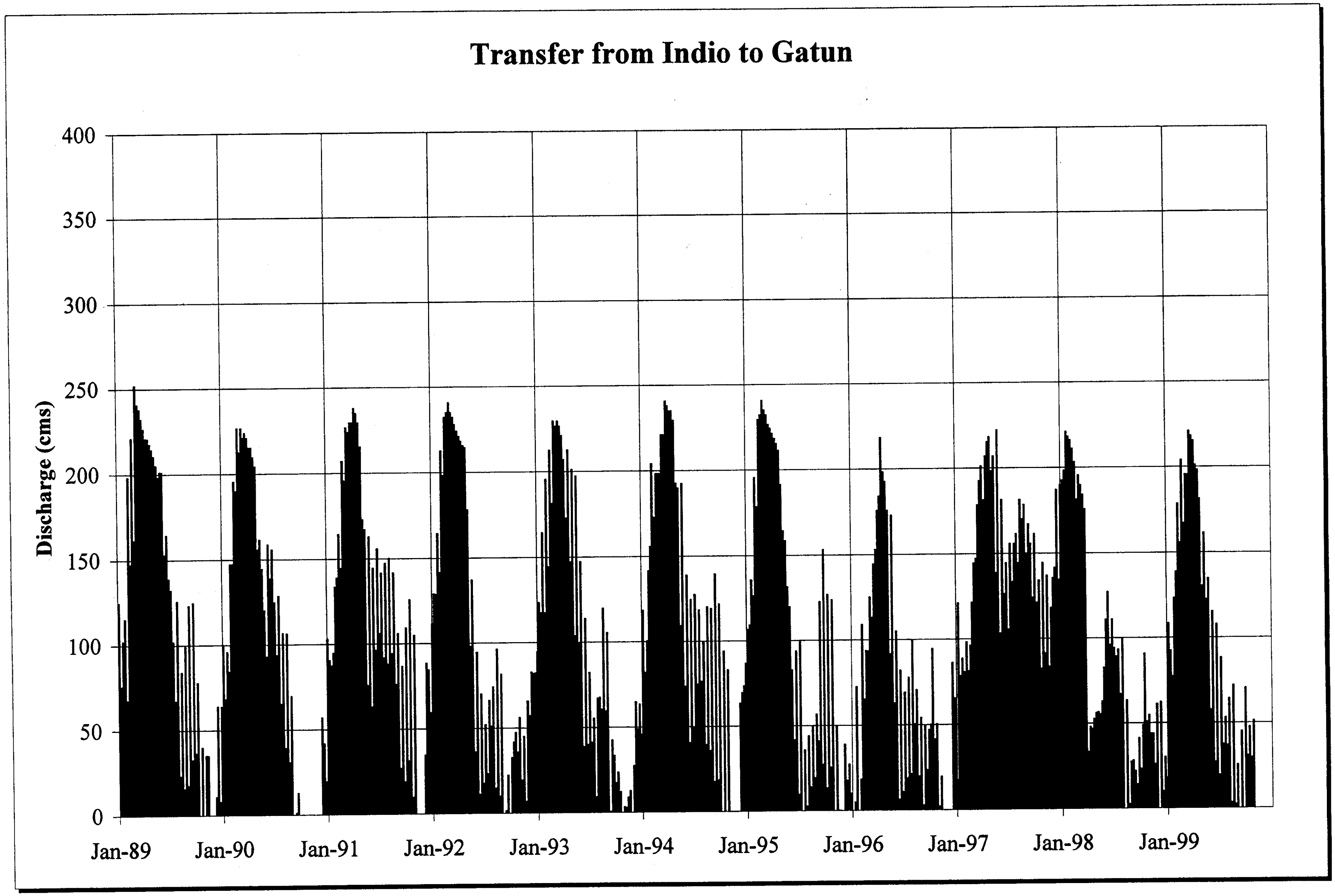

Reservoir Operations
110
100
90
80
70
60
50
40
Reservoir Elevation (m)
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

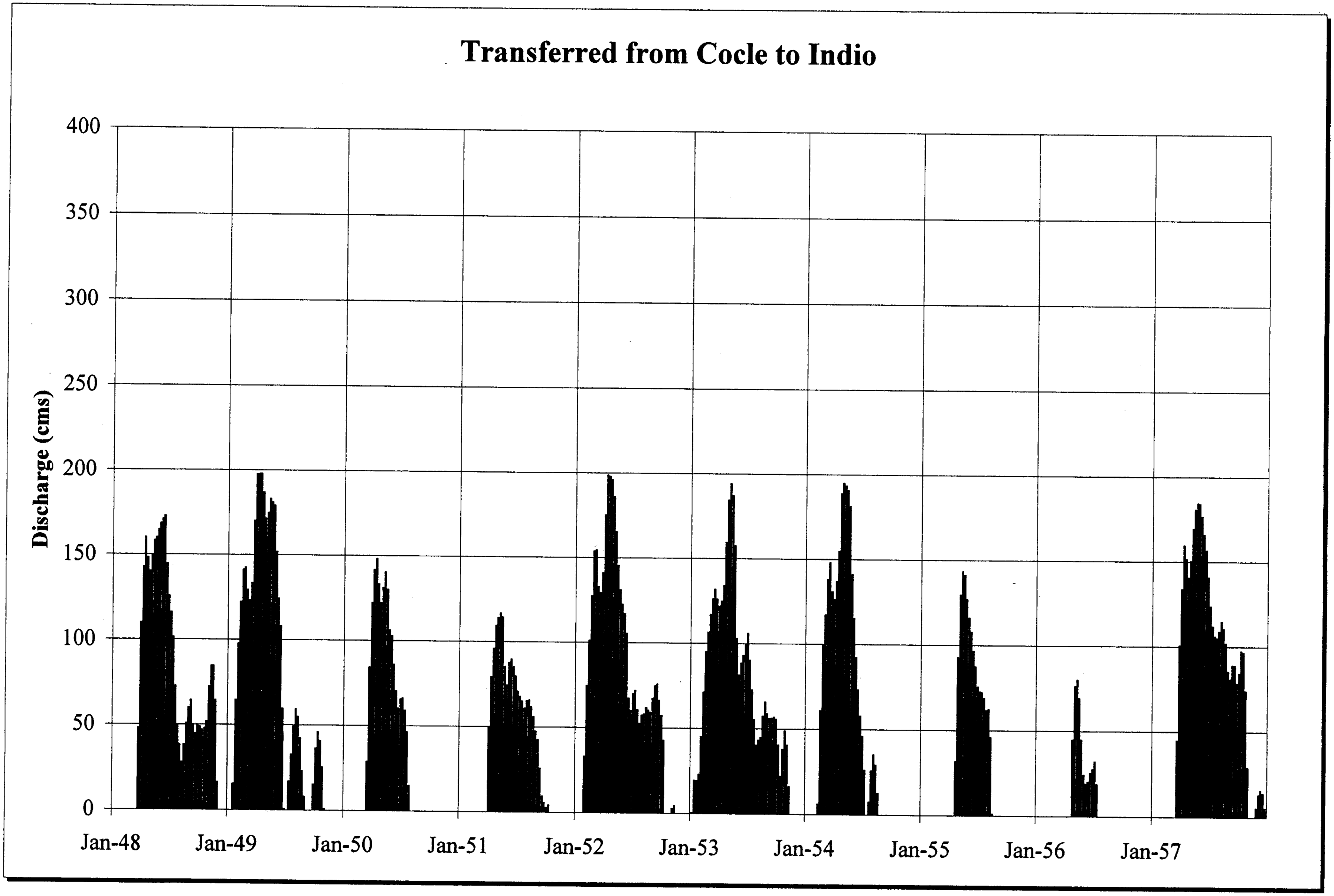

Transfer from Indio to Gatun
400
350
300
250
200
150
100
50
0
Discharge (cms)
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57

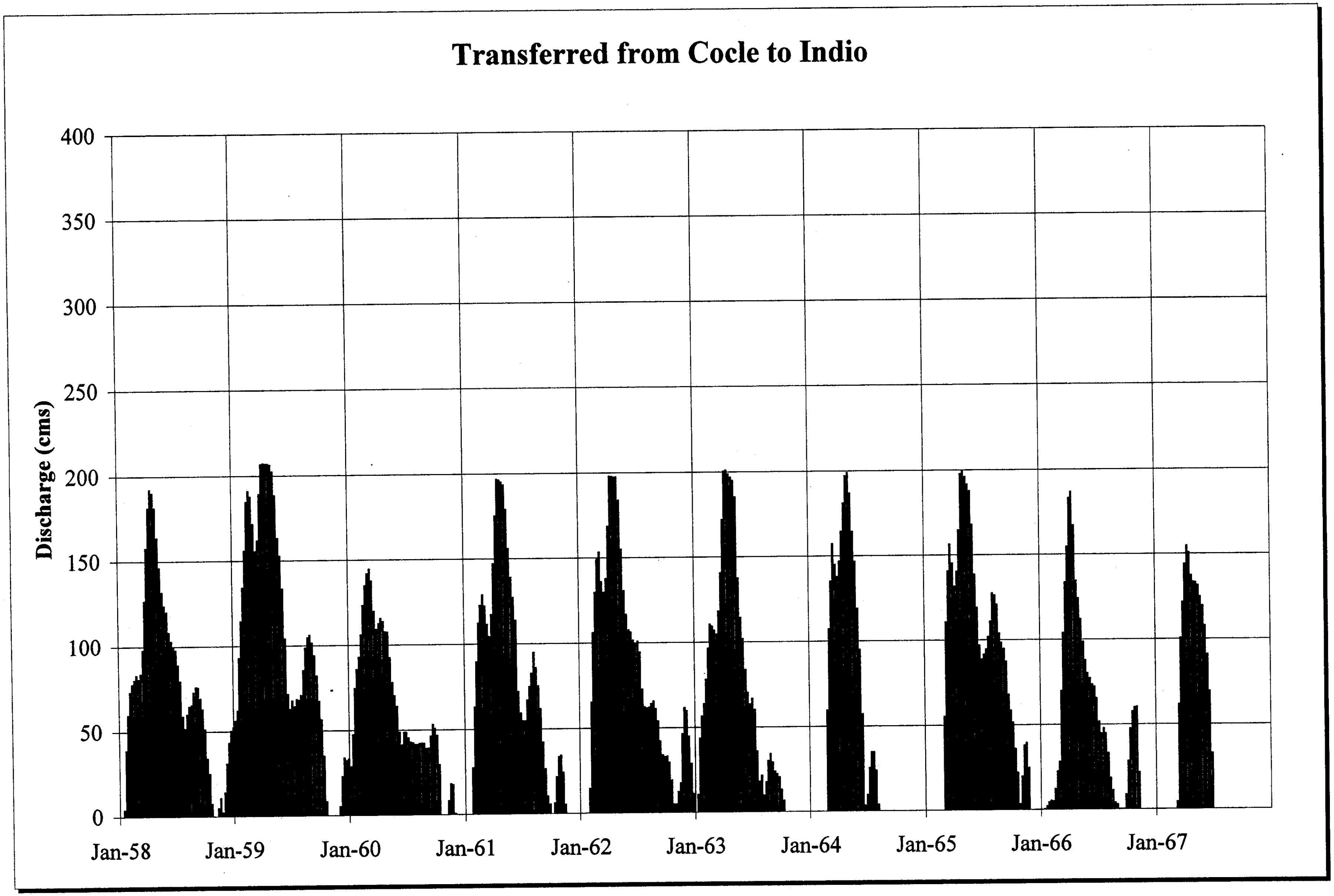

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67

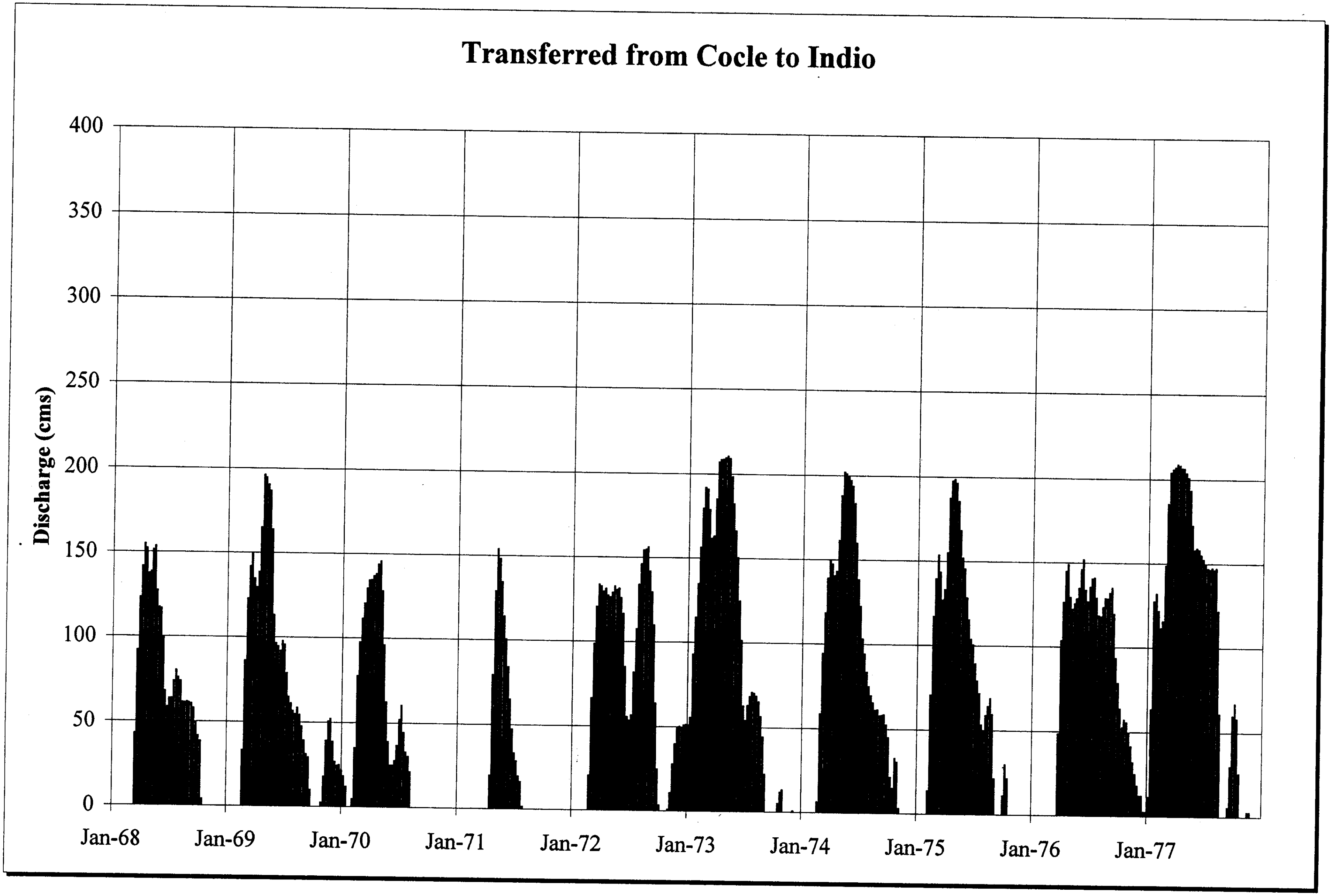

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77

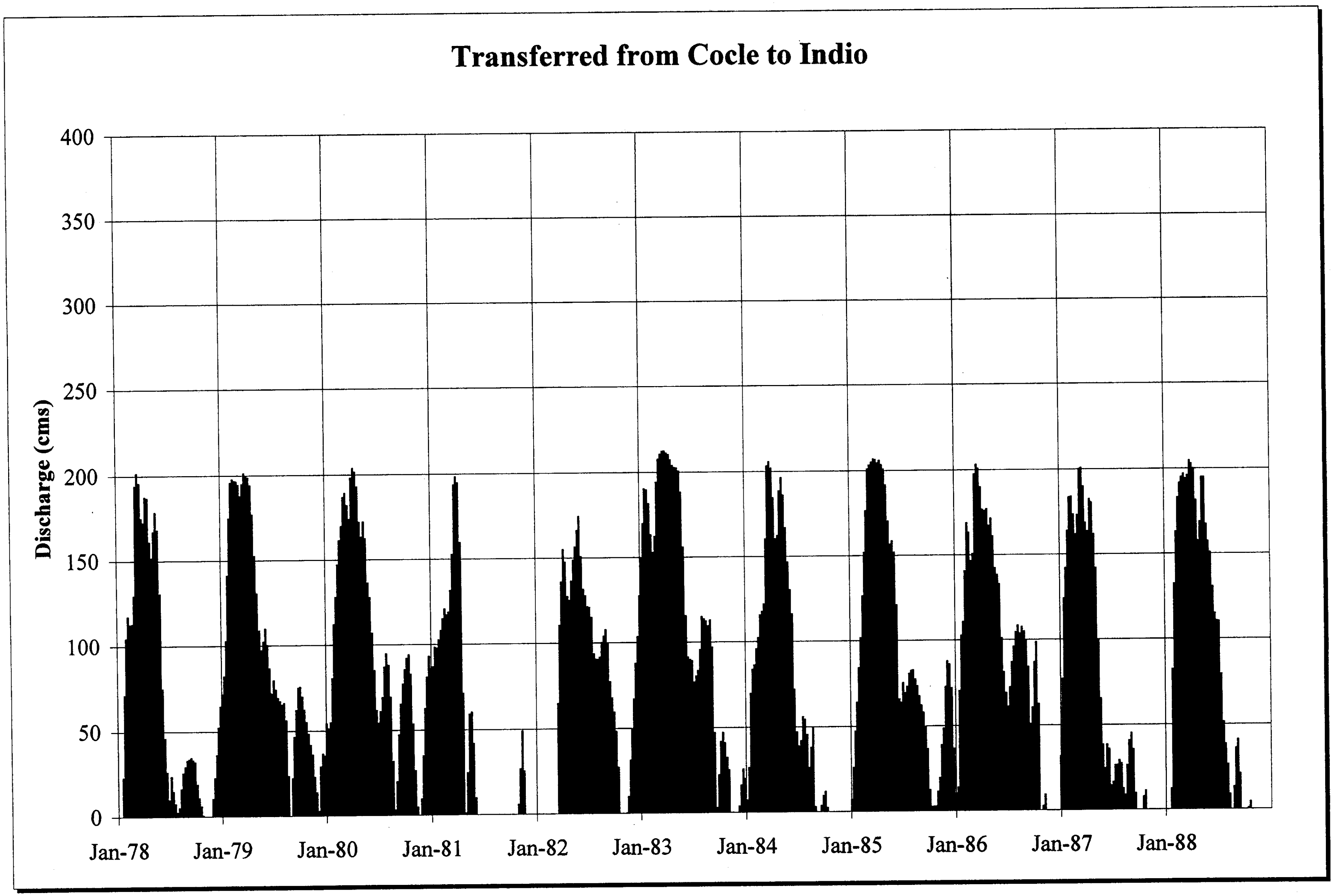

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88

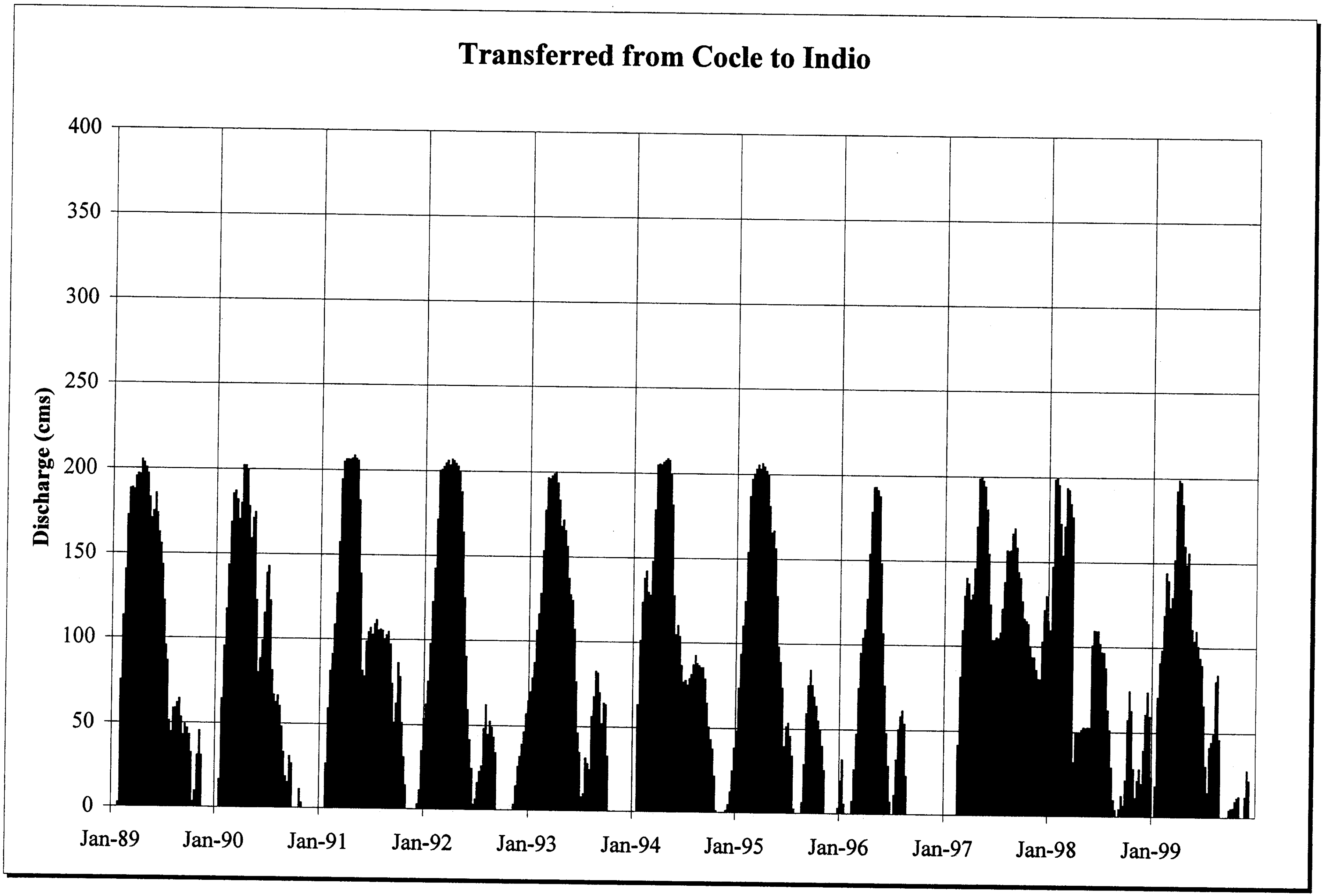

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

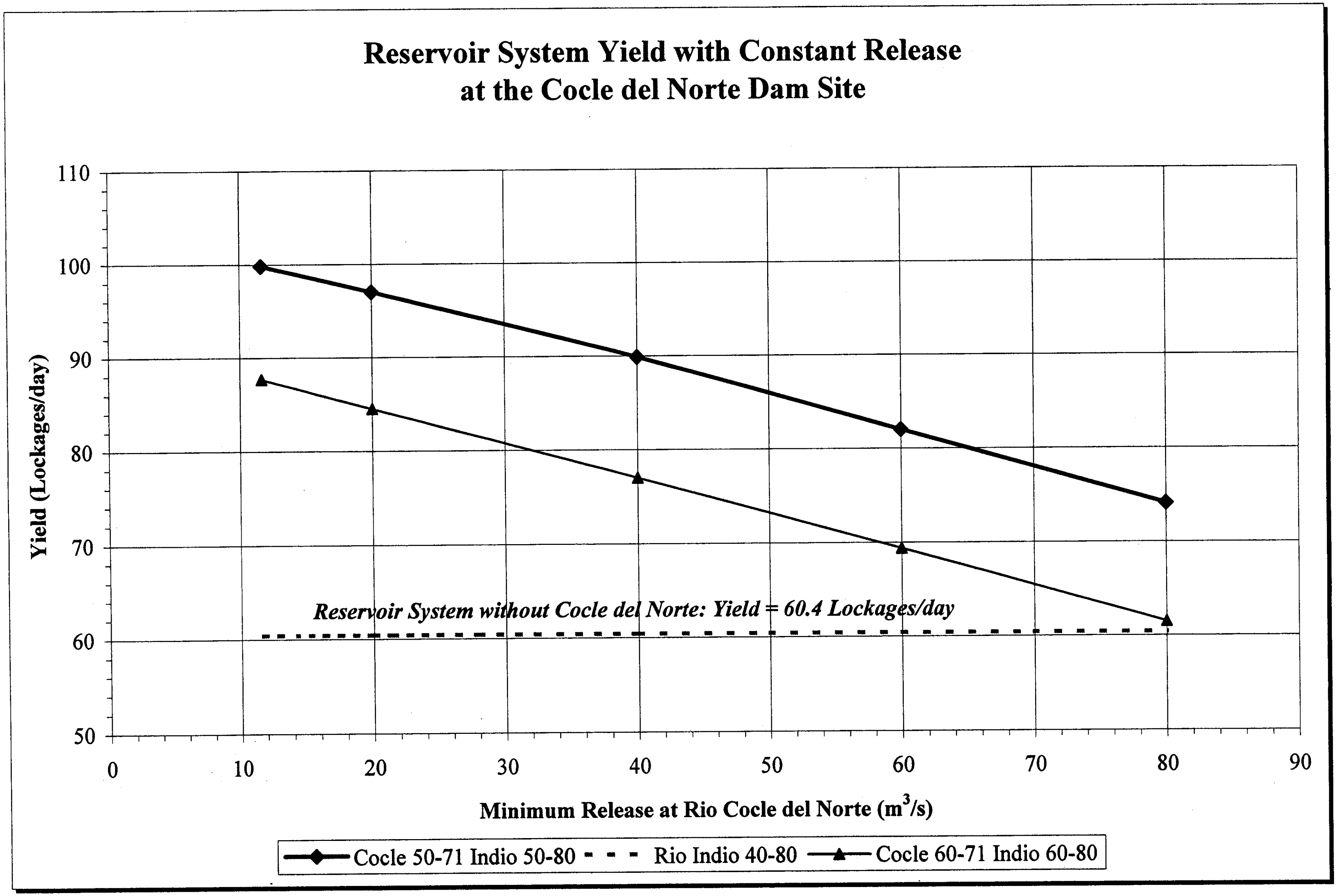

Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99


Reservoir System Yield with Constant Release
at the Cocle del Norte Dam Site
Yield (Lockages/day)
110
100
90
80
70
60
50
0
10
20
30
40
50
60
70
80
90
Minimum Release at Rio Cocle del Norte (m3/s)
Reservoir System without Cocle del Norte: Yield = 60.4 Lockages/day
Cocle 50-71 Indio 50-80
Rio Indio 40-80
Cocle 60-71 Indio 60-80

# ATTACHMENT 3

# ENERGY PRODUCTION ANALYSIS

# COCLE 50 – 71

# COCLE DEL NORTE RESERVOIR 50 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Maximum Water Supply Yield
## *Water Supply Yield: 106.1 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| **Tunnel Diameter (m)** | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| | 25 | 45.5 | 52.9 | 59.2 | 62.1 | 63.7 |
| | 30 | 63.8 | 68.4 | 71.4 | 72.0 | 70.0 |
| | 35 | 66.3 | 68.3 | 68.1 | 67.9 | 64.7 |
| | 40 | 55.3 | 56.4 | 55.4 | 53.0 | 51.1 |
| | 45 | 42.8 | | | | |
| **Maximum Output GWh/yr** | | 67.2 | 71.0 | 72.6 | 72.0 | 70.0 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| | 25 | 16.9 | 19.0 | 21.1 | 23.2 | 25.3 |
| | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 106.1 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 20m$^3$/s at Cocle Dam Site
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 97.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 78.8 | | | | 95.3 |
| | 35 | 95.4 | 100.8 | 104.6 | 106.1 | 104.4 |
| | 40 | 95.0 | 98.7 | 99.2 | 97.3 | 90.3 |
| | 45 | 80.6 | | 78.9 | | 69.2 |
| | 50 | 58.8 | | | | 51.9 |
| Maximum Output GWh/yr | | 97.1 | 102.1 | 105.6 | 106.9 | 104.4 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 97.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 89.9 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| **Tunnel Diameter (m)** | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| **Design Head (m)** | 30 | | | | | 79.7 |
| | 35 | 86.6 | 90.8 | 92.5 | 93.2 | 91.5 |
| | 40 | 88.0 | 91.1 | 92.1 | 90.8 | 87.3 |
| | 45 | 78.1 | 78.2 | 74.2 | 69.1 | 69.3 |
| | 50 | | 53.5 | | | 54.2 |
| **Maximum Output GWh/yr** | | 89.2 | 93.1 | 95.4 | 95.1 | 93.1 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| **Design Head (m)** | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 89.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS

## Constant Release of 60m$^3$/s at Cocle Dam Site
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 82.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 54.5 | | | | 60.1 |
| | 35 | 72.2 | 75.5 | 76.4 | 76.5 | 75.5 |
| | 40 | 77.2 | 79.1 | 79.4 | 79.6 | 78.9 |
| | 45 | 70.1 | 72.2 | 71.4 | 70.3 | 70.7 |
| | 50 | 55.9 | | | | 56.6 |
| Maximum Output GWh/yr | | 77.4 | 79.9 | 80.5 | 79.7 | 79.9 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 82.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 20m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 84.5 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| **Tunnel Diameter (m)** | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 31.9 | | | | 54.9 |
| | 35 | 86.1 | 92.3 | 95.9 | 97.6 | 99.0 |
| | 40 | 116.8 | 121.1 | 123.6 | 125.5 | 126.8 |
| | 45 | 118.0 | 122.1 | 124.8 | 124.3 | 122.6 |
| | 50 | 112.4 | 115.1 | 115.0 | 108.2 | 102.5 |
| **Maximum Output GWh/yr** | | 119.0 | 123.0 | 125.7 | 127.6 | 128.3 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 84.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40m$^3$/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 77.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 19.8 | | | | 27.9 |
| | 35 | 64.3 | | 68.4 | | 70.3 |
| | 40 | 95.5 | 97.7 | 99.1 | 100.1 | 100.8 |
| | 45 | 100.4 | 102.6 | 104.1 | 104.1 | 103.7 |
| | 50 | 97.3 | 98.4 | 98.3 | 96.6 | 95.9 |
| Maximum Output GWh/yr | | 100.8 | 103.0 | 104.4 | 105.4 | 105.5 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 77.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 60m$^3$/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 69.4 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Tunnel Diameter (m)** | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| **Design Head (m)** | 30 | 9.0 | | | | |
| | 35 | 38.1 | 38.6 | | | 39.7 |
| | 40 | 69.9 | 70.7 | 71.2 | 71.5 | 71.7 |
| | 45 | 77.6 | 78.4 | 78.9 | 78.9 | 78.8 |
| | 50 | 76.5 | 76.8 | 76.8 | 77.0 | 77.0 |
| **Maximum Output GWh/yr** | | 77.6 | 78.4 | 78.9 | 78.9 | 78.8 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Design Head (m)** | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 69.4 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80m$^3$/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 61.5 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 2.4 | | | | |
| | 35 | 11.1 | | | | 11.3 |
| | 40 | 43.9 | 44.8 | | 45.3 | 45.5 |
| | 45 | 60.0 | 60.3 | 60.6 | 60.8 | 60.8 |
| | 50 | 60.2 | 60.4 | 60.6 | 60.7 | 60.7 |
| Maximum Output GWh/yr | | 60.2 | 60.5 | 60.7 | 60.8 | 60.8 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 61.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50- 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Minimum Transfer from Indio to Gatun of 80 cms
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 97.5 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 170.5 | 188.5 | 194.1 | 196.8 | 198.5 |
| | 35 | 182.0 | 188.6 | 191.3 | 192.8 | 193.8 |
| | 40 | 164.6 | 178.9 | 181.8 | 181.9 | 178.4 |
| | 45 | 146.9 | | | | 159.0 |
| | 50 | 109.7 | | | | 123.5 |
| Maximum Output GWh/yr | | 182.6 | 190.8 | 194.2 | 196.8 | 198.5 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 97.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60- 71
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Minimum Transfer from Indio to Gatun of 80 cms
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 87.2 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Tunnel Diameter (m) | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Design Head (m) | 30 | 34.9 | | | | 48.1 |
| | 35 | 205.3 | 225.3 | 227.4 | 228.1 | 228.5 |
| | 40 | 220.5 | 226.2 | 227.3 | 228.1 | 228.6 |
| | 45 | 208.3 | 225.3 | 226.5 | 227.4 | 228.1 |
| | 50 | 197.6 | | | | 223.6 |
| Maximum Output GWh/yr | | 221.6 | 226.3 | 227.4 | 228.1 | 228.6 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 90 | 100 | 110 | 120 |
| Design Head (m) | 30 | 20.2 | 22.8 | 25.3 | 27.8 | 30.4 |
| | 35 | 23.6 | 26.6 | 29.5 | 32.5 | 35.4 |
| | 40 | 27.0 | 30.4 | 33.7 | 37.1 | 40.5 |
| | 45 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 |
| | 50 | 33.7 | 38.0 | 42.2 | 46.4 | 50.6 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 87.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# INDIO POWER PLANT - OUTPUT ANALYSIS

**Indio Reservoir Operation between El.50 and El.80**

**Minimum Release at Indio Dam site: 60 m3/s**

***Water Supply Yield: 71.6 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 70 | 80 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 4.70 | 5.00 |
| Design Head (m) | 45 | 130.9 | 159.3 | 191.2 | 218.0 | 225.6 |
| | 50 | 141.3 | 180.4 | 217.9 | 240.4 | 242.6 |
| | 55 | 140.0 | 188.0 | 231.8 | 241.1 | 243.2 |
| | 60 | 132.7 | 180.9 | 226.2 | 241.5 | 243.7 |
| | 65 | 124.9 | 171.7 | 216.2 | 241.3 | 243.7 |
| Maximum Output GWh/yr | | 142.9 | 188.2 | 232.5 | 241.5 | 243.7 |

## Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 70 | 80 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 4.70 | 5.00 |
| Design Head (m) | 45 | 15.2 | 19.0 | 0.0 | 0.0 | 0.0 |
| | 50 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 55 | 18.6 | 23.2 | 27.8 | 32.5 | 37.1 |
| | 60 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 65 | 21.9 | 27.4 | 32.9 | 38.4 | 43.9 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 70 | 80 |
| Design Head (m) | 45 | 15.2 | 19.0 | 22.8 | 26.6 | 30.4 |
| | 50 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 55 | 18.6 | 23.2 | 27.8 | 32.5 | 37.1 |
| | 60 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 65 | 21.9 | 27.4 | 32.9 | 38.4 | 43.9 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 71.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Maximum Water Supply Yield
## *Water Supply Yield: 106.1 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 65.2 | | | | 83.1 |
| | 60 | 73.1 | 80.5 | 87.4 | 99.1 | 109.3 |
| | 65 | 75.6 | 83.4 | 90.4 | 102.5 | 113.2 |
| | 70 | 76.3 | 84.4 | 91.5 | 103.7 | 114.7 |
| | 75 | 75.2 | | | | 113.0 |
| Maximum Output GWh/yr | | 76.8 | 84.9 | 92.1 | 104.4 | 115.4 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 0.0 | | | | |
| | 60 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |
| | 65 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |
| | 70 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |
| | 75 | 14.5 | | | | 14.5 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 106.1 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 20m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 97.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 104.9 | | | 124.0 | |
| | 60 | 120.2 | 132.6 | 143.6 | 163.0 | 179.8 |
| | 65 | 124.2 | 137.1 | 148.7 | 168.8 | 186.0 |
| | 70 | 125.4 | 138.6 | 150.4 | 170.8 | 188.3 |
| | 75 | 123.7 | 136.5 | 148.2 | 168.2 | 185.6 |
| Maximum Output GWh/yr | | 126.2 | 139.5 | 151.4 | 171.8 | 189.5 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 0.0 | | | | |
| | 60 | 20.2 | 25.3 | 30.4 | 30.9 | 31.0 |
| | 65 | 21.9 | 27.4 | 30.9 | 30.9 | 31.0 |
| | 70 | 23.6 | 29.5 | 30.9 | 30.9 | 31.0 |
| | 75 | 25.3 | 30.9 | 30.9 | 30.9 | 31.0 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 97.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS

### Constant Release of 40m$^3$/s at Cocle Dam Site
### Indio Reservoir Operating between El 50 and El 80
### *Water Supply Yield: 89.9 Lockages/day*

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 161.5 | 192.8 | | | 190.3 |
| | 60 | 175.4 | 198.0 | 210.1 | 230.2 | 247.9 |
| | 65 | 184.8 | 202.7 | 215.1 | 236.1 | 254.4 |
| | 70 | 183.2 | 204.2 | 216.9 | 238.1 | 256.8 |
| | 75 | 177.0 | 202.1 | 214.7 | 235.5 | 254.0 |
| Maximum Output GWh/yr | | 186.3 | 205.1 | 217.8 | 239.4 | 257.9 |

## Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 18.6 | 23.2 | | | 0.0 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 61.1 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 89.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 60m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 50 and El 80
## *Water Supply Yield: 82.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 161.8 | | | | 262.5 |
| | 60 | 175.0 | 218.8 | 262.7 | 299.6 | 317.8 |
| | 65 | 184.1 | 230.2 | 276.6 | 305.3 | 324.2 |
| | 70 | 182.4 | 228.2 | 274.7 | 307.3 | 326.6 |
| | 75 | 176.4 | 220.5 | 265.4 | 304.8 | 323.8 |
| Maximum Output GWh/yr | | 185.5 | 232.0 | 278.8 | 308.3 | 327.7 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 18.6 | | | | 0.0 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.50 and El.71, Indio operating between El. 50 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 82.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
### Constant Release of 20m$^3$/s at Cocle Dam Site
### Indio Reservoir Operating between El 60 and El 80
### *Water Supply Yield: 84.5 Lockages/day*

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 108.2 | | | | |
| | 60 | 137.9 | 157.2 | 175.9 | 210.1 | 240.9 |
| | 65 | 143.9 | 165.0 | 184.7 | 220.6 | 252.6 |
| | 70 | 146.3 | 167.9 | 188.3 | 224.8 | 257.7 |
| | 75 | 143.3 | 164.4 | 184.4 | 220.2 | 252.5 |
| Maximum Output GWh/yr | | 147.6 | 169.4 | 189.9 | 226.6 | 259.5 |

## Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 0.0 | | | | |
| | 60 | 20.2 | 25.3 | 30.4 | 33.3 | 33.3 |
| | 65 | 21.9 | 27.4 | 32.9 | 33.3 | 33.3 |
| | 70 | 23.6 | 29.5 | 33.3 | 33.3 | 33.3 |
| | 75 | 25.3 | 31.6 | 33.3 | 33.3 | 33.3 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 84.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 77.0 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 161.9 | | | | |
| | 60 | 176.7 | 208.4 | 228.7 | 265.4 | 298.2 |
| | 65 | 190.7 | 216.7 | 238.1 | 276.6 | 311.3 |
| | 70 | 193.0 | 219.7 | 241.8 | 281.1 | 316.7 |
| | 75 | 186.5 | 216.0 | 237.7 | 276.1 | 311.5 |
| Maximum Output GWh/yr | | 195.9 | 221.2 | 243.5 | 283.1 | 318.5 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 18.6 | | | | 0.0 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 77.0 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS

### Constant Release of $60m^3/s$ at Cocle Dam Site
### Indio Reservoir Operating between El 60 and El 80
### *Water Supply Yield: 69.4 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 162.1 | | | | 254.8 |
| | 60 | 176.9 | 221.1 | | 319.2 | 351.6 |
| | 65 | 190.9 | 238.6 | 286.4 | 329.8 | 363.6 |
| | 70 | 192.8 | 241.3 | 290.5 | 334.0 | 368.7 |
| | 75 | 186.3 | 233.2 | 280.6 | 329.3 | 363.4 |
| Maximum Output GWh/yr | | 195.6 | 244.9 | 294.6 | 335.9 | 370.5 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 18.6 | | | | 0.0 |
| | 60 | 20.2 | 25.3 | | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 69.4 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60 - 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80m³/s at Cocle Dam Site
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 61.5 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 161.8 | | | | 389.9 |
| | 60 | 176.5 | | | | 404.8 |
| | 65 | 190.1 | 237.6 | 285.3 | 380.3 | 413.1 |
| | 70 | 190.1 | 237.9 | 286.3 | 381.6 | 416.5 |
| | 75 | 183.6 | 229.9 | 276.6 | 368.7 | 412.8 |
| Maximum Output GWh/yr | | 192.9 | 241.1 | 290.5 | 387.1 | 417.9 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 61.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 50- 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
### Minimum Transfer from Indio to Gatun of 80 cms
### Indio Reservoir Operating between El 50 and El 80
### *Water Supply Yield: 97.5 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 63.4 | | | | 87.9 |
| | 60 | 76.5 | | | | 116.7 |
| | 65 | 79.1 | 87.3 | 95.0 | 108.8 | 120.7 |
| | 70 | 79.8 | 88.2 | 96.1 | 110.2 | 122.2 |
| | 75 | 78.7 | 86.9 | 94.6 | 108.4 | 120.4 |
| Maximum Output GWh/yr | | 80.3 | 88.8 | 96.8 | 110.9 | 123.0 |

**Firm Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 0.0 | | | | 0.0 |
| | 60 | 16.7 | | | | 16.8 |
| | 65 | 16.73 | 16.75 | 16.76 | 16.78 | 16.78 |
| | 70 | 16.73 | 16.75 | 16.76 | 16.78 | 16.78 |
| | 75 | 16.73 | 16.75 | 16.76 | 16.78 | 16.78 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 97.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 60- 71
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Minimum Transfer from Indio to Gatun of 80 cms
## Indio Reservoir Operating between El 60 and El 80
## *Water Supply Yield: 87.2 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 63.3 | | | | 96.8 |
| | 60 | 86.3 | | | | 143.8 |
| | 65 | 89.9 | 101.5 | 112.5 | 132.7 | 150.1 |
| | 70 | 91.2 | 103.1 | 114.5 | 135.0 | 152.9 |
| | 75 | 89.6 | 101.2 | 112.3 | 132.5 | 150.1 |
| Maximum Output GWh/yr | | 91.9 | 103.9 | 115.4 | 136.0 | 153.8 |

### Firm Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.60 | 4.00 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 0.0 | | | | 0.0 |
| | 60 | 18.1 | | | | 18.2 |
| | 65 | 18.1 | 18.1 | 18.2 | 18.2 | 18.2 |
| | 70 | 18.1 | 18.1 | 18.2 | 18.2 | 18.2 |
| | 75 | 18.1 | 18.1 | 18.2 | 18.2 | 18.2 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 80 | 100 |
| Design Head (m) | 55 | 18.6 | 23.2 | 27.8 | 37.1 | 46.4 |
| | 60 | 20.2 | 25.3 | 30.4 | 40.5 | 50.6 |
| | 65 | 21.9 | 27.4 | 32.9 | 43.9 | 54.8 |
| | 70 | 23.6 | 29.5 | 35.4 | 47.2 | 59.1 |
| | 75 | 25.3 | 31.6 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in October 2003. The system of reservoirs consists of Cocle operating between El.60 and El.71, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 87.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 350-m long tunnel.
8- The simulations cover 52 years.

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Maximum Reservoir System Yield**
***Water Supply Yield: 106.1 Lockages/day***

**Cocle del Norte Power Plant**

| | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **84.64 cms** |
| Discharge at Min Head | **84.32 cms** |
| Head Loss at Max Head Discharge | **1.26 meters** |
| Head Loss at Min Head Discharge | **1.25 meters** |
| Tunnel Diameter | **5.80 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **60,000 kW** |
| Maximum Turbine Discharge (at Hd) | **104.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.92 meters** |
| **Average Annual Output** | **117.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **14,528 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Maximum Reservoir System Yield**
***Water Supply Yield: 106.1 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **42.32 cms** |
| Discharge at Min Head | **42.16 cms** |
| Head Loss at Max Head Discharge | **1.46 meters** |
| Head Loss at Min Head Discharge | **1.45 meters** |
| Tunnel Diameter | **4.10 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **52.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.22 meters** |
| **Average Annual Output** | **86.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **14,507 kW** |

# INDIO HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Maximum Reservoir System Yield**
***Water Supply Yield: 106.1 Lockages/day***

| | |
|---|---|
| **Indio Power Plant** | |
| Design head | **55.00 meters** |
| Maximum Operating Head | **68.75 meters** |
| Minimum Operating Head | **35.75 meters** |
| Discharge at Max Head | **4.31 cms** |
| Discharge at Min Head | **4.34 cms** |
| Head Loss at Max Head Discharge | **0.01 meters** |
| Head Loss at Min Head Discharge | **0.01 meters** |
| Tunnel Diameter | **4.80 m** |
| Tunnel Length | **600 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **0.30 m/s** |
| Installed Capacity (at Hd) | **2,500 kW** |
| Maximum Turbine Discharge (at Hd) | **5.4 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **0.01 meters** |
| **Average Annual Output** | **9.3 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **2,341 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Maximum Reservoir System Yield**
***Water Supply Yield: 106.1 Lockages/day***

| **Isla Pablon Power Plant** | |
|---|---|
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **82.22 cms** |
| Discharge at Min Head | **81.91 cms** |
| Head Loss at Max Head Discharge | **3.03 meters** |
| Head Loss at Min Head Discharge | **3.01 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.30 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **101.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **4.63 meters** |
| **Average Annual Output** | **80.4 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Constant Minimum Releas at Cocle: 40 cms**
***Water Supply Yield: 95.1 Lockages/day***

| | |
|---|---|
| **Cocle del Norte Power Plant** | |
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **84.64 cms** |
| Discharge at Min Head | **84.32 cms** |
| Head Loss at Max Head Discharge | **1.26 meters** |
| Head Loss at Min Head Discharge | **1.25 meters** |
| Tunnel Diameter | **5.80 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **60,000 kW** |
| Maximum Turbine Discharge (at Hd) | **104.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.92 meters** |
| **Average Annual Output** | **226.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **51,515 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Constant Minimum Releas at Cocle: 40 cms**
***Water Supply Yield: 95.1 Lockages/day***

**Isla Pablon Power Plant**

| | |
|---|---|
| Design head | **38.00 meters** |
| Maximum Operating Head | **47.50 meters** |
| Minimum Operating Head | **24.70 meters** |
| Discharge at Max Head | **50.49 cms** |
| Discharge at Min Head | **50.30 cms** |
| Head Loss at Max Head Discharge | **1.14 meters** |
| Head Loss at Min Head Discharge | **1.13 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **1.41 m/s** |
| Installed Capacity (at Hd) | **20,000 kW** |
| Maximum Turbine Discharge (at Hd) | **62.38 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.75 meters** |
| **Average Annual Output** | **56.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Constant Minimum Releas at Cocle: 60 cms**
***Water Supply Yield: 86.8 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **84.64 cms** |
| Discharge at Min Head | **84.32 cms** |
| Head Loss at Max Head Discharge | **1.26 meters** |
| Head Loss at Min Head Discharge | **1.25 meters** |
| Tunnel Diameter | **5.80 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **60,000 kW** |
| Maximum Turbine Discharge (at Hd) | **104.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.92 meters** |
| **Average Annual Output** | **300.4 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **60,000 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.40 and El.80**
**Constant Minimum Releas at Cocle: 60 cms**
***Water Supply Yield: 86.8 Lockages/day***

| **Isla Pablon Power Plant** | |
|---|---|
| Design head | **38.00 meters** |
| Maximum Operating Head | **47.50 meters** |
| Minimum Operating Head | **24.70 meters** |
| Discharge at Max Head | **50.49 cms** |
| Discharge at Min Head | **50.30 cms** |
| Head Loss at Max Head Discharge | **1.14 meters** |
| Head Loss at Min Head Discharge | **1.13 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **1.41 m/s** |
| Installed Capacity (at Hd) | **20,000 kW** |
| Maximum Turbine Discharge (at Hd) | **62.38 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.75 meters** |
| **Average Annual Output** | **51.0 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**Constant Minimum Releas at Cocle: 80 cms**
***Water Supply Yield: 74.1 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **84.64 cms** |
| Discharge at Min Head | **84.32 cms** |
| Head Loss at Max Head Discharge | **1.26 meters** |
| Head Loss at Min Head Discharge | **1.25 meters** |
| Tunnel Diameter | **5.80 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **60,000 kW** |
| Maximum Turbine Discharge (at Hd) | **104.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.92 meters** |
| **Average Annual Output** | **398.3 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **60,000 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**Constant Minimum Releas at Cocle: 80 cms**
***Water Supply Yield: 74.1 Lockages/day***

| **Isla Pablon Power Plant** | |
|---|---|
| Design head | **38.00 meters** |
| Maximum Operating Head | **47.50 meters** |
| Minimum Operating Head | **24.70 meters** |
| Discharge at Max Head | **50.49 cms** |
| Discharge at Min Head | **50.30 cms** |
| Head Loss at Max Head Discharge | **1.14 meters** |
| Head Loss at Min Head Discharge | **1.13 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **1.41 m/s** |
| Installed Capacity (at Hd) | **20,000 kW** |
| Maximum Turbine Discharge (at Hd) | **62.38 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.75 meters** |
| **Average Annual Output** | **54.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.60 and El.71**
**Indio Reservoir Operation between El.60 and El.80**
**Constant Minimum Releas at Cocle: 80 cms**
***Water Supply Yield: 61.5 Lockages/day***

| | |
|---|---|
| **Cocle del Norte Power Plant** | |
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **84.64 cms** |
| Discharge at Min Head | **84.32 cms** |
| Head Loss at Max Head Discharge | **1.26 meters** |
| Head Loss at Min Head Discharge | **1.25 meters** |
| Tunnel Diameter | **5.80 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **60,000 kW** |
| Maximum Turbine Discharge (at Hd) | **104.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.92 meters** |
| **Average Annual Output** | **423.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **60,000 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.60 and El.71**
**Indio Reservoir Operation between El.60 and El.80**
**Constant Minimum Releas at Cocle: 80 cms**
***Water Supply Yield: 61.5 Lockages/day***

| **Isla Pablon Power Plant** | |
|---|---|
| Design head | **38.00 meters** |
| Maximum Operating Head | **47.50 meters** |
| Minimum Operating Head | **24.70 meters** |
| Discharge at Max Head | **50.49 cms** |
| Discharge at Min Head | **50.30 cms** |
| Head Loss at Max Head Discharge | **1.14 meters** |
| Head Loss at Min Head Discharge | **1.13 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **1.41 m/s** |
| Installed Capacity (at Hd) | **20,000 kW** |
| Maximum Turbine Discharge (at Hd) | **62.38 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.75 meters** |
| **Average Annual Output** | **28.9 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**Minimum Release at Indio Dam site: 60 m3/s**
***Water Supply Yield: 71.6 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **42.32 cms** |
| Discharge at Min Head | **42.16 cms** |
| Head Loss at Max Head Discharge | **1.46 meters** |
| Head Loss at Min Head Discharge | **1.45 meters** |
| Tunnel Diameter | **4.10 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **52.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.22 meters** |
| **Average Annual Output** | **109.5 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **16,811 kW** |

# INDIO HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**Minimum Release at Indio Dam site: 60 m3/s**
***Water Supply Yield: 71.6 Lockages/day***

**Indio Power Plant**

| | |
|---|---|
| Design head | **49.00 meters** |
| Maximum Operating Head | **61.25 meters** |
| Minimum Operating Head | **31.85 meters** |
| Discharge at Max Head | **58.06 cms** |
| Discharge at Min Head | **58.51 cms** |
| Head Loss at Max Head Discharge | **1.71 meters** |
| Head Loss at Min Head Discharge | **1.73 meters** |
| Tunnel Diameter | **4.80 m** |
| Tunnel Length | **600 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **4.01 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **72.57 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.66 meters** |
| **Average Annual Output** | **241.0 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **30,000 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**Minimum Release at Indio Dam site: 60 m3/s**
***Water Supply Yield: 71.6 Lockages/day***

| | |
|---|---|
| **Isla Pablon Power Plant** | |
| Design head | **31.00 meters** |
| Maximum Operating Head | **38.75 meters** |
| Minimum Operating Head | **20.15 meters** |
| Discharge at Max Head | **61.89 cms** |
| Discharge at Min Head | **61.65 cms** |
| Head Loss at Max Head Discharge | **1.72 meters** |
| Head Loss at Min Head Discharge | **1.71 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **1.73 m/s** |
| Installed Capacity (at Hd) | **20,000 kW** |
| Maximum Turbine Discharge (at Hd) | **76.5 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.62 meters** |
| **Average Annual Output** | **43.5 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**MinimumTransferred Discharge to Pablon of 80 m3/s**
***Water Supply Yield: 97.5 Lockages/day***

**Cocle del Norte Power Plant**

| | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **42.32 cms** |
| Discharge at Min Head | **42.16 cms** |
| Head Loss at Max Head Discharge | **1.46 meters** |
| Head Loss at Min Head Discharge | **1.45 meters** |
| Tunnel Diameter | **4.10 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **52.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.22 meters** |
| **Average Annual Output** | **90.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **16,755 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.50 and El.71**
**Indio Reservoir Operation between El.50 and El.80**
**MinimumTransferred Discharge to Pablon of 80 m3/s**
***Water Supply Yield: 97.5 Lockages/day***

| **Isla Pablon Power Plant** | |
|---|---|
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **82.22 cms** |
| Discharge at Min Head | **81.91 cms** |
| Head Loss at Max Head Discharge | **3.03 meters** |
| Head Loss at Min Head Discharge | **3.01 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.30 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **101.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **4.63 meters** |
| **Average Annual Output** | **191.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **30,000 kW** |

# COCLE HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.60 and El.71**
**Indio Reservoir Operation between El.60 and El.80**
**MinimumTransferred Discharge to Pablon of 80 m3/s**
***Water Supply Yield: 87.2 Lockages/day***

**Cocle del Norte Power Plant**

| | |
|---|---|
| Design head | **68.00 meters** |
| Maximum Operating Head | **85.00 meters** |
| Minimum Operating Head | **44.20 meters** |
| Discharge at Max Head | **42.32 cms** |
| Discharge at Min Head | **42.16 cms** |
| Head Loss at Max Head Discharge | **1.46 meters** |
| Head Loss at Min Head Discharge | **1.45 meters** |
| Tunnel Diameter | **4.10 m** |
| Tunnel Length | **350.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.96 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **52.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.22 meters** |
| **Average Annual Output** | **106.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **18,147 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**Cocle Reservoir Operation between El.60 and El.71**
**Indio Reservoir Operation between El.60 and El.80**
**MinimumTransferred Discharge to Pablon of 80 m3/s**
***Water Supply Yield: 87.2 Lockages/day***

| | |
|---|---|
| **Isla Pablon Power Plant** | |
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **82.22 cms** |
| Discharge at Min Head | **81.91 cms** |
| Head Loss at Max Head Discharge | **3.03 meters** |
| Head Loss at Min Head Discharge | **3.01 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.30 m/s** |
| Installed Capacity (at Hd) | **30,000 kW** |
| Maximum Turbine Discharge (at Hd) | **101.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **4.63 meters** |
| **Average Annual Output** | **227.5 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **30,000 kW** |

# COCLE DEL NORTE RESERVOIR 50 - 71

## Hydropower Potential

### *Strategy No1 - Maximize Cocle del Norte Hydropower Revenues*

| Strategy No.1 | | *Initial Output (2029)* | *2044 Output* | *2062 Output* | *2070 Output* | *Long-term Output (2081)* | *2029 PV of Revenues ($,000)* | *Annualized PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 167.0 | 157.6 | 146.3 | 147.4 | 72.3 | $70,520 | $8,472 |
| | Firm Capacity (MW) | 20.00 | 20.00 | 20.00 | 20.00 | 14.50 | | |
| 25 MW | Average Annual Energy (GWh) | 209.6 | 197.8 | 183.7 | 180.9 | 79.6 | $88,421 | $10,622 |
| | Firm Capacity (MW) | 25.00 | 25.00 | 25.00 | 25.00 | 14.50 | | |
| 30 MW | Average Annual Energy (GWh) | 252.7 | 238.6 | 221.5 | 192.0 | 86.4 | $106,437 | $12,787 |
| | Firm Capacity (MW) | 30.00 | 30.00 | 30.00 | 30.00 | 14.50 | | |
| 40 MW | Average Annual Energy (GWh) | 337.4 | 318.6 | 276.2 | 205.6 | 98.3 | $141,440 | $16,992 |
| | Firm Capacity (MW) | 40.00 | 40.00 | 40.00 | 40.00 | 14.50 | | |
| 50 MW | Average Annual Energy (GWh) | 401.9 | 383.7 | 289.7 | 217.1 | 108.7 | $169,262 | $20,334 |
| | Firm Capacity (MW) | 50.00 | 50.00 | 50.00 | 50.00 | 14.50 | | |
| 60 MW | Average Annual Energy (GWh) | 423.6 | 398.3 | 300.4 | 226.6 | 117.7 | $181,005 | $21,745 |
| | Firm Capacity (MW) | 60.00 | 60.00 | 60.00 | 51.52 | 14.50 | | |
| 75 MW | Average Annual Energy (GWh) | 450.5 | 415.3 | 313.5 | 238.7 | 129.3 | $196,678 | $23,628 |
| | Firm Capacity (MW) | 75.00 | 75.00 | 75.00 | 51.53 | 14.50 | | |
| **Isla Pablon Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 28.9 | 54.6 | 51.0 | 56.6 | 59.4 | $15,126 | $1,817 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 25 MW | Average Annual Energy (GWh) | 30.6 | 61.4 | 57.5 | 63.9 | 67.8 | $16,626 | $1,997 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 30 MW | Average Annual Energy (GWh) | 30.8 | 64.5 | 61.7 | 68.9 | 71.8 | $17,226 | $2,069 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 35 MW | Average Annual Energy (GWh) | 31.8 | 65.0 | 62.4 | 68.5 | 73.5 | $17,519 | $2,105 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 40 MW | Average Annual Energy (GWh) | 32.2 | 65.5 | 62.9 | 67.1 | 70.4 | $17,674 | $2,123 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Rio Indio Power Plant** | | | | | | | | |
| 2.5 MW | Average Annual Energy (GWh) | 11.4 | 11.4 | 9.4 | 9.2 | 9.3 | $4,215 | $506 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Gatun Power Plant** | | | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 39.0 | 16.5 | 7.6 | 5.2 | 2.8 | $10,529 | $1,265 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Madden Power Plant** | | | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 180.9 | 170.5 | 161.7 | 157.4 | 152.4 | $65,727 | $7,896 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |

# COCLE DEL NORTE RESERVOIR 50 - 71

## Hydropower Potential

### *Strategy No2 - Maximize Rio Indio Hydropower Revenues*

| Strategy No.2 | | *Initial Output (2029)* | *2041 Output* | *2054 Output* | *2067 Output* | *Long-term Output (2081)* | *2029 PV of Revenues ($,000)* | *Annualized PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 86.5 | 86.5 | 90.3 | 90.9 | 72.3 | $40,938 | $4,918 |
| | Firm Capacity (MW) | 16.77 | 16.77 | 17.09 | 17.04 | 14.50 | | |
| 25 MW | Average Annual Energy (GWh) | 98.2 | 98.2 | 102.7 | 103.2 | 79.6 | $45,358 | $5,449 |
| | Firm Capacity (MW) | 16.80 | 16.80 | 17.12 | 17.07 | 14.50 | | |
| 30 MW | Average Annual Energy (GWh) | 109.5 | 109.5 | 114.6 | 115.0 | 86.4 | $49,614 | $5,960 |
| | Firm Capacity (MW) | 16.81 | 16.81 | 17.14 | 17.09 | 14.50 | | |
| 40 MW | Average Annual Energy (GWh) | 130.1 | 130.1 | 135.5 | 135.0 | 98.3 | $57,324 | $6,887 |
| | Firm Capacity (MW) | 16.82 | 16.82 | 17.15 | 17.10 | 14.50 | | |
| **Isla Pablon Power Plant** | | | | | | | | |
| 15 MW | Average Annual Energy (GWh) | 34.7 | 34.7 | 51.1 | 67.1 | 53.3 | $13,912 | $1,671 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 20 MW | Average Annual Energy (GWh) | 41.1 | 41.1 | 61.8 | 83.3 | 66.1 | $16,563 | $1,990 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 25 MW | Average Annual Energy (GWh) | 45.2 | 45.2 | 69.3 | 94.8 | 75.9 | $18,297 | $2,198 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| 30 MW | Average Annual Energy (GWh) | 47.0 | 47.0 | 72.9 | 101.4 | 80.4 | $19,084 | $2,293 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Rio Indio Power Plant** | | | | | | | | |
| 15 MW | Average Annual Energy (GWh) | 95.1 | 95.1 | 117.9 | 81.0 | 9.3 | $43,627 | $5,241 |
| | Firm Capacity (MW) | 15.00 | 15.00 | 15.00 | 15.00 | 2.30 | | |
| 20 MW | Average Annual Energy (GWh) | 154.4 | 154.4 | 158.8 | 80.5 | 9.3 | $67,024 | $8,052 |
| | Firm Capacity (MW) | 20.00 | 20.00 | 20.00 | 20.00 | 2.30 | | |
| 25 MW | Average Annual Energy (GWh) | 206.2 | 206.2 | 162.8 | 80.4 | 9.3 | $86,585 | $10,402 |
| | Firm Capacity (MW) | 25.00 | 25.00 | 25.00 | 22.38 | 2.30 | | |
| 30 MW | Average Annual Energy (GWh) | 238.8 | 238.8 | 164.0 | 80.4 | 9.3 | $99,731 | $11,981 |
| | Firm Capacity (MW) | 30.00 | 30.00 | 30.00 | 22.41 | 2.30 | | |
| 35 MW | Average Annual Energy (GWh) | 242.5 | 242.5 | 165.0 | 80.4 | 9.3 | $103,407 | $12,423 |
| | Firm Capacity (MW) | 35.00 | 35.00 | 35.00 | 22.44 | 2.30 | | |
| **Gatun Power Plant** | | | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 53.3 | 14.3 | 7.8 | 5.0 | 2.8 | $12,092 | $1,453 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Madden Power Plant** | | | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 174.4 | 170.9 | 165.3 | 160.3 | 152.4 | $64,319 | $7,727 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |

# COCLE DEL NORTE RESERVOIR 50 - 71

## Hydropower Potential

### *Strategy No3 - Maximize Isla Pablon Hydropower Revenues*

| Strategy No.3 | | *Initial Output (2029)* | *2045 Output* | *2062 Output* | *2073 Output* | *Long-term Output (2081)* | *2029 PV of Revenues ($,000)* | *Annualized PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 85.3 | 85.3 | 85.3 | 75.6 | 72.3 | $40,934 | $4,918 |
| | Firm Capacity (MW) | 18.10 | 18.10 | 18.10 | 16.71 | 14.50 | | |
| 25 MW | Average Annual Energy (GWh) | 96.1 | 96.1 | 96.1 | 83.3 | 79.6 | $44,980 | $5,404 |
| | Firm Capacity (MW) | 18.13 | 18.13 | 18.13 | 16.74 | 14.50 | | |
| 30 MW | Average Annual Energy (GWh) | 106.7 | 106.7 | 106.7 | 90.7 | 86.4 | $48,946 | $5,880 |
| | Firm Capacity (MW) | 18.15 | 18.15 | 18.15 | 16.76 | 14.50 | | |
| 40 MW | Average Annual Energy (GWh) | 125.8 | 125.8 | 125.8 | 103.9 | 98.3 | $56,078 | $6,737 |
| | Firm Capacity (MW) | 18.16 | 18.16 | 18.16 | 16.77 | 14.50 | | |
| 50 MW | Average Annual Energy (GWh) | 142.7 | 142.7 | 142.7 | 115.7 | 108.7 | $62,389 | $7,495 |
| | Firm Capacity (MW) | 18.17 | 18.17 | 18.17 | 16.77 | 14.50 | | |
| 60 MW | Average Annual Energy (GWh) | 157.5 | 157.5 | 157.5 | 125.6 | 117.7 | $67,911 | $8,158 |
| | Firm Capacity (MW) | 18.17 | 18.17 | 18.17 | 16.78 | 14.50 | | |
| **Isla Pablon Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 174.0 | 174.0 | 174.0 | 158.2 | 66.1 | $74,958 | $9,005 |
| | Firm Capacity (MW) | 20 | 20 | 20 | 20 | 0 | | |
| 25 MW | Average Annual Energy (GWh) | 216.7 | 216.7 | 216.7 | 186.7 | 75.9 | $93,357 | $11,215 |
| | Firm Capacity (MW) | 25 | 25 | 25 | 25 | 0 | | |
| 30 MW | Average Annual Energy (GWh) | 227.5 | 227.5 | 227.5 | 191.6 | 80.4 | $99,866 | $11,997 |
| | Firm Capacity (MW) | 30 | 30 | 30 | 30 | 0 | | |
| 35 MW | Average Annual Energy (GWh) | 228.5 | 228.5 | 228.5 | 193.7 | 80.6 | $102,732 | $12,342 |
| | Firm Capacity (MW) | 35 | 35 | 35 | 35 | 0 | | |
| 40 MW | Average Annual Energy (GWh) | 228.8 | 228.8 | 228.8 | 193.2 | 77.5 | $105,328 | $12,653 |
| | Firm Capacity (MW) | 40 | 40 | 40 | 40 | 0 | | |
| **Rio Indio Power Plant** | | | | | | | | |
| 2.5 MW | Average Annual Energy (GWh) | 11.7 | 11.7 | 11.7 | 10.5 | 9.3 | $5,621 | $675 |
| | Firm Capacity (MW) | 2.5 | 2.5 | 2.5 | 2.5 | 0 | | |
| **Gatun Power Plant** | | | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 123.0 | 78.7 | 41.7 | 27.3 | 2.8 | $37,827 | $4,544 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |
| **Madden Power Plant** | | | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 178.2 | 173.7 | 169.8 | 167.5 | 152.4 | $65,891 | $7,916 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | | |

# ATTACHMENT 4

# COMPARATIVE COST ESTIMATES

# COCLE 50 - 71

# COMPARATIVE COST ESTIMATES
## 60-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 2,000 | $1,100 |
| Overburden Excavation | cu.m | $3.70 | 5,400 | $19,980 |
| Rock Excavation | cu.m | $9.20 | 2,800 | $25,760 |
| Portal Excavation | cu.m | $14.80 | 1,400 | $20,720 |
| Structural Concrete | cu.m | $145.00 | 6,550 | $949,750 |
| Formwork | sq.m | $46.80 | 13,750 | $643,500 |
| Steel Reinforcement | Ton | $1,320 | 295.0 | $389,400 |
| Steel Liner | Ton | $3,200 | 14.4 | $46,080 |
| Miscellaneous Metal Works | % | 5% | | $104,815 |
| ***Subtotal*** | | | | $2,201,105 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.80 x 2.50) and Hoist | Each | $405,000 | 3 | $1,215,000 |
| Stoplogs | Each | $85,000 | 3 | $255,000 |
| Trash Screen Bays | Each | $425,000 | 3 | $1,275,000 |
| Trash Rake | Each | $120,000 | 2 | $240,000 |
| Emergency Diesel Generator (50 kW) | Each | $62,500 | 1 | $62,500 |
| Power and Control Equipment | LS | $60,000 | 1 | $60,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $3,152,500 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 1,940 | $28,712 |
| Shaft Excavation | cu.m | $310.00 | 1,150 | $356,500 |
| Tunnel Excavation | cu.m | $115.00 | 9,070 | $1,043,050 |
| Shotcrete | sq.m | $45.90 | 3,740 | $171,666 |
| Rockbolts | L.m | $67.00 | 1,420 | $95,140 |
| Steel Ribs | kg | $6.00 | 51,300 | $307,800 |
| Tunnel Concrete Lining | sq.m | $165.00 | 3,300 | $544,500 |
| Shaft Concrete Lining | cu.m | $180.00 | 350 | $63,000 |
| Formwork (shaft) | sq.m | $46.80 | 730 | $34,164 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 17.5 | $23,100 |
| Structural Concrete (penstock) | cu.m | $145.00 | 730 | $105,850 |
| Formwork (penstock) | sq.m | $46.80 | 1,095 | $51,246 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 32.9 | $43,428 |
| Steel Penstock | Ton | $3,200 | 664.0 | $2,124,800 |
| Miscellaneous | % | 5% | | $249,648 |
| ***Subtotal*** | | | | $5,242,604 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.70 | 10,500 | $38,850 |
| Rock Excavation | cu.m | $9.20 | 3,500 | $32,200 |
| **Subtotal** | | | | $71,050 |

# COMPARATIVE COST ESTIMATES
## 60-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.70 | 35,000 | $129,500 |
| Rock Excavation | cu.m | $9.20 | 5,200 | $47,840 |
| Mass Concrete | cu.m | $116.00 | 6,520 | $756,320 |
| Structural Concrete | cu.m | $145.00 | 2,950 | $427,750 |
| Formwork | sq.m | $46.80 | 18,200 | $851,760 |
| Steel Reinforcement | Ton | $1,320 | 315.0 | $415,800 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 1,040 | $322,400 |
| Miscellaneous | % | 5% | | $147,569 |
| ***Subtotal*** | | | | $3,098,939 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.70 m dia) | Each | $550,000 | 3 | $1,650,000 |
| Turbine/Generator Unit (20 MW) | Each | $3,500,000 | 3 | $10,500,000 |
| 20-MW Unit Auxiliaries | Each | $350,000 | 3 | $1,050,000 |
| Draft Tube Gates | Each | $75,000 | 6 | $450,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (1.50 m dia) | Each | $218,750 | 1 | $218,750 |
| Pressure Reducing Control Valves (1.50 m dia) | Each | $437,500 | 1 | $437,500 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Semi-Gantry Crane | LS | $520,000 | 1 | $520,000 |
| *Miscellaneous Electrical* | | | | |
| Main Power Transformer -25 MVA | Each | $748,000 | 3 | $2,244,000 |
| Take-off Structures & OH lines to Switchyard | LS | $150,000 | 1 | $150,000 |
| Switchgear - 13.8 kV | LS | $125,000 | 1 | $125,000 |
| Station Service Transformer | Each | $110,000 | 1 | $110,000 |
| Stand-by Diesel Generator | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $450,000 | 1 | $450,000 |
| Control and Communication Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $900,000 | 1 | $900,000 |
| **Subtotal** | | | | $19,617,750 |
| ***Transmission System*** | | | | |
| *Switchyard* | | | | |
| 230-kV Equipment Bays | Each | $325,000 | 3 | $975,000 |
| Service Power Transformer - 5MV | Each | $112,500 | 1 | $112,500 |
| Protection, Control and Comm. Equip | LS | $650,000 | 1 | $650,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $325,000 | 1 | $325,000 |
| Steel structures | LS | $600,000 | 1 | $600,000 |
| Civil Work | LS | $350,000 | 1 | $350,000 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $125,000 | 1 | $125,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *230-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $62,500 | 109 | $6,812,500 |
| Conductors and Shield Wire | km | $62,500 | 109 | $6,812,500 |
| Insulators and Accessories | km | $31,250 | 109 | $3,406,250 |
| Grounding and Miscellaneous | % | 4.00% | | $681,250 |
| **Subtotal** | | | | $21,540,000 |
| | | | **TOTAL** | $44,256,689 |

# COMPARATIVE COST ESTIMATES

## PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME

**Panama**

**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **5.80 meters (Circular Section)**
*Method:* Basic Drill/Blast

**SUMMARY**

The following summary is prepared from the detailed analysis that follows

| | Total |
|---|---|
| Total Tunnel Excavation Price | **$1,625,000** |
| Total Tunnel Concrete Lining Price | **$544,400** |
| Total at January 1999 Level | **$2,169,400** |

| Method of Excavation | Analysis<br>Drill and Blast Method | | | | Totals |
|---|---|---|---|---|---|
| Type of Support Requirements | Type I | Type II | Type III | Type IV | |
| Finished Diameter (m) | 5.80 | 5.80 | 5.80 | 5.80 | |
| Finished Area (sq.m.) | 26.42 | 26.42 | 26.42 | 26.42 | |
| Excavated tunnel diameter | 6.80 | 6.80 | 6.80 | 6.80 | |
| Tunnel Length (m) | 13 | 125 | 75 | 38 | 250 |
| Excavation Volume (Pay cu.m/m) | 36.3 | 36.3 | 36.3 | 36.3 | |
| Excavation Volume (Pay cu.m) | 450 | 4,540 | 2,720 | 1,360 | 9,070 |
| Concrete Lining Thickness (m) | 0.50 | 0.50 | 0.50 | 0.50 | |
| Overbreak assumed (m) | 0.15 | 0.15 | 0.15 | 0.15 | |
| Shotcrete Lining Thickness (m) | 0.0 | 0.0 | 0.05 | 0.05 | |
| Shotcrete Area (sq.m) | 0 | 1,340 | 1,600 | 800 | 3,740 |
| Excavated Volume (Actual cu.m/m) | 39.6 | 39.6 | 39.6 | 39.6 | |
| Excavated Volume (Actual cu.m) | 490 | 4,950 | 2,970 | 1,480 | 9,890 |
| Loose Volume Mucking (cu.m) | 784 | 7,920 | 4,752 | 2,368 | 15,824 |
| Concrete Lining Volume (cu.m) | 165 | 1,646 | 988 | 494 | 3,293 |
| 2-meter long (#8) Rockbolts | 10 | 310 | 350 | 40 | 710 |
| Steel Sets (kg) | | | | 51,300 | 51,300 |
| Excavation Production (days) | 6 | 57 | 36 | 25 | 124 |
| Labor Cost - Excavation | 18,800 | 177,900 | 112,400 | 78,000 | 387,100 |
| Equipment Cost | 24,900 | 235,900 | 149,000 | 103,500 | 513,300 |
| Material Cost | 8,400 | 104,500 | 80,500 | 156,200 | 349,600 |
| **Tunnel Excavation Cost** | **52,100** | **518,300** | **341,900** | **337,700** | **1,250,000** |
| **Concrete Lining Cost, Total** | **23,200** | **207,500** | **125,300** | **62,700** | **418,700** |
| Contractors OH&P | 30% | 30% | 30% | 30% | |
| **Tunnel Excavation Price** | **$67,700** | **$673,800** | **$444,500** | **$439,000** | **$1,625,000** |
| **Tunnel Lining Price** | **$30,200** | **$269,800** | **$162,900** | **$81,500** | **$544,400** |
| **Tunnel Price** | **$97,900** | **$943,600** | **$607,400** | **$520,500** | **$2,169,400** |

## *Excavation Unit Price*

| | **Excavation** | **Shotcrete Lining** | **Rockbolts** | **Steel Sets** | **Miscellaneous** |
|---|---|---|---|---|---|
| **Labor Cost** | **$231,134** | **$22,919** | **$15,719** | **$46,478** | **$70,850** |
| **Equipment Cost** | **$172,456** | **$28,177** | **$1,476** | **$11,183** | **$300,008** |
| **Material Cost** | **$132,183** | **$37,026** | **$31,950** | **$102,600** | **$45,841** |
| **Subtotal** | **$535,773** | **$88,122** | **$49,145** | **$160,261** | **$416,699** |
| **Miscellaneous** | **$267,917** | **$44,066** | **$24,576** | **$80,140** | |
| | **$803,690** | **$132,188** | **$73,721** | **$240,401** | **$1,250,000** |
| **Contractors OH&P** | **$241,107** | **$39,656** | **$22,116** | **$72,120** | **$375,000** |
| | **$1,044,797** | **$171,844** | **$95,837** | **$312,521** | **$1,625,000** |
| **Quantities** | **9,070** | **3,740** | **1,420** | **51,300** | |
| **Unit Price** | **$115.19** | **$45.95** | **$67.49** | **$6.09** | |
| | **$/cu.m** | **$/sq.m** | **$/l.m** | **$/kg** | |

## *Concrete Lining Unit Price*

| | **Type I** | **Type II** | **Type III** | **Type IV** | **Avg. Price** |
|---|---|---|---|---|---|
| **Unit Price ($/cu.m) Concrete Lining** | **$183.43** | **$163.87** | **$164.91** | **$165.01** | **$165.33** |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **5.80 meters (Circular Section)**
*Method:* Basic Drill/Blast

**GEOLOGY**

Rock type as interpreted from site visits and geol mapping suggests four types of supports for the following lengths

| Tunneling Condition | Segment 1 |
|---|---|
| Roca Buena - Designation Type I | 5% |
| Roca Regular - Designation Type II | 50% |
| Roca Mala - Designation Type III | 30% |
| Roca Muy Mala - Designation Type IV | 15% |
| | 100% |

Type I - Roca Buena best rock conditions, minimal overbreak, generally self-supporting or requiring minimal support with shotcrete and spot bolting; full face excavation with normal advance

Type II - Roca Regular, good to fair rock conditions, moderate overbreak with rockbolt support and shotcrete; normal advance possible with proper bolting and shotcreting

Type III - Roca Mala, poor rock conditions, weathered or weak rock, loosely jointed, possible water inflows; Full face excavation with slower short advance and large overbreaks. Requires prompt support with pattern rockbolting and shotcrete

Type IV - Roca Muy Mala/Pesima, very poor rock conditions, full of fault and shear zones, mod to highly weathered, potential squeezing conditions in gouge; water inflows; possibly top heading and benching; prompt support within the open face with steel ribs and lagging, backpacking and shotcete with fabric; grouting may be necessary to control water; spiling possible in worst conditions.

Type V - Not mentioned above but worse than type IV and with high waterflows. Specific areas are not identified for above tunnels at this time

| Condition/Rock Type | | Q Values | Rock Mass Rating (RMR) |
|---|---|---|---|
| I | | > 7 | >60 |
| II | | 7 > Q >1 | 60>RMR>40 |
| III | | 1 > Q >.4 | 40>RMR>35 |
| IV | | .4> Q | 35 > RMR |
| Blastability | | Good | Medium |
| | SPR = | 0.38 | 0.47 |
| | | Basalt/Sandstones | |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **5.80 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

**SUPPORT**

| | | |
|---|---|---|
| Shotcrete Thickness | 5 cm Layers | Fiber or wire reinf |
| Rockbolts | 25 mm X 2 meter long w/epoxy | |
| Steel Ribs | 6" X 12" I section @ .5 to 1.5 spacing | |
| Lagging | 5 cm corrugated | |
| Dry Pack | 0.5 in. from Tunnel Muck | |

All tunnel analysis is based on geological interpretation presented on the Geology Studies

| | | |
|---|---|---|
| Length of Segment | | 250 Meters |
| Finished Diameter | | 5.80 Meters |
| Concrete Lining Thickness | | 0.50 Meters |
| Length of tunnel for each type | | |
| | Type I | 13 Meters |
| | Type II | 125 Meters |
| | Type III | 75 Meters |
| | Type IV | 38 Meters |

| | | | |
|---|---|---|---|
| Shotcrete with wire(or fibrous), 5 cm layers | | 0 SqM, Type I | None |
| | | 1,340 SqM, Type II | Crown only |
| | | 1,600 SqM, Type III | Crown and Ribs |
| | | 800 SqM, Type IV | Crown and Ribs |
| | Total Shotcrete | 3,740 SqM | |
| Rockbolts, 25 mm X 2 M Long | | 10 EA, Type I | 3 Bolts/@ 7.5 M Spacing |
| | | 310 EA, Type II | 5 Bolts/@ 2 M Spacing |
| | | 350 EA, Type III | 7 Bolts/@ 1.5 M Spacing |
| | | 40 EA, Type IV | 5 Bolts/@ 5 M Spacing |
| | Total Rockbolts | 710 EA | |
| Steel ribs, 6" X 12" X 45 KG/M | | 51,300 KG, Type IV | |

# COMPARATIVE COST ESTIMATES

## PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME

**Panama**

**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **5.80 meters (Circular Section)**
*Method:* Basic Drill/Blast

### TUNNEL EXCAVATION

| | Tunnel Crew | $$/HR | $$/HR |
|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 |
| 1 | Foreman | $10.00 | $10.00 |
| | Jumbo Drill Foreman | $10.00 | $0.00 |
| 8 | Miners | $6.70 | $53.60 |
| 1 | Blaster | $6.70 | $6.70 |
| 1 | Compressor Operator | $6.30 | $6.30 |
| 1 | Mucker Operator | $8.00 | $8.00 |
| 2 | Truck Drivers | $6.30 | $12.60 |
| | Dozer Operator | $8.00 | $0.00 |
| 1 | HVAC Electrician/Mechanics | $6.70 | $3.35 |
| 1 | Oilers | $6.30 | $3.15 |
| 2 | Rockbolters | $6.70 | $13.40 |
| 2 | Shotcreters | $6.70 | $13.40 |
| 1 | Pump Operators | $6.30 | $6.30 |
| 1 | Mechanics | $6.70 | $3.35 |
| 1 | Electricians | $6.70 | $3.35 |
| 22 | Total Crew, $$/Hr | | $156.00 |

| ROUNDS | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Meters/Round | 3.0 | 2.5 | 2.0 | 1.0 | |
| Vol/Round | 109.0 | 90.8 | 72.6 | 36.3 | |
| Holes/SqM | 2.5 | 2.5 | 2.2 | 2.0 | |
| No. of Holes | 134 | 134 | 123 | 116 | |
| Length of Holes (total, cum.) | 402 | 335 | 246 | 116 | |
| Drill Holes, Meters/Hr | 10 | 10 | 10 | 10 | |
| No. of drills | 4 | 4 | 4 | 4 | |
| Total Drilling/Hr | 40 | 40 | 40 | 40 | |
| Drilling Time | 10.1 | 8.4 | 6.2 | 2.9 | |
| Move in | 0.3 | 0.3 | 0.3 | 0.3 | |
| Total drilling Time | 10.4 | 8.7 | 6.5 | 3.2 | |
| **Blasting** | | | | | |
| Kg/CuM | 2.0 | 1.8 | 1.7 | 1.5 | |
| Kg/Round | 218 | 163 | 123 | 54 | |
| Load Time @ 80 Kg/Hr | 2.8 | 2.1 | 1.6 | 0.7 | |
| Add for blasting & Ventilating | 1.0 | 1.0 | 1.0 | 1.0 | |
| Total Blast time | 3.8 | 3.1 | 2.6 | 1.7 | |
| **Excavation Supports** | | | | | |
| Scaling | 0.3 | 0.3 | 0.3 | 0.5 | |
| Place supports | 0.2 | 1.0 | 1.5 | 3.0 | |
| Total Support Time | 0.5 | 1.3 | 1.8 | 3.5 | |
| **Muck** | | | | | |
| Move in | 0.5 | 0.5 | 0.5 | 0.5 | |
| Mucking at 10 CM/hr | 10.9 | 9.1 | 7.3 | 3.7 | |
| Total Muck Cycle | 11.4 | 9.6 | 7.8 | 4.2 | |
| **Total Cycle Hours** | 26.1 | 22.7 | 18.7 | 12.6 | |
| No of Rds with of 2 X 10 Hr Shifts | 0.8 | 0.9 | 1.1 | 1.6 | |
| Advance/Day | 2.2 | 2.2 | 2.1 | 1.5 | |
| Total number of Days for one Crew | 6 | 57 | 36 | 25 | 124 |
| Total explosives required | 1,000 | 8,200 | 4,700 | 2,100 | |
| Detonators | 350 | 3,690 | 3,525 | 1,680 | |
| Drill Bits & Steel | 1,700 | 16,800 | 9,300 | 4,400 | |

## COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **5.80 meters (Circular Section)**
*Method:* Basic Drill/Blast

| Plant & Equipment | Unit Operating Cos | Standby Cost | |
|---|---|---|---|
| 1 4 Drill Jumbo | $56.50 | $14.13 | $43.79 |
| 1 4 CuM Mucker | $31.25 | $7.81 | $24.22 |
| 2 Trucks, 5 CuM | $24.46 | $6.12 | $37.91 |
| 1 Shotcrete Pump | $23.56 | $5.89 | $18.26 |
| 1 Dozer | $44.50 | $11.13 | $34.49 |
| 2 Compressors, Electrical | $14.26 | $3.57 | $22.10 |
| 1 Dewatering Equipment | $7.53 | $1.88 | $5.84 |
| 2 100 HP Fans | $6.04 | $1.51 | $9.36 |
| 1 Drifters | $0.75 | $0.19 | $0.58 |
| 1 Flatbeds | $13.35 | $3.34 | $10.35 |
| Equipment Cost per hour | $222.20 | $55.55 | $206.89 |
| Utilization Factor | 70% | | |
| Actual Cost/Hr | $206.89 | | |

| | Type I | Type II | Type III | Type IV |
|---|---|---|---|---|
| Equipment & Plant, Local | $24,827 | $235,859 | $148,964 | $103,447 |

| Materials | | |
|---|---|---|
| Explosives | $1.50 | $$/KG |
| Detonators | $2.50 | $$/EA |
| Bits & Steel | $2.50 | $$/LM |
| Spiling | $150.00 | $$/EA |
| Shotcrete Cement | $120.00 | $$/TON |
| Shotcrete Aggregate | $4.00 | $$/TON |
| Steel Fibers | $1.20 | $$/KG |
| Wiremesh | $1.00 | $$/KG |
| Timber | $0.35 | $$/BF |
| Rockbolts | $45.00 | $$/EA |
| Steel Sets | $2.00 | $$/KG |
| Vent air line | $40.00 | $$/LM |
| Utility lines | $30.00 | $$/LM |
| ST&S | 5.00% | |

| | Type I | Type II | Type III | Type IV | Total |
|---|---|---|---|---|---|
| Explosives | $1,500 | $12,300 | $7,050 | $3,150 | $24,000 |
| Detonators | $875 | $9,225 | $8,813 | $4,200 | $23,113 |
| Bits & Steel | $4,250 | $42,000 | $23,250 | $11,000 | $80,500 |
| Spiling | $0 | $0 | $0 | $15,000 | $15,000 |
| Shotcrete Cement | $0 | $4,824 | $5,760 | $2,880 | $13,464 |
| Shotcrete Aggregate | $0 | $884 | $1,056 | $528 | $2,468 |
| Steel Fibers | $0 | $4,342 | $5,184 | $2,592 | $12,118 |
| Wiremesh | $0 | $3,216 | $3,840 | $1,920 | $8,976 |
| Timber | $0 | $0 | $630 | $438 | $1,068 |
| Rockbolts | $450 | $13,950 | $15,750 | $1,800 | $31,950 |
| Steel Sets | $0 | $0 | $0 | $102,600 | $102,600 |
| Vent air line | $500 | $5,000 | $3,000 | $1,500 | $10,000 |
| Utility lines | $375 | $3,750 | $2,250 | $1,125 | $7,500 |
| ST&S | $398 | $4,975 | $3,829 | $7,437 | $16,638 |
| Total Materials for tunnel work | $8,348 | $104,466 | $80,412 | $156,169 | $349,394 |

# COMPARATIVE COST ESTIMATES

## PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME

**Panama**

**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **5.80 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

| TUNNEL CONCRETE LINING | | | | | Total |
|---|---|---|---|---|---|
| Length | 13 | 125 | 75 | 38 | 250 |
| Quantity | 165 | 1,646 | 988 | 494 | 3,293 |
| Use Prefabricated Steel Forms on Dolly Each set 20 M Long and a 24 hour concrete placing will be used with 8 hours for placing forms and reinforcing (if any), 8 hours of concrete placing and 8 hours to cure, clean and move | | | | | |
| Average placing Rate (cu. M / day) | 50 | 50 | 50 | 50 | |
| No. of Steel Sets | 0 | 0 | 0 | 0 | 0 |
| Number of 10 hour work days | 4 | 33 | 20 | 10 | 67 |

| | **Concrete Lining Crew** | $$/HR | $$/HR | |
|---|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 | 0 |
| 1 | Foreman | $10.00 | $10.00 | |
| 0 | Form Foreman | $10.00 | $0.00 | |
| 8 | Miners | $6.70 | $53.60 | |
| 2 | Carpenters | $6.70 | $13.40 | |
| 1 | Compressor Operator | $6.30 | $6.30 | |
| 1 | Mucker Operator | $8.00 | $8.00 | |
| 2 | Flat Bed Operators | $6.30 | $12.60 | |
| 1 | HVAC Electrician/Mechanics | $6.70 | $6.70 | |
| 1 | Pump Operators | $6.30 | $6.30 | |
| 1 | Mechanics | $6.70 | $6.70 | |
| 1 | Electricians | $6.70 | $6.70 | |
| 20 | Total Crew, $$/Hr | | $142.80 | |
| | | | $95,676 | |

| | Plant & Equipment | Unit Oper | Unit Standby | Average |
|---|---|---|---|---|
| 1 | Johnson Type Low Profile + Ice Plant | $52.00 | $13.00 | $42.25 |
| 2 | Concrete Haulers | $17.62 | $4.41 | $28.63 |
| 2 | Lot Pumping Equipment | $17.21 | $4.30 | $27.97 |
| 1 | Lot fans | $5.25 | $1.31 | $4.27 |
| | | | | $103.11 |
| | Utility Factor | 75.00% | | |
| | Actual Cost/Hr | $103.11 | | |
| | Equipment Cost/Day | $2,062.29 | | |

| MATERIALS | | | | |
|---|---|---|---|---|
| Cement | 988 Tons @ | $120.00 | 118,540 | |
| Aggregate & Sand | 7,244 Tons @ | $4.00 | 28,976 | |
| Admixtures | 1,646 Gals @ | $15.00 | 24,696 | |
| Timber for Bulkheads | 495 SqM @ | $25.00 | 12,370 | 37,066 |
| | | | 184,583 | |

| Concrete Costs by Sections | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Labor Cost - Concrete | 5,700 | 47,100 | 28,600 | 14,300 | 95,700 |
| Equipment Cost | 8,249 | 68,055 | 41,246 | 20,623 | 138,173 |
| Material Cost | 9,229 | 92,291 | 55,375 | 27,687 | 184,583 |
| | | | | | 418,500 |
| TOTAL CONCRETE COST | $23,200 | $207,400 | $125,200 | $62,600 | $418,456 |
| Tunnel concrete Lining Cost | $23,178 | $207,447 | $125,221 | $62,610 | $418,456 |

# COMPARATIVE COST ESTIMATES
## 30-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 2,000 | $1,100 |
| Overburden Excavation | cu.m | $3.70 | 3,300 | $12,210 |
| Rock Excavation | cu.m | $9.20 | 2,300 | $21,160 |
| Portal Excavation | cu.m | $14.80 | 750 | $11,100 |
| Structural Concrete | cu.m | $145.00 | 3,800 | $551,000 |
| Formwork | sq.m | $46.80 | 7,980 | $373,464 |
| Steel Reinforcement | Ton | $1,320 | 171.0 | $225,720 |
| Steel Liner | Ton | $3,200 | 10.2 | $32,640 |
| Miscellaneous Metal Works | % | 5% | | $61,420 |
| ***Subtotal*** | | | | $1,289,814 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.20 x 2.40) and Hoist | Each | $285,000 | 2 | $570,000 |
| Trash Screen Panels | Each | $145,000 | 2 | $290,000 |
| Trash Rake | Each | $90,000 | 1 | $90,000 |
| Power and Control Equipment | LS | $45,000 | 1 | $45,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $1,040,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 350 | $5,180 |
| Shaft Excavation | cu.m | $310.00 | 840 | $260,400 |
| Tunnel Excavation | cu.m | $140.00 | 4,530 | $634,200 |
| Shotcrete | sq.m | $45.90 | 2,640 | $121,176 |
| Rockbolts | L.m | $67.00 | 1,420 | $95,140 |
| Steel Ribs | kg | $6.00 | 36,900 | $221,400 |
| Tunnel Concrete Lining | sq.m | $169.00 | 1,700 | $287,300 |
| Shaft Concrete Lining | cu.m | $180.00 | 310 | $55,800 |
| Formwork (shaft) | sq.m | $46.80 | 580 | $27,144 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 29.1 | $38,412 |
| Structural Concrete (penstock) | cu.m | $145.00 | 665 | $96,425 |
| Formwork (penstock) | sq.m | $46.80 | 1,200 | $56,160 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 29.9 | $39,468 |
| Steel Penstock | Ton | $3,200 | 301.4 | $964,480 |
| Miscellaneous | % | 5% | | $145,134 |
| ***Subtotal*** | | | | $3,047,819 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 1,500 | $825 |
| Overburden Excavation | cu.m | $3.70 | 3,400 | $12,580 |
| Rock Excavation | cu.m | $9.20 | 500 | $4,600 |
| **Subtotal** | | | | $18,005 |

# COMPARATIVE COST ESTIMATES
## 30-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 1,600 | $880 |
| Overburden Excavation | cu.m | $3.70 | 24,000 | $88,800 |
| Rock Excavation | cu.m | $9.20 | 3,600 | $33,120 |
| Mass Concrete | cu.m | $116.00 | 4,650 | $539,400 |
| Structural Concrete | cu.m | $145.00 | 2,070 | $300,150 |
| Formwork | sq.m | $46.80 | 13,150 | $615,420 |
| Steel Reinforcement | Ton | $1,320 | 225.0 | $297,000 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 720 | $223,200 |
| Miscellaneous | % | 5% | | $104,899 |
| ***Subtotal*** | | | | $2,202,869 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.30 m dia) | Each | $490,000 | 2 | $980,000 |
| Turbine/Generator Unit (15 MW) | Each | $2,975,000 | 2 | $5,950,000 |
| 8-MW Unit Auxiliaries | Each | $297,500 | 2 | $595,000 |
| Draft Tube Gates | Each | $65,000 | 4 | $260,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (0.65 m dia) | Each | $140,000 | 1 | $140,000 |
| Axial Flow Control Valves (0.65 m dia) | Each | $180,000 | 1 | $180,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Bridge Crane | LS | $450,000 | 1 | $450,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $525,000 | 1 | $525,000 |
| Station Service Transformer | Each | $75,000 | 1 | $75,000 |
| Stand-by Diesel Generator | Each | $150,000 | 1 | $150,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $250,000 | 1 | $250,000 |
| Control and Communication Equip | LS | $350,000 | 1 | $350,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $800,000 | 1 | $800,000 |
| **Subtotal** | | | | $10,892,500 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Main Transformer | MVA | $29,900 | 40 | $1,196,000 |
| Breakers, Disconnects, etc. | LS | $186,000 | 1 | $186,000 |
| Control Panels and other Equipment | LS | $414,000 | 1 | $414,000 |
| Steel Structures and Civil Works | LS | $245,000 | 1 | $245,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,550 | 61.9 | $1,952,945 |
| Conductors and Shield Wire | km | $10,620 | 61.9 | $657,378 |
| Insulators and Accessories | km | $5,900 | 61.9 | $365,210 |
| Grounding and Miscellaneous | % | 2.50% | | $74,388 |
| **Subtotal** | | | | $5,090,921 |
| | | | **TOTAL** | $18,186,290 |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **4.10 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

**SUMMARY**

The following summary is prepared from the detailed analysis that follows

| | Total |
|---|---|
| Total Tunnel Excavation Price | **$1,076,200** |
| Total Tunnel Concrete Lining Price | **$287,200** |
| Total at January 1999 Level | **$1,363,400** |

| | Analysis | | | | Totals |
|---|---|---|---|---|---|
| Method of Excavation | Drill and Blast Method | | | | |
| Type of Support Requirements | Type I | Type II | Type III | Type IV | |
| Finished Diameter (m) | 4.10 | 4.10 | 4.10 | 4.10 | |
| Finished Area (sq.m.) | 13.20 | 13.20 | 13.20 | 13.20 | |
| Excavated tunnel diameter | 4.80 | 4.80 | 4.80 | 4.80 | |
| Tunnel Length (m) | 13 | 125 | 75 | 38 | 250 |
| Excavation Volume (Pay cu.m/m) | 18.1 | 18.1 | 18.1 | 18.1 | |
| Excavation Volume (Pay cu.m) | 230 | 2,260 | 1,360 | 680 | 4,530 |
| Concrete Lining Thickness (m) | 0.35 | 0.35 | 0.35 | 0.35 | |
| Overbreak assumed (m) | 0.10 | 0.10 | 0.15 | 0.15 | |
| Shotcrete Lining Thickness (m) | 0.0 | 0.0 | 0.05 | 0.05 | |
| Shotcrete Area (sq.m) | 0 | 940 | 1,130 | 570 | 2,640 |
| Excavated Volume (Actual cu.m/m) | 19.6 | 19.6 | 20.4 | 20.4 | |
| Excavated Volume (Actual cu.m) | 250 | 2,450 | 1,530 | 770 | 5,000 |
| Loose Volume Mucking (cu.m) | 400 | 3,920 | 2,448 | 1,232 | 8,000 |
| Concrete Lining Volume (cu.m) | 80 | 804 | 542 | 271 | 1,697 |
| 2-meter long (#8) Rockbolts | 10 | 310 | 350 | 40 | 710 |
| Steel Sets (kg) | | | | 36,900 | 36,900 |
| Excavation Production (days) | 4 | 35 | 23 | 18 | 80 |
| Labor Cost - Excavation | 12,500 | 109,200 | 71,800 | 56,200 | 249,700 |
| Equipment Cost | 16,600 | 144,900 | 95,200 | 74,500 | 331,200 |
| Material Cost | 5,300 | 69,900 | 56,700 | 115,100 | 247,000 |
| **Tunnel Excavation Cost** | **34,400** | **324,000** | **223,700** | **245,800** | **827,900** |
| **Concrete Lining Cost, Total** | **11,600** | **104,400** | **68,700** | **36,200** | **220,900** |
| Contractors OH&P | 30% | 30% | 30% | 30% | |
| **Tunnel Excavation Price** | **$44,700** | **$421,200** | **$290,800** | **$319,500** | **$1,076,200** |
| **Tunnel Lining Price** | **$15,100** | **$135,700** | **$89,300** | **$47,100** | **$287,200** |
| **Tunnel Price** | **$59,800** | **$556,900** | **$380,100** | **$366,600** | **$1,363,400** |

## *Excavation Unit Price*

| | Excavation | Shotcrete Lining | Rockbolts | Steel Sets | Miscellaneous |
|---|---|---|---|---|---|
| **Labor Cost** | **$137,449** | **$16,178** | **$15,719** | **$33,431** | **$46,922** |
| **Equipment Cost** | **$103,102** | **$19,889** | **$1,476** | **$8,044** | **$198,688** |
| **Material Cost** | **$84,754** | **$26,136** | **$31,950** | **$73,800** | **$30,360** |
| **Subtotal** | **$325,305** | **$62,204** | **$49,145** | **$115,276** | **$275,970** |
| **Miscellaneous** | **$162,656** | **$31,102** | **$24,573** | **$57,639** | |
| | **$487,961** | **$93,306** | **$73,719** | **$172,914** | **$827,900** |
| **Contractors OH&P** | **$146,388** | **$27,992** | **$22,116** | **$51,874** | **$248,370** |
| | **$634,349** | **$121,298** | **$95,834** | **$224,789** | **$1,076,270** |
| **Quantities** | **4,530** | **2,640** | **1,420** | **36,900** | |
| **Unit Price** | **$140.03** | **$45.95** | **$67.49** | **$6.09** | |
| | **$/cu.m** | **$/sq.m** | **$/l.m** | **$/kg** | |

## *Concrete Lining Unit Price*

| | Type I | Type II | Type III | Type IV | Avg. Price |
|---|---|---|---|---|---|
| **Unit Price ($/cu.m) Concrete Lining** | **$187.80** | **$168.77** | **$164.78** | **$173.82** | **$169.21** |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **4.10 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

**GEOLOGY**

Rock type as interpreted from site visits and geol mapping suggests four types of supports for the following lengths

| Tunneling Condition | Segment 1 |
|---|---|
| Roca Buena - Designation Type I | 5% |
| Roca Regular - Designation Type II | 50% |
| Roca Mala - Designation Type III | 30% |
| Roca Muy Mala - Designation Type IV | 15% |
| | 100% |

Type I - Roca Buena best rock conditions, minimal overbreak, generally self-supporting or requiring minimal support with shotcrete and spot bolting; full face excavation with normal advance

Type II - Roca Regular, good to fair rock conditions, moderate overbreak with rockbolt support and shotcrete; normal advance possible with proper bolting and shotcreting

Type III - Roca Mala, poor rock conditions, weathered or weak rock, loosely jointed, possible water inflows; Full face excavation with slower short advance and large overbreaks. Requires prompt support with pattern rockbolting and shotcrete

Type IV - Roca Muy Mala/Pesima, very poor rock conditions, full of fault and shear zones, mod to highly weathered, potential squeezing conditions in gouge; water inflows; possibly top heading and benching; prompt support within the open face with steel ribs and lagging, backpacking and shotcete with fabric; grouting may be necessary to control water; spiling possible in worst conditions.

Type V - Not mentioned above but worse than type IV and with high waterflows. Specific areas are not identified for above tunnels at this time

| Condition/Rock Type | | Q Values | Rock Mass Rating (RMR) |
|---|---|---|---|
| I | | > 7 | >60 |
| II | | 7 > Q >1 | 60>RMR>40 |
| III | | 1 > Q >.4 | 40>RMR>35 |
| IV | | .4> Q | 35 > RMR |
| Blastability | | Good | Medium |
| | SPR = | 0.38 | 0.47 |
| | | Basalt/Sandstones | |

## COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **4.10 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

**SUPPORT**

| | | |
|---|---|---|
| Shotcrete Thickness | 5 cm Layers | Fiber or wire reinf |
| Rockbolts | 25 mm X 2 meter long w/epoxy | |
| Steel Ribs | 6" X 12" I section @ .5 to 1.5 spacing | |
| Lagging | 5 cm corrugated | |
| Dry Pack | 0.5 in. from Tunnel Muck | |

All tunnel analysis is based on geological interpretation presented on the Geology Studies

| | | | |
|---|---|---|---|
| Length of Segment | | 250 Meters | |
| Finished Diameter | | 4.10 Meters | |
| Concrete Lining Thickness | | 0.35 Meters | |
| Length of tunnel for each type | | | |
| | Type I | 13 Meters | |
| | Type II | 125 Meters | |
| | Type III | 75 Meters | |
| | Type IV | 38 Meters | |
| Shotcrete with wire(or fibrous), 5 cm layers | | 0 SqM, Type I | None |
| | | 940 SqM, Type II | Crown only |
| | | 1,130 SqM, Type III | Crown and Ribs |
| | | 570 SqM, Type IV | Crown and Ribs |
| | Total Shotcrete | 2,640 SqM | |
| Rockbolts, 25 mm X 2 M Long | | 10 EA, Type I | 3 Bolts/@ 7.5 M Spacing |
| | | 310 EA, Type II | 5 Bolts/@ 2 M Spacing |
| | | 350 EA, Type III | 7 Bolts/@ 1.5 M Spacing |
| | | 40 EA, Type IV | 5 Bolts/@ 5 M Spacing |
| | Total Rockbolts | 710 EA | |
| Steel ribs, 6" X 12" X 45 KG/M | | 36,900 KG, Type IV | |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **4.10 meters (Circular Section)**
*Method:* Basic Drill/Blast

## TUNNEL EXCAVATION

| | Tunnel Crew | $$/HR | $$/HR |
|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 |
| 1 | Foreman | $10.00 | $10.00 |
| | Jumbo Drill Foreman | $10.00 | $0.00 |
| 8 | Miners | $6.70 | $53.60 |
| 1 | Blaster | $6.70 | $6.70 |
| 1 | Compressor Operator | $6.30 | $6.30 |
| 1 | Mucker Operator | $8.00 | $8.00 |
| 2 | Truck Drivers | $6.30 | $12.60 |
| | Dozer Operator | $8.00 | $0.00 |
| 1 | HVAC Electrician/Mechanics | $6.70 | $3.35 |
| 1 | Oilers | $6.30 | $3.15 |
| 2 | Rockbolters | $6.70 | $13.40 |
| 2 | Shotcreters | $6.70 | $13.40 |
| 1 | Pump Operators | $6.30 | $6.30 |
| 1 | Mechanics | $6.70 | $3.35 |
| 1 | Electricians | $6.70 | $3.35 |
| 22 | Total Crew, $$/Hr | | $156.00 |

| ROUNDS | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Meters/Round | 3.0 | 2.5 | 2.0 | 1.0 | |
| Vol/Round | 54.3 | 45.2 | 36.2 | 18.1 | |
| Holes/SqM | 2.5 | 2.5 | 2.2 | 2.0 | |
| No. of Holes | 76 | 76 | 70 | 67 | |
| Length of Holes (total, cum.) | 228 | 190 | 140 | 67 | |
| Drill Holes, Meters/Hr | 10 | 10 | 10 | 10 | |
| No. of drills | 4 | 4 | 4 | 4 | |
| Total Drilling/Hr | 40 | 40 | 40 | 40 | |
| Drilling Time | 5.7 | 4.8 | 3.5 | 1.7 | |
| Move in | 0.3 | 0.3 | 0.3 | 0.3 | |
| Total drilling Time | 6.0 | 5.1 | 3.8 | 2.0 | |
| **Blasting** | | | | | |
| Kg/CuM | 2.0 | 1.8 | 1.7 | 1.5 | |
| Kg/Round | 109 | 81 | 62 | 27 | |
| Load Time @ 80 Kg/Hr | 1.4 | 1.1 | 0.8 | 0.4 | |
| Add for blasting & Ventilating | 1.0 | 1.0 | 1.0 | 1.0 | |
| Total Blast time | 2.4 | 2.1 | 1.8 | 1.4 | |
| **Excavation Supports** | | | | | |
| Scaling | 0.3 | 0.3 | 0.3 | 0.5 | |
| Place supports | 0.2 | 1.0 | 1.5 | 3.0 | |
| Total Support Time | 0.5 | 1.3 | 1.8 | 3.5 | |
| **Muck** | | | | | |
| Move in | 0.5 | 0.5 | 0.5 | 0.5 | |
| Mucking at 10 CM/hr | 5.5 | 4.6 | 3.7 | 1.9 | |
| Total Muck Cycle | 6.0 | 5.1 | 4.2 | 2.4 | |
| **Total Cycle Hours** | 14.9 | 13.6 | 11.6 | 9.3 | |
| No of Rds with of 2 X 10 Hr Shifts | 1.3 | 1.5 | 1.7 | 2.2 | |
| Advance/Day | 4.0 | 3.6 | 3.4 | 2.1 | |
| Total number of Days for one Crew | 4 | 35 | 23 | 18 | 80 |
| Total explosives required | 500 | 4,100 | 2,400 | 1,100 | |
| Detonators | 175 | 1,845 | 1,800 | 880 | |
| Drill Bits & Steel | 1,000 | 9,500 | 5,300 | 2,600 | |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Power Tunnel**
*Length:* **250 meters (Outlet portal to Shaft)**
*Diameter:* **4.10 meters (Circular Section)**
*Method:* Basic Drill/Blast

| Plant & Equipment | Unit Operating Cos | Standby Cost | |
|---|---|---|---|
| 1 4 Drill Jumbo | $56.50 | $14.13 | $43.79 |
| 1 4 CuM Mucker | $31.25 | $7.81 | $24.22 |
| 2 Trucks, 5 CuM | $24.46 | $6.12 | $37.91 |
| 1 Shotcrete Pump | $23.56 | $5.89 | $18.26 |
| 1 Dozer | $44.50 | $11.13 | $34.49 |
| 2 Compressors, Electrical | $14.26 | $3.57 | $22.10 |
| 1 Dewatering Equipment | $7.53 | $1.88 | $5.84 |
| 2 100 HP Fans | $6.04 | $1.51 | $9.36 |
| 1 Drifters | $0.75 | $0.19 | $0.58 |
| 1 Flatbeds | $13.35 | $3.34 | $10.35 |
| Equipment Cost per hour | $222.20 | $55.55 | $206.89 |
| Utilization Factor | 70% | | |
| Actual Cost/Hr | $206.89 | | |

| | Type I | Type II | Type III | Type IV |
|---|---|---|---|---|
| Equipment & Plant, Local | $16,552 | $144,826 | $95,171 | $74,482 |

| Materials | | |
|---|---|---|
| Explosives | $1.50 | $$/KG |
| Detonators | $2.50 | $$/EA |
| Bits & Steel | $2.50 | $$/LM |
| Spiling | $150.00 | $$/EA |
| Shotcrete Cement | $120.00 | $$/TON |
| Shotcrete Aggregate | $4.00 | $$/TON |
| Steel Fibers | $1.20 | $$/KG |
| Wiremesh | $1.00 | $$/KG |
| Timber | $0.35 | $$/BF |
| Rockbolts | $45.00 | $$/EA |
| Steel Sets | $2.00 | $$/KG |
| Vent air line | $40.00 | $$/LM |
| Utility lines | $30.00 | $$/LM |
| ST&S | 5.00% | |

| | Type I | Type II | Type III | Type IV | Total |
|---|---|---|---|---|---|
| Explosives | $750 | $6,150 | $3,600 | $1,650 | $12,150 |
| Detonators | $438 | $4,613 | $4,500 | $2,200 | $11,750 |
| Bits & Steel | $2,500 | $23,750 | $13,250 | $6,500 | $46,000 |
| Spiling | $0 | $0 | $0 | $15,000 | $15,000 |
| Shotcrete Cement | $0 | $3,384 | $4,068 | $2,052 | $9,504 |
| Shotcrete Aggregate | $0 | $620 | $746 | $376 | $1,742 |
| Steel Fibers | $0 | $3,046 | $3,661 | $1,847 | $8,554 |
| Wiremesh | $0 | $2,256 | $2,712 | $1,368 | $6,336 |
| Timber | $0 | $0 | $403 | $315 | $718 |
| Rockbolts | $450 | $13,950 | $15,750 | $1,800 | $31,950 |
| Steel Sets | $0 | $0 | $0 | $73,800 | $73,800 |
| Vent air line | $500 | $5,000 | $3,000 | $1,500 | $10,000 |
| Utility lines | $375 | $3,750 | $2,250 | $1,125 | $7,500 |
| ST&S | $251 | $3,326 | $2,697 | $5,477 | $11,750 |
| Total Materials for tunnel work | $5,263 | $69,844 | $56,636 | $115,010 | $246,754 |

# COMPARATIVE COST ESTIMATES

## PANAMA CANAL - RIO COCLE DEL NORTE HYDROELECTRIC SCHEME

**Panama**

**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Power Tunnel** |
| *Length:* | **250 meters (Outlet portal to Shaft)** |
| *Diameter:* | **4.10 meters (Circular Section)** |
| *Method:* | Basic Drill/Blast |

| TUNNEL CONCRETE LINING | | | | | Total |
|---|---|---|---|---|---|
| Length | 13 | 125 | 75 | 38 | 250 |
| Quantity | 80 | 804 | 542 | 271 | 1,697 |
| Use Prefabricated Steel Forms on Dolly Each set 20 M Long and a 24 hour concrete placing will be used with 8 hours for placing forms and reinforcing (if any), 8 hours of concrete placing and 8 hours to cure, clean and move | | | | | |
| Average placing Rate (cu. M / day) | 50 | 50 | 50 | 50 | |
| No. of Steel Sets | 0 | 0 | 0 | 0 | 0 |
| Number of 10 hour work days | 2 | 17 | 11 | 6 | 36 |

| | Concrete Lining Crew | $$/HR | $$/HR | |
|---|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 | 0 |
| 1 | Foreman | $10.00 | $10.00 | |
| 0 | Form Foreman | $10.00 | $0.00 | |
| 8 | Miners | $6.70 | $53.60 | |
| 2 | Carpenters | $6.70 | $13.40 | |
| 1 | Compressor Operator | $6.30 | $6.30 | |
| 1 | Mucker Operator | $8.00 | $8.00 | |
| 2 | Flat Bed Operators | $6.30 | $12.60 | |
| 1 | HVAC Electrician/Mechanics | $6.70 | $6.70 | |
| 1 | Pump Operators | $6.30 | $6.30 | |
| 1 | Mechanics | $6.70 | $6.70 | |
| 1 | Electricians | $6.70 | $6.70 | |
| 20 | Total Crew, $$/Hr | | $142.80 | |
| | | | $51,408 | |

| | Plant & Equipment | Unit Oper | Unit Standby | Average |
|---|---|---|---|---|
| 1 | Johnson Type Low Profile + Ice Plant | $52.00 | $13.00 | $42.25 |
| 2 | Concrete Haulers | $17.62 | $4.41 | $28.63 |
| 2 | Lot Pumping Equipment | $17.21 | $4.30 | $27.97 |
| 1 | Lot fans | $5.25 | $1.31 | $4.27 |
| | | | | $103.11 |
| | Utility Factor | 75.00% | | |
| | Actual Cost/Hr | $103.11 | | |
| | Equipment Cost/Day | $2,062.29 | | |

| MATERIALS | | | | |
|---|---|---|---|---|
| Cement | 509 Tons @ | $120.00 | 61,104 | |
| Aggregate & Sand | 3,734 Tons @ | $4.00 | 14,937 | |
| Admixtures | 849 Gals @ | $15.00 | 12,730 | |
| Timber for Bulkheads | 245 SqM @ | $25.00 | 6,116 | 18,846 |
| | | | 94,887 | |

| Concrete Costs by Sections | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Labor Cost - Concrete | 2,900 | 24,300 | 15,700 | 8,600 | 51,500 |
| Equipment Cost | 4,125 | 35,059 | 22,685 | 12,374 | 74,242 |
| Material Cost | 4,495 | 44,949 | 30,295 | 15,148 | 94,887 |
| | | | | | 220,600 |
| TOTAL CONCRETE COST | $11,500 | $104,300 | $68,700 | $36,100 | $220,630 |
| Tunnel concrete Lining Cost | $11,519 | $104,308 | $68,681 | $36,121 | $220,630 |

# COMPARATIVE COST ESTIMATES
# 30-MW Rio Indio Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 2,000 | $1,100 |
| Cofferdam | L.S. | $6,500,000 | 1 | $6,500,000 |
| Overburden Excavation | cu.m | $3.70 | 12,350 | $45,695 |
| Rock Excavation | cu.m | $9.60 | 6,120 | $58,752 |
| Portal Excavation | cu.m | $14.80 | 525 | $7,770 |
| Shaft Excavation | cu.m | $310.00 | 785 | $243,350 |
| Structural Concrete | cu.m | $145.00 | 725 | $105,125 |
| Shaft Concrete Lining | cu.m | $185.00 | 205 | $37,925 |
| Formwork | sq.m | $46.80 | 1,540 | $72,072 |
| Steel Reinforcement | Ton | $1,320 | 44.6 | $58,872 |
| Steel Liner | Ton | $3,200 | 5.2 | $16,640 |
| Rock Anchors | L.m | $67 | 1,270 | $85,090 |
| ***Subtotal*** | | | | $7,232,391 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.20 x 5.10) and Hoist | Each | $610,000 | 2 | $1,220,000 |
| Trash Screen Bays | Each | $100,000 | 8 | $800,000 |
| Trash Rake | Each | $90,000 | 1 | $90,000 |
| Power and Control Equipment | LS | $50,000 | 1 | $50,000 |
| Stand-by Diesel Generator (200 kW) | Each | $60,000 | 1 | $60,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $2,265,000 |
| **POWER TUNNEL & PENSTOCK** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 1,500 | $825 |
| Overburden Excavation | cu.m | $3.70 | 1,075 | $3,978 |
| Rock Excavation | cu.m | $9.60 | 780 | $7,488 |
| Portal Excavation | cu.m | $14.80 | 425 | $6,290 |
| Tunnel Excavation | cu.m | $122.50 | 14,780 | $1,810,550 |
| Shotcrete | sq.m | $46.00 | 7,390 | $339,940 |
| Rockbolts | L.m | $67.00 | 3,380 | $226,460 |
| Steel Ribs | kg | $6.00 | 102,400 | $614,400 |
| Tunnel Concrete Lining | sq.m | $165.00 | 5,550 | $915,750 |
| Formwork (tunnel) | sq.m | $46.20 | 5,280 | $243,936 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 80.9 | $106,788 |
| Structural Concrete (penstock) | cu.m | $145.00 | 225 | $32,625 |
| Formwork (penstock) | sq.m | $46.20 | 430 | $19,866 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 10.9 | $14,388 |
| Steel Penstock | cu.m | $3,200 | 466.7 | $1,493,440 |
| Miscellaneous | % | 5% | | $291,836 |
| ***Subtotal*** | | | | $6,128,560 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 3,750 | $2,063 |
| Overburden Excavation | cu.m | $3.70 | 2,050 | $7,585 |
| Rock Excavation | cu.m | $9.60 | 575 | $5,520 |
| **Subtotal** | | | | $15,168 |

# COMPARATIVE COST ESTIMATES
## 30-MW Rio Indio Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 5,040 | $2,772 |
| Overburden Excavation | cu.m | $3.70 | 16,500 | $61,050 |
| Rock Excavation | cu.m | $9.60 | 7,230 | $69,408 |
| Mass Concrete | cu.m | $116.00 | 2,750 | $319,000 |
| Structural Concrete | cu.m | $145.00 | 1,820 | $263,900 |
| Formwork | sq.m | $46.80 | 8,140 | $380,952 |
| Steel Reinforcement | Ton | $1,320 | 152.0 | $200,640 |
| Roof, siding, windows, doors, etc | sq.m | $300 | 760 | $228,000 |
| Miscellaneous | % | 5% | | $76,286 |
| ***Subtotal*** | | | | $1,602,008 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valves (2.55 m Dia) | Each | $950,000 | 2 | $1,900,000 |
| Turbine/Generator Units (15 MW) | Each | $3,150,000 | 2 | $6,300,000 |
| Unit Auxiliaries | Each | $315,000 | 2 | $630,000 |
| Draft Tube Gates (2.30m x 2.5m) | Each | $115,000 | 6 | $690,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $375,000 | 1 | $375,000 |
| Bridge Crane (90 T) | LS | $625,000 | 1 | $625,000 |
| Semi-Gantry Crane | LS | $125,000 | 1 | $125,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $343,750 | 1 | $343,750 |
| Main Power Transformer (20 MVA) | Each | $600,000 | 2 | $1,200,000 |
| Station Service Transformer (1 MVA) | Each | $68,750 | 1 | $68,750 |
| Stand-by Diesel Generator (500 kW) | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $420,000 | 1 | $420,000 |
| Control and Communication Equip | LS | $312,500 | 1 | $312,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $700,000 | 1 | $700,000 |
| **Subtotal** | | | | $13,940,000 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Civil Work | LS | $62,500 | 1 | $62,500 |
| Steel Structures | LS | $600,000 | 1 | $600,000 |
| Service Power Transformer (5 MVA) | Each | $93,750 | 1 | $93,750 |
| 115-kV Equipment Bay | Each | $225,000 | 3 | $675,000 |
| Protection, Control and Comm. Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $250,000 | 1 | $250,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $465,000 | 1 | $465,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,250 | 58.7 | $1,834,375 |
| Conductors and Shield Wire | km | $10,625 | 58.7 | $623,688 |
| Insulators and Accessories | km | $6,250 | 58.7 | $366,875 |
| Grounding and Miscellaneous | % | 2.75% | | $77,686 |
| **Subtotal** | | | | $6,157,623 |
| | | | **TOTAL** | $21,699,631 |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

***Feature:*** **Power Tunnel**
***Length:*** **600 meters (Outlet portal to Shaft)**
***Diameter:*** **4.80 meters (Circular Section)**
***Method:*** **Basic Drill/Blast**

**SUMMARY**
**The following summary is prepared from the detailed analysis that follows**

| | Total |
|---|---|
| Total Tunnel Excavation Price | $3,001,400 |
| Total Tunnel Concrete Lining Price | $915,900 |
| Total at January 1999 Level | $3,917,300 |

| | Analysis | | | | Totals |
|---|---|---|---|---|---|
| Method of Excavation | Drill and Blast Method | | | | |
| Type of Support Requirements | Type I | Type II | Type III | Type IV | |
| Finished Diameter (m) | 4.80 | 4.80 | 4.80 | 4.80 | |
| Finished Area (sq.m.) | 18.10 | 18.10 | 18.10 | 18.10 | |
| Excavated tunnel diameter | 5.60 | 5.60 | 5.60 | 5.60 | |
| Tunnel Length (m) | 30 | 300 | 180 | 90 | 600 |
| Excavation Volume (Pay cu.m/m) | 24.6 | 24.6 | 24.6 | 24.6 | |
| Excavation Volume (Pay cu.m) | 740 | 7,390 | 4,430 | 2,220 | 14,780 |
| Concrete Lining Thickness (m) | 0.40 | 0.40 | 0.40 | 0.40 | |
| Overbreak assumed (m) | 0.15 | 0.15 | 0.15 | 0.15 | |
| Shotcrete Lining Thickness (m) | 0.0 | 0.0 | 0.05 | 0.05 | |
| Shotcrete Area (sq.m) | 0 | 2,640 | 3,170 | 1,580 | 7,390 |
| Excavated Volume (Actual cu.m/m) | 27.3 | 27.3 | 27.3 | 27.3 | |
| Excavated Volume (Actual cu.m) | 820 | 8,200 | 4,920 | 2,460 | 16,400 |
| Loose Volume Mucking (cu.m) | 1,312 | 13,120 | 7,872 | 3,936 | 26,240 |
| Concrete Lining Volume (cu.m) | 277 | 2,773 | 1,664 | 832 | 5,546 |
| 2-meter long (#8) Rockbolts | 10 | 750 | 840 | 90 | 1,690 |
| Steel Sets (kg) | | | | 102,400 | 102,400 |
| Excavation Production (days) | 10 | 104 | 65 | 48 | 227 |
| Labor Cost - Excavation | 31,200 | 324,500 | 202,800 | 149,800 | 708,300 |
| Equipment Cost | 41,400 | 430,400 | 269,000 | 198,700 | 939,500 |
| Material Cost | 14,300 | 198,300 | 156,600 | 291,700 | 660,900 |
| Tunnel Excavation Cost | 86,900 | 953,200 | 628,400 | 640,200 | 2,308,700 |
| Concrete Lining Cost, Total | 36,500 | 350,400 | 211,700 | 105,900 | 704,500 |
| Contractors OH&P | 30% | 30% | 30% | 30% | |
| Tunnel Excavation Price | $113,000 | $1,239,200 | $816,900 | $832,300 | $3,001,400 |
| Tunnel Lining Price | $47,500 | $455,500 | $275,200 | $137,700 | $915,900 |
| Tunnel Price | $160,500 | $1,694,700 | $1,092,100 | $970,000 | $3,917,300 |

## *Excavation Unit Price*

| | Excavation | Shotcrete Lining | Rockbolts | Steel Sets | Miscellaneous |
|---|---|---|---|---|---|
| Labor Cost | $401,961 | $45,287 | $37,417 | $92,774 | $130,861 |
| Equipment Cost | $303,869 | $55,676 | $3,514 | $22,323 | $554,118 |
| Material Cost | $222,220 | $73,161 | $76,050 | $204,800 | $84,669 |
| Subtotal | $928,050 | $174,123 | $116,980 | $319,898 | $769,649 |
| Miscellaneous | $464,100 | $87,076 | $58,499 | $159,974 | |
| | $1,392,150 | $261,199 | $175,480 | $479,872 | $2,308,700 |
| Contractors OH&P | $417,645 | $78,360 | $52,644 | $143,962 | $692,610 |
| | $1,809,795 | $339,558 | $228,123 | $623,834 | $3,001,310 |
| Quantities | 14,780 | 7,390 | 3,380 | 102,400 | |
| Unit Price | $122.45 | $45.95 | $67.49 | $6.09 | |
| | $/cu.m | $/sq.m | $/l.m | $/kg | |

## *Concrete Lining Unit Price*

| | Type I | Type II | Type III | Type IV | Avg. Price |
|---|---|---|---|---|---|
| Unit Price ($/cu.m) Concrete Lining | $171.28 | $164.25 | $165.39 | $165.51 | $165.13 |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME**
Panama
Feasibility Level Cost for Tunneling

| | |
|---|---|
| *Feature:* | Power Tunnel |
| *Length:* | 600 meters (Outlet portal to Shaft) |
| *Diameter:* | 4.80 meters (Circular Section) |
| *Method:* | Basic Drill/Blast |

**GEOLOGY**
Rock type as interpreted from site visits and geol mapping suggests four types of supports for the following lengths

| Tunneling Condition | Segment 1 |
|---|---|
| Roca Buena - Designation Type I | 5% |
| Roca Regular - Designation Type II | 50% |
| Roca Mala - Designation Type III | 30% |
| Roca Muy Mala - Designation Type IV | 15% |
| | 100% |

Type I - Roca Buena best rock conditions, minimal overbreak, generally self-supporting or requiring minimal support with shotcrete and spot bolting; full face excavation with normal advance

Type II - Roca Regular, good to fair rock conditions, moderate overbreak with rockbolt support and shotcrete; normal advance possible with proper bolting and shotcreting

Type III - Roca Mala, poor rock conditions, weathered or weak rock, loosely jointed, possible water inflows; Full face excavation with slower short advance and large overbreaks. Requires prompt support with pattern rockbolting and shotcrete

Type IV - Roca Muy Mala/Pesima, very poor rock conditions, full of fault and shear zones, mod to highly weathered, potential squeezing conditi in gouge; water inflows; possibly top heading and benching; prompt support within the open face with steel ribs and lagging, backpacking anc shotcete with fabric; grouting may be necessary to control water; spiling possible in worst conditions.

