GOVERNMENT OF PAKISTAN

PROVINCE OF EAST PAKISTAN

MASTER REPORT
VOLUME I

THE KARNAFULI PROJECT
AND
POWER SURVEY WITH ECONOMIC ANALYSIS

PREPARED FOR

FOREIGN OPERATIONS ADMINISTRATION, U.S.A.

BY

INTERNATIONAL ENGINEERING COMPANY, INC.

74 NEW MONTGOMERY STREET

SAN FRANCISCO, CALIFORNIA, U.S.A.

MARCH 1955

74 NEW MONTGOMERY STREET
SAN FRANCISCO 5, CALIFORNIA

March 21, 1955

C. P. DUNN
PRESIDENT

Office of the Country Director
United States Operations Mission to Pakistan
United States Embassy
Karachi, Pakistan

Dear Sir:

It is my pleasure to transmit herewith the "Master Report" prepared in accordance with our contractual agreement dated March 24, 1954 with the Foreign Operations Administration. The "Master Report" comprises the following:

VOLUME I
THE KARNAFULI PROJECT
AND
POWER SURVEY WITH ECONOMIC ANALYSIS

VOLUME II
KARNAFULI PROJECT SPECIFICATIONS

VOLUME III
KARNAFULI PROJECT DRAWINGS

The Master Report concludes and finalizes the preliminary studies contained in the "Reconnaissance Report" submitted on August 23, 1954.

The scope of the report has followed that outlined by the terms of reference and as further determined by our several conferences. The information herein presented will enable you to evaluate the Karnafuli Project and assess the power situation in East Pakistan.

We have appreciated this opportunity of working with the United States Operations Mission to Pakistan on this project which has a number of unusual problems to evaluate and solve. During this work we have enjoyed the complete cooperation of your organization as well as that of the Government of Pakistan.

Very truly yours,

INTERNATIONAL ENGINEERING COMPANY, INC.

C P Dunn

C. P. Dunn
President

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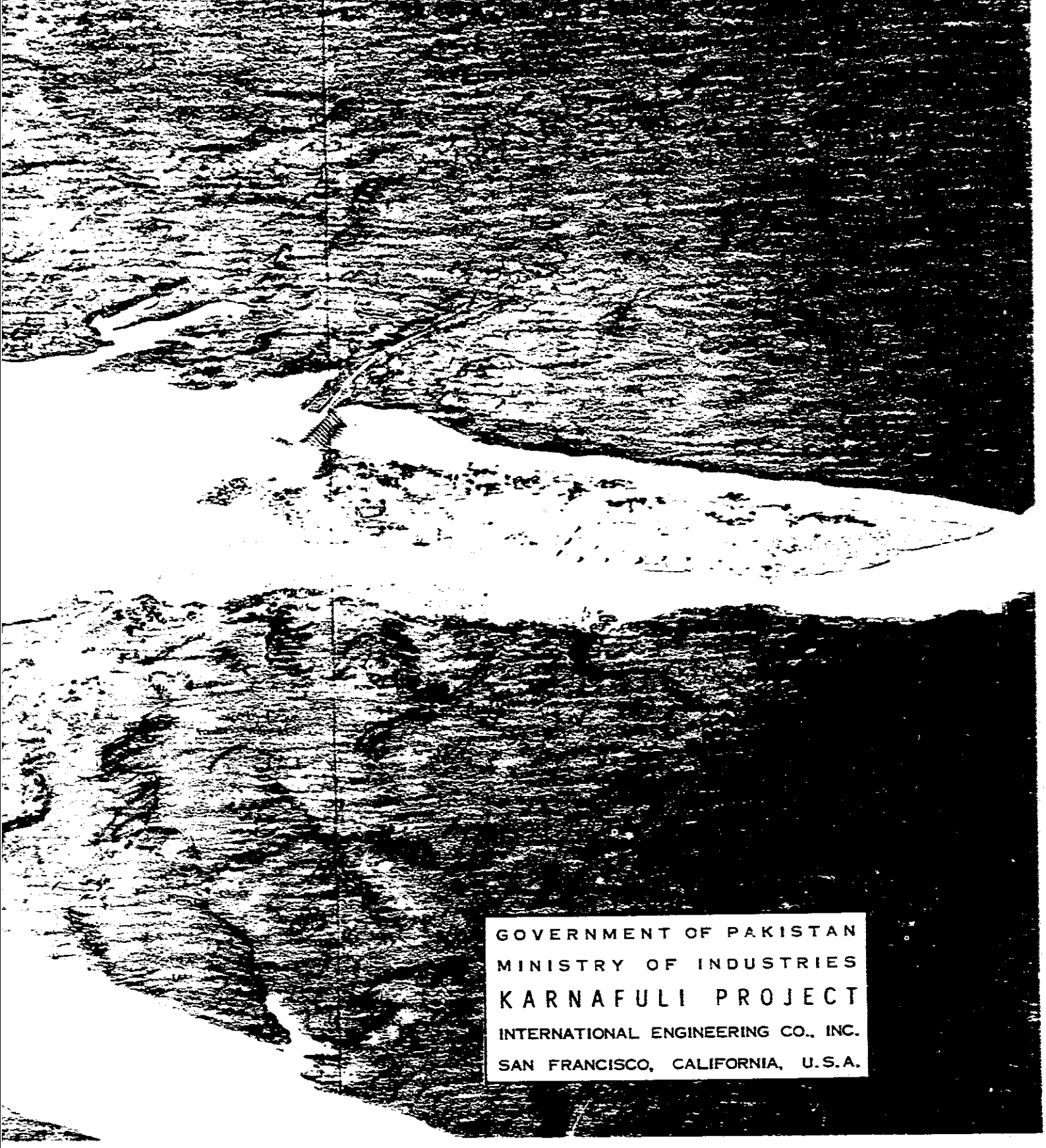
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT
INTERNATIONAL ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA, U.S.A.

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THE KARNAFULI PROJECT

AND

POWER SURVEY WITH ECONOMIC ANALYSIS

CONTENTS

CONVERSION FACTORS

PART I
SUMMARY AND CONCLUSIONS

SYNOPSIS

CHAPTER I SUMMARY AND CONCLUSIONS

PART II
INTRODUCTION

CHAPTER II INTRODUCTION

2.01 Purpose
2.02 Authority
2.03 Scope
2.04 Sources of Information
2.05 Acknowledgments
2.06 Field Personnel of the Consulting Engineers

PART III
POWER SURVEY AND POWER REQUIREMENTS
OF EAST PAKISTAN WITH ANALYSIS AND RECOMMENDATIONS

CHAPTER III GENERAL DESCRIPTION OF EAST PAKISTAN

3.01 Climate
3.02 Geography and Geology
3.03 People
3.04 Industries
3.05 General Economy of Pakistan

CHAPTER IV FIELD SURVEY OF EXISTING AND PLANNED POWER GENERATION AND FUTURE CONSUMPTION

4.01 Field Organization
4.02 Field Survey
4.03 Existing Generating Plants
4.04 Plants Under Construction and on Order
4.05 Total Installed and Planned Capacity

CHAPTER V DEVELOPMENT OF AN INTEGRATED POWER TRANSMISSION AND DISTRIBUTION SYSTEM

5.01 Existing Power Facilities
5.02 Transmission System Development

CHAPTER VI PRESENT AND ESTIMATED FUTURE POWER DEMAND IN DACCA AND CHITTAGONG AREAS

6.01 Introduction
6.02 Jute Industry
6.03 Cotton Textile Industry
6.04 Utilities and Secondary Industries
6.05 Summary - Forecast of Demand for Electric Energy
6.06 Other Possible Demands
6.07 Estimate of Demand Furnished by the Government of Pakistan
6.08 Comparison of Demand Forecast by Consulting Engineers and Estimate Furnished by the Government
6.09 Installations Required to Meet Forecasted Demand

CHAPTER VII ECONOMIC ANALYSIS

7.01 Introduction
7.02 Analysis of Schemes I and II
7.03 Comparison of Schemes I and II On Sinking Fund Basis
7.04 Operation and Debt Service Expenditures - Hydro System With Thermal Support As Recommended
7.05 Summary and Recommendations

PART IV
DESIGN OF THE KARNAFULI PROJECT

CHAPTER VIII PROJECT STUDIES

8.01 General
8.02 Sites Considered
8.03 Geology

CHAPTER VIII (Continued)

8.04 Foundation Investigations
8.05 Borrow Investigations
8.06 Aggregate Investigation
8.07 Laboratory Tests

CHAPTER IX HYDROLOGY AND WATER SUPPLY

9.01 General Characteristics
9.02 Rainfall Stations
9.03 River Gaging Stations
9.04 Evaporation
9.05 Daily Runoff
9.06 Floods of Record
9.07 Flood Potential of Basin
9.08 Storms and Storm Transposition
9.09 Design Rainstorm
9.10 Observed Unitgraphs
9.11 Design Unitgraph
9.12 Inflow Design Flood
9.13 Required Spillway Capacity
9.14 Construction Flood
9.15 Siltation
9.16 Hydrologic Network for Project Operation

CHAPTER X FLOODS AND FLOOD CONTROL

10.01 General Flood Situation
10.02 Floods of Record
10.03 Evaluation of Flood Damages
10.04 Spillway Design and Operation
10.05 General Reservoir Operations
10.06 Operations of Observed Floods
10.07 Assessment for Flood Control
10.08 Costs and Benefits

CHAPTER XI NAVIGATION

11.01 Importance of Waterways
11.02 Present River Transportation
11.03 History of Channel Improvements
11.04 General Effects of the Project
11.05 Lake Navigation
11.06 River Navigation
11.07 Future River Traffic
11.08 Revenue From Navigation Locks
11.09 River Navigation Improvement
11.10 The Port of Chittagong

CHAPTER XII HYDROELECTRIC POWER

12.01 General
12.02 Power Capability

CHAPTER XIII PROJECT FEATURES

13.01 General
13.02 Existing Features
13.03 River Diversion
13.04 Main Dam and Saddle Dam
13.05 Diversion and Outlet Tunnel
13.06 Spillway
13.07 Navigation Locks
13.08 Power Plant
13.09 Future Power Plant
13.10 Switchyard
13.11 Transmission and Switching Station Facilities

CHAPTER XIV ESTIMATES OF QUANTITIES AND COSTS

14.01 General
14.02 Schedule of Work
14.03 Quantities
14.04 Costs

CHAPTER XV SUMMARY OF BENEFITS

15.01 Power Benefits
15.02 Forestry
15.03 Fish Industry
15.04 Flood Control
15.05 Navigation
15.06 Agriculture
15.07 General Industrial Expansion
15.08 Summary and Cost-Benefit Ratio

EXHIBITS

EXHIBITS 1 THROUGH 27

APPENDIXES

A. CAPITAL AND ANNUAL COSTS - SCHEME I

B. CAPITAL AND ANNUAL COSTS - SCHEME II

C. CAPITAL AND ANNUAL COSTS - SCHEME IIa

D. OPERATION AND DEBT SERVICE

E. PROJECT QUANTITIES

F. AGRICULTURE AND LAND RECLAMATION

G. FORESTRY

CONVERSION FACTORS

United States dollars are used throughout this report with conversions as follows:

$1.00 U.S. = 3.300 Rupees

$100,000 U.S. = 3.3 Lacs of Rupees

$10,000,000 U.S. = 3.3 Crores of Rupees

Other factors commonly used in East Pakistan are:

1 Rupee = 16 Annas

1 Lac = 100,000

1 Crore = 10,000,000

1 Maund = 40 Seer

1 Maund = 82 Pounds (U.S.)

1 Ton = 2,240 Pounds (U.S.)

PART I

SUMMARY AND CONCLUSIONS

SYNOPSIS

A detailed power survey of East Pakistan has shown that the rapid industrial development of East Pakistan has been accomplished in spite of the unavailability of central station power. Industries have been required to finance and operate individual small inefficient plants to sustain their needs. Further development of the industries is essential to process the agricultural products of the province. These industries will require additional power which must be supplied either by the construction of thermal plants using imported fuel or by hydroelectric power from the Karnafuli Project which is now under construction.

The Karnafuli Project, which can be in operation in 1958, is the most economical source of power, being 32% cheaper than thermal plants when compared for the year 1965. The initial development will comprise the Karnafuli Project with an 80,000 kw initial power plant, 15,000 kw thermal plant at Dacca, 165 kv transmission line extending to Chittagong and Dacca, and a distribution system.

The Karnafuli Project will supply power substantially cheaper than thermal plants. The saving for the year 1965, for example, will be $2,648,000 of which $2,461,000 are in foreign exchange. This is the net saving after full allowance for all costs of the Karnafuli Project.

The revenue from power sales alone, at lower than prevailing rates, will meet all costs for operation, interest, and loan repayment required for the entire Karnafuli Project, transmission lines, and distribution facilities.

All the foregoing cost comparisons are based on qualified engineering supervision which is essential for the success of this project and on execution by an experienced construction organization with efficiencies equal to best United States practice.

After careful investigations and thorough study the Karnafuli Project has been found to be economically sound and entirely feasible from an engineering standpoint. As a multiple purpose project the cost-benefit ratio shows it to be unusually attractive. The immediate construction of the Karnafuli Project under qualified engineering supervision is recommended on the basis of the Specifications and Drawings, Volumes II and III of this report.

CHAPTER I

SUMMARY AND CONCLUSIONS

This report presents the results of intensive studies during the past year of the two major assignments of the terms of reference; first, a Power Survey with Economic Analysis and, second, the investigation and design of the Karnafuli Project with the preparation of "Specifications" which form Volume II of this report and the "Drawings" which form Volume III.

The Karnafuli Project is a major hydroelectric, flood control and navigation development on the Karnafuli River 40 miles upstream from Chittagong. Preliminary work on the project has been completed and construction is underway. The project comprises an earth dam 153 feet high, diversion works, navigation locks and a hydroelectric powerplant with a recommended initial installation of two 40,000 kw units and provision for a future unit.

For the "Power Survey and Economic Analysis", which forms Part III of this volume, a detailed physical census has been made and verified of all existing power plants in East Pakistan including plants under construction and those proposed. The present and expected future power demand and consumption has been similarly investigated and verified by the field survey. It has been found that the major load centers are at Chittagong and Dacca and it is recommended that service be provided to these areas initially with extension of the transmission and distribution system to serve other areas as funds permit. A very conservative estimate was made of the future power demand and consumption, which was used as a basis for economic studies. To determine the most economical means of meeting the power requirements of East Pakistan many schemes have been considered. The three most attractive schemes which have been studied in detail are: Scheme I - Thermal Plants at Dacca and Chittagong without interconnecting transmission lines; Scheme II - Karnafuli Project with navigation locks, transmission lines and supporting thermal plant at Dacca, and Scheme IIa - which is the same as Scheme II except the locks are not included in the initial project.

The results of these studies have been compared for the year 1965 which is conservative since it is prior to the full utilization of Karnafuli power. Scheme II will be 32% cheaper than the all-thermal power Scheme I and the annual net savings in foreign exchange from use of hydro power will be $2,461,000. This is the net savings after deducting the annual interest and sinking fund depreciation and operating costs of the Karnafuli Project, Scheme II.

If the construction of the locks is deferred as assumed in Scheme IIa, the cost of power will be 36% cheaper than Scheme I and the annual net savings in foreign exchange will be $2,650,000.

The cost to complete the construction work of the Karnafuli Project assuming construction efficiencies equivalent to United States practice, with navigation locks as shown on the drawings, including interest during construction and substantial contingencies is estimated to be $53,569,000. The final cost of the Karnafuli Project, including the above, plus reservoir lands, money already spent, engineering and administration amounts to $72,131,000. The additional features required to establish the complete hydro-thermal power system as an operating utility have capital costs including contingencies, lands and interest during construction as follows: 165 kv transmission line Karnafuli-Chittagong-Dacca, $11,361,000; distribution system, $2,192,000; and 15,000 kw thermal support and standby plant at Dacca, $3,435,000. The power capability of the hydro-thermal system is estimated at 540 million kwh for the year 1968 based on the assumptions made as to characteristics of the load.

Annual charges for operation, administration, interest and debt service (loan payments) for the complete hydro-thermal system composed of the Karnafuli Project with navigation locks, transmission lines, distribution system, and supporting thermal plant amount to $6,741,000 for the year 1965 during which it is conservatively estimated that 431.8 million kwh of energy will be sold. This is equivalent to 1.56 cents per kwh which is very substantially below prevailing rates in East Pakistan. The above computations assume that all project costs are chargeable to power and does not include revenue from navigation or flood control. It is concluded that the project is attractive as a public utility.

The development of the design of Karnafuli Project is described in Part IV of this volume. Alternative dam sites along the Karnafuli River have been studied and it is recommended that the present site above Kaptai be retained.

The Karnafuli Project will involve many engineering and construction problems of exceptional difficulty, however, with experienced engineering supervision these problems can be solved satisfactorily.

It is considered that the eventual traffic on the Karnafuli River will require navigation locks at the dam site and these facilities have been included in the specifications and drawings. However, the Government of Pakistan may decide that existing river traffic does not justify the large capital outlay required for navigation locks at this time, in which case, the construction of the locks may conveniently be deferred until some future date.

The benefits of the project in addition to power include flood control, navigation, commercial fishing, and the opening of a vast area surrounding the reservoir for timber industry and agriculture. Based on these benefits, the cost benefit ratio for the year 1965 is computed to be 1.96 which is considered exceptionally high. The Karnafuli Project is clearly shown to be a project of outstanding merit and of great importance to East Pakistan.

Recommendations in summary are as follows:

First — Immediate completion of the Karnafuli Project. Since foundation conditions are difficult and construction features important for successful completion, the preparation of detailed construction drawings and field supervision of construction should be in charge of a qualified engineering organization experienced in projects of this type. The construction of this project for reasons of safety and economy should be in the hands of an experienced construction organization.

Second — Initial installation of two 40,000 kw units in the Karnafuli Power Plant with space for a third unit. Project layout to provide space for a future power plant when required.

Third — Immediate action to initiate final design and layout of necessary transmission line, switching station, and distribution system.

Fourth — Construction of the above transmission and distribution system under qualified engineering supervision with completion timed to be available for service when the Karnafuli Power Plant is completed. This system to include 15,000 kw of supporting thermal plant and a 10,000 kw synchronous condenser at Dacca together with necessary switching stations.

PART II

INTRODUCTION

CHAPTER II

INTRODUCTION

2.01 PURPOSE

The "Master Report" presents in three volumes the final results of intensive work on the two major assignments of the terms of reference. The Power Survey and Economic Analysis contained in Part III of this volume and covering the first major assignment is a comprehensive survey and forecast of the power problem in East Pakistan. It includes an engineering and economic analysis of the present and future power situation and presents in detail the recommended solution.

The second major assignment is the analysis and design of the Karnafuli Multiple Purpose Project now under construction in East Pakistan. The design of this major project is developed in Part IV of this volume and the Specifications and Drawings are contained in Volumes II and III respectively of this report.

The "Master Report" supplements and finalizes the preliminary studies of the "Reconnaissance Report" issued in August 1954 and the "Report on the Electrical Development of East Pakistan" preliminary drafts of which were issued in October, December and December 15, 1954, for the purpose of review by the World Bank for Reconstruction and Development.

The history of the previous studies of the Karnafuli Project has been reported in detail in the "Reconnaissance Report" and will be considered only in their essentials in this report.

All references to costs and valuations referred to herein are in terms of U.S. dollars or dollar equivalents unless otherwise stated.

2.02 AUTHORITY

The authority for the work is contained in a contract dated March 24, 1954 between the United States of America, represented by the Foreign Operations Administration, and International Engineering Company, Inc. (herein designated as the Consulting Engineers).

2.03 SCOPE

The execution of this report has required comprehensive investigations and studies in many fields. The work has been based on first hand

verification of all important conditions. All conclusions and designs have been based on entirely independent analyses and designs. Previous reports have been reviewed and evaluated. The following tabulation presents some representative items from among the major fields of investigation:

1. Field survey and inventory of existing and proposed power plants in East Pakistan

2. Field survey of the present and expected future demand for power in East Pakistan and characteristics of the connected load

3. Selection of major load centers and layout of transmission and distribution facilities

4. Meteorological and hydrologic studies for the determination of required reservoir capacity, spillway capacity, required flood-control storage and navigation requirements

5. Economic analyses and comparisons of hydro vs thermal power generation

6. Hydro power reservoir operation studies to determine the Karnafuli Project power potential, and the relation of the project to the future power needs of East Pakistan

7. Surveys of potentially irrigable lands

8. Investigations of foundations for dam, powerhouse, spillway, locks and tunnel

9. Supervision of drilling and boring to determine foundation conditions

10. Soil laboratory studies to determine the properties of foundation and borrow materials

11. The development of designs and specifications for the Karnafuli Project after studies of alternates

12. Preparation of the "Master Report" based on the completed investigation with economic appraisal of the results of the various studies. The "Master Report" includes recommendations regarding the completion of the Project, with contract drawings, specifications and cost estimates.

2.04 SOURCES OF INFORMATION

Hydroelectric developments on the Karnafuli River have been studied since 1906. There are many reports which have been studied and evaluated by the Consulting Engineers as described in the "Reconnaissance Report".

2.05 ACKNOWLEDGMENTS

Grateful acknowledgment must be made of the excellent cooperation of the Officers of the Government of Pakistan. The willing and cheerful assistance of these Officers was a great aid and satisfaction to the Consulting Engineers. It is not feasible to acknowledge in full all persons who aided in the work but it is hoped that the organizations and their principals listed herein will convey the appreciation of the Consulting Engineers to all concerned.

The principal sources of assistance were:

Foreign Operations Administration of the United States Government, at Washington, D.C.; Mr. H. E. Stassen, Director; Mr. E. P. Herman, Officer for Contract Relations, Mr. Adolph J. Bennett, Project Manager, Industrial Technical Assistance Division.

United States Operations Mission to Pakistan, at Karachi, Dacca and Chittagong; Mr. R. R. Will, Country Director; and Mr. E. E. Byrns, Water Resources Advisor.

Ministry of Industries, Government of Pakistan, at Karachi; Mr. A. Khalilee, Secretary; Mr. K. Azeemuddin, Chief Engineer for Karnafuli and Warsak Projects.

Central Engineering Authority, Government of Pakistan, at Karachi; Mr. Mohsin Ali, Chairman.

Communication, Building and Irrigation Department, Government of East Pakistan, at Dacca; Mr. A. Majid, Secretary; Mr. K. A. Hussain, Chief Engineer, Irrigation Branch.

Electricity Directorate of Commerce, Labor and Industry Department at Dacca; Mr. W. C. Patton, Chief Engineer.

Karnafuli Project Circle, Chittagong Hill Tracts, at the dam site; Messrs. Z. Islam and F. Islam, respectively former and present Superintending Engineers.

Pakistan Industrial Development Corporation; Mr. M. A. Basith, General Manager.

2.06 FIELD PERSONNEL OF THE CONSULTING ENGINEERS

The following engineers represented the Consulting Engineers in East Pakistan:

Mr. H. W. Birkeland, Chief Project Engineer; Mr. J. P. Hawke, General Civil Engineer, and after 14 May 1954 Chief Project Engineer; Mr. E. M. Shay, Foundation and Soils Engineer; Mr. L. Flutsch, Electrical Engineer; Mr. F. Prusow, Estimating Engineer; Mr. E. E. Foster, Hydrological and Hydraulic Engineer; Mr. R. D. Flannery, Agricultural Engineer; and Mr. J. R. Fontenrose, Administrative Engineer.

PART III

POWER SURVEY AND POWER REQUIREMENTS OF EAST PAKISTAN WITH ANALYSIS AND RECOMMENDATIONS

CHAPTER III

GENERAL DESCRIPTION OF EAST PAKISTAN

3.01 CLIMATE

The climate of East Pakistan is tropical, with high temperatures and high humidity. There are two seasons, the dry winter season from October to April and the monsoon season from May to September. The monsoons are winds set up by the low air pressure over the heated land masses of Asia and the high air pressure over the relatively cooler ocean. They are laden with moisture which is precipitated as the air moves inland and is forced upward. The average annual rainfall near the eastern boundary ranges from 108 inches at Chittagong near the coast to 439 inches at Cherrapunji, located a short distance beyond the northern boundary in the hills 28 miles north of Sylhet. The average annual rainfall for the entire province is about 76 inches, of which 65 inches falls during the monsoon season. High land masses to the east effectively shield the area from violent typhoons. Spent typhoons, however, enter the province and undoubtedly cause a small part of the annual rainfall. Even during the wet season there are occasional dry periods lasting long enough to damage growing crops and serious famines have resulted. On the other hand, much of the land is flooded every summer by the combination of overflowing rivers and direct rainfall.

3.02 GEOGRAPHY AND GEOLOGY

East Pakistan (Exhibit 1) consists of the Province of East Bengal. The southern edge lies on the Bay of Bengal and the province is completely surrounded by India on the land except the extreme southeast corner, which adjoins Burma for a little more than 100 miles. Nearly all of East Pakistan is a remarkably flat alluvial plain built by the meandering and overflow of the Ganges, the Brahmaputra, and several smaller rivers. The average slope, north to south, is roughly one foot in four miles. Portions of the plain are covered by jungles and swamps. Along the north shore of the Bay of Bengal, delta country extends from 80 to 100 miles inland, with an intricate network of sloughs joining the various rivers. The entire province, in fact, is laced with a dense network of watercourses and a large part of it is flooded each year.

The districts of Chittagong and Chittagong Hill Tracts form a long irregular strip of land in the extreme southeast that is nearly detached from the rest of East Pakistan. Chittagong District is a narrow band of flat coastal country along the east shore of the Bay of Bengal. Adjoining it on the east, Chittagong Hill Tracts consists of a zone of high parallel ridges formed by lateral compression and folding of the sandstones and shales. These ranges of hills reach elevations of more than 2,000 feet,

but the rivers flowing between the ridges and cutting through them have very flat grades. The hills are densely forested, game is plentiful, and only a small percentage of the hill area is cultivated.

The capital of East Pakistan is Dacca, located not far from the geographic center of the province. The principal port is Chittagong, on the Karnafuli River about nine miles from the coast. This is the only port in the province that is equipped to handle ocean-going ships. The Eastern Bengal Railway owned by the Pakistan Government, connects Chittagong and Dacca with other parts of the country and with the Indian railways. It has recently modernized its passenger-train service by the introduction of new diesel-electric locomotives. The total area of East Pakistan is 54,000 square miles of which about 60 percent is cultivated. The average population density is about 1,000 per square mile. In Dacca District the density is about 1,600 per square mile, in Chittagong District about 900 per square mile, and in Chittagong Hill Tracts District about 60 per square mile.