Type V - Not mentioned above but worse than type IV and with high waterflows. Specific areas are not identified for above tunnels at this time

| Condition/Rock Type | | Q Values | Rock Mass Rating (RMR) |
|---|---|---|---|
| I | | > 7 | >60 |
| II | | 7 > Q >1 | 60>RMR>40 |
| III | | 1 > Q >.4 | 40>RMR>35 |
| IV | | .4> Q | 35 > RMR |
| **Blastability** | | **Good** | **Medium** |
| | SPR = | 0.38 | 0.47 |
| | | Basalt/Sandstones | |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | Power Tunnel |
| *Length:* | 600 meters (Outlet portal to Shaft) |
| *Diameter:* | 4.80 meters (Circular Section) |
| *Method:* | Basic Drill/Blast |

| SUPPORT | | |
|---|---|---|
| Shotcrete Thickness | 5 cm Layers | Fiber or wire reinf |
| Rockbolts | 25 mm X 2 meter long w/epoxy | |
| Steel Ribs | 6" X 12" I section @ .5 to 1.5 spacing | |
| Lagging | 5 cm corrugated | |
| Dry Pack | 0.5 in. from Tunnel Muck | |

All tunnel analysis is based on geological interpretation presented on the Geology Studies

| | | | |
|---|---|---|---|
| Length of Segment | | 600 Meters | |
| Finished Diameter | | 4.80 Meters | |
| Concrete Lining Thickness | | 0.40 Meters | |
| Length of tunnel for each type | | | |
| | Type I | 30 Meters | |
| | Type II | 300 Meters | |
| | Type III | 180 Meters | |
| | Type IV | 90 Meters | |
| Shotcrete with wire(or fibrous), 5 cm layers | | 0 SqM, Type I | None |
| | | 2,640 SqM, Type II | Crown only |
| | | 3,170 SqM, Type III | Crown and Ribs |
| | | 1,580 SqM, Type IV | Crown and Ribs |
| | Total Shotcrete | 7,390 SqM | |
| Rockbolts, 25 mm X 2 M Long | | 10 EA, Type I | 3 Bolts/@ 7.5 M Spacing |
| | | 750 EA, Type II | 5 Bolts/@ 2 M Spacing |
| | | 840 EA, Type III | 7 Bolts/@ 1.5 M Spacing |
| | | 90 EA, Type IV | 5 Bolts/@ 5 M Spacing |
| | Total Rockbolts | 1,690 EA | |
| Steel ribs, 6" X 12" X 45 KG/M | | 102,400 KG, Type IV | |

# COMPARATIVE COST ESTIMATES

## PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME

**Panama**

**Feasibility Level Cost for Tunneling**

***Feature:*** **Power Tunnel**
***Length:*** **600 meters (Outlet portal to Shaft)**
***Diameter:*** **4.80 meters (Circular Section)**
***Method:*** **Basic Drill/Blast**

**TUNNEL EXCAVATION**

| | Tunnel Crew | $$/HR | $$/HR |
|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 |
| 1 | Foreman | $10.00 | $10.00 |
| | Jumbo Drill Foreman | $10.00 | $0.00 |
| 8 | Miners | $6.70 | $53.60 |
| 1 | Blaster | $6.70 | $6.70 |
| 1 | Compressor Operator | $6.30 | $6.30 |
| 1 | Mucker Operator | $8.00 | $8.00 |
| 2 | Truck Drivers | $6.30 | $12.60 |
| | Dozer Operator | $8.00 | $0.00 |
| 1 | HVAC Electrician/Mechanics | $6.70 | $3.35 |
| 1 | Oilers | $6.30 | $3.15 |
| 2 | Rockbolters | $6.70 | $13.40 |
| 2 | Shotcreters | $6.70 | $13.40 |
| 1 | Pump Operators | $6.30 | $6.30 |
| 1 | Mechanics | $6.70 | $3.35 |
| 1 | Electricians | $6.70 | $3.35 |
| 22 | Total Crew, $$/Hr | | $156.00 |

| ROUNDS | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Meters/Round | 3.0 | 2.5 | 2.0 | 1.0 | |
| Vol/Round | 73.9 | 61.6 | 49.3 | 24.6 | |
| Holes/SqM | 2.5 | 2.5 | 2.2 | 2.0 | |
| No. of Holes | 97 | 97 | 90 | 85 | |
| Length of Holes (total, cum.) | 291 | 243 | 180 | 85 | |
| Drill Holes, Meters/Hr | 10 | 10 | 10 | 10 | |
| No. of drills | 4 | 4 | 4 | 4 | |
| Total Drilling/Hr | 40 | 40 | 40 | 40 | |
| Drilling Time | 7.3 | 6.1 | 4.5 | 2.2 | |
| Move in | 0.3 | 0.3 | 0.3 | 0.3 | |
| Total drilling Time | 7.6 | 6.4 | 4.8 | 2.5 | |
| **Blasting** | | | | | |
| Kg/CuM | 2.0 | 1.8 | 1.7 | 1.5 | |
| Kg/Round | 148 | 111 | 84 | 37 | |
| Load Time @ 80 Kg/Hr | 1.9 | 1.4 | 1.1 | 0.5 | |
| Add for blasting & Ventilating | 1.0 | 1.0 | 1.0 | 1.0 | |
| Total Blast time | 2.9 | 2.4 | 2.1 | 1.5 | |
| **Excavation Supports** | | | | | |
| Scaling | 0.3 | 0.3 | 0.3 | 0.5 | |
| Place supports | 0.2 | 1.0 | 1.5 | 3.0 | |
| Total Support Time | 0.5 | 1.3 | 1.8 | 3.5 | |
| **Muck** | | | | | |
| Move in | 0.5 | 0.5 | 0.5 | 0.5 | |
| Mucking at 10 CM/hr | 7.4 | 6.2 | 5.0 | 2.5 | |
| Total Muck Cycle | 7.9 | 6.7 | 5.5 | 3.0 | |
| **Total Cycle Hours** | 18.9 | 16.8 | 14.2 | 10.5 | |
| No of Rds with of 2 X 10 Hr Shifts | 1.1 | 1.2 | 1.4 | 1.9 | |
| Advance/Day | 3.1 | 2.9 | 2.8 | 1.9 | |
| Total number of Days for one Crew | 10 | 104 | 65 | 48 | 227 |
| Total explosives required | 1,500 | 13,400 | 7,600 | 3,400 | |
| Detonators | 525 | 6,030 | 5,700 | 2,720 | |
| Drill Bits & Steel | 3,000 | 29,100 | 16,200 | 7,700 | |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**
***Feature:*** **Power Tunnel**
***Length:*** **600 meters (Outlet portal to Shaft)**
***Diameter:*** **4.80 meters (Circular Section)**
***Method:*** **Basic Drill/Blast**

| Plant & Equipment | Unit Operating | Standby Cost | |
|---|---|---|---|
| 1 4 Drill Jumbo | $56.50 | $14.13 | $43.79 |
| 1 4 CuM Mucker | $31.25 | $7.81 | $24.22 |
| 2 Trucks, 5 CuM | $24.46 | $6.12 | $37.91 |
| 1 Shotcrete Pump | $23.56 | $5.89 | $18.26 |
| 1 Dozer | $44.50 | $11.13 | $34.49 |
| 2 Compressors, Electrical | $14.26 | $3.57 | $22.10 |
| 1 Dewatering Equipment | $7.53 | $1.88 | $5.84 |
| 2 100 HP Fans | $6.04 | $1.51 | $9.36 |
| 1 Drifters | $0.75 | $0.19 | $0.58 |
| 1 Flatbeds | $13.35 | $3.34 | $10.35 |
| Equipment Cost per hour | $222.20 | $55.55 | $206.89 |
| Utilization Factor | 70% | | |
| Actual Cost/Hr | $206.89 | | |

| | Type I | Type II | Type III | Type IV |
|---|---|---|---|---|
| Equipment & Plant, Local | **$41,379** | **$430,340** | **$268,962** | **$198,618** |

| Materials | | |
|---|---|---|
| Explosives | $1.50 | $$/KG |
| Detonators | $2.50 | $$/EA |
| Bits & Steel | $2.50 | $$/LM |
| Spiling | $150.00 | $$/EA |
| Shotcrete Cement | $120.00 | $$/TON |
| Shotcrete Aggregate | $4.00 | $$/TON |
| Steel Fibers | $1.20 | $$/KG |
| Wiremesh | $1.00 | $$/KG |
| Timber | $0.35 | $$/BF |
| Rockbolts | $45.00 | $$/EA |
| Steel Sets | $2.00 | $$/KG |
| Vent air line | $40.00 | $$/LM |
| Utility lines | $30.00 | $$/LM |
| ST&S | 5.00% | |

| | Type I | Type II | Type III | Type IV | Total |
|---|---|---|---|---|---|
| Explosives | $2,250 | $20,100 | $11,400 | $5,100 | $38,850 |
| Detonators | $1,313 | $15,075 | $14,250 | $6,800 | $37,438 |
| Bits & Steel | $7,500 | $72,750 | $40,500 | $19,250 | $140,000 |
| Spiling | $0 | $0 | $0 | $15,000 | $15,000 |
| Shotcrete Cement | $0 | $9,504 | $11,412 | $5,688 | $26,604 |
| Shotcrete Aggregate | $0 | $1,742 | $2,092 | $1,043 | $4,877 |
| Steel Fibers | $0 | $8,554 | $10,271 | $5,119 | $23,944 |
| Wiremesh | $0 | $6,336 | $7,608 | $3,792 | $17,736 |
| Timber | $0 | $0 | $1,138 | $840 | $1,978 |
| Rockbolts | $450 | $33,750 | $37,800 | $4,050 | $76,050 |
| Steel Sets | $0 | $0 | $0 | $204,800 | $204,800 |
| Vent air line | $1,200 | $12,000 | $7,200 | $3,600 | $24,000 |
| Utility lines | $900 | $9,000 | $5,400 | $2,700 | $18,000 |
| ST&S | $681 | $9,441 | $7,454 | $13,889 | $31,464 |
| **Total Materials for tunnel work** | **$14,293** | **$198,252** | **$156,524** | **$291,671** | **$660,740** |

# COMPARATIVE COST ESTIMATES

**PANAMA CANAL - RIO INDIO HYDROELECTRIC SCHEME**
**Panama**
**Feasibility Level Cost for Tunneling**
***Feature:*** **Power Tunnel**
***Length:*** **600 meters (Outlet portal to Shaft)**
***Diameter:*** **4.80 meters (Circular Section)**
***Method:*** **Basic Drill/Blast**

| TUNNEL CONCRETE LINING | | | | | Total |
|---|---|---|---|---|---|
| Length | 30 | 300 | 180 | 90 | 600 |
| Quantity | 277 | 2,773 | 1,664 | 832 | 5,546 |
| Use Prefabricated Steel Forms on Dolly Each set 20 M Long and a 24 hour concrete placing will be used with 8 hours for placing forms and reinforcing (if any), 8 hours of concrete placing and 8 hours to cure, clean and move | | | | | |
| Average placing Rate (cu. M / day) | 50 | 50 | 50 | 50 | |
| No. of Steel Sets | 0 | 0 | 0 | 0 | 0 |
| Number of 10 hour work days | 6 | 56 | 34 | 17 | 113 |

| | Concrete Lining Crew | $$/HR | $$/HR | |
|---|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 | 0 |
| 1 | Foreman | $10.00 | $10.00 | |
| 0 | Form Foreman | $10.00 | $0.00 | |
| 8 | Miners | $6.70 | $53.60 | |
| 2 | Carpenters | $6.70 | $13.40 | |
| 1 | Compressor Operator | $6.30 | $6.30 | |
| 1 | Mucker Operator | $8.00 | $8.00 | |
| 2 | Flat Bed Operators | $6.30 | $12.60 | |
| 1 | HVAC Electrician/Mechanics | $6.70 | $6.70 | |
| 1 | Pump Operators | $6.30 | $6.30 | |
| 1 | Mechanics | $6.70 | $6.70 | |
| 1 | Electricians | $6.70 | $6.70 | |
| 20 | Total Crew, $$/Hr | | $142.80 | |
| | | | $161,364 | |

| | Plant & Equipment | Unit Oper | Unit Standby | Average |
|---|---|---|---|---|
| 1 | Johnson Type Low Profile + Ice Plant | $52.00 | $13.00 | $42.25 |
| 2 | Concrete Haulers | $17.62 | $4.41 | $28.63 |
| 2 | Lot Pumping Equipment | $17.21 | $4.30 | $27.97 |
| 1 | Lot fans | $5.25 | $1.31 | $4.27 |
| | | | | $103.11 |
| | Utility Factor | 75.00% | | |
| | Actual Cost/Hr | $103.11 | | |
| | Equipment Cost/Day | $2,062.29 | | |

| MATERIALS | | | | |
|---|---|---|---|---|
| Cement | 1,664 Tons @ | $120.00 | 199,673 | |
| Aggregate & Sand | 12,202 Tons @ | $4.00 | 48,809 | |
| Admixtures | 2,773 Gals @ | $15.00 | 41,599 | |
| Timber for Bulkheads | 784 SqM @ | $25.00 | 19,604 | 61,202 |
| | | | 309,685 | |

| Concrete Costs by Sections | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Labor Cost - Concrete | 8,600 | 80,000 | 48,600 | 24,300 | 161,500 |
| Equipment Cost | 12,374 | 115,488 | 70,118 | 35,059 | 233,038 |
| Material Cost | 15,484 | 154,842 | 92,905 | 46,453 | 309,685 |
| | | | | | 704,200 |
| TOTAL CONCRETE COST | $36,500 | $350,300 | $211,600 | $105,800 | $704,223 |

# COMPARATIVE COST ESTIMATES

## 30-MW Isla Pablon Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 7,000 | $3,850 |
| Overburden Excavation | cu.m | $3.70 | 25,100 | $92,870 |
| Rock Excavation | cu.m | $9.60 | 6,680 | $64,128 |
| Portal Excavation | cu.m | $14.80 | 1,025 | $15,170 |
| Mass Concrete | cu.m | $116.00 | 3,130 | $363,080 |
| Structural Concrete | cu.m | $145.00 | 2,220 | $321,900 |
| Formwork | sq.m | $46.80 | 9,750 | $456,300 |
| Steel Reinforcement | Ton | $1,320 | 178.7 | $235,884 |
| Steel Penstock | Ton | $3,200 | 140.0 | $448,000 |
| Roof, siding, windows, doors, etc | sq.m | $300 | 840 | $252,000 |
| Miscellaneous Metal Works | % | 5% | | $112,659 |
| ***Subtotal*** | | | | $2,365,841 |
| ***Steel Liner*** | | | | |
| Steel Plate | T | $3,200 | 1,647 | $5,270,400 |
| Miscellaneous | % | 5% | | $263,520 |
| ***Subtotal*** | | | | $5,533,920 |
| ***Isla Pablon Surge Tank*** | | | | |
| Site Preparation | sq.m | $0.55 | 6,400 | $3,520 |
| Overburden Excavation | cu.m | $3.70 | 37,000 | $136,900 |
| Rock Excavation | cu.m | $9.20 | 10,032 | $92,294 |
| Large Diameter Shaft Excavation | cu.m | $14.50 | 34,370 | $498,365 |
| Shaft Excavation | cu.m | $310.00 | 785 | $243,350 |
| Shotcrete | sq.m | $45.90 | 1,500 | $68,850 |
| Shaft Concret Lining | cu.m | $180.00 | 200 | $36,000 |
| Structural Concrete | cu.m | $145.00 | 9,095 | $1,318,775 |
| Formwork | sq.m | $46.80 | 10,256 | $479,981 |
| Steel Reinforcement | Ton | $1,320 | 409.3 | $540,276 |
| Rock Anchors | L.m | $56 | 5,080 | $283,972 |
| Miscellaneous Support | % | 5% | | $185,114 |
| ***Subtotal*** | | | | $3,887,397 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valves (2.90 m Dia) | Each | $975,000 | 2 | $1,950,000 |
| Turbine/Generator Units (15 MW) | Each | $3,150,000 | 2 | $6,300,000 |
| Unit Auxiliaries | Each | $315,000 | 2 | $630,000 |
| Axial Flow Regulating Valves (1.50 m Dia) | Each | $560,000 | 2 | $1,120,000 |
| Draft Tube Gates (1.80m x 2.25m) | Each | $110,000 | 6 | $660,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $375,000 | 1 | $375,000 |
| Bridge Crane (75 T) | LS | $550,000 | 1 | $550,000 |
| Semi-Gantry Crane | LS | $125,000 | 1 | $125,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $343,750 | 1 | $343,750 |
| Main Power Transformer (20 MVA) | Each | $600,000 | 2 | $1,200,000 |
| Station Service Transformer (1 MVA) | Each | $68,750 | 1 | $68,750 |
| Stand-by Diesel Generator (500 kW) | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $420,000 | 1 | $420,000 |
| Control and Communication Equip | LS | $290,000 | 1 | $290,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $650,000 | 1 | $650,000 |
| **Subtotal** | | | | $14,932,500 |

# COMPARATIVE COST ESTIMATES

## 30-MW Isla Pablon Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Civil Work | LS | $62,500 | 1 | $62,500 |
| Steel Structures | LS | $600,000 | 1 | $600,000 |
| Service Power Transformer (5 MVA) | Each | $93,750 | 1 | $93,750 |
| 115-kV Equipment Bay | Each | $225,000 | 3 | $675,000 |
| Protection, Control and Comm. Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $250,000 | 1 | $250,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $465,000 | 1 | $465,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,250 | 47.1 | $1,471,875 |
| Conductors and Shield Wire | km | $10,625 | 47.1 | $500,438 |
| Insulators and Accessories | km | $6,250 | 47.1 | $294,375 |
| Grounding and Miscellaneous | % | 2.75% | | $62,334 |
| **Subtotal** | | | | $5,584,021 |
| | | | **TOTAL** | $22,882,363 |
| | | | | $32,303,680 |

# COMPARATIVE COST ESTIMATES

## INDIO - GATUN TRANSFER TUNNEL

**Panama**

**Feasibility Level Cost for Tunneling**

*Feature:* **Transfer Tunnel**
*Length:* **8,250 meters**
*Diameter:* **6.50 meters (D-shaped Section)**
*Method:* Basic Drill/Blast

**SUMMARY**

The following summary is prepared from the detailed analysis that follows

| | Total |
|---|---|
| Total Tunnel Excavation Price | **$45,304,500** |
| Total Tunnel Concrete Lining Price | **$10,578,400** |
| Total at January 2003 Level | **$55,882,900** |

| Method of Excavation | Analysis<br>Drill and Blast Method | | | | Totals |
|---|---|---|---|---|---|
| Type of Support Requirements | Type I | Type II | Type III | Type IV | |
| Finished Diameter (m) | 6.50 | 6.50 | 6.50 | 6.50 | |
| Finished Area (sq.m.) | 37.72 | 37.72 | 37.72 | 37.72 | |
| Excavated tunnel diameter | 7.20 | 7.20 | 7.20 | 7.20 | |
| Tunnel Length (m) | 2,063 | 3,300 | 2,475 | 413 | 8,250 |
| Excavation Volume (Pay cu.m/m) | 46.28 | 46.28 | 46.28 | 46.28 | |
| Excavation Volume (Pay cu.m) | 95,450 | 152,720 | 114,540 | 19,090 | 381,800 |
| Concrete Lining Thickness (m) | 0.35 | 0.35 | 0.35 | 0.35 | |
| Overbreak assumed (m) | 0.10 | 0.10 | 0.15 | 0.15 | |
| Shotcrete Lining Thickness (m) | 0.00 | 0.05 | 0.05 | 0.05 | |
| Shotcrete Area (sq.m) | 0 | 37,320 | 45,810 | 7,640 | 90,770 |
| Excavated Volume (Actual cu.m/m) | 48.9 | 48.9 | 50.2 | 50.2 | |
| Excavated Volume (Actual cu.m) | 100,820 | 161,320 | 124,280 | 20,710 | 407,130 |
| Loose Volume Mucking (cu.m) | 161,312 | 258,112 | 198,848 | 33,136 | 651,408 |
| Concrete Lining Volume (cu.m) | 23,033 | 36,853 | 30,932 | 5,155 | 95,974 |
| 2-meter long (#8) Rockbolts | 830 | 8,250 | 11,550 | 410 | 21,040 |
| Steel Sets (kg) | | | | 357,900 | 357,900 |
| Excavation Production (days) | 625 | 1,065 | 825 | 207 | 2,722 |
| Labor Cost - Excavation | 2,475,000 | 4,217,400 | 3,267,000 | 819,800 | 10,779,200 |
| Equipment Cost | 3,600,000 | 6,134,400 | 4,752,000 | 1,192,400 | 15,678,800 |
| Material Cost | 1,446,400 | 3,024,900 | 2,780,000 | 1,140,300 | 8,391,600 |
| **Tunnel Excavation Cost** | **7,521,400** | **13,376,700** | **10,799,000** | **3,152,500** | **34,849,600** |
| **Concrete Lining Cost, Total** | **1,952,600** | **3,122,900** | **2,622,900** | **438,800** | **8,137,200** |
| Contractors OH&P | 30% | 30% | 30% | 30% | |
| **Tunnel Excavation Price** | **$9,777,800** | **$17,389,700** | **$14,038,700** | **$4,098,300** | **$45,304,500** |
| **Tunnel Lining Price** | **$2,538,400** | **$4,059,800** | **$3,409,800** | **$570,400** | **$10,578,400** |
| **Tunnel Price** | **$12,316,200** | **$21,449,500** | **$17,448,500** | **$4,668,700** | **$55,882,900** |

## *Excavation Unit Price*

| | Excavation | Shotcrete Lining | Rockbolts | Steel Sets | Miscellaneous |
|---|---|---|---|---|---|
| Labor Cost | $7,457,593 | $556,248 | $465,826 | $324,257 | $1,975,276 |
| Equipment Cost | $6,509,067 | $683,852 | $43,742 | $78,022 | $8,364,117 |
| Material Cost | $4,552,337 | $898,623 | $946,800 | $715,800 | $1,278,040 |
| Subtotal | $18,518,997 | $2,138,723 | $1,456,368 | $1,118,080 | $11,617,433 |
| Miscellaneous | $9,260,574 | $1,069,486 | $728,268 | $559,105 | |
| | $27,779,571 | $3,208,208 | $2,184,636 | $1,677,184 | $34,849,600 |
| Contractors OH&P | $8,333,871 | $962,463 | $655,391 | $503,155 | $10,454,880 |
| | $36,113,442 | $4,170,671 | $2,840,027 | $2,180,340 | $45,304,480 |
| Quantities | 381,800 | 90,770 | 42,080 | 357,900 | |
| Unit Price | $94.59 | $45.95 | $67.49 | $6.09 | |
| | $/cu.m | $/sq.m | $/l.m | $/kg | |

## *Concrete Lining Unit Price*

| | Type I | Type II | Type III | Type IV | Avg. Price |
|---|---|---|---|---|---|
| Unit Price ($/cu.m) Concrete Lining | $110.21 | $110.16 | $110.24 | $110.64 | $110.22 |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **6.50 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

## GEOLOGY

Rock type as interpreted from site visits and geol mapping suggests four types of supports for the following lengths

| Tunneling Condition | Segment 1 |
|---|---|
| Roca Buena - Designation Type I | 25% |
| Roca Regular - Designation Type II | 40% |
| Roca Mala - Designation Type III | 30% |
| Roca Muy Mala - Designation Type IV | 5% |
| | 100% |

Type I - Roca Buena best rock conditions, minimal overbreak, generally self-supporting or requiring minimal support with shotcrete and spot bolting; full face excavation with normal advance

Type II - Roca Regular, good to fair rock conditions, moderate overbreak with rockbolt support and shotcrete; normal advance possible with proper bolting and shotcreting

Type III - Roca Mala, poor rock conditions, weathered or weak rock, loosely jointed, possible water inflows; Full face excavation with slower short advance and large overbreaks. Requires prompt support with pattern rockbolting and shotcrete

Type IV - Roca Muy Mala/Pesima, very poor rock conditions, full of fault and shear zones, mod to highly weathered, potential squeezing conditions in gouge; water inflows; possibly top heading and benching; prompt support within the open face with steel ribs and lagging, backpacking and shotcete with fabric; grouting may be necessary to control water; spiling possible in worst conditions.

Type V - Not mentioned above but worse than type IV and with high waterflows. Specific areas are not identified for above tunnels at this time

| Condition/Rock Type | | Q Values | Rock Mass Rating (RMR) |
|---|---|---|---|
| I | | > 7 | >60 |
| II | | 7 > Q >1 | 60>RMR>40 |
| III | | 1 > Q >.4 | 40>RMR>35 |
| IV | | .4> Q | 35 > RMR |
| Blastability | | Good | Medium |
| | SPR = | 0.38 | 0.47 |
| | | Basalt/Sandstones | |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **6.50 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

**SUPPORT**

| | | |
|---|---|---|
| Shotcrete Thickness | 5 cm Layers | Fiber or wire reinf |
| Rockbolts | 25 mm X 2 meter long w/epoxy | |
| Steel Ribs | 6" X 12" I section @ .5 to 1.5 spacing | |
| Lagging | 5 cm corrugated | |
| Dry Pack | 0.5 in. from Tunnel Muck | |

All tunnel analysis is based on geological interpretation presented on the Geology Studies

| | | |
|---|---|---|
| Length of Segment | 8,250 Meters | |
| Finished Diameter | 6.50 Meters | |
| Concrete Lining Thickness | 0.35 Meters | |
| Length of tunnel for each type | | |
| Type I | 2,063 Meters | |
| Type II | 3,300 Meters | |
| Type III | 2,475 Meters | |
| Type IV | 413 Meters | |
| Shotcrete with wire(or fibrous), 5 cm layers | 0 SqM, Type I | None |
| | 37,320 SqM, Type II | Crown only |
| | 45,810 SqM, Type III | Crown and Ribs |
| | 7,640 SqM, Type IV | Crown and Ribs |
| Total Shotcrete | 90,770 SqM | |
| Rockbolts, 25 mm X 2 M Long | 830 EA, Type I | 3 Bolts/@ 7.5 M Spacing |
| | 8,250 EA, Type II | 5 Bolts/@ 2 M Spacing |
| | 11,550 EA, Type III | 7 Bolts/@ 1.5 M Spacing |
| | 410 EA, Type IV | 5 Bolts/@ 5 M Spacing |
| Total Rockbolts | 21,040 EA | |
| Steel ribs, 6" X 12" X 45 KG/M | 357,900 KG, Type IV | |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **6.50 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

**TUNNEL EXCAVATION**

| | **Tunnel Crew** | $$/HR | $$/HR |
|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 |
| 1 | Foreman | $10.00 | $10.00 |
| 1 | Jumbo Drill Foreman | $10.00 | $10.00 |
| 8 | Miners | $6.70 | $53.60 |
| 1 | Blaster | $6.70 | $6.70 |
| 1 | Compressor Operator | $6.30 | $6.30 |
| 4 | Mucker Operator | $8.00 | $32.00 |
| 2 | Truck Drivers | $6.30 | $12.60 |
| 1 | Dozer Operator | $8.00 | $8.00 |
| 1 | HVAC Electrician/Mechanics | $6.70 | $3.35 |
| 1 | Oilers | $6.30 | $3.15 |
| 2 | Rockbolters | $6.70 | $13.40 |
| 2 | Shotcreters | $6.70 | $13.40 |
| 1 | Pump Operators | $6.30 | $6.30 |
| 1 | Mechanics | $6.70 | $3.35 |
| 1 | Electricians | $6.70 | $3.35 |
| 27 | Total Crew, $$/Hr | | $198.00 |

| ROUNDS | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Meters/Round | 3.0 | 2.5 | 2.0 | 1.0 | |
| Vol/Round | 146.7 | 122.2 | 100.4 | 50.2 | |
| Holes/SqM | 2.5 | 2.5 | 2.2 | 2.0 | |
| No. of Holes | 139 | 139 | 125 | 116 | |
| Length of Holes (total, cum.) | 417 | 348 | 250 | 116 | |
| Drill Holes, Meters/Hr | 10 | 10 | 10 | 10 | |
| No. of drills | 6 | 6 | 6 | 6 | |
| Total Drilling/Hr | 60 | 60 | 60 | 60 | |
| Drilling Time | 7.0 | 5.8 | 4.2 | 2.0 | |
| Move in | 0.3 | 0.3 | 0.3 | 0.3 | |
| Total drilling Time | 7.3 | 6.1 | 4.5 | 2.3 | |
| **Blasting** | | | | | |
| Kg/CuM | 2.0 | 1.8 | 1.7 | 1.5 | |
| Kg/Round | 293 | 220 | 171 | 75 | |
| Load Time @ 80 Kg/Hr | 3.7 | 2.8 | 2.2 | 1.0 | |
| Add for blasting & Ventilating | 1.0 | 1.0 | 1.0 | 1.0 | |
| Total Blast time | 4.7 | 3.8 | 3.2 | 2.0 | |
| **Excavation Supports** | | | | | |
| Scaling | 0.3 | 0.3 | 0.3 | 0.5 | |
| Place supports | 0.2 | 1.0 | 1.5 | 3.0 | |
| Total Support Time | 0.5 | 1.3 | 1.8 | 3.5 | |
| **Muck** | | | | | |
| Move in | 0.5 | 0.5 | 0.5 | 0.5 | |
| Mucking at 50 CM/hr | 4.7 | 4.0 | 3.3 | 1.7 | |
| Total Muck Cycle | 5.2 | 4.5 | 3.8 | 2.2 | |
| **Total Cycle Hours** | 17.7 | 15.7 | 13.3 | 10.0 | |
| No of Rds with of 2 X 10 Hr Shifts | 1.1 | 1.3 | 1.5 | 2.0 | |
| Advance/Day | 3.3 | 3.1 | 3.0 | 2.0 | |
| Total number of Days for one Crew | 625 | 1,065 | 825 | 207 | 2,722 |
| Total explosives required | 201,700 | 290,400 | 211,300 | 31,100 | |
| Detonators | 70,595 | 130,680 | 158,475 | 24,880 | |
| Drill Bits & Steel | 286,700 | 458,700 | 309,400 | 47,900 | |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Transfer Tunnel**
*Length:* **8,250 meters**
*Diameter:* **6.50 meters (D-shaped Section)**
*Method:* Basic Drill/Blast

| Plant & Equipment | Unit Operating Cos | Standby Cost | |
|---|---|---|---|
| 1 6 Drill Jumbo | $67.40 | $16.85 | $52.24 |
| 4 4 CuM Mucker | $31.25 | $7.81 | $96.88 |
| 2 Trucks, 25 CuM | $24.46 | $6.12 | $37.91 |
| 1 Shotcrete Pump | $23.56 | $5.89 | $18.26 |
| 1 Dozer | $44.50 | $11.13 | $34.49 |
| 2 Compressors, Electrical | $14.26 | $3.57 | $22.10 |
| 1 Dewatering Equipment | $7.53 | $1.88 | $5.84 |
| 2 100 HP Fans | $6.04 | $1.51 | $9.36 |
| 1 Drifters | $0.75 | $0.19 | $0.58 |
| 1 Flatbeds | $13.35 | $3.34 | $10.35 |
| Equipment Cost per hour | $233.10 | $58.28 | $288.00 |
| Utilization Factor | 70% | | |
| Actual Cost/Hr | $288.00 | | |

| | Type I | Type II | Type III | Type IV |
|---|---|---|---|---|
| Equipment & Plant | $3,599,972 | $6,134,352 | $4,751,963 | $1,192,311 |

| Materials | | |
|---|---|---|
| Explosives | $1.50 | $$/KG |
| Detonators | $2.50 | $$/EA |
| Bits & Steel | $2.50 | $$/LM |
| Spiling | $150.00 | $$/EA |
| Shotcrete Cement | $120.00 | $$/TON |
| Shotcrete Aggregate | $4.00 | $$/TON |
| Steel Fibers | $1.20 | $$/KG |
| Wiremesh | $1.00 | $$/KG |
| Timber | $0.35 | $$/BF |
| Rockbolts | $45.00 | $$/EA |
| Steel Sets | $2.00 | $$/KG |
| Vent air line | $40.00 | $$/LM |
| Utility lines | $30.00 | $$/LM |
| ST&S | 5.00% | |

| | Type I | Type II | Type III | Type IV | Total |
|---|---|---|---|---|---|
| Explosives | $302,550 | $435,600 | $316,950 | $46,650 | $1,101,750 |
| Detonators | $176,488 | $326,700 | $396,188 | $62,200 | $961,575 |
| Bits & Steel | $716,750 | $1,146,750 | $773,500 | $119,750 | $2,756,750 |
| Spiling | $0 | $0 | $0 | $15,000 | $15,000 |
| Shotcrete Cement | $0 | $134,352 | $164,916 | $27,504 | $326,772 |
| Shotcrete Aggregate | $0 | $24,631 | $30,235 | $5,042 | $59,908 |
| Steel Fibers | $0 | $120,917 | $148,424 | $24,754 | $294,095 |
| Wiremesh | $0 | $89,568 | $109,944 | $18,336 | $217,848 |
| Timber | $0 | $0 | $14,438 | $3,623 | $18,060 |
| Rockbolts | $37,350 | $371,250 | $519,750 | $18,450 | $946,800 |
| Steel Sets | $0 | $0 | $0 | $715,800 | $715,800 |
| Vent air line | $82,500 | $132,000 | $99,000 | $16,500 | $330,000 |
| Utility lines | $61,875 | $99,000 | $74,250 | $12,375 | $247,500 |
| ST&S | $68,876 | $144,038 | $132,380 | $54,299 | $399,593 |
| Total Materials for tunnel work | $1,446,388 | $3,024,806 | $2,779,974 | $1,140,283 | $8,391,451 |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Transfer Tunnel**
*Length:* **8,250 meters**
*Diameter:* **6.50 meters (D-shaped Section)**
*Method:* Basic Drill/Blast

| TUNNEL CONCRETE LINING | | | | | Total |
|---|---|---|---|---|---|
| Length | 2063 | 3300 | 2475 | 413 | 8,250 |
| Quantity | 23,033 | 36,853 | 30,932 | 5,155 | 95,974 |
| Use Prefabricated Steel Forms on Dolly Each set 20 M Long and a 24 hour concrete placing will be used with 8 hours for placing forms and reinforcing (if any), 8 hours of concrete placing and 8 hours to cure, clean and move | | | | | |
| Average placing Rate (cu. M / day) | 150 | 150 | 150 | 150 | |
| No. of Steel Sets | 0 | 0 | 0 | 0 | 0 |
| Number of 10 hour work days | 154 | 246 | 207 | 35 | 642 |

Concrete Lining Crew

| | | Local | Local Total | |
|---|---|---|---|---|
| 1 | Walker | $12.50 | $12.50 | 0 |
| 1 | Foreman | $10.00 | $10.00 | |
| 1 | Form Foreman | $10.00 | $10.00 | |
| 8 | Miners | $6.70 | $53.60 | |
| 2 | Carpenters | $6.70 | $13.40 | |
| 1 | Compressor Operator | $6.30 | $6.30 | |
| 2 | Mucker Operator | $8.00 | $16.00 | |
| 2 | Flat Bed Operators | $6.30 | $12.60 | |
| 1 | HVAC Electrician/Mechanics | $6.70 | $6.70 | |
| 1 | Pump Operators | $6.30 | $6.30 | |
| 1 | Mechanics | $6.70 | $6.70 | |
| 1 | Electricians | $6.70 | $6.70 | |
| 22 | Total Crew, $$/Hr | | $160.80 | |
| | | | $1,032,336 | |

| | Plant & Equipment | Unit Oper | Unit Standby | Average |
|---|---|---|---|---|
| 1 | Johnson Type Low Profile + Ice Plant | $52.00 | $13.00 | $42.25 |
| 1 | Batching Plant | $52.89 | $13.22 | $42.97 |
| 1 | Cement Silos | $9.65 | $2.41 | $7.84 |
| 1 | Standby Generators | $5.00 | $1.25 | $4.06 |
| 2 | Concrete Haulers | $17.62 | $4.41 | $28.63 |
| 2 | Lot Pumping Equipment | $17.21 | $4.30 | $27.97 |
| 1 | Lot fans | $5.25 | $1.31 | $4.27 |
| | | | | $157.99 |
| | Utility Factor | 75.00% | | |
| | Actual Cost/Hr | $157.99 | | |
| | Equipment Cost/Day | $1,579.91 | | |

| MATERIALS | | | | | |
|---|---|---|---|---|---|
| Cement | 34,551 Tons @ | | $122.00 | 4,215,177 | |
| Aggregate & Sand | 211,143 Tons @ | | $4.00 | 844,571 | |
| Admixtures | 47,987 Gals @ | | $15.00 | 719,805 | |
| Timber for Bulkheads | 12,428 SqM @ | | $25.00 | 310,694 | 1,030,498 |
| | | | | 6,090,246 | |
| Concrete Costs by Sections | Type I | Type II | Type III | Type IV | |
| Labor Cost - Concrete | 247,600 | 395,600 | 332,900 | 56,300 | 1,032,400 |
| Equipment Cost | 243,306 | 388,657 | 327,041 | 55,297 | 1,014,300 |
| Material Cost | 1,461,631 | 2,338,610 | 1,962,862 | 327,144 | 6,090,246 |
| | | | | | 8,136,900 |
| TOTAL CONCRETE COST | $1,952,500 | $3,122,900 | $2,622,800 | $438,700 | $8,136,946 |

# COMPARATIVE COST ESTIMATES

## INDIO - GATUN TRANSFER TUNNEL

**Panama**

**Feasibility Level Cost for Tunneling**

*Feature:* **Transfer Tunnel**
*Length:* **8,250 meters**
*Diameter:* **7.00 meters (D-shaped Section)**
*Method:* Basic Drill/Blast

**SUMMARY**

The following summary is prepared from the detailed analysis that follows

| | Total |
|---|---|
| Total Tunnel Excavation Price | **$49,872,800** |
| Total Tunnel Concrete Lining Price | **$11,333,200** |
| Total at January 2003 Level | **$61,206,000** |

| Method of Excavation | Analysis<br>Drill and Blast Method | | | | Totals |
|---|---|---|---|---|---|
| Type of Support Requirements | Type I | Type II | Type III | Type IV | |
| Finished Diameter (m) | 7.00 | 7.00 | 7.00 | 7.00 | |
| Finished Area (sq.m.) | 43.74 | 43.74 | 43.74 | 43.74 | |
| Excavated tunnel diameter | 7.70 | 7.70 | 7.70 | 7.70 | |
| Tunnel Length (m) | 2,063 | 3,300 | 2,475 | 413 | 8,250 |
| Excavation Volume (Pay cu.m/m) | 52.93 | 52.93 | 52.93 | 52.93 | |
| Excavation Volume (Pay cu.m) | 109,160 | 174,660 | 131,000 | 21,830 | 436,650 |
| Concrete Lining Thickness (m) | 0.35 | 0.35 | 0.35 | 0.35 | |
| Overbreak assumed (m) | 0.10 | 0.10 | 0.15 | 0.15 | |
| Shotcrete Lining Thickness (m) | 0.00 | 0.05 | 0.05 | 0.05 | |
| Shotcrete Area (sq.m) | 0 | 39,910 | 48,990 | 8,170 | 97,070 |
| Excavated Volume (Actual cu.m/m) | 55.7 | 55.7 | 57.1 | 57.1 | |
| Excavated Volume (Actual cu.m) | 114,910 | 183,850 | 141,400 | 23,570 | 463,730 |
| Loose Volume Mucking (cu.m) | 183,856 | 294,160 | 226,240 | 37,712 | 741,968 |
| Concrete Lining Volume (cu.m) | 24,690 | 39,505 | 33,141 | 5,524 | 102,860 |
| 2-meter long (#8) Rockbolts | 830 | 8,250 | 11,550 | 410 | 21,040 |
| Steel Sets (kg) | | | | 381,800 | 381,800 |
| Excavation Production (days) | 688 | 1,179 | 917 | 218 | 3,002 |
| Labor Cost - Excavation | 2,724,500 | 4,668,900 | 3,631,400 | 863,300 | 11,888,100 |
| Equipment Cost | 3,962,900 | 6,791,000 | 5,281,900 | 1,255,700 | 17,291,500 |
| Material Cost | 1,614,400 | 3,319,600 | 3,021,800 | 1,228,300 | 9,184,100 |
| **Tunnel Excavation Cost** | **8,301,800** | **14,779,500** | **11,935,100** | **3,347,300** | **38,363,700** |
| **Concrete Lining Cost, Total** | **2,092,900** | **3,348,600** | **2,807,800** | **468,500** | **8,717,800** |
| Contractors OH&P | 30% | 30% | 30% | 30% | |
| **Tunnel Excavation Price** | **$10,792,300** | **$19,213,400** | **$15,515,600** | **$4,351,500** | **$49,872,800** |
| **Tunnel Lining Price** | **$2,720,800** | **$4,353,200** | **$3,650,100** | **$609,100** | **$11,333,200** |
| **Tunnel Price** | **$13,513,100** | **$23,566,600** | **$19,165,700** | **$4,960,600** | **$61,206,000** |

### ***Excavation Unit Price***

| | Excavation | Shotcrete Lining | Rockbolts | Steel Sets | Miscellaneous |
|---|---|---|---|---|---|
| **Labor Cost** | **$8,307,055** | **$594,855** | **$465,826** | **$345,911** | **$2,174,454** |
| **Equipment Cost** | **$7,225,693** | **$731,316** | **$43,742** | **$83,232** | **$9,207,516** |
| **Material Cost** | **$5,105,795** | **$960,993** | **$946,800** | **$763,600** | **$1,406,912** |
| **Subtotal** | **$20,638,544** | **$2,287,163** | **$1,456,368** | **$1,192,743** | **$12,788,882** |
| **Miscellaneous** | **$10,320,461** | **$1,143,713** | **$728,268** | **$596,440** | |
| | **$30,959,004** | **$3,430,877** | **$2,184,636** | **$1,789,184** | **$38,363,700** |
| **Contractors OH&P** | **$9,287,701** | **$1,029,263** | **$655,391** | **$536,755** | **$11,509,110** |
| | **$40,246,705** | **$4,460,140** | **$2,840,026** | **$2,325,939** | **$49,872,810** |
| **Quantities** | **436,650** | **97,070** | **42,080** | **381,800** | |
| **Unit Price** | **$92.17** | **$45.95** | **$67.49** | **$6.09** | |
| | **$/cu.m** | **$/sq.m** | **$/l.m** | **$/kg** | |

### ***Concrete Lining Unit Price***

| | Type I | Type II | Type III | Type IV | Avg. Price |
|---|---|---|---|---|---|
| **Unit Price ($/cu.m) Concrete Lining** | **$110.20** | **$110.19** | **$110.14** | **$110.27** | **$110.18** |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **7.00 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

## GEOLOGY

Rock type as interpreted from site visits and geol mapping suggests four types of supports for the following lengths

| Tunneling Condition | Segment 1 |
|---|---|
| Roca Buena - Designation Type I | 25% |
| Roca Regular - Designation Type II | 40% |
| Roca Mala - Designation Type III | 30% |
| Roca Muy Mala - Designation Type IV | 5% |
| | 100% |

Type I - Roca Buena best rock conditions, minimal overbreak, generally self-supporting or requiring minimal support with shotcrete and spot bolting; full face excavation with normal advance

Type II - Roca Regular, good to fair rock conditions, moderate overbreak with rockbolt support and shotcrete; normal advance possible with proper bolting and shotcreting

Type III - Roca Mala, poor rock conditions, weathered or weak rock, loosely jointed, possible water inflows; Full face excavation with slower short advance and large overbreaks. Requires prompt support with pattem rockbolting and shotcrete

Type IV - Roca Muy Mala/Pesima, very poor rock conditions, full of fault and shear zones, mod to highly weathered, potential squeezing conditions in gouge; water inflows; possibly top heading and benching; prompt support within the open face with steel ribs and lagging, backpacking and shotcete with fabric; grouting may be necessary to control water; spiling possible in worst conditions.

Type V - Not mentioned above but worse than type IV and with high waterflows. Specific areas are not identified for above tunnels at this time

| Condition/Rock Type | | Q Values | Rock Mass Rating (RMR) |
|---|---|---|---|
| I | | > 7 | >60 |
| II | | 7 > Q >1 | 60>RMR>40 |
| III | | 1 > Q >.4 | 40>RMR>35 |
| IV | | .4> Q | 35 > RMR |
| Blastability | | Good | Medium |
| | SPR = | 0.38 | 0.47 |
| | | Basalt/Sandstones | |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **7.00 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

**SUPPORT**

| | | |
|---|---|---|
| Shotcrete Thickness | 5 cm Layers | Fiber or wire reinf |
| Rockbolts | 25 mm X 2 meter long w/epoxy | |
| Steel Ribs | 6" X 12" I section @ .5 to 1.5 spacing | |
| Lagging | 5 cm corrugated | |
| Dry Pack | 0.5 in. from Tunnel Muck | |

All tunnel analysis is based on geological interpretation presented on the Geology Studies

| | | | |
|---|---|---|---|
| Length of Segment | | 8,250 Meters | |
| Finished Diameter | | 7.00 Meters | |
| Concrete Lining Thickness | | 0.35 Meters | |
| Length of tunnel for each type | | | |
| | Type I | 2,063 Meters | |
| | Type II | 3,300 Meters | |
| | Type III | 2,475 Meters | |
| | Type IV | 413 Meters | |
| Shotcrete with wire(or fibrous), 5 cm layers | | 0 SqM, Type I | None |
| | | 39,910 SqM, Type II | Crown only |
| | | 48,990 SqM, Type III | Crown and Ribs |
| | | 8,170 SqM, Type IV | Crown and Ribs |
| | Total Shotcrete | 97,070 SqM | |
| Rockbolts, 25 mm X 2 M Long | | 830 EA, Type I | 3 Bolts/@ 7.5 M Spacing |
| | | 8,250 EA, Type II | 5 Bolts/@ 2 M Spacing |
| | | 11,550 EA, Type III | 7 Bolts/@ 1.5 M Spacing |
| | | 410 EA, Type IV | 5 Bolts/@ 5 M Spacing |
| | Total Rockbolts | 21,040 EA | |
| Steel ribs, 6" X 12" X 45 KG/M | | 381,800 KG, Type IV | |

# COMPARATIVE COST ESTIMATES

**INDIO - GATUN TRANSFER TUNNEL**
**Panama**
**Feasibility Level Cost for Tunneling**

*Feature:* **Transfer Tunnel**
*Length:* **8,250 meters**
*Diameter:* **7.00 meters (D-shaped Section)**
*Method:* Basic Drill/Blast

**TUNNEL EXCAVATION**

| | **Tunnel Crew** | **$$/HR** | **$$/HR** |
|---|---|---|---|
| 1 | Walker | $10.00 | $12.50 |
| 1 | Foreman | $10.00 | $10.00 |
| 1 | Jumbo Drill Foreman | $10.00 | $10.00 |
| 8 | Miners | $6.70 | $53.60 |
| 1 | Blaster | $6.70 | $6.70 |
| 1 | Compressor Operator | $6.30 | $6.30 |
| 4 | Mucker Operator | $8.00 | $32.00 |
| 2 | Truck Drivers | $6.30 | $12.60 |
| 1 | Dozer Operator | $8.00 | $8.00 |
| 1 | HVAC Electrician/Mechanics | $6.70 | $3.35 |
| 1 | Oilers | $6.30 | $3.15 |
| 2 | Rockbolters | $6.70 | $13.40 |
| 2 | Shotcreters | $6.70 | $13.40 |
| 1 | Pump Operators | $6.30 | $6.30 |
| 1 | Mechanics | $6.70 | $3.35 |
| 1 | Electricians | $6.70 | $3.35 |
| 27 | Total Crew, $$/Hr | | $198.00 |

| **ROUNDS** | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Meters/Round | 3.0 | 2.5 | 2.0 | 1.0 | |
| Vol/Round | 167.1 | 139.3 | 114.3 | 57.1 | |
| Holes/SqM | 2.5 | 2.5 | 2.2 | 2.0 | |
| No. of Holes | 157 | 157 | 141 | 131 | |
| Length of Holes (total, cum.) | 471 | 393 | 282 | 131 | |
| Drill Holes, Meters/Hr | 10 | 10 | 10 | 10 | |
| No. of drills | 6 | 6 | 6 | 6 | |
| Total Drilling/Hr | 60 | 60 | 60 | 60 | |
| Drilling Time | 7.9 | 6.6 | 4.7 | 2.2 | |
| Move in | 0.3 | 0.3 | 0.3 | 0.3 | |
| Total drilling Time | 8.2 | 6.9 | 5.0 | 2.5 | |
| **Blasting** | | | | | |
| Kg/CuM | 2.0 | 1.8 | 1.7 | 1.5 | |
| Kg/Round | 334 | 251 | 194 | 86 | |
| Load Time @ 80 Kg/Hr | 4.2 | 3.2 | 2.5 | 1.1 | |
| Add for blasting & Ventilating | 1.0 | 1.0 | 1.0 | 1.0 | |
| Total Blast time | 5.2 | 4.2 | 3.5 | 2.1 | |
| **Excavation Supports** | | | | | |
| Scaling | 0.3 | 0.3 | 0.3 | 0.5 | |
| Place supports | 0.2 | 1.0 | 1.5 | 3.0 | |
| Total Support Time | 0.5 | 1.3 | 1.8 | 3.5 | |
| **Muck** | | | | | |
| Move in | 0.5 | 0.5 | 0.5 | 0.5 | |
| Mucking at 50 CM/hr | 5.4 | 4.5 | 3.7 | 1.9 | |
| Total Muck Cycle | 5.9 | 5.0 | 4.2 | 2.4 | |
| **Total Cycle Hours** | 19.8 | 17.4 | 14.5 | 10.5 | |
| No of Rds with of 2 X 10 Hr Shifts | 1.0 | 1.1 | 1.4 | 1.9 | |
| Advance/Day | 3.0 | 2.8 | 2.7 | 1.9 | |
| Total number of Days for one Crew | 688 | 1,179 | 917 | 218 | 3,002 |
| Total explosives required | 229,900 | 331,000 | 240,400 | 35,400 | |
| Detonators | 80,465 | 148,950 | 180,300 | 28,320 | |
| Drill Bits & Steel | 323,900 | 518,100 | 349,000 | 54,100 | |

# COMPARATIVE COST ESTIMATES

## INDIO - GATUN TRANSFER TUNNEL

**Panama**

**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **7.00 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

| Plant & Equipment | Unit Operating Cos | Standby Cost | |
|---|---|---|---|
| 1 6 Drill Jumbo | $67.40 | $16.85 | $52.24 |
| 4 4 CuM Mucker | $31.25 | $7.81 | $96.88 |
| 2 Trucks, 25 CuM | $24.46 | $6.12 | $37.91 |
| 1 Shotcrete Pump | $23.56 | $5.89 | $18.26 |
| 1 Dozer | $44.50 | $11.13 | $34.49 |
| 2 Compressors, Electrical | $14.26 | $3.57 | $22.10 |
| 1 Dewatering Equipment | $7.53 | $1.88 | $5.84 |
| 2 100 HP Fans | $6.04 | $1.51 | $9.36 |
| 1 Drifters | $0.75 | $0.19 | $0.58 |
| 1 Flatbeds | $13.35 | $3.34 | $10.35 |
| Equipment Cost per hour | $233.10 | $58.28 | $288.00 |
| Utilization Factor | 70% | | |
| Actual Cost/Hr | $288.00 | | |

| | Type I | Type II | Type III | Type IV |
|---|---|---|---|---|
| Equipment & Plant | $3,962,849 | $6,790,987 | $5,281,879 | $1,255,670 |

| Materials | | |
|---|---|---|
| Explosives | $1.50 | $$/KG |
| Detonators | $2.50 | $$/EA |
| Bits & Steel | $2.50 | $$/LM |
| Spiling | $150.00 | $$/EA |
| Shotcrete Cement | $120.00 | $$/TON |
| Shotcrete Aggregate | $4.00 | $$/TON |
| Steel Fibers | $1.20 | $$/KG |
| Wiremesh | $1.00 | $$/KG |
| Timber | $0.35 | $$/BF |
| Rockbolts | $45.00 | $$/EA |
| Steel Sets | $2.00 | $$/KG |
| Vent air line | $40.00 | $$/LM |
| Utility lines | $30.00 | $$/LM |
| ST&S | 5.00% | |

| | Type I | Type II | Type III | Type IV | Total |
|---|---|---|---|---|---|
| Explosives | $344,850 | $496,500 | $360,600 | $53,100 | $1,255,050 |
| Detonators | $201,163 | $372,375 | $450,750 | $70,800 | $1,095,088 |
| Bits & Steel | $809,750 | $1,295,250 | $872,500 | $135,250 | $3,112,750 |
| Spiling | $0 | $0 | $0 | $15,000 | $15,000 |
| Shotcrete Cement | $0 | $143,676 | $176,364 | $29,412 | $349,452 |
| Shotcrete Aggregate | $0 | $26,341 | $32,333 | $5,392 | $64,066 |
| Steel Fibers | $0 | $129,308 | $158,728 | $26,471 | $314,507 |
| Wiremesh | $0 | $95,784 | $117,576 | $19,608 | $232,968 |
| Timber | $0 | $0 | $16,048 | $3,815 | $19,863 |
| Rockbolts | $37,350 | $371,250 | $519,750 | $18,450 | $946,800 |
| Steel Sets | $0 | $0 | $0 | $763,600 | $763,600 |
| Vent air line | $82,500 | $132,000 | $99,000 | $16,500 | $330,000 |
| Utility lines | $61,875 | $99,000 | $74,250 | $12,375 | $247,500 |
| ST&S | $76,874 | $158,074 | $143,895 | $58,489 | $437,332 |
| Total Materials for tunnel work | $1,614,362 | $3,319,558 | $3,021,793 | $1,228,262 | $9,183,975 |

# COMPARATIVE COST ESTIMATES

## INDIO - GATUN TRANSFER TUNNEL

**Panama**

**Feasibility Level Cost for Tunneling**

| | |
|---|---|
| *Feature:* | **Transfer Tunnel** |
| *Length:* | **8,250 meters** |
| *Diameter:* | **7.00 meters (D-shaped Section)** |
| *Method:* | Basic Drill/Blast |

| TUNNEL CONCRETE LINING | | | | | Total |
|---|---|---|---|---|---|
| Length | 2063 | 3300 | 2475 | 413 | 8,250 |
| Quantity | 24,690 | 39,505 | 33,141 | 5,524 | 102,860 |
| Use Prefabricated Steel Forms on Dolly Each set 20 M Long and a 24 hour concrete placing will be used with 8 hours for placing forms and reinforcing (if any), 8 hours of concrete placing and 8 hours to cure, clean and move | | | | | |
| Average placing Rate (cu. M / day) | 150 | 150 | 150 | 150 | |
| No. of Steel Sets | 0 | 0 | 0 | 0 | 0 |
| Number of 10 hour work days | 165 | 264 | 221 | 37 | 687 |

Concrete Lining Crew

| | Local | Local Total | | |
|---|---|---|---|---|
| 1 Walker | $10.00 | $12.50 | | 0 |
| 1 Foreman | $10.00 | $10.00 | | |
| 1 Form Foreman | $10.00 | $10.00 | | |
| 8 Miners | $6.70 | $53.60 | | |
| 2 Carpenters | $6.70 | $13.40 | | |
| 1 Compressor Operator | $6.30 | $6.30 | | |
| 2 Mucker Operator | $8.00 | $16.00 | | |
| 2 Flat Bed Operators | $6.30 | $12.60 | | |
| 1 HVAC Electrician/Mechanics | $6.70 | $6.70 | | |
| 1 Pump Operators | $6.30 | $6.30 | | |
| 1 Mechanics | $6.70 | $6.70 | | |
| 1 Electricians | $6.70 | $6.70 | | |
| 22 Total Crew, $$/Hr | | $160.80 | | |
| | | $1,104,696 | | |

| Plant & Equipment | Unit Oper | Unit Standby | Average |
|---|---|---|---|
| 1 Johnson Type Low Profile + Ice Plant | $52.00 | $13.00 | $42.25 |
| 1 Batching Plant | $52.89 | $13.22 | $42.97 |
| 1 Cement Silos | $9.65 | $2.41 | $7.84 |
| 1 Standby Generators | $5.00 | $1.25 | $4.06 |
| 2 Concrete Haulers | $17.62 | $4.41 | $28.63 |
| 2 Lot Pumping Equipment | $17.21 | $4.30 | $27.97 |
| 1 Lot fans | $5.25 | $1.31 | $4.27 |
| | | | $157.99 |
| Utility Factor | 75.00% | | |
| Actual Cost/Hr | $157.99 | | |
| Equipment Cost/Day | $1,579.91 | | |

| MATERIALS | | | | |
|---|---|---|---|---|
| Cement | 37,030 Tons @ | $122.00 | 4,517,612 | |
| Aggregate & Sand | 226,292 Tons @ | $4.00 | 905,168 | |
| Admixtures | 51,430 Gals @ | $15.00 | 771,450 | |
| Timber for Bulkheads | 13,335 SqM @ | $25.00 | 333,372 | 1,104,822 |
| | | | 6,527,603 | |

| Concrete Costs by Sections | Type I | Type II | Type III | Type IV | |
|---|---|---|---|---|---|
| Labor Cost - Concrete | 265,300 | 424,500 | 355,400 | 59,500 | 1,104,700 |
| Equipment Cost | 260,685 | 417,095 | 349,159 | 58,457 | 1,085,396 |
| Material Cost | 1,566,877 | 2,507,003 | 2,103,191 | 350,532 | 6,527,603 |
| | | | | | 8,717,700 |
| TOTAL CONCRETE COST | $2,092,900 | $3,348,600 | $2,807,700 | $468,500 | $8,717,698 |

## COMPARATIVE COST ESTIMATES
## 45-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 1,800 | $990 |
| Overburden Excavation | cu.m | $3.20 | 4,750 | $15,200 |
| Rock Excavation | cu.m | $8.80 | 2,500 | $22,000 |
| Portal Excavation | cu.m | $14.80 | 1,050 | $15,540 |
| Structural Concrete | cu.m | $145.00 | 6,200 | $899,000 |
| Formwork | sq.m | $46.50 | 13,000 | $604,500 |
| Steel Reinforcement | Ton | $1,320 | 280.0 | $369,600 |
| Steel Liner | Ton | $3,200 | 12.6 | $40,320 |
| Miscellaneous Metal Works | % | 5% | | $98,358 |
| ***Subtotal*** | | | | $2,065,508 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.80 x 2.50) and Hoist | Each | $255,000 | 3 | $765,000 |
| Stoplogs | Each | $85,000 | 3 | $255,000 |
| Trash Screen Bays | Each | $235,000 | 3 | $705,000 |
| Trash Rake | Each | $100,000 | 2 | $200,000 |
| Emergency Diesel Generator (50 kW) | Each | $62,500 | 1 | $62,500 |
| Power and Control Equipment | LS | $50,000 | 1 | $50,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $37,500 | 1 | $37,500 |
| **Subtotal** | | | | $2,075,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 1,670 | $24,716 |
| Shaft Excavation | cu.m | $310.00 | 920 | $285,200 |
| Tunnel Excavation | cu.m | $125.00 | 7,950 | $993,750 |
| Shotcrete | sq.m | $46.00 | 3,230 | $148,580 |
| Rockbolts | L.m | $67.00 | 1,230 | $82,410 |
| Steel Ribs | kg | $6.00 | 49,500 | $297,000 |
| Tunnel Concrete Lining | sq.m | $165.00 | 2,850 | $470,250 |
| Shaft Concrete Lining | cu.m | $180.00 | 260 | $46,800 |
| Formwork (shaft) | sq.m | $46.50 | 630 | $29,295 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 13.0 | $17,160 |
| Structural Concrete (penstock) | cu.m | $145.00 | 550 | $79,750 |
| Formwork (penstock) | sq.m | $46.50 | 945 | $43,943 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 24.5 | $32,340 |
| Steel Penstock | Ton | $3,200 | 575.0 | $1,840,000 |
| Miscellaneous | % | 5% | | $219,560 |
| ***Subtotal*** | | | | $4,610,753 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 8,000 | $25,600 |
| Rock Excavation | cu.m | $8.80 | 2,650 | $23,320 |
| **Subtotal** | | | | $48,920 |

# COMPARATIVE COST ESTIMATES
## 45-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 29,800 | $95,360 |
| Rock Excavation | cu.m | $8.80 | 4,450 | $39,160 |
| Mass Concrete | cu.m | $116.00 | 5,540 | $642,640 |
| Structural Concrete | cu.m | $145.00 | 2,520 | $365,400 |
| Formwork | sq.m | $46.50 | 15,470 | $719,355 |
| Steel Reinforcement | Ton | $1,320 | 268.0 | $353,760 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 890 | $275,900 |
| Miscellaneous | % | 5% | | $124,579 |
| ***Subtotal*** | | | | $2,616,154 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.70 m dia) | Each | $350,000 | 3 | $1,050,000 |
| Turbine/Generator Unit (20 MW) | Each | $3,160,000 | 3 | $9,480,000 |
| 20-MW Unit Auxiliaries | Each | $316,000 | 3 | $948,000 |
| Draft Tube Gates | Each | $65,000 | 6 | $390,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (1.50 m dia) | Each | $218,750 | 1 | $218,750 |
| Pressure Reducing Control Valves (1.50 m dia) | Each | $437,500 | 1 | $437,500 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Semi-Gantry Crane | LS | $430,000 | 1 | $430,000 |
| *Miscellaneous Electrical* | | | | |
| Main Power Transformer -20 MVA | Each | $350,000 | 3 | $1,050,000 |
| Switchgear - 13.8 kV | LS | $110,000 | 1 | $110,000 |
| Station Service Transformer | Each | $40,000 | 1 | $40,000 |
| Stand-by Diesel Generator | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $325,000 | 1 | $325,000 |
| Control and Communication Equip | LS | $360,000 | 1 | $360,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $850,000 | 1 | $850,000 |
| **Subtotal** | | | | $16,126,750 |
| ***Transmission System*** | | | | |
| *Switchyard* | | | | |
| 230-kV Equipment Bays | Each | $250,000 | 3 | $750,000 |
| Service Power Transformer - 5MV | Each | $112,500 | 1 | $112,500 |
| Protection, Control and Comm. Equip | LS | $512,500 | 1 | $512,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $825,000 | 1 | $825,000 |
| Steel structures | LS | $600,000 | 1 | $600,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| Civil Work | LS | $350,000 | 1 | $350,000 |
| *La Chorrera Substation* | | | | |
| 230-kV Equipment Bays | LS | $250,000 | 1 | $250,000 |
| Control Panels and other Equipment | LS | $125,000 | 1 | $125,000 |
| Cabling -MV & LV Power Control, Comm. | LS | $100,000 | 1 | $100,000 |
| *230-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $62,500 | 109 | $6,812,500 |
| Conductors and Shield Wire | km | $62,500 | 109 | $6,812,500 |
| Insulators and Accessories | km | $31,250 | 109 | $3,406,250 |
| Grounding and Miscellaneous | % | 4.00% | | $681,250 |
| **Subtotal** | | | | $21,381,250 |
| | | | **TOTAL** | $40,124,154 |
| | | | | $48,924,334 |

# COMPARATIVE COST ESTIMATES
## 60-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 2,000 | $1,100 |
| Overburden Excavation | cu.m | $3.20 | 5,400 | $17,280 |
| Rock Excavation | cu.m | $8.80 | 2,800 | $24,640 |
| Portal Excavation | cu.m | $14.80 | 1,400 | $20,720 |
| Structural Concrete | cu.m | $145.00 | 6,550 | $949,750 |
| Formwork | sq.m | $46.50 | 13,750 | $639,375 |
| Steel Reinforcement | Ton | $1,320 | 295.0 | $389,400 |
| Steel Liner | Ton | $3,200 | 14.4 | $46,080 |
| Miscellaneous Metal Works | % | 5% | | $104,417 |
| ***Subtotal*** | | | | $2,192,762 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.80 x 2.50) and Hoist | Each | $375,000 | 3 | $1,125,000 |
| Stoplogs | Each | $125,000 | 3 | $375,000 |
| Trash Screen Bays | Each | $312,500 | 3 | $937,500 |
| Trash Rake | Each | $106,250 | 2 | $212,500 |
| Emergency Diesel Generator (50 kW) | Each | $62,500 | 1 | $62,500 |
| Power and Control Equipment | LS | $50,000 | 1 | $50,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $37,500 | 1 | $37,500 |
| **Subtotal** | | | | $2,800,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 1,940 | $28,712 |
| Shaft Excavation | cu.m | $310.00 | 1,150 | $356,500 |
| Tunnel Excavation | cu.m | $115.00 | 9,070 | $1,043,050 |
| Shotcrete | sq.m | $46.00 | 3,740 | $172,040 |
| Rockbolts | L.m | $67.00 | 1,420 | $95,140 |
| Steel Ribs | kg | $6.00 | 51,300 | $307,800 |
| Tunnel Concrete Lining | sq.m | $165.00 | 3,300 | $544,500 |
| Shaft Concrete Lining | cu.m | $180.00 | 350 | $63,000 |
| Formwork (shaft) | sq.m | $46.50 | 730 | $33,945 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 17.5 | $23,100 |
| Structural Concrete (penstock) | cu.m | $145.00 | 730 | $105,850 |
| Formwork (penstock) | sq.m | $46.50 | 1,095 | $50,918 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 32.9 | $43,428 |
| Steel Penstock | Ton | $3,200 | 664.0 | $2,124,800 |
| Miscellaneous | % | 5% | | $249,639 |
| ***Subtotal*** | | | | $5,242,422 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 10,500 | $33,600 |
| Rock Excavation | cu.m | $8.80 | 3,500 | $30,800 |
| **Subtotal** | | | | $64,400 |

# COMPARATIVE COST ESTIMATES
## 60-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 35,000 | $112,000 |
| Rock Excavation | cu.m | $8.80 | 5,200 | $45,760 |
| Mass Concrete | cu.m | $116.00 | 6,520 | $756,320 |
| Structural Concrete | cu.m | $145.00 | 2,950 | $427,750 |
| Formwork | sq.m | $46.50 | 18,200 | $846,300 |
| Steel Reinforcement | Ton | $1,320 | 315.0 | $415,800 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 1,040 | $322,400 |
| Miscellaneous | % | 5% | | $146,317 |
| ***Subtotal*** | | | | $3,072,647 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.30 m dia) | Each | $437,500 | 3 | $1,312,500 |
| Turbine/Generator Unit (20 MW) | Each | $3,750,000 | 3 | $11,250,000 |
| 20-MW Unit Auxiliaries | Each | $375,000 | 3 | $1,125,000 |
| Draft Tube Gates | Each | $80,000 | 6 | $480,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (1.50 m dia) | Each | $218,500 | 1 | $218,500 |
| Pressure Reducing Control Valves (1.50 m dia) | Each | $437,500 | 1 | $437,500 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $112,500 | 1 | $112,500 |
| Semi-Gantry Crane | LS | $470,000 | 1 | $470,000 |
| *Miscellaneous Electrical* | | | | |
| Main Power Transformer -25 MVA | Each | $437,500 | 3 | $1,312,500 |
| Switchgear - 13.8 kV | LS | $125,000 | 1 | $125,000 |
| Station Service Transformer | Each | $50,000 | 1 | $50,000 |
| Stand-by Diesel Generator | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $450,000 | 1 | $450,000 |
| Control and Communication Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $1,000,000 | 1 | $1,000,000 |
| **Subtotal** | | | | $18,968,500 |
| ***Transmission System*** | | | | |
| *Switchyard* | | | | |
| 230-kV Equipment Bays | Each | $312,500 | 3 | $937,500 |
| Service Power Transformer - 5MV | Each | $112,500 | 1 | $112,500 |
| Protection, Control and Comm. Equip | LS | $562,500 | 1 | $562,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $875,000 | 1 | $875,000 |
| Steel structures | LS | $600,000 | 1 | $600,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| Civil Work | LS | $350,000 | 1 | $350,000 |
| *La Chorrera Substation* | | | | |
| 230-kV Equipment Bays | LS | $312,500 | 1 | $312,500 |
| Control Panels and other Equipment | LS | $125,000 | 1 | $125,000 |
| Cabling -MV & LV Power Control, Comm. | LS | $100,000 | 1 | $100,000 |
| *230-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $62,500 | 109 | $6,812,500 |
| Conductors and Shield Wire | km | $62,500 | 109 | $6,812,500 |
| Insulators and Accessories | km | $31,250 | 109 | $3,406,250 |
| Grounding and Miscellaneous | % | 4.00% | | $681,250 |
| **Subtotal** | | | | $21,731,250 |
| | | | **TOTAL** | $43,772,397 |
| | | | | $54,071,980 |

# COMPARATIVE COST ESTIMATES
## 75-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 2,200 | $1,210 |
| Overburden Excavation | cu.m | $3.20 | 6,050 | $19,360 |
| Rock Excavation | cu.m | $8.80 | 3,200 | $28,160 |
| Portal Excavation | cu.m | $14.80 | 1,760 | $26,048 |
| Structural Concrete | cu.m | $145.00 | 7,050 | $1,022,250 |
| Formwork | sq.m | $46.50 | 14,800 | $688,200 |
| Steel Reinforcement | Ton | $1,320 | 320.0 | $422,400 |
| Steel Liner | Ton | $3,200 | 16.0 | $51,200 |
| Miscellaneous Metal Works | % | 5% | | $112,941 |
| ***Subtotal*** | | | | $2,371,769 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.80 x 2.50) and Hoist | Each | $520,000 | 3 | $1,560,000 |
| Stoplogs | Each | $175,000 | 3 | $525,000 |
| Trash Screen Bays | Each | $390,000 | 3 | $1,170,000 |
| Trash Rake | Each | $115,000 | 2 | $230,000 |
| Emergency Diesel Generator (50 kW) | Each | $62,500 | 1 | $62,500 |
| Power and Control Equipment | LS | $60,000 | 1 | $60,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $37,500 | 1 | $37,500 |
| **Subtotal** | | | | $3,645,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 2,180 | $32,264 |
| Shaft Excavation | cu.m | $310.00 | 1,450 | $449,500 |
| Tunnel Excavation | cu.m | $113.00 | 11,400 | $1,288,200 |
| Shotcrete | sq.m | $46.00 | 4,600 | $211,600 |
| Rockbolts | L.m | $67.00 | 1,720 | $115,240 |
| Steel Ribs | kg | $6.00 | 57,800 | $346,800 |
| Tunnel Concrete Lining | sq.m | $165.00 | 3,950 | $651,750 |
| Shaft Concrete Lining | cu.m | $180.00 | 440 | $79,200 |
| Formwork (shaft) | sq.m | $46.50 | 820 | $38,130 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 22.0 | $29,040 |
| Structural Concrete (penstock) | cu.m | $145.00 | 920 | $133,400 |
| Formwork (penstock) | sq.m | $46.50 | 1,230 | $57,195 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 41.3 | $54,516 |
| Steel Penstock | Ton | $3,200 | 908.0 | $2,905,600 |
| Miscellaneous | % | 5% | | $319,622 |
| ***Subtotal*** | | | | $6,712,057 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 13,500 | $43,200 |
| Rock Excavation | cu.m | $8.80 | 4,400 | $38,720 |
| **Subtotal** | | | | $81,920 |

# COMPARATIVE COST ESTIMATES
# 75-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.20 | 38,500 | $123,200 |
| Rock Excavation | cu.m | $8.80 | 5,720 | $50,336 |
| Mass Concrete | cu.m | $116.00 | 7,890 | $915,240 |
| Structural Concrete | cu.m | $145.00 | 3,250 | $471,250 |
| Formwork | sq.m | $46.50 | 21,400 | $995,100 |
| Steel Reinforcement | Ton | $1,320 | 371.0 | $489,720 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 1,150 | $356,500 |
| Miscellaneous | % | 5% | | $170,067 |
| ***Subtotal*** | | | | $3,571,413 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.70 m dia) | Each | $520,000 | 3 | $1,560,000 |
| Turbine/Generator Unit (25 MW) | Each | $4,600,000 | 3 | $13,800,000 |
| 25-MW Unit Auxiliaries | Each | $460,000 | 3 | $1,380,000 |
| Draft Tube Gates | Each | $105,000 | 6 | $630,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (1.50 m dia) | Each | $218,750 | 1 | $218,750 |
| Pressure Reducing Control Valves (1.50 m dia) | Each | $437,500 | 1 | $437,500 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Semi-Gantry Crane | LS | $520,000 | 1 | $520,000 |
| *Miscellaneous Electrical* | | | | |
| Main Power Transformer -30 MVA | Each | $525,000 | 3 | $1,575,000 |
| Switchgear - 13.8 kV | LS | $150,000 | 1 | $150,000 |
| Station Service Transformer | Each | $60,000 | 1 | $60,000 |
| Stand-by Diesel Generator | Each | $275,000 | 1 | $275,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $545,000 | 1 | $545,000 |
| Control and Communication Equip | LS | $390,000 | 1 | $390,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $1,200,000 | 1 | $1,200,000 |
| **Subtotal** | | | | $22,928,750 |
| ***Transmission System*** | | | | |
| *Switchyard* | | | | |
| 230-kV Equipment Bays | Each | $375,000 | 3 | $1,125,000 |
| Service Power Transformer - 5MV | Each | $112,500 | 1 | $112,500 |
| Protection, Control and Comm. Equip | LS | $612,500 | 1 | $612,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $925,000 | 1 | $925,000 |
| Steel structures | LS | $600,000 | 1 | $600,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| Civil Work | LS | $350,000 | 1 | $350,000 |
| *La Chorrera Substation* | | | | |
| 230-kV Equipment Bays | LS | $375,000 | 1 | $375,000 |
| Control Panels and other Equipment | LS | $125,000 | 1 | $125,000 |
| Cabling -MV & LV Power Control, Comm. | LS | $100,000 | 1 | $100,000 |
| *230-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $62,500 | 109 | $6,812,500 |
| Conductors and Shield Wire | km | $62,500 | 109 | $6,812,500 |
| Insulators and Accessories | km | $31,250 | 109 | $3,406,250 |
| Grounding and Miscellaneous | % | 4.00% | | $681,250 |
| **Subtotal** | | | | $22,081,250 |
| | | | **TOTAL** | $48,581,413 |
| | | | | $61,392,159 |

# ATTACHMENT 5

# ECONOMIC ANALYSIS

# COCLE 50 -71

## ECONOMIC ANALYSIS

# Rio Cocle del Norte Hydropower Component
# Economic Return Summary

| | Construction Cost | O&M Annual Cost | Period from 2032 to 2091 | | | Internal Rate of Return |
|---|---|---|---|---|---|---|
| | | | Avg Annual Energy (GWh) | Avg Firm Capacity (MW) | Annual Revenue | |
| **3 x 20-MW Power Plant at Cocle del Norte** | $77,325,000 | $1,394,700 | 292.5 | 48.8 | $16,089,503 | 22.6% |
| **2 x 15-MW Power Plant at Cocle del Norte** | $32,056,000 | $595,400 | 100.3 | 17.2 | $5,546,233 | 14.6% |
| **2 x 15-MW Power Plant at Rio Indio** | $53,679,000 | $930,500 | 131.5 | 21.6 | $7,212,973 | 18.4% |
| **2 x 15-MW Power Plant at Isla Pablon** | $55,167,000 | $913,800 | 193.6 | 24.3 | $10,167,975 | 17.5% |

**Energy Value** $45 per MWh
**Firm Capacity Value** $60 per kW-yr

## Energy Production Estimates (GWh/yr)

| Year | 3 x 20-MW Power Plant at Cocle del Norte Strategy 1 | 2 x 15-MW Power Plant at Cocle del Norte Strategy 2 | 2 x 15-MW Power Plant at Cocle del Norte Strategy 3 | 2 x 15-MW Power Plant at Rio Indio Strategy 2 | 2 x 15-MW Power Plant at Isla Pablon Strategy 3 |
|---|---|---|---|---|---|
| 2029 | 423.6 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2030 | 421.9 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2031 | 420.2 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2032 | 418.5 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2033 | 416.9 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2034 | 415.2 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2035 | 413.5 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2036 | 411.8 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2037 | 410.1 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2038 | 408.4 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2039 | 406.7 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2040 | 405.0 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2041 | 403.4 | 109.5 | 106.7 | 238.8 | 227.5 |
| 2042 | 401.7 | 109.9 | 106.7 | 233.0 | 227.5 |
| 2043 | 400.0 | 110.3 | 106.7 | 227.3 | 227.5 |
| 2044 | 398.3 | 110.7 | 106.7 | 221.5 | 227.5 |
| 2045 | 392.9 | 111.1 | 106.7 | 215.8 | 227.5 |
| 2046 | 387.4 | 111.5 | 106.7 | 210.0 | 227.5 |
| 2047 | 382.0 | 111.9 | 106.7 | 204.3 | 227.5 |
| 2048 | 376.5 | 112.2 | 106.7 | 198.5 | 227.5 |
| 2049 | 371.1 | 112.6 | 106.7 | 192.8 | 227.5 |
| 2050 | 365.7 | 113.0 | 106.7 | 187.0 | 227.5 |
| 2051 | 360.2 | 113.4 | 106.7 | 181.3 | 227.5 |
| 2052 | 354.8 | 113.8 | 106.7 | 175.5 | 227.5 |
| 2053 | 349.4 | 114.2 | 106.7 | 169.8 | 227.5 |
| 2054 | 343.9 | 114.6 | 106.7 | 164.0 | 227.5 |
| 2055 | 338.5 | 114.6 | 106.7 | 157.6 | 227.5 |
| 2056 | 333.0 | 114.7 | 106.7 | 151.1 | 227.5 |
| 2057 | 327.6 | 114.7 | 106.7 | 144.7 | 227.5 |
| 2058 | 322.2 | 114.7 | 106.7 | 138.3 | 227.5 |
| 2059 | 316.7 | 114.8 | 106.7 | 131.8 | 227.5 |
| 2060 | 311.3 | 114.8 | 106.7 | 125.4 | 227.5 |
| 2061 | 305.8 | 114.8 | 106.7 | 119.0 | 227.5 |
| 2062 | 300.4 | 114.8 | 106.7 | 112.6 | 227.5 |
| 2063 | 291.2 | 114.9 | 105.2 | 106.1 | 224.2 |
| 2064 | 282.0 | 114.9 | 103.8 | 99.7 | 221.0 |
| 2065 | 272.7 | 114.9 | 102.3 | 93.3 | 217.7 |
| 2066 | 263.5 | 115.0 | 100.9 | 86.8 | 214.4 |
| 2067 | 254.3 | 115.0 | 99.4 | 80.4 | 211.2 |
| 2068 | 245.1 | 113.0 | 98.0 | 75.3 | 207.9 |
| 2069 | 235.8 | 110.9 | 96.5 | 70.2 | 204.7 |
| 2070 | 226.6 | 108.9 | 95.1 | 65.2 | 201.4 |
| 2071 | 216.7 | 106.8 | 93.6 | 60.1 | 198.1 |
| 2072 | 206.8 | 104.8 | 92.2 | 55.0 | 194.9 |
| 2073 | 196.9 | 102.7 | 90.7 | 49.9 | 191.6 |
| 2074 | 187.0 | 100.7 | 90.2 | 44.9 | 177.7 |
| 2075 | 177.1 | 98.7 | 89.6 | 39.8 | 163.8 |
| 2076 | 167.2 | 96.6 | 89.1 | 34.7 | 149.9 |
| 2077 | 157.3 | 94.6 | 88.6 | 29.6 | 136.0 |
| 2078 | 147.4 | 92.5 | 88.0 | 24.5 | 122.1 |
| 2079 | 137.5 | 90.5 | 87.5 | 19.5 | 108.2 |
| 2080 | 127.6 | 88.4 | 86.9 | 14.4 | 94.3 |
| 2081 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2082 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2083 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2084 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2085 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2086 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2087 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |
| 2088 | 117.7 | 86.4 | 86.4 | 9.3 | 80.4 |

**Firm Capacity Estimates (MW-yr)**

| Year | 3 x 20-MW Power Plant at Cocle del Norte Strategy 1 | 2 x 15-MW Power Plant at Cocle del Norte Strategy 2 | 2 x 15-MW Power Plant at Cocle del Norte Strategy 3 | 2 x 15-MW Power Plant at Rio Indio Strategy 2 | 2 x 15-MW Power Plant at Isla Pablon Strategy 3 |
|---|---|---|---|---|---|
| 2029 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2030 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2031 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2032 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2033 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2034 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2035 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2036 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2037 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2038 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2039 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2040 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2041 | 60.00 | 16.81 | 18.15 | 30.00 | 30.00 |
| 2042 | 60.00 | 16.84 | 18.15 | 30.00 | 30.00 |
| 2043 | 60.00 | 16.86 | 18.15 | 30.00 | 30.00 |
| 2044 | 60.00 | 16.89 | 18.15 | 30.00 | 30.00 |
| 2045 | 60.00 | 16.91 | 18.15 | 30.00 | 30.00 |
| 2046 | 60.00 | 16.94 | 18.15 | 30.00 | 30.00 |
| 2047 | 60.00 | 16.96 | 18.15 | 30.00 | 30.00 |
| 2048 | 60.00 | 16.99 | 18.15 | 30.00 | 30.00 |
| 2049 | 60.00 | 17.01 | 18.15 | 30.00 | 30.00 |
| 2050 | 60.00 | 17.04 | 18.15 | 30.00 | 30.00 |
| 2051 | 60.00 | 17.06 | 18.15 | 30.00 | 30.00 |
| 2052 | 60.00 | 17.09 | 18.15 | 30.00 | 30.00 |
| 2053 | 60.00 | 17.11 | 18.15 | 30.00 | 30.00 |
| 2054 | 60.00 | 17.14 | 18.15 | 30.00 | 30.00 |
| 2055 | 60.00 | 17.14 | 18.15 | 29.42 | 30.00 |
| 2056 | 60.00 | 17.13 | 18.15 | 28.83 | 30.00 |
| 2057 | 60.00 | 17.13 | 18.15 | 28.25 | 30.00 |
| 2058 | 60.00 | 17.12 | 18.15 | 27.66 | 30.00 |
| 2059 | 60.00 | 17.12 | 18.15 | 27.08 | 30.00 |
| 2060 | 60.00 | 17.12 | 18.15 | 26.50 | 30.00 |
| 2061 | 60.00 | 17.11 | 18.15 | 25.91 | 30.00 |
| 2062 | 60.00 | 17.11 | 18.15 | 25.33 | 30.00 |
| 2063 | 58.94 | 17.11 | 18.02 | 24.75 | 30.00 |
| 2064 | 57.88 | 17.10 | 17.90 | 24.16 | 30.00 |
| 2065 | 56.82 | 17.10 | 17.77 | 23.58 | 30.00 |
| 2066 | 55.76 | 17.09 | 17.64 | 22.99 | 30.00 |
| 2067 | 54.70 | 17.09 | 17.52 | 22.41 | 30.00 |
| 2068 | 53.64 | 16.91 | 17.39 | 20.97 | 30.00 |
| 2069 | 52.58 | 16.72 | 17.27 | 19.54 | 30.00 |
| 2070 | 51.52 | 16.54 | 17.14 | 18.10 | 30.00 |
| 2071 | 48.15 | 16.35 | 17.01 | 16.66 | 30.00 |
| 2072 | 44.79 | 16.17 | 16.89 | 15.23 | 30.00 |
| 2073 | 41.42 | 15.98 | 16.76 | 13.79 | 30.00 |
| 2074 | 38.06 | 15.80 | 16.48 | 12.36 | 26.25 |
| 2075 | 34.69 | 15.61 | 16.20 | 10.92 | 22.50 |
| 2076 | 31.33 | 15.43 | 15.91 | 9.48 | 18.75 |
| 2077 | 27.96 | 15.24 | 15.63 | 8.05 | 15.00 |
| 2078 | 24.60 | 15.06 | 15.35 | 6.61 | 11.25 |
| 2079 | 21.23 | 14.87 | 15.07 | 5.17 | 7.50 |
| 2080 | 17.87 | 14.69 | 14.78 | 3.74 | 3.75 |
| 2081 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2082 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2083 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2084 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2085 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2086 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2087 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |
| 2088 | 14.50 | 14.50 | 14.50 | 2.30 | 0.00 |

# 3 x 20-MW Power Plant at Cocle del Norte

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $19,331,250 | | | | -$19,331,250 |
| 2030 | $23,197,500 | | | | -$23,197,500 |
| 2031 | $34,796,250 | | | | -$34,796,250 |
| 2032 | | $1,394,700 | $19,062,000 | $3,600,000 | $21,267,300 |
| 2033 | | $1,394,700 | $18,986,100 | $3,600,000 | $21,191,400 |
| 2034 | | $1,394,700 | $18,910,200 | $3,600,000 | $21,115,500 |
| 2035 | | $1,394,700 | $18,834,300 | $3,600,000 | $21,039,600 |
| 2036 | | $1,394,700 | $18,758,400 | $3,600,000 | $20,963,700 |
| 2037 | | $1,394,700 | $18,682,500 | $3,600,000 | $20,887,800 |
| 2038 | | $1,394,700 | $18,606,600 | $3,600,000 | $20,811,900 |
| 2039 | | $1,394,700 | $18,530,700 | $3,600,000 | $20,736,000 |
| 2040 | | $1,394,700 | $18,454,800 | $3,600,000 | $20,660,100 |
| 2041 | | $1,394,700 | $18,378,900 | $3,600,000 | $20,584,200 |
| 2042 | | $1,394,700 | $18,303,000 | $3,600,000 | $20,508,300 |
| 2043 | | $1,394,700 | $18,227,100 | $3,600,000 | $20,432,400 |
| 2044 | | $1,394,700 | $18,151,200 | $3,600,000 | $20,356,500 |
| 2045 | | $1,394,700 | $18,075,300 | $3,600,000 | $20,280,600 |
| 2046 | | $1,394,700 | $17,999,400 | $3,600,000 | $20,204,700 |
| 2047 | | $1,394,700 | $17,923,500 | $3,600,000 | $20,128,800 |
| 2048 | | $1,394,700 | $17,678,750 | $3,600,000 | $19,884,050 |
| 2049 | | $1,394,700 | $17,434,000 | $3,600,000 | $19,639,300 |
| 2050 | | $1,394,700 | $17,189,250 | $3,600,000 | $19,394,550 |
| 2051 | | $1,394,700 | $16,944,500 | $3,600,000 | $19,149,800 |
| 2052 | | $1,394,700 | $16,699,750 | $3,600,000 | $18,905,050 |
| 2053 | | $1,394,700 | $16,455,000 | $3,600,000 | $18,660,300 |
| 2054 | | $1,394,700 | $16,210,250 | $3,600,000 | $18,415,550 |
| 2055 | | $1,394,700 | $15,965,500 | $3,600,000 | $18,170,800 |
| 2056 | | $1,394,700 | $15,720,750 | $3,600,000 | $17,926,050 |
| 2057 | | $1,394,700 | $15,476,000 | $3,600,000 | $17,681,300 |
| 2058 | | $1,394,700 | $15,231,250 | $3,600,000 | $17,436,550 |
| 2059 | | $1,394,700 | $14,986,500 | $3,600,000 | $17,191,800 |
| 2060 | | $1,394,700 | $14,741,750 | $3,600,000 | $16,947,050 |
| 2061 | $23,327,391 | $1,394,700 | $14,497,000 | $3,600,000 | -$6,625,091 |
| 2062 | | $1,394,700 | $14,252,250 | $3,600,000 | $16,457,550 |
| 2063 | | $1,394,700 | $14,007,500 | $3,600,000 | $16,212,800 |
| 2064 | | $1,394,700 | $13,762,750 | $3,600,000 | $15,968,050 |
| 2065 | | $1,394,700 | $13,518,000 | $3,600,000 | $15,723,300 |
| 2066 | | $1,394,700 | $13,102,875 | $3,536,400 | $15,244,575 |
| 2067 | | $1,394,700 | $12,687,750 | $3,472,800 | $14,765,850 |
| 2068 | | $1,394,700 | $12,272,625 | $3,409,200 | $14,287,125 |
| 2069 | | $1,394,700 | $11,857,500 | $3,345,600 | $13,808,400 |
| 2070 | | $1,394,700 | $11,442,375 | $3,282,000 | $13,329,675 |
| 2071 | | $1,394,700 | $11,027,250 | $3,218,400 | $12,850,950 |
| 2072 | | $1,394,700 | $10,612,125 | $3,154,800 | $12,372,225 |
| 2073 | | $1,394,700 | $10,197,000 | $3,091,200 | $11,893,500 |
| 2074 | | $1,394,700 | $9,751,500 | $2,889,273 | $11,246,073 |
| 2075 | | $1,394,700 | $9,306,000 | $2,687,345 | $10,598,645 |
| 2076 | | $1,394,700 | $8,860,500 | $2,485,418 | $9,951,218 |
| 2077 | | $1,394,700 | $8,415,000 | $2,283,491 | $9,303,791 |
| 2078 | | $1,394,700 | $7,969,500 | $2,081,564 | $8,656,364 |
| 2079 | | $1,394,700 | $7,524,000 | $1,879,636 | $8,008,936 |
| 2080 | | $1,394,700 | $7,078,500 | $1,677,709 | $7,361,509 |
| 2081 | | $1,394,700 | $6,633,000 | $1,475,782 | $6,714,082 |
| 2082 | | $1,394,700 | $6,187,500 | $1,273,855 | $6,066,655 |
| 2083 | | $1,394,700 | $5,742,000 | $1,071,927 | $5,419,227 |
| 2084 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2085 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2086 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2087 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2088 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2089 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2090 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2091 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $10,614,000 |
| Equipment Cost | $21,637,000 |
| Transmission System | $21,540,000 |
| **Subtotal** | **$53,791,000** |
| Contingencies | $13,448,000 |
| Engineering & Administration (15%) | $10,086,000 |
| **Project Development Cost** | **$77,325,000** |

**Annual Operation & Maintenance Costs**

| | |
|---|---|
| Civil Work Maintenance | $152,576 |
| Equipment Maintenance | $777,580 |
| Transmission Maintenance | $464,456 |
| **Total O&M** | **$1,394,700** |

| | |
|---|---|
| **Internal Rate of Return** | **22.6%** |

**ECONOMIC ANALYSIS**

# 2 x 15-MW Power Plant at Cocle del Norte

| Year | Project Cost | Annual Operation O&M | Annual Operation Energy Revenue | Annual Operation Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $8,014,000 | | | | -$8,014,000 |
| 2030 | $9,616,800 | | | | -$9,616,800 |
| 2031 | $14,425,200 | | | | -$14,425,200 |
| 2032 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2033 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2034 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2035 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2036 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2037 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2038 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2039 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2040 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2041 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2042 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2043 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2044 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2045 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2046 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2047 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2048 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2049 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2050 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2051 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2052 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2053 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2054 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2055 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2056 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2057 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2058 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2059 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2060 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2061 | $12,126,750 | $595,400 | $4,801,500 | $1,089,000 | -$6,831,650 |
| 2062 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2063 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2064 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2065 | | $595,400 | $4,801,500 | $1,089,000 | $5,295,100 |
| 2066 | | $595,400 | $4,736,045 | $1,081,418 | $5,222,064 |
| 2067 | | $595,400 | $4,670,591 | $1,073,836 | $5,149,027 |
| 2068 | | $595,400 | $4,605,136 | $1,066,255 | $5,075,991 |
| 2069 | | $595,400 | $4,539,682 | $1,058,673 | $5,002,955 |
| 2070 | | $595,400 | $4,474,227 | $1,051,091 | $4,929,918 |
| 2071 | | $595,400 | $4,408,773 | $1,043,509 | $4,856,882 |
| 2072 | | $595,400 | $4,343,318 | $1,035,927 | $4,783,845 |
| 2073 | | $595,400 | $4,277,864 | $1,028,345 | $4,710,809 |
| 2074 | | $595,400 | $4,212,409 | $1,020,764 | $4,637,773 |
| 2075 | | $595,400 | $4,146,955 | $1,013,182 | $4,564,736 |
| 2076 | | $595,400 | $4,081,500 | $1,005,600 | $4,491,700 |
| 2077 | | $595,400 | $4,057,313 | $988,650 | $4,450,563 |
| 2078 | | $595,400 | $4,033,125 | $971,700 | $4,409,425 |
| 2079 | | $595,400 | $4,008,938 | $954,750 | $4,368,288 |
| 2080 | | $595,400 | $3,984,750 | $937,800 | $4,327,150 |
| 2081 | | $595,400 | $3,960,563 | $920,850 | $4,286,013 |
| 2082 | | $595,400 | $3,936,375 | $903,900 | $4,244,875 |
| 2083 | | $595,400 | $3,912,188 | $886,950 | $4,203,738 |
| 2084 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2085 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2086 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2087 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2088 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2089 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2090 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |
| 2091 | | $595,400 | $3,888,000 | $870,000 | $4,162,600 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $6,559,000 |
| Equipment Cost | $11,248,000 |
| Transmission System | $4,493,000 |
| **Subtotal** | **$22,300,000** |
| Contingencies | $5,575,000 |
| Engineering & Administration (15%) | $4,181,000 |
| **Project Development Cost** | **$32,056,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $94,286 |
| Equipment Maintenance | $404,225 |
| Transmission Maintenance | $96,880 |
| **Total O&M** | **$595,400** |
| **Internal Rate of Return** | **14.6%** |

ECONOMIC ANALYSIS

# 2 x 15-MW Power Plant at Rio Indio

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $13,419,750 | | | | -$13,419,750 |
| 2030 | $16,103,700 | | | | -$16,103,700 |
| 2031 | $24,155,550 | | | | -$24,155,550 |
| 2032 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2033 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2034 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2035 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2036 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2037 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2038 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2039 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2040 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2041 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2042 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2043 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2044 | | $930,500 | $10,746,000 | $1,800,000 | $11,615,500 |
| 2045 | | $930,500 | $10,487,077 | $1,800,000 | $11,356,577 |
| 2046 | | $930,500 | $10,228,154 | $1,800,000 | $11,097,654 |
| 2047 | | $930,500 | $9,969,231 | $1,800,000 | $10,838,731 |
| 2048 | | $930,500 | $9,710,308 | $1,800,000 | $10,579,808 |
| 2049 | | $930,500 | $9,451,385 | $1,800,000 | $10,320,885 |
| 2050 | | $930,500 | $9,192,462 | $1,800,000 | $10,061,962 |
| 2051 | | $930,500 | $8,933,538 | $1,800,000 | $9,803,038 |
| 2052 | | $930,500 | $8,674,615 | $1,800,000 | $9,544,115 |
| 2053 | | $930,500 | $8,415,692 | $1,800,000 | $9,285,192 |
| 2054 | | $930,500 | $8,156,769 | $1,800,000 | $9,026,269 |
| 2055 | | $930,500 | $7,897,846 | $1,800,000 | $8,767,346 |
| 2056 | | $930,500 | $7,638,923 | $1,800,000 | $8,508,423 |
| 2057 | | $930,500 | $7,380,000 | $1,800,000 | $8,249,500 |
| 2058 | | $930,500 | $7,090,615 | $1,764,969 | $7,925,085 |
| 2059 | | $930,500 | $6,801,231 | $1,729,938 | $7,600,669 |
| 2060 | | $930,500 | $6,511,846 | $1,694,908 | $7,276,254 |
| 2061 | $17,471,016 | $930,500 | $6,222,462 | $1,659,877 | -$10,519,177 |
| 2062 | | $930,500 | $5,933,077 | $1,624,846 | $6,627,423 |
| 2063 | | $930,500 | $5,643,692 | $1,589,815 | $6,303,008 |
| 2064 | | $930,500 | $5,354,308 | $1,554,785 | $5,978,592 |
| 2065 | | $930,500 | $5,064,923 | $1,519,754 | $5,654,177 |
| 2066 | | $930,500 | $4,775,538 | $1,484,723 | $5,329,762 |
| 2067 | | $930,500 | $4,486,154 | $1,449,692 | $5,005,346 |
| 2068 | | $930,500 | $4,196,769 | $1,414,662 | $4,680,931 |
| 2069 | | $930,500 | $3,907,385 | $1,379,631 | $4,356,515 |
| 2070 | | $930,500 | $3,618,000 | $1,344,600 | $4,032,100 |
| 2071 | | $930,500 | $3,389,464 | $1,258,414 | $3,717,379 |
| 2072 | | $930,500 | $3,160,929 | $1,172,229 | $3,402,657 |
| 2073 | | $930,500 | $2,932,393 | $1,086,043 | $3,087,936 |
| 2074 | | $930,500 | $2,703,857 | $999,857 | $2,773,214 |
| 2075 | | $930,500 | $2,475,321 | $913,671 | $2,458,493 |
| 2076 | | $930,500 | $2,246,786 | $827,486 | $2,143,771 |
| 2077 | | $930,500 | $2,018,250 | $741,300 | $1,829,050 |
| 2078 | | $930,500 | $1,789,714 | $655,114 | $1,514,329 |
| 2079 | | $930,500 | $1,561,179 | $568,929 | $1,199,607 |
| 2080 | | $930,500 | $1,332,643 | $482,743 | $884,886 |
| 2081 | | $930,500 | $1,104,107 | $396,557 | $570,164 |
| 2082 | | $930,500 | $875,571 | $310,371 | $255,443 |
| 2083 | | $930,500 | $647,036 | $224,186 | -$59,279 |
| 2084 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2085 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2086 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2087 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2088 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2089 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2090 | | $930,500 | $418,500 | $138,000 | -$374,000 |
| 2091 | | $930,500 | $418,500 | $138,000 | -$374,000 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $14,978,000 |
| Equipment Cost | $16,205,000 |
| Transmission System | $6,158,000 |
| **Subtotal** | **$37,341,000** |
| Contingencies | $9,336,000 |
| Engineering & Administration (15%) | $7,002,000 |
| **Project Development Cost** | **$53,679,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $215,309 |
| Equipment Maintenance | $582,367 |
| Transmission Maintenance | $132,782 |
| **Total O&M** | **$930,500** |
| **Internal Rate of Return** | **18.4%** |

**ECONOMIC ANALYSIS**

# 2 x 15-MW Power Plant at Isla Pablon

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $13,791,750 | | | | -$13,791,750 |
| 2030 | $16,550,100 | | | | -$16,550,100 |
| 2031 | $24,825,150 | | | | -$24,825,150 |
| 2032 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2033 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2034 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2035 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2036 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2037 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2038 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2039 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2040 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2041 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2042 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2043 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2044 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2045 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2046 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2047 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2048 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2049 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2050 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2051 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2052 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2053 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2054 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2055 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2056 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2057 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2058 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2059 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2060 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2061 | $16,099,641 | $913,800 | $10,237,500 | $1,800,000 | -$4,975,941 |
| 2062 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2063 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2064 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2065 | | $913,800 | $10,237,500 | $1,800,000 | $11,123,700 |
| 2066 | | $913,800 | $10,090,636 | $1,800,000 | $10,976,836 |
| 2067 | | $913,800 | $9,943,773 | $1,800,000 | $10,829,973 |
| 2068 | | $913,800 | $9,796,909 | $1,800,000 | $10,683,109 |
| 2069 | | $913,800 | $9,650,045 | $1,800,000 | $10,536,245 |
| 2070 | | $913,800 | $9,503,182 | $1,800,000 | $10,389,382 |
| 2071 | | $913,800 | $9,356,318 | $1,800,000 | $10,242,518 |
| 2072 | | $913,800 | $9,209,455 | $1,800,000 | $10,095,655 |
| 2073 | | $913,800 | $9,062,591 | $1,800,000 | $9,948,791 |
| 2074 | | $913,800 | $8,915,727 | $1,800,000 | $9,801,927 |
| 2075 | | $913,800 | $8,768,864 | $1,800,000 | $9,655,064 |
| 2076 | | $913,800 | $8,622,000 | $1,800,000 | $9,508,200 |
| 2077 | | $913,800 | $7,996,500 | $1,575,000 | $8,657,700 |
| 2078 | | $913,800 | $7,371,000 | $1,350,000 | $7,807,200 |
| 2079 | | $913,800 | $6,745,500 | $1,125,000 | $6,956,700 |
| 2080 | | $913,800 | $6,120,000 | $900,000 | $6,106,200 |
| 2081 | | $913,800 | $5,494,500 | $675,000 | $5,255,700 |
| 2082 | | $913,800 | $4,869,000 | $450,000 | $4,405,200 |
| 2083 | | $913,800 | $4,243,500 | $225,000 | $3,554,700 |
| 2084 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2085 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2086 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2087 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2088 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2089 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2090 | | $913,800 | $3,618,000 | $0 | $2,704,200 |
| 2091 | | $913,800 | $3,618,000 | $0 | $2,704,200 |

**Cost Summary**

| | |
|---|---|
| Civil Work Cost | $17,860,000 |
| Equipment Cost | $14,933,000 |
| Transmission System | $5,584,000 |
| **Subtotal** | **$38,377,000** |
| Contingencies | $9,594,000 |
| Engineering & Administration (15%) | $7,196,000 |
| **Project Development Cost** | **$55,167,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $256,738 |
| Equipment Maintenance | $536,655 |
| Transmission Maintenance | $120,405 |
| **Total O&M** | **$913,800** |
| **Internal Rate of Return** | **17.5%** |

## Energy Production Estimates (GWh/yr)

| Year | Gatun | | | Madden | | | Strategy 2 above Strategy 1 | Strategy 3 above Strategy 1 |
|---|---|---|---|---|---|---|---|---|
| | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 1 | Strategy 2 | Strategy 3 | | |
| 2029 | 39.0 | 53.3 | 123.0 | 180.9 | 174.4 | 178.2 | 7.8 | 81.3 |
| 2030 | 37.5 | 50.1 | 120.2 | 180.2 | 174.1 | 177.9 | 6.5 | 80.4 |
| 2031 | 36.0 | 46.8 | 117.5 | 179.5 | 173.8 | 177.6 | 5.1 | 79.6 |
| 2032 | 34.5 | 43.6 | 114.7 | 178.8 | 173.5 | 177.4 | 3.8 | 78.7 |
| 2033 | 33.0 | 40.3 | 111.9 | 178.1 | 173.2 | 177.1 | 2.4 | 77.9 |
| 2034 | 31.5 | 37.1 | 109.2 | 177.4 | 172.9 | 176.8 | 1.1 | 77.0 |
| 2035 | 30.0 | 33.8 | 106.4 | 176.7 | 172.7 | 176.5 | -0.3 | 76.2 |
| 2036 | 28.5 | 30.6 | 103.6 | 176.0 | 172.4 | 176.2 | -1.6 | 75.3 |
| 2037 | 27.0 | 27.3 | 100.9 | 175.4 | 172.1 | 176.0 | -3.0 | 74.4 |
| 2038 | 25.5 | 24.1 | 98.1 | 174.7 | 171.8 | 175.7 | -4.3 | 73.6 |
| 2039 | 24.0 | 20.8 | 95.3 | 174.0 | 171.5 | 175.4 | -5.7 | 72.7 |
| 2040 | 22.5 | 17.6 | 92.5 | 173.3 | 171.2 | 175.1 | -7.0 | 71.9 |
| 2041 | 21.0 | 14.3 | 89.8 | 172.6 | 170.9 | 174.8 | -8.4 | 71.0 |
| 2042 | 19.5 | 13.8 | 87.0 | 171.9 | 170.5 | 174.5 | -7.1 | 70.2 |
| 2043 | 18.0 | 13.3 | 84.2 | 171.2 | 170.0 | 174.3 | -5.9 | 69.3 |
| 2044 | 16.5 | 12.8 | 81.5 | 170.5 | 169.6 | 174.0 | -4.6 | 68.5 |
| 2045 | 16.0 | 12.3 | 78.7 | 170.0 | 169.2 | 173.7 | -4.5 | 66.4 |
| 2046 | 15.5 | 11.8 | 76.5 | 169.5 | 168.7 | 173.5 | -4.5 | 65.0 |
| 2047 | 15.0 | 11.3 | 74.3 | 169.0 | 168.3 | 173.2 | -4.4 | 63.5 |
| 2048 | 14.5 | 10.8 | 72.2 | 168.5 | 167.9 | 173.0 | -4.4 | 62.1 |
| 2049 | 14.0 | 10.3 | 70.0 | 168.1 | 167.5 | 172.8 | -4.3 | 60.7 |
| 2050 | 13.5 | 9.8 | 67.8 | 167.6 | 167.0 | 172.6 | -4.3 | 59.3 |
| 2051 | 13.0 | 9.3 | 65.6 | 167.1 | 166.6 | 172.3 | -4.2 | 57.8 |
| 2052 | 12.5 | 8.8 | 63.5 | 166.6 | 166.2 | 172.1 | -4.2 | 56.4 |
| 2053 | 12.1 | 8.3 | 61.3 | 166.1 | 165.7 | 171.9 | -4.1 | 55.0 |
| 2054 | 11.6 | 7.8 | 59.1 | 165.6 | 165.3 | 171.6 | -4.1 | 53.6 |
| 2055 | 11.1 | 7.6 | 56.9 | 165.1 | 164.9 | 171.4 | -3.7 | 52.2 |
| 2056 | 10.6 | 7.4 | 54.8 | 164.6 | 164.5 | 171.2 | -3.3 | 50.7 |
| 2057 | 10.1 | 7.2 | 52.6 | 164.1 | 164.1 | 170.9 | -2.9 | 49.3 |
| 2058 | 9.6 | 6.9 | 50.4 | 163.7 | 163.8 | 170.7 | -2.5 | 47.9 |
| 2059 | 9.1 | 6.7 | 48.2 | 163.2 | 163.4 | 170.5 | -2.2 | 46.5 |
| 2060 | 8.6 | 6.5 | 46.1 | 162.7 | 163.0 | 170.3 | -1.8 | 45.0 |
| 2061 | 8.1 | 6.3 | 43.9 | 162.2 | 162.6 | 170.0 | -1.4 | 43.6 |
| 2062 | 7.6 | 6.1 | 41.7 | 161.7 | 162.2 | 169.8 | -1.0 | 42.2 |
| 2063 | 7.3 | 5.9 | 40.4 | 161.2 | 161.8 | 169.6 | -0.8 | 41.5 |
| 2064 | 7.0 | 5.6 | 39.1 | 160.6 | 161.5 | 169.4 | -0.5 | 40.8 |
| 2065 | 6.7 | 5.4 | 37.8 | 160.1 | 161.1 | 169.2 | -0.3 | 40.2 |
| 2066 | 6.4 | 5.2 | 36.5 | 159.6 | 160.7 | 169.0 | -0.1 | 39.5 |
| 2067 | 6.1 | 5.0 | 35.2 | 159.0 | 160.3 | 168.8 | 0.2 | 38.8 |
| 2068 | 5.8 | 4.8 | 33.8 | 158.5 | 159.7 | 168.5 | 0.3 | 38.1 |
| 2069 | 5.5 | 4.7 | 32.5 | 157.9 | 159.2 | 168.3 | 0.4 | 37.4 |
| 2070 | 5.2 | 4.5 | 31.2 | 157.4 | 158.6 | 168.1 | 0.5 | 36.8 |
| 2071 | 5.0 | 4.4 | 29.9 | 156.9 | 158.0 | 167.9 | 0.5 | 35.9 |
| 2072 | 4.8 | 4.2 | 28.6 | 156.5 | 157.5 | 167.7 | 0.4 | 35.1 |
| 2073 | 4.5 | 4.1 | 27.3 | 156.0 | 156.9 | 167.5 | 0.4 | 34.2 |
| 2074 | 4.3 | 3.9 | 24.2 | 155.6 | 156.4 | 165.6 | 0.3 | 29.9 |
| 2075 | 4.1 | 3.7 | 21.2 | 155.1 | 155.8 | 163.7 | 0.3 | 25.7 |
| 2076 | 3.9 | 3.6 | 18.1 | 154.7 | 155.2 | 161.8 | 0.2 | 21.4 |
| 2077 | 3.7 | 3.4 | 15.1 | 154.2 | 154.7 | 160.0 | 0.2 | 17.1 |
| 2078 | 3.5 | 3.3 | 12.0 | 153.8 | 154.1 | 158.1 | 0.1 | 12.8 |
| 2079 | 3.2 | 3.1 | 8.9 | 153.3 | 153.5 | 156.2 | 0.1 | 8.6 |
| 2080 | 3.0 | 3.0 | 5.9 | 152.9 | 153.0 | 154.3 | 0.0 | 4.3 |
| 2081 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2082 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2083 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2084 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2085 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2086 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2087 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |
| 2088 | 2.8 | 2.8 | 2.8 | 152.4 | 152.4 | 152.4 | 0.0 | 0.0 |

ECONOMIC ANALYSIS

# Strategy 1

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $19,331,250 | | | | -$19,331,250 |
| 2030 | $23,197,500 | | | | -$23,197,500 |
| 2031 | $34,796,250 | | | | -$34,796,250 |
| 2032 | | $1,394,700 | $19,062,000 | $3,600,000 | $21,267,300 |
| 2033 | | $1,394,700 | $18,986,100 | $3,600,000 | $21,191,400 |
| 2034 | | $1,394,700 | $18,910,200 | $3,600,000 | $21,115,500 |
| 2035 | | $1,394,700 | $18,834,300 | $3,600,000 | $21,039,600 |
| 2036 | | $1,394,700 | $18,758,400 | $3,600,000 | $20,963,700 |
| 2037 | | $1,394,700 | $18,682,500 | $3,600,000 | $20,887,800 |
| 2038 | | $1,394,700 | $18,606,600 | $3,600,000 | $20,811,900 |
| 2039 | | $1,394,700 | $18,530,700 | $3,600,000 | $20,736,000 |
| 2040 | | $1,394,700 | $18,454,800 | $3,600,000 | $20,660,100 |
| 2041 | | $1,394,700 | $18,378,900 | $3,600,000 | $20,584,200 |
| 2042 | | $1,394,700 | $18,303,000 | $3,600,000 | $20,508,300 |
| 2043 | | $1,394,700 | $18,227,100 | $3,600,000 | $20,432,400 |
| 2044 | | $1,394,700 | $18,151,200 | $3,600,000 | $20,356,500 |
| 2045 | | $1,394,700 | $18,075,300 | $3,600,000 | $20,280,600 |
| 2046 | | $1,394,700 | $17,999,400 | $3,600,000 | $20,204,700 |
| 2047 | | $1,394,700 | $17,923,500 | $3,600,000 | $20,128,800 |
| 2048 | | $1,394,700 | $17,678,750 | $3,600,000 | $19,884,050 |
| 2049 | | $1,394,700 | $17,434,000 | $3,600,000 | $19,639,300 |
| 2050 | | $1,394,700 | $17,189,250 | $3,600,000 | $19,394,550 |
| 2051 | | $1,394,700 | $16,944,500 | $3,600,000 | $19,149,800 |
| 2052 | | $1,394,700 | $16,699,750 | $3,600,000 | $18,905,050 |
| 2053 | | $1,394,700 | $16,455,000 | $3,600,000 | $18,660,300 |
| 2054 | | $1,394,700 | $16,210,250 | $3,600,000 | $18,415,550 |
| 2055 | | $1,394,700 | $15,965,500 | $3,600,000 | $18,170,800 |
| 2056 | | $1,394,700 | $15,720,750 | $3,600,000 | $17,926,050 |
| 2057 | | $1,394,700 | $15,476,000 | $3,600,000 | $17,681,300 |
| 2058 | | $1,394,700 | $15,231,250 | $3,600,000 | $17,436,550 |
| 2059 | | $1,394,700 | $14,986,500 | $3,600,000 | $17,191,800 |
| 2060 | | $1,394,700 | $14,741,750 | $3,600,000 | $16,947,050 |
| 2061 | $23,327,391 | $1,394,700 | $14,497,000 | $3,600,000 | -$6,625,091 |
| 2062 | | $1,394,700 | $14,252,250 | $3,600,000 | $16,457,550 |
| 2063 | | $1,394,700 | $14,007,500 | $3,600,000 | $16,212,800 |
| 2064 | | $1,394,700 | $13,762,750 | $3,600,000 | $15,968,050 |
| 2065 | | $1,394,700 | $13,518,000 | $3,600,000 | $15,723,300 |
| 2066 | | $1,394,700 | $13,102,875 | $3,536,400 | $15,244,575 |
| 2067 | | $1,394,700 | $12,687,750 | $3,472,800 | $14,765,850 |
| 2068 | | $1,394,700 | $12,272,625 | $3,409,200 | $14,287,125 |
| 2069 | | $1,394,700 | $11,857,500 | $3,345,600 | $13,808,400 |
| 2070 | | $1,394,700 | $11,442,375 | $3,282,000 | $13,329,675 |
| 2071 | | $1,394,700 | $11,027,250 | $3,218,400 | $12,850,950 |
| 2072 | | $1,394,700 | $10,612,125 | $3,154,800 | $12,372,225 |
| 2073 | | $1,394,700 | $10,197,000 | $3,091,200 | $11,893,500 |
| 2074 | | $1,394,700 | $9,751,500 | $2,889,273 | $11,246,073 |
| 2075 | | $1,394,700 | $9,306,000 | $2,687,345 | $10,598,645 |
| 2076 | | $1,394,700 | $8,860,500 | $2,485,418 | $9,951,218 |
| 2077 | | $1,394,700 | $8,415,000 | $2,283,491 | $9,303,791 |
| 2078 | | $1,394,700 | $7,969,500 | $2,081,564 | $8,656,364 |
| 2079 | | $1,394,700 | $7,524,000 | $1,879,636 | $8,008,936 |
| 2080 | | $1,394,700 | $7,078,500 | $1,677,709 | $7,361,509 |
| 2081 | | $1,394,700 | $6,633,000 | $1,475,782 | $6,714,082 |
| 2082 | | $1,394,700 | $6,187,500 | $1,273,855 | $6,066,655 |
| 2083 | | $1,394,700 | $5,742,000 | $1,071,927 | $5,419,227 |
| 2084 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2085 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2086 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2087 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2088 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2089 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2090 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |
| 2091 | | $1,394,700 | $5,296,500 | $870,000 | $4,771,800 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $10,614,000 |
| Equipment Cost | $21,637,000 |
| Transmission System | $21,540,000 |
| **Subtotal** | **$53,791,000** |
| Contingencies | $13,448,000 |
| Engineering & Administration (15%) | $10,086,000 |
| **Project Development Cost** | **$77,325,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $152,576 |
| Equipment Maintenance | $777,580 |
| Transmission Maintenance | $464,456 |
| **Total O&M** | **$1,394,700** |
| **Internal Rate of Return** | **22.6%** |

## ECONOMIC ANALYSIS

# Strategy 2

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $21,433,500 | | | | -$21,433,500 |
| 2030 | $25,720,200 | | | | -$25,720,200 |
| 2031 | $38,580,300 | | | | -$38,580,300 |
| 2032 | | $1,525,900 | $16,024,500 | $2,808,600 | $17,307,200 |
| 2033 | | $1,525,900 | $15,963,825 | $2,808,600 | $17,246,525 |
| 2034 | | $1,525,900 | $15,903,150 | $2,808,600 | $17,185,850 |
| 2035 | | $1,525,900 | $15,842,475 | $2,808,600 | $17,125,175 |
| 2036 | | $1,525,900 | $15,781,800 | $2,808,600 | $17,064,500 |
| 2037 | | $1,525,900 | $15,721,125 | $2,808,600 | $17,003,825 |
| 2038 | | $1,525,900 | $15,660,450 | $2,808,600 | $16,943,150 |
| 2039 | | $1,525,900 | $15,599,775 | $2,808,600 | $16,882,475 |
| 2040 | | $1,525,900 | $15,539,100 | $2,808,600 | $16,821,800 |
| 2041 | | $1,525,900 | $15,478,425 | $2,808,600 | $16,761,125 |
| 2042 | | $1,525,900 | $15,417,750 | $2,808,600 | $16,700,450 |
| 2043 | | $1,525,900 | $15,357,075 | $2,808,600 | $16,639,775 |
| 2044 | | $1,525,900 | $15,296,400 | $2,808,600 | $16,579,100 |
| 2045 | | $1,525,900 | $15,111,946 | $2,810,123 | $16,396,169 |
| 2046 | | $1,525,900 | $14,927,492 | $2,811,646 | $16,213,238 |
| 2047 | | $1,525,900 | $14,743,038 | $2,813,169 | $16,030,308 |
| 2048 | | $1,525,900 | $14,504,135 | $2,814,692 | $15,792,927 |
| 2049 | | $1,525,900 | $14,265,231 | $2,816,215 | $15,555,546 |
| 2050 | | $1,525,900 | $14,026,327 | $2,817,738 | $15,318,165 |
| 2051 | | $1,525,900 | $13,787,423 | $2,819,262 | $15,080,785 |
| 2052 | | $1,525,900 | $13,548,519 | $2,820,785 | $14,843,404 |
| 2053 | | $1,525,900 | $13,309,615 | $2,822,308 | $14,606,023 |
| 2054 | | $1,525,900 | $13,070,712 | $2,823,831 | $14,368,642 |
| 2055 | | $1,525,900 | $12,831,808 | $2,825,354 | $14,131,262 |
| 2056 | | $1,525,900 | $12,592,904 | $2,826,877 | $13,893,881 |
| 2057 | | $1,525,900 | $12,354,000 | $2,828,400 | $13,656,500 |
| 2058 | | $1,525,900 | $12,083,250 | $2,793,138 | $13,350,488 |
| 2059 | | $1,525,900 | $11,812,500 | $2,757,877 | $13,044,477 |
| 2060 | | $1,525,900 | $11,541,750 | $2,722,615 | $12,738,465 |
| 2061 | $29,597,766 | $1,525,900 | $11,271,000 | $2,687,354 | -$17,165,312 |
| 2062 | | $1,525,900 | $11,000,250 | $2,652,092 | $12,126,442 |
| 2063 | | $1,525,900 | $10,729,500 | $2,616,831 | $11,820,431 |
| 2064 | | $1,525,900 | $10,458,750 | $2,581,569 | $11,514,419 |
| 2065 | | $1,525,900 | $10,188,000 | $2,546,308 | $11,208,408 |
| 2066 | | $1,525,900 | $9,910,688 | $2,511,046 | $10,895,834 |
| 2067 | | $1,525,900 | $9,633,375 | $2,475,785 | $10,583,260 |
| 2068 | | $1,525,900 | $9,356,063 | $2,440,523 | $10,270,686 |
| 2069 | | $1,525,900 | $9,078,750 | $2,405,262 | $9,958,112 |
| 2070 | | $1,525,900 | $8,801,438 | $2,370,000 | $9,645,538 |
| 2071 | | $1,525,900 | $8,486,196 | $2,272,714 | $9,233,011 |
| 2072 | | $1,525,900 | $8,170,955 | $2,175,429 | $8,820,484 |
| 2073 | | $1,525,900 | $7,855,714 | $2,078,143 | $8,407,957 |
| 2074 | | $1,525,900 | $7,533,058 | $1,980,857 | $7,988,016 |
| 2075 | | $1,525,900 | $7,210,403 | $1,883,571 | $7,568,074 |
| 2076 | | $1,525,900 | $6,887,747 | $1,786,286 | $7,148,132 |
| 2077 | | $1,525,900 | $6,565,091 | $1,689,000 | $6,728,191 |
| 2078 | | $1,525,900 | $6,242,435 | $1,591,714 | $6,308,249 |
| 2079 | | $1,525,900 | $5,919,779 | $1,494,429 | $5,888,308 |
| 2080 | | $1,525,900 | $5,597,123 | $1,397,143 | $5,468,366 |
| 2081 | | $1,525,900 | $5,274,468 | $1,299,857 | $5,048,425 |
| 2082 | | $1,525,900 | $4,951,812 | $1,202,571 | $4,628,483 |
| 2083 | | $1,525,900 | $4,629,156 | $1,105,286 | $4,208,542 |
| 2084 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2085 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2086 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2087 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2088 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2089 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2090 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |
| 2091 | | $1,525,900 | $4,306,500 | $1,008,000 | $3,788,600 |

### Cost Summary

| | |
|---|---|
| Civil Work Cost | $21,537,000 |
| Equipment Cost | $27,453,000 |
| Transmission System | $10,651,000 |
| **Subtotal** | **$59,641,000** |
| Contingencies | $14,910,000 |
| Engineering & Administration (15%) | $11,183,000 |
| **Project Development Cost** | **$85,734,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $309,594 |
| Equipment Maintenance | $986,592 |
| Transmission Maintenance | $229,662 |
| **Total O&M** | **$1,525,900** |
| **Internal Rate of Return** | **17.1%** |