3.03 PEOPLE

Most of the 51 million inhabitants of East Pakistan are engaged in agriculture. Because of the flatness of the country and the frequent flooding, a large part of the land is suited only to wet-crop farming, rice being the principal crop.

The typical farmer of East Pakistan is a hard and earnest worker. He tends his farm by hand methods and takes pride in neat and orderly cultivation. His farm is from two to three acres in size and his family consists of six or seven persons. Cottage industries are an important part of Pakistani life. Home-spun goods, pottery, and many other home products are bartered at the local bazaars. Self-sufficiency is the farmer's way of life and comparatively little money passes through his hands. Nine-tenths of the cultivated land is devoted to food crops, mainly rice for family consumption, and only one-tenth is used for cash crops. An important article of diet is fish, both fresh and dried or salted. These are taken mostly from local streams, although there is some trade in ocean fish.

Life in the sparsely settled Chittagong Hill Tracts offers a contrast to that in the rest of East Pakistan. There are comparatively few bottomlands and only a small part of the district is under cultivation. The hill tribesmen frequently burn patches of brushland and grow annual crops on them for one or two seasons, after which the land is left to return to jungle growth. Many kinds of tropical fruits are grown in the area. There is an abundance of wild game and hunting makes up a large part of the livelihood of the hill people. Forestry, including the cutting of bamboo for building cottages and sungrass for thatching them is a profitable activity. Hardwood logs, bamboo, and sungrass are rafted down the Karnafuli to be marketed

in the lower country, where a large amount of bamboo is used for paper pulp.

A small but rapidly increasing part of the population is employed in industrial plants, such as jute, cotton, silk, paper, and fertilizer mills. The welfare of these workers is protected by enlightened labor laws.

The people of East Pakistan are outstanding in their energy, self-reliance, and strength to withstand hardships. Religion enters strongly into their daily lives and the dominant Moslem faith of the country encourages each individual to better the lot of his family and his nation through sound endeavor. The average man is intelligent and adaptable to changing conditions. When employed in industry he quickly becomes a capable skilled workman and he will overlook no opportunity to acquire experience in the construction and industrial trades.

3.04 INDUSTRIES

Previous to the partition, the prime industry of East Bengal was agriculture, virtually excluding all other activities. The situation is much the same at the present time, with the important exception that the foundations for extensive industrialization are now being laid. The Government of Pakistan is actively fostering the manufacturing industries by planning and building pilot plants of various kinds. Shares in these enterprises are being sold to corporations and individuals. Established or experimental industries include the manufacture of textiles, glass, ceramic products, aluminum utensils, leather, soap, cosmetics, drugs, salt, fuel alcohol, furniture, rubber shoes, buttons, plastic articles, silverware and a number of other products. The Government has made extensive studies of agricultural methods in order to help the farmers increase their production of food and raw materials. A plant has been built to manufacture ammonium sulfate fertilizer in large quantities at low cost. Agricultural and other technical schools have been established. Training groups have been set up to provide instruction in the cottage industries, especially the weaving of cotton and silk fabrics.

The local raw materials available to the industries of East Pakistan are the soil itself and its vegetal produce. Sand and gravel suitable for concrete aggregates are found in the vicinity of Sylhet, and clay from which brick is made is found in all parts of the province. The forests of the Sundarbans and Chittagong Hill Tracts supply fuel, timber for construction, wood for match and furniture factories, and bamboo for a paper mill. The principal agricultural produce for industry is jute, which before partition was shipped to Calcutta for processing. Much of the jute is now being processed in recently constructed jute mills such as those at Narayanganj near Dacca and at Chittagong. Other products of industrial importance are cotton, silk, tea, hemp, hides, tobacco, betel nuts, and sugar cane.

Mineral resources, other than sand, gravel, and clay mentioned above, are not yet known to exist in commercial quantities or qualities. Oil has been found in the Patharia Forest region, but not in sufficient quantity to warrant production. Lignite deposits of low quality have been located in the Sylhet and Tippera Districts. Except for oil and lignite, it is probable that no important mineral discoveries will be made since the land is entirely of sedimentary origin.

The electrical power required for the expansion of industry has been supplied up to the present time by steam and diesel generating plants. Both of these depend upon imported fuels, either coal or oil. Some thought has been given to the use of local wood for firing steam boilers. It is also possible that lignite might be burned in specially designed steam plants. The opportunities for hydroelectric power generation are limited by the topography of the area. Only one river, the Karnafuli, has been found to be attractive for power development on a large scale.

Although the industrial development of East Pakistan is still in its infancy, it is progressing rapidly. Business conditions are good and there are excellent opportunities for the profitable investment of foreign capital.

3.05 GENERAL ECONOMY OF PAKISTAN

Pakistan does not now enjoy an economically balanced trade position. Although almost exclusively an agricultural nation, supplementary foodstuffs must be brought in. Practically all of the manufactured goods, machinery, and fuels are imported. The principal import commodities, in descending order of tonnage, are oil, coal, cereal grains, salt, cement, and steel. To ease the pressure of a dense and increasing population and raise the standard of living of the people, improvement of the foreign exchange situation is necessary.

Looking toward a balanced economy, the Government of Pakistan has embarked upon a program to increase agricultural and industrial production. This will develop the export trade and at the same time reduce the per capita imports of those goods which can be produced economically within the country. The principal export commodity of East Pakistan at the present time is jute, of which the province produces three-quarters of the world supply. Much of the jute produced in East Pakistan is now processed before export and it is expected that in years to come all of it will be exported in processed form. Other important items of export are tea, sugar, hides, cotton, and betel nuts. Plywood, dimension lumber, furniture, paper, and other wood products afford excellent opportunities for increasing the export trade.

Greater industrial activity is increasing the amount of fuel that must be imported for the generation of power. Fuel imports can be materially reduced and the economic situation enhanced by the use of hydroelectric power produced in East Pakistan.

CHAPTER IV

FIELD SURVEY OF EXISTING AND PLANNED POWER GENERATION AND FUTURE CONSUMPTION

4.01 FIELD ORGANIZATION

A survey was made by the Consulting Engineers in 1954 to inventory all existing electrical installations in East Pakistan, to observe the conditions under which the plants operated, and to discuss with various parties their needs and plans for future developments. This survey was made entirely independently of previous investigations.

The survey group consisted of eight graduate Electrical Engineers from the Irrigation Department, Government of East Pakistan, organized under the direction of the Consulting Engineers and charged with obtaining new field data for a comprehensive power census. The field survey was directed and conducted by Messrs. H. W. Birkeland, J. P. Hawke and L. Flutsch for the Consultants, with Mr. W. Choudhuri, Executive Engineer (Electrical), Irrigation Department, Government of East Pakistan.

4.02 FIELD SURVEY

The collection of field data was accomplished by assigning districts to the survey engineers. Each engineer was provided with questionnaire forms to obtain factual data such as the number, ratings, manufacturer of units, fuel consumption, cost of generation, consumer load and power factor, condition of the plant and equipment, and data for estimating the future needs and developments.

The mechanics of the field survey consisted of visiting the existing generating and industrial plants in all districts of East Pakistan. Discussions were held with the local engineers and management about proposed and probable future demands and developments. In areas where there were no existing plants, conferences were held with local engineers from other departments of the government and with town officials in an effort to determine their needs and to arrive at the probable demand for electric energy, if such energy could be made available.

The Consulting Engineers exercised close control of the field forces at all times and personally visited about 80% of the total installed capacity of East Pakistan and checked the field data. After completion of the field survey the Consulting Engineers rechecked the data and found it to be in good agreement with the reports of the Electricity Directorate of the Government of East Pakistan. Their latest available report, however, did not include the more recent plants.

The results of the field survey presented in this report include data on existing generating plants, plants under construction and plants on order. The forecasts of power demand and consumption presented herein are based on carefully considered data obtained in the survey. The forecasts are conservative and can reasonably be expected to take place. As in the case with any forecast, they should be reviewed in future years and adjusted for additional expansions in industries which have not been considered at this time.

The field survey covered the generating and industrial plants in 16 districts in East Pakistan. All field data and records of the survey are on file in the San Francisco offices of the Consulting Engineers.

4.03 EXISTING GENERATING PLANTS

Full tabulations of all plants visited are listed in Table IV-1 and IV-2, segregated by district and town. Plants vary from relatively new low pressure steam plants to over-age diesel engine units with very poor efficiency. The maintenance of diesel plants has been particularly troublesome due to the lack of factory service facilities and import restrictions which make it difficult to obtain needed maintenance parts and materials. Many of the plants are obsolete, inefficient or uneconomical to operate, and should, in the opinion of the Consulting Engineers, be retired, relocated, or placed on standby service when central station power becomes available.

TABLE IV-1

EXISTING GENERATING CAPACITIES AT MAJOR LOAD CENTERS

			INSTALLED CAPACITY			
			Diesel		Steam	
District	Town	Name of Plant	Units	kw	Units	kw
Dacca	Narayanganj	East Pakistan Jute Marketing Society	2	546		
	Narayanganj	Olympia Textile, Ltd.	6	450		
	Narayanganj	Tula Ram Bachraj Co.	1	50		
	Narayanganj	Dhakeswari Cotton Mills	2	425	1	4,200
	Narayanganj	Bawa Jute Mill	4	451		
	Narayanganj	Lazarus Co.	2	67		
	Narayanganj	Chittaranjan Cotton Mill			1	1,000

District	Town	Name of Plant	INSTALLED CAPACITY Diesel Units	Diesel kw	Steam Units	Steam kw	
Dacca	Narayanganj	Jamal Jute Baling	1	260			
	Narayanganj	Adamjee Jute Mill	3	2,610			
	Narayanganj	Ralli Bros.	2	30			
	Narayanganj	Kumudini Welfare Trust	5	640			
	Narayanganj	Chittagong Elect.	5	1,600			
	Narayanganj	Gov't Dock Yard Narayanganj	4	207			
	Narayanganj	Luxmi Narayan Cotton Mills			1	500	
	Narayanganj	Sonakunda Baling Co.	3	65			
	Sorachora	IGN & Rly Co., Ltd.	3	205			
	Postogola	Dacca Flour Mill	5	425			
	Tejgaon	Nabisco	3	165			
	Tejgaon	Bengal Rubber Industries	3	275			
	Dacca	Elect. Directorate	9	512			
	Dacca	Dacca Elect. Supply Co., Ltd.			3	6,000	
	Dacca	Engineering College	3	130			
	Munshiganj	Munshiganj Elect. Supply	2	32			
	Daulatpur	M.M.Ispahani Co., Ltd.	3	248			
	Mirpur	Brick & Tiles Co.	2	160			
				9,653		11,700	
		DISTRICT TOTAL					21,3531
Chittagong	Pahartali	East Bengal Railway			3	3,000	
	Pahartali	Ispahani, Ltd.	6	1,956			
	Sholashahar	Amin Jute Mills	3	55			
	Sholashahar	Pakistan Oxy. & Acet.	2	185			
	Sholashahar	Mousel Company	1	30			
	Chittagong	James Finlay Co., Ltd.	2	50			
	Chittagong	Chittagong Elect. & Supply	7	1,025			
	Chittagong	Volkart Bros.	3	460			
	Chittagong	IGN & RSN Co.	2	44			

TABLE IV-1 (Continued)

District	Town	Name of Plant	INSTALLED CAPACITY Diesel Units	Diesel kw	Steam Units	Steam kw	
Chittagong	Chandraghona	Karnafuli Paper Mill			2	9,000	
	Karnafuli	Karnafuli Proj.	8	637			
	Dewanhat	Steel Bros. & Co.	2	41			
	Kalurghat	Khan Match Co.	2	110			
	Patia	B.O.C. Co.	-	80			
				4,673		12,000	
		DISTRICT TOTAL					16,673 kw
Khulna	Khulna	Electricity Directorate	7	410			
	Khulna	M.M. Ispahani	3	247			
	Rupsa	Pakistan Match Factory	4	220			
	Goalpara	Crescent Jute Mills	5	2,500			
	Daulatpur	Khulna Industries Mill	3	247			
	Daulatpur	Helal Jute Press	1	16			
				3,640			
		DISTRICT TOTAL					3,640 kw
Sylhet	Sylhet	Sylhet Electric Supply Co.	5	600			
	Fenchuganj	IGN & Rly Co.	2	50			
	Kulaura	East Bengal Railway	2	20			
	Shaistaganj	East Bengal Railway	2	20			
	Chhatak	Assam Bengal Cement Co.	3	145	2	3,000	
	Patharia	B.O.C. Pakistan Concession	-	100			
	Srimangal	East Bengal Railway	2	20			
				955		3,000	
		DISTRICT TOTAL					3,955 kw
Tippera	Comilla	Comilla Electric Supply Co.	5	422			
	Comilla	Maynamati Military HQ	2	30			
	Akhaura	East Bengal Railway	5	80			
	Brahmanbaria	Gov't Elect. Supply	2	66			
	Chandpur	Gov't Elect. Supply	4	242			
	Chandpur	East Bengal Railway	3	50			
	Laksham	East Bengal Railway	4	80			
				970			
		DISTRICT TOTAL					970 kw
TOTAL INSTALLED CAPACITY - MAJOR LOAD CENTERS							46,591 kw

TABLE IV-2

SUMMARY OF EXISTING GENERATING PLANT IN REMAINING DISTRICTS

District	Town	Name of Plant	INSTALLED CAPACITY KW Diesel	Steam	TOTAL
Rangpur	Rangpur	Chittagong Engr. & Elect.	496		
	Saidpur	East Bengal Railway		1,500	
	Testamukhghat	East Bengal Railway	20		
			516	1,500	2,016
Dinajpur	Setabganj	Setabganj Sugar Mills	90	154	
	Parbatipur	Electricity Supply	150		
			240	154	394
Bogra	Bogra	Elect. of Bogra, Ltd.	173		
	Santahar	East Bengal Railway	255		
			428		428
Pabna	Pabna	Pabna Elect. Supply	440		
	Sirajganj	Electricity Supply	245		
	Sirajganj Ghat	East Bengal Railway	20		
			705		705
Rajshahi	Rajshahi	Chittagong Engr. & Elect.	515		
	Gopalpur	North Bengal Sugar Mills	380		
			895		895
Noakhali	Choumohoni	Electric Supply	335		335
Bakrarganj	Barisal	Roy & Company	630		
	Barisal	RSN & IGN Engineering Workshop	225		
			855		855
Mymensingh	Mirzapur	Kumudini Hospital	170		
	Mymensingh	Mymensingh Elect. Supply	160	200	
	Sarishabari	Sim & Co., Ltd.	207		
	Kishorganj	Kish. Sugar Mill		175	
			537	375	912
Faridpur	Rajbari	Bharat Elect. Co.	72		
	Faridpur	Chittagong Elect. Supply	370		
			442		442
Kushtia	Kushtia	Mohini Mills	824		
	Darsanna	Carew Co.	225	800	
			1,049	800	1,849
Jessore	Jessore	Electricity Supply Co.	170		170
		TOTAL - OTHER DISTRICTS			9,001 kw

4.04 PLANTS UNDER CONSTRUCTION AND ON ORDER

The Government of East Pakistan in November 1954 advised that delivery had been completed on new diesel generating equipment totaling 27,757 kw of European manufacture for the Dacca-Chittagong areas. These are low speed units of 640, 870, 1,087 and 1,468 kw ratings and are now being installed. Fifteen units totaling 18,432 kw are being installed at Siddhirganj and the remaining 10 units totaling 9,325 kw are being installed at Chittagong.

At the time of the field survey, it was observed that 2,610 kw of the above new diesel plant for the Dacca area was temporarily installed and operating at the Adamjee Jute Mill. The foundations and buildings for the remaining diesel units in the Dacca and Chittagong Districts were under construction. It is considered that these diesel plants may be in full operation by the end of 1955. It was also observed that additional steam units for the Karnafuli Paper Mill and the Assam Bengal Cement Company had been delivered and were being installed.

The proposed site for the 30,000 kw steam plant at Siddhirganj was also inspected, but no work had been started on the construction of the plant. The government has reported that about $940,000 has been paid as progress payments to manufacturers of the plant equipment and that delivery of the steam plant equipment is expected in 1955. The Consulting Engineers would not expect that the plant could be in operation much before mid 1957.

A listing of plants under construction or on order is presented in the following Table IV-3:

TABLE IV-3

NEW PLANTS ORDERED, UNDER CONSTRUCTION OR AWAITING INSTALLATION

District	Town	Name of Plant	Diesel Units	Diesel kw	Steam Units	Steam kw	Total kw
Dacca	Siddhirganj	Elect. Directorate	12[1]	15,822[1]	1	30,000	45,822[1]
Chittagong	Chittagong	Elect. Directorate	10	9,325			
Chittagong	Chandraghona	Karnafuli Paper Mill			1	4,500	13,825
Sylhet	Chhatak	Assam Bengal Cement Co.			1	4,500	4,500
Khulna	Goalpara	Elect. Directorate	9	10,000			10,000
Tippera	Comilla	Maynamati Military HQ	2	329			
Tippera	Akhaura	East Bengal Railway	3	150			479
Kushtia	Kushtia	Mohini Mills	1	120	1	[illegible]00	
Kushtia	Hardinge Bridge	Colombo Plant Ganges-Kobadak			2	10,000	11,320
Rangpur	Rangpur	Chittagong Engr. & Elect.	1	160			160
Mymensingh	Mymensingh	Electric Supply Co.	1	100			100
Rajshahi	Rajshahi	Chittagong Engr. & Elect.	1	280			
Rajshahi	Gopalpur	North Bengal Sugar Mills			1	100	380
Jessore	Jessore	Electricity Supply Co.	2	358			358
		TOTAL					86,944[1] kw

[1] Does not include 2,610 kw of diesel in 3 units temporarily installed and operating at the Adamjee Jute Mill, listed in Table IV-1.

4.05 TOTAL INSTALLED AND PLANNED CAPACITY

The installed capacity in East Pakistan was found to be 55,592 kw from plants of various sizes and ages (Section 4.03). In Section 4.04 plants under construction or planned will have a total capacity of 86,944 kw. The combined capacity of all facilities will therefore be 142,536 kw by 1957.

4.06 LOAD CENTERS

The survey shows the greatest power demand falls in the heavily populated Dacca-Chittagong areas which are the industrial centers of East Pakistan. These centers have a plentiful supply of labor and easy access to a port for transport of raw materials and finished products. It is expected that the major development of industries will take place in these areas providing there is adequate expansion of generation and distribution facilities.

Certain industries, which are dependent upon geographical location of existing raw material are of necessity located near the source of materials. Industries in this category include:

Karnafuli Paper Mill - Located in the Chittagong Hill Tracts, the mill at present has steam plants capable of supplying its needs for electricity and process steam.

Tea Industry - Major industry in the Sylhet area. The Government reports that 26,458 tons of tea were exported during 1952-53. At present the process of tea drying is carried out by coal or oil fuel.

Cement Plant - Located in Sylhet district near the only known major source of limestone deposits to which East Pakistan has access.

Irrigation and Drainage - The present system of agriculture throughout East Pakistan is basically primitive and follows practices set down by generations of the farmers. There is however a large potential for land reclamation as described in detail in Appendix F. Major schemes or proposals are under consideration as follows:

a. Ganges - Kobadak Scheme formulated by the United Nations Food and Agricultural Organization in conjunction with the East Bengal Irrigation Department for development of the delta of the Ganges River in the Kushtia, Jessore and Khulna districts. The Colombo Plan Administration is erecting a 10,000 kw steam plant for the initial stage of this scheme.

b. Land Reclamation in Mymensingh, Sylhet, Dacca, Tippera, and Chittagong Districts. These Districts were selected as the areas most susceptible to agricultural development with the possible availability of electrical energy from the Karnafuli Project.

CHAPTER V

DEVELOPMENT OF AN INTEGRATED POWER TRANSMISSION AND DISTRIBUTION SYSTEM

5.01 EXISTING POWER FACILITIES

The transmission facilities presently existing in East Pakistan are limited to local networks operating in the immediate vicinity of Dacca and Chittagong at 33 and 11 kv, and comprise approximately 20 circuit miles of 33 kv overhead system and 30 miles of 11 kv underground cable. There are no transmission lines operating at voltages higher than 33 kv in the country.

Distribution facilities are limited to some 230/400 volt, 3-phase, 4-wire installations constructed by the electric supply authorities in the larger cities. Very little expansion has taken place in the systems which are now operating with a demand in excess of capacity. Electric energy is simply not available to domestic consumers in large sections of the major cities of the Dacca and Chittagong Districts.

The present population of East Pakistan is approximately 51 million persons and the present installed and new plant capacity is 142,536 kw or 2.79 watts per capita.

By comparison the published data for several other countries show an installed capacity per capita as follows:

POPULATION AND INSTALLED POWER OF OTHER COUNTRIES

Country	Population Millions	Installed Capacity - M W	Watts Per Capita
USA	159.7	107,330	672
Sweden	7.13	4,755	667
Great Britain	50.6	19,500	385
Germany - West	49.0	13,500	276
Japan	86.7	11,700	135
Brazil	55.77	2,195	39.4
Greece	7.77	260	33.5
Turkey	22.46	502	22.4
Iraq	5.10	60	11.8
Iran	19.52	196	10.0
India	367.0	2,700	7.36
Saudia Arabia	5.50	25	4.55
Indo-China	25.5	100	3.92
Burma	19.05	65	3.41
China	500.00	1,450	2.90

Comparing the installed capacity per capita of East Pakistan with that of other nations indicates that the need for development in East Pakistan is greater than that of most other nations, including such countries as Turkey and India, which started late in the development of electrical installations.

Reference to station log book records indicated that in almost every case the peak demand for electric power approximated and often exceeded the installed capacity of the generating plant. Discussions with operating staffs showed that at times of high demand the operating voltage, and in the case of small plants, frequency, fell to values below normal. In addition to the need for new generating capacity at this time, a dire need exists for new installations and extensions of distribution facilities to make available energy to consumers who presently desire power. There is a waiting list of applications for electric supply at Dacca and Chittagong and for some time the Dacca Electric Supply Co. has refused to accept additional applicants on its large waiting list.

5.02 TRANSMISSION SYSTEM DEVELOPMENT

In order that the generating stations shall form a properly integrated system, able to supply energy from the most economical source, a system of high-voltage transmission lines will ultimately be needed to link the major load centers and generating plants. It is expected that the load will develop primarily in the Dacca and Chittagong Districts. As the demand for electric energy develops in the Sylhet and Khulna areas and for the Ganges-Kobadak Scheme, expansion of transmission facilities will be required.

Immediate construction of a transmission system to serve Dacca, Chittagong, Sylhet, Khulna and Ganges-Kobadak would involve quite a large capital expenditure. The timing of the construction of this system is dependent upon the growth of loads in the areas and upon the availability of foreign capital for development. It does not appear feasible to provide such an extensive system at this time.

The initial installations should be based on plans for the ultimate development in order that the sections of the transmission system initially built will ultimately be a part of the over-all development with minor or no modification. With the construction of the Karnafuli hydroelectric project there would be an immediate need for a transmission line from the dam site to the Chittagong and Dacca areas.

Without the Karnafuli Project there would not appear to be an immediate necessity to construct the transmission line between Dacca and Chittagong and it may be deferred until the demand for energy in the two areas becomes so large that savings in spare capacity would justify the

expenditure. This will not occur until the cost of the combined spare plant capacity which can be eliminated by the line is in excess of the cost of the line.

The Consulting Engineers are of the opinion that the transmission system should be expanded in stages as required to meet the development of loads and to keep pace with the growing demand for energy.

The initial stage of development will require the construction of transmission facilities linking Dacca with Chittagong and with the Karnafuli Project. Approximately 187 miles of 165 kv transmission line with switching stations would be required. Because of the relatively large capacity to be installed at Karnafuli and the demand for firm power at Dacca, it is proposed that the line should be designed as a double circuit for ease of maintenance and reliability of operation; but initially constructed with conductors in place for one circuit only.

As additional demand for firm energy develops in Sylhet and Khulna, the second stage of expansion of the transmission lines would be constructed consisting of transmission facilities linking Dacca with Hardinge Bridge and Khulna and also Dacca and Sylhet District. Approximately 275 miles of additional single circuit 165 kv transmission line would be constructed concurrent with the completion of the second circuit from Karnafuli to Chittagong, when the third hydro unit is placed in service. During this second stage the load in the Dacca and Chittagong areas is expected to increase substantially. The original transmission circuit from Karnafuli to Dacca and the second circuit from Karnafuli to Chittagong will probably be of sufficient capacity to meet the demand for a considerable time. It is proposed that the second circuit from Chittagong to the receiving station in the Dacca area be strung as soon as load conditions make such an addition desirable.

The ultimate transmission system may consist of extensions of the above lines to include links from Hardinge Bridge and Habiganj (Sylhet) with Sirajganj, Bogra and Rangpur, and the installation of the second circuit from Chittagong to Dacca.

Exhibits 2 and 3 have been prepared showing the initial and progressive development of the transmission facilities.

CHAPTER VI

PRESENT AND ESTIMATED FUTURE POWER DEMAND IN DACCA AND CHITTAGONG AREAS

6.01 INTRODUCTION

Prior to the partition of the Indian Sub-Continent in 1947, the agricultural products of East Bengal (now East Pakistan) were processed in plants located in the Calcutta area. The government has since aided in the formation of the Pakistan Industrial Development Corporation (P.I.D.C.) and the Pakistan Industrial Finance Corporation for the development of industries, to process the agricultural produce of the country and to fill a widespread demand within the country for consumer goods. Industrial development in East Pakistan has progressed rapidly since the partition, with the major expansion taking place in the Dacca and Chittagong areas. Expansion to date has been the more remarkable since it has been done in spite of a shortage of electric power, with each major industry financing its own power plant. The industrial development has been limited only by the availability of foreign exchange for providing the necessary plants and facilities and not by the lack of demand of products for domestic consumption and export. Future development of East Pakistan will undoubtedly be influenced by world economic conditions. The estimated power demands and consumption projected in this report are based on very conservative rates of industrial development.

As previously stated, it is expected that the initial stage of future expansion will be primarily in the Dacca-Chittagong areas. The following paragraphs present the existing power situation in the Dacca-Chittagong areas and the expected future demand. The loads are considered for the jute industry, cotton textile industry, utilities and secondary industries and other possible demands.

6.02 JUTE INDUSTRY

In 1947 East Pakistan did not contain a single jute spinning mill although 75 percent of the world crop was produced in the country; in addition, the lack of baling presses did not permit export of all of the crop in bales.