# Strategy 3

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $21,806,000 | | | | -$21,806,000 |
| 2030 | $26,167,200 | | | | -$26,167,200 |
| 2031 | $39,250,800 | | | | -$39,250,800 |
| 2032 | | $1,509,200 | $18,697,500 | $2,889,000 | $20,077,300 |
| 2033 | | $1,509,200 | $18,658,950 | $2,889,000 | $20,038,750 |
| 2034 | | $1,509,200 | $18,620,400 | $2,889,000 | $20,000,200 |
| 2035 | | $1,509,200 | $18,581,850 | $2,889,000 | $19,961,650 |
| 2036 | | $1,509,200 | $18,543,300 | $2,889,000 | $19,923,100 |
| 2037 | | $1,509,200 | $18,504,750 | $2,889,000 | $19,884,550 |
| 2038 | | $1,509,200 | $18,466,200 | $2,889,000 | $19,846,000 |
| 2039 | | $1,509,200 | $18,427,650 | $2,889,000 | $19,807,450 |
| 2040 | | $1,509,200 | $18,389,100 | $2,889,000 | $19,768,900 |
| 2041 | | $1,509,200 | $18,350,550 | $2,889,000 | $19,730,350 |
| 2042 | | $1,509,200 | $18,312,000 | $2,889,000 | $19,691,800 |
| 2043 | | $1,509,200 | $18,273,450 | $2,889,000 | $19,653,250 |
| 2044 | | $1,509,200 | $18,234,900 | $2,889,000 | $19,614,700 |
| 2045 | | $1,509,200 | $18,196,350 | $2,889,000 | $19,576,150 |
| 2046 | | $1,509,200 | $18,157,800 | $2,889,000 | $19,537,600 |
| 2047 | | $1,509,200 | $18,119,250 | $2,889,000 | $19,499,050 |
| 2048 | | $1,509,200 | $18,026,250 | $2,889,000 | $19,406,050 |
| 2049 | | $1,509,200 | $17,962,235 | $2,889,000 | $19,342,035 |
| 2050 | | $1,509,200 | $17,898,221 | $2,889,000 | $19,278,021 |
| 2051 | | $1,509,200 | $17,834,206 | $2,889,000 | $19,214,006 |
| 2052 | | $1,509,200 | $17,770,191 | $2,889,000 | $19,149,991 |
| 2053 | | $1,509,200 | $17,706,176 | $2,889,000 | $19,085,976 |
| 2054 | | $1,509,200 | $17,642,162 | $2,889,000 | $19,021,962 |
| 2055 | | $1,509,200 | $17,578,147 | $2,889,000 | $18,957,947 |
| 2056 | | $1,509,200 | $17,514,132 | $2,889,000 | $18,893,932 |
| 2057 | | $1,509,200 | $17,450,118 | $2,889,000 | $18,829,918 |
| 2058 | | $1,509,200 | $17,386,103 | $2,889,000 | $18,765,903 |
| 2059 | | $1,509,200 | $17,322,088 | $2,889,000 | $18,701,888 |
| 2060 | | $1,509,200 | $17,258,074 | $2,889,000 | $18,637,874 |
| 2061 | $28,226,391 | $1,509,200 | $17,194,059 | $2,889,000 | -$9,652,532 |
| 2062 | | $1,509,200 | $17,130,044 | $2,889,000 | $18,509,844 |
| 2063 | | $1,509,200 | $17,066,029 | $2,889,000 | $18,445,829 |
| 2064 | | $1,509,200 | $17,002,015 | $2,889,000 | $18,381,815 |
| 2065 | | $1,509,200 | $16,938,000 | $2,889,000 | $18,317,800 |
| 2066 | | $1,509,200 | $16,695,051 | $2,881,418 | $18,067,269 |
| 2067 | | $1,509,200 | $16,452,102 | $2,873,836 | $17,816,739 |
| 2068 | | $1,509,200 | $16,209,153 | $2,866,255 | $17,566,208 |
| 2069 | | $1,509,200 | $15,966,205 | $2,858,673 | $17,315,677 |
| 2070 | | $1,509,200 | $15,723,256 | $2,851,091 | $17,065,147 |
| 2071 | | $1,509,200 | $15,480,307 | $2,843,509 | $16,814,616 |
| 2072 | | $1,509,200 | $15,237,358 | $2,835,927 | $16,564,085 |
| 2073 | | $1,509,200 | $14,994,409 | $2,828,345 | $16,313,555 |
| 2074 | | $1,509,200 | $14,744,045 | $2,820,764 | $16,055,609 |
| 2075 | | $1,509,200 | $14,493,682 | $2,813,182 | $15,797,664 |
| 2076 | | $1,509,200 | $14,243,318 | $2,805,600 | $15,539,718 |
| 2077 | | $1,509,200 | $13,401,153 | $2,563,650 | $14,455,603 |
| 2078 | | $1,509,200 | $12,558,989 | $2,321,700 | $13,371,489 |
| 2079 | | $1,509,200 | $11,716,824 | $2,079,750 | $12,287,374 |
| 2080 | | $1,509,200 | $10,874,659 | $1,837,800 | $11,203,259 |
| 2081 | | $1,509,200 | $10,032,494 | $1,595,850 | $10,119,144 |
| 2082 | | $1,509,200 | $9,190,330 | $1,353,900 | $9,035,030 |
| 2083 | | $1,509,200 | $8,348,165 | $1,111,950 | $7,950,915 |
| 2084 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2085 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2086 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2087 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2088 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2089 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2090 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |
| 2091 | | $1,509,200 | $7,506,000 | $870,000 | $6,866,800 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $24,419,000 |
| Equipment Cost | $26,181,000 |
| Transmission System | $10,077,000 |
| **Subtotal** | **$60,677,000** |
| Contingencies | $15,170,000 |
| Engineering & Administration (15%) | $11,377,000 |
| **Project Development Cost** | **$87,224,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $351,023 |
| Equipment Maintenance | $940,880 |
| Transmission Maintenance | $217,285 |
| **Total O&M** | **$1,509,200** |
| **Internal Rate of Return** | **19.5%** |

| | Energy Production Estimates | | | Firm Capacity (MW-yr) | | |
|---|---|---|---|---|---|---|
| Year | 3 x 15-MW Power Plant at Cocle del Norte | 3 x 20-MW Power Plant at Cocle del Norte | 3 x 25-MW Power Plant at Cocle del Norte | 3 x 15-MW Power Plant at Cocle del Norte | 3 x 20-MW Power Plant at Cocle del Norte | 3 x 25-MW Power Plant at Cocle del Norte |
| 2029 | 380.2 | 423.6 | 450.5 | 45.00 | 60.00 | 75.00 |
| 2030 | 378.8 | 421.9 | 448.2 | 45.00 | 60.00 | 75.00 |
| 2031 | 377.4 | 420.2 | 445.8 | 45.00 | 60.00 | 75.00 |
| 2032 | 376.0 | 418.5 | 443.5 | 45.00 | 60.00 | 75.00 |
| 2033 | 374.6 | 416.9 | 441.1 | 45.00 | 60.00 | 75.00 |
| 2034 | 373.2 | 415.2 | 438.8 | 45.00 | 60.00 | 75.00 |
| 2035 | 371.8 | 413.5 | 436.4 | 45.00 | 60.00 | 75.00 |
| 2036 | 370.4 | 411.8 | 434.1 | 45.00 | 60.00 | 75.00 |
| 2037 | 368.9 | 410.1 | 431.7 | 45.00 | 60.00 | 75.00 |
| 2038 | 367.5 | 408.4 | 429.4 | 45.00 | 60.00 | 75.00 |
| 2039 | 366.1 | 406.7 | 427.0 | 45.00 | 60.00 | 75.00 |
| 2040 | 364.7 | 405.0 | 424.7 | 45.00 | 60.00 | 75.00 |
| 2041 | 363.3 | 403.4 | 422.3 | 45.00 | 60.00 | 75.00 |
| 2042 | 361.9 | 401.7 | 420.0 | 45.00 | 60.00 | 75.00 |
| 2043 | 360.5 | 400.0 | 417.6 | 45.00 | 60.00 | 75.00 |
| 2044 | 359.1 | 398.3 | 415.3 | 45.00 | 60.00 | 75.00 |
| 2045 | 355.0 | 392.9 | 409.6 | 45.00 | 60.00 | 75.00 |
| 2046 | 351.0 | 387.4 | 404.0 | 45.00 | 60.00 | 75.00 |
| 2047 | 346.9 | 382.0 | 398.3 | 45.00 | 60.00 | 75.00 |
| 2048 | 342.8 | 376.5 | 392.7 | 45.00 | 60.00 | 75.00 |
| 2049 | 338.7 | 371.1 | 387.0 | 45.00 | 60.00 | 75.00 |
| 2050 | 334.7 | 365.7 | 381.4 | 45.00 | 60.00 | 75.00 |
| 2051 | 330.6 | 360.2 | 375.7 | 45.00 | 60.00 | 75.00 |
| 2052 | 326.5 | 354.8 | 370.1 | 45.00 | 60.00 | 75.00 |
| 2053 | 322.5 | 349.4 | 364.4 | 45.00 | 60.00 | 75.00 |
| 2054 | 318.4 | 343.9 | 358.7 | 45.00 | 60.00 | 75.00 |
| 2055 | 314.3 | 338.5 | 353.1 | 45.00 | 60.00 | 75.00 |
| 2056 | 310.2 | 333.0 | 347.4 | 45.00 | 60.00 | 75.00 |
| 2057 | 306.2 | 327.6 | 341.8 | 45.00 | 60.00 | 75.00 |
| 2058 | 302.1 | 322.2 | 336.1 | 45.00 | 60.00 | 75.00 |
| 2059 | 298.0 | 316.7 | 330.5 | 45.00 | 60.00 | 75.00 |
| 2060 | 293.9 | 311.3 | 324.8 | 45.00 | 60.00 | 75.00 |
| 2061 | 289.9 | 305.8 | 319.2 | 45.00 | 60.00 | 75.00 |
| 2062 | 285.8 | 300.4 | 313.5 | 45.00 | 60.00 | 75.00 |
| 2063 | 276.6 | 291.2 | 304.2 | 45.00 | 58.94 | 72.07 |
| 2064 | 267.5 | 282.0 | 294.8 | 45.00 | 57.88 | 69.13 |
| 2065 | 258.3 | 272.7 | 285.5 | 45.00 | 56.82 | 66.20 |
| 2066 | 249.1 | 263.5 | 276.1 | 45.00 | 55.76 | 63.27 |
| 2067 | 239.9 | 254.3 | 266.8 | 45.00 | 54.70 | 60.33 |
| 2068 | 230.8 | 245.1 | 257.4 | 45.00 | 53.64 | 57.40 |
| 2069 | 221.6 | 235.8 | 248.1 | 45.00 | 52.58 | 54.46 |
| 2070 | 212.4 | 226.6 | 238.7 | 45.00 | 51.52 | 51.53 |
| 2071 | 202.5 | 216.7 | 228.8 | 42.23 | 48.15 | 48.16 |
| 2072 | 192.6 | 206.8 | 218.8 | 39.45 | 44.79 | 44.80 |
| 2073 | 182.7 | 196.9 | 208.9 | 36.68 | 41.42 | 41.43 |
| 2074 | 172.8 | 187.0 | 198.9 | 33.91 | 38.06 | 38.06 |
| 2075 | 162.9 | 177.1 | 189.0 | 31.14 | 34.69 | 34.70 |
| 2076 | 153.1 | 167.2 | 179.0 | 28.36 | 31.33 | 31.33 |
| 2077 | 143.2 | 157.3 | 169.1 | 25.59 | 27.96 | 27.97 |
| 2078 | 133.3 | 147.4 | 159.1 | 22.82 | 24.60 | 24.60 |
| 2079 | 123.4 | 137.5 | 149.2 | 20.05 | 21.23 | 21.23 |
| 2080 | 113.5 | 127.6 | 139.2 | 17.27 | 17.87 | 17.87 |
| 2081 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2082 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2083 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2084 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2085 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2086 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2087 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |
| 2088 | 103.6 | 117.7 | 129.3 | 14.50 | 14.50 | 14.50 |

# 3 x 15MW

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $16,310,000 | | | | -$16,310,000 |
| 2030 | $19,572,000 | | | | -$19,572,000 |
| 2031 | $29,358,000 | | | | -$29,358,000 |
| 2032 | | $1,154,900 | $17,109,000 | $2,700,000 | $18,654,100 |
| 2033 | | $1,154,900 | $17,045,700 | $2,700,000 | $18,590,800 |
| 2034 | | $1,154,900 | $16,982,400 | $2,700,000 | $18,527,500 |
| 2035 | | $1,154,900 | $16,919,100 | $2,700,000 | $18,464,200 |
| 2036 | | $1,154,900 | $16,855,800 | $2,700,000 | $18,400,900 |
| 2037 | | $1,154,900 | $16,792,500 | $2,700,000 | $18,337,600 |
| 2038 | | $1,154,900 | $16,729,200 | $2,700,000 | $18,274,300 |
| 2039 | | $1,154,900 | $16,665,900 | $2,700,000 | $18,211,000 |
| 2040 | | $1,154,900 | $16,602,600 | $2,700,000 | $18,147,700 |
| 2041 | | $1,154,900 | $16,539,300 | $2,700,000 | $18,084,400 |
| 2042 | | $1,154,900 | $16,476,000 | $2,700,000 | $18,021,100 |
| 2043 | | $1,154,900 | $16,412,700 | $2,700,000 | $17,957,800 |
| 2044 | | $1,154,900 | $16,349,400 | $2,700,000 | $17,894,500 |
| 2045 | | $1,154,900 | $16,286,100 | $2,700,000 | $17,831,200 |
| 2046 | | $1,154,900 | $16,222,800 | $2,700,000 | $17,767,900 |
| 2047 | | $1,154,900 | $16,159,500 | $2,700,000 | $17,704,600 |
| 2048 | | $1,154,900 | $15,976,250 | $2,700,000 | $17,521,350 |
| 2049 | | $1,154,900 | $15,793,000 | $2,700,000 | $17,338,100 |
| 2050 | | $1,154,900 | $15,609,750 | $2,700,000 | $17,154,850 |
| 2051 | | $1,154,900 | $15,426,500 | $2,700,000 | $16,971,600 |
| 2052 | | $1,154,900 | $15,243,250 | $2,700,000 | $16,788,350 |
| 2053 | | $1,154,900 | $15,060,000 | $2,700,000 | $16,605,100 |
| 2054 | | $1,154,900 | $14,876,750 | $2,700,000 | $16,421,850 |
| 2055 | | $1,154,900 | $14,693,500 | $2,700,000 | $16,238,600 |
| 2056 | | $1,154,900 | $14,510,250 | $2,700,000 | $16,055,350 |
| 2057 | | $1,154,900 | $14,327,000 | $2,700,000 | $15,872,100 |
| 2058 | | $1,154,900 | $14,143,750 | $2,700,000 | $15,688,850 |
| 2059 | | $1,154,900 | $13,960,500 | $2,700,000 | $15,505,600 |
| 2060 | | $1,154,900 | $13,777,250 | $2,700,000 | $15,322,350 |
| 2061 | $19,624,031 | $1,154,900 | $13,594,000 | $2,700,000 | -$4,484,931 |
| 2062 | | $1,154,900 | $13,410,750 | $2,700,000 | $14,955,850 |
| 2063 | | $1,154,900 | $13,227,500 | $2,700,000 | $14,772,600 |
| 2064 | | $1,154,900 | $13,044,250 | $2,700,000 | $14,589,350 |
| 2065 | | $1,154,900 | $12,861,000 | $2,700,000 | $14,406,100 |
| 2066 | | $1,154,900 | $12,448,125 | $2,700,000 | $13,993,225 |
| 2067 | | $1,154,900 | $12,035,250 | $2,700,000 | $13,580,350 |
| 2068 | | $1,154,900 | $11,622,375 | $2,700,000 | $13,167,475 |
| 2069 | | $1,154,900 | $11,209,500 | $2,700,000 | $12,754,600 |
| 2070 | | $1,154,900 | $10,796,625 | $2,700,000 | $12,341,725 |
| 2071 | | $1,154,900 | $10,383,750 | $2,700,000 | $11,928,850 |
| 2072 | | $1,154,900 | $9,970,875 | $2,700,000 | $11,515,975 |
| 2073 | | $1,154,900 | $9,558,000 | $2,700,000 | $11,103,100 |
| 2074 | | $1,154,900 | $9,112,909 | $2,533,636 | $10,491,645 |
| 2075 | | $1,154,900 | $8,667,818 | $2,367,273 | $9,880,191 |
| 2076 | | $1,154,900 | $8,222,727 | $2,200,909 | $9,268,736 |
| 2077 | | $1,154,900 | $7,777,636 | $2,034,545 | $8,657,282 |
| 2078 | | $1,154,900 | $7,332,545 | $1,868,182 | $8,045,827 |
| 2079 | | $1,154,900 | $6,887,455 | $1,701,818 | $7,434,373 |
| 2080 | | $1,154,900 | $6,442,364 | $1,535,455 | $6,822,918 |
| 2081 | | $1,154,900 | $5,997,273 | $1,369,091 | $6,211,464 |
| 2082 | | $1,154,900 | $5,552,182 | $1,202,727 | $5,600,009 |
| 2083 | | $1,154,900 | $5,107,091 | $1,036,364 | $4,988,555 |
| 2084 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2085 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2086 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2087 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2088 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2089 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2090 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |
| 2091 | | $1,154,900 | $4,662,000 | $870,000 | $4,377,100 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $9,342,000 |
| Equipment Cost | $18,202,000 |
| Transmission System | $21,381,000 |
| **Subtotal** | **$48,925,000** |
| Contingencies | $7,805,000 |
| Engineering & Administration (15%) | $8,510,000 |
| **Project Development Cost** | **$65,240,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $128,920 |
| Equipment Maintenance | $601,804 |
| Transmission Maintenance | $424,146 |
| **Total O&M** | **$1,154,900** |
| **Internal Rate of Return** | **23.4%** |

## ECONOMIC ANALYSIS

# 3 x 20MW

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $18,029,500 | | | | -$18,029,500 |
| 2030 | $21,635,400 | | | | -$21,635,400 |
| 2031 | $32,453,100 | | | | -$32,453,100 |
| 2032 | | $1,296,800 | $19,062,000 | $3,600,000 | $21,365,200 |
| 2033 | | $1,296,800 | $18,986,100 | $3,600,000 | $21,289,300 |
| 2034 | | $1,296,800 | $18,910,200 | $3,600,000 | $21,213,400 |
| 2035 | | $1,296,800 | $18,834,300 | $3,600,000 | $21,137,500 |
| 2036 | | $1,296,800 | $18,758,400 | $3,600,000 | $21,061,600 |
| 2037 | | $1,296,800 | $18,682,500 | $3,600,000 | $20,985,700 |
| 2038 | | $1,296,800 | $18,606,600 | $3,600,000 | $20,909,800 |
| 2039 | | $1,296,800 | $18,530,700 | $3,600,000 | $20,833,900 |
| 2040 | | $1,296,800 | $18,454,800 | $3,600,000 | $20,758,000 |
| 2041 | | $1,296,800 | $18,378,900 | $3,600,000 | $20,682,100 |
| 2042 | | $1,296,800 | $18,303,000 | $3,600,000 | $20,606,200 |
| 2043 | | $1,296,800 | $18,227,100 | $3,600,000 | $20,530,300 |
| 2044 | | $1,296,800 | $18,151,200 | $3,600,000 | $20,454,400 |
| 2045 | | $1,296,800 | $18,075,300 | $3,600,000 | $20,378,500 |
| 2046 | | $1,296,800 | $17,999,400 | $3,600,000 | $20,302,600 |
| 2047 | | $1,296,800 | $17,923,500 | $3,600,000 | $20,226,700 |
| 2048 | | $1,296,800 | $17,678,750 | $3,600,000 | $19,981,950 |
| 2049 | | $1,296,800 | $17,434,000 | $3,600,000 | $19,737,200 |
| 2050 | | $1,296,800 | $17,189,250 | $3,600,000 | $19,492,450 |
| 2051 | | $1,296,800 | $16,944,500 | $3,600,000 | $19,247,700 |
| 2052 | | $1,296,800 | $16,699,750 | $3,600,000 | $19,002,950 |
| 2053 | | $1,296,800 | $16,455,000 | $3,600,000 | $18,758,200 |
| 2054 | | $1,296,800 | $16,210,250 | $3,600,000 | $18,513,450 |
| 2055 | | $1,296,800 | $15,965,500 | $3,600,000 | $18,268,700 |
| 2056 | | $1,296,800 | $15,720,750 | $3,600,000 | $18,023,950 |
| 2057 | | $1,296,800 | $15,476,000 | $3,600,000 | $17,779,200 |
| 2058 | | $1,296,800 | $15,231,250 | $3,600,000 | $17,534,450 |
| 2059 | | $1,296,800 | $14,986,500 | $3,600,000 | $17,289,700 |
| 2060 | | $1,296,800 | $14,741,750 | $3,600,000 | $17,044,950 |
| 2061 | $23,469,703 | $1,296,800 | $14,497,000 | $3,600,000 | -$6,669,503 |
| 2062 | | $1,296,800 | $14,252,250 | $3,600,000 | $16,555,450 |
| 2063 | | $1,296,800 | $14,007,500 | $3,600,000 | $16,310,700 |
| 2064 | | $1,296,800 | $13,762,750 | $3,600,000 | $16,065,950 |
| 2065 | | $1,296,800 | $13,518,000 | $3,600,000 | $15,821,200 |
| 2066 | | $1,296,800 | $13,102,875 | $3,536,400 | $15,342,475 |
| 2067 | | $1,296,800 | $12,687,750 | $3,472,800 | $14,863,750 |
| 2068 | | $1,296,800 | $12,272,625 | $3,409,200 | $14,385,025 |
| 2069 | | $1,296,800 | $11,857,500 | $3,345,600 | $13,906,300 |
| 2070 | | $1,296,800 | $11,442,375 | $3,282,000 | $13,427,575 |
| 2071 | | $1,296,800 | $11,027,250 | $3,218,400 | $12,948,850 |
| 2072 | | $1,296,800 | $10,612,125 | $3,154,800 | $12,470,125 |
| 2073 | | $1,296,800 | $10,197,000 | $3,091,200 | $11,991,400 |
| 2074 | | $1,296,800 | $9,751,500 | $2,889,273 | $11,343,973 |
| 2075 | | $1,296,800 | $9,306,000 | $2,687,345 | $10,696,545 |
| 2076 | | $1,296,800 | $8,860,500 | $2,485,418 | $10,049,118 |
| 2077 | | $1,296,800 | $8,415,000 | $2,283,491 | $9,401,691 |
| 2078 | | $1,296,800 | $7,969,500 | $2,081,564 | $8,754,264 |
| 2079 | | $1,296,800 | $7,524,000 | $1,879,636 | $8,106,836 |
| 2080 | | $1,296,800 | $7,078,500 | $1,677,709 | $7,459,409 |
| 2081 | | $1,296,800 | $6,633,000 | $1,475,782 | $6,811,982 |
| 2082 | | $1,296,800 | $6,187,500 | $1,273,855 | $6,164,555 |
| 2083 | | $1,296,800 | $5,742,000 | $1,071,927 | $5,517,127 |
| 2084 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2085 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2086 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2087 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2088 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2089 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2090 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |
| 2091 | | $1,296,800 | $5,296,500 | $870,000 | $4,869,700 |

### Cost Summary

| | |
|---|---|
| Civil Work Cost | $10,572,000 |
| Equipment Cost | $21,769,000 |
| Transmission System | $21,731,000 |
| **Subtotal** | **$54,072,000** |
| Contingencies | $8,639,000 |
| Engineering & Administration (15%) | $9,407,000 |
| **Project Development Cost** | **$72,118,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $145,894 |
| Equipment Maintenance | $719,738 |
| Transmission Maintenance | $431,089 |
| **Total O&M** | **$1,296,800** |
| **Internal Rate of Return** | **24.1%** |

## ECONOMIC ANALYSIS

# 3 x 25MW

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $20,480,750 | | | | -$20,480,750 |
| 2030 | $24,576,900 | | | | -$24,576,900 |
| 2031 | $36,865,350 | | | | -$36,865,350 |
| 2032 | | $1,492,500 | $20,272,500 | $4,500,000 | $23,280,000 |
| 2033 | | $1,492,500 | $20,166,900 | $4,500,000 | $23,174,400 |
| 2034 | | $1,492,500 | $20,061,300 | $4,500,000 | $23,068,800 |
| 2035 | | $1,492,500 | $19,955,700 | $4,500,000 | $22,963,200 |
| 2036 | | $1,492,500 | $19,850,100 | $4,500,000 | $22,857,600 |
| 2037 | | $1,492,500 | $19,744,500 | $4,500,000 | $22,752,000 |
| 2038 | | $1,492,500 | $19,638,900 | $4,500,000 | $22,646,400 |
| 2039 | | $1,492,500 | $19,533,300 | $4,500,000 | $22,540,800 |
| 2040 | | $1,492,500 | $19,427,700 | $4,500,000 | $22,435,200 |
| 2041 | | $1,492,500 | $19,322,100 | $4,500,000 | $22,329,600 |
| 2042 | | $1,492,500 | $19,216,500 | $4,500,000 | $22,224,000 |
| 2043 | | $1,492,500 | $19,110,900 | $4,500,000 | $22,118,400 |
| 2044 | | $1,492,500 | $19,005,300 | $4,500,000 | $22,012,800 |
| 2045 | | $1,492,500 | $18,899,700 | $4,500,000 | $21,907,200 |
| 2046 | | $1,492,500 | $18,794,100 | $4,500,000 | $21,801,600 |
| 2047 | | $1,492,500 | $18,688,500 | $4,500,000 | $21,696,000 |
| 2048 | | $1,492,500 | $18,434,000 | $4,500,000 | $21,441,500 |
| 2049 | | $1,492,500 | $18,179,500 | $4,500,000 | $21,187,000 |
| 2050 | | $1,492,500 | $17,925,000 | $4,500,000 | $20,932,500 |
| 2051 | | $1,492,500 | $17,670,500 | $4,500,000 | $20,678,000 |
| 2052 | | $1,492,500 | $17,416,000 | $4,500,000 | $20,423,500 |
| 2053 | | $1,492,500 | $17,161,500 | $4,500,000 | $20,169,000 |
| 2054 | | $1,492,500 | $16,907,000 | $4,500,000 | $19,914,500 |
| 2055 | | $1,492,500 | $16,652,500 | $4,500,000 | $19,660,000 |
| 2056 | | $1,492,500 | $16,398,000 | $4,500,000 | $19,405,500 |
| 2057 | | $1,492,500 | $16,143,500 | $4,500,000 | $19,151,000 |
| 2058 | | $1,492,500 | $15,889,000 | $4,500,000 | $18,896,500 |
| 2059 | | $1,492,500 | $15,634,500 | $4,500,000 | $18,642,000 |
| 2060 | | $1,492,500 | $15,380,000 | $4,500,000 | $18,387,500 |
| 2061 | $28,650,094 | $1,492,500 | $15,125,500 | $4,500,000 | -$10,517,094 |
| 2062 | | $1,492,500 | $14,871,000 | $4,500,000 | $17,878,500 |
| 2063 | | $1,492,500 | $14,616,500 | $4,500,000 | $17,624,000 |
| 2064 | | $1,492,500 | $14,362,000 | $4,500,000 | $17,369,500 |
| 2065 | | $1,492,500 | $14,107,500 | $4,500,000 | $17,115,000 |
| 2066 | | $1,492,500 | $13,686,750 | $4,323,975 | $16,518,225 |
| 2067 | | $1,492,500 | $13,266,000 | $4,147,950 | $15,921,450 |
| 2068 | | $1,492,500 | $12,845,250 | $3,971,925 | $15,324,675 |
| 2069 | | $1,492,500 | $12,424,500 | $3,795,900 | $14,727,900 |
| 2070 | | $1,492,500 | $12,003,750 | $3,619,875 | $14,131,125 |
| 2071 | | $1,492,500 | $11,583,000 | $3,443,850 | $13,534,350 |
| 2072 | | $1,492,500 | $11,162,250 | $3,267,825 | $12,937,575 |
| 2073 | | $1,492,500 | $10,741,500 | $3,091,800 | $12,340,800 |
| 2074 | | $1,492,500 | $10,293,955 | $2,889,818 | $11,691,273 |
| 2075 | | $1,492,500 | $9,846,409 | $2,687,836 | $11,041,745 |
| 2076 | | $1,492,500 | $9,398,864 | $2,485,855 | $10,392,218 |
| 2077 | | $1,492,500 | $8,951,318 | $2,283,873 | $9,742,691 |
| 2078 | | $1,492,500 | $8,503,773 | $2,081,891 | $9,093,164 |
| 2079 | | $1,492,500 | $8,056,227 | $1,879,909 | $8,443,636 |
| 2080 | | $1,492,500 | $7,608,682 | $1,677,927 | $7,794,109 |
| 2081 | | $1,492,500 | $7,161,136 | $1,475,945 | $7,144,582 |
| 2082 | | $1,492,500 | $6,713,591 | $1,273,964 | $6,495,055 |
| 2083 | | $1,492,500 | $6,266,045 | $1,071,982 | $5,845,527 |
| 2084 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2085 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2086 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2087 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2088 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2089 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2090 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |
| 2091 | | $1,492,500 | $5,818,500 | $870,000 | $5,196,000 |

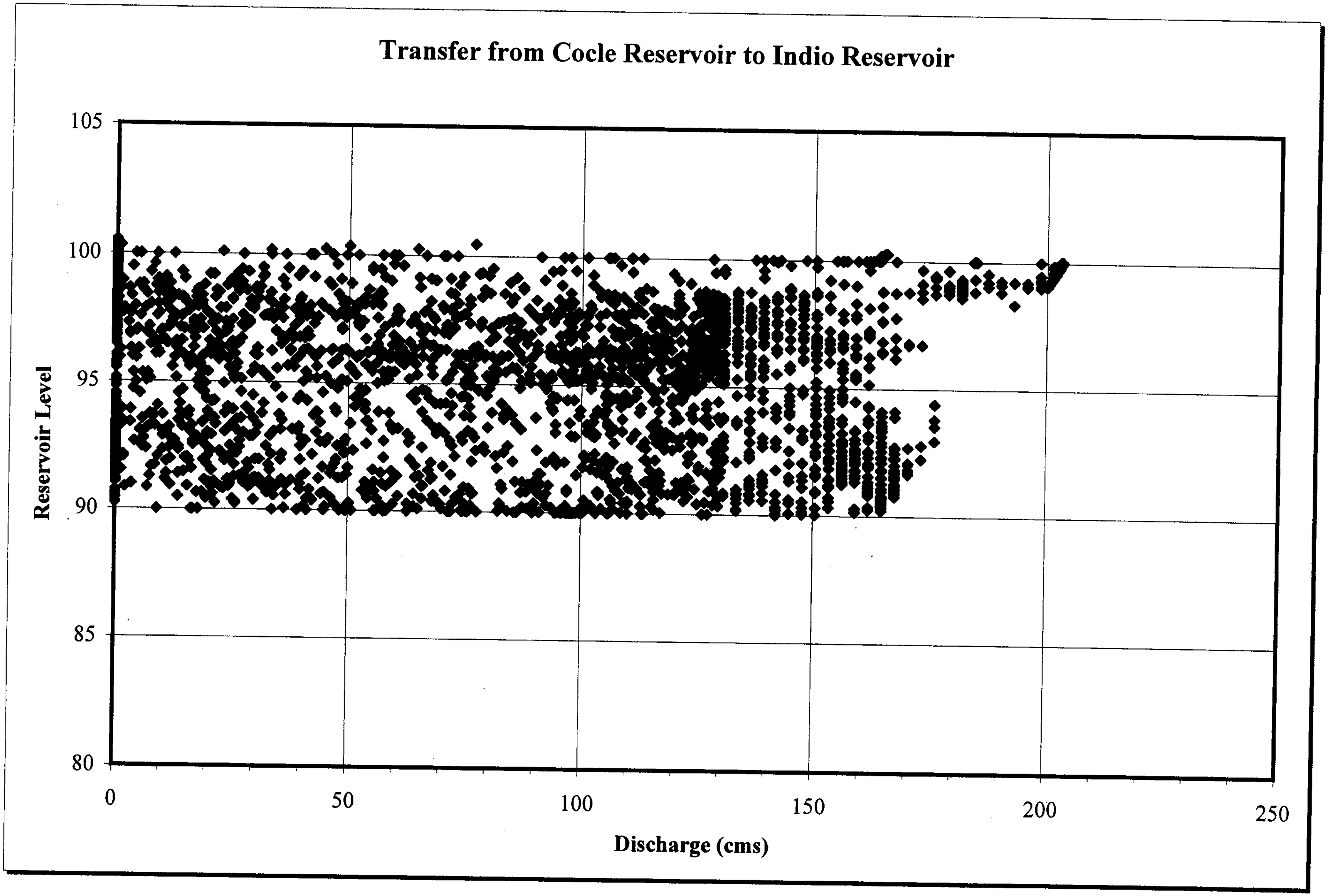
### Cost Summary

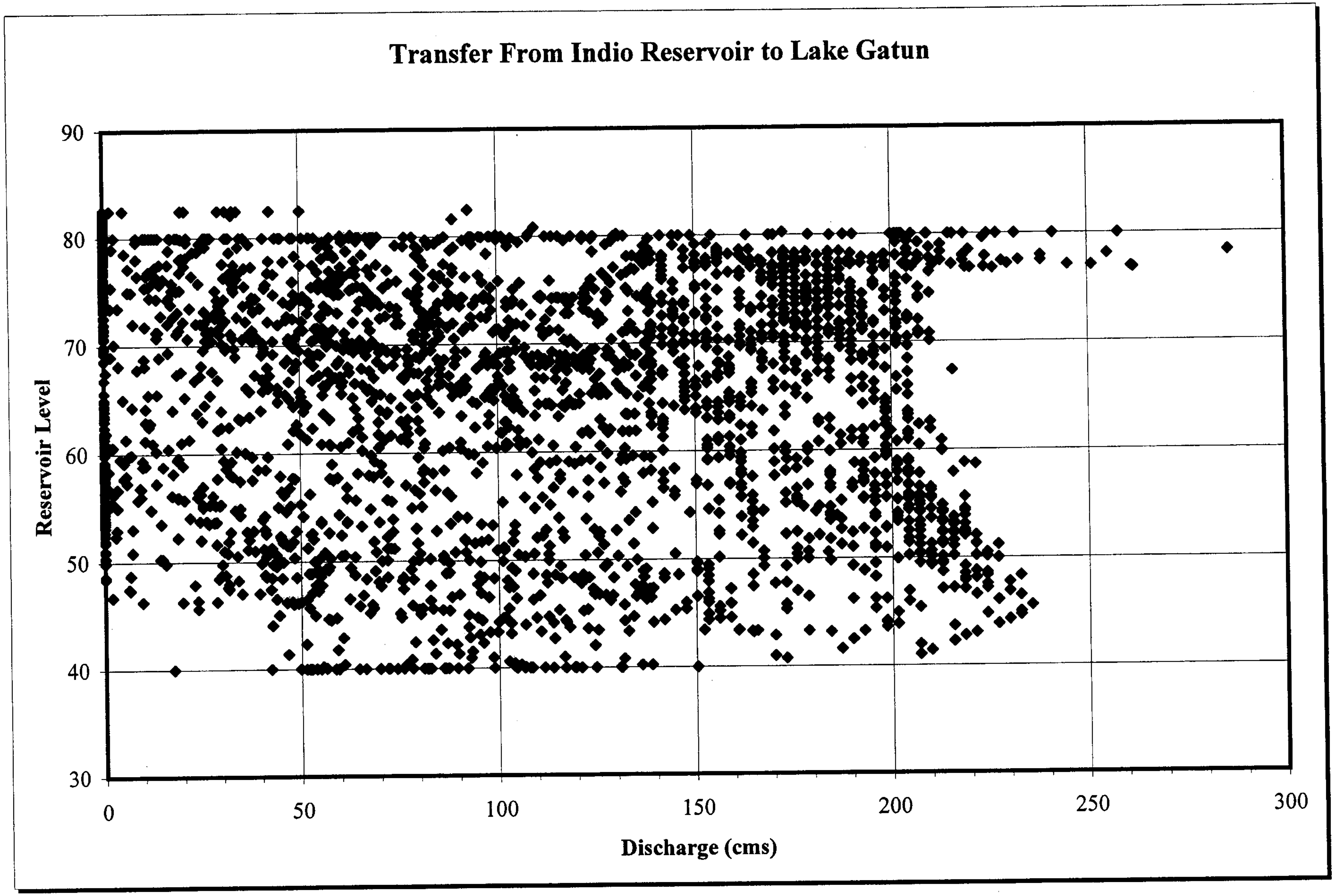
| | |
|---|---|
| Civil Work Cost | $12,737,000 |
| Equipment Cost | $26,574,000 |
| Transmission System | $22,081,000 |
| **Subtotal** | **$61,392,000** |
| Contingencies | $9,845,000 |
| Engineering & Administration (15%) | $10,686,000 |
| **Project Development Cost** | **$81,923,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $175,771 |
| Equipment Maintenance | $878,603 |
| Transmission Maintenance | $438,032 |
| **Total O&M** | **$1,492,500** |
| **Internal Rate of Return** | **23.2%** |

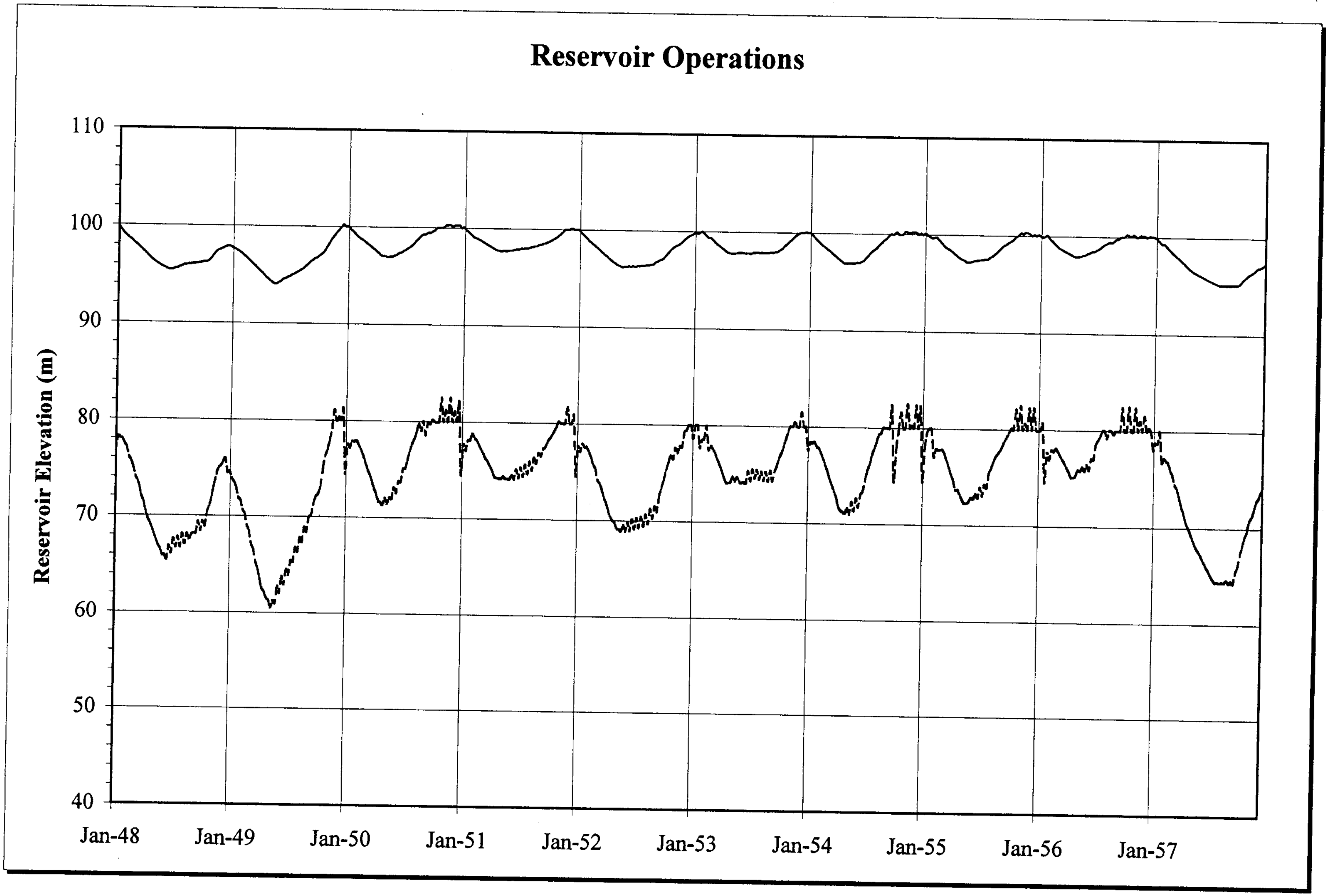
# ATTACHMENT 6

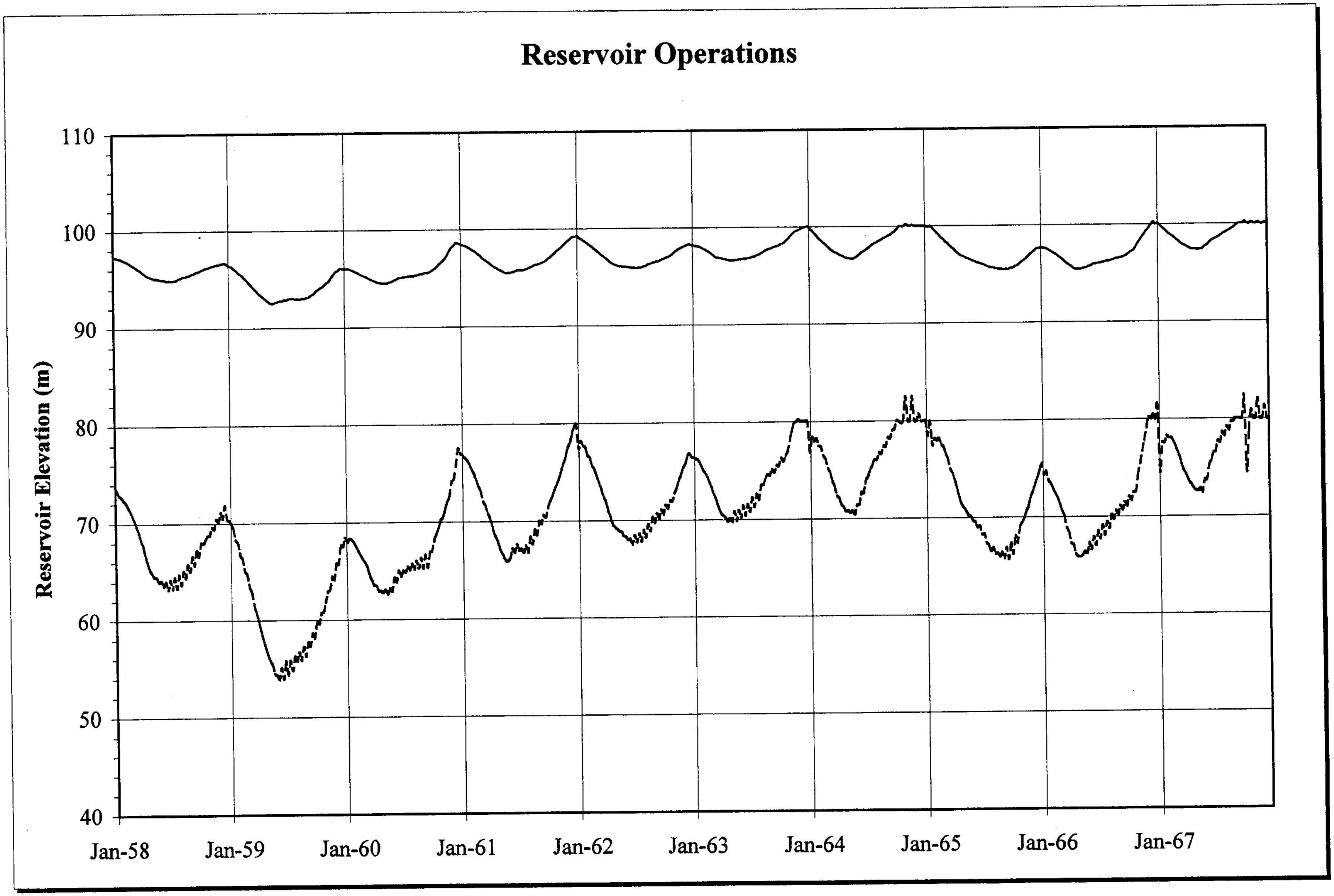
# PROPOSED RESERVOIR OPERATION

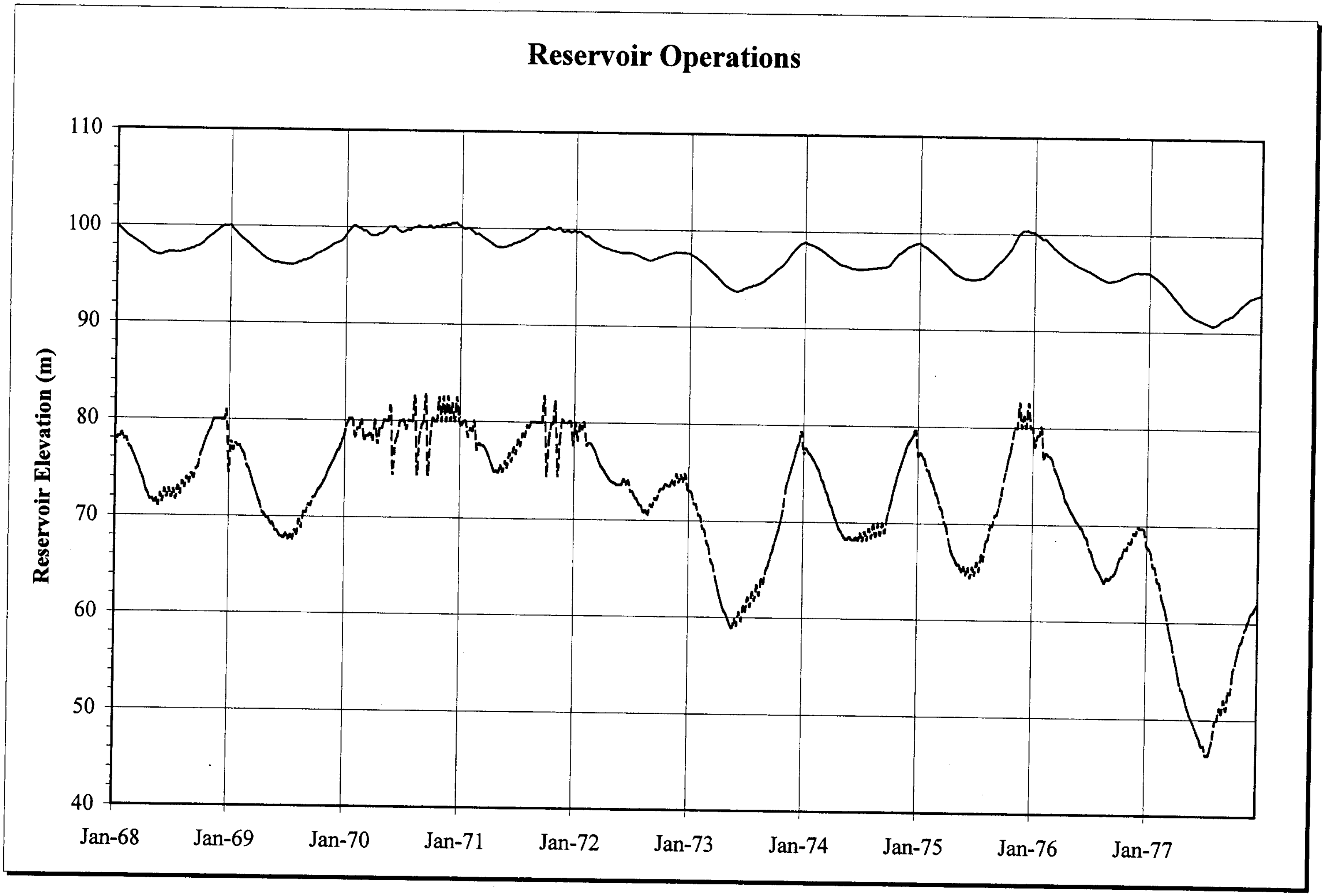
# COCLE 90 - 100

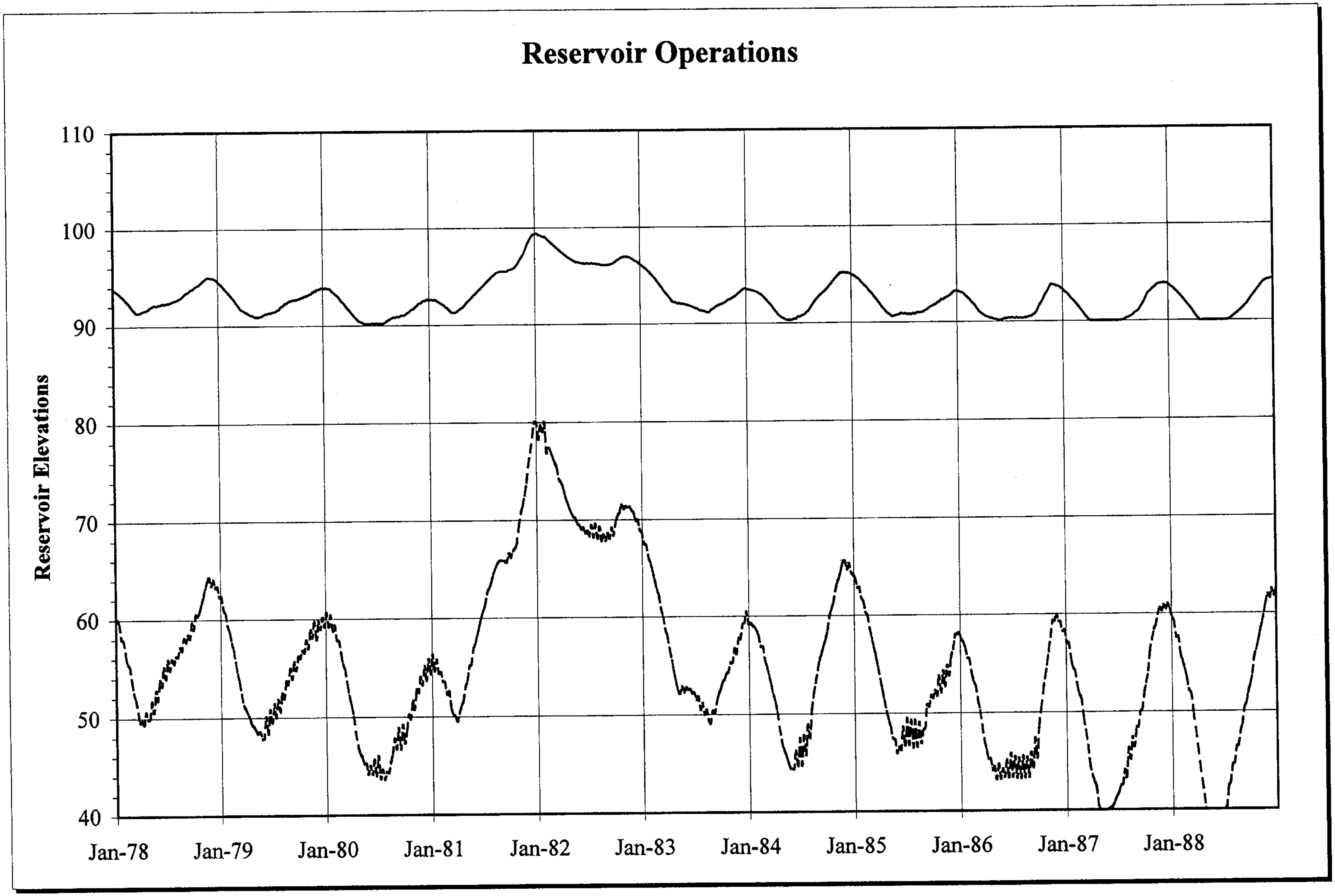

Transfer from Cocle Reservoir to Indio Reservoir
105
100
95
90
85
80
Reservoir Level
0
50
100
150
200
250
Discharge (cms)

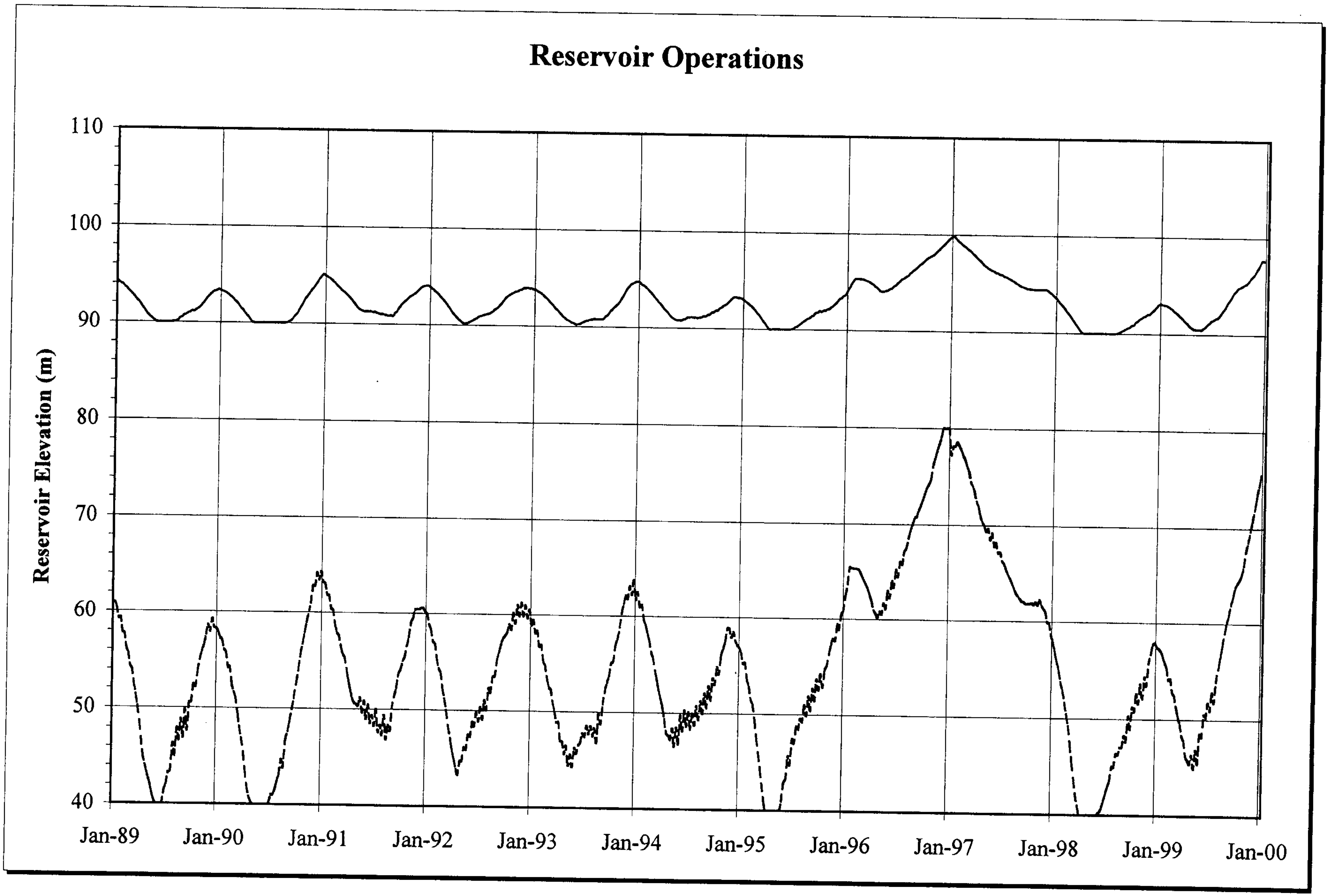

Transfer From Indio Reservoir to Lake Gatun
90
80
70
60
50
40
30
Reservoir Level
0
50
100
150
200
250
300
Discharge (cms)

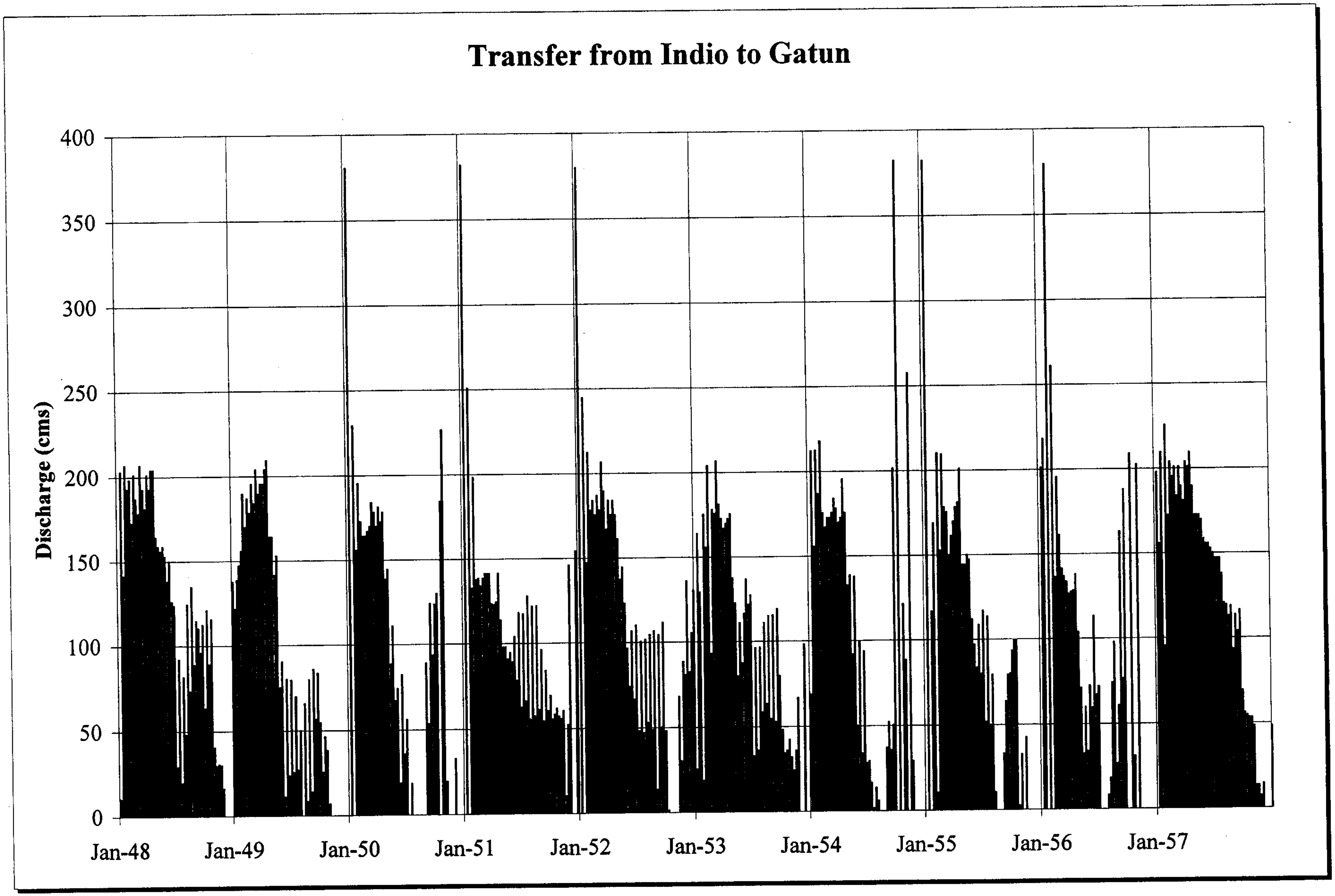

Reservoir Operations
Reservoir Elevation (m)
110
100
90
80
70
60
50
40
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57

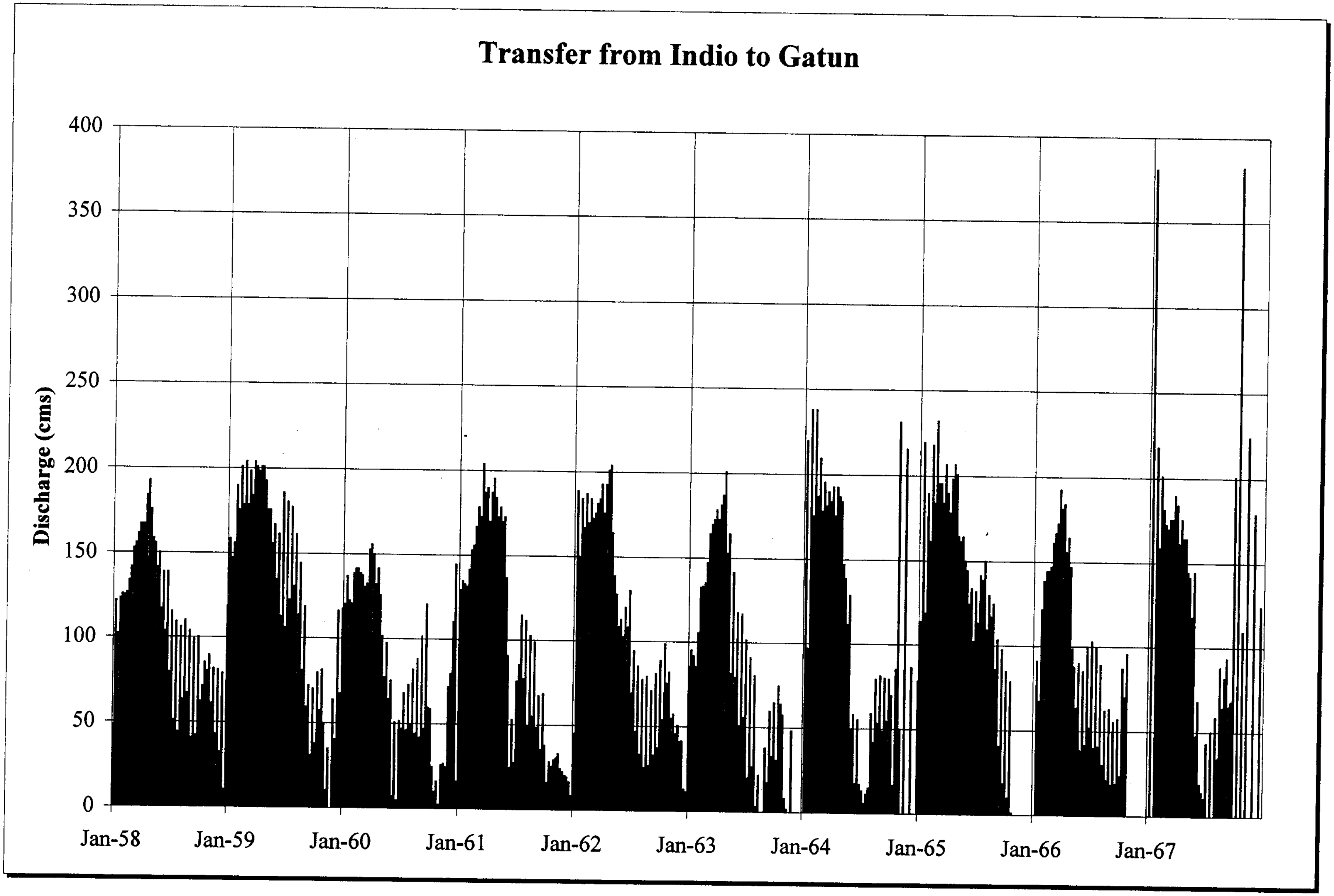

Reservoir Operations
110
100
90
80
70
60
50
40
Reservoir Elevation (m)
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67

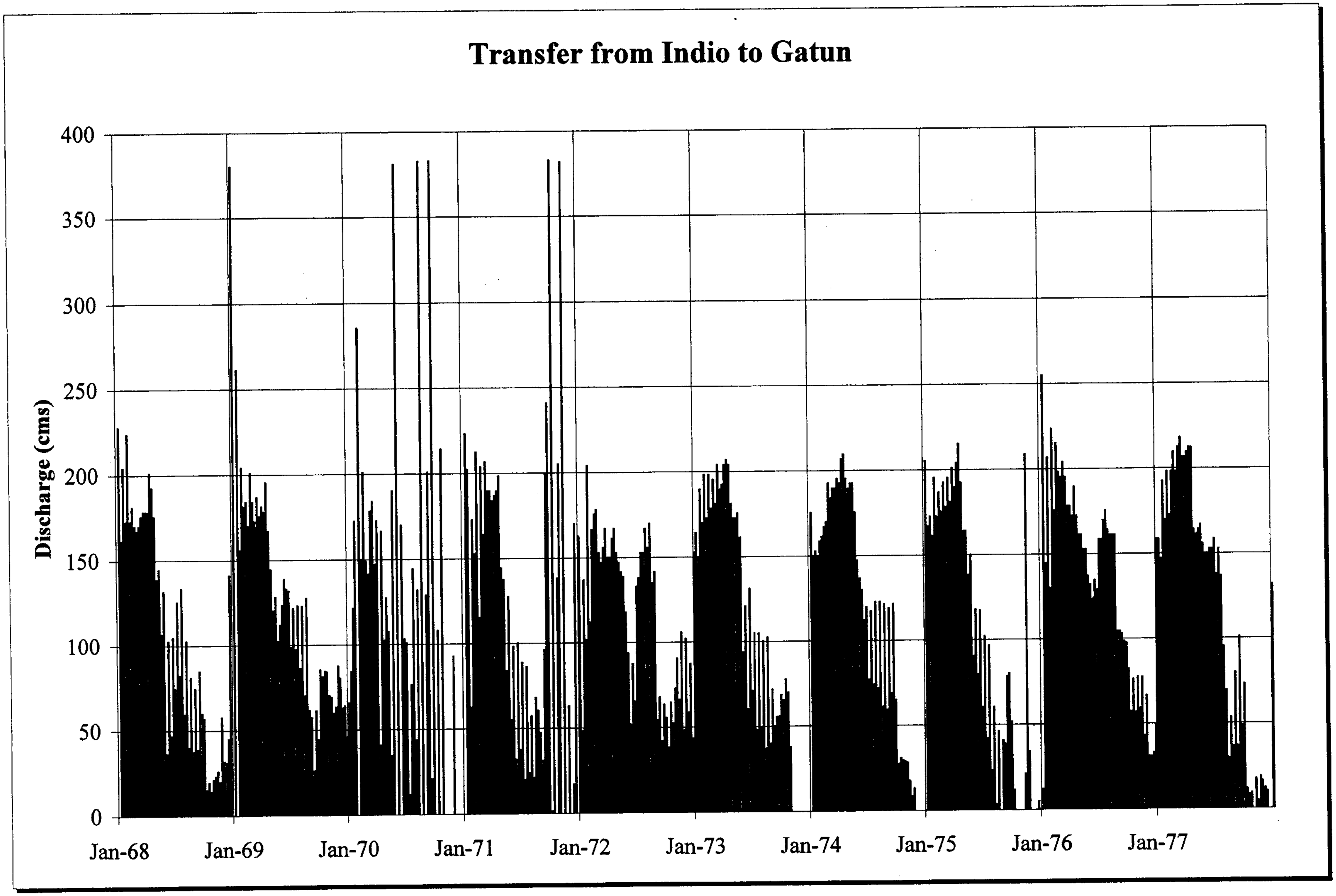

Reservoir Operations
Reservoir Elevation (m)
110
100
90
80
70
60
50
40
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77