Since 1947 private industrial companies have been formed and with the cooperation and assistance of the government, have undertaken the construction and operation of jute processing and weaving facilities.

The Consulting Engineers visited the major jute processing plants in the Dacca and Chittagong areas. At the time of the survey, 5 jute weaving mills were in operation with an aggregate number of 2,400 looms. The number of looms in each mill are noted below.

Name of Mill	Location	No. of Looms
Adamjee Jute Mills	Siddhirganj	2,000
Bawa Jute Mill	Narayanganj	100
Victory Jute Mill	Chittagong	100
Amin Jute Mill	Chittagong	100
Chittagong Jute Mfg. Co.	Kalurghat	100
	Total Existing Looms	2,400

The question of future expansion was discussed with officials of the P.I.D.C. and with prominent persons in private industry. Present plans envisage setting up 6,850 additional looms by 1958 in several areas surrounding Dacca, Chittagong and Comilla as follows:

Name of Mill	Location	Additional Looms
Dacca Area		
Adamjee Jute Mills	Siddhirganj	1,000
Dada Jute Mill	Ghorasal	1,000
Bawa Jute Mill	Narayanganj	150
Yakub Ahmed Bros	Dumra	500
Dacca Jute Mill	Dacca	500
Zakaria Jute Mill	Tongi	750
Narsingdi Jute Mill	Narsingdi	750
Latif Bawany Jute Mill	Dumra	450
Karin Jute Mill	Dumra	450
Chittagong Area		
Amin Jute Mill	Chittagong	400
Victory Jute Mill	Chittagong	400
Comilla Area		
Hajiganj Jute Mill	Hajiganj	500 (1)
	Total Planned Expansion	6,850

(1) Planned expansion to 1,000 in 1960.

Expansion beyond 1958 has been estimated as 6 percent per annum of the installation at 1958, except at Hajiganj where it is understood a further 500 looms will be installed in 1960.

The operation of the jute mills and associated processing plants require electric energy. It is estimated that the connected load will be 3.6 kw per loom with an additional connected load of approximately 9% for other services related to the plants. It is reported that jute mill operation is on two 8-hour shifts per day, 6 days per week basis and energy requirements have been computed on that basis assuming 90% operation of the equipment. A load factor of 50% is assumed for the additional services.

The rate at which the additional looms will be installed and brought to operation is dependent upon availability of power supply, labor and finance. After the discussion with Pakistan officials the rate of expansion in Table VI-1 has been adopted:

TABLE VI-1

CONNECTED LOAD FOR JUTE INDUSTRY

Area	No. of Looms Installed	Connected Load kw	Annual Energy Demand kwh-Millions
		1954	
Dacca	2,100	8,119	36.03
Chittagong	300	1,189	5.25
Comilla	—	—	—
Totals	2,400	9,308	41.28
		1955	
Dacca	2,800	11,075	48.93
Chittagong	600	2,361	10.42
Comilla	—	—	—
Totals	3,400	13,436	59.35
		1956	
Dacca	4,956	19,523	86.25
Chittagong	900	3,546	15.66
Comilla	250	1,000	—
Totals	6,106	24,069	101.91
		1958	
Dacca	7,650	30,163	133.16
Chittagong	1,100	4,280	18.97
Comilla	500	1,980	8.90
Totals	9,250	36,423	161.03
		1960	
Dacca	8,620	34,145	150.63
Chittagong	1,230	4,806	21.27
Comilla	1,000	3,900	17.52
Totals	10,850	42,851	189.42

6.03 COTTON TEXTILE INDUSTRY

Prior to partition the whole cotton crop, estimated to be 15,000 bales annually, was processed in the Calcutta district; cotton cloth and yarn being then distributed to East Bengal. It has been estimated that approximately 30 yards of textile material are required annually by each person. In 1949 the amount available in East Pakistan was 9 yards per person and in 1954 it became necessary to ration cloth. There is, accordingly, a substantial market for cotton textiles. East Pakistan possesses a potential labor force to work in what is termed "cottage industries". There are many small home-owned looms and an actual demand for cotton for these industries.

The P.I.D.C., in cooperation with private industry, is arranging for the construction of additional spinning and weaving facilities. The Consulting Engineers visited the major cotton textile mills in the Dacca-Chittagong districts and observed the operations. There were at the time of the survey 10 major plants in operation as follows:

Name of Mill	Location	Spindles	Looms
Dhakeswari Cotton Mills Ltd. No. 1	Narayanganj	30,440	808
Dhakeswari Cotton Mills Ltd. No. 2	Narayanganj	21,280	554
Chittaranjan Cotton Mills	Narayanganj	20,242	252
Luxmi Narayan Cotton Mills	Narayanganj	15,628	298
Olympia Textile Mills	Narayanganj	27,400	None
Bandhab Cotton Mills Ltd.	Narayanganj	1,965	None
Adarsha Cotton and Weaving	Narayanganj	25,000	145
Dacca Cotton Mills	Dacca	9,500	120
National Cotton Mills Ltd.	Chittagong	12,975	152
Muslin Cotton Mills	Kaliganj	44,800	None
	Total in Operation	209,230	2,329

The expansion of the industry was discussed with officials of P.I.D.C. and with prominent persons in the industry. It is definitely understood that several mills contemplate expansion and that new mills will be set up. The program is not finally planned but the following mills are expected to be in operation by the end of 1958:

Name of Mill	Location	Spindles
Dacca Area		
Dacca Spinning Company	Tongi	12,500
Zeenat Textiles Ltd.	Tongi	25,000
Ahmad Sett Bros.	Dumra	25,000
E. P. Provincial Co-operative Jute Marketing Society	Dumra	12,500

Name of Mill	Location	Spindles
Chittagong Area		
Pakistan Textiles Ltd.	Chittagong	12,500
M. M. Ispahani Ltd.	Chittagong	12,500
Asiatic Cotton Mills	Chittagong	12,500
Messrs. A. K. Khan	Chittagong	25,000
	Expansion by 1958	137,500

There is at present a shortage of looms in comparison with the number of spindles for making yarn. It has been assumed that as the number of looms is increased the present proportions of looms and spindles will be maintained. As a result all of the yarn cannot be made into cloth and there will be an excess of spun cotton yarn available for cottage industries.

Electric energy is required for the operation of the mills and development is predicated on this energy being made available. It is estimated that the connected load is 0.025 kw per spindle and 0.5 kw per loom with an additional connected load of approximately 9% for other services related to the plant. It is reported that cotton mill operation is on the basis of two 8-hour shifts per day, 6 days each week. Energy requirements have been computed on that basis assuming 80% operation of the equipment. A load factor of 50% is assumed for the additional services.

The rapidity with which the additional mills can be brought into operation is dependent upon the availability of power supply, labor and finance. After discussion with Pakistan officials the rate of expansion shown in Table VI-2 has been adopted.

TABLE VI-2

CONNECTED LOADS FOR COTTON TEXTILE INDUSTRY

Area		Number Installed	Connected Load kw	Annual Energy Demand kwh-Millions
		1954		
Dacca	Spindles	196,255	6,411	25.28
	Looms	2,177		
Chittagong	Spindles	12,975	441	1.72
	Looms	152		
Totals	Spindles	209,230	6,852	27.00
	Looms	2,329		

TABLE VI-2 (Continued)

Area		Number Installed	Connected Load kw	Annual Energy Demand kwh-Millions
		1955		
Dacca	Spindles	201,65	6,733	26.43
	Looms	2,22		
Chittagong	Spindles	17,475	581	2.28
	Looms	191		
Totals	Spindles	219,130	7,314	28.71
	Looms	2,414		
		1956		
Dacca	Spindles	220,675	7,314	28.71
	Looms	2,387		
Chittagong	Spindles	33,325	1,093	4.29
	Looms	327		
Totals	Spindles	254,000	8,407	33.00
	Looms	2,714		
		1958		
Dacca	Spindles	271,255	8,939	35.07
	Looms	2,807		
Chittagong	Spindles	75,475	2,408	9.48
	Looms	677		
Totals	Spindles	346,730	11,347	44.55
	Looms	3,484		
		1960		
Dacca	Spindles	301,660	9,987	39.16
	Looms	3,080		
Chittagong	Spindles	83,050	2,661	10.46
	Looms	742		
Totals	Spindles	384,710	12,648	49.62
	Looms	3,822		

6.04 UTILITIES AND SECONDARY INDUSTRIES

At the present time there are many small industries in operation in the Dacca and Chittagong areas. These industries, individually of small capacity, constitute secondary industries which are necessary to furnish part of the demands of the country generally and of the primary industries.

The Consulting Engineers visited the plants and observed that in most instances the owners had installed their own diesel generating equipment and that the remaining plants, where energy requirements were low, purchased energy from the local utility supply company.

From the records available, it is not practicable to distinguish between the energy furnished by the utility supply companies for domestic purposes and the energy furnished for small industry. However, the capacity of independent generating plants of the secondary industries and utility supply companies has been surveyed and these are listed in Table VI-3.

TABLE VI-3

EXISTING GENERATING FACILITIES OF UTILITY AND SECONDARY INDUSTRIAL PLANTS IN DACCA, CHITTAGONG AND COMILLA AREAS

District	Town	Name of Plant	Installed Capacity-kw Diesel	Steam	Total
1. Dacca	Narayanganj	Tula Ram Bachraj Co.	50		
	Narayanganj	Lazarus Co.	67		
	Narayanganj	Ralli Bros.	30		
	Narayanganj	Kumudini Welfare Trust	640		
	Narayanganj	Chittagong Elect.	1,600		
	Narayanganj	Goy't Dock Yard Narayanganj	207		
	Narayanganj	Sonakanda Baling Co.	65		
	Narayanganj	IGN & Rly Co., Ltd.	205		
	Postogola	Dacca Flour Mill	425		
	Tejgaon	Nabisco	165		
	Tejgaon	Bengal Rubber Industries	275		
	Dacca	Elect. Directorate	612		
	Dacca	Dacca Elect. Supply Co., Ltd.		6,000	
	Dacca	Engineering College	130		
	Munshiganj	Munshiganj Elect. Supply	32		
	Daulatpur	M. M. Ispahani Co., Ltd.	248		
	Mirpur	Brick & Tiles Co.	160		
		DISTRICT TOTAL	4,911	6,000	10,911
2. Chittagong	Pahartali	East Bengal Railway		3,000	
	Pahartali	Ispahani Ltd.	1,956		
	Sholashahar	Pakistan Oxy. & Acet.	185		
	Sholashahar	Mousel Company	30		
	Chittagong	James Finlay Co., Ltd.	50		
	Chittagong	Chittagong Elect.& Supply	1,025		
	Chittagong	Volkart Bros.	460		
	Chittagong	IGN & RSN Co.	44		
	Dewanhat	Steel Bros.& Co.	41		
	Kalurghat	Khan Match Co.	110		
	Patia	B.O.C. Co.	80		
		DISTRICT TOTAL	3,981	3,000	6,981
3. Tippera	Comilla	Comilla Elect. Supply	422		
	Comilla	Moynamati Military HQ	30		
		DISTRICT TOTAL	452		452
TOTAL - Dacca, Chittagong, and Comilla Areas					18,344

It is not expected that the government will be active participants in the development of these secondary industries but will depend upon private industrialists for establishment and expansion. Government officials have, however, expressed the intention of encouraging the development of the following industries:

1. Saw mills and allied wood-working plants to furnish building materials and furniture utilizing timber from the forests in the Chittagong Hill Tracts.

2. Tanning and leather working establishments to cure hides and skins of which 6,300,000 pieces were exported in 1949. A company is considering setting up facilities at Chittagong and Hazaribagh in conjunction with the P.I.D.C.

3. Match industry. The production of matches is an active industry and the operators have stated that they intend to increase production materially during the next five years.

4. Brick and tile manufacture. At present this work is carried out manually. The demand for the product requires that some mechanization be introduced.

5. Rubber products manufacture. The production of bicycle tires and footwear is undertaken on a small scale at present.

6. Chemical manufacture. There is a need for the manufacture of pharmaceutical products and chemical fertilizers.

7. Food processing. Except for a number of small oil and rice husking mills and a flour mill in Dacca, there is almost no food processing undertaken at present. It is planned to set up cold storage plants for fruit, fish and other perishables as well as additional mills for flour, oilseed extraction and rice husking.

There is a potential labor force among the people living in villages who are mainly engaged in agriculture and have spare time to work at home or in village community centers. It is usual practice to set up small industrial machinery, such as looms for cotton textiles, in suitable centers and to undertake production. The machinery is very simple and frequently hand operated. These "cottage" industries are, however, a potential demand for electric lighting and some small power equipment.

A tabulation of utility systems and secondary industries showing the existing demands and the Consulting Engineers estimates of future demands is listed in Table VI-4. The requirements of the utility systems include energy furnished for domestic purposes, for secondary industries purchas-

ing energy and for the small demands of the cottage industries. Secondary industries which presently have their independent generating plants have been tabulated separately. For the purpose of this report, it has been assumed that the connected load of secondary industries and the requirements of the utility system will, due to lack of facilities, remain constant until 1956 and then increase at approximately 8 percent compounded annually thereafter. Energy is computed on the basis of 70% diversity and 50% load factor.

TABLE VI-4

CONNECTED LOADS FOR UTILITY SYSTEMS AND SECONDARY INDUSTRY

Area	Type of Load	Connected Load kw	Annual Energy Demand kwh-Millions
		1954 thru 1956	
Dacca	Utility System	8,244	25.28
	Secondary Industry	2,667	8.17
Chittagong	Utility System	1,025	3.14
	Secondary Industry	5,956	18.26
Comilla	Utility System	422	1.29
	Secondary Industry	30	0.09
	TOTALS	18,344	56.23
		1958	
Dacca	Utility System	9,616	29.49
	Secondary Industry	3,111	9.53
Chittagong	Utility System	1,196	3.66
	Secondary Industry	6,947	21.30
Comilla	Utility System	492	1.50
	Secondary Industry	35	0.11
	TOTALS	21,397	65.59
		1960	
Dacca	Utility System	11,216	34.40
	Secondary Industry	3,629	11.12
Chittagong	Utility System	1,395	4.27
	Secondary Industry	8,103	24.84
Comilla	Utility System	574	1.75
	Secondary Industry	41	0.13
	TOTALS	24,958	76.51

6.05 SUMMARY - FORECAST OF DEMAND FOR ELECTRIC ENERGY

There exists among the primary and secondary industries a substantial potential demand for electric energy. A forecast for future demand requirements has been prepared as shown in Table VI-5, and in graphic form on Exhibits 4 and 5.

This forecast is based on the conservative estimates of the requirements for the primary industries previously described. The demands for secondary industries and utilities have been estimated on the basis that their requirements will increase at a rate of 8 percent compounded annually.

In Table VI-5, the figure of 18,344 kw in 1955 shown under the heading "Utility System and Secondary Industry" is the total of the capacity existing at present at the electric supply companies in the area and the private plants shown in detail in Table VI-3, "Existing Generating Facilities of Utility and Secondary Industrial Plants in Dacca, Chittagong and Comilla Areas". In each case, it has been assumed that because of the present inadequate distribution system no increase will accrue until the distribution system is improved. The first increase is assumed to take place in late 1957.

A diversity factor of 70% has been applied to the total connected load to obtain the peak demand load (diversified demand) which is considered to be conservative and reasonable.

TABLE VI-5

SUMMARY FORECAST OF DEMAND FOR ELECTRIC ENERGY DACCA, CHITTAGONG AND COMILLA AREAS

	1955		1958		1960	
INDUSTRY	Connected Load - kw	Annual Energy Demand kwh Millions	Connected Load - kw	Annual Energy Demand kwh Millions	Connected Load - kw	Annual Energy Demand kwh Millions
Jute	13,436	59.35	36,423	161.03	42,851	189.42
Cotton Textiles	7,314	28.71	11,347	44.55	12,648	49.62
Utility System & Secondary Industry	18,344	56.23	21,397	65.59	24,958	76.51
Totals	39,094	144.29	69,167	271.17	80,457	315.55
Diversified Demand D.F. = 0.70	27,400		48,400		56,300	

TABLE VI (Continued)

INDUSTRY	1962 Connected Load - kw	1962 Annual Energy Demand kwh Millions	1964 Connected Load - kw	1964 Annual Energy Demand kwh Millions	1965 Connected Load - kw	1965 Annual Energy Demand kwh Millions
Jute & Cotton Textiles	62,360	268.59	70,070	301.79	74,090	319.08
Utility System & Secondary Industry	29,120	89.23	33,960	104.07	36,785	112.72
Totals	91,480	357.82	104,030	405.86	110,875	431.80
Diversified Demand D.F. = 0.70	64,000		72,800		77,600	

INDUSTRY	1966 Connected Load - kw	1966 Annual Energy Demand kwh Millions	1968 Connected Load - kw	1968 Annual Energy Demand kwh Millions	1970 Connected Load - kw	1970 Annual Energy Demand kwh Millions
Jute & Cotton Textiles	78,110	336.36	87,160	375.19	97,320	418.83
Utility System & Secondary Industry	39,610	121.38	46,200	141.58	53,880	165.15
Totals	117,720	457.74	133,360	516.77	151,200	583.98
Diversified Demand D.F. = 0.70	82,400		93,400		106,000	

6.06 OTHER POSSIBLE DEMANDS

Steel Processing Industry - There is a demand for steel products in the form of corrugated sheet and light structural shapes in East Pakistan. The P.I.D.C. has under active consideration the construction of a steel processing plant at Chittagong. The plant would be capable of melting scrap and billet and rolling the material to shape. Electric furnaces and rolling equipment would be utilized.

This development is still in the planning stage. It is assumed that the initial operations will be on a small scale and will probably not develop to any degree before 1960.

For the steel industry an allowance as listed on the following page has been made in the compilation of demand for energy as a possible load.

	1960	1962	1964	1966 through 1970
Connected load - kw	1,000	1,000	3,000	5,000
Kwh Millions	4.38	4.38	13.14	21.90

Irrigation and Drainage Pumping - The Consulting Engineers estimate that it would be practicable for the government to undertake development of the irrigation and drainage schemes in the Dacca and Chittagong areas during the period to 1965, approximately as shown in the following table. It is considered that the suitable areas in the Tippera district are too widespread for inclusion in the initial phases of the development. Pumping requirements for irrigation and drainage of a typical area are derived in Appendix F.

	Area Under Irrigation Acres		Connected Load kw	
District	1960	1965	1960	1965
Dacca	—	3,680	—	100
Chittagong	36,800	110,400	1,000	3,000

Paper Industry - The demand for paper in the whole of Pakistan, based on past imports, is estimated to be between 30,000 and 40,000 tons annually which up to 1954 was met by imports. The Government has sponsored the development of the Karnafuli Paper Mills to produce paper from bamboo. The manufacturing plant is installed and in 1954 the mill was in operation with a daily production of approximately 50 tons of paper. When the plant is in full operation, output is expected to reach 100 tons of finished paper per day.

Electric energy is generated in the plant as a part of the production of required process steam; an oil-fired plant is used. There is sufficient plant capacity, totaling 9,000 kw installed at present and an additional 4,500 kw under erection, to furnish both the required electric energy and steam. However, the electric energy production means the consumption of fuel. With the planned future expansion of the paper mill it may eventually be found desirable to purchase power to supplement that produced by process steam as is now quite common among the paper mills of the Pacific Northwest in the United States.

As the Karnafuli Paper Mill at Chandraghona is capable at present of supplying its own demands for process steam and electric energy, the industry is not considered as a possible demand within the immediate future and has not been included in the studies.

Summary - The Consulting Engineers are of the opinion that if the steel processing industry is set up and if the irrigation and drainage schemes are established, they will create an additional demand for energy as shown in Table VI-6 and on Exhibits 4 and 5. This demand will be in addition to that forecasted for the primary and secondary industries.

TABLE VI-6

POSSIBLE ADDITIONAL DEMAND
DACCA, CHITTAGONG AND COMILLA AREAS

	In 1960		In 1962		In 1964	
INDUSTRY	Connected Load - kw	Energy Demand kwh Millions	Connected Load - kw	Energy Demand kwh Millions	Connected Load - kw	Energy Demand kwh Millions
Steel Processing	1,000	4.38	1,000	4.38	3,000	13.14
Irrigation & Drainage Pumping	1,000	2.63	1,500	3.94	2,500	6.57
Total	2,000	7.01	2,500	8.32	5,500	19.71
Diversified Demand D.F. = 0.70	1,400		1,750		3,850	

	In 1966		In 1968		In 1970	
INDUSTRY	Connected Load - kw	Energy Demand kwh Millions	Connected Load - kw	Energy Demand kwh Millions	Connected Load - kw	Energy Demand kwh Millions
Steel Processing	5,000	21.90	5,000	21.90	5,000	21.90
Irrigation & Drainage Pumping	3,700	9.74	4,500	11.82	5,000	13.14
Total	8,700	31.64	9,500	33.72	10,000	35.04
Diversified Demand D.F. = 0.70	6,090		6,650		7,000	

6.07 ESTIMATE OF DEMAND FURNISHED BY THE GOVERNMENT OF PAKISTAN

The Pakistan Industrial Development Corporation and the government have prepared an estimate of the future demand for electric energy in the Dacca and Chittagong areas. These estimates include the requirements of those industries which normally furnish their own power, i.e. paper produc-

tion, as well as some industries which are located in areas that will require initial construction of more extensive transmission lines than are recommended in this report. Examples of these are the cement plant at Chhatak and tea drying.

The estimate prepared by the government is tabulated below, divided into categories as shown. Connected load is stated to be 66 percent greater than the demand.

GOVERNMENT OF PAKISTAN ESTIMATES

INDUSTRY	DEMAND KW			
	1955	1958	1960	1965
INDUSTRIES NORMALLY FURNISHING THEIR OWN POWER OR IN AREAS NOT ECONOMICAL TO SERVE AT THIS TIME				
Paper and Pulp	9,000	9,000	15,000	15,000
Rayon	0	0	10,000	10,000
Cement	3,000	4,500	4,500	4,500
Tea Drying	1,000	2,000	12,000	35,000
Total Demand - kw	13,000	15,500	41,500	64,500
Connected Load - kw	21,580	25,730	68,890	107,070
PRIMARY AND SECONDARY INDUSTRIES				
Jute Processing	20,565	22,305	27,115	27,115
Cotton Textiles	8,790	17,275	21,275	24,775
Domestic Consumption	4,050	5,580	8,580	18,240
Secondary Industries				
Jute Pressing and Baling	1,500	2,750	3,500	5,000
Rubber	600	800	1,000	2,000
Leather	400	600	800	1,500
Brick and Tile	150	300	450	600
Match	150	300	450	600
Chemical	200	250	300	500
Cold Storage and Ice	200	300	500	800
Cottage Industries	200	800	1,600	4,800
Miscellaneous	400	600	800	1,200
Total Demand - kw	37,205	51,860	66,370	87,130
Connected Load - kw	61,760	86,088	110,174	144,636

GOVERNMENT OF PAKISTAN ESTIMATES (Continued)

	1955	1958	1960	1965
INDUSTRIES, THE START OF WHICH, IN THE OPINION OF THE ENGINEERS, MAY BE DELAYED				
Steel Processing	0	1,500	3,000	5,000
Saw Mills	100	150	300	600
Flour Mills	300	500	700	1,200
Irrigation Pumping	0	2,000	6,000	16,000
Miscellaneous	500	1,000	2,000	3,000
Total Demand - kw	900	5,150	12,000	25,800
Connected Load - kw	1,494	8,549	19,920	42,828

6.08 COMPARISON OF DEMAND FORECAST BY CONSULTING ENGINEERS AND ESTIMATE FURNISHED BY THE GOVERNMENT

A summary comparison of the demands for the primary and secondary industries as estimated by the Government of Pakistan, and as forecasted by the Consulting Engineers is listed as follows:

Estimate of Total Primary and Secondary Power Demands - kw

	1955	1958	1960	1965
Government Estimates	37,205	51,860	66,370	87,130
Consulting Engineer's Forecast	27,400	48,400	56,300	77,600

For the purposes of this report, the lower conservative forecast of demand for electric energy will be used herein in determining the requirements for generating capacities.

6.09 INSTALLATIONS REQUIRED TO MEET FORECASTED DEMAND

Chapter IV of this report has set forth the results of a survey of the existing generating plant in East Pakistan. In this chapter, the present and the future demands are predicted. This section sets forth the relationship between present demand and available capacity and between forecasted demand and capacity for the next 15 years in the Dacca-Chittagong-Comilla areas.

The field survey determined that there are generating capacities in the areas as follows:

	Existing Generating Capacities at Time of Field Survey[1]	Additional Generating Capacities Upon Completion of Remaining New Diesel Plant[2]
Dacca Area	21,353 kw	15,822 kw (Does not include 2,610 kw installed at Adamjee Jute Mill or the proposed 30,000 kw Steam Plant)
Chittagong Area	7,673 kw (Does not include 9,000 kw Steam Plant at Paper Mill)	9,325 kw (Does not include 4,500 kw Steam Plant at Paper Mill)
Comilla Area	452 kw	329 kw
Totals	29,478 kw	25,476 kw

A total of 54,954 kw of capacity will thus be installed in the area by the end of 1955. Excluding 3,000 kw of steam plant at the Dacca Electric Supply Co. and the 2,610 kw diesel plant at the Adamjee Jute Mill as shown in Table IV-1, this figure includes 23,868 kw of existing plant in non-interconnected systems, most of which are obsolete, inefficient or uneconomical in operation or in poor operating condition and require replacement or retirement.

The figure of 54,954 kw of generating capacity represents the installed capacity and not the capacity available to supply the demand. In a non-interconnected thermal system some spare capacity is usually required in thermal plants to provide for maintenance and operational purposes, but this spare capacity in one plant is not available to meet the demand for additional capacity in another area.

Wherever peak demand approaches the installed capacity the older units are of necessity kept in service. It is estimated that two or three years will elapse before the distribution system in the Dacca and Chittagong areas will develop to a point where the obsolete plants can be retired. It is therefore assumed that the obsolete and inefficient plant is retired over a period of 5 years after 1958.

(1) Included in Table IV-1 (2) Included in Table IV-3

Table VI-7 shows the conservative forecast of demand and the available installed capacity which has been estimated for the next 15 years on the very optimistic basis that 90 percent of the aggregate installed capacity, including the small non-interconnected units, will be available for meeting the demand. It is likely that the available capacity for meeting the demand will be substantially less than that shown in the tabulation.

TABLE VI-7

	Dacca-Chittagong-Comilla Areas			
Year Ending	Forecasted Demand kw	Aggregate Capacity of Existing and Delivered Plants[1] kw	Available Capacity kw	Forecasted Requirements For New Capacity kw
1955	27,400	54,954	49,460	0
1956	35,500	54,954	49,460	0
1958	48,400	54,954	49,460	0
1960	56,300	45,409	40,870	15,430
1962	64,000	35,859	32,270	31,730
1964	72,800	31,086	27,980	44,820
1965	77,600	31,086	27,980	49,620
1966	82,400	31,086	27,980	54,420
1968	93,400	31,086	27,980	65,420
1970	106,000	31,086	27,980	78,020

(1) Does not include the 30,000 kw steam plant projected for Dacca nor the plant at Karnafuli Paper Mill comprising 9,000 kw plus 4,500 kw now being installed.

7.01 INTRODUCTION

The expansion of generating capacities required to meet the demand for electric energy can be accomplished by various schemes. The Consulting Engineers have studied expansion by means of steam and diesel plants as well as hydro and thermal combinations. From these studies, two schemes were developed worthy of detailed analysis:

Scheme I - Thermal plants totaling 75,000 kw at Dacca and Chittagong with no initial system interconnections between the two areas.

Scheme II - Karnafuli Project of 80,000 kw capacity connected via Chittagong with a 165 kv transmission line to a 15,000 kw thermal plant at Dacca.

Economic comparisons of the two schemes have been made on the sinking fund principle in accordance with the Federal Power Commission (USA) procedures for such studies. As an additional factor of conservatism, the years 1960 and 1965 were selected for comparison which are prior to the predicted maximum utilization of Karnafuli power. As previously stated a very conservative forecast of demand has been arrived at which indicates a demand of 56,300 kw in 1960 and 77,600 kw in 1965. The capacity and energy generation of the non-interconnected all-thermal system, Scheme I, has been computed on the basis as shown in Table VII-1.

TABLE VII-1

CAPACITY AND DEMAND FOR NON-INTERCONNECTED ALL-THERMAL SYSTEM - SCHEME I

	In Year 1960			
	System Demand		Plant	
Location	Peak kw	Energy kwh Millions	Capacity kw	Generation Net kwh Millions
Dacca [1]	44,430	254.71	60,000	262.0
Chittagong	11,870	60.84	15,000	62.0
Total	56,300	315.55	75,000	324.0

[1] Comilla included with Dacca.

51

TABLE VII-1 (Continued)

	In Year 1965			
	System Demand		Plant	
Location	Peak kw	Energy kwh Millions	Capacity kw	Generation Net kwh Millions
Dacca[1]	60,800	346.37	80,000	356.0
Chittagong	16,800	85.43	25,000	87.6
Total	77,600	431.80	105,000	443.6

[1] Comilla included with Dacca.

Assuming the same system demand, the capacity and energy generation of the hydro system with sufficient thermal support at Dacca to provide energy during line outages is as shown in Table VII-2.

TABLE VII-2

CAPACITY AND DEMAND FOR HYDRO SYSTEM WITH THERMAL SUPPORT - SCHEME II

In Year 1960				
System Demand		Plant		
Peak kw	Energy kwh Millions		Capacity kw	Generation Net kwh Millions
56,300	315.55	Hydro	80,000	294.0
		Thermal Support	15,000	30.0
		Total	95,000	324.0

In Year 1965				
System Demand		Plant		
Peak kw	Energy kwh Millions		Capacity kw	Generation Net kwh Millions
77,600	431.80	Hydro	80,000	413.6
		Thermal Support	15,000	30.0
		Total	95,000	443.6

In the analysis of either scheme, the cost of providing the necessary network of distribution facilities at the load areas has been assumed to be the same for either scheme and is excluded from the comparison.

7.02 ANALYSIS OF SCHEMES I AND II

Scheme I - All-Thermal System - The estimated capital costs of thermal plants for the Dacca and Chittagong areas have been computed in Appendix A as $17,175,000 for the year 1960 and $24,045,000 for 1965. The estimates are based on modern steam plants and include cost of equipment, land and buildings, oil handling and storage facilities, import duties and taxes, interest during construction and engineering and construction.

Large modern central station steam plants operate on steam pressures in the order of 1,100 to 1,400 psi. Operating conditions in East Pakistan do not lend themselves to use of such plants. For ease in operation and maintenance, plants operating with lower steam pressures in the order of 600 psi have been assumed for East Pakistan at some sacrifice in the over-all efficiencies as compared to operation at higher steam pressures.

The computations of costs have been assumed to be for modern steam plants but in actual fact, will undoubtedly consist of the existing plants augmented by additional plant. The older existing plant is less efficient than modern plant and will definitely result in higher operating costs and additional maintenance costs. However, in order to be conservative, it has been assumed that the costs will not exceed those of a modern plant.

The annual cost of operating the all-thermal system based on a life expectancy of 20 years has been computed in Appendix A for the capacity, demand and generation as shown in Table VII-1 and is summarized in Table VII-3.

TABLE VII-3

SCHEME I - ALL-THERMAL SYSTEM
ANNUAL COSTS IN MILLIONS OF DOLLARS

	In 1960		In 1965	
	Foreign Currency	Pakistan Currency	Foreign Currency	Pakistan Currency
Interest	0.660	0.139	0.924	0.195
Sinking Fund	0.399	0.141	0.559	0.197
Operation	0.197	0.197	0.276	0.276
Maintenance	0.110	0.110	0.150	0.150
Fuel-Dacca	2.177	1.310	2.958	1.780
Fuel-Chittagong	0.515	0.096	0.728	0.135
Sub-Total	4.058	1.993	5.595	2.733
Total Annual Costs	6.051 Millions		8.328 Millions	
Energy to Consumers, Millions kwh	315.55		431.80	
Net valuation per kwh sold	$0.0192		$0.0193	

Scheme II - Hydro System with Thermal Support - In the analysis of the hydro system with thermal support, the capital and annual costs of each of the following individual features comprising the scheme have been computed in Appendix B, and consist of:

a. 15,000 kw thermal plant for support of Karnafuli Hydroelectric Project

b. 165 kv transmission line

c. Receiving stations.

Based on the same assumptions as given in the analysis for the all-thermal system, and as computed in Appendix B, the estimated capital cost of a 15,000 kw thermal plant is $3,435,000. The annual cost of this plant generating an assumed 30 million kwh during line outages for the years 1960 and 1965 are summarized in Table VII-4 which follows.

The thermal plant will probably be a combination of steam and diesel units. The exact proportions of steam and diesel cannot be known at this time and will be determined by a detailed physical inventory and economic analysis at the time of completion of the Karnafuli Project. For

the purpose of the computations it has been conservatively assumed that the total annual expenditures per kwh of such diesel plant as is retained will be the same as that of steam.

TABLE VII-4

SCHEME II - ANNUAL COSTS
IN MILLIONS OF DOLLARS FOR SUPPORTING THERMAL PLANT

	Foreign Currency	Pakistan Currency
Interest	0.132	0.028
Sinking Fund	0.080	0.028
Operation	0.039	0.039
Maintenance	0.010	0.010
Fuel (Dacca)	0.249	0.150
Sub-Total	0.510	0.255
Total Annual Cost	0.765 Millions	

The Karnafuli Project comprising an earthfill dam, spillway, diversion dam outlet tunnel, navigation locks and powerhouse with intake structure is described in detail in Part IV of this report. The estimated capital cost of these features is presented in Appendix B for the initial development of a three-unit power plant with two units installed. The capital cost, which includes land compensation, money already spent with interest, construction costs, interest during construction, contractor's fee, contractor's contingencies, import duties, taxes and engineering contingencies is $72,131,000.

The annual costs for the Karnafuli Project in the years chosen would be as shown in Table VII-5 which follows:

TABLE VII-5

SCHEME II - ANNUAL COSTS
IN MILLIONS OF DOLLARS FOR KARNAFULI PROJECT

	Foreign Currency	Pakistan Currency
Interest	1.698	1.336
Sinking Fund	0.290	0.307
Operation and Maintenance	0.109	0.394
Sub-Total	2.097	2.037
Total Annual Cost	4.134 Millions	

The hydro system will require the construction of a transmission line between Karnafuli, Chittagong and Dacca. The design has been studied, and for the purposes of this report, a 165 kv transmission line of modern design has been selected and has been shown on Exhibit 2. The line would be constructed initially for a single circuit, with provisions for a second circuit on the same tower. The proposed single circuit line augmented with a synchronous condenser at Dacca will be required to transmit 80,000 kw from the hydro plant, delivering 20,000 kw at Chittagong and 60,000 kw at Dacca. The initial circuit is capable of transmitting 80,000 kw the full distance to Dacca with line losses and regulation within commercial limits.

It is considered that the line between Chittagong and Dacca will be constructed to run first from Chittagong north, parallel to the road system in the Halda Valley, then crossing the coastal range of hills to Feni. This route, instead of following the railway and main road to Feni, avoids the unfavorable effects of salt-laden air and high winds. In general, it is assumed that the towers would be located on relatively high ground wherever possible out of flood waters, and in areas subject to flooding, the foundations would be extended to an elevation above normal flood stage.

It is contemplated that the line will be aluminum conductors, steel reinforced, supported by disc type suspension insulators and strung on double circuit steel towers of lattice construction with a continuous ground wire placed to effectively shield the line conductors from direct lightning strokes.

It is reported that the permanent material for the transmission line will be furnished by the Canadian Government as aid under the Colombo Plan. However, for the purpose of making an economic comparison, it has been assumed that cost of the transmission is chargeable to Scheme II.

Construction and operation of the 165 kv transmission line requires the construction of switching and transformer stations. The initial development would require switching and transformer stations at Chittagong and Dacca. Each station would include high-voltage switchgear, transformer units and sufficient medium-voltage switchgear to adequately control the distribution of energy from the station. It is estimated that a receiving station having a capacity of 75,000 kva would be required at Dacca and one having a capacity of 37,500 kva at Chittagong.

The exact arrangement of the stations has not been determined but it is contemplated that air blast or oil circuit breakers will provide control of the lines and transformer banks. Transformers may be of the oil filled type, single or three phase units depending on the existing transportation and clearance limitations. The secondary voltages would be chosen to coordinate with existing installations or distribution systems in so far as practicable.

At Dacca there would be a synchronous condenser to furnish reactive kva, improve regulation and reduce line losses. Preliminary estimates show that a condenser having a capacity on the order of 10,000 kva would be required.

An industrial development is planned at Hajiganj and this can readily be supplied with energy by a transformer station located at Comilla; service can also be furnished to the town at that point. It is estimated that a station with a capacity of 6,000 kva would be required in the Comilla area. The receiving stations would be linked into the existing and expanded distribution system.

From Appendix B, the transmission line, receiving stations and synchronous condenser are estimated to cost $11,361,000 including land, duties and interest during construction.

The annual costs for the transmission line and receiving stations in the years 1960 and 1965 based on a life expectancy of 35 years would be as shown in Table VII-6.

TABLE VII-6

SCHEME II - ANNUAL COSTS IN MILLIONS OF DOLLARS FOR TRANSMISSION LINE AND RECEIVING STATIONS

	In 1960	
	Foreign Currency	Pakistan Currency
Interest	0.401	0.117
Sinking Fund	0.089	0.050
Operation and Maintenance	0.037	0.087
Sub-Total	0.527	0.254
Total Annual Cost	0.781 Millions	

The total annual cost of Scheme II, hydro system with thermal support and navigation locks is summarized in Table VII-7.

TABLE VII-7

SCHEME II - HYDRO SYSTEM WITH THERMAL SUPPORT
TOTAL ANNUAL COSTS IN MILLIONS OF DOLLARS

	In 1960		In 1965	
	Foreign Currency	Pakistan Currency	Foreign Currency	Pakistan Currency
15,000 kw Thermal Plant	0.510	0.255	0.510	0.255
Karnafuli Project	2.097	2.037	2.097	2.037
Transmission Line and Receiving Stations	0.527	0.254	0.527	0.254
Sub-Totals	3.134	2.546	3.134	2.546
Total Annual Costs	5.680 Millions		5.680 Millions	
Gross Generation, Million kwh	324.00		443.60	
Energy to Consumers	315.55		431.80	
Net Valuation per kwh sold (Based on life expectancies of system)	$0.0180		$0.0132	

The Government of Pakistan according to recent indications is considering deferring the construction of the navigation locks and providing temporary materials handling equipment to transfer cargo past the dam. If the construction of the navigation locks is deferred, there would be a reduction of the capital costs of the Karnafuli Project. The capital costs for Scheme IIa, hydro system without the navigation locks, have been computed to be $65,636,000 in Appendix C.

Elimination of the navigation locks with the lower annual costs of Scheme IIa as computed in Appendix C will result in a more favorable unit cost per kwh as shown in Table VII-8.

SCHEME IIa - HYDRO SYSTEM WITH THERMAL SUPPORT
TOTAL ANNUAL COSTS IN MILLIONS OF DOLLARS
(Navigation Locks not Included)

	In 1960		In 1965	
	Foreign Currency	Pakistan Currency	Foreign Currency	Pakistan Currency
15,000 kw Thermal Plant	0.510	0.255	0.510	0.255
Karnafuli Project	1.908	1.856	1.908	1.856
Transmission Line and Receiving Stations	0.527	0.254	0.527	0.254
Sub-Totals	2.945	2.365	2.945	2.365
Total Annual Costs	5.310 Millions		5.310 Millions	
Energy to Consumers, Million kwh	315.55		431.80	
Net valuation per kwh sold (Based on life expectancies of system)	$0.0168		$0.0123	

7.03 COMPARISON OF SCHEME I AND SCHEME II, ON SINKING FUND BASIS

The annual cost of generation for the all-thermal system, and the hydro system with thermal support has been computed on the sinking fund depreciation basis. The results are summarized as follows:

	All-Thermal System Scheme I		Hydro System with Thermal Support (with navigation locks) Scheme II		Hydro System with Thermal Support (without navigation locks) Scheme IIa	
	In 1960	In 1965	In 1960	In 1965	In 1960	In 1965
Total Annual Costs - Millions of Dollars	6.051	8.328	5.680	5.680	5.310	5.310
Foreign Currency Requirements - Millions of Dollars	4.058	5.595	3.134	3.134	2.945	2.945
Net valuation per kwh sold	$0.0192	$0.0193	$0.0180	$0.0132	$0.0168	$0.0123

59

Scheme I is based on thermal plants located at load centers in the Dacca-Chittagong areas, and for purposes of comparison, it was also assumed that small thermal plants would serve the Comilla area without requiring transmission lines and that the cost of generation is the same as for the larger stations at Dacca.

Scheme II consists of the Karnafuli Project with 15,000 kw of supporting thermal plant in the Dacca area with a 165 kv transmission line from Karnafuli to Chittagong and Dacca-Narayanganj, complete with necessary switching stations.

In computing the cost of power for Scheme II, all costs of the Karnafuli Project have been charged to power production. This very conservative procedure represents the outside or maximum cost of hydroelectric power.

The cost of power for Scheme II is 32% less than that for Scheme I when computed in the above conservative manner. Actually the Karnafuli Project is an exceptionally attractive multi-purpose project. The savings in foreign exchange will be $2,461,000 for the year 1965.

7.04 OPERATION AND DEBT SERVICE EXPENDITURES - HYDRO SYSTEM WITH THERMAL SUPPORT AS RECOMMENDED

It is assumed that the currency requirements for execution of the Karnafuli Project and its associated features will be borrowed. In order that all debts be amortized and interest payments met, sufficient revenue must be raised to cover both operation and debt service.

For the purpose of determining the required revenue to cover both operation and debt service, the hydro system with thermal support is assumed to consist of the Karnafuli Project, a thermal plant in the Dacca area, a transmission line from Karnafuli to Dacca via Chittagong, receiving stations at Chittagong, Dacca and Comilla, a synchronous condenser located at the Dacca receiving station, and distribution facilities to connect with the loads in each area.

The present existing distribution facilities must be augmented to serve the major consumers as estimated in the forecast of power demand and consumption. Exhibit 2 sets forth the existing high voltage distribution system and shows the extent of the proposed new feeders operating at 33 kv.

In conjunction with the above distribution system additional step-down substations will be required at local load centers to transform energy to 3.3 kv and 230/400 volts and some low voltage distribution lines. This will make energy available to the smaller industries and will enable industries which have private plants to be connected to the distribution system without excessive cost.

A detailed computation of the annual expenditures for operation and debt service have been made in Appendix D and includes expenditures for the Karnafuli Project, 187 miles of 165 kv transmission line, receiving stations, synchronous condenser, 84 miles of single circuit 33 kv distribution line, seven 5,000 kva substations and 40 miles of low voltage (3,300 and 230/400 volt) distribution line of overhead open wire construction.

The computations were made on the following basis:

a. All foreign currency loans are amortized in level annual payments over 20 years at 5% interest compounded semi-annually. All local currency loans bear 3-1/2% interest compounded semi-annually, and are amortized in level annual payments over 50 years except the loan for the thermal plant which is amortized in 20 years.

b. Operation and Maintenance - the same as computed for the sinking fund analysis.

In summary, the annual expenditures for the hydro system, including a distribution system will be:

	Annual Costs In Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Karnafuli Project (with Navigation Locks)	2.849	2.031	4.880
Transmission Lines and Receiving Stations	0.684	0.230	0.914
Distribution System	0.123	0.058	0.181
15,000 kw Thermal Plant	0.511	0.255	0.766
TOTAL ANNUAL EXPENDITURES (In millions)	4.167	2.574	6.741

	In 1960	In 1965
Energy to Consumers, Million kwh	315.55	431.80
Minimum Average Return Required per kwh Sold (Based on Amortization of loans)	$0.0214	$0.0156

In order to make the Karnafuli Hydroelectric Project self-liquidating a minimum average return will be required of 2.14 cents per kwh sold in 1960 and as the demand for energy increases, the minimum return required will reduce to 1.56 cents per kwh sold in 1965.

The present rates for energy in East Pakistan are about 5 to 8 cents per kwh for industrial power and heating, and about 11 to 15 cents per kwh for domestic lighting and appliances. Regardless of whether an all-thermal system or a hydro system is ultimately chosen, there are additional potentials for development of industries and expansions in the use of electric energy for domestic purposes with the availability of energy at a lower rate than presently exists.

The sale of hydroelectric energy has the advantage over the all-thermal system in that, at the end of the amortization period, all foreign loan payments and interest payments would cease yet the economical life of the hydro structures would continue for at least another thirty years. For the all-thermal system the foreign currency expenditures for fuel would continue into the future, with the probability that the economically useful life of the thermal plants would be much less than that of the hydro.

7.05 SUMMARY AND RECOMMENDATIONS

In Section 7.03 it has been shown that the Karnafuli hydro system with thermal support is the most economical means of meeting the power demand in East Pakistan. For the year 1965 power costs for this system were found to be 32% lower than those produced by an all-thermal system and the annual savings in foreign exchange would be $2,461,000. Savings will be even greater in later years when the power consumption increases, and in the event the construction of the navigation locks is deferred there will be an additional saving.

The economic effects of deferring the construction of the Karnafuli Project have been considered and it has been found that it will be uneconomical to defer the project.

The annual charges for operation and debt services have been presented in Section 7.04 and it was shown that the power rates necessary to raise the required revenue will be substantially lower than existing rates.

Based on these analyses and the detailed investigations elsewhere in this report the following recommendations are made:

First: Immediate completion of the Karnafuli Project. Since foundation conditions are difficult and construction procedures important for successful completion, the preparation of detailed construction drawings and field supervision should be in charge of qualified engineering organizations

experienced in projects of this type. The construction of this project, for reasons of safety and economy, should be in the hands of an experienced construction organization.

Second: Initial installation of two 40,000 kw units in the Karnafuli power plant with space provided for a third unit. Project layout should reserve space for a future additional power plant when required.

Third: The final surveys and engineering design of the necessary transmission lines, switching stations and distribution systems should be initiated immediately.

Fourth: Sufficient existing or new thermal plant with 15,000 kw capacity should be provided in the Dacca area for standby and support of the Karnafuli Project.

Fifth: The first stage of the necessary transmission and distribution system should be constructed with completion timed to be available for service when the first unit of the Karnafuli power plant is in operation. This would include switching stations and the 10,000 kw synchronous condenser required at Dacca.

Sixth: The installation of the 30,000 kw steam plant projected for installation at Dacca should be reviewed with consideration given to installing part or all of this capacity at other locations in East or West Pakistan where a greater need for thermal power may exist.

Seventh: In areas beyond the limits of the transmission and distribution system herein proposed, it is recommended that power requirements up to 2,000 kw be supplied by low or intermediate speed diesel units. Where the demand exceeds 2,000 kw, steam plants should be considered.

Eighth: The third generating unit should be installed as soon as justified by the power demand, which is presently estimated to be in 1968.

Ninth: The extensions of the transmission and distribution systems should be done as rapidly as the load growth justifies and as financial resources permit.

8.01 GENERAL

History - The first engineering investigation of the hydroelectric power potential of the Karnafuli basin was a brief reconnaissance made in 1906-07. This was followed by Grieve's study and report in 1923 which recommended the Barkal site.

The partition in 1949 resulted in the Barkal dam site being located in East Pakistan but with a large part of the reservoir extending beyond the boundary into Assam. Due to the difficulty in obtaining reservoir lands beyond the boundary the Barkal site is no longer considered practicable for development by the Government of Pakistan.

The Merz Rendel Vatten (Pakistan) Report in 1950 recommended a concrete buttress dam at Chilardak. The Government of Pakistan did not follow the above recommendation because it was considered that a dam at Chilardak would not properly develop the power potential of the Karnafuli River and because suitable construction materials were not available near the site.

The Irrigation Department, Government of East Pakistan studied in 1950-51 dam sites further downstream at Kaptai and Chitmaram. For reasons which will be subsequently stated the Kaptai site was adopted and work has been underway at this site since 1952.

Present Status - The preliminary work for the Karnafuli Project at Kaptai has been substantially completed and construction of the project is underway. By July 1954 approximately $8,297,000 had been spent in purchasing construction equipment and in performing the following described work:

1. Site clearing

2. Construction town, complete with permanent masonry family housing, office buildings, and school buildings; also water, electric, and sewage systems

3. Construction shops and warehouses

4. Paved village streets and storm drains

5. Water supply reservoirs

6. Soils Laboratory complete with equipment

7. Construction equipment - 39 Euclid trucks, 3 Euclid loaders, 2 - 54B Bucyrus Erie crane-shovel combinations, 7 - 300 cfm air compressors, 9 Caterpillar D-8 tractors, 1 - TD-9 International tractor, and supporting tools and equipment

8. Supply of construction materials including brick, steel, and cement

9. Reservoir and dam site surveys

10. Foundation and borrow drilling and testing

11. Diversion of the river through diversion channel

12. Upstream cofferdam

13. Spillway excavation (partial)

14. Excavation for dam foundation

15. Access road - Karnafuli site to Chittagong (in progress)

16. Special engineering work requested by Consulting Engineers (stream gaging, soils explorations and laboratory tests).

8.02 SITES CONSIDERED

Barkal - The Barkal site is situated about 18 miles below the international boundary. It affords the best foundation to be found along the river. However as previously stated much of the reservoir extends beyond the international boundary into Assam and the Barkal site is no longer considered practicable.

Chilardak - The Chilardak site situated about nine miles upstream from Rangamati was investigated in considerable detail in 1949-50.

The Consulting Engineers examined this site in April 1954 and found its topography to be reasonably satisfactory. However, there are certain disadvantages. Whereas the site is favorable for a dam in that the river is confined in a narrow channel with steep hills on both sides, it is so restrictive that construction would be very difficult. With the project considered as a multi-purpose one, that is for power, flood control, and navigation, it becomes a serious problem to provide space for the necessary features. The large amount of excavation required would add greatly to the cost of the job.

The abutment and foundation conditions were found to be adequate. The left abutment was composed of alternate thick bands of shale and sandstone. Intense folding and faulting was evident and the orientation of the beds ranged from vertical to nearly horizontal. In the upper inspection gallery the rock was found to be thin-bedded, dark grey, medium-hard shale with soft partings. The right abutment was composed largely of soft sandstones. With the abutment conditions as found, an earthfill dam appears best suited to this site.

East Pakistan will require a much greater block of power than can be generated at this site. A site with a greater reservoir capacity and additional inflow would obviously be more effective for both power production and flood control.

A particularly difficult problem would be encountered in transporting materials and equipment to the site. A good all-weather road from Chittagong, adequate for heavy transport, would be very expensive both to construct and maintain. Transportation by water would require dredging of the upper reaches of the river.

Chitmaram - The Government's engineers in 1950-51 investigated the Chitmaram site, located between Chitmaram and Chandraghona, but abandoned it after preliminary surveys and explorations.

The site was examined by the Consulting Engineers in April and May 1954, and it was found that topographically it is similar to the Chilardak site although it provides somewhat more space for construction. The abutments appear satisfactory for an earth dam but they have not been investigated by core drilling. Explorations in the valley bottom and river terraces were restricted to determining the top of the underlying shale, which was found to be deeply eroded. An intensive program of foundation investigation, borrow exploration, and laboratory testing requiring about ten months would be required for the complete evaluation of this site. Field inspection indicates that the foundation conditions here may not be as good as those at the Kaptai site upstream. It is likely that the valley sediments are finer grained and not as well consolidated.

The steep valley wall at the Chitmaram site does not provide natural sites for the necessary appurtenant structures. Heavy excavation of the valley walls would be required to provide sites for the powerhouse, spillway, navigation locks and diversion works.

A dam at the Chitmaram site would flood the Chitmaram Buddist Temple and Shrines, a historic and sacred site visited by pilgrims from all parts of the Orient. Valuable teak forests and tea gardens would also be flooded.

This dam site, being located farther downstream than the Kaptai site, consequently has a somewhat larger reservoir. Transportation of materials and equipment to this site would not be nearly as difficult as to the Chilardak site.

The Consulting Engineers, after a careful study of all the foregoing considerations and all the available data, believe that any possible advantages the Chitmaram site might have would not be sufficient to offset the value of the work that has already been completed at the Kaptai site at a cost of about $8,297,000.

Kaptai - Studies, surveys, and explorations were in 1951 shifted to the Kaptai Site, located 3.2 miles upstream from the village of Kaptai. Investigations have continued since then, and actual construction was undertaken late in 1952.

Representatives of the Consulting Engineers resided at the site from April 5 to July 15, 1954, and during that period all aspects of the site were thoroughly examined. When comparing this site with Chitmaram, it was found that one small tributary, the Kaptai Khal, some reservoir capacity, and a small amount of head had been sacrificed. On the other hand, a site had been found where the topography is open and reasonably suitable for the locating of all features. This does not mean that excavation quantities are small; they are still large and it appears at this time that most of the material will have to be wasted.