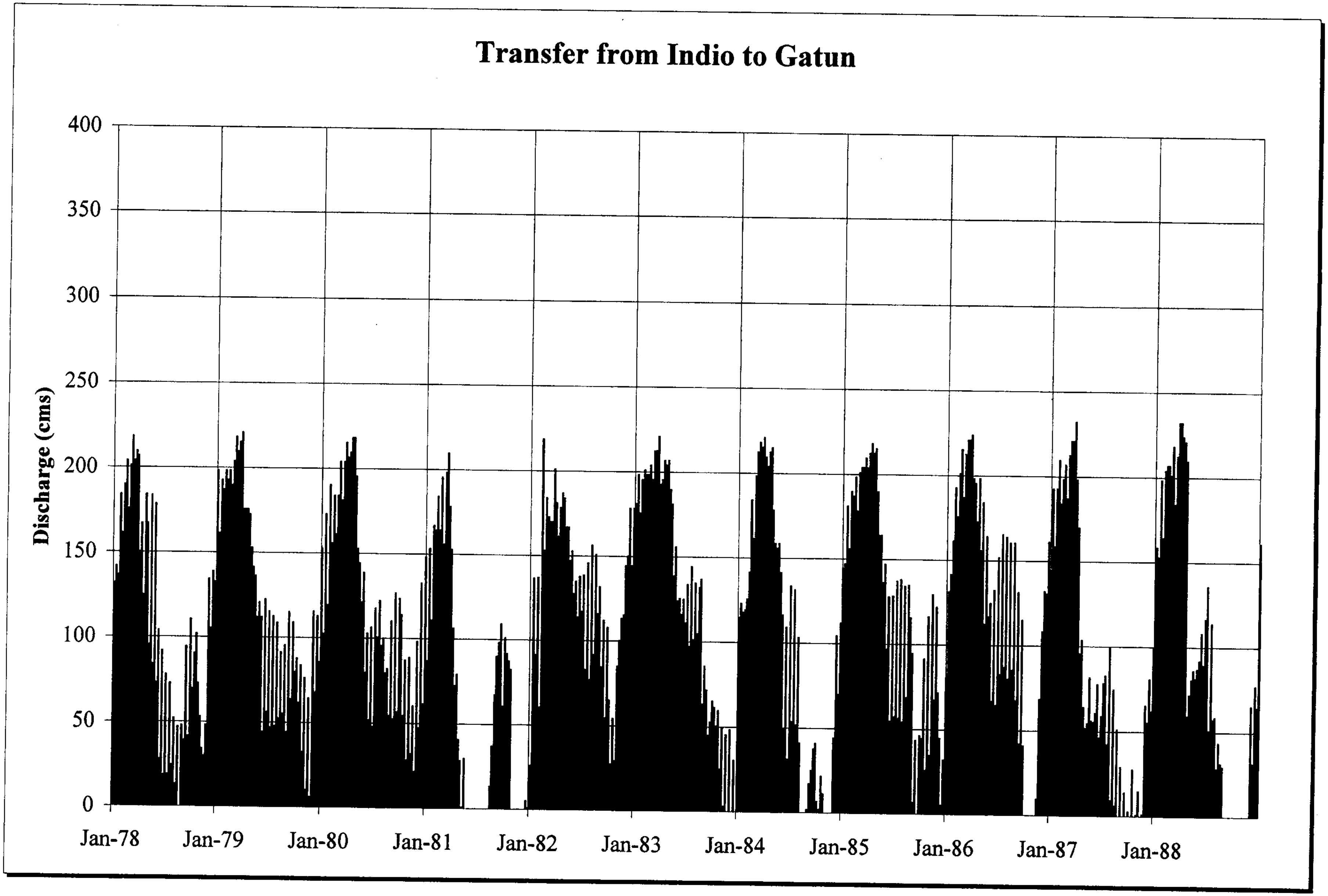

Reservoir Operations
110
100
90
80
70
60
50
40
Reservoir Elevations
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88

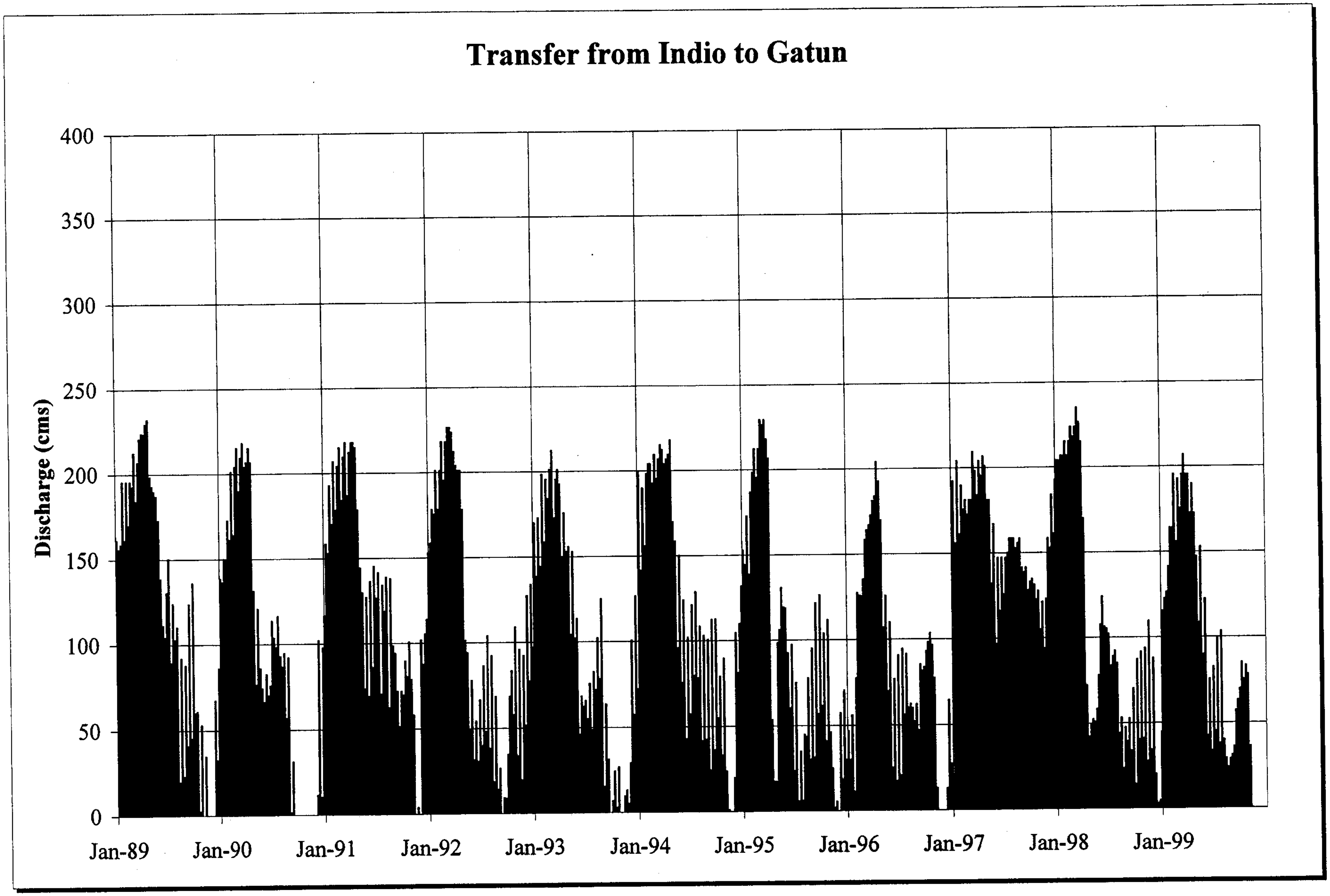

Reservoir Operations
Reservoir Elevation (m)
110
100
90
80
70
60
50
40
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

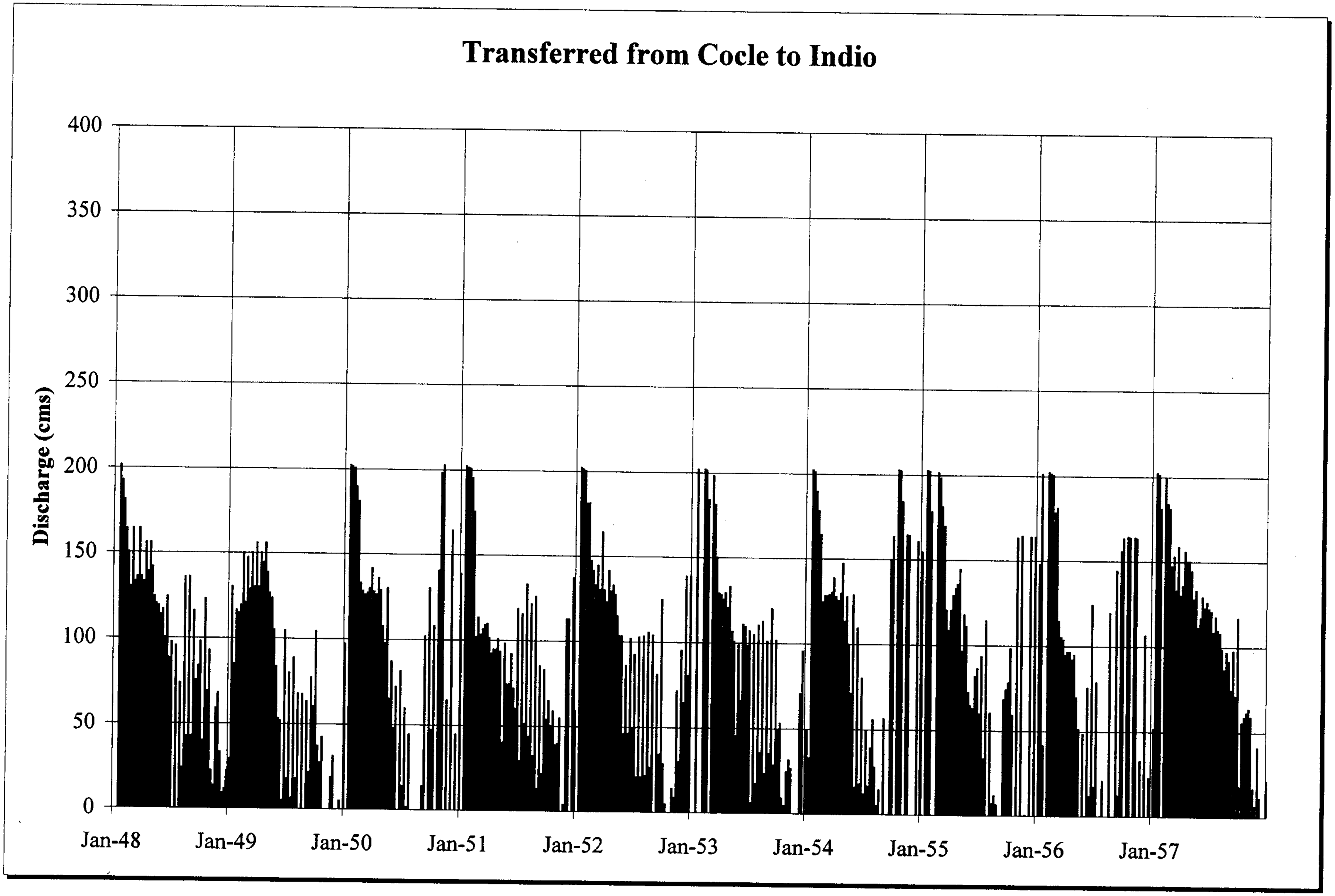

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57

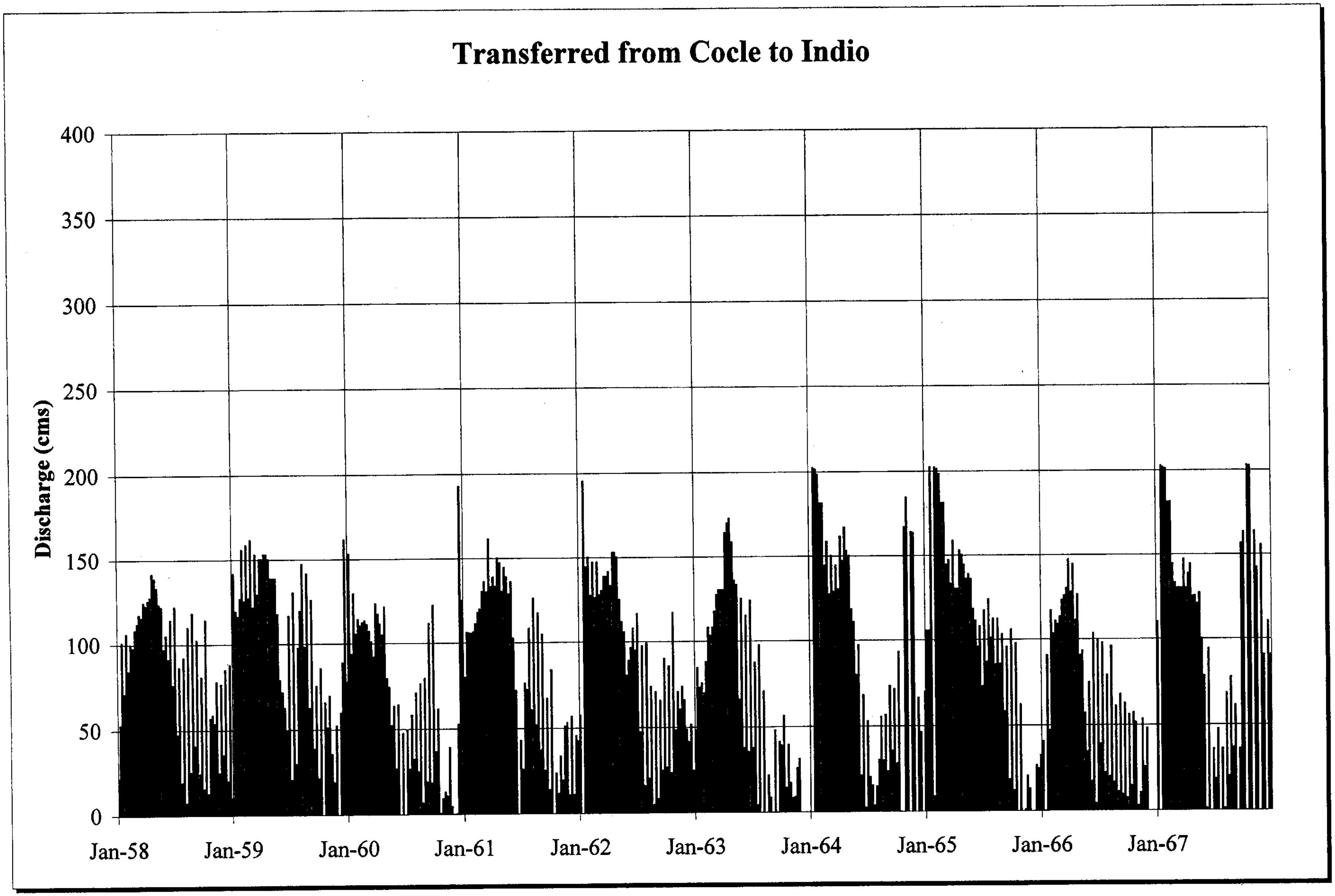

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67

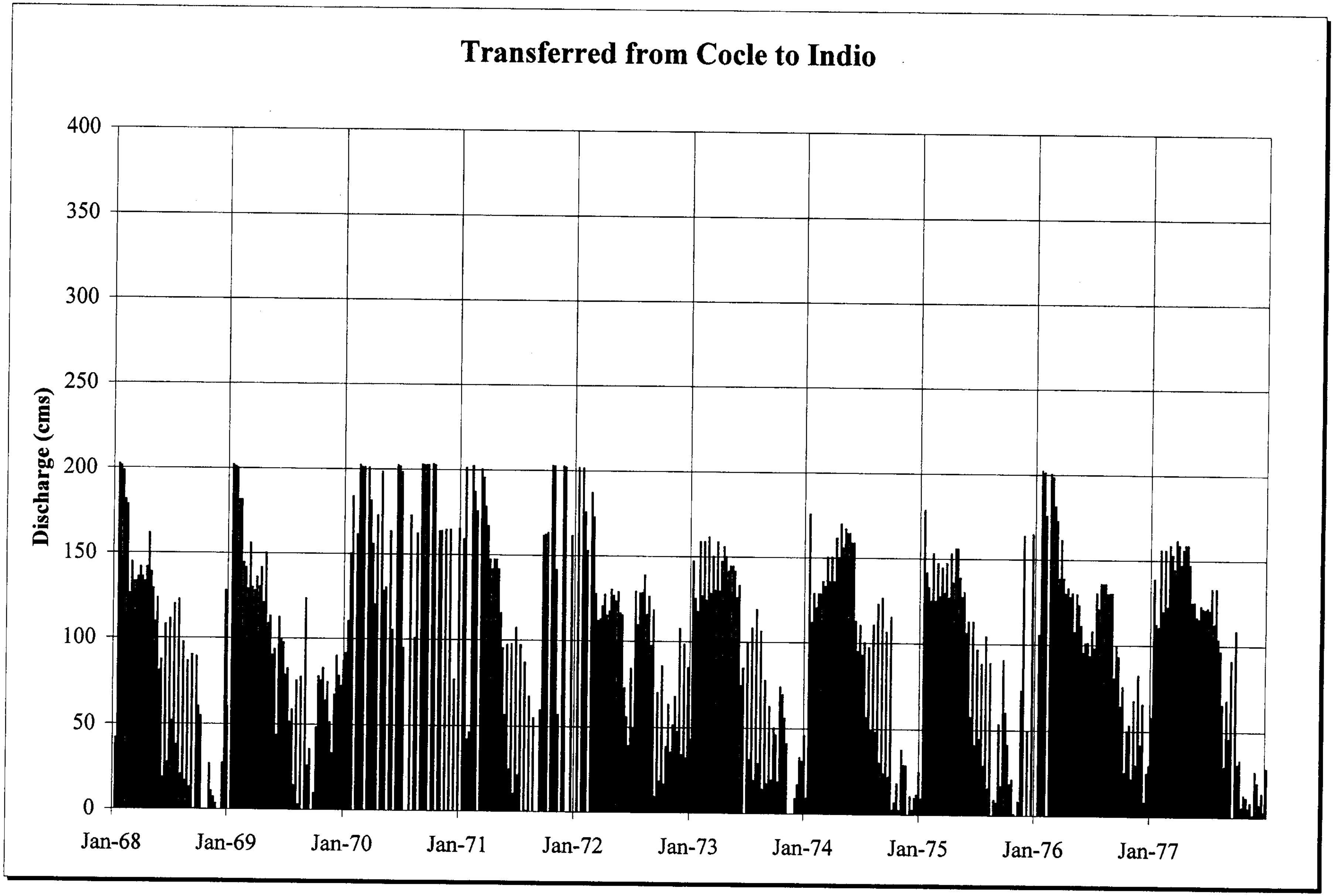

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77

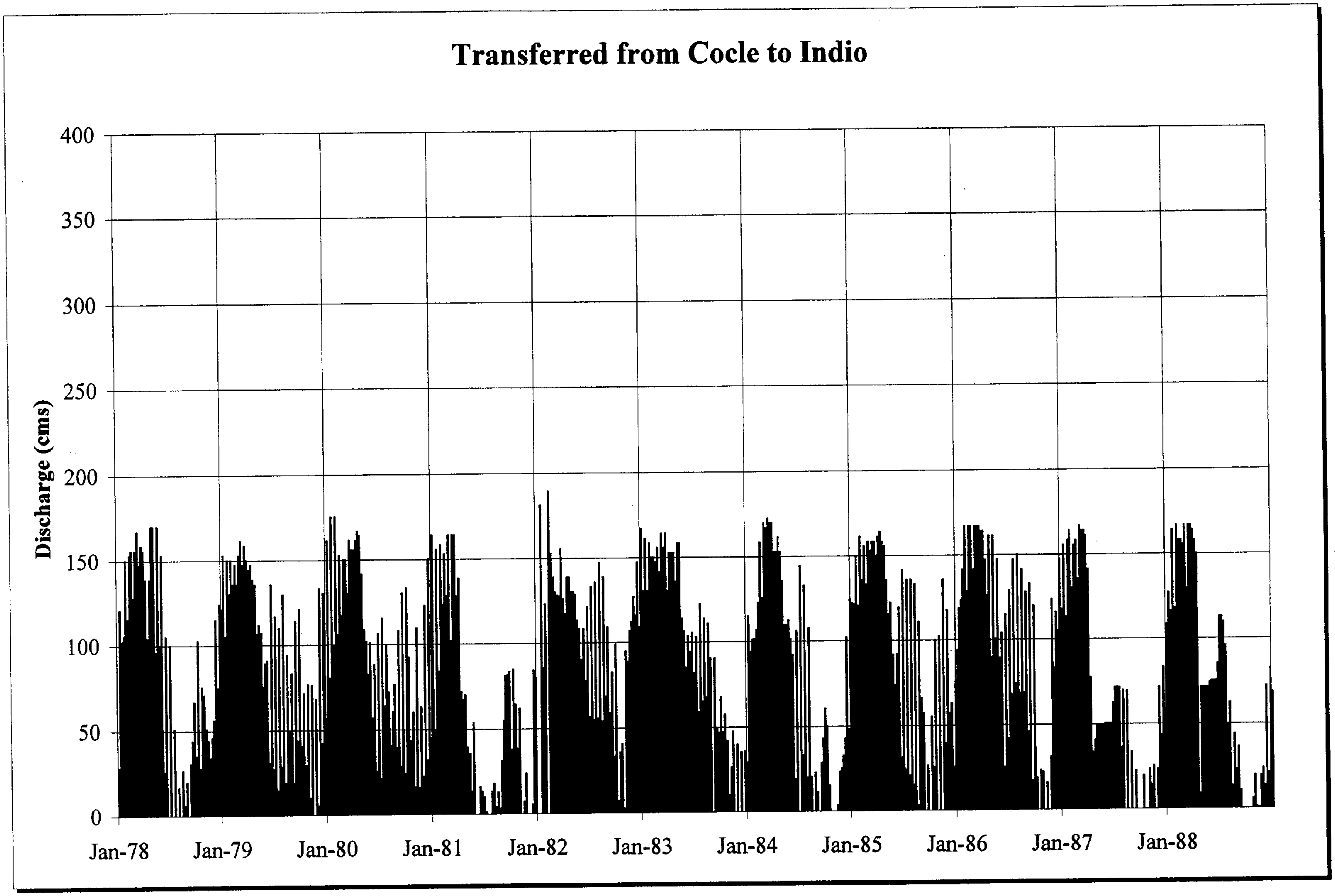

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88

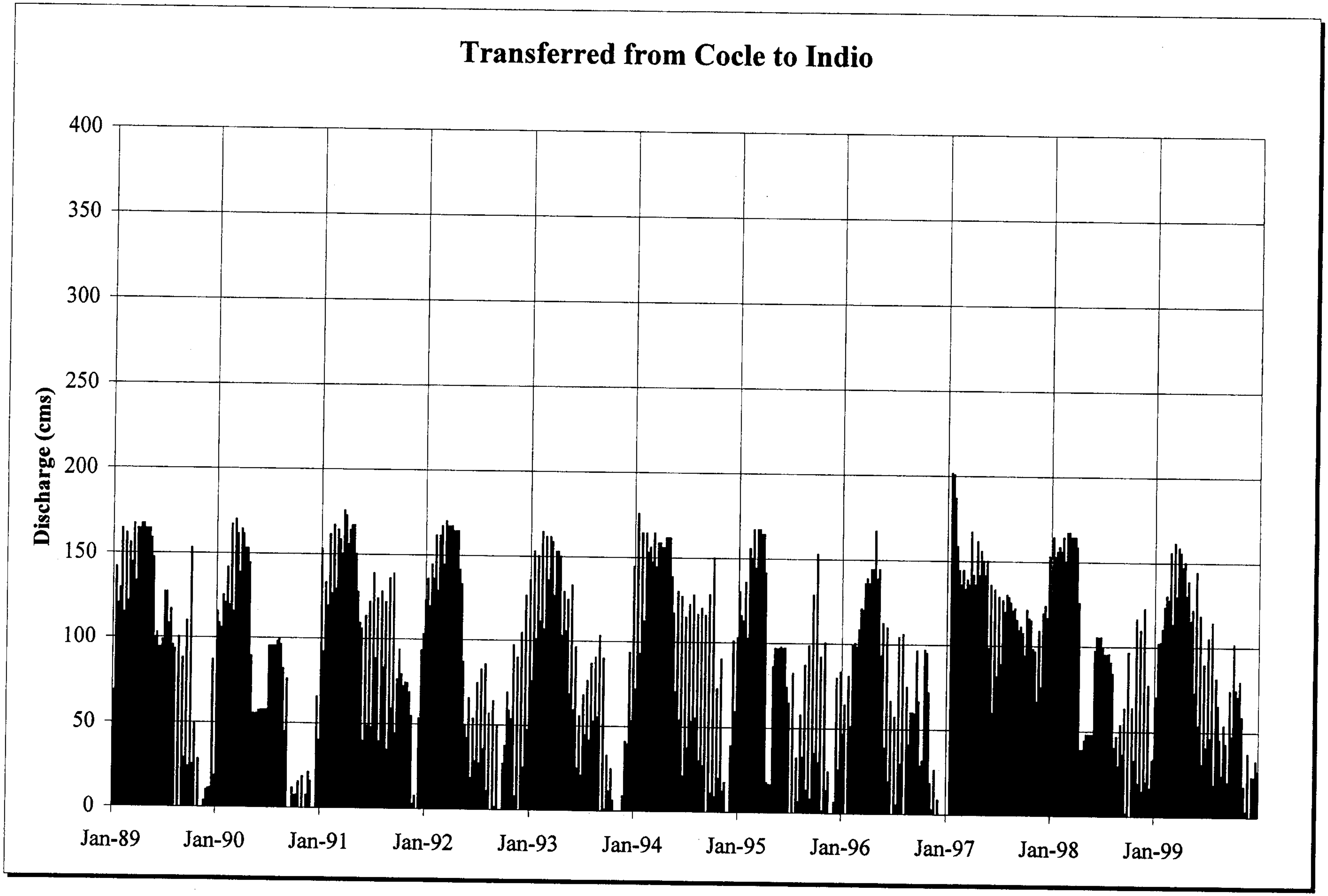

Transfer from Indio to Gatun
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

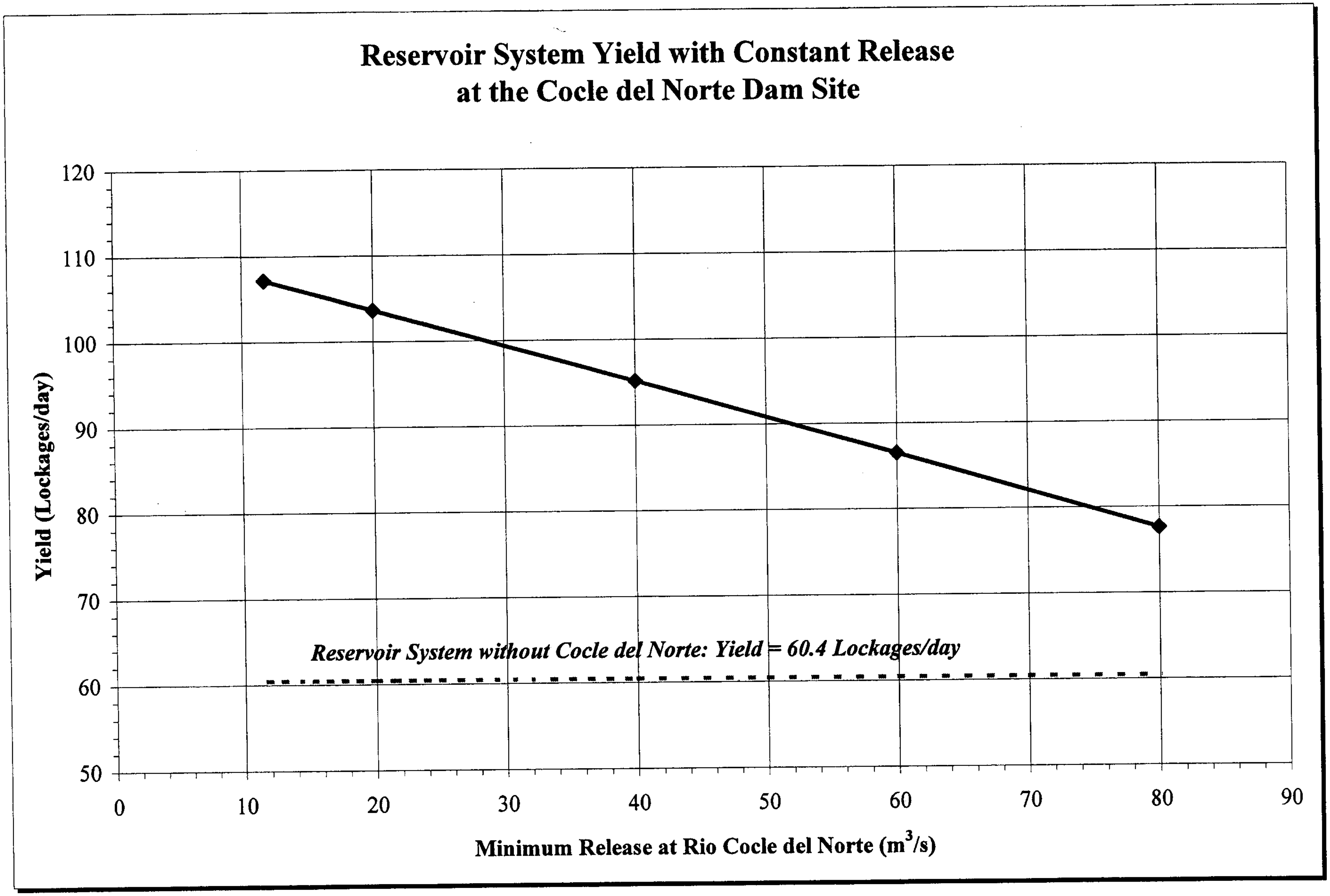

Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57

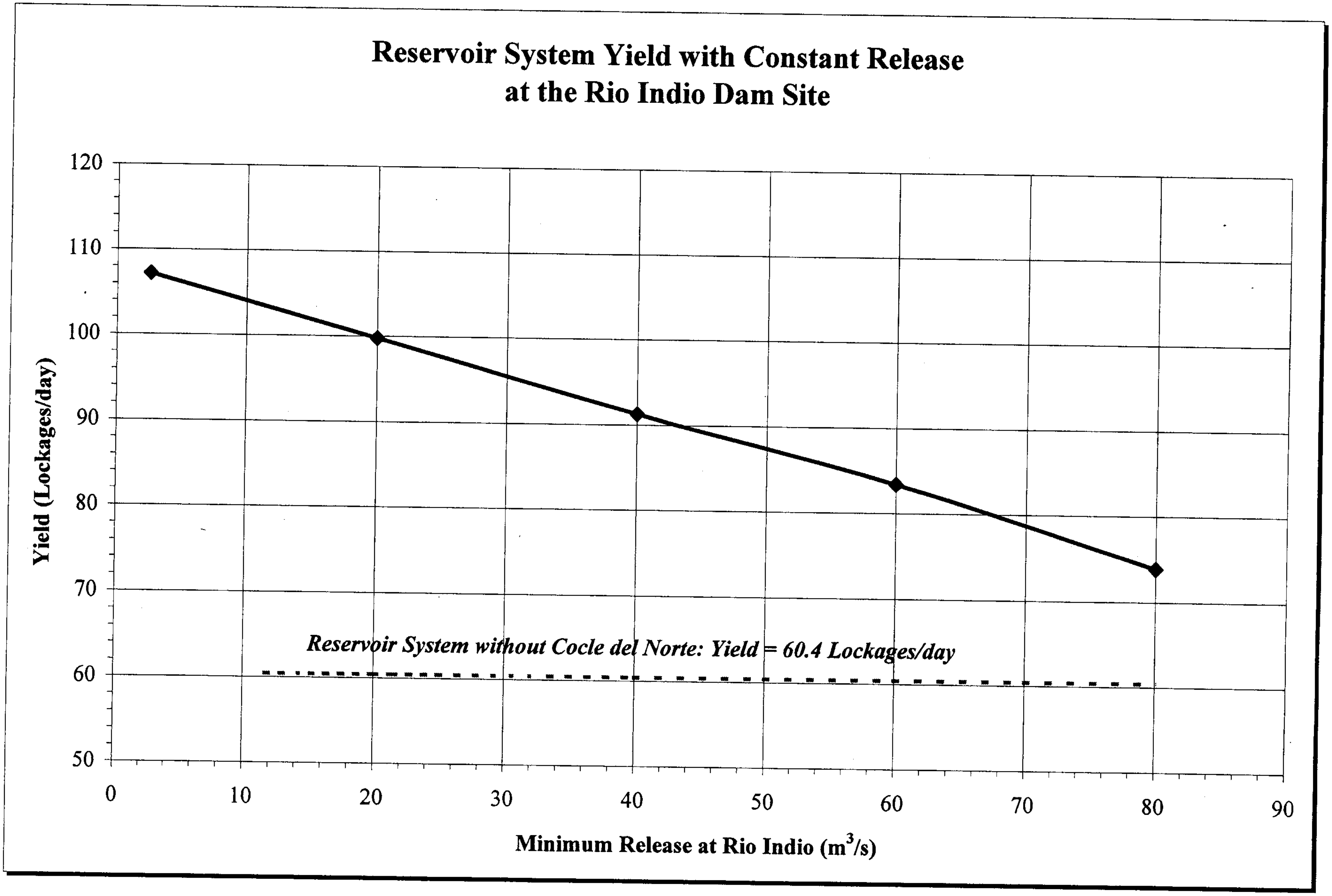

Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88


Transferred from Cocle to Indio
Discharge (cms)
400
350
300
250
200
150
100
50
0
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99


Reservoir System Yield with Constant Release
at the Cocle del Norte Dam Site
120
110
100
90
80
70
60
50
Yield (Lockages/day)
Reservoir System without Cocle del Norte: Yield = 60.4 Lockages/day
0
10
20
30
40
50
60
70
80
90
Minimum Release at Rio Cocle del Norte (m3/s)


Reservoir System Yield with Constant Release
at the Rio Indio Dam Site
Yield (Lockages/day)
120
110
100
90
80
70
60
50
Reservoir System without Cocle del Norte: Yield = 60.4 Lockages/day
0
10
20
30
40
50
60
70
80
90
Minimum Release at Rio Indio (m3/s)

# ATTACHMENT 7

# ENERGY PRODUCTION ANALYSIS

# COCLE 90 - 100

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Maximum Water Supply Yield
## *Water Supply Yield: 107.2 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.10 | 7.10 | 7.10 | 7.10 | 7.10 |
| Design Head (m) | 25 | 26.5 | 32.3 | 38.5 | 46.9 | 55.8 |
| | 30 | 42.5 | 56.7 | 73.2 | 90.7 | 110.5 |
| | 35 | 80.6 | 103.6 | 130.7 | 141.6 | 141.9 |
| | 40 | 118.6 | 138.8 | 149.7 | 152.5 | 148.2 |
| | 45 | 120.5 | 135.9 | 143.4 | 142.3 | 135.9 |
| | 50 | 111.0 | 123.9 | 126.6 | 122.2 | 110.4 |
| Maximum Output GWh/yr | | 122.6 | 140.0 | 149.7 | 152.5 | 148.9 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 107.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
### Constant Release of 80m$^3$/s at Cocle Dam Site
### *Water Supply Yield: 77.6 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 25 | 2.3 | | | | |
| | 30 | 2.1 | | | | |
| | 35 | 3.3 | 4.1 | 4.9 | 6.4 | 7.2 |
| | 40 | 3.6 | 5.5 | 6.6 | 7.5 | 7.9 |
| | 45 | 7.0 | 8.1 | 9.0 | 9.6 | 9.7 |
| | 50 | 6.7 | 7.6 | 8.3 | 8.6 | 8.5 |
| Maximum Output GWh/yr | | 7.0 | 8.1 | 9.1 | 9.8 | 10.1 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 77.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 60m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 86.5 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 25 | 20.2 | 24.7 | 27.3 | 28.1 | 27.8 |
| | 30 | 30.0 | 36.6 | 41.7 | 44.6 | 45.0 |
| | 35 | 55.1 | 67.4 | 79.1 | 88.0 | 91.6 |
| | 40 | 84.1 | 96.9 | 104.4 | 107.6 | 108.5 |
| | 45 | 87.7 | 98.3 | 104.2 | 106.7 | 107.7 |
| | 50 | 81.8 | 90.2 | 95.6 | 98.6 | 100.5 |
| Maximum Output GWh/yr | | 89.2 | 100.0 | 107.0 | 109.7 | 110.5 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 86.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40m$^3$/s at Cocle Dam Site
### *Water Supply Yield: 95.2 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Tunnel Diameter (m)** | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| **Design Head (m)** | 25 | 23.9 | 28.8 | 33.8 | 36.6 | 36.3 |
| | 30 | 36.0 | 44.6 | 53.2 | 61.8 | 65.9 |
| | 35 | 63.3 | 79.9 | 95.5 | 112.6 | 119.6 |
| | 40 | 99.0 | 116.8 | 126.7 | 132.5 | 134.4 |
| | 45 | 103.8 | 117.2 | 124.9 | 128.3 | 130.2 |
| | 50 | 96.8 | 107.5 | 113.6 | 116.0 | 117.2 |
| **Maximum Output GWh/yr** | | 105.3 | 119.1 | 127.8 | 132.5 | 134.4 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Design Head (m)** | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 95.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 20m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 103.7 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Tunnel Diameter (m)** | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| **Design Head (m)** | 25 | 26.0 | 31.4 | 37.4 | 43.2 | 45.2 |
| | 30 | 40.1 | 50.4 | 62.7 | 76.6 | 86.5 |
| | 35 | 72.2 | 90.6 | 111.5 | 133.5 | 140.4 |
| | 40 | 110.4 | 131.9 | 144.5 | 151.0 | 152.4 |
| | 45 | 117.5 | 133.7 | 142.8 | 145.8 | 145.8 |
| | 50 | 108.7 | 122.2 | 128.6 | 130.7 | 129.1 |
| **Maximum Output GWh/yr** | | 118.8 | 135.9 | 147.4 | 152.3 | 153.1 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Design Head (m)** | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Indio reservoir to Lake Gatun as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 103.7 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80 $m^3/s$ at Indio Dam Site
## *Water Supply Yield: 73.9 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 30 | 19.0 | | | | |
| | 35 | 37.7 | | 45.9 | 46.3 | 46.4 |
| | 40 | 56.2 | 63.9 | 66.1 | 66.8 | 66.9 |
| | 45 | 60.0 | 65.1 | 66.9 | 67.3 | 67.3 |
| | 50 | 57.2 | 62.0 | 63.8 | 64.2 | 64.2 |
| Maximum Output GWh/yr | | 61.0 | 66.7 | 68.8 | 69.3 | 69.4 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 73.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 60 m³/s at Indio Dam Site
### *Water Supply Yield: 82.6 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 30 | 26.8 | | | | |
| | 35 | 48.6 | 59.1 | 66.5 | 71.0 | 73.3 |
| | 40 | 77.7 | 89.3 | 95.4 | 97.6 | 98.3 |
| | 45 | 80.9 | 90.3 | 95.3 | 96.9 | 97.1 |
| | 50 | 76.6 | 84.2 | 88.6 | 91.0 | 91.6 |
| Maximum Output GWh/yr | | 82.2 | 91.9 | 97.5 | 99.2 | 99.9 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 82.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40m$^3$/s at Indio Dam Site
## *Water Supply Yield: 91.3 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 30 | 34.0 | | | | |
| | 35 | 59.7 | 73.1 | 87.0 | 98.8 | 103.8 |
| | 40 | 94.2 | 110.3 | 118.5 | 123.3 | 124.9 |
| | 45 | 97.8 | 109.8 | 116.8 | 119.6 | 121.3 |
| | 50 | 91.8 | 101.6 | 107.4 | 110.6 | 113.2 |
| Maximum Output GWh/yr | | 99.0 | 111.8 | 120.1 | 124.1 | 125.6 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 91.3 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
### Constant Release of 20m$^3$/s at Indio Dam Site
### *Water Supply Yield: 99.8 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Tunnel Diameter (m)** | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 30 | 38.2 | | | | |
| | 35 | 67.8 | 85.1 | 102.8 | 123.4 | 131.5 |
| | 40 | 107.5 | 127.4 | 138.5 | 144.3 | 146.8 |
| | 45 | 113.5 | 128.5 | 137.3 | 140.7 | 142.0 |
| | 50 | 105.9 | 118.5 | 124.5 | 126.5 | 126.5 |
| **Maximum Output GWh/yr** | | 114.4 | 130.6 | 140.6 | 145.2 | 147.1 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 99.8 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
### Minimum Transfer from Indio to Gatun of 80 m3/s
### *Water Supply Yield: 105.9 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 30 | 63.3 | | | | |
| | 35 | 97.6 | | 109.0 | | |
| | 40 | 122.0 | 135.9 | 137.0 | | |
| | 45 | 123.4 | 133.9 | 134.9 | | |
| | 50 | 111.4 | 123.0 | 123.7 | | |
| Maximum Output GWh/yr | | 127.3 | 139.0 | 140.0 | | |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 105.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# ISLA PABLON POWER PLANT - OUTPUT ANALYSIS
### Minimum Transfer from Indio to Gatun of 80 m3/s
### and Indio Reservoir between El.60 and El.80
### *Water Supplied: 70 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 7.50 | 7.50 | 7.50 | 7.50 | 7.50 |
| Design Head (m) | 35 | 8.8 | | | | |
| | 40 | 166.6 | 207.8 | 212.0 | 215.9 | 218.5 |
| | 45 | 260.9 | 284.3 | 288.3 | 291.0 | 292.2 |
| | 50 | 273.8 | 283.8 | 286.6 | 288.5 | 289.7 |
| | 55 | 262.0 | 281.6 | 284.2 | 285.9 | 286.8 |
| Maximum Output GWh/yr | | 273.8 | 284.6 | 188.4 | 291.4 | 293.0 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |
| | 50 | 33.7 | 42.2 | 50.6 | 59.1 | 67.5 |
| | 55 | 37.1 | 46.4 | 55.7 | 65.0 | 74.2 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 70 Lockages/day at a reliability of 100%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
### Maximum Water Supply Yield
### *Water Supply Yield: 107.2 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 5.50 | 5.65 | 6.20 | 6.70 | 7.15 |
| Design Head (m) | 20 | 34.1 | 40.1 | 44.0 | 50.8 | 52.9 |
| | 25 | 54.3 | 64.7 | 71.5 | 77.1 | 84.8 |
| | 30 | 64.2 | 77.8 | 94.4 | 103.8 | 110.2 |
| | 35 | 64.3 | 79.4 | 100.2 | 116.0 | 127.2 |
| | 40 | 58.3 | 72.2 | 93.1 | 108.3 | 118.9 |
| Maximum Output GWh/yr | | 65.7 | 80.3 | 100.2 | 116.3 | 127.2 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 107.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80m³/s at Cocle Dam Site
## *Water Supply Yield: 77.6 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 5.50 | 5.65 | 6.20 | 6.70 | 7.15 |
| Design Head (m) | 25 | 15.4 | | | | |
| | 30 | 16.5 | | | | |
| | 35 | 19.4 | 23.9 | 30.0 | 33.4 | 34.8 |
| | 40 | 22.4 | 28.2 | 35.0 | 38.8 | 40.4 |
| | 45 | 19.5 | 24.4 | 29.3 | 32.2 | 34.0 |
| Maximum Output GWh/yr | | 22.4 | 28.2 | 35.0 | 38.8 | 40.4 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 77.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 60m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 86.5 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 5.50 | 5.65 | 6.20 | 6.70 | 7.15 |
| Design Head (m) | 20 | 20.9 | 24.2 | 24.5 | 23.9 | 23.4 |
| | 25 | 33.3 | 37.4 | 39.8 | 41.0 | 42.7 |
| | 30 | 43.1 | 47.7 | 49.5 | 50.4 | 51.9 |
| | 35 | 51.2 | 57.8 | 60.3 | 61.4 | 62.2 |
| | 40 | 48.7 | 55.3 | 59.9 | 62.4 | 63.8 |
| Maximum Output GWh/yr | | 51.2 | 57.8 | 61.6 | 63.6 | 64.8 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 86.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 40m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 95.2 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Tunnel Diameter (m)** | | 5.50 | 5.65 | 6.20 | 6.70 | 7.15 |
| **Design Head (m)** | 20 | 26.9 | 32.5 | 35.9 | 37.2 | 37.0 |
| | 25 | 42.1 | 47.9 | 56.0 | 60.0 | 61.3 |
| | 30 | 55.3 | 64.2 | 71.2 | 73.9 | 75.5 |
| | 35 | 60.3 | 71.4 | 83.1 | 89.3 | 90.3 |
| | 40 | 56.6 | 66.8 | 78.6 | 85.3 | 88.2 |
| **Maximum Output GWh/yr** | | 60.3 | 71.4 | 83.1 | 89.7 | 92.4 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| **Design Head (m)** | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 95.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 20m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 103.7 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 5.50 | 5.65 | 6.20 | 6.70 | 7.15 |
| Design Head (m) | 20 | 30.3 | 36.1 | 44.4 | 48.2 | 50.3 |
| | 25 | 51.1 | 59.0 | 66.0 | 75.5 | 79.9 |
| | 30 | 62.3 | 74.6 | 88.6 | 96.0 | 98.8 |
| | 35 | 64.6 | 78.4 | 96.6 | 110.0 | 116.8 |
| | 40 | 59.2 | 72.0 | 90.6 | 102.4 | 110.4 |
| Maximum Output GWh/yr | | 65.5 | 78.9 | 96.6 | 110.0 | 116.8 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 103.7 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80 $m^3/s$ at Indio Dam Site
## *Water Supply Yield: 73.9 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.40 |
| Design Head (m) | 20 | 38.0 | | | | 53.5 |
| | 25 | 66.6 | | | | 87.5 |
| | 30 | 90.3 | 101.8 | 109.7 | 115.3 | 118.5 |
| | 35 | 101.8 | 114.3 | 122.9 | 128.9 | 132.2 |
| | 40 | 96.2 | 107.5 | 115.2 | 120.4 | 123.2 |
| Maximum Output GWh/yr | | 102.5 | 114.9 | 123.6 | 129.5 | 132.7 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 73.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 60 $m^3/s$ at Indio Dam Site
## *Water Supply Yield: 82.6 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.40 |
| Design Head (m) | 20 | 38.0 | | | | |
| | 25 | 60.1 | | | | |
| | 30 | 81.7 | 92.9 | 101.7 | 108.4 | 112.4 |
| | 35 | 89.7 | 101.8 | 111.2 | 118.0 | 121.8 |
| | 40 | 84.1 | 95.0 | 103.5 | 109.5 | 113.0 |
| Maximum Output GWh/yr | | 90.3 | 102.4 | 111.9 | 118.7 | 122.5 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 82.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 40 $m^3/s$ at Indio Dam Site
## *Water Supply Yield: 91.3 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.40 |
| Design Head (m) | 20 | 36.3 | | | | |
| | 25 | 58.0 | | | | |
| | 30 | 77.4 | 89.2 | 98.8 | 106.1 | 110.6 |
| | 35 | 84.9 | 97.8 | 108.3 | 115.9 | 120.2 |
| | 40 | 78.9 | 90.5 | 99.9 | 106.4 | 110.5 |
| Maximum Output GWh/yr | | 84.9 | 97.8 | 108.3 | 115.4 | 120.2 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 91.3 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 20 $m^3/s$ at Indio Dam Site
## *Water Supply Yield: 99.8 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.40 |
| Design Head (m) | 20 | 35.3 | | | | |
| | 25 | 55.2 | | | | |
| | 30 | 73.4 | 85.6 | 95.8 | 103.3 | 108.2 |
| | 35 | 80.3 | 93.6 | 104.5 | 112.6 | 117.4 |
| | 40 | 75.3 | 87.5 | 97.3 | 104.4 | 108.9 |
| Maximum Output GWh/yr | | 80.3 | 93.6 | 104.5 | 113.1 | 118.0 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 99.8 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Minimum Transfer from Indio to Gatun of 80 m3/s
## *Water Supply Yield: 105.9 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 | 180 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.90 | 7.20 |
| Design Head (m) | 25 | 38.3 | | | | | |
| | 30 | 47.1 | 57.9 | 68.2 | 78.2 | 94.6 | 107.2 |
| | 35 | 51.4 | 63.0 | 74.1 | 84.8 | 103.8 | 120.4 |
| | 40 | 59.1 | 71.1 | 82.1 | 91.7 | 114.8 | 132.0 |
| | 45 | 51.3 | 61.4 | 69.9 | 77.6 | 95.6 | 109.8 |
| Maximum Output | | 59.1 | 71.1 | 82.1 | 92.2 | 115.7 | 132.0 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 | 180 |
| Design Head (m) | 25 | 16.9 | 21.1 | 25.3 | 29.5 | 33.7 | 38.0 |
| | 30 | 20.2 | 25.3 | 30.4 | 35.4 | 40.5 | 45.6 |
| | 35 | 23.6 | 29.5 | 35.4 | 41.3 | 47.2 | 53.2 |
| | 40 | 27.0 | 33.7 | 40.5 | 47.2 | 54.0 | 60.7 |
| | 45 | 30.4 | 38.0 | 45.6 | 53.2 | 60.7 | 68.3 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 105.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 8.4-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# CANO SUCIO POWER PLANT - OUTPUT ANALYSIS
## Minimum Transfer from Indio to Gatun of 80 m3/s
## and Indio Reservoir between El.60 and El.80
## *Water Supplied: 70 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Tunnel Diameter (m) | | 6.40 | 6.40 | 6.40 | 6.40 | 6.40 |
| Design Head (m) | 15 | 31.5 | 39.3 | | | 61.1 |
| | 18 | 48.0 | 56.3 | 64.2 | 71.2 | 77.5 |
| | 20 | 47.9 | 56.3 | 63.5 | 70.0 | 76.0 |
| | 23 | 33.5 | 38.3 | 42.2 | 45.4 | 48.1 |
| | 26 | 23.5 | | | | 29.9 |
| Maximum Output GWh/yr | | 48.6 | 57.4 | 65.0 | 71.8 | 78.0 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 80 | 100 | 120 | 140 | 160 |
| Design Head (m) | 15 | 10.1 | 12.7 | 15.2 | 17.7 | 20.2 |
| | 18 | 12.1 | 15.2 | 18.2 | 21.3 | 24.3 |
| | 20 | 13.5 | 16.9 | 20.2 | 23.6 | 27.0 |
| | 23 | 15.5 | 19.4 | 23.3 | 27.2 | 31.0 |
| | 26 | 17.5 | 21.9 | 26.3 | 30.7 | 35.1 |

Output computations are based on weekly transferred discharges from the Cocle reservoir to the Indio reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 60 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 70 Lockages/day at a reliability of 100%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on an 1.1-km long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Maximum Water Supply Yield
### *Water Supply Yield: 107.2 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Tunnel Diameter (m) | | 3.00 | 3.00 | 3.00 | 3.60 | 4.40 |
| Design Head (m) | 80 | | | | | |
| | 85 | | | | | |
| | 90 | | | | | |
| | 95 | 67.9 | 75.6 | 75.6 | 75.6 | 75.6 |
| | 100 | | | | | |
| Maximum Output GWh/yr | | 67.9 | 75.6 | 75.6 | 75.6 | 75.6 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Design Head (m) | 80 | 6.7 | 10.1 | 13.5 | 27.0 | 40.5 |
| | 85 | 7.2 | 10.8 | 14.3 | 28.7 | 43.0 |
| | 90 | 7.6 | 11.4 | 15.2 | 30.4 | 45.6 |
| | 95 | 8.0 | 12.0 | 16.0 | 32.1 | 48.1 |
| | 100 | 8.4 | 12.7 | 16.9 | 33.7 | 50.6 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 107.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# COCLE POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 80m$^3$/s at Cocle Dam Site
## *Water Supply Yield: 77.6 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 40 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 4.80 | 4.80 | 4.80 | 4.80 | 4.80 |
| Design Head (m) | 80 | | | | | |
| | 85 | | | | | |
| | 90 | | | | | |
| | 95 | 130.5 | 260.9 | 391.3 | 520.9 | 533.2 |
| | 100 | | | | | |
| Maximum Output GWh/yr | | 130.5 | 260.9 | 391.3 | 520.9 | 533.2 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 40 | 60 | 80 | 100 |
| Design Head (m) | 80 | 13.5 | 27.0 | 40.5 | 54.0 | 67.5 |
| | 85 | 14.3 | 28.7 | 43.0 | 57.4 | 71.7 |
| | 90 | 15.2 | 30.4 | 45.6 | 60.7 | 75.9 |
| | 95 | 16.0 | 32.1 | 48.1 | 64.1 | 80.1 |
| | 100 | 16.9 | 33.7 | 50.6 | 67.5 | 84.4 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 77.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# COCLE POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 60m$^3$/s at Cocle Dam Site**

***Water Supply Yield: 86.5 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Tunnel Diameter (m) | | 4.40 | 4.40 | 4.40 | 4.40 | 4.40 |
| Design Head (m) | 80 | | | | | |
| | 85 | | | | | |
| | 90 | | | | | |
| | 95 | 66.2 | 99.3 | 132.5 | 264.9 | 397.3 |
| | 100 | | | | | |
| Maximum Output GWh/yr | | 66.2 | 99.3 | 132.5 | 264.9 | 397.3 |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Design Head (m) | 80 | 6.7 | 10.1 | 13.5 | 27.0 | 40.5 |
| | 85 | 7.2 | 10.8 | 14.3 | 28.7 | 43.0 |
| | 90 | 7.6 | 11.4 | 15.2 | 30.4 | 45.6 |
| | 95 | 8.0 | 12.0 | 16.0 | 32.1 | 48.1 |
| | 100 | 8.4 | 12.7 | 16.9 | 33.7 | 50.6 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 86.5 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# COCLE POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 40m³/s at Cocle Dam Site**

***Water Supply Yield: 95.2 Lockages/day***

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Tunnel Diameter (m) | | 3.60 | 3.60 | 3.60 | 3.60 | 4.40 |
| Design Head (m) | 80 | | | | | |
| | 85 | | | | | |
| | 90 | | | | | |
| | 95 | 66.0 | 99.0 | 132.0 | 263.8 | 274.7 |
| | 100 | | | | | |
| Maximum Output GWh/yr | | 66.0 | 99.0 | 132.0 | 263.8 | 274.7 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Design Head (m) | 80 | 6.7 | 10.1 | 13.5 | 27.0 | 40.5 |
| | 85 | 7.2 | 10.8 | 14.3 | 28.7 | 43.0 |
| | 90 | 7.6 | 11.4 | 15.2 | 30.4 | 45.6 |
| | 95 | 8.0 | 12.0 | 16.0 | 32.1 | 48.1 |
| | 100 | 8.4 | 12.7 | 16.9 | 33.7 | 50.6 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 95.2 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# COCLE POWER PLANT - OUTPUT ANALYSIS

**Constant Release of 20m³/s at Cocle Dam Site**

***Water Supply Yield: 103.7 Lockages/day***

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Tunnel Diameter (m) | | 3.00 | 3.00 | 3.00 | 3.60 | 4.40 |
| Design Head (m) | 80 | | | | | |
| | 85 | | | | | |
| | 90 | | | | | |
| | 95 | 67.3 | 100.9 | 134.4 | 138.0 | 138.7 |
| | 100 | | | | | |
| Maximum Output GWh/yr | | 67.3 | 100.9 | 134.4 | 138.0 | 138.7 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 15 | 20 | 40 | 60 |
| Design Head (m) | 80 | 6.7 | 10.1 | 13.5 | 27.0 | 40.5 |
| | 85 | 7.2 | 10.8 | 14.3 | 28.7 | 43.0 |
| | 90 | 7.6 | 11.4 | 15.2 | 30.4 | 45.6 |
| | 95 | 8.0 | 12.0 | 16.0 | 32.1 | 48.1 |
| | 100 | 8.4 | 12.7 | 16.9 | 33.7 | 50.6 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 103.7 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# INDIO POWER PLANT - OUTPUT ANALYSIS
### Constant Release of 80m$^3$/s at Indio Dam Site
### *Water Supply Yield: 73.9 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.00 | 3.00 | 3.60 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 30.0 | 60.1 | 120.2 | 180.2 | 240.3 | 264.4 |
| | 60 | 34.8 | 69.7 | 139.3 | 208.9 | 278.5 | 313.1 |
| | 65 | 33.5 | 67.0 | 134.0 | 200.9 | 267.8 | 297.0 |
| | 70 | 31.0 | 62.1 | 124.1 | 186.1 | 248.1 | 278.7 |
| | 75 | | | | | 224.3 | |
| Maximum Output | | 34.8 | 69.7 | 139.4 | 209.1 | 278.8 | 314.8 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Design Head (m) | 55 | 4.6 | 9.3 | 18.6 | 27.8 | 37.1 | 46.4 |
| | 60 | 5.1 | 10.1 | 20.2 | 30.4 | 40.5 | 50.6 |
| | 65 | 5.5 | 11.0 | 21.9 | 32.9 | 43.9 | 54.8 |
| | 70 | 5.9 | 11.8 | 23.6 | 35.4 | 47.2 | 59.1 |
| | 75 | 6.3 | 12.7 | 25.3 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 73.9 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# INDIO POWER PLANT - OUTPUT ANALYSIS
## Constant Release of 60m$^3$/s at Indio Dam Site
## *Water Supply Yield: 82.6 Lockages/day*

### Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.00 | 3.00 | 3.60 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 23.8 | 47.6 | 128.4 | 175.6 | 189.7 | 189.7 |
| | 60 | 21.9 | 43.7 | 126.0 | 212.6 | 241.8 | 241.8 |
| | 65 | 19.9 | 39.8 | 119.8 | 206.8 | 232.3 | 232.3 |
| | 70 | | 34.1 | 108.3 | 195.0 | 217.3 | 217.3 |
| | 75 | | | | 176.6 | 203.0 | 203.0 |
| Maximum Output | | 25.2 | 50.2 | 129.0 | 212.9 | 240.5 | 240.5 |

### Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Design Head (m) | 55 | 4.6 | 9.3 | 18.6 | 27.8 | 37.1 | 46.4 |
| | 60 | 5.1 | 10.1 | 20.2 | 30.4 | 40.5 | 50.6 |
| | 65 | 5.5 | 11.0 | 21.9 | 32.9 | 43.9 | 54.8 |
| | 70 | 5.9 | 11.8 | 23.6 | 35.4 | 47.2 | 59.1 |
| | 75 | 6.3 | 12.7 | 25.3 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 82.6 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# INDIO POWER PLANT - OUTPUT ANALYSIS

### Constant Release of 40m$^3$/s at Indio Dam Site
### *Water Supply Yield: 91.3 Lockages/day*

**Average Annual Output (GWh)**

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| **Tunnel Diameter (m)** | | 3.00 | 3.00 | 3.60 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 30.3 | 60.7 | 118.0 | 123.4 | 121.0 | 119.1 |
| | 60 | 34.8 | 69.7 | 142.1 | 164.0 | 164.9 | 165.4 |
| | 65 | 33.6 | 67.2 | 138.6 | 158.1 | 161.1 | 162.5 |
| | 70 | 31.6 | 63.1 | 130.7 | 148.6 | 151.7 | 152.9 |
| | 75 | | | | | | |
| **Maximum Output** | | 34.8 | 69.7 | 142.5 | 164.0 | 166.0 | 167.3 |

**Installed Capacity (MW)**

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Design Head (m) | 55 | 4.6 | 9.3 | 18.6 | 27.8 | 37.1 | 46.4 |
| | 60 | 5.1 | 10.1 | 20.2 | 30.4 | 40.5 | 50.6 |
| | 65 | 5.5 | 11.0 | 21.9 | 32.9 | 43.9 | 54.8 |
| | 70 | 5.9 | 11.8 | 23.6 | 35.4 | 47.2 | 59.1 |
| | 75 | 6.3 | 12.7 | 25.3 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 91.3 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE DEL NORTE RESERVOIR 90 - 100
# INDIO POWER PLANT - OUTPUT ANALYSIS

**Constant Release of $20m^3/s$ at Indio Dam Site**

***Water Supply Yield: 99.8 Lockages/day***

## Average Annual Output (GWh)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Tunnel Diameter (m) | | 3.00 | 3.00 | 3.60 | 4.40 | 5.00 | 5.60 |
| Design Head (m) | 55 | 27.6 | 55.2 | 59.7 | 58.1 | 57.8 | |
| | 60 | 36.6 | 73.1 | 82.2 | 82.6 | 82.9 | |
| | 65 | 36.2 | 72.5 | 80.6 | 81.7 | 81.9 | |
| | 70 | 34.4 | 68.9 | 76.0 | 77.3 | 77.6 | |
| | 75 | | | | | | |
| Maximum Output | | 36.7 | 73.4 | 82.7 | 83.7 | 84.0 | |

## Installed Capacity (MW)

| | | Maximum Power Discharge (cms) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 40 | 60 | 80 | 100 |
| Design Head (m) | 55 | 4.6 | 9.3 | 18.6 | 27.8 | 37.1 | 46.4 |
| | 60 | 5.1 | 10.1 | 20.2 | 30.4 | 40.5 | 50.6 |
| | 65 | 5.5 | 11.0 | 21.9 | 32.9 | 43.9 | 54.8 |
| | 70 | 5.9 | 11.8 | 23.6 | 35.4 | 47.2 | 59.1 |
| | 75 | 6.3 | 12.7 | 25.3 | 38.0 | 50.6 | 63.3 |

Output computations are based on weekly releases discharged from the Cocle reservoir as specified by the HEC-5 run performed by the ACP in July 2003. The system of reservoirs consists of Cocle operating between El.90 and El.100, Indio operating between El. 40 and El. 80 and a deepened Lake Gatun to allow operation between El. 23.93 (78.5 ft) and 26.75 (87.75 ft). The system supplies 99.8 Lockages/day at a reliability of 99.6%.