Foundations for the several structures have been explored thoroughly. Although the site presents a few difficulties, the Consulting Engineers find that the construction of the dam and appurtenances is entirely feasible. The power potential of this site is substantial, and flood control can be achieved for all floods of record. Water transportation of heavy materials and equipment to the site can be accomplished without difficulty, and light transport can be either by water or by a road now under construction.

The site satisfies the functional requirements, has been exhaustively explored, is technically feasible, is accessible, much construction has been done, and a substantial sum of money has been invested. With consideration of all of these factors, the Consulting Engineers recommend that the Karnafuli Project be constructed at the Kaptai site.

8.03 GEOLOGY

The reservoir of the Karnafuli Project lies within the area known as the Chittagong Hill Tracts which is characterized by low rolling hills. The Hill Tracts stand in contrast to the remaining portions of East Pakistan which are generally rich, low lying, delta lands. The geologic column in the vicinity of the Karnafuli dam site is as follows:

Approximate Thickness - Feet	Formation
0-100	Karnafuli Alluvium - Recent
1200 maximum	Tipan Sandstone, (Miocene Pliocene)
1300 maximum	Surma Shale - (Miocene Pliocene)

The Tipan and Surma formations are the result of deposition by some great river in Miocene-Pliocene time. These geologically young sedimentary rocks are now being compressed laterally by the great tectonic forces which have raised the Himalayas. This compression has resulted in hill ranges consisting of a series of long north-south folds in the originally horizontally bedded sediments.

The Karnafuli River has cut through several of these parallel ranges of low hills notably the Silchari Range near the present dam site, the Chilardak Range above Rangamati, and the Barkal Range at Barkal Rapids. The reservoir thus takes a somewhat unusual shape as a result of being divided into several parallel reaches by the above hill ranges.

At the dam site the foundation rocks consist almost exclusively of medium to medium-hard siltstones and shales. Physical tests indicate that even the weakest strata will have strengths far greater than the moderate loads to be imposed by the proposed structures. Sliding tests to determine the shearing strength of the foundation shale have shown exceptional strength. Minor gentle folding is quite general and its limited local effects will not be expected to adversely effect the design and construction of the proposed structures. Intensive foundation explorations have been made at the site of each of the proposed structures. Detailed discussion of the foundation conditions will be included in subsequent paragraphs dealing with each of the major structures.

The Karnafuli Project is located in an area usually considered to be of moderate seismic activity. However, extensive records of earthquake activity are not available and it is well known that severe earthquakes have been experienced in Assam and Burma. On August 15, 1950 an earthquake of magnitude 8.25 to 8.50 on the Richter Scale occurred whose epicenter was about 400 statute miles northeast of the Karnafuli site. All structures including the dam, saddle dams, powerhouse, spillway, outlet works and navigation locks have accordingly been designed for earthquake resistance using forces of 0.10 gravity applied horizontally.

68

8.04 FOUNDATION INVESTIGATIONS

The Government of Pakistan has conducted extensive foundation investigations, requested by the Consulting Engineers, at the sites of the various features of the Karnafuli Project. These investigations have included over 56 thousand feet of core borings, several hundred feet of undisturbed soil sampling and a number of open excavations.

In addition to establishing the geologic structures of the foundations, the explorations have also been directed toward determining physical properties of the materials, particularly their structural properties and permeability. Determination of structural properties has included laboratory tests of the compressive strength of rock cores and undisturbed soil samples. Permeability determinations have been made in the laboratory. Supplementing these, large scale pumping tests were conducted in place.

Logs of a large number of core borings were available to the Consulting Engineers when they arrived at the site in April 1954. A study of the results of these investigations revealed a number of specific problems requiring further exploration. A program of additional test boring was therefore established following conferences with Mr. Azeemuddin, Chief Engineer, Karnafuli and Warsak Projects, who ordered immediate execution of this work. This phase of the exploratory program was completed by the middle of July. Results of these explorations indicated the need for further explorations in order to resolve problems which were revealed. The Consulting Engineers prepared a program of supplemental investigations which was promptly instituted at the direction of Mr. Azeemuddin. This program is essentially complete except as will be noted.

Main Dam - About 140 borings and test pits have been made in this area. These explorations reveal that at the damsite the Karnafuli River has carved an 1100-foot wide valley through the surrounding low hills of the Silchari Range. Before the Government of Pakistan commenced construction operations, the river occupied a 500-foot wide channel on the left side of the valley. A terrace formed by a 60-foot thick bed of very fine sediments rises about 60 feet above the streambed on the right bank. Brown silty and sandy clays comprise about the upper 25 feet of this deposit and are underlain by blue silty clay. The boundary between the blue and brown clays marks the approximate elevation of the ground water level inasmuch as the blue clay turns brown on exposure to air. Both materials are of medium plasticity; the blue clay has a soft to medium-soft consistency in place, whereas the brown clay is somewhat firmer havin been partly consolidated by desiccation. The diversion channel constructed by the Government cuts through the right side of the terrace so that an island has been formed between the original river channel and the diversion channel. The site is crossed, beneath the terrace, by an abandoned stream channel which extends 60 to 70 feet below the present streambed. The lower portion of the channel is filled largely with uniform medium sand which becomes

silty toward the top. Deep borings in the left bank borrow area indicate that this channel apparently crosses the present riverbed upstream of the site. For the most part the present riverbed at the dam site consists of a 10 to 20 foot thick deposit of silty sand.

The recent sediments are underlain generally by shale and siltstone of varying hardness. The shale contains a 15 to 20 foot thick bed of compact sand which slopes down from the hills on the left bank and is found from 110 to 150 feet below the top of the shale at the dam site.

For design of the main dam the following essential information was required: 1) the strength in-place of the clay deposit in order to permit the designers to establish stable slopes for the embankment, and 2) the permeability of the underlying sand in order to determine necessary provisions for controlling underseepage.

Investigation of the strength of the clay formations involved an extensive program of test borings and undisturbed sampling. The Consulting Engineers, working in cooperation with the engineers of the Government of Pakistan and its contractor, the Swiss Boring Overseas Corporation Limited, successfully developed detailed procedures and equipment for recovering undisturbed samples from foundation test borings.

Certain conservative design criteria have been established for the shear strength of the blue and brown clays based upon previous laboratory tests on undisturbed samples recovered from the test borings. It is essential that detailed foundation explorations be continued to confirm these criteria or demonstrate the necessity for additional stability investigations of the embankment. Continuous samples should be taken throughout the entire depth of the clay deposit to the top of the underlying sand. Samples may be taken either from drill holes by thin-wall tube samplers or from test pits by carving block samples from benches. The clays are relatively soft and easily remolded, and the shearing resistance is sensitive to slight changes in water content. Extreme care in sampling and handling is therefore essential so that disturbance to the specimens is minimized and laboratory test results are truly representative.

The permeability of the sand deposit was determined by means of three large-scale pumping tests, conducted by Swiss Boring Overseas Limited, which yielded fairly consistent results. Laboratory tests were also performed on these materials. The sand is apparently relatively pervious, the values of the coefficient of permeability obtained by the various tests varying from $10\text{-}50 \times 10^{-9}$ cm per sec. Because of the considerable length of the path of percolation which results from the blanketing effect of the broad base of the dam and the overlying clay, the quantity of underseepage will be of insignificant magnitude and can be readily and safely handled by the drainage provisions which will be installed. Over a period of time the quantity will diminish appreciably as siltation of the streambed behind the dam increases the effective length of the blanket and the path of seepage.

Spillway - The spillway gate structure is located at a saddle in the hills adjacent to the left abutment of the dam. The channel follows a natural ravine which discharges into the river below the dam site. Over 150 borings and test pits were made in this area. The gate structure is founded entirely on medium-hard, compact blue shale and siltstone which lie in approximately horizontal beds at this location. A 20 to 30-foot thick layer of compact sand is interbedded within the shale. This bed dips generally in a westerly direction from about 50 to 90 feet below the foundation of the gate structure and is encountered again at considerable depth beneath the dam site. A short distance below the bed of compact sand, the shale is underlain by a deposit of sandstone of indefinite extent which is interbedded with thick beds of compact blue shale. The sandstone outcrops in the hills adjacent to the left abutment of the gate structure. Continuing along the ravine, the shale deposits gradually decrease in thickness and the deeper lying shale beds disappear. At the lower end of the ravine the shale is covered by a thick mantle of alluvial clayey silt.

The foundation shale under the gate structure showed exceptionally high strength. Compressive tests on 3 by 5 inch cylinders of the shale indicated a strength of 73 tons per square foot. This is ample for the structural loads which will be imposed. Some of the shale in the foundation under the lined channel is softer and of lower strength than that under the gate structure. The superimposed loads are insignificant in this area and the shale will provide adequate support. Some of the underlying sandstone is well cemented and nearly impervious whereas others, particularly near the gate structure, are uncemented or weakly cemented and are more pervious.

Powerhouse - The powerhouse site is a saddle in the range of hills which separates the ends of the long hair-pin bend in the river below the dam site. A total of 31 borings were made in this area. The foundation consists of medium to compact shale underlain by soft sandstone. Investigations were started at a site at the center of the saddle. However, borings indicated that the top of the sandstone at this location is above the deepest excavation level for the powerhouse substructure. The sandstone which is poorly cemented is under artesian head and will therefore present a considerable unwatering problem during excavation to avoid serious disturbance of the material. Moreover, the control of uplift pressures on the foundation would be complicated by the presence of sandstone immediately below the structure. The borings also disclosed that the level of the top of the sandstone drops off toward the west and explorations were, therefore, continued in this direction. In its present location at the west end of the saddle, the deepest portion of the powerhouse substructure is at least 20 feet above the top of the sandstone deposit. It will be necessary to make suitable provisions for drainage of the sandstone deposit in order to reduce artesian pressures and preclude a blowout through the shale during construction, since the shale cover in the deepest portion of the excavation is insufficient to withstand the existing pressure in the sandstone.

Explorations were also conducted at a possible powerhouse site on the left bank between the spillway and the main dam. At this site the powerhouse would also be founded on a compact blue shale with a bed of compact sand from 20 to 30 feet below the deepest portion of the substructure. This location was eliminated by other considerations.

Locks - The navigation locks cut through a ridge in the hills to the west of the powerhouse site. Eight borings were made in this area. These indicate that the lock chambers will be founded on soft or compact shales varying in location. Either material will provide foundations which are competent to support the loads to which they will be subjected. There is evidence that the soft sandstone underlying the shale in the powerhouse area also extends below the lock area. However, it is apparently at such depth below the foundation that it should present no special problems.

Diversion Tunnel - The diversion tunnel will be excavated through a ridge of the right abutment of the dam. A number of borings were made in the vicinity of the tunnel alignment and supplemented by test trenches. Study of the explorations and outcrops indicates that the tunnel will pass through essentially horizontally bedded deposits of grey and blue soft shale and blue compact shale which do not air slack rapidly.

8.05 BORROW INVESTIGATIONS

During the period from April 5, 1954 to July 13, 1954, an intensive investigation was conducted to locate sources of impervious and pervious borrow material for construction of the dam embankment. Terraces on both sides of the Karnafuli River, just upstream of the dam, were explored as potential sources of impervious material. A borrow area for pervious material on the left abutment upstream from the spillway was also explored at this time.

Explorations were made generally by test pits and supplemented by auger borings and side hill trenches. Samples of representative materials were tested in the project soils laboratory and in soils laboratories in the United States.

Certain design criteria have been established for the shear strength of these embankment materials based on results of these laboratory tests. These criteria have been used in analyzing the stability of the embankment section. Detailed explorations and laboratory testing should be continued to establish whether these criteria are satisfied by the materials. If these explorations reveal that the criteria cannot practicably be satisfied, it will be necessary to make additional stability studies of the embankment slopes. Specimens for laboratory testing should be obtained by blending materials throughout various depths so that the soil tested will be representative of material which would be excavated by construction equipment.

It will be absolutely necessary to maintain proper engineering control of all phases of embankment construction in order to obtain a safe structure. A well-trained crew of soils engineers will be required to oversee construction at all times, and make periodic determinations of moisture content, compacted density, thickness of layers, distribution of the various material within the embankment, etc., to insure compliance with specifications.

Impervious Material - Eleven test pits were excavated in the left bank impervious borrow area and nine in the right bank area. In several instances the test pits were extended by hand augers. The explorations reveal that ample quantities of suitable impervious materials are present within economic hauling distance of the dam.

The impervious materials consist of brown silty and sandy clays. When these materials are compacted in the embankment to specified densities, they should have a high shear strength and form a dense impervious fill.

Pervious Material - Pervious material for the embankment will consist of medium to fine sand from a deposit of uncemented sandstone. Test pit explorations in the borrow areas north of the spillway intake channel and near the powerhouse site reveal that there is a sufficient quantity of this material available for constructing the embankment section as shown on the drawings.

Materials from Required Excavation - A considerable portion of the material excavated for the various structures will be used for constructing the dam embankment. These materials will include rock fragments from shale excavation, and silty sand and clayey silts from common excavations. Investigations should be conducted to establish the suitability of the different materials for the various portions of the embankment section in accordance with the design criteria.

8.06 AGGREGATE INVESTIGATION

The location of suitable concrete aggregates in East Pakistan within economical hauling distances is a serious problem. There is a remarkable absence of satisfactory rock and graded sands in the Karnafuli River Basin. Investigation has resulted in the following information.

Coarse Aggregate - Considerable effort has been expended endeavoring to locate suitable coarse aggregate. Two possible sources, field or "jungle" stone and so-called "beach" boulders were considered and have been rejected.

"Jungle" stone is found in the bottoms of the steep nullahs or draws formed by tributaries to the Karnafuli River. It consists of hard sandy

concretions contained in the shales and deposited due to erosion of the shale beds. The very limited quantities available and difficulties of recovery obviate the use of these stones.

"Beach" boulders consist of similar concretions lying in boulder fields along the ocean beaches below Cox's Bazaar, 65 to 90 miles south of Chittagong on the Bay of Bengal. Fairly large deposits are located at Cox's Bazaar, Inani, and Patnatek. High tides cover the boulders which are encrusted with marine life and partially buried in the beach sand. Again, expense of recovery and limited quantities force rejection of this source.

The Consulting Engineers recommend development of the Bholaganj gravel deposit in the Sylhet district, one of three similar deposits investigated along the northeast border of East Pakistan.

Gravel and boulders are carried down from the Khasi Hills in Assam during the yearly floods of various streams. Rock types, varying in size from sand to 12-inch boulders, were found to be granites, grandiorites, trap-rock, quartzites, or hard sandstones with some limestones. With proper crushing and grading these hard, durable stones will produce excellent concrete aggregates. Supply at Bholaganj is ample, estimated to be in excess of 12 million cubic yards. It will be necessary to transport the finished product 11 miles overland to the rail head at Chhatak, then 263 miles by rail to the Kalurghat Bridge above Chittagong. At Kalurghat or at Chittagong, the crushed rock must be transferred to barges for towing to the job site. For the quantities of aggregate required, a railroad extension to Bholaganj from Chhatak may be economical. Such a transportation link, together with the development of the extensive gravel deposit would be of permanent benefit to East Pakistan for future public works.

Sand - Two sand sources, other than those associated with Sylhet gravel deposits, were located in the Kodala Chari and at Ichamati. A very fine sand is also available at the project site. However, due to fineness, its use should be restricted to blending purposes.

The Kodala sand, quartzitic in origin, is of very uniform gradation with a deficiency of coarse sizes. Eighty-eight percent of the volume ranges in grain size from 0.6 mm to 0.2 mm (U.S. std series 30 to 80 mesh screen). While suitable concrete has been obtained using this sand, normal practice will require blending with coarser sizes to obtain specification gradation. Adequate quantities exist which can be economically processed. A 3-mile overland haul from the pit to the river is necessary. At the river, trucks could be ferried, and continue by a road now under construction to the project site 9 miles further. An alternate route would be to transfer the sand and haul by river barge.

Sand pits at Ichamati have also been sampled. The samples obtained indicate Ichamati sand to be slightly finer than that at Kodala. Again, blending

with coarse sizes will be necessary. The haul distance to the project is approximately 17 miles via the new project access road. No river crossing is required.

It is recommended that the majority of the fine aggregates be obtained from either Ichamati or Kodala locations with the Kodala sand preferred.

Production of coarse aggregates from riverbed deposits in the Sylhet District will result in a considerable recovery of natural and crushed sands. Proper classification of this product will furnish the coarser sands, approximately 30%, needed for blending with the finer Kodala or Ichamati sands.

8.07 LABORATORY TESTS

Soil samples from the dam foundation and borrow areas, shale rock cores, and concrete aggregate materials were tested in an extensive laboratory program. A large number of samples were sent to the United States for testing by the Consulting Engineers. Additional tests were performed in the Karnafuli Project Soil Mechanics Laboratory.

Tests by the Consulting Engineers - The following laboratory tests were performed on undisturbed specimens from the foundations of the dam: unconfined compressive strength, quick triaxial shear, natural moisture content, one-dimensional consolidation, specific gravity, and Atterburg limits. A summary of typical test results on foundation materials is given in Table VIII-1. The following tests were performed on samples of borrow area materials: compaction, triaxial shear, permeability, specific gravity, Atterburg limits and grain size analysis. A summary of typical test results on foundation materials is given in Table VIII-2. Locations of the drill holes and test pits referred to in the tables are shown on Exhibits 10 to 14 and 17 and 18 of Volume III.

Tests in Karnafuli Soils Laboratory - A large number of tests were performed in the Karnafuli Project Soils Laboratory. The following tests were performed on undisturbed samples of foundation material: torsion shear (Hvorslev apparatus), unconfined compression, one-dimensional consolidation, moisture content, specific gravity, mechanical analysis and Atterburg limits. The following tests were performed on borrow area materials: compaction, torsion shear, mechanical analysis, specific gravity and Atterburg limits. Compression tests were also performed on shale cores.

TABLE VIII-1

SUMMARY OF TYPICAL SOIL LABORATORY TEST RESULTS
KARNAFULI DAM FOUNDATION MATERIALS

Drill Hole Number	Location	Depth Ft	Type of Material	Natural Moisture Content Percent	Dry Density Lb Per Cu Ft	Atterburg Limits L_w	Atterburg Limits P_w	Atterburg Limits I_w	Unconfined Compressive Strength PSF	Triaxial Quick Shear Strength: Lateral Pressure PSF	Triaxial Quick Shear Strength: Max Deviator Stress PSF	Compression Index	Coefficient of Permeability Cm Per Sec
P-2	Right Bank	16.1	Brown Clay	25.6	98.6	-	-	-	4,250	-	-	-	-
"	" "	16.7	" "	24.3	100.8	-	-	-	6,420	-	-	0.221	$10-30 \times 10^{-9}$
"	" "	20.6	" "	18.1	109.5	-	-	-	-	3,500	6,380	-	-
"	" "	23.0	" "	21.9	102.1	-	-	-	4,090	-	-	-	-
"	" "	24.0	" "	19.4	106.3	-	-	-	-	12,600	5,520	0.156	6×10^{-9}
"	" "	38.5	Blue Clay	27.8	99.	-	-	-	-	775	960	-	-
"	" "	38.5	" "	29.3	98.	-	-	-	-	1,080	1,080	-	-
"	" "	38.5	" "	28.0	98.	-	-	-	-	1,280	1,200	-	-
"	" "	38.5	" "	28.9	99.	-	-	-	-	1,430	1,280	-	-
"	" "	38.5	" "	30.1	97.	-	-	-	-	1,800	980	-	-
"	" "	41.0	" "	30.8	97	-	-	-	-	2,150	880	-	-
"	" "	41.6	" "	29.3	94.0	-	-	-	-	14,320	1,540	0.192	$20-40 \times 10^{-9}$
"	" "	42.3	" "	27.4	98.1	-	-	-	1,890	-	-	0.180	30×10^{-9}
"	" "	42.6	" "	29.1	95.2	-	-	-	-	3,500	2,250	-	-
54	" "	25.0	Brown Clay	25.9	102.	31.5	21.5	10.0	1,300	-	-	-	-
"	" "	27.4	" "	28.2	97.	-	-	-	-	3,600	1,310	-	-
"	" "	31.8	" "	30.7	94.	-	-	-	980	-	-	-	-
"	" "	32.4	" "	33.0	92.	-	-	-	-	3,600	1,450	-	-
55	" "	13.1	" "	24.6	102.	-	-	-	2,450	-	-	0.213	$10-30 \times 10^{-9}$
"	" "	16.4	" "	24.8	101.	-	-	-	-	3,600	2,230	-	-
"	" "	18.4	Gr Si Sand	19.5	110.	-	-	-	-	1,420	6,500	-	-
"	" "	33.3	Blue Clay	26.6	100.	-	-	-	-	1,000	2,080	-	-
"	" "	33.3	" "	27.6	99.	-	-	-	-	3,600	1,640	-	-
"	" "	40.2	" "	28.0	97.	-	-	-	1,470	-	-	0.164	$20-50 \times 10^{-9}$
"	" "	43.6	" "	30.2	95.	-	-	-	1,560	-	-	-	-
"	" "	46.8	" "	29.1	95.5	-	-	-	1,560	-	-	-	-
"	" "	52.2	" "	24.4	104.0	-	-	-	-	1,000	900	-	-
"	" "	52.8	" "	23.9	103.0	-	-	-	-	3,600	2,200	-	-
"	" "	53.5	" "	24.5	103.5	-	-	-	-	7,800	2,450	-	-
56	" "	32.8	Brown Clay	30.6	94.3	-	-	-	1,430	-	-	0.208	$10-50 \times 10^{-9}$
57	" "	41.9	Blue Clay	27.8	98.	29.4	21.1	8.3	-	14,400	1,600	-	-
"	" "	48.6	" "	28.8	98.	-	-	-	-	3,600	1,040	-	-
"	" "	49.2	" "	27.0	99.1	-	-	-	1,770	-	-	-	-
58	" "	17.1	Brown Clay	27.8	97.5	-	-	-	-	2,880	4,180	-	-
"	" "	17.6	" "	26.8	98.0	-	-	-	-	5,740	4,160	-	-
"	" "	18.1	" "	24.4	100.6	-	-	-	-	11,800	6,720	-	-
"	" "	36.2	Blue Clay	28.6	98.0	-	-	-	-	7,200	1,620	-	-
"	" "	54.2	" "	31.2	92.6	-	-	-	2,190	-	-	-	-
"	" "	55.0	" "	33.5	90.6	-	-	-	2,260	-	-	-	-
59	" "	44.7	" "	30.6	92.9	-	-	-	1,250	-	-	-	-
"	" "	52.3	" "	25.1	101.2	-	-	-	2,030	-	-	-	-
"	" "	52.8	" "	29.5	95.1	-	-	-	1,700	-	-	-	-

TABLE VIII-2

SUMMARY OF TYPICAL SOIL LABORATORY TEST RESULTS
KARNAFULI BORROW AREA MATERIALS

Drill Hole or Test Pit No.	Location	Depth Ft	Type of Material	Atterburg Limits			Compaction Tests		Triaxial Quick Shear Strength		Moisture Content Percent	Dry Density PSF
				L_w	P_w	I_w	Optimum Moisture	Maximum Density PSF (Dry)	ϕ Degrees	Cohesion PSF		
1, 2, 3-Composite	Left Bank	Composite	Impervious	-	-	-	-	-	11.5	3,000	26	103 ϕ
"	" "	"	"	-	-	-	-	-	26 *	1,800 *	24	103 ϕ
Composite	" "	"	"	38.8	20.7	18.1	-	-	11	4,000	19.4	110.6ϕ
Composite	" "	"	"	39.0	20.7	18.3	14.5	118.2	31.5	2,100	18.6 ı	113.3
Composite	Right Bank	"	"	35.8	19.6	16.2	-	-	3	9,700	15.0	120 ϕ
Composite	" "	"	"	-	-	-	14.3	117.2	20	2,160	19.0 ı	113.2
9	Left Bank	"	Sand	22.4	NP	-	10.6	117.8	27	1,760	19.0 ı	112.9

* Triaxial quick-consolidated test.

ϕ Specimen prepared in Karnafuli Project Laboratory

ı Specimen saturated before test.

HYDROLOGY AND WATER SUPPLY

9.01 GENERAL CHARACTERISTICS

The watershed of Karnafuli River (Exhibit 7) lies just within the tropics with only the northern tip of tributary basins extending above the latitude of the Tropic of Cancer. The portion above the Kaptai dam site in the Silchari Range is long and narrow and the longitudinal axis lies approximately 15 degrees west of north. This elongation of the basin is produced by long tributaries which lie within narrow valleys between roughly parallel ridges known as the Lushai Hills, through which the main stem of the Karnafuli River has cut its channel. The ridges, which lie in the main direction of the watershed, begin near the Bay of Bengal and each successive ridge increases in altitude until the crest is reached in Burma; the peak elevations of these hills exceed 8,000 feet, thus forming an appreciable barrier to moisture-laden winds. The topography of the lower portion of the Karnafuli River watershed is fairly flat and low but, as may be inferred from the foregoing statements, the upstream portion is rugged.

The area of the full watershed of the Karnafuli River is 5,500 square miles. The area above the dam site is 4,250 square miles, and above the principal stream-gaging station at Rangamati is 3,800 square miles.

The watershed is well covered with vegetation, varying in density from the well cultivated rice fields in the south to unbroken jungle in the north. The northern hills are generally covered with forest, much of it being bamboo, except small areas that are burned and cleared locally for cultivation.

The climate of the Karnafuli River basin is tropical of a marked monsoon type. Although some rains may be expected during every month of the year, the heavy precipitation occurs in the summer monsoon; the heaviest falling in June, July and August. Rains begin to increase in April and decrease through September and October. During December and January rainfall is lighter, being normally less than 1.0 inch. The normal rainfall at two pertinent stations is as follows:

Month	Normal Rainfall, Inches Chittagong	Rangamati
Jan	0.24	0.32
Feb	1.10	0.63
Mar	2.46	1.56
Apr	5.93	5.08
May	10.42	11.59
June	20.99	17.15
July	23.83	20.21
Aug	20.42	19.03
Sept	12.64	13.19
Oct	7.09	5.53
Nov	2.17	1.66
Dec	0.64	0.69
Year, Total	107.93	96.64

The distribution of mean annual rainfall in East Pakistan is shown on Exhibit 8. The distribution by months is shown on Exhibit 9.

Meteorological stations which furnish data of other elements of weather are as follows, together with the mean data:

Month	Temperature, Degrees F Chittagong	Comilla	Srimangal
Jan	66.9	65.7	63.5
Feb	70.5	69.8	67.3
Mar	77.2	73.4	75.8
Apr	81.0	82.8	80.7
May	82.2	83.0	81.6
June	81.8	82.6	82.7
July	81.4	82.4	83.4
Aug	81.1	82.2	83.1
Sept	81.8	82.8	82.8
Oct	80.2	80.8	79.6
Nov	74.6	74.0	72.6
Dec	68.1	67.0	65.0
Year, mean	77.2	77.2	76.5

The data for mean relative humidity for the same stations are as follows:

Relative Humidity, Percent

Month	Chittagong	Comilla	Srimangal
Jan	77	75	84
Feb	71	71	77
Mar	73	72	79
Apr	75	71	77
May	77	75	81
June	83	82	86
July	86	85	86
Aug	86	84	85
Sept	84	80	85
Oct	83	73	84
Nov	81	75	83
Dec	82	77	84
Year, mean	79.8	76.7	82.6

For the same three stations the normal wind velocities, irrespective of direction are as follows:

Normal Wind Velocities, Miles per Hour

Month	Chittagong	Comilla	Srimangal
Jan	4.3	1.3	1.6
Feb	5.1	1.7	2.3
Mar	6.2	3.9	3.8
Apr	7.6	5.0	4.1
May	7.4	5.1	3.8
June	8.1	5.9	3.7
July	8.1	5.4	3.7
Aug	7.4	4.6	3.4
Sept	5.4	3.7	2.9
Oct	3.6	1.8	2.0
Nov	3.6	1.3	1.4
Dec	3.6	1.2	1.3
Year, mean	5.87	3.41	2.83

9.02 RAINFALL STATIONS

The following stations furnished data of daily rainfall pertinent to the Karnafuli watershed, for a period of one year or more:

Station	Period
Bandarban	1936-47; 1952-53
Barkal	1946-50; 1952-53
Dimagiri	1945-49
Dighinala	1947-51; 1952-53
Kaptai	1947-50; 1952-53
Lama	1947-48; 1952-53
Lungleh	1945-49
Maralchari	1947-48; 1952-53
Myanimukh	1947-50; 1952-53
Manikchari	1947-49; 1953
Panchari	1947-51; 1952-53
Rangamati	1913-51; 1952-53

9.03 RIVER GAGING STATIONS

Records of river stage are available from thirteen gages on the Karnafuli River from Thegamukh on the Indian border to the mouth, as follows:

1. Thegamukh
2. Bara Harina Khal
3. Bara Harina
4. Chota Harina
5. Barkal I.B.
6. Barkal Dispensary Ghat
7. Chilardak
8. Rangamati
9. Kaptai
10. Kodala
11. Enayethat
12. Sadarghat (at Chittagong)
13. Patenga (at the mouth of the river)

In addition to the above, gages were established in 1954 at a point just above the upstream cofferdam at the dam site and at Chowdhury Chara, near the site of the powerhouse. The gages at Kaptai, Chowdhury Chara, Kodala and the three downstream points are in tidewater at all times. The gage above the cofferdam and that at Rangamati are slightly affected at times by the tides.

Although the gages at Thegamukh and Bara Harina will be important in matters regarding land acquisition in the upper end of the reservoir, and the gages from Kodala to Patenga are important to navigation, the gages that are fundamental to the hydrology of the project are those at Rangamati, Karnafuli Office Landing, and the powerhouse site at Chowdhury Chara. The Rangamati record provides the basis for the water supply studies and is the source of the unitgraphs used in the derivation of the design flood. The gage record at the Office Landing represents the water level into which the spillway will discharge and that at Chowdhury Chara represents the tailwater level at the powerhouse. Because the Rangamati gaging station will be flooded when the reservoir fills, and the spillway of the dam will be a gated structure, the river discharge in future years will have to be determined from the turbine operation and from the gages at the Office Landing and Chowdhury Chara. Since these two gages are in tidewater, the momentary spillway discharge will be computed from the stages at Chowdhury Chara and the Office Landing and the fall of the water surface between the two gages, the actual rating being developed from the channel cross section and current-meter measurements.

The station at Rangamati was established in 1935 and was operated almost continuously except for about one year 1942-43 when operation was suspended because of the war. The period of record was 1935-42 and 1943-54. During the period of record the frequency of reading has varied; in the latter years it was read regularly each hour from 6:00 A.M. to 6:00 P.M. Discharge measurements by floats and by current-meter had been made at both Rangamati and the dam site in previous years and additional measurements were made in 1954 by the Consulting Engineers, using both current-meter gagings and slope-area studies. Additional current-meter measurements at Karnafuli dam site late in 1954 were made by Karnafuli Project engineers at the request of the Consulting Engineers. However, the variable tidal effect upon both stage and discharge at the Office Landing was found to be great enough to prevent the precise rating of that station by ordinary methods. With the establishment of the gage at Chowdhury Chara in July, 1954 it became possible to determine the hourly variations of the hydraulic gradient in the 5-mile reach between the Office Landing and Chowdhury Chara. With these values, channel cross sections, and current-meter measurements, it will be a relatively simple matter to establish and maintain a discharge rating for the reach.

The stage-discharge relation used for the determination of daily discharge at Rangamati was based upon the various measurements described above and also upon slope-area determinations from the high-water marks of the floods of 1929 and 1946. The latter studies were by E. A. Moore, Superintending Engineer of East Bengal Circle, and are cited in his report[1] dated November 30, 1946.

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[1] Preliminary Report on the Karnafuli Flood Control, River Improvement and Power Schemes.

A discharge relation curve for tailwater levels at the powerhouse is shown in Exhibit 18. This curve was developed from current-meter measurements, stages at Chowdhury Chara, and the observed water surface gradients between the Office Landing and Chowdhury Chara. It corresponds to an "average" tidal condition, that is, to an imaginary state in which the tide is at mean stage but is neither rising nor falling.

9.04 EVAPORATION

In making the power studies it was necessary to compute estimated monthly evaporation from the mean data of temperature, humidity, and wind velocity given previously. It is considered that this procedure gives acceptable accuracy over a long period of time, but since it does not follow cyclic fluctuations of climate, it may deviate somewhat in extreme years. However, the effect of reservoir evaporation upon power potential is small and the deviations are considered of little importance.

The average monthly evaporation from free water surfaces was computed for Chittagong and Comilla by the Rohwer formula,[1]

$$E = C(1.465-0.0186B)\,(0.44 + 0.118W)\,(e_s-e_d)$$

in which E = the evaporation in inches per 24 hours.

C = a coefficient

B = the mean barometer reading in inches of mercury at 32° F

W = the mean velocity of the ground wind, or water surface wind in miles per hour

e_s = the mean vapor pressure of saturated vapor at the temperature of the water surface in inches of mercury

e_d = the mean vapor pressure of saturated air at the dew point in inches of mercury

In order to remain on the conservative side, the pan coefficient C was given the unusually high value of 0.80. The barometric pressure was assumed to be constant at 29.92 inches. The water temperature and air temperature were assumed to be identical. The average monthly values of reservoir evaporation as computed by the Rohwer formula and adopted for use in the operation study were as follows:

Jan	3.5 inches	July	4.5 inches
Feb	4.5 inches	Aug	4.0 inches
Mar	6.5 inches	Sept	4.0 inches
April	7.5 inches	Oct	3.0 inches
May	7.0 inches	Nov	3.0 inches
June	5.5 inches	Dec	2.5 inches

Year, total 55.5 inches

(1) Rohwer, C., Evaporation from Free Water Surfaces, U.S. Dept. Agr. Tech. Bull. 271, 1931.

9.05 DAILY RUNOFF

There is an excellent gaging record on the Karnafuli River at Rangamati, dating back to 1935. Rainfall records at Rangamati started in 1913. Because of the many uncertainties to be encountered in converting point rainfall into average rainfall over a basin of such large area and varied orographic conditions and of estimating the depth of basin retention to be applied to each rain event, the probable error of a runoff record derived from rainfall would be great. Since the existing record of gage height is reliable and the rating curve is well defined by various discharge measurements that show close agreement, no attempt was made to estimate the runoff of the Karnafuli previous to the establishment of the Rangamati gaging station in 1935.

A rating curve and table for the Rangamati gage were constructed from the data previously discussed in Section 9.03, and applied to the observed gage heights to obtain daily discharge for the entire period of record. The discharge hydrographs for Rangamati are shown in Exhibits 10 to 12 inclusive. The runoff at Rangamati was transferred to the dam site by increasing it 11 percent in proportion to the difference in catchment area. Because of the possibility of receiving heavy rainfall on an intervening tributary there may be inaccuracies in individual days but over a period of time these discrepancies will average out. With only 11 percent difference in watershed area, the method may be considered reasonably accurate for periods of one month or more. The computed average monthly runoff volume and discharge at the dam site, based on the record from June 1935 through April 1954 are as follows:

Month	Runoff Thousand Acre-Feet	Mean Discharge Cfs
Jan	84	1,310
Feb	63	1,120
Mar	70	1,130
April	127	2,130
May	585	9,880
June	1,780	29,900
July	2,350	37,300
Aug	3,170	51,500
Sept	2,610	44,000
Oct	1,350	21,600
Nov	331	5,370
Dec	184	2,990

9.06 FLOODS OF RECORD

As is inevitable in regions of heavy rainfall, Karnafuli River is subject to floods of varying magnitude. Although there is rain with occasional freshets during the non-monsoon season, such rises in flow are comparatively small and result in no damage. The large floods are confined to the monsoon season, June to October.

The only long record of streamflow near the dam site is that at Rangamati for which data were collected from 1935 to 1954, except that data for the monsoons of 1942 and 1954 are not available. This length of record, although adequate for determining average basin runoff, is not long enough for a valid frequency study of flood peak discharge. However, some idea of the frequencies of the smaller peaks can be gained from a tabulation of those that occurred during the period of record. The crests that equalled or exceeded 150,000 cfs at Rangamati are listed in descending order as follows:

		Peak Discharge in Cfs	
Order of Magnitude	Date of Peak	Rangamati	Dam Site (Rangamati plus 11%)
1	July 12, 1946	233,000	259,000
2	August 8, 1947	215,000	239,000
3	August 1, 1947	194,000	215,000
4	June 15, 1947	185,000	205,000
5	September 9, 1947	172,000	191,000
6	August 2, 1939	170,000	189,000
7	July 6, 1941	158,000	175,000
8	August 11, 1937	155,000	172,000
9	August 13, 1935	155,000	172,000
10	September 25, 1938	154,000	171,000
11	October 5, 6, 1951	153,000	170,000
12	August 25, 1954	153,000	170,000
13	July 19, 1941	150,000	166,000

All but the first four of the above lie within a range of 25,000 cfs. It should be noted that not all of the events tabulated are strictly independent; the same unstable air mass may have produced more than one of the storms and in certain cases the residual flow from one event has contributed materially to the peak flow of another.

The volumes and average flows of the four events of record that exceed 175,000 cfs are as follows:

Date of Period	Rangamati Volume Acre-Feet	Rangamati Average Flow Cfs	Dam Site Volume Acre-Feet	Dam Site Average Flow Cfs
1946, July 8-20	3,439,200	132,280	3,817,500	146,800
1947, June 12-21	2,266,600	113,330	2,515,900	125,800
1947, July 29-August 18*	5,543,200	131,980	6,154,000	144,000

* This period contains two peaks.

The above volumes include the flow for all days between the minimal preceding and following the flood. Data for the dam site were derived by adding 11 percent to values for Rangamati.

Additional discussion of the floods of 1929, July 1946, and August 1947 with respect to flood damage and flood routing appears in Chapter X.

9.07 FLOOD POTENTIAL OF THE BASIN

It is desirable, as a preliminary approach, to review some of the more common methods of estimating flood potential.

In a region where there are not sufficient records of extreme floods, maximum expected discharge is often computed by empirical methods. One of the best known and most satisfactory of these is Creager's formula:

$$Q = 46\ CA^{(0.894A^{-0.048})}$$

in which A is the drainage area in square miles and C is a constant usually taken as 100 for regions of relatively great flood potential. For the 4,200 square miles above the Karnafuli dam site, with C equal to 100, the Creager formula gives a maximum peak discharge of 679,000 cfs.

Creager's formula was developed from envelope curves of peak discharge, using data collected from many different parts of the earth. When plotted on log-log paper, the slope and curvature are almost identical with those of the formula proposed in the Karnafuli Project Report by Mr. Khaja Azeemuddin,

$$Q = 2100A^{0.92-0.071 \log A}$$

86

Although envelope curves established for different climatic zones and provinces show similar form and curvature, they differ materially in slope. In the lower range of the curve, the slope depends largely upon the intensity-area characteristics of local convective storms. In the higher range the slope is more effected by the total areal extent of the heavier storms and their effectiveness in producing runoff from a large part of the basin at nearly the same time. The shape and topography of a drainage basin are necessarily disregarded in an envelope curve study, although the applicability of the curve may be greatly affected by these elements. Therefore, although Creager's formula has been found generally applicable to average basin conditions, it would be imprudent to accept it for the somewhat unusual conditions of Karnifuli Basin without corroboration.

A valid envelope curve of flood peaks in East Pakistan would have to be based on data of the maximum floods from various drainage areas in Bengal, Assam, and Burma, experienced during a period of many years. The excellent 18-year record of the daily discharge of the Karnafuli does not include any floods rare enough for such a purpose. Although there are data of extreme floods under somewhat similar conditions in India, Australia, Hawaii, the Philippines and the Gulf Coast of the United States, the combination of topography, exposure, shape of basin and storm types of the Karnafuli is not duplicated. Evidence that an envelope curve should not be applied to Karnafuli River was produced in connection with the unitgraph analysis (Section 9.10) when a peculiarity of the runoff behavior of the Karnafuli was discovered. During high stages, the flood flow from each day's rainfall runs off in two distinct parts, the principal peak of unit flow being followed, a few days later, by a secondary peak or shoulder. When these unit flows from successive days of rain are combined in the river, the crest of the entire flood is flattened by this splitting of the unit peaks and the maximum discharge is materially reduced. An extreme flood in Karnafuli River at Rangamati therefore does not attain the peak rates that might occur in other watersheds of similar area and potential volume of runoff, and the inflow design flood for Karnafuli should be derived on the basis of expected rainfall, retention and concentration of unit flows.

9.08 STORMS AND STORM TRANSPOSITION

Storms of a number of different types pass over the watershed of the Karnafuli River. First there are thunderstorms associated with surface northwesterly squalls in which wind speed may equal a gale force. However, the quantity of precipitation from these storms is not great since they occur in the non-monsoon season.

During the monsoon, June to October, rainstorms move in a northerly direction in accordance with the general seasonal movement of the atmosphere. These rainstorms vary greatly in magnitude and intensity, yet a single storm does not appear to be of sufficient extent to cover the entire

watershed. Rather there appear to be rainy periods, perhaps of two to four days, during which many of these individual storms pass over the basin, each precipitating on a portion of the area. The number, frequency and intensity of the storms determine the resulting runoff.

The watershed is also subject to typhoons, the well-known rotating tropical storm. Unfortunately the available meteorological data are not adequate to isolate and study these storms. It is probable that the intense precipitation required to produce the highest floods of record is the result of such storms. There are certain indications, such as on-shore winds, high tides, as well as heavy precipitation, that suggest that typhoons or storms of near typhoon intensity may have caused or accompanied the storms that caused the high flood of 1946.

The foregoing situation illustrates why storm transposition is not practicable on the Karnafuli River watershed. Excepting possibly typhoons, the rain comes in storms that cover only a part of the basin, there being no storms (other than typhoons) comparable to the wide-spread extratropical storms experienced in more northerly latitudes. Moreover the region is unique, meteorologically speaking, and relatively small. There is little possibility of finding an area with similar conditions and storms that could be transposed because difference in topography, inflow of moisture-bearing winds, etc., preclude storm transposition as it is known in the United States. Furthermore, the fragmentary meteorological records now available and the lack of sufficient recording rain gages prevent any such study.

Instead of storm transposition a study was made of the storms that produced past floods. Eight past floods were studied for the development of the unitgraphs and, for each, the rainfall was analyzed as far as the data permitted to determine the mean distribution over the watershed and the sequence of daily intensity. The average weighted rainfall received for the four floods previously mentioned is as shown below:

June 1946	22.2 inches in 4 days
June 1947	13.8 inches in 4 days
July-August 1947	13.3 inches in 3 days
August 1947	11.63 inches in 4 days

The average proportion of the storm rainfall received each day of the events analyzed was found to be as follows:

First day	38.7 percent
Second day	29.3 percent
Third day	20.7 percent
Fourth day	11.3 percent

9.09 DESIGN RAINSTORM

Since records from the Karnafuli River watershed could not suffice for an estimate of the maximum probable rainfall, recourse was necessarily made to world records of maximum rainfall that were published in the Monthly Weather Review. Data of rainfalls were plotted for depth-accumulation curves for Cherrapunji, in Assam, India; Baguio, Philippine Islands; Funkiko, Formosa; and Silver Hill, Jamaica. Available information indicates that these stations are located at some relatively comparable elevation and are subject to the same air masses and storms as may be expected at the eastern edge of the Karnafuli watershed at an elevation of some 4,000 feet. From the uppermost of those graphs, which was determined by data from Baguio rainfall, a depth of 88 inches for a four-day storm was obtained. Since these data were of observed rainfall, it was considered necessary to add an allowance of 10 percent to be certain of a maximum probable rainfall. The total rainfall was therefore taken as 97 inches for a four-day storm which was accepted as the point rainfall at the eastern edge of the watershed. Then, since not all of the watershed is subject to the same orographic effect, this depth was reduced for other stations than Lungleh and the mean depth computed by means of Thiessen weights; the mean depth in round numbers is 59 inches. This four-day depth was converted into a daily sequence for computing the design flood, by applying the average daily ratios for Karnafuli Basin, given in Section 9.08. The design rainfall sequence is as follows:

First day	23 inches
Second day	17 inches
Third day	12 inches
Fourth day	7 inches
Total	59 inches

9.10 OBSERVED UNITGRAPHS

In selecting periods of record for the determination of unitgraphs, the five highest events were chosen for analysis as being most likely to represent the runoff behavior of the Karnafuli under flood conditions. In addition, three smaller events were analyzed to provide a comparison of behavior at lower stages. The events of the latter group were chosen largely on the basis of the probable ease and accuracy with which the direct runoff from a single storm could be isolated, but considering also the range of peak flow and flood volume that they represented. The events selected for analysis were as follows:

Date of Peak	Peak Discharge at Rangamati, Cfs
July 12, 1946	233,000
August 8, 1947	215,000
August 1, 1947	194,000
June 15, 1947	185,000
September 9, 1947	172,000
August 2, 1945	137,000
July 9, 1947	132,000
September 30, 1949	88,400

It was found by inspection that the lag between the occurrence of a small increment of excess rain and the passage of half of the runoff produced thereby would be about three to five days. Twenty-four hours would be roughly one quarter of the lag time and therefore a short enough period for "unit duration", that is, each day's increment of generated runoff could be treated as a unit and any fluctuations of the momentary rainfall intensity during that time would not materially affect the shape of the resulting hydrograph.

The first step in the direct analysis was to plot hydrographs of daily discharge on semilogarithmic calendar paper for several typical years of record and to determine the coefficient of normal daily recession of ground-water flow. This was found to be 0.97. Hydrographs including the eight high-flood events were then similarly plotted and trial hydrographs of ground-water flow constructed on the same sheets. Daily values of net, or direct, runoff were plotted on semilogarithmic paper using a more expanded time scale. The ground-water hydrograph was then adjusted and the new trial values of direct runoff were plotted until plausible and consistent hydrographs of direct runoff and corresponding ground-water runoff were obtained. The coefficient of normal daily recession of direct runoff (the interflow phase) was found to be 0.69.

The hydrographs of direct runoff of the eight selected flood events were rounded in shape and appeared to result from excess rain of three to four days duration, this assumption being supported by such rainfall records as were available. The hydrographs were so highly compounded that trial one-day unitgraphs could not be isolated from them by inspection, the excess rainfall having been, in effect, continuous for each storm period. It was therefore necessary to use the method of progressive addition[1]. This procedure is tedious but can be made extremely precise because the exact reproduction of the flood hydrograph is inherent in the process of separation and because the first and last unitgraphs from each sequence are developed independently and compared directly. It is customary to make repeated adjustments during a trial run in order to reduce the num-

[1] Unitgraph Procedures, U.S. Bureau of Reclamation, November 1952.

ber of runs required. In the present study, however, no adjustments of any kind were allowed. This rule was adopted because the shape of the unitgraphs was so unusual that they could not be accepted without rigorous proof. For each combination of a flood event and an excess rainfall sequence, a full run in each direction was made. The graphs from the complete forward and reversed runs were superimposed and if they were not in reasonable agreement, a new rainfall sequence was set up and the process repeated.

The significance of superimposing the graphs of the two runs lies in the fact that any given part of the unitgraph is defined, in the forward run, by one part of the flood hydrograph, while in the reversed run it is defined by a different part. Consequently if the behavior of the runoff from any day's rain of the sequence is definitely abnormal because of a spotty distribution of rainfall in the basin, or if there is a material error in either the basic record or the ground-water separation, the two graphs cannot be brought into coincidence. This was the case in two (July 1947 and September 1947) of the eight events used in the present study and those unitgraphs were discarded. Satisfactory agreement of the runs was obtained in the other six events which are shown with their unitgraphs in Exhibit 13. It should be noted that in this stage of processing, neither the ordinates of the unitgraph nor the assumed daily increments of excess rain are in standard units, the values actually being ratios. They could have been kept in inches and cfs by adjusting the daily rainfall increments of each trial so that the sum of the sequence would equal the observed runoff. This was tried and abandoned because of the extreme difficulty of estimating a new trial sequence by inspection of previous trials in which all of the increments had been altered simultaneously. Any established sequence and graph, however, can readily be converted into standard units.

For each of the six derived unitgraphs, the lag was computed in hours from the start of unit excess rain to the hour when half of the volume had been discharged. These values are included with other pertinent data for all of the eight events originally studied, in the following table, and arranged in descending order of maximum direct discharge:

Date of Peak	Maximum Storm Discharge, Cfs	Total Direct Runoff, Inches	Lag Hours
July 12, 1946	226,500	17.2	103
June 15, 1947	181,100	11.7	86
Aug 1, 1947	175,600	10.5	86
Aug 8, 1947	160,200	11.0	84
Sept 9, 1947	154,700	8.0	*
July 9, 1947	126,900	9.2	*
Aug 2, 1945	115,500	6.4	62
Sept 30, 1949	74,000	3.4	47

* Unitgraphs from these events could not be determined accurately.

91

Two highly significant characteristics of Karnafuli River came to light in the course of the unitgraph analysis. The first is the great variation of the lag time with increases in the peak stage, from 47 hours for an event with a peak discharge of 74,000 cfs to 103 hours for an event with a peak of 226,500 cfs (the values are plotted in Exhibit 14). This phenomenon is quite common in much larger watersheds, but in most basins small enough for the application of the unitgraph method, the basin lag is considered to have a constant value for all floods.

The second peculiarity is in the characteristic shape of the unitgraphs, mentioned briefly in Section 9.07. With the single exception of the event of September 1949, which is a much smaller event than the other seven, all of them gave quite definite evidence that the unit excess rain runs off in two distinct parts, the flow from one portion of the basin being delayed until after the crest from the other portion has passed the gage. The same phenomenon is present but not prominent in the 1949 event, which is shown in the upper right-hand block of Exhibit 13. This event resulted either from a storm of unusual pattern, so that the second part of the runoff failed to concentrate, or else the timing of the runoff was affected by the relatively low river stage and the absence of over-bank flows. The 1945 event, with a runoff volume of only 6.4 inches, produced a unitgraph that is similar in a number of respects to that of 1949.

9.11 DESIGN UNITGRAPH

The six accepted unitgraphs were converted into dimensionless form to eliminate the effects of individual lag and volume so that a direct comparison could be made. In this process, the volume of the unitgraph in cfs-days is determined from the ordinates, assumed for this purpose to be in cfs units, and the coefficient of interflow recession. The ratio of lag to volume is applied as a factor to each ordinate to determine the corresponding dimensionless ordinate. The abscissae are expressed in percent of the lag. The six dimensionless graphs are shown in Exhibit 15. It is at once apparent that they form two distinct patterns, the unitgraphs from the highest two events (Figure C) being materially higher and steeper than those from the other four. The unitgraphs from the smallest two events are shown in Figure A and those from the next two are in Figure B. There is a slight difference in pattern between those two groups, but it is no greater than the individual variations within the groups. The average dimensionless unitgraph of each of the three pairs has been plotted in Figure D. The average of the graphs from the two highest events will produce the more critical flood crest and it has been adopted for the derivation of the inflow design flood.

In order to evaluate the adopted dimensionless unitgraph for application at the dam site, values of the volume and lag must be supplied. The volume will be that of one inch of generated runoff from the basin area of 4,250 square miles, or 114,000 cfs-days. Since it has already been found

92

that the lag varies with the intensity of the flood, a relationship must be established that can be applied to the design flood. It may safely be assumed that the lag depends upon the average levels in the tributary channels during the main period of concentration and that these are closely related to the volume of runoff generated during the storm. The total rainfall of the design sequence (Section 9.09) is 59 inches, and the average retention rate of the observed events that were analyzed in the unitgraph study was 1.0 inch per day. With the application of this retention rate to the four-day design sequence, the total excess rain becomes 55 inches. The relation curve of lag at Rangamati and excess rain based on the observed events is shown in Exhibit 14, the lag for the design flood being determined as 151 hours from the start of the unit increment of excess rain to the passage of one-half the volume of runoff generated by it.

The lag at the dam site will, of course, be longer than that at Rangamati, but with the reservoir filled, the difference will be largely offset by the increased hydraulic efficiency within the pool. Accordingly, a lag of 151 hours and a runoff volume of 114,000 cfs-days were used to evaluate the average of the dimensionless unitgraphs from the two events having the greatest maximum storm discharge (July 12, 1946 and June 15, 1947). The resulting unitgraph is shown in Figure E of Exhibit 15. Daily mean values were picked from this unitgraph. The total volume was then computed and found to be three percent too small, this error having resulted mainly from the smoothing of the two basic unitgraphs and the averaging of the two dimensionless graphs. The daily unitgraph ordinates were adjusted proportionally to a total volume of 114,000 cfs-days (including the ultimate volume under the recession limb as computed from the coefficient of interflow recession, 0.69), resulting in the following values:

Day	Thousand Cfs Per inch of Runoff	Day	Thousand Cfs Per Inch of Runoff
1	1.3	10	7.7
2	3.6	11	7.6
3	6.6	12	6.9
4	10.6	13	5.3
5	12.9	14	3.4
6	12.8	15*	2.5
7	10.8	16	1.8
8	8.7	17	1.2
9	7.8	18	.8

* The recession is exponential beyond this point.