The following assumptions were made:

1- The Max Power Discharge occurs at the Design head
2- The Installed Capacity is that at Max Power Discharge and Design Head
3- For net head greater than the design head the maximum output is limited by the Inst. Cap.
4- The plan overall efficiency is equal to 86%
5- Maximum net head on turbine is 125% of the design head
6- Minimum net head on turbine is 65% of the design head
7- The head losses are based on a 600-m long tunnel.
8- The simulations cover 52 years.

# COCLE HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Cocle Dam Site**
***Water Supply Yield: 86.5 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **95.00 meters** |
| Maximum Operating Head | **118.75 meters** |
| Minimum Operating Head | **61.75 meters** |
| Discharge at Max Head | **75.73 cms** |
| Discharge at Min Head | **75.44 cms** |
| Head Loss at Max Head Discharge | **1.50 meters** |
| Head Loss at Min Head Discharge | **1.49 meters** |
| Tunnel Diameter | **5.00 m** |
| Tunnel Length | **600.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **3.80 m/s** |
| Installed Capacity (at Hd) | **75,000 kW** |
| Maximum Turbine Discharge (at Hd) | **93.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.29 meters** |
| **Average Annual Output** | **413.4 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **134,447 kW** |

# CANO SUCIO HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Cocle Dam Site**
***Water Supply Yield: 86.5 Lockages/day***

| | |
|---|---|
| **Cano Sucio Power Plant** | |
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **68.52 cms** |
| Discharge at Min Head | **68.26 cms** |
| Head Loss at Max Head Discharge | **0.94 meters** |
| Head Loss at Min Head Discharge | **0.94 meters** |
| Tunnel Diameter | **6.40 m** |
| Tunnel Length | **1100.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.63 m/s** |
| Installed Capacity (at Hd) | **25,000 kW** |
| Maximum Turbine Discharge (at Hd) | **84.7 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.44 meters** |
| **Average Annual Output** | **54.2 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Cocle Dam Site**
***Water Supply Yield: 86.5 Lockages/day***

| **Isla Pablon Power Plant** | |
| --- | --- |
| Design head | **42.00 meters** |
| Maximum Operating Head | **52.50 meters** |
| Minimum Operating Head | **27.30 meters** |
| Discharge at Max Head | **91.36 cms** |
| Discharge at Min Head | **91.01 cms** |
| Head Loss at Max Head Discharge | **3.74 meters** |
| Head Loss at Min Head Discharge | **3.72 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **112.9 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **5.72 meters** |
| **Average Annual Output** | **103.8 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Indio Dam Site**
***Water Supply Yield: 82.6 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **95.00 meters** |
| Maximum Operating Head | **118.75 meters** |
| Minimum Operating Head | **61.75 meters** |
| Discharge at Max Head | **12.12 cms** |
| Discharge at Min Head | **12.07 cms** |
| Head Loss at Max Head Discharge | **0.67 meters** |
| Head Loss at Min Head Discharge | **0.67 meters** |
| Tunnel Diameter | **3.00 m** |
| Tunnel Length | **600.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.12 m/s** |
| Installed Capacity (at Hd) | **12,000 kW** |
| Maximum Turbine Discharge (at Hd) | **15.0 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.03 meters** |
| **Average Annual Output** | **75.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **24,561 kW** |

# CANO SUCIO HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Indio Dam Site**
***Water Supply Yield: 82.6 Lockages/day***

| | |
|---|---|
| **Cano Sucio Power Plant** | |
| Design head | **36.00 meters** |
| Maximum Operating Head | **45.00 meters** |
| Minimum Operating Head | **23.40 meters** |
| Discharge at Max Head | **66.62 cms** |
| Discharge at Min Head | **66.36 cms** |
| Head Loss at Max Head Discharge | **0.89 meters** |
| Head Loss at Min Head Discharge | **0.88 meters** |
| Tunnel Diameter | **6.40 m** |
| Tunnel Length | **1100.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **25,000 kW** |
| Maximum Turbine Discharge (at Hd) | **82.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.36 meters** |
| **Average Annual Output** | **91.8 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# INDIO HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Indio Dam Site**
***Water Supply Yield: 82.6 Lockages/day***

| **Indio Power Plant** | |
|---|---|
| Design head | **59.00 meters** |
| Maximum Operating Head | **73.75 meters** |
| Minimum Operating Head | **38.35 meters** |
| Discharge at Max Head | **64.29 cms** |
| Discharge at Min Head | **64.79 cms** |
| Head Loss at Max Head Discharge | **1.74 meters** |
| Head Loss at Min Head Discharge | **1.76 meters** |
| Tunnel Diameter | **5.00 m** |
| Tunnel Length | **600 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **4.09 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **80.4 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.71 meters** |
| **Average Annual Output** | **240.5 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Constant Release of 60 m3/s at Indio Dam Site**
***Water Supply Yield: 82.6 Lockages/day***

**Isla Pablon Power Plant**

| | |
|---|---|
| Design head | **42.00 meters** |
| Maximum Operating Head | **52.50 meters** |
| Minimum Operating Head | **27.30 meters** |
| Discharge at Max Head | **91.36 cms** |
| Discharge at Min Head | **91.01 cms** |
| Head Loss at Max Head Discharge | **3.74 meters** |
| Head Loss at Min Head Discharge | **3.72 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **112.9 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **5.72 meters** |
| **Average Annual Output** | **95.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# CANO SUCIO HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Minimum Transfer from Indio to Gatun of 80 m3/s**
***Water Supply Yield: 105.9 Lockages/day***

| | |
|---|---|
| **Cano Sucio Power Plant** | |
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **66.62 cms** |
| Discharge at Min Head | **66.36 cms** |
| Head Loss at Max Head Discharge | **0.89 meters** |
| Head Loss at Min Head Discharge | **0.88 meters** |
| Tunnel Diameter | **6.40 m** |
| Tunnel Length | **1100.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **24,305 kW** |
| Maximum Turbine Discharge (at Hd) | **82.3 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.36 meters** |
| **Average Annual Output** | **52.8 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Minimum Transfer from Indio to Gatun of 80 m3/s**
***Water Supply Yield: 105.9 Lockages/day***

| | |
|---|---|
| **Isla Pablon Power Plant** | |
| Design head | **42.00 meters** |
| Maximum Operating Head | **52.50 meters** |
| Minimum Operating Head | **27.30 meters** |
| Discharge at Max Head | **91.36 cms** |
| Discharge at Min Head | **91.01 cms** |
| Head Loss at Max Head Discharge | **3.74 meters** |
| Head Loss at Min Head Discharge | **3.72 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **112.9 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **5.72 meters** |
| **Average Annual Output** | **139.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**and Indio Reservoir between El.60 and El.80**
**Minimum Transfer from Indio to Gatun of 80 m3/s**
***Water Supplied: 70.0 Lockages/day***

| | |
|---|---|
| **Isla Pablon Power Plant** | |
| Design head | **42.00 meters** |
| Maximum Operating Head | **52.50 meters** |
| Minimum Operating Head | **27.30 meters** |
| Discharge at Max Head | **91.36 cms** |
| Discharge at Min Head | **91.01 cms** |
| Head Loss at Max Head Discharge | **3.74 meters** |
| Head Loss at Min Head Discharge | **3.72 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **112.9 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **5.72 meters** |
| **Average Annual Output** | **285.8 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **89,620 kW** |

# COCLE HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**

**Maximum Water Supply Yield**

***Water Supply Yield: 107.2 Lockages/day***

| | |
|---|---|
| **Cocle del Norte Power Plant** | |
| Design head | **95.00 meters** |
| Maximum Operating Head | **118.75 meters** |
| Minimum Operating Head | **61.75 meters** |
| Discharge at Max Head | **12.12 cms** |
| Discharge at Min Head | **12.07 cms** |
| Head Loss at Max Head Discharge | **0.67 meters** |
| Head Loss at Min Head Discharge | **0.67 meters** |
| Tunnel Diameter | **3.00 m** |
| Tunnel Length | **600.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.12 m/s** |
| Installed Capacity (at Hd) | **12,000 kW** |
| Maximum Turbine Discharge (at Hd) | **15.0 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.03 meters** |
| **Average Annual Output** | **75.6 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **24,557 kW** |

# COCLE HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**
**Maximum Water Supply Yield**
***Water Supply Yield: 107.2 Lockages/day***

| **Cocle del Norte Power Plant** | |
|---|---|
| Design head | **95.00 meters** |
| Maximum Operating Head | **118.75 meters** |
| Minimum Operating Head | **61.75 meters** |
| Discharge at Max Head | **75.73 cms** |
| Discharge at Min Head | **75.44 cms** |
| Head Loss at Max Head Discharge | **2.50 meters** |
| Head Loss at Min Head Discharge | **2.48 meters** |
| Tunnel Diameter | **5.00 m** |
| Tunnel Length | **600.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **4.77 m/s** |
| Installed Capacity (at Hd) | **75,000 kW** |
| Maximum Turbine Discharge (at Hd) | **93.6 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **3.82 meters** |
| **Average Annual Output** | **76.0 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **24,694 kW** |

# CANO SUCIO HYDROELECTRIC SCHEME

**Reservoir Operation between El.90 and El.100**

**Maximum Water Supply Yield**

***Water Supply Yield: 107.2 Lockages/day***

| | |
|---|---|
| **Cano Sucio Power Plant** | |
| Design head | **35.00 meters** |
| Maximum Operating Head | **43.75 meters** |
| Minimum Operating Head | **22.75 meters** |
| Discharge at Max Head | **68.52 cms** |
| Discharge at Min Head | **68.26 cms** |
| Head Loss at Max Head Discharge | **0.94 meters** |
| Head Loss at Min Head Discharge | **0.94 meters** |
| Tunnel Diameter | **6.40 m** |
| Tunnel Length | **1100.00 m** |
| Tunnel Friction Coefficient | **0.015** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.63 m/s** |
| Installed Capacity (at Hd) | **25,000 kW** |
| Maximum Turbine Discharge (at Hd) | **84.7 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **1.44 meters** |
| **Average Annual Output** | **80.7 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# INDIO HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Maximum Water Supply Yield**
***Water Supply Yield: 107.2 Lockages/day***

| | |
|---|---|
| **Indio Power Plant** | |
| Design head | **59.00 meters** |
| Maximum Operating Head | **73.75 meters** |
| Minimum Operating Head | **38.35 meters** |
| Discharge at Max Head | **4.02 cms** |
| Discharge at Min Head | **4.05 cms** |
| Head Loss at Max Head Discharge | **1.87 meters** |
| Head Loss at Min Head Discharge | **1.90 meters** |
| Tunnel Diameter | **1.50 m** |
| Tunnel Length | **600 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.84 m/s** |
| Installed Capacity (at Hd) | **2,500 kW** |
| Maximum Turbine Discharge (at Hd) | **5.0 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **2.92 meters** |
| **Average Annual Output** | **10.5 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# INDIO HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**

**Maximum Water Supply Yield**

***Water Supply Yield: 107.2 Lockages/day***

| | |
|---|---|
| **Indio Power Plant** | |
| Design head | **59.00 meters** |
| Maximum Operating Head | **73.75 meters** |
| Minimum Operating Head | **38.35 meters** |
| Discharge at Max Head | **64.29 cms** |
| Discharge at Min Head | **64.79 cms** |
| Head Loss at Max Head Discharge | **2.09 meters** |
| Head Loss at Min Head Discharge | **2.12 meters** |
| Tunnel Diameter | **4.80 m** |
| Tunnel Length | **600 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **4.44 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **80.4 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **3.27 meters** |
| **Average Annual Output** | **9.8 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# ISLA PABLON HYDROELECTRIC SCHEME

**with Cocle reservoir Operation between El.90 and El.100**
**Maximum Water Supply Yield**
***Water Supply Yield: 107.2 Lockages/day***

**Isla Pablon Power Plant**

| | |
|---|---|
| Design head | **42.00 meters** |
| Maximum Operating Head | **52.50 meters** |
| Minimum Operating Head | **27.30 meters** |
| Discharge at Max Head | **91.36 cms** |
| Discharge at Min Head | **91.01 cms** |
| Head Loss at Max Head Discharge | **3.74 meters** |
| Head Loss at Min Head Discharge | **3.72 meters** |
| Tunnel Diameter | **7.50 m** |
| Tunnel Length | **8400 m** |
| Tunnel Friction Coefficient | **0.014** |
| Tunnel Velocity at Maximum Turbine Discharge | **2.56 m/s** |
| Installed Capacity (at Hd) | **40,000 kW** |
| Maximum Turbine Discharge (at Hd) | **112.9 cms** |
| Plant Efficiency | **86%** |
| Head Loss at Max Turbine Discharge | **5.72 meters** |
| **Average Annual Output** | **155.9 GWh** |
| **Firm Capacity (Exceeded 95% of the time 8 hr per day)** | **0 kW** |

# COCLE DEL NORTE RESERVOIR 90 - 100

## Hydropower Potential

### *Strategy No1 - Maximize Cocle del Norte Hydropower Revenues*

| Strategy No.1 | | *Initial Output (2032)* | *2062 Output* | *2071 Output* | *2078 Output* | *Long-term Output (2082)* | *2032 PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | | |
| 25 MW | Average Annual Energy (GWh) | 206.6 | 206.6 | 210.5 | 138.0 | 76.0 | $89,648 |
| | Firm Capacity (MW) | 25 | 25 | 25 | 25 | 24.7 | |
| 35 MW | Average Annual Energy (GWh) | 289.2 | 289.2 | 274.7 | 138.0 | 76.0 | $125,277 |
| | Firm Capacity (MW) | 35 | 35 | 35 | 35 | 24.7 | |
| 50 MW | Average Annual Energy (GWh) | 406.9 | 404.9 | 277.1 | 138.0 | 76.0 | $175,970 |
| | Firm Capacity (MW) | 50 | 50 | 50 | 45.1 | 24.7 | |
| 70 MW | Average Annual Energy (GWh) | 536.5 | 413.4 | 277.1 | 138.0 | 76.0 | $230,922 |
| | Firm Capacity (MW) | 70 | 70 | 70 | 45.1 | 24.7 | |
| 90 MW | Average Annual Energy (GWh) | 542.2 | 413.4 | 277.1 | 138.0 | 76.0 | $242,122 |
| | Firm Capacity (MW) | 90 | 90 | 90 | 45.1 | 24.7 | |
| 110 MW | Average Annual Energy (GWh) | 546.9 | 413.4 | 277.1 | 138.0 | 76.0 | $254,244 |
| | Firm Capacity (MW) | 110 | 110 | 90 | 45.1 | 24.7 | |
| 135 MW | Average Annual Energy (GWh) | 549.0 | 413.4 | 277.1 | 138.0 | 76.0 | $267,294 |
| | Firm Capacity (MW) | 135 | 135 | 90 | 45.1 | 24.7 | |
| **Isla Pablon Power Plant** | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 69.1 | 69.1 | 81.0 | 89.3 | 94.0 | $25,993 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 90.0 | 90.0 | 108.0 | 122.4 | 131.0 | $33,884 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 103.8 | 103.8 | 125.0 | 143.4 | 155.9 | $39,090 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 109.3 | 109.3 | 132.3 | 152.4 | 167.0 | $41,170 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| **Cano Sucio Power Plant** | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 46.7 | 46.7 | 58.4 | 66.0 | 67.7 | $17,596 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 25 MW | Average Annual Energy (GWh) | 54.2 | 58.8 | 68.9 | 78.4 | 80.7 | $20,432 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 58.8 | 58.8 | 77.6 | 89.3 | 92.2 | $22,190 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| 35 MW | Average Annual Energy (GWh) | 60.1 | 60.1 | 83.7 | 98.2 | 102.1 | $22,718 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| **Rio Indio Power Plant** | | | | | | | |
| 2.5 MW | Average Annual Energy (GWh) | 10.4 | 10.4 | 10.4 | 10.4 | 10.4 | $3,896 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| **Gatun Power Plant** | | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 54.5 | 16.2 | 14.2 | 13.0 | 12.6 | $16,679 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |
| **Madden Power Plant** | | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 187.9 | 165.5 | 161.8 | 158.4 | 157.0 | $67,521 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | |

# COCLE DEL NORTE RESERVOIR 90 - 100

## Hydropower Potential

### *Strategy No2 - Maximize Rio Indio Hydropower Revenues*

| Strategy No.2 | | *Initial Output (2032)* | *2044 Output* | *2055 Output* | *2067 Output* | *2075 Output* | *Long-term Output (2082)* | *2032 PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | | | |
| 10 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | $33,350 |
| | Firm Capacity (MW) | 10 | 10 | 10 | 10 | 10 | 10 | |
| 15 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | $35,848 |
| | Firm Capacity (MW) | 15 | 15 | 15 | 15 | 15 | 15 | |
| 20 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | $38,345 |
| | Firm Capacity (MW) | 20 | 20 | 20 | 20 | 20 | 20 | |
| 25 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | 75.7 | $40,692 |
| | Firm Capacity (MW) | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | |
| **Isla Pablon Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 48.6 | 48.6 | 64.0 | 76.6 | 87.9 | 94.0 | $19,227 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 62.6 | 62.6 | 84.4 | 102.6 | 118.8 | 131.0 | $24,907 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 68.4 | 68.4 | 95.6 | 117.2 | 137.5 | 155.9 | $27,431 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 69.3 | 69.3 | 99.3 | 124.2 | 145.5 | 167.0 | $27,966 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Cano Sucio Power Plant** | | | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 88.9 | 88.9 | 79.5 | 73.9 | 69.0 | 67.7 | $32,717 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 25 MW | Average Annual Energy (GWh) | 104.3 | 104.3 | 91.8 | 86.3 | 81.4 | 80.7 | $38,328 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 114.3 | 114.3 | 101.7 | 96.7 | 92.2 | 92.2 | $42,078 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 35 MW | Average Annual Energy (GWh) | 121.8 | 121.8 | 109.9 | 105.5 | 102.1 | 102.1 | $44,936 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Rio Indio Power Plant** | | | | | | | | |
| 30 MW | Average Annual Energy (GWh) | 214.8 | 214.6 | 212.9 | 161.6 | 76.3 | 10.4 | $79,186 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 286.1 | 286.1 | 240.5 | 162.9 | 76.3 | 10.4 | $103,300 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 314.8 | 314.8 | 241.9 | 163.5 | 76.3 | 10.4 | $112,630 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| 60 MW | Average Annual Energy (GWh) | 314.8 | 314.8 | 241.9 | 163.5 | 76.3 | 10.4 | $112,630 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Gatun Power Plant** | | | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 54.5 | 20.1 | 16.9 | 14.5 | 13.5 | 12.6 | $13,567 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Madden Power Plant** | | | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 187.9 | 171.4 | 167.2 | 163.4 | 159.9 | 157.0 | $66,910 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | |

# COCLE DEL NORTE RESERVOIR 90 - 100

## Hydropower Potential

### *Strategy No3 - Maximize Isla Pablon Hydropower Revenues*

| Strategy No.3 | | *Initial Output (2032)* | *2039 Output* | *2080 Output* | *Long-term Output (2082)* | *2032 PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | |
| 10 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $33,350 |
| | Firm Capacity (MW) | 10 | 10 | 10 | 10 | |
| 15 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $35,848 |
| | Firm Capacity (MW) | 15 | 15 | 15 | 15 | |
| 20 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $38,345 |
| | Firm Capacity (MW) | 20 | 20 | 20 | 20 | |
| 25 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $40,692 |
| | Firm Capacity (MW) | 24.7 | 24.7 | 24.7 | 24.7 | |
| **Isla Pablon Power Plant** | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 93.9 | 93.9 | 93.9 | 94.0 | $35,173 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 133.2 | 133.2 | 133.2 | 133.2 | $49,894 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 139.7 | 139.7 | 139.7 | 155.9 | $52,345 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 141.0 | 141.0 | 141.0 | 167.0 | $52,841 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Cano Sucio Power Plant** | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 45.3 | 45.3 | 45.3 | 67.7 | $16,990 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 64.6 | 64.6 | 64.6 | 92.2 | $24,224 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 81.3 | 81.3 | 81.3 | 109.9 | $30,481 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 111.3 | 111.3 | 111.3 | 126.0 | $41,705 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| 60 MW | Average Annual Energy (GWh) | 131.1 | 131.1 | 131.1 | 132.6 | $49,109 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Rio Indio Power Plant** | | | | | | |
| 2.5 MW | Average Annual Energy (GWh) | 10.4 | 10.4 | 10.4 | 10.4 | $3,896 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Gatun Power Plant** | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 138.1 | 98.1 | 23.0 | 12.6 | $39,424 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Madden Power Plant** | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 188.6 | 184.7 | 160.2 | 157.0 | $68,888 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |

# COCLE DEL NORTE RESERVOIR 90 - 100

## Hydropower Potential

### *Strategy No3A - Maximize Isla Pablon Hydropower Revenues with Indio reservoir Operating between El.60 and El.80*

| Strategy No.3A | | *Initial Output (2032)* | *2039 Output* | *2079 Output* | *Long-term Output (2082)* | *2032 PV(12%) of Revenues ($,000)* |
|---|---|---|---|---|---|---|
| **Cocle del Norte Power Plant** | | | | | | |
| 10 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $33,350 |
| | Firm Capacity (MW) | 10 | 10 | 10 | 10 | |
| 15 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $35,848 |
| | Firm Capacity (MW) | 15 | 15 | 15 | 15 | |
| 20 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $38,345 |
| | Firm Capacity (MW) | 20 | 20 | 20 | 20 | |
| 25 MW | Average Annual Energy (GWh) | 75.7 | 75.7 | 75.7 | 75.7 | $40,692 |
| | Firm Capacity (MW) | 24.7 | 24.7 | 24.7 | 24.7 | |
| **Isla Pablon Power Plant** | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 158.0 | 158.0 | 144.7 | 94.0 | $67,776 |
| | Firm Capacity (MW) | 20 | 20 | 0 | 0 | |
| 30 MW | Average Annual Energy (GWh) | 258.1 | 258.1 | 211.8 | 133.2 | $108,677 |
| | Firm Capacity (MW) | 30 | 30 | 0 | 0 | |
| 40 MW | Average Annual Energy (GWh) | 285.8 | 285.8 | 220.3 | 155.9 | $122,963 |
| | Firm Capacity (MW) | 40 | 40 | 0 | 0 | |
| 50 MW | Average Annual Energy (GWh) | 290.9 | 290.9 | 220.3 | 167.0 | $129,257 |
| | Firm Capacity (MW) | 50 | 50 | 0 | 0 | |
| **Cano Sucio Power Plant** | | | | | | |
| 20 MW | Average Annual Energy (GWh) | 66.7 | 66.7 | 65.8 | 40.1 | $24,930 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Rio Indio Power Plant** | | | | | | |
| 2.5 MW | Average Annual Energy (GWh) | 13.6 | 13.6 | 11.9 | 10.4 | $6,281 |
| | Firm Capacity (MW) | 2.5 | 2.5 | 2.5 | 0 | |
| **Gatun Power Plant** | | | | | | |
| 24 MW | Average Annual Energy (GWh) | 138.1 | 98.1 | 23.0 | 12.6 | $39,424 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |
| **Madden Power Plant** | | | | | | |
| 36 MW | Average Annual Energy (GWh) | 188.6 | 184.7 | 160.2 | 157.0 | $68,888 |
| | Firm Capacity (MW) | 0 | 0 | 0 | 0 | |

# Cano Sucio Hydropower

| Transferred Flows | | Cocle Reservoir Leve | | Indio Reservoir Level | | Gross Head | | Net Head | | Monthly Energy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percent of the time | Exceeded Flow (cms) | Percent of the time | Exceeded Elev. (m) | Percent of the time | Exceeded Elev. (m) | Percent of the time | Exceeded Head (m) | Percent of the time | Exceeded Head (m) | Percent of the time | Exceeded Energy (MWh) | Exceeded Energy (MWh) |
| 2% | 201.5 | 2% | 100.1 | 2% | 80.2 | 2% | 49.2 | 2% | 47.4 | 2% | 18,200 | 4200.0 |
| 5% | 173.1 | 5% | 100.0 | 5% | 80.0 | 5% | 45.5 | 5% | 43.7 | 5% | 18,200 | 4200.0 |
| 10% | 161.8 | 10% | 99.5 | 10% | 78.8 | 10% | 42.8 | 10% | 40.7 | 10% | 18,200 | 4200.0 |
| 15% | 153.3 | 15% | 98.9 | 15% | 77.5 | 15% | 40.8 | 15% | 38.4 | 15% | 16,458 | 3798.0 |
| 20% | 142.0 | 20% | 98.4 | 20% | 76.3 | 20% | 39.0 | 20% | 36.5 | 20% | 14,539 | 3355.2 |
| 25% | 133.5 | 25% | 97.9 | 25% | 74.8 | 25% | 37.1 | 25% | 34.6 | 25% | 13,015 | 3003.5 |
| 30% | 128.1 | 30% | 97.6 | 30% | 73.7 | 30% | 35.2 | 30% | 33.1 | 30% | 11,760 | 2713.7 |
| 35% | 120.8 | 35% | 97.1 | 35% | 72.1 | 35% | 33.4 | 35% | 31.3 | 35% | 10,579 | 2441.4 |
| 40% | 112.5 | 40% | 96.7 | 40% | 70.7 | 40% | 31.4 | 40% | 29.5 | 40% | 9,760 | 2252.3 |
| 45% | 104.6 | 45% | 96.3 | 45% | 69.2 | 45% | 29.7 | 45% | 27.8 | 45% | 7,304 | 1685.7 |
| 50% | 96.1 | 50% | 95.9 | 50% | 67.8 | 50% | 28.2 | 50% | 26.5 | 50% | 4,198 | 968.7 |
| 55% | 84.2 | 55% | 95.4 | 55% | 65.7 | 55% | 27.0 | 55% | 25.4 | 55% | 1,539 | 355.2 |
| 60% | 71.8 | 60% | 94.8 | 60% | 63.4 | 60% | 26.0 | 60% | 24.1 | 60% | 0 | 0.0 |
| 65% | 59.0 | 65% | 93.9 | 65% | 60.6 | 65% | 25.1 | 65% | 23.1 | 65% | 0 | 0.0 |
| 70% | 48.3 | 70% | 93.2 | 70% | 58.0 | 70% | 24.0 | 70% | 22.1 | 70% | 0 | 0.0 |
| 75% | 35.6 | 75% | 92.7 | 75% | 55.6 | 75% | 23.1 | 75% | 21.3 | 75% | 0 | 0.0 |
| 80% | 24.2 | 80% | 92.1 | 80% | 53.0 | 80% | 22.2 | 80% | 20.3 | 80% | 0 | 0.0 |
| 85% | 14.3 | 85% | 91.4 | 85% | 50.6 | 85% | 21.5 | 85% | 19.7 | 85% | 0 | 0.0 |
| 90% | 1.5 | 90% | 90.9 | 90% | 48.3 | 90% | 20.4 | 90% | 18.6 | 90% | 0 | 0.0 |
| 95% | 0.0 | 95% | 90.3 | 95% | 44.8 | 95% | 19.9 | 95% | 14.6 | 95% | 0 | 0.0 |
| 98% | 0.0 | 98% | 90.0 | 98% | 40.8 | 98% | 19.3 | 98% | 12.9 | 98% | 0 | 0.0 |

# Isla Pablon Hydropower

| Transferred Flows | | Tunnel No1 Discharge | | Tunnel No2 Discharge | | Indio Reservoir Level | | Gross Head | | Net Head | | Monthly Energy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percent of the time | Exceeded Flow (cms) | Percent of the time | Exceeded Flow (cms) | Percent of the time | Exceeded Flow (cms) | Percent of the time | Exceeded Elev. (m) | Percent of the time | Exceeded Head (m) | Percent of the time | Exceeded Head (m) | Percent of the time | Exceeded Energy (MWh) | Exceeded Energy (MWh) |
| 2% | 218.3 | 2% | 90.0 | 2% | 154.0 | 2% | 80.2 | 2% | 53.5 | 2% | 53.3 | 2% | 29,120 | 6720.0 |
| 5% | 209.2 | 5% | 79.9 | 5% | 139.2 | 5% | 80.0 | 5% | 53.3 | 5% | 52.3 | 5% | 29,120 | 6720.0 |
| 10% | 198.5 | 10% | 70.3 | 10% | 120.4 | 10% | 78.8 | 10% | 52.1 | 10% | 49.2 | 10% | 29,120 | 6720.0 |
| 15% | 187.2 | 15% | 64.3 | 15% | 112.9 | 15% | 77.5 | 15% | 50.9 | 15% | 47.3 | 15% | 28,615 | 6603.5 |
| 20% | 175.8 | 20% | 60.1 | 20% | 112.9 | 20% | 76.3 | 20% | 49.8 | 20% | 45.6 | 20% | 26,413 | 6095.2 |
| 25% | 164.5 | 25% | 51.6 | 25% | 112.9 | 25% | 74.8 | 25% | 48.5 | 25% | 44.5 | 25% | 24,414 | 5634.0 |
| 30% | 153.2 | 30% | 40.3 | 30% | 112.9 | 30% | 73.7 | 30% | 47.4 | 30% | 43.3 | 30% | 22,660 | 5229.3 |
| 35% | 141.8 | 35% | 29.0 | 35% | 112.9 | 35% | 72.1 | 35% | 46.0 | 35% | 42.1 | 35% | 20,604 | 4754.9 |
| 40% | 129.9 | 40% | 17.0 | 40% | 112.9 | 40% | 70.7 | 40% | 44.7 | 40% | 40.6 | 40% | 18,650 | 4303.8 |
| 45% | 121.2 | 45% | 8.3 | 45% | 112.9 | 45% | 69.2 | 45% | 43.4 | 45% | 39.1 | 45% | 16,622 | 3835.9 |
| 50% | 107.6 | 50% | 0.0 | 50% | 107.6 | 50% | 67.8 | 50% | 42.0 | 50% | 37.6 | 50% | 14,220 | 3281.5 |
| 55% | 96.0 | 55% | 0.0 | 55% | 96.0 | 55% | 65.7 | 55% | 40.1 | 55% | 36.1 | 55% | 9,875 | 2278.8 |
| 60% | 83.5 | 60% | 0.0 | 60% | 83.5 | 60% | 63.4 | 60% | 38.0 | 60% | 34.1 | 60% | 4,795 | 1106.6 |
| 65% | 71.9 | 65% | 0.0 | 65% | 71.9 | 65% | 60.6 | 65% | 35.4 | 65% | 31.9 | 65% | 0 | 0.0 |
| 70% | 60.3 | 70% | 0.0 | 70% | 60.3 | 70% | 58.0 | 70% | 33.0 | 70% | 29.5 | 70% | 0 | 0.0 |
| 75% | 50.1 | 75% | 0.0 | 75% | 50.1 | 75% | 55.6 | 75% | 30.8 | 75% | 26.9 | 75% | 0 | 0.0 |
| 80% | 37.0 | 80% | 0.0 | 80% | 37.0 | 80% | 53.0 | 80% | 28.3 | 80% | 24.1 | 80% | 0 | 0.0 |
| 85% | 23.8 | 85% | 0.0 | 85% | 23.8 | 85% | 50.6 | 85% | 26.1 | 85% | 21.2 | 85% | 0 | 0.0 |
| 90% | 4.9 | 90% | 0.0 | 90% | 4.9 | 90% | 48.3 | 90% | 23.9 | 90% | 18.3 | 90% | 0 | 0.0 |
| 95% | 0.0 | 95% | 0.0 | 95% | 0.0 | 95% | 44.8 | 95% | 20.6 | 95% | 14.7 | 95% | 0 | 0.0 |
| 98% | 0.0 | 98% | 0.0 | 98% | 0.0 | 98% | 40.8 | 98% | 16.7 | 98% | 11.4 | 98% | 0 | 0.0 |

# ATTACHMENT 8

# COMPARATIVE COST ESTIMATES

# COCLE 90 – 100

# COMPARATIVE COST ESTIMATES
# 90-MW rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Overburden Excavation | cu.m | $3.70 | 4,500 | $16,650 |
| Rock Excavation | cu.m | $9.20 | 2,310 | $21,252 |
| Portal Excavation | cu.m | $14.80 | 1,620 | $23,976 |
| Structural Concrete | cu.m | $145.00 | 6,930 | $1,004,850 |
| Formwork | sq.m | $46.80 | 14,320 | $670,176 |
| Steel Reinforcement | Ton | $1,320 | 312.0 | $411,840 |
| Steel Liner | Ton | $3,200 | 14.4 | $46,080 |
| Miscellaneous Metal Works | % | 5% | | $109,741 |
| ***Subtotal*** | | | | $2,304,565 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.60 x 3.40) and Hoist | Each | $420,000 | 3 | $1,260,000 |
| Stoplogs | Each | $87,500 | 3 | $262,500 |
| Trash Screen Bays | Each | $425,000 | 3 | $1,275,000 |
| Trash Rake | Each | $120,000 | 2 | $240,000 |
| Emergency Diesel Generator (50 kW) | Each | $62,500 | 1 | $62,500 |
| Power and Control Equipment | LS | $60,000 | 1 | $60,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $3,205,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Portal Excavation | cu.m | $14.80 | 1,940 | $28,712 |
| Shaft Excavation | cu.m | $310.00 | 2,450 | $759,500 |
| Tunnel Excavation | cu.m | $185.00 | 8,180 | $1,513,300 |
| Shotcrete | sq.m | $45.90 | 6,600 | $302,940 |
| Rockbolts | L.m | $67.00 | 2,500 | $167,500 |
| Steel Ribs | kg | $6.00 | 18,250 | $109,500 |
| Tunnel Concrete Lining | sq.m | $172.00 | 1,900 | $326,800 |
| Shaft Concrete Lining | cu.m | $180.00 | 570 | $102,600 |
| Formwork (shaft) | sq.m | $46.80 | 1,330 | $62,244 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 62.3 | $82,236 |
| Structural Concrete (penstock) | cu.m | $145.00 | 850 | $123,250 |
| Formwork (penstock) | sq.m | $46.80 | 1,640 | $76,752 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 39.0 | $51,480 |
| Steel Penstock | cu.m | $3,200 | 1,142.0 | $3,654,400 |
| Miscellaneous | % | 5% | | $368,061 |
| ***Subtotal*** | | | | $7,729,275 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.70 | 10,500 | $38,850 |
| Rock Excavation | cu.m | $9.20 | 3,500 | $32,200 |
| **Subtotal** | | | | $71,050 |

# COMPARATIVE COST ESTIMATES
## 90-MW rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Overburden Excavation | cu.m | $3.70 | 37,500 | $138,750 |
| Rock Excavation | cu.m | $9.20 | 5,270 | $48,484 |
| Mass Concrete | cu.m | $116.00 | 6,940 | $805,040 |
| Structural Concrete | cu.m | $145.00 | 3,030 | $439,350 |
| Formwork | sq.m | $46.80 | 19,530 | $914,004 |
| Steel Reinforcement | Ton | $1,320 | 325.0 | $429,000 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 1,100 | $341,000 |
| Miscellaneous | % | 5% | | $155,781 |
| ***Subtotal*** | | | | $3,271,409 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (2.80 m dia) | Each | $580,000 | 3 | $1,740,000 |
| Turbine/Generator Unit (30 MW) | Each | $4,200,000 | 3 | $12,600,000 |
| 30-MW Unit Auxiliaries | Each | $600,000 | 3 | $1,800,000 |
| Draft Tube Gates | Each | $75,000 | 6 | $450,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (1.50 m dia) | Each | $218,750 | 1 | $218,750 |
| Pressure Reducing Control Valves (1.50 m dia) | Each | $437,500 | 1 | $437,500 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Semi-Gantry Crane | LS | $600,000 | 1 | $600,000 |
| *Miscellaneous Electrical* | | | | |
| Main Power Transformer -35 MVA | Each | $515,000 | 3 | $1,545,000 |
| Take-off Structures & OH lines to Switchyard | LS | $150,000 | 1 | $150,000 |
| Switchgear - 13.8 kV | LS | $125,000 | 1 | $125,000 |
| Station Service Transformer | Each | $110,000 | 1 | $110,000 |
| Stand-by Diesel Generator | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $550,000 | 1 | $550,000 |
| Control and Communication Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $1,200,000 | 1 | $1,200,000 |
| **Subtotal** | | | | $22,338,750 |
| ***Transmission System*** | | | | |
| *Switchyard* | | | | |
| 230-kV Equipment Bays | Each | $325,000 | 3 | $975,000 |
| Service Power Transformer - 5MV | Each | $112,500 | 1 | $112,500 |
| Protection, Control and Comm. Equip | LS | $650,000 | 1 | $650,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $325,000 | 1 | $325,000 |
| Steel structures | LS | $600,000 | 1 | $600,000 |
| Civil Work | LS | $350,000 | 1 | $350,000 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $125,000 | 1 | $125,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *230-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $62,500 | 109 | $6,812,500 |
| Conductors and Shield Wire | km | $62,500 | 109 | $6,812,500 |
| Insulators and Accessories | km | $31,250 | 109 | $3,406,250 |
| Grounding and Miscellaneous | % | 4.00% | | $681,250 |
| **Subtotal** | | | | $21,540,000 |
| | | | **TOTAL** | $47,150,159 |

# COMPARATIVE COST ESTIMATES
## 16-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Overburden Excavation | cu.m | $3.70 | 2,500 | $9,250 |
| Rock Excavation | cu.m | $9.20 | 1,280 | $11,776 |
| Portal Excavation | cu.m | $14.80 | 350 | $5,180 |
| Structural Concrete | cu.m | $145.00 | 3,250 | $471,250 |
| Formwork | sq.m | $46.80 | 7,840 | $366,912 |
| Steel Reinforcement | Ton | $1,320 | 146.3 | $193,116 |
| Steel Liner | Ton | $3,200 | 4.5 | $14,400 |
| Miscellaneous Metal Works | % | 5% | | $53,594 |
| ***Subtotal*** | | | | $1,125,478 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.10 x 2.30) and Hoist | Each | $285,000 | 1 | $285,000 |
| Trash Screen Panels | Each | $35,000 | 9 | $315,000 |
| Trash Rake | Each | $90,000 | 1 | $90,000 |
| Power and Control Equipment | LS | $45,000 | 1 | $45,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $780,000 |
| **SHAFT, TUNNEL & MANIFOLD** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Overburden Excavation | cu.m | $3.70 | 0 | $0 |
| Rock Excavation | cu.m | $9.20 | 0 | $0 |
| Portal Excavation | cu.m | $14.80 | 420 | $6,216 |
| Shaft Excavation | cu.m | $310.00 | 603 | $186,930 |
| Tunnel Excavation | cu.m | $220.00 | 2,010 | $442,200 |
| Shotcrete | sq.m | $45.90 | 3,270 | $150,093 |
| Rockbolts | L.m | $67.00 | 1,320 | $88,440 |
| Steel Ribs | kg | $6.00 | 9,050 | $54,300 |
| Tunnel Concrete Lining | sq.m | $172.00 | 880 | $151,360 |
| Shaft Concrete Lining | cu.m | $180.00 | 270 | $48,600 |
| Formwork (shaft) | sq.m | $46.80 | 570 | $26,676 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 29.1 | $38,412 |
| Structural Concrete (penstock) | cu.m | $145.00 | 260 | $37,700 |
| Formwork (penstock) | sq.m | $46.80 | 525 | $24,570 |
| Steel Reinforcement (penstock) | Ton | $1,320 | 11.7 | $15,444 |
| Steel Penstock | cu.m | $3,200 | 243.0 | $777,600 |
| Miscellaneous | % | 5% | | $102,427 |
| ***Subtotal*** | | | | $2,150,968 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Overburden Excavation | cu.m | $3.70 | 3,400 | $12,580 |
| Rock Excavation | cu.m | $9.20 | 500 | $4,600 |
| **Subtotal** | | | | $17,180 |

# COMPARATIVE COST ESTIMATES
## 16-MW Rio Cocle del Norte Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Overburden Excavation | cu.m | $3.70 | 7,500 | $27,750 |
| Rock Excavation | cu.m | $9.20 | 1,800 | $16,560 |
| Mass Concrete | cu.m | $116.00 | 1,620 | $187,920 |
| Structural Concrete | cu.m | $145.00 | 910 | $131,950 |
| Formwork | sq.m | $46.80 | 5,850 | $273,780 |
| Steel Reinforcement | Ton | $1,320 | 72.3 | $95,436 |
| Roof, siding, windows, doors, etc | sq.m | $310 | 420 | $130,200 |
| Miscellaneous | % | 5% | | $43,180 |
| ***Subtotal*** | | | | $906,776 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valve (1.80 m dia) | Each | $310,000 | 2 | $620,000 |
| Turbine/Generator Unit (8 MW) | Each | $1,560,000 | 2 | $3,120,000 |
| 8-MW Unit Auxiliaries | Each | $156,000 | 2 | $312,000 |
| Draft Tube Gates (8 MW) | Each | $90,000 | 4 | $360,000 |
| *Tunnel Release* | | | | |
| Main Inlet Valves (0.65 m dia) | Each | $140,000 | 1 | $140,000 |
| Axial Flow Control Valves (0.65 m dia) | Each | $180,000 | 1 | $180,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $187,500 | 1 | $187,500 |
| Bridge Crane | LS | $250,000 | 1 | $250,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $525,000 | 1 | $525,000 |
| Station Service Transformer | Each | $75,000 | 1 | $75,000 |
| Stand-by Diesel Generator | Each | $143,750 | 1 | $143,750 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $187,500 | 1 | $187,500 |
| Control and Communication Equip | LS | $150,000 | 1 | $150,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $800,000 | 1 | $800,000 |
| **Subtotal** | | | | $7,050,750 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Main Transformer | MVA | $29,900 | 20 | $598,000 |
| Breakers, Disconnects, etc. | LS | $186,000 | 1 | $186,000 |
| Control Panels and other Equipment | LS | $414,000 | 1 | $414,000 |
| Steel Structures and Civil Works | LS | $245,000 | 1 | $245,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,550 | 61.9 | $1,952,945 |
| Conductors and Shield Wire | km | $10,620 | 61.9 | $657,378 |
| Insulators and Accessories | km | $5,900 | 61.9 | $365,210 |
| Grounding and Miscellaneous | % | 2.50% | | $74,388 |
| **Subtotal** | | | | $4,492,921 |
| | | | **TOTAL** | $12,450,447 |

# COMPARATIVE COST ESTIMATES

## 20-MW Cano Sucio Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **TAILRACE TUNNEL** | | | | |
| Cofferdam | LS | $6,250,000 | 1 | $6,250,000 |
| Tunnel Excavation | cu.m | $80.00 | 12,856 | $1,028,480 |
| Shotcrete | sq.m | $45.90 | 3,740 | $171,666 |
| Rockbolts | l.m. | $67.00 | 2,700 | $180,900 |
| ***Subtotal*** | | | | $7,631,046 |
| **POWERHOUSE** | **Unit** | **Unit Cost** | **Quantity** | **Amount** |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 4,200 | $2,310 |
| Adit Excavation | cu.m | $85.00 | 7,811 | $663,935 |
| Cavern Excavation | cu.m | $80.00 | 10,450 | $836,000 |
| Mass Concrete | cu.m | $116.00 | 3,120 | $361,920 |
| Structural Concrete | cu.m | $145.00 | 2,613 | $378,885 |
| Formwork | sq.m | $46.80 | 11,220 | $525,096 |
| Steel Reinforcement | Ton | $1,320 | 167.0 | $220,440 |
| Steel Penstock | Ton | $3,200 | 142.0 | $454,400 |
| Shotcrete | sq.m | $45.90 | 5,320 | $244,188 |
| Rockbolts | l.m. | $67.00 | 4,500 | $301,500 |
| Miscellaneous Metal Works | % | 5% | | $199,434 |
| ***Subtotal*** | | | | $4,188,108 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valves | Each | $305,000 | 2 | $610,000 |
| Turbine/Generator Units | Each | $2,440,000 | 2 | $4,880,000 |
| Unit Auxiliaries | Each | $244,000 | 2 | $488,000 |
| Draft Tube Gates | Each | $107,500 | 4 | $430,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $250,000 | 1 | $250,000 |
| Bridge Crane | LS | $287,500 | 1 | $287,500 |
| Gantry Crane | LS | $93,750 | 1 | $93,750 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $375,000 | 1 | $375,000 |
| Station Service Transformer | Each | $56,000 | 1 | $56,000 |
| Stand-by Diesel Generator | Each | $143,750 | 1 | $143,750 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $187,500 | 1 | $187,500 |
| Control and Communication Equip | LS | $170,000 | 1 | $170,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $650,000 | 1 | $650,000 |
| **Subtotal** | | | | $8,621,500 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Main Transformer | MVA | $29,900 | 25 | $747,500 |
| Breakers, Disconnects, etc. | LS | $225,000 | 1 | $225,000 |
| Control Panels and other Equipment | LS | $350,000 | 1 | $350,000 |
| Steel Structures and Civil Works | LS | $210,000 | 1 | $210,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,550 | 8.5 | $268,175 |
| Conductors and Shield Wire | km | $10,620 | 8.5 | $90,270 |
| Insulators and Accessories | km | $5,900 | 8.5 | $50,150 |
| Grounding and Miscellaneous | % | 2.50% | | $10,215 |
| **Subtotal** | | | | $1,951,310 |
| | | | **TOTAL** | $14,760,918 |

# COMPARATIVE COST ESTIMATES
## 40-MW Rio Indio Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWER INTAKE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 0 | $0 |
| Cofferdam | L.S. | $6,500,000 | 1 | $6,500,000 |
| Overburden Excavation | cu.m | $3.70 | 12,350 | $45,695 |
| Rock Excavation | cu.m | $9.60 | 6,120 | $58,752 |
| Portal Excavation | cu.m | $14.80 | 525 | $7,770 |
| Shaft Excavation | cu.m | $310.00 | 785 | $243,350 |
| Structural Concrete | cu.m | $145.00 | 725 | $105,125 |
| Shaft Concrete Lining | cu.m | $185.00 | 205 | $37,925 |
| Formwork | sq.m | $46.80 | 1,540 | $72,072 |
| Steel Reinforcement | Ton | $1,320 | 44.6 | $58,872 |
| Steel Liner | Ton | $3,200 | 5.2 | $16,640 |
| Rock Anchors | L.m | $67 | 1,270 | $85,090 |
| ***Subtotal*** | | | | $7,231,291 |
| ***Equipment*** | | | | |
| Wheeled Intake Gate (3.50 x 5.20) and Hoist | Each | $650,000 | 2 | $1,300,000 |
| Trash Screen Bays | Each | $112,500 | 8 | $900,000 |
| Trash Rake | Each | $90,000 | 1 | $90,000 |
| Power and Control Equipment | LS | $50,000 | 1 | $50,000 |
| Stand-by Diesel Generator (200 kW) | Each | $60,000 | 1 | $60,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $45,000 | 1 | $45,000 |
| **Subtotal** | | | | $2,445,000 |
| **POWER TUNNEL & PENSTOCK** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 1,500 | $825 |
| Overburden Excavation | cu.m | $3.70 | 1,075 | $3,978 |
| Rock Excavation | cu.m | $9.60 | 780 | $7,488 |
| Portal Excavation | cu.m | $14.80 | 425 | $6,290 |
| Tunnel Excavation | cu.m | $185.00 | 16,964 | $3,138,340 |
| Shotcrete | sq.m | $45.90 | 5,650 | $259,335 |
| Rockbolts | L.m | $67.00 | 4,300 | $288,100 |
| Steel Ribs | kg | $6.00 | 14,500 | $87,000 |
| Tunnel Concrete Lining | sq.m | $172.00 | 6,110 | $1,050,920 |
| Formwork (tunnel) | sq.m | $46.20 | 3,020 | $139,524 |
| Steel Reinforcement (tunnel) | Ton | $1,320 | 71.2 | $93,984 |
| Structural Concrete (penstock) | cu.m | $145.00 | 250 | $36,250 |
| Formwork (penstock) | sq.m | $46.20 | 445 | $20,559 |
| Steel Reinforcement (penstock) | Ton | $220 | 11.3 | $2,486 |
| Steel Penstock | cu.m | $3,200 | 941.0 | $3,011,200 |
| Miscellaneous | % | 5% | | $407,314 |
| ***Subtotal*** | | | | $8,553,592 |
| **TAILRACE** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 3,750 | $2,063 |
| Overburden Excavation | cu.m | $3.70 | 2,050 | $7,585 |
| Rock Excavation | cu.m | $9.60 | 575 | $5,520 |
| **Subtotal** | | | | $15,168 |

# COMPARATIVE COST ESTIMATES
## 40-MW Rio Indio Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **POWERHOUSE & TRANSMISSION** | | | | |
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 5,040 | $2,772 |
| Overburden Excavation | cu.m | $3.70 | 16,500 | $61,050 |
| Rock Excavation | cu.m | $9.60 | 7,230 | $69,408 |
| Mass Concrete | cu.m | $116.00 | 2,820 | $327,120 |
| Structural Concrete | cu.m | $145.00 | 1,880 | $272,600 |
| Formwork | sq.m | $46.80 | 8,260 | $386,568 |
| Steel Reinforcement | Ton | $1,320 | 155.0 | $204,600 |
| Roof, siding, windows, doors, etc | sq.m | $300 | 780 | $234,000 |
| Miscellaneous | % | 5% | | $77,906 |
| ***Subtotal*** | | | | $1,636,024 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valves (2.70 m Dia) | Each | $1,090,000 | 2 | $2,180,000 |
| Turbine/Generator Units (20 MW) | Each | $3,650,000 | 2 | $7,300,000 |
| Unit Auxiliaries | Each | $365,000 | 2 | $730,000 |
| Draft Tube Gates (2.40m x 2.75m) | Each | $125,000 | 6 | $750,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $375,000 | 1 | $375,000 |
| Bridge Crane (90 T) | LS | $625,000 | 1 | $625,000 |
| Semi-Gantry Crane | LS | $125,000 | 1 | $125,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $343,750 | 1 | $343,750 |
| Main Power Transformer (25 MVA) | Each | $750,000 | 2 | $1,500,000 |
| Station Service Transformer (1 MVA) | Each | $68,750 | 1 | $68,750 |
| Stand-by Diesel Generator (500 kW) | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $437,500 | 1 | $437,500 |
| Control and Communication Equip | LS | $312,500 | 1 | $312,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $750,000 | 1 | $750,000 |
| **Subtotal** | | | | $15,747,500 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Civil Work | LS | $62,500 | 1 | $62,500 |
| Steel Structures | LS | $600,000 | 1 | $600,000 |
| Service Power Transformer (5 MVA) | Each | $93,750 | 1 | $93,750 |
| 115-kV Equipment Bay | Each | $225,000 | 3 | $675,000 |
| Protection, Control and Comm. Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $250,000 | 1 | $250,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $465,000 | 1 | $465,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,250 | 58.7 | $1,834,375 |
| Conductors and Shield Wire | km | $10,625 | 58.7 | $623,688 |
| Insulators and Accessories | km | $6,250 | 58.7 | $366,875 |
| Grounding and Miscellaneous | % | 2.75% | | $77,686 |
| **Subtotal** | | | | $6,157,623 |
| | | | **TOTAL** | $23,541,147 |

# COMPARATIVE COST ESTIMATES

## 40-MW Isla Pablon Power Plant

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| **Tailrace** | | | | |
| *Civil Work* | | | | |
| Site Preparation | sq.m | $0.55 | 60,000 | $33,000 |
| Overburden Excavation | cu.m | $3.70 | 295,000 | $1,091,500 |
| Rock Excavation | cu.m | $9.60 | 36,000 | $345,600 |
| Dredging | cu.m | $18.00 | 33,000 | $594,000 |
| **POWERHOUSE** | | | | |
| *Civil Work* | | | | |
| Site Preparation | sq.m | $0.55 | 7,000 | $3,850 |
| Overburden Excavation | cu.m | $3.70 | 31,300 | $115,810 |
| Rock Excavation | cu.m | $9.60 | 8,910 | $85,536 |
| Portal Excavation | cu.m | $14.80 | 1,025 | $15,170 |
| Mass Concrete | cu.m | $116.00 | 3,915 | $454,140 |
| Structural Concrete | cu.m | $145.00 | 2,610 | $378,450 |
| Formwork | sq.m | $46.80 | 11,745 | $549,666 |
| Steel Reinforcement | Ton | $1,320 | 215.3 | $284,196 |
| Steel Penstock | Ton | $3,200 | 187.0 | $598,400 |
| Roof, siding, windows, doors, etc | sq.m | $300 | 1,080 | $324,000 |
| Miscellaneous Metal Works | % | 5% | | $140,461 |
| ***Subtotal*** | | | | $2,949,679 |
| ***Equipment*** | | | | |
| *Power Generating* | | | | |
| Main Inlet Valves (3.30 m Dia) | Each | $1,207,500 | 2 | $2,415,000 |
| Turbine/Generator Units (20 MW) | Each | $4,025,000 | 2 | $8,050,000 |
| Unit Auxiliaries | Each | $402,500 | 2 | $805,000 |
| Axial Flow Regulating Valves (1.65 m Dia) | Each | $625,000 | 2 | $1,250,000 |
| Draft Tube Gates (2.40m x 2.75m) | Each | $125,000 | 6 | $750,000 |
| *Miscellaneous Mechanical* | | | | |
| Dewatering System | LS | $375,000 | 1 | $375,000 |
| Bridge Crane (90 T) | LS | $625,000 | 1 | $625,000 |
| Semi-Gantry Crane | LS | $125,000 | 1 | $125,000 |
| *Miscellaneous Electrical* | | | | |
| Switchgear - 13.8 kV | LS | $343,750 | 1 | $343,750 |
| Main Power Transformer (25 MVA) | Each | $750,000 | 2 | $1,500,000 |
| Station Service Transformer (1 MVA) | Each | $68,750 | 1 | $68,750 |
| Stand-by Diesel Generator (500 kW) | Each | $250,000 | 1 | $250,000 |
| Station Auxiliaries (light, HVAC, etc.) | LS | $437,500 | 1 | $437,500 |
| Control and Communication Equip | LS | $312,500 | 1 | $312,500 |
| Cabling, MV & LV Power, Cont/Comm | LS | $750,000 | 1 | $750,000 |
| **Subtotal** | | | | $18,057,500 |
| ***Transmission System*** | | | | |
| *115-kV Substation* | | | | |
| Civil Work | LS | $62,500 | 1 | $62,500 |
| Steel Structures | LS | $600,000 | 1 | $600,000 |
| Service Power Transformer (5 MVA) | Each | $93,750 | 1 | $93,750 |
| 115-kV Equipment Bay | Each | $225,000 | 3 | $675,000 |
| Protection, Control and Comm. Equip | LS | $375,000 | 1 | $375,000 |
| Cabling, MV & LV Power, Cont/Comm | LS | $250,000 | 1 | $250,000 |
| Control Building Auxiliaries | LS | $43,750 | 1 | $43,750 |
| *La Chorrera Substation* | | | | |
| Breakers, Disconnects, etc. | LS | $400,000 | 1 | $400,000 |
| Control Panels and other Equipment | LS | $465,000 | 1 | $465,000 |
| Steel Structures and Civil Works | LS | $290,000 | 1 | $290,000 |
| *115-kV Transmission Line* | | | | |
| Civil Works (survey, Found., Struc.) | km | $31,250 | 47.1 | $1,471,875 |
| Conductors and Shield Wire | km | $10,625 | 47.1 | $500,438 |
| Insulators and Accessories | km | $6,250 | 47.1 | $294,375 |
| Grounding and Miscellaneous | % | 2.75% | | $62,334 |
| **Subtotal** | | | | $5,584,021 |
| | | | **TOTAL** | $26,591,200 |

# COMPARATIVE COST ESTIMATES
## Cano Sucio Surge Tank

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 6,400 | $3,520 |
| Overburden Excavation | cu.m | $3.70 | 37,000 | $136,900 |
| Rock Excavation | cu.m | $9.20 | 10,032 | $92,294 |
| Large Diameter Shaft Excavation | cu.m | $14.50 | 17,534 | $254,243 |
| Shaft Excavation | cu.m | $310.00 | 785 | $243,350 |
| Shotcrete | sq.m | $45.90 | 1,500 | $68,850 |
| Shaft Concret Lining | cu.m | $180.00 | 200 | $36,000 |
| Structural Concrete | cu.m | $145.00 | 6,496 | $941,920 |
| Formwork | sq.m | $46.80 | 7,326 | $342,857 |
| Steel Reinforcement | Ton | $1,320 | 259.8 | $342,936 |
| Rock Anchors | L.m | $56 | 3,630 | $202,917 |
| Miscellaneous Support | % | 5% | | $133,289 |
| ***Subtotal*** | | | | $2,799,077 |

# COMPARATIVE COST ESTIMATES
## Isla Pablon Surge Tank

| | Unit | Unit Cost | Quantity | Amount |
|---|---|---|---|---|
| ***Civil Work*** | | | | |
| Site Preparation | sq.m | $0.55 | 6,400 | $3,520 |
| Overburden Excavation | cu.m | $3.70 | 37,000 | $136,900 |
| Rock Excavation | cu.m | $9.20 | 10,032 | $92,294 |
| Large Diameter Shaft Excavation | cu.m | $14.50 | 34,370 | $498,365 |
| Shaft Excavation | cu.m | $310.00 | 785 | $243,350 |
| Shotcrete | sq.m | $45.90 | 1,500 | $68,850 |
| Shaft Concret Lining | cu.m | $180.00 | 200 | $36,000 |
| Structural Concrete | cu.m | $145.00 | 9,095 | $1,318,775 |
| Formwork | sq.m | $46.80 | 10,256 | $479,981 |
| Steel Reinforcement | Ton | $1,320 | 409.3 | $540,276 |
| Rock Anchors | L.m | $56 | 5,080 | $283,972 |
| Miscellaneous Support | % | 5% | | $185,114 |
| ***Subtotal*** | | | | $3,887,397 |

*Note* 35-meter Diameter Tank

# ATTACHMENT 9

# ECONOMIC ANALYSIS

# COCLE 90 - 100

# ECONOMIC ANALYSIS

## Rio Cocle del Norte Hydropower Component
## Economic Return Summary

| | Construction Cost | O&M Annual Cost | Period from 2032 to 2091 | | | Internal Rate of Return |
|---|---|---|---|---|---|---|
| | | | Avg Annual Energy (GWh) | Avg Firm Capacity (MW) | Annual Revenue | |
| 3 x 30-MW Power Plant at Cocle del Norte | $86,911,000 | $1,574,800 | 355.8 | 73.4 | $20,411,300 | 26.4% |
| 2 x 8-MW Power Plant at Cocle del Norte | $23,753,000 | $438,700 | 75.7 | 16.0 | $4,366,500 | 14.6% |
| 2 x 20-MW Power Plant at Rio Indio | $60,069,000 | $1,037,300 | 170.9 | 0.0 | $7,689,000 | 16.9% |
| 2 x 20-MW Power Plant at Isla Pablon | $64,069,000 | $1,070,200 | 216.5 | 18.7 | $10,863,400 | 18.7% |