9.12 INFLOW DESIGN FLOOD

The design sequence of rainfall excess was determined from the rainfall sequence of Section 9.10 by subtracting the average observed retention of one inch per day. The daily rainfall excess is as follows:

First day	22 inches
Second day	16 inches
Third day	11 inches
Fourth day	6 inches
Total	55 inches

The daily unitgraph ordinates of Section 9.11 were applied to the above values and the increments added to obtain the mean daily values of direct discharge. An assumed discharge of 10,000 cfs from ground water flow was combined with the direct discharge to give the mean daily discharge of the maximum probable flood. The hydrograph of the latter is shown in Exhibit 16, and is adopted as the inflow design flood.

9.13 REQUIRED SPILLWAY CAPACITY

In order to determine the spillway capacity required to pass the design flood, a reservoir routing detailed in Sections 10.04 and 10.05 was performed. The hydrograph of routed outflow is shown in Exhibit 16, the maximum discharge being 523,000 cfs. The effective capacity of the spillway therefore should be no smaller than that value.

9.14 CONSTRUCTION FLOOD

Floods to be anticipated during construction can be estimated from the records of Rangamati gaging station, adjusted to the larger drainage area above the dam site. There are the two seasons to be considered; the dry season, November to May inclusive, and the monsoon season, June to October inclusive, during which time the large floods may be expected. In 18 years of hydrographs for the Rangamati station plotted in Exhibits 10 to 12 all but two years show floods exceeding 100,000 cfs. In six years there were floods exceeding 150,000 cfs, and in two years, floods greater then 200,000 cfs. It appears from this that a construction flood at Karnafuli dam site during the monsoon should be in the range of 150,000 to 200,000 cfs; that is the diversion works required to function during the monsoon should be capable of passing that flow.

Unseasonally high runoff sometimes occurs during the non-monsoon months and provision must be made for such occurrences. The most critical of record is the event of November and December 1938 which had a peak discharge of 42,200 cfs.

9.15 SILTATION

The appearance of the streamflow shows that a material amount of silt is carried by the Karnafuli. The importance of silt movement is indicated by the changes that occur in the channel, especially below the mouth of Halda River and in the navigable channel below Chittagong. Nevertheless, the silt load in the Karnafuli River is not excessive. The catchment area is well forested so that erosion is limited. The principal source of silt is said to be erosion from areas in the Hills that are cleared and burned over in preparation for one-season cultivation by the Hill tribes. This practice is known as "jhuming". The proportion of the watershed subjected to these clearing operations is very small, probably on the order of 1.0 percent of the total area. Not only is the vegetation on the watershed dense but due to the moist warm climate, recovery on the cleared areas is rapid; hence, even though erosion may be high from the cleared plots for a season, the total silt from that source cannot become excessive.

Data have been obtained with silt samplers at Chilardak and Barkal during the period September to November 1948 and provide a basis for estimating the silt load and life of the reservoir. The data of silt concentrations taken at Chilardak were plotted against the discharge at Rangamati. Chilardak is located a relatively short distance upstream from Rangamati and, although there is a large tributary entering between the two stations, both are located on the flatter portion of the watershed. It is considered therefore that the concentration of silt at Chilardak would not vary significantly from that at Rangamati. The resulting silt-rating curve was considered to be as accurate as can ordinarily be expected for such curves. It was recognized that the silt concentration in the river during the first freshets of the monsoon season would be somewhat greater than during the months when the actual silt sampling at Chilardak was performed and also that there is a moving bed load of which the sampling took no account. To allow for these two items the weights of suspended load indicated by the silt-rating curve were increased 25 percent to obtain the equivalent total weight of sediment. The dry weight of the deposited sediment was assumed to be 60 pounds per cubic foot.

The daily inflow into the reservoir was estimated by adding 11 percent to the daily discharge at Rangamati for the entire period of streamflow record. The daily sediment load deposited in the reservoir was determined from the daily inflow in the manner described above. The average annual deposit was found to be 24 million tons or 19,000 acre-feet. At that rate, 300 years would be required to fill the reservoir completely.

The practice of jhuming is now forbidden by law and it is expected that it will be vigorously suppressed. In any event the practice will not be continued on the steep river banks, as in the past. For this reason, the annual sediment load as estimated in this report is probably much greater than will actually occur in future years and the life of the reservoir should be correspondingly longer.

9.16 HYDROLOGIC NETWORK FOR PROJECT OPERATION

In order to operate the Karnafuli Project efficiently it is necessary that there be installed a network of observation stations on and adjacent to the watershed above the project. This network should include meteorologic, hydrometric and silt observation stations. The meteorologic and hydrometric stations are obviously needed to determine the rainfall received, together with other meteorologic data, and to determine the inflow of water to the reservoir as nearly as feasible and the effect of streamflow regulation below the project. Because of the great volume of flood flow as compared with available storage capacity the operation of the reservoir during the monsoon must depend in part upon foreknowledge of expected inflow. The preservation of the dam in extreme floods may be dependent upon adequate flood warning. The stations for observation of silt are needed to determine and observe the deposition of silt on the principal tributaries and the mainstem entering from India. Observations near Bara Harina are important in connection with reservoir land acquisitions.

Arrangements can no doubt be made to receive precipitation reports from stations in India. The immediate operational forecasts of inflow will be based on these reports as well as the reports of the river discharge at the boundary station, increments of precipitation at the dam site and about five other points in the drainage area between the boundary and the dam site, and antecedent soil moisture conditions in the basin. For more advanced warnings, reports of temperature, humidity, barometric pressure, and the speed and direction of winds can be used to determine the location, extent and potential of atmospheric disturbances in and near the basin. In times of flood danger, observers should report by radio at frequent intervals unless automatic radio gages are used. In addition to the reporting network, a number of non-reporting rainfall stations should be established, to provide a more dense pattern for use in developing and checking the forecast procedures, and for better estimates of antecedent soil moisture conditions.

In order to maintain complete records of inflow, outflow and losses, it would be necessary to measure streamflow at stations near the Indian boundary, below the dam and on all of the major tributaries between those points. Since the station below the dam will be in tidewater and all of the others, if readily accessible, would likely be affected by variable backwater from the reservoir, a slope range with two gages and observers would presumably be required at each station. In view of the costs of installation and maintenance and the office and field work required to develop and maintain the ratings and process the daily records, it appears more practical to establish only the two primary gaging stations, one near the boundary and one below the dam, and to insure accurate and continuous records from them by maintaining a systematic program of gagings, inspections and periodic checking of levels and cross sections. A staff gage in the reservoir at the dam is needed for determining the reservoir level and one at the powerhouse for tailwater level. The latter gage could probably be used

also for the lower of the two gages of the slope range. In this case, the turbines would have to be rated for discharge and the discharge of the tailrace would be computed from powerhouse records.

In addition to a rain gage (preferably an automatic recorder) at the powerhouse, at least five radio reporting rainfall stations should be installed. The sites will have to be selected on the basis of areal pattern, accessibility for periodic inspection and reliable radio transmission. A good pattern would be Thegamukh, Myanimukh, Panchari Bazar, a point about 20 miles northeast of Dighinala, and a point about 20 miles southeast of Kaptai. At least five more rain gages (non-reporting stations with daily observations) should be maintained to increase the density of the network for the hydrologic studies needed to develop the forecasting procedure.

Data of temperature, humidity, barometric pressure, wind speed and wind direction should be obtained at the dam or powerhouse and by phone or radio from Chittagong if possible. If similar data can be obtained from some of the radio reporting network stations, such as the boundary station, it will prove a great help in the preparation of advanced forecasts. It is possible that an exchange of such meteorological information with Indian agencies could be arranged, with benefit to both countries.

Since it appears impracticable to make direct measurements of reservoir inflow, evaporation studies will not benefit the project directly except as they may be used to help estimate antecedent moisture conditions for operational forecasts. However, because of the almost complete lack of such data in Asia, an evaporation station should be maintained at the dam for the sake of the future value of the records to the people of Pakistan and neighboring countries.

Silt observation stations are recommended for the following localities:

Thegamukh (mouth of Thega Creek)

Kodala

Mahalchari on Chingri Creek

Tintilla on Kassalong Creek

Tinkonia on Rankhiang Creek

Dighinala on Myani Creek

The suspended silt should be sampled at all the above stations. If no regular discharge records are being obtained, a rough determination of discharge should be made by floats or otherwise, at the time of each sampling. In addition, at all stations except Kodala, silt ranges should be

laid out. These ranges would be simply lines surveyed across the valley at intervals of 2 or 3 miles, the uppermost being at or above the point of first deposition in the reservoir. Depths of sediment can be measured once a year. The station at Thegamukh again is important because of international complications.

The installation of hydroclimatic equipment should be assigned priorities according to the following schedule:

1. The permanent gaging stations at the boundary and below the dam should be established immediately and current-meter gagings to establish their discharge ratings should be commenced

2. The precipitation stations (probably five) of the radio reporting network should be given the next order of priority so that they can be used for warnings during the construction period; that enough records will have been obtained before the dam is finished to establish the relation of runoff to current rainfall and antecedent moisture; and that the procedure and schedule of transmission can be tested out in actual practice and modified as found desirable

3. The non-reporting precipitation stations should be established and the records started, as an aid to the determination of precipitation-discharge relationships

4. Any temperature, humidity and wind equipment that is to be operated at the field stations should be installed and the records started

5. The remaining hydroclimatic equipment that is to be operated at the dam and powerhouse, including evaporation pan and barometer, can be installed as soon as the permanent sites are available

6. The silt ranges should be surveyed before the reservoir fills.

CHAPTER X

FLOODS AND FLOOD CONTROL

10.01 GENERAL FLOOD SITUATION

Floods occur on the Karnafuli River only during the monsoon season, June to September inclusive. Although there are appreciable rains outside of these months, the runoff is not great enough to exceed the capacity of the channel.

Floods in Karnafuli River continue at high stage for several days. They are likely to occur during the period of spring high tides. Strong on-shore winds of typhoon type accompanying certain rainstorms may also tend to raise the tidal level, aggravating the flood condition. However, the major cause of severe flooding in the lower basin is the fact that the local flood flow from the relatively sluggish Halda River system usually does not reach its maximum rate at the river junction until the crest of the Karnafuli has arrived downstream to combine with it. Flood-control storage in Karnafuli Reservoir will therefore have a two-fold effect. It will not only reduce the maximum discharge rate of the main river but it will also delay the crest three to four days, while the peak flow from Halda River moves on to the ocean.

10.02 FLOODS OF RECORD

Historically, there are three known floods that have caused extensive damage; these occurred in June 1929, July 1946, and August 1947. Information on these floods had previously been assembled from all available data by Mr. E. A. Moore and appears in his report. Liberal use has been made of Mr. Moore's flood information in this chapter.

The magnitudes of the above mentioned three high floods were as follows, based on stages recorded at station Rangamati:

		Discharge in Cfs		
Year	Stage, Ft P.W.D.[1] Datum	Moore's Report	MRVP[2] Report	Consulting Engineers
1929	62.3	283,000	Not given	260,000
1946	59.8	245,000	213,000	234,000
1947	57.1	Not given	203,000	215,000

[1] Public Works Department

[2] Mertz Rendel Vatten, Pakistan - Consulting Engineers

The flood of June 1929 was considered to be the highest known flood for the period considered. It has not been exceeded since then. It was determined that the stage was approximately 2.5 feet higher at Rangamati than the high flood of July 1946. The second highest known flood is that of July 1946. This flood was apparently synchronized with high tides at the mouth of the Karnafuli River and heavy local rainfall on the tributary, Halda, which was in flood also. The area flooded is shown approximately in Exhibit 7. Similarly the flood of August 1947, the third highest known, was also reported to have been synchronized with strong on-shore winds, high tides, extensive inundation of the coast, and local floods on the Halda River. These flooded areas are also shown in Exhibit 7. Not all the area shown inundated in 1947 can be considered as flooded by the Karnafuli River, since it is not probable that the river water would submerge the shore lands as outlined. Just where the dividing line should be is difficult to determine but cognizance is taken of the situation in estimating the damages.

No other floods than those mentioned are recorded as having caused damage, although undoubtedly there were smaller floods that caused lesser damage. Hydrographs discussed in Chapter IX and presented in Exhibits 10 to 12 show eight years with floods below 140,000 cfs at Rangamati; two years between 140,000 and 150,000 cfs; five years between 150,000 and 160,000 cfs; one year between 160,000 and 200,000 cfs and two years above 200,000 cfs (not including that of 1929).

The discharge rate of 160,000 cfs at Rangamati or the uncontrolled rate of 175,000 cfs at the dam site represents the most probable annual flood peak; therefore it can safely be assumed that the normal river profile corresponding to this flow will not cause flood damage. Whenever possible, however, it will be desirable to hold the maximum reservoir release to a rate not more than the probable annual flood at the dam site (175,000 cfs) because it will be augmented downstream by uncontrolled inflow from the Halda River and a few minor tributaries.

10.03 EVALUATION OF FLOOD DAMAGES

Within 24 years there have occurred three floods known to be of a magnitude that would cause serious damage; those of 1929, 1946, and 1947. This is equivalent to one serious flood in 8 years.

A damage survey was made immediately following the flood of July 1946 by Mr. E. A. Moore. Regarding this flood his report states, "The total damage done to crops, homesteads, and personal belongings . . . within the inundated area . . . has been reported after a careful investigation. These figures were carefully compiled from reliable statistics supplied by the Civil Authorities and from detailed examination of the area immediately after the flood had passed".

The value of the damages given are as follows:

Aus Paddy (autumn rice)	$ 303,000
Pan baras (fences)	46,000
Fish	76,000
Homestead buildings	372,000
Household belongings and supplies	515,000
Total	$1,312,000

An area of 92 square miles suffered particularly heavy damage, being inundated from 2 to 15 feet. The Commissioner of Relief, Bengal, reported that 465 square miles were affected of which 325 square miles were paddy lands. The same source reported that 90 percent of the aus crop was calculated to have been lost, which was equivalent to 560,000 maunds (23,000 tons) of rice. At the present market price of $4.848 per maund this would be approximately $2,700,000 which sum does not include damage to paddy lands.

For proper evaluation of the foregoing damages, it must be borne in mind that high tide and local rains on the lower tributaries were in part responsible for the flooding on the lower reaches. However, inspection of the flooded area for 1946, Exhibit 7, indicates that the inundation could have been caused by the Karnafuli River. As stated previously, any large flood would meet ordinary high tide and may be combined with unusual spring tides or typhoons. The damage ascribed to the 1946 flood does not appear excessive. On the other hand, an estimate of $6,000,000 damage caused in 1947 has not been included because it probably includes damage sustained along the coast and other losses which cannot be ascribed to the upper reaches of the Karnafuli River. Offsetting this aspect is the likelihood of other smaller floods (other than the three highest) that would cause lesser amounts of damage.

The data available are not suitable for the construction of a stage-damage curve. Consequently, it is not possible to determine the average annual damage by probability methods. However, an answer can be obtained by averaging the three highest floods, 1929, 1946, and 1947, over the period 1929 to 1953. These three floods reached stages within a few feet of each other and may reasonably be assumed to have caused a similar amount of damage. On this assumption the total damage given above, $1,312,000, may

be ascribed to each of the three large floods. Although no damage surveys have been made for lesser floods, it may be assumed that peak discharges as small as 180,000 cfs at Rangamati would cause damage and if the high stage lasted several days, the damage might be serious. A rough indication of the loss resulting from major floods alone may be obtained from the occurrence of $1,312,000 of damage three times in twenty-four years, representing an average loss of $164,000 per year during that period.

10.04 SPILLWAY DESIGN AND OPERATION

The spillway design provides for the passing of an outflow of 525,000 cfs over a spillway located on the left bank of the dam and discharging through a channel into the river some distance below the dam. Because of certain headwater limitations the Project Circle proposed to maintain the normal maximum pool level at El 108 and the maximum flood-control level at El 119. It is undesirable to maintain pool levels higher than 108 feet. During floods, however, the reservoir can properly occupy such channels as would normally be filled at flood times if the Karnafuli Project did not exist. This situation permits flood storage to El 119. It is considered necessary, however, to discharge this storage as soon as conditions downstream from the project permit. These requirements of elevation fix the storage available for flood control but are adequate for containing the Inflow Design Flood provided the principles of reservoir operation given in the next section are followed.

10.05 GENERAL RESERVOIR OPERATIONS

In order to gain the maximum utility from the Project for power and flood control it is necessary that certain general principles of operation be established and observed. Since power is the principal source of benefits the operation should first obtain the maximum energy with smallest possible handicaps imposed by other sources of benefit. To this end the reservoir will be drawn down during the dry season for energy production and will be refilled as soon as practicable after the beginning of the monsoon season and should in all cases be full to El 108 by October 1 of each year. These requirements mean that the reservoir will probably be full at the beginning of any flood except at the start of the monsoon season. Therefore all flood routing was assumed to begin with the reservoir at El 108. The operations for flood control are determined to a large extent by the need for handling the inflow design flood, but consideration has also been given to reducing the smaller freshets as much as practicable. The general operating procedures were assumed to be as follows:

1. The existence of a meteorologic and hydrometric network sufficient to give advance notice of unusual rainfall and runoff

2. Reservoir level at El 108

3. Although 16 gates are provided, only 15 are assumed for routing purposes

4. Hold the reservoir level to El 108 by releasing water until the outflow reaches 130,000 cfs. At this discharge the top of the gates will be at El 117.6 with 15 gates open or El 117.1 with 16 open

5. When the gates reach the above elevation, allow reservoir level to rise

6. Open gates fully as need is indicated by information from meteorologic and hydrometric network

The inflow design flood was routed through the reservoir in accordance with the above principles and the result is shown in Exhibit 16. The maximum outflow was 523,000 cfs and maximum level of reservoir El 118.9, both of which are satisfactory.

10.06 OPERATIONS OF OBSERVED FLOODS

Four observed flood peaks exceeding 200,000 cfs (See Section 9.06) were also routed through the reservoir in accordance with the above principles, with the following reductions in flow:

Date	Flow at Kaptai, Cfs		Reduction	
	Natural	Routed	Cfs	Percent
1946, July 8-20	258,000	147,000	111,000	43
1947, June 12-21	205,000	138,000	67,000	33
1947, July 29-August 18*	238,000	158,000	80,000	34

*This period contains two peaks.

Hydrographs of these floods and routed outflows are shown in Exhibit 17.

10.07 ASSESSMENT FOR FLOOD CONTROL

Because of the complexity of establishing actual financial losses to the property owners during prior floods, it has not been considered advisable to secure a return to the project for flood control benefits by means of assessment on property benefited.

10.08 COSTS AND BENEFITS

The project will not eliminate all future flood damage but will greatly reduce it. It is expected that all known floods of record will be reduced to outflow discharge not exceeding 160,000 cfs, which precludes damage from Karnafuli floods of record that originated above the dam. The average annual damage from known floods is $164,000, which is also the annual benefit from flood control.

Essentially the same project design would be required for any multiple-purpose project with power generation and essentially the same rules of operation of the reservoir would be required since such rules are dictated by considerations of the inflow design flood. Therefore no special costs are incurred to secure the flood-control benefits and accordingly no revenue is anticipated from flood control.

CHAPTER XI

NAVIGATION

11.01 IMPORTANCE OF WATERWAYS

The river and its tributaries are almost the sole arteries of travel in Karnafuli Basin, the only land route being a rough jeep road between Chittagong and Rangamati. Because of the hilly terrain and dense pattern of watercourses, the construction of even a sparse network of market roads would be extremely costly. At full-pool stage, Karnafuli Reservoir will provide nearly 400 miles of navigable, slack-water channels in an area that is now practically inaccessible. The improvement of the extent and efficiency of the navigable waters will result in a public benefit comparable to that from an elaborate program of road construction in a less humid country. At the same time, the increased efficiency of the Port of Chittagong and its channel to the sea will be of direct benefit to the foreign commerce of the nation.

11.02 PRESENT RIVER TRANSPORTATION

The flow of Karnafuli River at the dam site varies from less than 300 cfs during part of the dry season to more than 100,000 cfs during the monsoons, the greatest recorded flow being nearly 300,000 cfs. Sand bars in the river impede navigation during the dry season and at high water the swift current and floating debris make river transport hazardous.

A considerable part of the present traffic on Karnafuli River consists of sampans and "country boats". The latter are long craft similar to dugout canoes. They are reinforced by ribs and usually have a third or more of their length covered by matting to shelter the crew. The larger country boats can carry twenty or more persons, or up to one ton of gross load. Sampans and country boats are used to transport passengers and small freight, the latter including local produce such as fruits, vegetables, pottery, firewood, thatch grass, and many other items. These boats have a shallow draft and are able to navigate some of the tributary streams, as well as the main river below Rangamati and with difficulty up to Barkal Rapids.

There are 15 public motor launches carrying passengers on Karnafuli River. They can carry from 25 to 50 persons and draw from three to five feet of water. There are also a number of government launches of similar capacity. During the low-water period November to May, launches are often unable to navigate farther upstream than a point about five miles below Rangamati. Between the dam site and Chittagong, launches of three-foot

draft can usually operate during low water, provided they cross the sand bars at high tide. Launches of greater draft are quite likely to run aground.

Heavy freight is carried on flat barges of 50 tons or more capacity. The barges are moved by towboats and draw up to five feet when fully loaded. During low water it is necessary to reduce the loads to provide clearance over the sand bars. Many of the barges carry only half capacity during these periods. The cargoes include cotton, jute, lumber, fuel oil, household supplies, sulfite for paper manufacture and paper. The latter is the produce of the Chandraghona Paper Mill about 9 miles below the project site. It is desirable to make shipments of paper during the non-monsoon season, whenever possible, to avoid the danger of damage from rain. As this is also the period of low water, the barges must often be loaded to only half their capacity to reduce draft.

Timber is moved from the forests by binding it into rafts which are floated downstream, usually during the high-water season. Bamboo is added to the rafts to provide buoyancy. Shipments of bamboo are also made into rafts for transportation, usually during the low-water season because of the length of the rafts and the difficulty of handling them in swift water. Much of the bamboo goes to the Chandraghona mill where it is used for pulp.

11.03 HISTORY OF CHANNEL IMPROVEMENTS

Training works to provide scouring velocities in the main channel after the end of the monsoon season have been tried at Kodala, Manikchari, Bardam, and Chengrimukh. The operation was successful at the latter point but not at the other three. The principal causes of failure were the washing out of the training spurs during freshets, lack of sufficient flow between freshets to scour the channel, and the large volume of new deposits brought down by each freshet.

Continual dredging has been carried on in the Port of Chittagong and in the ship channel below the Port. Training walls and revetments are also employed in the ship channel but it has not been possible to stabilize the channel to any appreciable degree.

11.04 GENERAL EFFECTS OF THE PROJECT

The lake levels maintained by Karnafuli Dam will normally vary between El 85 feet and El 108 feet, rarely falling below El 80 feet or rising above El 112 feet. The rapids near Barkal and Bara Harina will be submerged. At the lower end of Barkal Rapid the water at full pool level will be about 90 feet deep, or 85 feet higher than the present normal low-water level. The depth at the head of the rapids at Bara Harina will be about 26 feet.

The flow of the river below the dam will be regulated by controlled releases from reservoir storage. Immediately below the powerhouse the discharge will normally vary between 5,000 cfs and 13,000 cfs when two generating units are in operation, or up to 20,000 cfs with three units operating. The flow will increase when water is discharged over the spillway, but will rarely exceed 130,000 cfs. If the power output should be curtailed or the plant shut down, emergency releases for navigation will be made through the spillway gates or if the reservoir is below El 78, may be made through the slide gate in the diversion tunnel intake structure.

All of the bed load and virtually all of the suspended material that enters the reservoir will be trapped there and the flow immediately below the powerhouse will be practically clear water.

The dam will have no appreciable effect upon tidal flows because the range of tide is quite small at the dam site and almost nil at Rangamati, and the present channel between these points has relatively little storage capacity. The present effect of natural storage and release in the few miles of tidal reach above Kaptai is therefore an insignificant part of the total effect in the lower river.

11.05 LAKE NAVIGATION

The reservoir will create such a comprehensive network of navigable waterways that an area of roughly one thousand square miles between Karnafuli Dam and the Indian border will be served directly by lake transportation. This is largely a country of hills and forest land. Almost every part of it will be within three or four miles of an arm of the lake during the months when the water level is at full pool stage. Country produce and minor freight can be collected from a considerably larger area by utilizing dugouts on the tributary streams to bring cargoes down to the lake to be shipped to Chittagong on larger boats. Logs can be skidded to the lake shore or floated down the tributary streams into the lake.

The existence of a through waterway from Chittagong, navigable by heavy barges, will make it practicable to establish industrial plants on the lake shore for the production of dimension lumber, wood pulp, fiber products, plywood, small hardwood articles and other products.

According to the present plan the locks (Exhibit 24) at the dam will consist of three lifts, each chamber being 200 feet long by 50 feet wide. The various types of river and lake traffic drawing up to six feet can be handled at all stages of the river and reservoir except at unusually high or low stages of infrequent occurrence and short duration. The locks probably cannot be justified considering economics on the basis of present river traffic alone. They will, however, contribute materially to the develop-

ment of the reservoir area. As mentioned previously, a certain amount of river traffic and commerce is now existing and it is possible that it is in the best interest of the government to maintain this traffic with as little disruption as possible. Alternative means have been considered for handling traffic past the dam.

Much of the freight traffic could be handled by a ropeway of the "Skyhook" type which employs a diesel powered crab operating on cables. Trucks could also be used by which bamboo and timber could be handled directly from the reservoir to the mills. Several types of conveyors have also been considered. The first cost of any of the above systems would be much less than that of the locks. However, any of these alternatives would interrupt present river traffic. It would be difficult, if not impossible, to move the present public launches from the river up into the reservoir by any of the above systems. It would also require a considerable labor force to accomplish the necessary cargo handling and rigging. While a marine railway could handle the launches, its general usefulness would be limited.

The Government of Pakistan may wish to review the necessity of immediate construction of the navigation locks to serve the present river traffic. Should it be determined that construction of the locks may be deferred, the capital cost of the initial project may be substantially reduced.