**Energy Value** $45 per MWh
**Firm Capacity Value** $60 per kW-yr

## Energy Production Estimates (GWh/yr)

| Year | 3 x 30-MW Power Plant at Cocle del Norte | 2 x 8-MW Power Plant at Cocle del Norte | 2 x 20-MW Power Plant at Rio Indio | 2 x 20-MW Power Plant at Isla Pablon |
|---|---|---|---|---|
| 2032 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2033 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2034 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2035 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2036 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2037 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2038 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2039 | 542.2 | 75.7 | 286.1 | 285.8 |
| 2040 | 542.2 | 75.7 | 286.1 | 282.6 |
| 2041 | 542.2 | 75.7 | 286.1 | 279.5 |
| 2042 | 542.2 | 75.7 | 286.1 | 276.3 |
| 2043 | 542.2 | 75.7 | 286.1 | 273.1 |
| 2044 | 542.2 | 75.7 | 286.1 | 270.0 |
| 2045 | 542.2 | 75.7 | 282.0 | 266.8 |
| 2046 | 542.2 | 75.7 | 277.8 | 263.6 |
| 2047 | 542.2 | 75.7 | 273.7 | 260.5 |
| 2048 | 542.2 | 75.7 | 269.5 | 257.3 |
| 2049 | 533.0 | 75.7 | 265.4 | 254.1 |
| 2050 | 523.8 | 75.7 | 261.2 | 250.9 |
| 2051 | 514.6 | 75.7 | 257.1 | 247.8 |
| 2052 | 505.4 | 75.7 | 252.9 | 244.6 |
| 2053 | 496.2 | 75.7 | 248.8 | 241.4 |
| 2054 | 487.0 | 75.7 | 244.6 | 238.3 |
| 2055 | 477.8 | 75.7 | 240.5 | 235.1 |
| 2056 | 468.6 | 75.7 | 234.0 | 231.9 |
| 2057 | 459.4 | 75.7 | 227.6 | 228.8 |
| 2058 | 450.2 | 75.7 | 221.1 | 225.6 |
| 2059 | 441.0 | 75.7 | 214.6 | 222.4 |
| 2060 | 431.8 | 75.7 | 208.2 | 219.3 |
| 2061 | 422.6 | 75.7 | 201.7 | 216.1 |
| 2062 | 413.4 | 75.7 | 195.2 | 212.9 |
| 2063 | 398.3 | 75.7 | 188.8 | 209.8 |
| 2064 | 383.1 | 75.7 | 182.3 | 206.6 |
| 2065 | 368.0 | 75.7 | 175.8 | 203.4 |
| 2066 | 352.8 | 75.7 | 169.4 | 200.3 |
| 2067 | 337.7 | 75.7 | 162.9 | 197.1 |
| 2068 | 322.5 | 75.7 | 152.1 | 193.9 |
| 2069 | 307.4 | 75.7 | 141.3 | 190.8 |
| 2070 | 292.2 | 75.7 | 130.4 | 187.6 |
| 2071 | 277.1 | 75.7 | 119.6 | 184.4 |
| 2072 | 257.2 | 75.7 | 108.8 | 181.2 |
| 2073 | 237.4 | 75.7 | 98.0 | 178.1 |
| 2074 | 217.5 | 75.7 | 87.1 | 174.9 |
| 2075 | 197.6 | 75.7 | 76.3 | 171.7 |
| 2076 | 177.7 | 75.7 | 66.9 | 168.6 |
| 2077 | 157.9 | 75.7 | 57.5 | 165.4 |
| 2078 | 138.0 | 75.7 | 48.1 | 162.2 |
| 2079 | 122.5 | 75.7 | 38.6 | 159.1 |
| 2080 | 107.0 | 75.7 | 29.2 | 155.9 |
| 2081 | 91.5 | 75.7 | 19.8 | 155.9 |
| 2082 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2083 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2084 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2085 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2086 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2087 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2088 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2089 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2090 | 76.0 | 75.7 | 10.4 | 155.9 |
| 2091 | 76.0 | 75.7 | 10.4 | 155.9 |

## Firm Capacity Estimates (MW-yr)

| Year | 3 x 30-MW Power Plant at Cocle del Norte | 2 x 8-MW Power Plant at Cocle del Norte | 2 x 20-MW Power Plant at Rio Indio | 2 x 20-MW Power Plant at Isla Pablon |
|---|---|---|---|---|
| 2032 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2033 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2034 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2035 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2036 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2037 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2038 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2039 | 90.00 | 16.00 | 0.00 | 40.00 |
| 2040 | 90.00 | 16.00 | 0.00 | 39.02 |
| 2041 | 90.00 | 16.00 | 0.00 | 38.05 |
| 2042 | 90.00 | 16.00 | 0.00 | 37.07 |
| 2043 | 90.00 | 16.00 | 0.00 | 36.10 |
| 2044 | 90.00 | 16.00 | 0.00 | 35.12 |
| 2045 | 90.00 | 16.00 | 0.00 | 34.15 |
| 2046 | 90.00 | 16.00 | 0.00 | 33.17 |
| 2047 | 90.00 | 16.00 | 0.00 | 32.20 |
| 2048 | 90.00 | 16.00 | 0.00 | 31.22 |
| 2049 | 90.00 | 16.00 | 0.00 | 30.24 |
| 2050 | 90.00 | 16.00 | 0.00 | 29.27 |
| 2051 | 90.00 | 16.00 | 0.00 | 28.29 |
| 2052 | 90.00 | 16.00 | 0.00 | 27.32 |
| 2053 | 90.00 | 16.00 | 0.00 | 26.34 |
| 2054 | 90.00 | 16.00 | 0.00 | 25.37 |
| 2055 | 90.00 | 16.00 | 0.00 | 24.39 |
| 2056 | 90.00 | 16.00 | 0.00 | 23.41 |
| 2057 | 90.00 | 16.00 | 0.00 | 22.44 |
| 2058 | 90.00 | 16.00 | 0.00 | 21.46 |
| 2059 | 90.00 | 16.00 | 0.00 | 20.49 |
| 2060 | 90.00 | 16.00 | 0.00 | 19.51 |
| 2061 | 90.00 | 16.00 | 0.00 | 18.54 |
| 2062 | 90.00 | 16.00 | 0.00 | 17.56 |
| 2063 | 90.00 | 16.00 | 0.00 | 16.59 |
| 2064 | 90.00 | 16.00 | 0.00 | 15.61 |
| 2065 | 90.00 | 16.00 | 0.00 | 14.63 |
| 2066 | 90.00 | 16.00 | 0.00 | 13.66 |
| 2067 | 90.00 | 16.00 | 0.00 | 12.68 |
| 2068 | 90.00 | 16.00 | 0.00 | 11.71 |
| 2069 | 90.00 | 16.00 | 0.00 | 10.73 |
| 2070 | 90.00 | 16.00 | 0.00 | 9.76 |
| 2071 | 90.00 | 16.00 | 0.00 | 8.78 |
| 2072 | 83.59 | 16.00 | 0.00 | 7.80 |
| 2073 | 77.17 | 16.00 | 0.00 | 6.83 |
| 2074 | 70.76 | 16.00 | 0.00 | 5.85 |
| 2075 | 64.34 | 16.00 | 0.00 | 4.88 |
| 2076 | 57.93 | 16.00 | 0.00 | 3.90 |
| 2077 | 51.51 | 16.00 | 0.00 | 2.93 |
| 2078 | 45.10 | 16.00 | 0.00 | 1.95 |
| 2079 | 40.00 | 16.00 | 0.00 | 0.98 |
| 2080 | 34.90 | 16.00 | 0.00 | 0.00 |
| 2081 | 29.80 | 16.00 | 0.00 | 0.00 |
| 2082 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2083 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2084 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2085 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2086 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2087 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2088 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2089 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2090 | 24.70 | 16.00 | 0.00 | 0.00 |
| 2091 | 24.70 | 16.00 | 0.00 | 0.00 |

## ECONOMIC ANALYSIS

# 3 x 30-MW Power Plant at Cocle del Norte

| Year | Project Cost | O&M (Annual Operation) | Energy Revenue (Annual Operation) | Capacity Revenue (Annual Operation) | Total |
|---|---|---|---|---|---|
| 2029 | $21,727,750 | | | | -$21,727,750 |
| 2030 | $26,073,300 | | | | -$26,073,300 |
| 2031 | $39,109,950 | | | | -$39,109,950 |
| 2032 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2033 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2034 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2035 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2036 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2037 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2038 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2039 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2040 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2041 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2042 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2043 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2044 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2045 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2046 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2047 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2048 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2049 | | $1,574,800 | $23,985,000 | $5,400,000 | $27,810,200 |
| 2050 | | $1,574,800 | $23,571,000 | $5,400,000 | $27,396,200 |
| 2051 | | $1,574,800 | $23,157,000 | $5,400,000 | $26,982,200 |
| 2052 | | $1,574,800 | $22,743,000 | $5,400,000 | $26,568,200 |
| 2053 | | $1,574,800 | $22,329,000 | $5,400,000 | $26,154,200 |
| 2054 | | $1,574,800 | $21,915,000 | $5,400,000 | $25,740,200 |
| 2055 | | $1,574,800 | $21,501,000 | $5,400,000 | $25,326,200 |
| 2056 | | $1,574,800 | $21,087,000 | $5,400,000 | $24,912,200 |
| 2057 | | $1,574,800 | $20,673,000 | $5,400,000 | $24,498,200 |
| 2058 | | $1,574,800 | $20,259,000 | $5,400,000 | $24,084,200 |
| 2059 | | $1,574,800 | $19,845,000 | $5,400,000 | $23,670,200 |
| 2060 | | $1,574,800 | $19,431,000 | $5,400,000 | $23,256,200 |
| 2061 | $27,539,625 | $1,574,800 | $19,017,000 | $5,400,000 | -$4,697,425 |
| 2062 | | $1,574,800 | $18,603,000 | $5,400,000 | $22,428,200 |
| 2063 | | $1,574,800 | $17,921,500 | $5,400,000 | $21,746,700 |
| 2064 | | $1,574,800 | $17,240,000 | $5,400,000 | $21,065,200 |
| 2065 | | $1,574,800 | $16,558,500 | $5,400,000 | $20,383,700 |
| 2066 | | $1,574,800 | $15,877,000 | $5,400,000 | $19,702,200 |
| 2067 | | $1,574,800 | $15,195,500 | $5,400,000 | $19,020,700 |
| 2068 | | $1,574,800 | $14,514,000 | $5,400,000 | $18,339,200 |
| 2069 | | $1,574,800 | $13,832,500 | $5,400,000 | $17,657,700 |
| 2070 | | $1,574,800 | $13,151,000 | $5,400,000 | $16,976,200 |
| 2071 | | $1,574,800 | $12,469,500 | $5,400,000 | $16,294,700 |
| 2072 | | $1,574,800 | $11,575,286 | $5,015,143 | $15,015,629 |
| 2073 | | $1,574,800 | $10,681,071 | $4,630,286 | $13,736,557 |
| 2074 | | $1,574,800 | $9,786,857 | $4,245,429 | $12,457,486 |
| 2075 | | $1,574,800 | $8,892,643 | $3,860,571 | $11,178,414 |
| 2076 | | $1,574,800 | $7,998,429 | $3,475,714 | $9,899,343 |
| 2077 | | $1,574,800 | $7,104,214 | $3,090,857 | $8,620,271 |
| 2078 | | $1,574,800 | $6,210,000 | $2,706,000 | $7,341,200 |
| 2079 | | $1,574,800 | $5,512,500 | $2,400,000 | $6,337,700 |
| 2080 | | $1,574,800 | $4,815,000 | $2,094,000 | $5,334,200 |
| 2081 | | $1,574,800 | $4,117,500 | $1,788,000 | $4,330,700 |
| 2082 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2083 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2084 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2085 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2086 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2087 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2088 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2089 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2090 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2091 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |

### Cost Summary

| | |
|---|---|
| Civil Work Cost | $13,376,000 |
| Equipment Cost | $25,544,000 |
| Transmission System | $21,540,000 |
| **Subtotal** | **$60,460,000** |
| Contingencies | $15,115,000 |
| Engineering & Administration (15%) | $11,336,000 |
| **Project Development Cost** | **$86,911,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $192,280 |
| Equipment Maintenance | $917,988 |
| Transmission Maintenance | $464,456 |
| **Total O&M** | **$1,574,800** |
| **Internal Rate of Return** | **26.4%** |

# 2 x 8-MW Power Plant at Cocle del Norte

| | | Annual Operation | | | |
|---|---|---|---|---|---|
| Year | Project Cost | O&M | Energy Revenue | Capacity Revenue | Total |
| 2029 | $5,938,250 | | | | -$5,938,250 |
| 2030 | $7,125,900 | | | | -$7,125,900 |
| 2031 | $10,688,850 | | | | -$10,688,850 |
| 2032 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2033 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2034 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2035 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2036 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2037 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2038 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2039 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2040 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2041 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2042 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2043 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2044 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2045 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2046 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2047 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2048 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2049 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2050 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2051 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2052 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2053 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2054 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2055 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2056 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2057 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2058 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2059 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2060 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2061 | $8,442,797 | $438,700 | $3,406,500 | $960,000 | -$4,514,997 |
| 2062 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2063 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2064 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2065 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2066 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2067 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2068 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2069 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2070 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2071 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2072 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2073 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2074 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2075 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2076 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2077 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2078 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2079 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2080 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2081 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2082 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2083 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2084 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2085 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2086 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2087 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2088 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2089 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2090 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |
| 2091 | | $438,700 | $3,406,500 | $960,000 | $3,927,800 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $4,200,000 |
| Equipment Cost | $7,831,000 |
| Transmission System | $4,493,000 |
| **Subtotal** | **$16,524,000** |
| Contingencies | $4,131,000 |
| Engineering & Administration (15%) | $3,098,000 |
| **Project Development Cost** | **$23,753,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $60,375 |
| Equipment Maintenance | $281,427 |
| Transmission Maintenance | $96,880 |
| **Total O&M** | **$438,700** |
| | |
| **Internal Rate of Return** | **14.6%** |

ECONOMIC ANALYSIS

# 2 x 20-MW Power Plant at Rio Indio

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $15,017,250 | | | | -$15,017,250 |
| 2030 | $18,020,700 | | | | -$18,020,700 |
| 2031 | $27,031,050 | | | | -$27,031,050 |
| 2032 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2033 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2034 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2035 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2036 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2037 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2038 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2039 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2040 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2041 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2042 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2043 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2044 | | $1,037,300 | $12,874,500 | $0 | $11,837,200 |
| 2045 | | $1,037,300 | $12,687,955 | $0 | $11,650,655 |
| 2046 | | $1,037,300 | $12,501,409 | $0 | $11,464,109 |
| 2047 | | $1,037,300 | $12,314,864 | $0 | $11,277,564 |
| 2048 | | $1,037,300 | $12,128,318 | $0 | $11,091,018 |
| 2049 | | $1,037,300 | $11,941,773 | $0 | $10,904,473 |
| 2050 | | $1,037,300 | $11,755,227 | $0 | $10,717,927 |
| 2051 | | $1,037,300 | $11,568,682 | $0 | $10,531,382 |
| 2052 | | $1,037,300 | $11,382,136 | $0 | $10,344,836 |
| 2053 | | $1,037,300 | $11,195,591 | $0 | $10,158,291 |
| 2054 | | $1,037,300 | $11,009,045 | $0 | $9,971,745 |
| 2055 | | $1,037,300 | $10,822,500 | $0 | $9,785,200 |
| 2056 | | $1,037,300 | $10,531,500 | $0 | $9,494,200 |
| 2057 | | $1,037,300 | $10,240,500 | $0 | $9,203,200 |
| 2058 | | $1,037,300 | $9,949,500 | $0 | $8,912,200 |
| 2059 | | $1,037,300 | $9,658,500 | $0 | $8,621,200 |
| 2060 | | $1,037,300 | $9,367,500 | $0 | $8,330,200 |
| 2061 | $19,614,328 | $1,037,300 | $9,076,500 | $0 | -$11,575,128 |
| 2062 | | $1,037,300 | $8,785,500 | $0 | $7,748,200 |
| 2063 | | $1,037,300 | $8,494,500 | $0 | $7,457,200 |
| 2064 | | $1,037,300 | $8,203,500 | $0 | $7,166,200 |
| 2065 | | $1,037,300 | $7,912,500 | $0 | $6,875,200 |
| 2066 | | $1,037,300 | $7,621,500 | $0 | $6,584,200 |
| 2067 | | $1,037,300 | $7,330,500 | $0 | $6,293,200 |
| 2068 | | $1,037,300 | $6,843,375 | $0 | $5,806,075 |
| 2069 | | $1,037,300 | $6,356,250 | $0 | $5,318,950 |
| 2070 | | $1,037,300 | $5,869,125 | $0 | $4,831,825 |
| 2071 | | $1,037,300 | $5,382,000 | $0 | $4,344,700 |
| 2072 | | $1,037,300 | $4,894,875 | $0 | $3,857,575 |
| 2073 | | $1,037,300 | $4,407,750 | $0 | $3,370,450 |
| 2074 | | $1,037,300 | $3,920,625 | $0 | $2,883,325 |
| 2075 | | $1,037,300 | $3,433,500 | $0 | $2,396,200 |
| 2076 | | $1,037,300 | $3,009,857 | $0 | $1,972,557 |
| 2077 | | $1,037,300 | $2,586,214 | $0 | $1,548,914 |
| 2078 | | $1,037,300 | $2,162,571 | $0 | $1,125,271 |
| 2079 | | $1,037,300 | $1,738,929 | $0 | $701,629 |
| 2080 | | $1,037,300 | $1,315,286 | $0 | $277,986 |
| 2081 | | $1,037,300 | $891,643 | $0 | -$145,657 |
| 2082 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2083 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2084 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2085 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2086 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2087 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2088 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2089 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2090 | | $1,037,300 | $468,000 | $0 | -$569,300 |
| 2091 | | $1,037,300 | $468,000 | $0 | -$569,300 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $17,436,000 |
| Equipment Cost | $18,193,000 |
| Transmission System | $6,158,000 |
| **Subtotal** | **$41,787,000** |
| Contingencies | $10,447,000 |
| Engineering & Administration (15%) | $7,835,000 |
| **Project Development Cost** | **$60,069,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $250,643 |
| Equipment Maintenance | $653,811 |
| Transmission Maintenance | $132,782 |
| **Total O&M** | **$1,037,300** |
| **Internal Rate of Return** | **16.9%** |

**ECONOMIC ANALYSIS**

# 2 x 20-MW Power Plant at Isla Pablon

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $16,017,250 | | | | -$16,017,250 |
| 2030 | $19,220,700 | | | | -$19,220,700 |
| 2031 | $28,831,050 | | | | -$28,831,050 |
| 2032 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2033 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2034 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2035 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2036 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2037 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2038 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2039 | | $1,070,200 | $12,861,000 | $2,400,000 | $14,190,800 |
| 2040 | | $1,070,200 | $12,718,427 | $2,341,463 | $13,989,690 |
| 2041 | | $1,070,200 | $12,575,854 | $2,282,927 | $13,788,580 |
| 2042 | | $1,070,200 | $12,433,280 | $2,224,390 | $13,587,471 |
| 2043 | | $1,070,200 | $12,290,707 | $2,165,854 | $13,386,361 |
| 2044 | | $1,070,200 | $12,148,134 | $2,107,317 | $13,185,251 |
| 2045 | | $1,070,200 | $12,005,561 | $2,048,780 | $12,984,141 |
| 2046 | | $1,070,200 | $11,862,988 | $1,990,244 | $12,783,032 |
| 2047 | | $1,070,200 | $11,720,415 | $1,931,707 | $12,581,922 |
| 2048 | | $1,070,200 | $11,577,841 | $1,873,171 | $12,380,812 |
| 2049 | | $1,070,200 | $11,435,268 | $1,814,634 | $12,179,702 |
| 2050 | | $1,070,200 | $11,292,695 | $1,756,098 | $11,978,593 |
| 2051 | | $1,070,200 | $11,150,122 | $1,697,561 | $11,777,483 |
| 2052 | | $1,070,200 | $11,007,549 | $1,639,024 | $11,576,373 |
| 2053 | | $1,070,200 | $10,864,976 | $1,580,488 | $11,375,263 |
| 2054 | | $1,070,200 | $10,722,402 | $1,521,951 | $11,174,154 |
| 2055 | | $1,070,200 | $10,579,829 | $1,463,415 | $10,973,044 |
| 2056 | | $1,070,200 | $10,437,256 | $1,404,878 | $10,771,934 |
| 2057 | | $1,070,200 | $10,294,683 | $1,346,341 | $10,570,824 |
| 2058 | | $1,070,200 | $10,152,110 | $1,287,805 | $10,369,715 |
| 2059 | | $1,070,200 | $10,009,537 | $1,229,268 | $10,168,605 |
| 2060 | | $1,070,200 | $9,866,963 | $1,170,732 | $9,967,495 |
| 2061 | $19,468,781 | $1,070,200 | $9,724,390 | $1,112,195 | -$9,702,396 |
| 2062 | | $1,070,200 | $9,581,817 | $1,053,659 | $9,565,276 |
| 2063 | | $1,070,200 | $9,439,244 | $995,122 | $9,364,166 |
| 2064 | | $1,070,200 | $9,296,671 | $936,585 | $9,163,056 |
| 2065 | | $1,070,200 | $9,154,098 | $878,049 | $8,961,946 |
| 2066 | | $1,070,200 | $9,011,524 | $819,512 | $8,760,837 |
| 2067 | | $1,070,200 | $8,868,951 | $760,976 | $8,559,727 |
| 2068 | | $1,070,200 | $8,726,378 | $702,439 | $8,358,617 |
| 2069 | | $1,070,200 | $8,583,805 | $643,902 | $8,157,507 |
| 2070 | | $1,070,200 | $8,441,232 | $585,366 | $7,956,398 |
| 2071 | | $1,070,200 | $8,298,659 | $526,829 | $7,755,288 |
| 2072 | | $1,070,200 | $8,156,085 | $468,293 | $7,554,178 |
| 2073 | | $1,070,200 | $8,013,512 | $409,756 | $7,353,068 |
| 2074 | | $1,070,200 | $7,870,939 | $351,220 | $7,151,959 |
| 2075 | | $1,070,200 | $7,728,366 | $292,683 | $6,950,849 |
| 2076 | | $1,070,200 | $7,585,793 | $234,146 | $6,749,739 |
| 2077 | | $1,070,200 | $7,443,220 | $175,610 | $6,548,629 |
| 2078 | | $1,070,200 | $7,300,646 | $117,073 | $6,347,520 |
| 2079 | | $1,070,200 | $7,158,073 | $58,537 | $6,146,410 |
| 2080 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2081 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2082 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2083 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2084 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2085 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2086 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2087 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2088 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2089 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2090 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |
| 2091 | | $1,070,200 | $7,015,500 | $0 | $5,945,300 |

**Cost Summary**

| | |
|---|---|
| Civil Work Cost | $20,927,000 |
| Equipment Cost | $18,058,000 |
| Transmission System | $5,584,000 |
| **Subtotal** | **$44,569,000** |
| Contingencies | $11,143,000 |
| Engineering & Administration (15%) | $8,357,000 |
| **Project Development Cost** | **$64,069,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $300,826 |
| Equipment Maintenance | $648,959 |
| Transmission Maintenance | $120,405 |
| **Total O&M** | **$1,070,200** |
| **Internal Rate of Return** | **18.7%** |

## Energy Production Estimates (GWh/yr)

| Year | Gatun | | | Madden | | | Strategy 2 above Strategy 1 | Strategy 3A above Strategy 1 |
|---|---|---|---|---|---|---|---|---|
| | Strategy 1 | Strategy 2 | Strategy 3A | Strategy 1 | Strategy 2 | Strategy 3A | | |
| 2032 | 54.5 | 54.5 | 138.1 | 187.9 | 187.9 | 188.6 | 0.0 | 84.3 |
| 2033 | 53.2 | 51.6 | 132.4 | 187.2 | 186.5 | 188.0 | -2.2 | 80.0 |
| 2034 | 52.0 | 48.8 | 126.7 | 186.4 | 185.2 | 187.5 | -4.5 | 75.8 |
| 2035 | 50.7 | 45.9 | 121.0 | 185.7 | 183.8 | 186.9 | -6.7 | 71.5 |
| 2036 | 49.4 | 43.0 | 115.2 | 184.9 | 182.4 | 186.4 | -8.9 | 67.3 |
| 2037 | 48.1 | 40.2 | 109.5 | 184.2 | 181.0 | 185.8 | -11.1 | 63.0 |
| 2038 | 46.9 | 37.3 | 103.8 | 183.4 | 179.7 | 185.3 | -13.4 | 58.8 |
| 2039 | 45.6 | 34.4 | 98.1 | 182.7 | 178.3 | 184.7 | -15.6 | 54.5 |
| 2040 | 44.3 | 31.6 | 96.3 | 182.0 | 176.9 | 184.1 | -17.8 | 54.1 |
| 2041 | 43.0 | 28.7 | 94.4 | 181.2 | 175.5 | 183.5 | -20.0 | 53.7 |
| 2042 | 41.8 | 25.8 | 92.6 | 180.5 | 174.2 | 182.9 | -22.3 | 53.3 |
| 2043 | 40.5 | 23.0 | 90.8 | 179.7 | 172.8 | 182.3 | -24.5 | 52.9 |
| 2044 | 39.2 | 20.1 | 88.9 | 179.0 | 171.4 | 181.7 | -26.7 | 52.5 |
| 2045 | 37.9 | 19.8 | 87.1 | 178.2 | 171.0 | 181.1 | -25.3 | 52.1 |
| 2046 | 36.7 | 19.5 | 85.3 | 177.5 | 170.6 | 180.5 | -24.0 | 51.7 |
| 2047 | 35.4 | 19.2 | 83.4 | 176.7 | 170.3 | 179.9 | -22.6 | 51.2 |
| 2048 | 34.1 | 18.9 | 81.6 | 176.0 | 169.9 | 179.3 | -21.3 | 50.8 |
| 2049 | 32.8 | 18.6 | 79.8 | 175.3 | 169.5 | 178.7 | -19.9 | 50.4 |
| 2050 | 31.5 | 18.4 | 78.0 | 174.5 | 169.1 | 178.1 | -18.6 | 50.0 |
| 2051 | 30.3 | 18.1 | 76.1 | 173.8 | 168.7 | 177.5 | -17.2 | 49.6 |
| 2052 | 29.0 | 17.8 | 74.3 | 173.0 | 168.3 | 176.9 | -15.9 | 49.2 |
| 2053 | 27.7 | 17.5 | 72.5 | 172.3 | 168.0 | 176.3 | -14.5 | 48.8 |
| 2054 | 26.4 | 17.2 | 70.6 | 171.5 | 167.6 | 175.7 | -13.2 | 48.4 |
| 2055 | 25.2 | 16.9 | 68.8 | 170.8 | 167.2 | 175.1 | -11.8 | 48.0 |
| 2056 | 23.9 | 16.7 | 67.0 | 170.0 | 166.9 | 174.5 | -10.3 | 47.6 |
| 2057 | 22.6 | 16.5 | 65.1 | 169.3 | 166.6 | 173.9 | -8.8 | 47.2 |
| 2058 | 21.3 | 16.3 | 63.3 | 168.5 | 166.3 | 173.3 | -7.3 | 46.8 |
| 2059 | 20.0 | 16.1 | 61.5 | 167.8 | 165.9 | 172.7 | -5.8 | 46.4 |
| 2060 | 18.8 | 15.9 | 59.6 | 167.0 | 165.6 | 172.2 | -4.2 | 46.0 |
| 2061 | 17.5 | 15.7 | 57.8 | 166.3 | 165.3 | 171.6 | -2.7 | 45.6 |
| 2062 | 16.2 | 15.5 | 56.0 | 165.5 | 165.0 | 171.0 | -1.2 | 45.2 |
| 2063 | 16.0 | 15.3 | 54.1 | 165.1 | 164.7 | 170.4 | -1.1 | 43.4 |
| 2064 | 15.8 | 15.1 | 52.3 | 164.7 | 164.4 | 169.8 | -1.0 | 41.6 |
| 2065 | 15.5 | 14.9 | 50.5 | 164.3 | 164.0 | 169.2 | -0.9 | 39.8 |
| 2066 | 15.3 | 14.7 | 48.6 | 163.9 | 163.7 | 168.6 | -0.8 | 38.0 |
| 2067 | 15.1 | 14.5 | 46.8 | 163.4 | 163.4 | 168.0 | -0.6 | 36.2 |
| 2068 | 14.9 | 14.4 | 45.0 | 163.0 | 163.0 | 167.4 | -0.6 | 34.5 |
| 2069 | 14.6 | 14.3 | 43.1 | 162.6 | 162.5 | 166.8 | -0.5 | 32.7 |
| 2070 | 14.4 | 14.1 | 41.3 | 162.2 | 162.1 | 166.2 | -0.4 | 30.9 |
| 2071 | 14.2 | 14.0 | 39.5 | 161.8 | 161.7 | 165.6 | -0.3 | 29.1 |
| 2072 | 14.0 | 13.9 | 37.7 | 161.3 | 161.2 | 165.0 | -0.3 | 27.3 |
| 2073 | 13.9 | 13.8 | 35.8 | 160.8 | 160.8 | 164.4 | -0.2 | 25.5 |
| 2074 | 13.7 | 13.6 | 34.0 | 160.3 | 160.3 | 163.8 | -0.1 | 23.7 |
| 2075 | 13.5 | 13.5 | 32.2 | 159.9 | 159.9 | 163.2 | 0.0 | 22.0 |
| 2076 | 13.3 | 13.4 | 30.3 | 159.4 | 159.5 | 162.6 | 0.1 | 20.2 |
| 2077 | 13.2 | 13.2 | 28.5 | 158.9 | 159.1 | 162.0 | 0.3 | 18.4 |
| 2078 | 13.0 | 13.1 | 26.7 | 158.4 | 158.7 | 161.4 | 0.4 | 16.7 |
| 2079 | 12.9 | 13.0 | 24.8 | 158.1 | 158.2 | 160.8 | 0.3 | 14.7 |
| 2080 | 12.8 | 12.9 | 23.0 | 157.7 | 157.8 | 160.2 | 0.2 | 12.7 |
| 2081 | 12.7 | 12.7 | 17.8 | 157.4 | 157.4 | 158.6 | 0.1 | 6.4 |
| 2082 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2083 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2084 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2085 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2086 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2087 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2088 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2089 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2090 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |
| 2091 | 12.6 | 12.6 | 12.6 | 157.0 | 157.0 | 157.0 | 0.0 | 0.0 |

ECONOMIC ANALYSIS

# Strategy 1

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $21,727,750 | | | | -$21,727,750 |
| 2030 | $26,073,300 | | | | -$26,073,300 |
| 2031 | $39,109,950 | | | | -$39,109,950 |
| 2032 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2033 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2034 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2035 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2036 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2037 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2038 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2039 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2040 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2041 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2042 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2043 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2044 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2045 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2046 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2047 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2048 | | $1,574,800 | $24,399,000 | $5,400,000 | $28,224,200 |
| 2049 | | $1,574,800 | $23,985,000 | $5,400,000 | $27,810,200 |
| 2050 | | $1,574,800 | $23,571,000 | $5,400,000 | $27,396,200 |
| 2051 | | $1,574,800 | $23,157,000 | $5,400,000 | $26,982,200 |
| 2052 | | $1,574,800 | $22,743,000 | $5,400,000 | $26,568,200 |
| 2053 | | $1,574,800 | $22,329,000 | $5,400,000 | $26,154,200 |
| 2054 | | $1,574,800 | $21,915,000 | $5,400,000 | $25,740,200 |
| 2055 | | $1,574,800 | $21,501,000 | $5,400,000 | $25,326,200 |
| 2056 | | $1,574,800 | $21,087,000 | $5,400,000 | $24,912,200 |
| 2057 | | $1,574,800 | $20,673,000 | $5,400,000 | $24,498,200 |
| 2058 | | $1,574,800 | $20,259,000 | $5,400,000 | $24,084,200 |
| 2059 | | $1,574,800 | $19,845,000 | $5,400,000 | $23,670,200 |
| 2060 | | $1,574,800 | $19,431,000 | $5,400,000 | $23,256,200 |
| 2061 | $27,539,625 | $1,574,800 | $19,017,000 | $5,400,000 | -$4,697,425 |
| 2062 | | $1,574,800 | $18,603,000 | $5,400,000 | $22,428,200 |
| 2063 | | $1,574,800 | $17,921,500 | $5,400,000 | $21,746,700 |
| 2064 | | $1,574,800 | $17,240,000 | $5,400,000 | $21,065,200 |
| 2065 | | $1,574,800 | $16,558,500 | $5,400,000 | $20,383,700 |
| 2066 | | $1,574,800 | $15,877,000 | $5,400,000 | $19,702,200 |
| 2067 | | $1,574,800 | $15,195,500 | $5,400,000 | $19,020,700 |
| 2068 | | $1,574,800 | $14,514,000 | $5,400,000 | $18,339,200 |
| 2069 | | $1,574,800 | $13,832,500 | $5,400,000 | $17,657,700 |
| 2070 | | $1,574,800 | $13,151,000 | $5,400,000 | $16,976,200 |
| 2071 | | $1,574,800 | $12,469,500 | $5,400,000 | $16,294,700 |
| 2072 | | $1,574,800 | $11,575,286 | $5,015,143 | $15,015,629 |
| 2073 | | $1,574,800 | $10,681,071 | $4,630,286 | $13,736,557 |
| 2074 | | $1,574,800 | $9,786,857 | $4,245,429 | $12,457,486 |
| 2075 | | $1,574,800 | $8,892,643 | $3,860,571 | $11,178,414 |
| 2076 | | $1,574,800 | $7,998,429 | $3,475,714 | $9,899,343 |
| 2077 | | $1,574,800 | $7,104,214 | $3,090,857 | $8,620,271 |
| 2078 | | $1,574,800 | $6,210,000 | $2,706,000 | $7,341,200 |
| 2079 | | $1,574,800 | $5,512,500 | $2,400,000 | $6,337,700 |
| 2080 | | $1,574,800 | $4,815,000 | $2,094,000 | $5,334,200 |
| 2081 | | $1,574,800 | $4,117,500 | $1,788,000 | $4,330,700 |
| 2082 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2083 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2084 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2085 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2086 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2087 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2088 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2089 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2090 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |
| 2091 | | $1,574,800 | $3,420,000 | $1,482,000 | $3,327,200 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $13,376,000 |
| Equipment Cost | $25,544,000 |
| Transmission System | $21,540,000 |
| **Subtotal** | **$60,460,000** |
| Contingencies | $15,115,000 |
| Engineering & Administration (15%) | $11,336,000 |
| **Project Development Cost** | **$86,911,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $192,280 |
| Equipment Maintenance | $917,988 |
| Transmission Maintenance | $464,456 |
| **Total O&M** | **$1,574,800** |
| | |
| **Internal Rate of Return** | **26.4%** |

**ECONOMIC ANALYSIS**

# Strategy 2

| Year | Project Cost | Annual Operation: O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $20,955,500 | | | | -$20,955,500 |
| 2030 | $25,146,600 | | | | -$25,146,600 |
| 2031 | $37,719,900 | | | | -$37,719,900 |
| 2032 | | $1,476,000 | $16,281,000 | $960,000 | $15,765,000 |
| 2033 | | $1,476,000 | $16,180,768 | $960,000 | $15,664,768 |
| 2034 | | $1,476,000 | $16,080,536 | $960,000 | $15,564,536 |
| 2035 | | $1,476,000 | $15,980,304 | $960,000 | $15,464,304 |
| 2036 | | $1,476,000 | $15,880,071 | $960,000 | $15,364,071 |
| 2037 | | $1,476,000 | $15,779,839 | $960,000 | $15,263,839 |
| 2038 | | $1,476,000 | $15,679,607 | $960,000 | $15,163,607 |
| 2039 | | $1,476,000 | $15,579,375 | $960,000 | $15,063,375 |
| 2040 | | $1,476,000 | $15,479,500 | $960,000 | $14,963,500 |
| 2041 | | $1,476,000 | $15,379,625 | $960,000 | $14,863,625 |
| 2042 | | $1,476,000 | $15,279,750 | $960,000 | $14,763,750 |
| 2043 | | $1,476,000 | $15,179,875 | $960,000 | $14,663,875 |
| 2044 | | $1,476,000 | $15,080,000 | $960,000 | $14,564,000 |
| 2045 | | $1,476,000 | $14,954,182 | $960,000 | $14,438,182 |
| 2046 | | $1,476,000 | $14,828,364 | $960,000 | $14,312,364 |
| 2047 | | $1,476,000 | $14,702,545 | $960,000 | $14,186,545 |
| 2048 | | $1,476,000 | $14,576,727 | $960,000 | $14,060,727 |
| 2049 | | $1,476,000 | $14,451,195 | $960,000 | $13,935,195 |
| 2050 | | $1,476,000 | $14,325,662 | $960,000 | $13,809,662 |
| 2051 | | $1,476,000 | $14,200,130 | $960,000 | $13,684,130 |
| 2052 | | $1,476,000 | $14,074,597 | $960,000 | $13,558,597 |
| 2053 | | $1,476,000 | $13,949,065 | $960,000 | $13,433,065 |
| 2054 | | $1,476,000 | $13,823,532 | $960,000 | $13,307,532 |
| 2055 | | $1,476,000 | $13,698,000 | $960,000 | $13,182,000 |
| 2056 | | $1,476,000 | $13,475,036 | $960,000 | $12,959,036 |
| 2057 | | $1,476,000 | $13,252,071 | $960,000 | $12,736,071 |
| 2058 | | $1,476,000 | $13,029,107 | $960,000 | $12,513,107 |
| 2059 | | $1,476,000 | $12,806,143 | $960,000 | $12,290,143 |
| 2060 | | $1,476,000 | $12,583,179 | $960,000 | $12,067,179 |
| 2061 | $28,057,125 | $1,476,000 | $12,360,214 | $960,000 | -$16,212,911 |
| 2062 | | $1,476,000 | $12,137,250 | $960,000 | $11,621,250 |
| 2063 | | $1,476,000 | $11,851,500 | $960,000 | $11,335,500 |
| 2064 | | $1,476,000 | $11,565,750 | $960,000 | $11,049,750 |
| 2065 | | $1,476,000 | $11,280,000 | $960,000 | $10,764,000 |
| 2066 | | $1,476,000 | $10,994,250 | $960,000 | $10,478,250 |
| 2067 | | $1,476,000 | $10,708,500 | $960,000 | $10,192,500 |
| 2068 | | $1,476,000 | $10,224,563 | $960,000 | $9,708,562 |
| 2069 | | $1,476,000 | $9,740,625 | $960,000 | $9,224,625 |
| 2070 | | $1,476,000 | $9,256,688 | $960,000 | $8,740,688 |
| 2071 | | $1,476,000 | $8,772,750 | $960,000 | $8,256,750 |
| 2072 | | $1,476,000 | $8,289,884 | $960,000 | $7,773,884 |
| 2073 | | $1,476,000 | $7,807,018 | $960,000 | $7,291,018 |
| 2074 | | $1,476,000 | $7,324,152 | $960,000 | $6,808,152 |
| 2075 | | $1,476,000 | $6,841,286 | $960,000 | $6,325,286 |
| 2076 | | $1,476,000 | $6,422,786 | $960,000 | $5,906,786 |
| 2077 | | $1,476,000 | $6,004,286 | $960,000 | $5,488,286 |
| 2078 | | $1,476,000 | $5,585,786 | $960,000 | $5,069,786 |
| 2079 | | $1,476,000 | $5,157,964 | $960,000 | $4,641,964 |
| 2080 | | $1,476,000 | $4,730,143 | $960,000 | $4,214,143 |
| 2081 | | $1,476,000 | $4,302,321 | $960,000 | $3,786,321 |
| 2082 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2083 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2084 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2085 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2086 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2087 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2088 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2089 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2090 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |
| 2091 | | $1,476,000 | $3,874,500 | $960,000 | $3,358,500 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $21,636,000 |
| Equipment Cost | $26,024,000 |
| Transmission System | $10,651,000 |
| **Subtotal** | **$58,311,000** |
| Contingencies | $14,578,000 |
| Engineering & Administration (15%) | $10,933,000 |
| **Project Development Cost** | **$83,822,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $311,018 |
| Equipment Maintenance | $935,238 |
| Transmission Maintenance | $229,662 |
| **Total O&M** | **$1,476,000** |
| **Internal Rate of Return** | **15.8%** |

# Strategy 3A

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $21,955,500 | | | | -$21,955,500 |
| 2030 | $26,346,600 | | | | -$26,346,600 |
| 2031 | $39,519,900 | | | | -$39,519,900 |
| 2032 | | $1,508,900 | $20,061,000 | $3,360,000 | $21,912,100 |
| 2033 | | $1,508,900 | $19,869,429 | $3,360,000 | $21,720,529 |
| 2034 | | $1,508,900 | $19,677,857 | $3,360,000 | $21,528,957 |
| 2035 | | $1,508,900 | $19,486,286 | $3,360,000 | $21,337,386 |
| 2036 | | $1,508,900 | $19,294,714 | $3,360,000 | $21,145,814 |
| 2037 | | $1,508,900 | $19,103,143 | $3,360,000 | $20,954,243 |
| 2038 | | $1,508,900 | $18,911,571 | $3,360,000 | $20,762,671 |
| 2039 | | $1,508,900 | $18,720,000 | $3,360,000 | $20,571,100 |
| 2040 | | $1,508,900 | $18,559,110 | $3,301,463 | $20,351,673 |
| 2041 | | $1,508,900 | $18,398,220 | $3,242,927 | $20,132,246 |
| 2042 | | $1,508,900 | $18,237,329 | $3,184,390 | $19,912,820 |
| 2043 | | $1,508,900 | $18,076,439 | $3,125,854 | $19,693,393 |
| 2044 | | $1,508,900 | $17,915,549 | $3,067,317 | $19,473,966 |
| 2045 | | $1,508,900 | $17,754,659 | $3,008,780 | $19,254,539 |
| 2046 | | $1,508,900 | $17,593,768 | $2,950,244 | $19,035,112 |
| 2047 | | $1,508,900 | $17,432,878 | $2,891,707 | $18,815,685 |
| 2048 | | $1,508,900 | $17,271,988 | $2,833,171 | $18,596,259 |
| 2049 | | $1,508,900 | $17,111,383 | $2,774,634 | $18,377,117 |
| 2050 | | $1,508,900 | $16,950,779 | $2,716,098 | $18,157,976 |
| 2051 | | $1,508,900 | $16,790,174 | $2,657,561 | $17,938,835 |
| 2052 | | $1,508,900 | $16,629,570 | $2,599,024 | $17,719,694 |
| 2053 | | $1,508,900 | $16,468,965 | $2,540,488 | $17,500,553 |
| 2054 | | $1,508,900 | $16,308,361 | $2,481,951 | $17,281,412 |
| 2055 | | $1,508,900 | $16,147,756 | $2,423,415 | $17,062,271 |
| 2056 | | $1,508,900 | $15,987,152 | $2,364,878 | $16,843,130 |
| 2057 | | $1,508,900 | $15,826,547 | $2,306,341 | $16,623,989 |
| 2058 | | $1,508,900 | $15,665,943 | $2,247,805 | $16,404,847 |
| 2059 | | $1,508,900 | $15,505,338 | $2,189,268 | $16,185,706 |
| 2060 | | $1,508,900 | $15,344,733 | $2,130,732 | $15,966,565 |
| 2061 | $27,911,578 | $1,508,900 | $15,184,129 | $2,072,195 | -$12,164,154 |
| 2062 | | $1,508,900 | $15,023,524 | $2,013,659 | $15,528,283 |
| 2063 | | $1,508,900 | $14,800,134 | $1,955,122 | $15,246,356 |
| 2064 | | $1,508,900 | $14,576,744 | $1,896,585 | $14,964,429 |
| 2065 | | $1,508,900 | $14,353,354 | $1,838,049 | $14,682,502 |
| 2066 | | $1,508,900 | $14,129,963 | $1,779,512 | $14,400,576 |
| 2067 | | $1,508,900 | $13,906,573 | $1,720,976 | $14,118,649 |
| 2068 | | $1,508,900 | $13,683,183 | $1,662,439 | $13,836,722 |
| 2069 | | $1,508,900 | $13,459,793 | $1,603,902 | $13,554,795 |
| 2070 | | $1,508,900 | $13,236,402 | $1,545,366 | $13,272,868 |
| 2071 | | $1,508,900 | $13,013,012 | $1,486,829 | $12,990,941 |
| 2072 | | $1,508,900 | $12,790,693 | $1,428,293 | $12,710,086 |
| 2073 | | $1,508,900 | $12,568,375 | $1,369,756 | $12,429,231 |
| 2074 | | $1,508,900 | $12,346,056 | $1,311,220 | $12,148,375 |
| 2075 | | $1,508,900 | $12,123,737 | $1,252,683 | $11,867,520 |
| 2076 | | $1,508,900 | $11,901,418 | $1,194,146 | $11,586,664 |
| 2077 | | $1,508,900 | $11,679,099 | $1,135,610 | $11,305,809 |
| 2078 | | $1,508,900 | $11,456,780 | $1,077,073 | $11,024,954 |
| 2079 | | $1,508,900 | $11,225,140 | $1,018,537 | $10,734,777 |
| 2080 | | $1,508,900 | $10,993,500 | $960,000 | $10,444,600 |
| 2081 | | $1,508,900 | $10,707,750 | $960,000 | $10,158,850 |
| 2082 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2083 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2084 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2085 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2086 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2087 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2088 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2089 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2090 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |
| 2091 | | $1,508,900 | $10,422,000 | $960,000 | $9,873,100 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $25,127,000 |
| Equipment Cost | $25,889,000 |
| Transmission System | $10,077,000 |
| **Subtotal** | **$61,093,000** |
| Contingencies | $15,274,000 |
| Engineering & Administration (15%) | $11,455,000 |
| **Project Development Cost** | **$87,822,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $361,201 |
| Equipment Maintenance | $930,386 |
| Transmission Maintenance | $217,285 |
| **Total O&M** | **$1,508,900** |
| | |
| **Internal Rate of Return** | **20.3%** |

| | Energy Production Estimates | | | Firm Capacity (MW-yr) | | |
|---|---|---|---|---|---|---|
| Year | 3 x 20-MW Power Plant at Cocle del Norte | 3 x 25-MW Power Plant at Cocle del Norte | 3 x 30-MW Power Plant at Cocle del Norte | 3 x 20-MW Power Plant at Cocle del Norte | 3 x 25-MW Power Plant at Cocle del Norte | 3 x 30-MW Power Plant at Cocle del Norte |
| 2032 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2033 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2034 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2035 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2036 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2037 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2038 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2039 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2040 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2041 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2042 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2043 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2044 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2045 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2046 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2047 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2048 | 471.7 | 538.0 | 542.2 | 60.00 | 75.00 | 90.00 |
| 2049 | 467.5 | 529.1 | 533.0 | 60.00 | 75.00 | 90.00 |
| 2050 | 463.4 | 520.2 | 523.8 | 60.00 | 75.00 | 90.00 |
| 2051 | 459.2 | 511.3 | 514.6 | 60.00 | 75.00 | 90.00 |
| 2052 | 455.0 | 502.4 | 505.4 | 60.00 | 75.00 | 90.00 |
| 2053 | 450.9 | 493.5 | 496.2 | 60.00 | 75.00 | 90.00 |
| 2054 | 446.7 | 484.6 | 487.0 | 60.00 | 75.00 | 90.00 |
| 2055 | 442.6 | 475.7 | 477.8 | 60.00 | 75.00 | 90.00 |
| 2056 | 438.4 | 466.8 | 468.6 | 60.00 | 75.00 | 90.00 |
| 2057 | 434.2 | 457.9 | 459.4 | 60.00 | 75.00 | 90.00 |
| 2058 | 430.1 | 449.0 | 450.2 | 60.00 | 75.00 | 90.00 |
| 2059 | 425.9 | 440.1 | 441.0 | 60.00 | 75.00 | 90.00 |
| 2060 | 421.7 | 431.2 | 431.8 | 60.00 | 75.00 | 90.00 |
| 2061 | 417.6 | 422.3 | 422.6 | 60.00 | 75.00 | 90.00 |
| 2062 | 413.4 | 413.4 | 413.4 | 60.00 | 75.00 | 90.00 |
| 2063 | 398.3 | 398.3 | 398.3 | 60.00 | 75.00 | 90.00 |
| 2064 | 383.1 | 383.1 | 383.1 | 60.00 | 75.00 | 90.00 |
| 2065 | 368.0 | 368.0 | 368.0 | 60.00 | 75.00 | 90.00 |
| 2066 | 352.8 | 352.8 | 352.8 | 60.00 | 75.00 | 90.00 |
| 2067 | 337.7 | 337.7 | 337.7 | 60.00 | 75.00 | 90.00 |
| 2068 | 322.5 | 322.5 | 322.5 | 60.00 | 75.00 | 90.00 |
| 2069 | 307.4 | 307.4 | 307.4 | 60.00 | 75.00 | 90.00 |
| 2070 | 292.2 | 292.2 | 292.2 | 60.00 | 75.00 | 90.00 |
| 2071 | 277.1 | 277.1 | 277.1 | 60.00 | 75.00 | 90.00 |
| 2072 | 257.2 | 257.2 | 257.2 | 57.87 | 70.73 | 83.59 |
| 2073 | 237.4 | 237.4 | 237.4 | 55.74 | 66.46 | 77.17 |
| 2074 | 217.5 | 217.5 | 217.5 | 53.61 | 62.19 | 70.76 |
| 2075 | 197.6 | 197.6 | 197.6 | 51.49 | 57.91 | 64.34 |
| 2076 | 177.7 | 177.7 | 177.7 | 49.36 | 53.64 | 57.93 |
| 2077 | 157.9 | 157.9 | 157.9 | 47.23 | 49.37 | 51.51 |
| 2078 | 138.0 | 138.0 | 138.0 | 45.10 | 45.10 | 45.10 |
| 2079 | 122.5 | 122.5 | 122.5 | 40.00 | 40.00 | 40.00 |
| 2080 | 107.0 | 107.0 | 107.0 | 34.90 | 34.90 | 34.90 |
| 2081 | 91.5 | 91.5 | 91.5 | 29.80 | 29.80 | 29.80 |
| 2082 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2083 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2084 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2085 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2086 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2087 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2088 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2089 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2090 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |
| 2091 | 76.0 | 76.0 | 76.0 | 24.70 | 24.70 | 24.70 |

ECONOMIC ANALYSIS

# 3 x 20MW

| | | Annual Operation | | | |
|---|---|---|---|---|---|
| Year | Project Cost | O&M | Energy Revenue | Capacity Revenue | Total |
| 2029 | $17,454,500 | | | | -$17,454,500 |
| 2030 | $20,945,400 | | | | -$20,945,400 |
| 2031 | $31,418,100 | | | | -$31,418,100 |
| 2032 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2033 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2034 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2035 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2036 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2037 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2038 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2039 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2040 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2041 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2042 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2043 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2044 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2045 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2046 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2047 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2048 | | $1,185,500 | $21,226,500 | $3,600,000 | $23,641,000 |
| 2049 | | $1,185,500 | $21,039,107 | $3,600,000 | $23,453,607 |
| 2050 | | $1,185,500 | $20,851,714 | $3,600,000 | $23,266,214 |
| 2051 | | $1,185,500 | $20,664,321 | $3,600,000 | $23,078,821 |
| 2052 | | $1,185,500 | $20,476,929 | $3,600,000 | $22,891,429 |
| 2053 | | $1,185,500 | $20,289,536 | $3,600,000 | $22,704,036 |
| 2054 | | $1,185,500 | $20,102,143 | $3,600,000 | $22,516,643 |
| 2055 | | $1,185,500 | $19,914,750 | $3,600,000 | $22,329,250 |
| 2056 | | $1,185,500 | $19,727,357 | $3,600,000 | $22,141,857 |
| 2057 | | $1,185,500 | $19,539,964 | $3,600,000 | $21,954,464 |
| 2058 | | $1,185,500 | $19,352,571 | $3,600,000 | $21,767,071 |
| 2059 | | $1,185,500 | $19,165,179 | $3,600,000 | $21,579,679 |
| 2060 | | $1,185,500 | $18,977,786 | $3,600,000 | $21,392,286 |
| 2061 | $18,873,656 | $1,185,500 | $18,790,393 | $3,600,000 | $2,331,237 |
| 2062 | | $1,185,500 | $18,603,000 | $3,600,000 | $21,017,500 |
| 2063 | | $1,185,500 | $17,921,500 | $3,600,000 | $20,336,000 |
| 2064 | | $1,185,500 | $17,240,000 | $3,600,000 | $19,654,500 |
| 2065 | | $1,185,500 | $16,558,500 | $3,600,000 | $18,973,000 |
| 2066 | | $1,185,500 | $15,877,000 | $3,600,000 | $18,291,500 |
| 2067 | | $1,185,500 | $15,195,500 | $3,600,000 | $17,610,000 |
| 2068 | | $1,185,500 | $14,514,000 | $3,600,000 | $16,928,500 |
| 2069 | | $1,185,500 | $13,832,500 | $3,600,000 | $16,247,000 |
| 2070 | | $1,185,500 | $13,151,000 | $3,600,000 | $15,565,500 |
| 2071 | | $1,185,500 | $12,469,500 | $3,600,000 | $14,884,000 |
| 2072 | | $1,185,500 | $11,575,286 | $3,472,286 | $13,862,071 |
| 2073 | | $1,185,500 | $10,681,071 | $3,344,571 | $12,840,143 |
| 2074 | | $1,185,500 | $9,786,857 | $3,216,857 | $11,818,214 |
| 2075 | | $1,185,500 | $8,892,643 | $3,089,143 | $10,796,286 |
| 2076 | | $1,185,500 | $7,998,429 | $2,961,429 | $9,774,357 |
| 2077 | | $1,185,500 | $7,104,214 | $2,833,714 | $8,752,429 |
| 2078 | | $1,185,500 | $6,210,000 | $2,706,000 | $7,730,500 |
| 2079 | | $1,185,500 | $5,512,500 | $2,400,000 | $6,727,000 |
| 2080 | | $1,185,500 | $4,815,000 | $2,094,000 | $5,723,500 |
| 2081 | | $1,185,500 | $4,117,500 | $1,788,000 | $4,720,000 |
| 2082 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2083 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2084 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2085 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2086 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2087 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2088 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2089 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2090 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |
| 2091 | | $1,185,500 | $3,420,000 | $1,482,000 | $3,716,500 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $13,529,000 |
| Equipment Cost | $17,506,000 |
| Transmission System | $21,169,000 |
| **Subtotal** | **$52,204,000** |
| Contingencies | $8,507,000 |
| Engineering & Administration (15%) | $9,107,000 |
| **Project Development Cost** | **$69,818,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $186,700 |
| Equipment Maintenance | $578,792 |
| Transmission Maintenance | $419,940 |
| **Total O&M** | **$1,185,500** |
| **Internal Rate of Return** | **27.3%** |

## ECONOMIC ANALYSIS

# 3 x 25MW

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $19,244,750 | | | | -$19,244,750 |
| 2030 | $23,093,700 | | | | -$23,093,700 |
| 2031 | $34,640,550 | | | | -$34,640,550 |
| 2032 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2033 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2034 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2035 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2036 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2037 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2038 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2039 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2040 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2041 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2042 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2043 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2044 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2045 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2046 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2047 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2048 | | $1,328,100 | $24,210,000 | $4,500,000 | $27,381,900 |
| 2049 | | $1,328,100 | $23,809,500 | $4,500,000 | $26,981,400 |
| 2050 | | $1,328,100 | $23,409,000 | $4,500,000 | $26,580,900 |
| 2051 | | $1,328,100 | $23,008,500 | $4,500,000 | $26,180,400 |
| 2052 | | $1,328,100 | $22,608,000 | $4,500,000 | $25,779,900 |
| 2053 | | $1,328,100 | $22,207,500 | $4,500,000 | $25,379,400 |
| 2054 | | $1,328,100 | $21,807,000 | $4,500,000 | $24,978,900 |
| 2055 | | $1,328,100 | $21,406,500 | $4,500,000 | $24,578,400 |
| 2056 | | $1,328,100 | $21,006,000 | $4,500,000 | $24,177,900 |
| 2057 | | $1,328,100 | $20,605,500 | $4,500,000 | $23,777,400 |
| 2058 | | $1,328,100 | $20,205,000 | $4,500,000 | $23,376,900 |
| 2059 | | $1,328,100 | $19,804,500 | $4,500,000 | $22,976,400 |
| 2060 | | $1,328,100 | $19,404,000 | $4,500,000 | $22,575,900 |
| 2061 | $22,735,500 | $1,328,100 | $19,003,500 | $4,500,000 | -$560,100 |
| 2062 | | $1,328,100 | $18,603,000 | $4,500,000 | $21,774,900 |
| 2063 | | $1,328,100 | $17,921,500 | $4,500,000 | $21,093,400 |
| 2064 | | $1,328,100 | $17,240,000 | $4,500,000 | $20,411,900 |
| 2065 | | $1,328,100 | $16,558,500 | $4,500,000 | $19,730,400 |
| 2066 | | $1,328,100 | $15,877,000 | $4,500,000 | $19,048,900 |
| 2067 | | $1,328,100 | $15,195,500 | $4,500,000 | $18,367,400 |
| 2068 | | $1,328,100 | $14,514,000 | $4,500,000 | $17,685,900 |
| 2069 | | $1,328,100 | $13,832,500 | $4,500,000 | $17,004,400 |
| 2070 | | $1,328,100 | $13,151,000 | $4,500,000 | $16,322,900 |
| 2071 | | $1,328,100 | $12,469,500 | $4,500,000 | $15,641,400 |
| 2072 | | $1,328,100 | $11,575,286 | $4,243,714 | $14,490,900 |
| 2073 | | $1,328,100 | $10,681,071 | $3,987,429 | $13,340,400 |
| 2074 | | $1,328,100 | $9,786,857 | $3,731,143 | $12,189,900 |
| 2075 | | $1,328,100 | $8,892,643 | $3,474,857 | $11,039,400 |
| 2076 | | $1,328,100 | $7,998,429 | $3,218,571 | $9,888,900 |
| 2077 | | $1,328,100 | $7,104,214 | $2,962,286 | $8,738,400 |
| 2078 | | $1,328,100 | $6,210,000 | $2,706,000 | $7,587,900 |
| 2079 | | $1,328,100 | $5,512,500 | $2,400,000 | $6,584,400 |
| 2080 | | $1,328,100 | $4,815,000 | $2,094,000 | $5,580,900 |
| 2081 | | $1,328,100 | $4,117,500 | $1,788,000 | $4,577,400 |
| 2082 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2083 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2084 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2085 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2086 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2087 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2088 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2089 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2090 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |
| 2091 | | $1,328,100 | $3,420,000 | $1,482,000 | $3,573,900 |

### Cost Summary

| | |
|---|---|
| Civil Work Cost | $15,285,000 |
| Equipment Cost | $21,088,000 |
| Transmission System | $21,169,000 |
| **Subtotal** | **$57,542,000** |
| Contingencies | $9,396,000 |
| Engineering & Administration (15%) | $10,041,000 |
| **Project Development Cost** | **$76,979,000** |

**Annual Operation & Maintenance Costs**

| | |
|---|---|
| Civil Work Maintenance | $210,933 |
| Equipment Maintenance | $697,222 |
| Transmission Maintenance | $419,940 |
| **Total O&M** | **$1,328,100** |

| | |
|---|---|
| **Internal Rate of Return** | **28.5%** |

ECONOMIC ANALYSIS

# 3 x 30MW

| Year | Project Cost | Annual Operation O&M | Energy Revenue | Capacity Revenue | Total |
|---|---|---|---|---|---|
| 2029 | $21,535,250 | | | | -$21,535,250 |
| 2030 | $25,842,300 | | | | -$25,842,300 |
| 2031 | $38,763,450 | | | | -$38,763,450 |
| 2032 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2033 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2034 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2035 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2036 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2037 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2038 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2039 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2040 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2041 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2042 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2043 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2044 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2045 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2046 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2047 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2048 | | $1,499,500 | $24,399,000 | $5,400,000 | $28,299,500 |
| 2049 | | $1,499,500 | $23,985,000 | $5,400,000 | $27,885,500 |
| 2050 | | $1,499,500 | $23,571,000 | $5,400,000 | $27,471,500 |
| 2051 | | $1,499,500 | $23,157,000 | $5,400,000 | $27,057,500 |
| 2052 | | $1,499,500 | $22,743,000 | $5,400,000 | $26,643,500 |
| 2053 | | $1,499,500 | $22,329,000 | $5,400,000 | $26,229,500 |
| 2054 | | $1,499,500 | $21,915,000 | $5,400,000 | $25,815,500 |
| 2055 | | $1,499,500 | $21,501,000 | $5,400,000 | $25,401,500 |
| 2056 | | $1,499,500 | $21,087,000 | $5,400,000 | $24,987,500 |
| 2057 | | $1,499,500 | $20,673,000 | $5,400,000 | $24,573,500 |
| 2058 | | $1,499,500 | $20,259,000 | $5,400,000 | $24,159,500 |
| 2059 | | $1,499,500 | $19,845,000 | $5,400,000 | $23,745,500 |
| 2060 | | $1,499,500 | $19,431,000 | $5,400,000 | $23,331,500 |
| 2061 | $27,066,328 | $1,499,500 | $19,017,000 | $5,400,000 | -$4,148,828 |
| 2062 | | $1,499,500 | $18,603,000 | $5,400,000 | $22,503,500 |
| 2063 | | $1,499,500 | $17,921,500 | $5,400,000 | $21,822,000 |
| 2064 | | $1,499,500 | $17,240,000 | $5,400,000 | $21,140,500 |
| 2065 | | $1,499,500 | $16,558,500 | $5,400,000 | $20,459,000 |
| 2066 | | $1,499,500 | $15,877,000 | $5,400,000 | $19,777,500 |
| 2067 | | $1,499,500 | $15,195,500 | $5,400,000 | $19,096,000 |
| 2068 | | $1,499,500 | $14,514,000 | $5,400,000 | $18,414,500 |
| 2069 | | $1,499,500 | $13,832,500 | $5,400,000 | $17,733,000 |
| 2070 | | $1,499,500 | $13,151,000 | $5,400,000 | $17,051,500 |
| 2071 | | $1,499,500 | $12,469,500 | $5,400,000 | $16,370,000 |
| 2072 | | $1,499,500 | $11,575,286 | $5,015,143 | $15,090,929 |
| 2073 | | $1,499,500 | $10,681,071 | $4,630,286 | $13,811,857 |
| 2074 | | $1,499,500 | $9,786,857 | $4,245,429 | $12,532,786 |
| 2075 | | $1,499,500 | $8,892,643 | $3,860,571 | $11,253,714 |
| 2076 | | $1,499,500 | $7,998,429 | $3,475,714 | $9,974,643 |
| 2077 | | $1,499,500 | $7,104,214 | $3,090,857 | $8,695,571 |
| 2078 | | $1,499,500 | $6,210,000 | $2,706,000 | $7,416,500 |
| 2079 | | $1,499,500 | $5,512,500 | $2,400,000 | $6,413,000 |
| 2080 | | $1,499,500 | $4,815,000 | $2,094,000 | $5,409,500 |
| 2081 | | $1,499,500 | $4,117,500 | $1,788,000 | $4,406,000 |
| 2082 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2083 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2084 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2085 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2086 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2087 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2088 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2089 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2090 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |
| 2091 | | $1,499,500 | $3,420,000 | $1,482,000 | $3,402,500 |

## Cost Summary

| | |
|---|---|
| Civil Work Cost | $18,075,000 |
| Equipment Cost | $25,105,000 |
| Transmission System | $21,169,000 |
| **Subtotal** | **$64,349,000** |
| Contingencies | $10,556,000 |
| Engineering & Administration (15%) | $11,236,000 |
| **Project Development Cost** | **$86,141,000** |
| **Annual Operation & Maintenance Costs** | |
| Civil Work Maintenance | $249,435 |
| Equipment Maintenance | $830,034 |
| Transmission Maintenance | $419,940 |
| **Total O&M** | **$1,499,500** |
| **Internal Rate of Return** | **26.6%** |