11.06 RIVER NAVIGATION

The maintenance of an average dry-season flow of about 10,000 cfs below the powerhouse should provide at least five feet of water over the sand bars so that ordinary river traffic can cross them at low tide. The desilting of the water in the reservoir will stop the heavy movement of silt from the headwaters into the lower river. This, alone, would eventually stabilize the channel but a number of years would elapse before the effect became noticeable at Chittagong. The clear water discharged from the reservoir will commence to degrade the soft river bottom immediately below the point of release and will pick up a substantial load of silt before it reaches the first sand-bar zone near Kodala. As the depth of the upstream part of the channel is brought to an equilibrium, the zone of degradation will move gradually downstream, stabilizing the channel as it goes.

The process of channel stabilization can be hastened by the construction of training spurs and revetments. The impounding of the freshets will make it relatively easy to maintain such works. If flushing becomes necessary it can be accomplished by controlled releases from the reservoir.

The benefits to river traffic below the dam will arise from improved navigation depths, stabilized channels, regulated river flows, and the impounding of the freshets. Barge loads will no longer need to be reduced

during the dry season, and the swift currents that combine with floating debris to make navigation difficult during the monsoon season will be eliminated.

The Karnafuli Project will increase both population and industrial activity in the basin, with a corresponding increase in local freight and passenger traffic. The anticipated expansion of the output of the Chandraghona Paper Mill alone will provide 30,000 tons annually of additional freight to Chittagong. The shipments of paper will be especially benefited because they can be made during the dry season, thus avoiding damage from moisture. Incoming barge shipments of sulfite and fuel oil as well as the downriver rafting of bamboo will be correspondingly increased. This traffic will especially benefit from improved navigation depths and the elimination of swift currents.

11.07 FUTURE RIVER TRAFFIC

Present river freight on the Karnafuli consists principally of supplies and equipment brought in from the Port of Chittagong, forest produce and other materials moved down the river, and local small freight including country produce and locally manufactured articles. With the exception of the paper produced annually by the Chandraghona Paper Mill (this is shipped by barge to Chittagong and does not pass the dam site) the freight handled by the larger boats, barges, and rafts consists almost entirely of forest products and cotton. The present annual tonnage of large freight passing the dam site is estimated as follows:

Timber	16,000 tons
Bamboo, all purposes	143,000 tons
Firewood	14,000 tons
Sungrass (for thatching)	26,000 tons
Cotton	5,000 tons

The tonnage listed represents traffic bound downstream. Except for the commodities that are moved in rafts, each thousand tons of freight brought down will require the additional locking of about 24 boats, including empty cargo boats and barges returning upstream and towboats in either direction.

There are also five passenger launches operating on regular schedules. These launches pass the dam site about 1,500 times per year in each direction, a total of 3,000 passages. Although there will be increased passenger traffic in future years, it has been assumed, for the purpose of estimating revenues, that the number of daily launches will remain constant.

With the addition of nearly 400 miles of navigable waterways in the hill country, the extensive forest resources of a large area that is now out of reach will be utilized.

The present and anticipated future annual tonnage of the various important items of freight passing the dam, consisting principally of forest products, is summarized as follows:

At the present time	204,000 tons
Upon completion of the dam	306,900 tons
5 years after completion	341,200 tons
10 years after completion	348,400 tons
15 years after completion	355,200 tons

11.08 REVENUE FROM NAVIGATION LOCKS

Toll rates have been established on several inland waterways in East Pakistan (including Karnapara Khal, Madaripur Bhil, Kaksiala Khal, and Taltala Khal) under the Bengal Canals Act of 1864. It is understood that in accordance with the same policy, tolls will be charged for the use of the navigation locks at Karnafuli Dam.

After the completion of the dam the great increase in the total mileage of navigable channels serving areas that are now inaccessible, the maintenance of navigable depths over the sand bars at all seasons, and the elimination of swift currents will justify the collection of tolls even though none are charged at the present time.

After a study of the tolls charged on other waterways in Pakistan, with recognition of the present toll-free use of the Karnafuli River, and after consultation with the Superintending Engineer, Karnafuli Project, a lockage toll of $0.606 per ton has been used for estimating the annual revenue from the navigation locks.

Since it is established policy on other waterways to exempt small craft from the payment of tolls, it is assumed that boats of less than 25 maunds cargo capacity (roughly one ton) would be passed through the locks free of charge. This would exempt the sampans and smaller boats, which carry country produce and passengers locally. Firewood, sungrass, and cotton are usually carried either on boats of over 25 maunds capacity or on barges (sungrass, often on rafts) and would be subject to tolls. The expected annual gross revenue is estimated as follows:

Upon completion of the dam	$186,000
5 years after completion	$207,000
10 years after completion	$211,000
15 years after completion	$215,000

11.09 RIVER NAVIGATION IMPROVEMENT

Although the revenue from lock tolls is only a small part of the total benefit to river traffic passing the dam, it affords the only available basis for estimating the benefit. There is a substantial amount of freight traffic on the lower river that does not pass the dam site. The benefit to that traffic, estimated on a similar basis, would be $15,000 annually.

11.10 THE PORT OF CHITTAGONG

Chittagong, about nine miles upstream from the mouth of the Karnafuli, is the principal port of East Pakistan. Although it has been an important port for centuries, the partition has made it the chief trade outlet for the entire province and the volume of its commerce has more than doubled since that time. The Port of Chittagong is connected with the interior by the East Bengal Railway and by river steamers that navigate the various inland waterways. The growth in volume of ocean freight handled through the port since the partition is shown in the following tabulation:

Year	Imports, tons	Exports, tons
1948-49	413,877	666,638
1949-50	786,267	1,085,361
1950-51	1,268,600	1,695,031
1951-52	1,203,777	1,649,155
1952-53	1,213,004	1,703,107
1953-54	1,005,849	1,532,337

In order to handle the increased traffic, extensive improvements to the port facilities have been made and more are in progress. There are now twelve berths, six moorings, and two swinging buoys, so that twenty ocean-going vessels can be accommodated at a time. The port is equipped with cranes and other machinery for mechanical operation, and has storage accommodations and other facilities of a modern port.

By constant dredging, an attempt is made to maintain a depth of 25 feet at low water alongside the berths, but this has proved difficult to accomplish. Most ocean ships that visit the port draw between 25 and 30 feet of water when fully loaded. Three bars must be crossed between the ocean and the harbor. The "outer bar" lies just outside the river mouth, the "inner bar" is two miles up from the mouth, and the "Gupta bar" is at a bend of the river five miles below the port. The latter is the ruling bar and great difficulty has been experienced in maintaining a minimum depth of 12 feet over it at low tide. Except during the driest months, vessels of draft not exceeding 22 feet can usually cross at high tide. Considerable lighterage is necessary for incoming vessels fully loaded. Ships bound for Chittagong are sometimes required to wait offshore as long as ten days and it is not uncommon to see six ships, or even more, waiting at the same time.

Attempts have been made in past years to increase the depth of the ship channel by the construction of training walls, spurs and jetties. These were found to be effective as long as they served as silt traps but as soon as the equilibrium of silt load and deposition became re-established, the bars were again built up. The improvement of ruling depths in the channel and port has been the subject of much study. Among the investigators is Sir Claude C. Inglis, who has studied the problem at first hand and from models, over a period of five or six years. He states[1] that the proposed Karnafuli Dam will be of great benefit to the Port of Chittagong by the improvement of the ruling depth, the elimination of silt from upstream sources, a marked reduction of bed movement, and facilitating the training of the river through the elimination of freshets and the maintenance of large minimum flows.

The maintenance of a deeper ship channel and harbor is not practicable under present conditions, even with continuous dredging, because of the shifting sand bars and the heavy silt load that is brought down the river with each freshet. Probably some dredging will always be required but the amount will be greatly reduced after the heavy downstream movement of silt has been stopped. It will be a simple matter to maintain deep water in the harbor and the channel to the sea so that the larger vessels can visit the port without having to wait for lighterage or tide.

The principal benefits to ocean shipping will be those of reduced turn-around time and the elimination of lighterage costs.

The principal benefits to the Port of Chittagong, resulting from the Karnafuli Project, will be as follows:

1. The greatly increased dry-weather flow of the river will provide greater depths for navigation in the harbor and in the ship channel to the sea

[1] Inglis, Sir Claude C., "Third Report on Training the Karnafuli River," Eastern Pakistan, 1953.

2. The trapping by the reservoir of all silt from headwater sources will eventually result in deep and stable channels

3. The elimination of large freshets during the monsoon season will stop the silting of the harbor and the formation of new bars in the channel. It will also make it easy to maintain successful channel training works if any should be found desirable

4. The establishment of direct freight service between the Port and a large interior area that is now inaccessible will increase the commerce of the Port

5. Greater production and local wealth in the Karnafuli Basin will increase the commerce of the port and a substantial part of this benefit will be attributable to the extension of the navigable channels and the improved navigability of the main river

6. The greater accessibility of the harbor to ocean-going vessels and the reduction of turn-around time alone will increase the commerce of the port to a moderate extent.

The present expense of dredging the harbor, berthing areas, and the ship channel to the sea is a direct cost to the port. The expense of lighterage and of the time lost by vessels is paid directly by the ship owners, but it is repaid indirectly by Pakistani business and industry in the form of increased freight costs. The annual benefit from reduction in lighterage and harbor dredging alone has been estimated as $845,000. As previously stated, this benefit will not be realized immediately upon completion of the project. The benefit from the reduction of turn-around time of ships would be difficult to estimate accurately. It appears that a reasonable estimate of only the direct and tangible benefits to the port and to vessels using it, resulting from improved navigability of the river system, is at least $1,000,000 per year. Since reliable costs of turn-around time are not available, only $845,000 of benefit to the port has been included in summaries contained in Chapter XV.

CHAPTER XII

HYDROELECTRIC POWER

12.01 GENERAL

In preparing the Reconnaissance Report extensive studies were made to determine the power potentialities of the Karnafuli Reservoir. These early studies were based on some very preliminary considerations as to the characteristics of the connected load. Final studies, based on the very conservative estimates of future power demand and consumption developed in Part III of this volume have been used in establishing the plant capacity.

As a result of these studies an initial installation of two units is recommended. Each unit will consist of a kaplan-type turbine with a rated output of 50,000 hp at average weighted head. The turbines will be direct-connected to 40,000 kw generators. The upper reservoir levels have previously been established by the Government Engineers based on land acquisition considerations. The normal upper operating pool is El 108.0 and the flood surcharge El 119.0. These criteria have determined the upper operating pool elevations.

12.02 POWER CAPABILITY

Reservoir operation studies based on eighteen years of flow records (1935-1953) were made to determine the usable energy that can be produced and the capacity to be provided. The average over-all efficiency of the intake, turbine, generator and step-up transformer was assumed to be 80 percent. Transmission loss from plant to the load center was estimated to be 10.7%. These studies show that the Karnafuli reservoir will provide net firm power of a constant output of 50,000 kw.

Using a utilization factor of 0.95, overload capacity of 15 percent and a load factor of 65 percent, the Karnafuli Power Plant with the initial two units installed is capable of producing an average annual energy of 488 million kwh at plant. The recommended operating rule curve provides that the minimum reservoir elevation shall be El 75.0. At this minimum reservoir level the plant peaking capacity was found to be 68,700 kw.

The installation of the third 40,000 kw unit in the Karnafuli Power Plant will increase the average annual energy only a relatively small amount. Its chief value will be for use in increasing the peaking capability and supplying additional energy during the monsoon season. For these reasons space has been provided for a third unit when the system demand justifies its installation.

As the system demand and consumption increase, it will be possible to feed into the system more and more energy produced from monsoon flow. In the early years of the project, however, it will not be possible to make use of the increased energy available during the monsoon season when the runoff is high. Therefore, as the system load increases the energy production at Karnafuli will increase. The greatest utility of the Karnafuli power will be reached in future years when it will be operating in a system containing a substantial proportion of thermal power.

The economic analyses in this report have neglected any possible revenue from the sale of monsoon power or secondary energy.

CHAPTER XIII

PROJECT FEATURES

13.01 GENERAL

The Karnafuli Project is a multi-purpose project; its primary purpose is to produce power. Flood control and extension of and improvement to navigation are secondary functions. There will be provided an earthfill dam, a spillway, a power plant, a flight of locks, a low-level reservoir outlet and diversion tunnel, and a transmission line and receiving stations. The general layout showing the relation of these features is shown in Exhibit 19. The topography and the foundations of the project area are such that the various features cannot economically be grouped together and made integral with each other. Alternate sites for the various structures have been considered, and the final locations have been selected based on economic studies and foundation conditions. Work already accomplished has also influenced the location of the various features.

In the description of locations and details of features, it should be noted that these in some cases differ from the proposed layout of the project as shown in the Reconnaissance Report. Such differences are partly due to a better knowledge of foundation conditions and embankment materials which have been determined since the preparation of the above report. In other cases it became apparent that, as the final design progressed, certain alterations would result in more economical structures. Although it is believed that the present general layout and structures can be considered as final, it should not be overlooked that certain adjustments will have to be made both during the preparation of detailed construction drawings and as the excavation progresses and the foundations become exposed.

13.02 EXISTING FEATURES

The river is presently being diverted through an excavated channel in the right bank of the river at the dam site. This channel is approximately 3,200 feet long, curved in plan and extends from the existing upstream cofferdam to below the toe of the downstream slope of the dam. It is trapezoidal in cross section with a minimum base width of 140 feet and 45° side slopes. The invert is at El 3.0. A 25-foot wide berm is provided at approximately mid-height in the left side slope. Both side slopes are in parts protected by mattresses of brick in wire baskets, reinforced gunite, and steel sheet piling anchored with cables.

The existing upstream cofferdam was completed in 1954. It contains about 500,000 cubic yards of embankment and rises 50 feet above the normal river surface to El 62.0. The embankment was constructed by end dumping on the existing river bottom materials. The embankment material was obtained from the diversion channel and spillway excavation. The upstream slope of the cofferdam is protected by mattresses of brick in wire baskets.

Considerable excavation has been completed in the spillway channel. It is also understood that further excavation of the spillway channel is now in progress and that excavation for the main dam foundation is well advanced. In addition to the above, extensive work on the construction camp, permanent quarters, and camp facilities has been accomplished. (See Chapter VIII).

13.03 RIVER DIVERSION

The high flood potential of the Karnafuli River has been a determining factor in establishing the program of river diversion to permit construction of the main dam. During the monsoon season, which extends from May through October, floods of from 150,000 to 200,000 cfs are not uncommon. Because of the heavy rains during the monsoons, construction activity on the dam will be restricted largely to dry seasons from November through April. It is planned that embankment construction will extend over three seasons, and river diversion will be carried on in two stages. It is essential that the final closure section be constructed in one dry season.

> Stage I - Stage I extends over a two-year period during which all stream flow, including heavy floods of monsoon periods, will be diverted through the existing right bank channel. A portion of the dam, to the left of the diversion channel, and second-stage diversion works will be constructed at this time.
>
> Stage II - Stage II is the closure stage and will extend over a single dry season immediately following Stage I. During this stage the river will be diverted through a tunnel in the right abutment and the closure section of the dam must be completed to a sufficient height to prevent overtopping by the subsequent monsoon flood.

Stage II cannot commence until high water has receded. Daily flows ranging from 138 to 6,000 cfs have been recorded during the dry season. However, an exceptional daily average flow of 124,000 cfs was recorded in May 1941.

Additional cofferdams will be required upstream and downstream to unwater the diversion channel area during Stage II. An upstream cofferdam will be constructed across the entrance to the diversion channel. The top of the cofferdam has been set at El 50.0 based on routing critical December floods through the tunnel with adequate freeboard. The cofferdam

should be constructed at a rate of about 5,000 cubic yards a day to preclude any hazard of washout by floods. The downstream cofferdam will be located immediately upstream of the end of diversion outlet channel.

It is essential that construction of other features of the project be coordinated with the diversion scheme.

13.04 MAIN DAM AND SADDLE DAM

The main dam will be an 1,800-foot long earthfill embankment. The general layout and sections of the dam are shown on Exhibits 20 and 21.

The maximum section is located at the old river channel where a portion of the dam will be founded on shale bedrock and the remainder on a deposit of fine to medium sand. At the maximum section, the dam will rise 153 feet above the deepest excavation level with a base length of 870 feet. The section consists primarily of homogeneous, compacted impervious material. A 10-foot thick layer of pervious sand will be placed on the foundation under the downstream third of the dam. The blanket will serve to collect seepage through the dam and also to lower the phreatic line improving the stability of the section. A comparatively thin zone of pervious sand is located on the downstream slope as a secondary measure for controlling seepage through the dam.

On the right bank, where the dam is founded on a terrace composed of 50 to 60 feet of silty and sandy clay, the maximum height is about 90 feet. The cross section is similar to that in the old river channel, except that extended berms have been provided both upstream and downstream for purposes of stability. The berms will tend to distribute the embankment load so that maximum stresses in the foundation will not exceed the shear strength of the materials.

A system of vertical sand drains has been provided in the right bank clay deposit under the downstream portion of the dam. The purpose of these drains is to accelerate consolidation of the clay deposit, thereby increasing its shearing resistance in the period immediately after construction when stress conditions govern the design.

The right bank terrace is underlain by a deep deposit of fine to medium sand which fills an abandoned river channel. A line of relief wells fully penetrating this deposit has been provided downstream of the axis to prevent the development of excessive uplift pressures. Underseepage will be collected in the relief wells and transported through a header system to the downstream face of the dam. Seepage studies based on conservative assumptions indicate that discharge from the wells will be insignificant and that the loss of water will have no effect upon the storage for power at the site. Moreover, discharge will decrease rapidly as siltation of the reservoir forms an impervious upstream blanket.

Piezometers will be installed in the buried channel in the foundation of the dam downstream from the relief wells. This installation will be used to observe hydrostatic pressure due to seepage and thus determine whether the wells are functioning properly at any time. Another group of piezometers will be installed in the dam foundation in the vicinity of the sand drains for observation of the progress of consolidation. Both installations should be observed at regular intervals, both during and after construction of the dam. If readings indicate that the relief wells or sand drains are not functioning properly, remedial measures should be instituted immediately.

The upstream slope of the dam above the minimum reservoir level is protected against wave action by 20-inch thick brick paving laid on a sand filter blanket. The downstream slope is similarly paved below tail water level. Above tail water level the downstream slope is sodded to provide protection against surface runoff during the heavy monsoon rains. A system of paved gutters along the berms with connecting gutters on the slopes serves to collect runoff.

Conservative practices have been used in designing the embankment. Stability analyses indicate that the dam is amply safe for all conditions of loading, provided that all design criteria are satisfied. To insure the safety of the dam, it will therefore be necessary to continue detailed investigations on embankment and foundation materials before and during construction of the dam, as described in Appendix A of Volume II, Specifications. It will further be necessary to maintain exceptionally careful control during construction over all operations on the foundation and the embankment, so that all portions of the embankment satisfy the design criteria and all drainage installations function properly.

13.05 DIVERSION AND OUTLET TUNNEL

A diversion and outlet tunnel is a required feature at the Karnafuli Project. Not only will it be necessary to divert the river during the second-stage construction of the dam, but provisions will also have to be made for release when the reservoir level is below the spillway crest (El 78) and when due to some emergency condition flow through the turbines is insufficient to satisfy downstream water requirements. From a study of alternatives in regard to both type and location, the present layout has been adopted.

A tunnel with an inside diameter of 15'-0" is located in the right abutment of the main dam (see Exhibit 22). In this location it is possible to take advantage of the approach of the power plant forebay channel on the upstream side of the tunnel and of a natural draw on the downstream side. The entire tunnel is concrete lined to a circular section. A cutoff grout ring is provided in the downstream portion of the tunnel at the intersection of projected axis of dam.

A gate structure consisting of two passageways is located at the portal of the tunnel. It houses three 6-ft x 7.5-ft slide gates, one in the left hand passageway and two in tandem in the right hand passageway. Only two sets of electro-mechanical operators will be provided. Initially they will be installed on the two upstream gates and used only during river diversion. After completion of the second-stage construction of the dam and the required diversion, the two upstream gates will be closed and the reservoir will begin to fill. The operator will then be removed from the left gate and permanently installed on the downstream right hand gate. Only the right water passageway will be used for reservoir outlet purposes. This passage has been designed for a capacity of approximately 2,000 cfs with reservoir stage at El 60.0. The tunnel has been designed as a free flow conduit under heads up to the maximum dry season flood reservoir stage (El 44) with all gates fully opened. It will also operate as a free flow conduit with one gate closed under heads up to reservoir El 78.0 (spillway crest). The gate should not be used under heads greater than reservoir El 80.0. Above El 80.0 releases will be controlled with the spillway gates. The upstream gate is provided for emergency use and to permit maintenance of the downstream or operating gate. Trashracks are provided at the upstream portal to prevent debris from blocking the water passageways. Access to the chamber is through an inclined steel-lined concrete shaft with the entrance above El 119.0.

13.06 SPILLWAY

A gated-chute spillway, designed for a maximum capacity of 525,000 cfs, is located in a saddle in the left bank of the proposed earthfill dam (see Exhibit 23). Essentially it consists of a gate structure and a converging escape channel. Further studies of the spillway and additional foundation information received since the completion of the Reconnaissance Report indicated that the stilling basin shown therein could be safely eliminated, resulting in a substantial saving. The spillway hydraulic design follows very closely that successfully used on a number of important projects. While the general aspects of this design have been well proven, due to the complexity of the hydraulic aspects of this type of spillway it is desirable that the details be verified by hydraulic model tests prior to the preparation of the construction drawings.

The spillway gate structure consists of an ogee crest at El 78.0 surmounted with radial gates. There are 16 gates, each 40 feet long by 30 feet high, separated by 6-1/2 ft thick piers. The total net length of the crest is 640 feet. The top of the gates is at El 108.0, normal high reservoir surface. With the reservoir surcharged to El 119.0, the required capacity is provided by 15 gates, one additional gate being provided as insurance against malfunctioning. Each gate is operated by its individual electric motor-driven hoist mounted on the hoist deck at El 127.0. An emergency power source consists of two portable gasoline engines provided with a mechanical drive which may be directly connected to the gate hoists in case of electric power failure.

Sequence of gate operation is important because of the converging discharge channel. The gates must be opened one at a time in equal increments not to exceed two feet, beginning with the center gates and successively raising the gates on either side until all gates have been raised to the same elevation. Further opening should be accomplished in the same manner and closing should be done in reverse order. This procedure is necessary to insure even flow in the channel. The gate motor hoists are controlled by limit switches which permit only limited travel of the gates without resetting and preclude human error in raising the gates. The spillway gate structure is provided with a temporary one-lane access bridge. Provisions have been made for the future installation of a two-lane highway bridge when required.

The spillway escape channel has been tapered for economic reasons. It consists of a concrete-lined transition section adjacent to the gate structure and a straight unlined section downstream from the transition. It is anticipated that a hydraulic jump will occur at maximum flow in the lower portion of the unlined channel. Any erosion that may occur will be far removed from any structure and will not present any anticipated operating difficulties.

A deep grout curtain is constructed at the upstream end of the structure to reduce under-seepage. Uplift pressures under the structure are reduced by drains under the concrete and by relief wells at the downstream end of the structure. Piezometer tubes in the piers provide a ready means of checking the proper functioning of the relief wells.

Similarily, the concrete slab in the transition section of the spillway channel is provided with a drainage system to prevent uplift pressures from dislocating the slab. Relief wells are also provided in the downstream cutoff of the concrete lining.

13.07 NAVIGATION LOCKS

The navigation locks (see Exhibit 24) consist of three chambers, each 50 feet wide by 200 feet long in the clear, with a minimum clearance over the miter gate sills of seven and one-half feet. These general dimensions were recommended by the Karnafuli Project Circle and are consistent with other navigation locks in East Pakistan. Other pertinent features of the locks are the upper guide walls, the operations building, the lower guard wall and all the necessary operating equipment. For the upper chamber, the maximum lift is 35.5 feet, and for the middle and lower chambers it is 30.5 feet. Maximum filling time for each chamber is 16 minutes.

The locks are so oriented that they line up with the river downstream. A guard wall is provided at the downstream end to deflect the current away from the immediate vicinity of the lock entrance. On the upstream end there is a straight approach channel out into deep water. A guide wall is provided at the upstream end to facilitate entrance into the locks.

The lock walls and bottom slab are combined in the design into a "U"-shaped structure of reinforced concrete. The walls contain the culvert system, gate operating machinery, towing machinery and the various mooring devices and water level indicators.

The hydraulic filling and emptying system consists of a longitudinal culvert in each wall with lateral ports at floor level connecting to the upper and lower pools and to each of the chambers. This system has been selected for simplicity and economy. The flow is controlled by segmental valves in the culvert. Bulkheads are provided and so positioned that it is possible to unwater the segmental valve recesses for access to the valves for maintenance or replacement. During normal operation, the bulkhead slots are equipped with slot fillers to give a smooth culvert section and prevent cavitation. Vertical air vents are provided in each chamber section of the culverts to relieve entrapped air.

The lock gates are constructed of structural steel and are of the miter type. Gates have been designed to permit complete unwatering of all chambers. At the upstream and downstream entrances to the locks, recesses are provided for emergency dams which make it possible to unwater all chambers for maintenance of the miter gates, or for other purposes. Both the segmental valves and the miter gates are electrically operated. All gate operating machinery is capable of operating while completely submerged.

Facilities for mooring vessels or rafts are provided at both the upstream and downstream entrances to the locks. Floating mooring bits, line hooks and check posts are provided within the locks for vessels or rafts in transit. There is a movable towing bit in each chamber to provide motive power for vessels or rafts moving through the locks.

The control tower houses the lock emergency power generator, the lighting controls, and the control panel for the miter gates and segmental valves. Water elevation indicated by floats in each of the chambers is transmitted electrically to the control tower. In addition to the float gages, staff gages are provided in each chamber to show water elevation. While the gate and segmental valve machinery may be operated from either the control tower or the deck, the towing machinery can be operated from the deck only.

A two-lane structural steel bridge spans the locks at the upper entrance forming a link in the highway connecting the project and Chittagong.

It is expected that navigation will be interrupted when the reservoir is above El 108 because such levels will be accompanied by substantial flood discharges from the spillway, and the downstream river would be non-navigable for that reason.

13.08 POWER PLANT

Site - The power plant site (see Exhibits 25 and 26) has been selected as the preferred location after reviewing all available geologic data obtained from boring logs and after comparative economic studies for several possible locations. The site combines the advantages of maximum economy and suitable foundation conditions with good approach channel and tailrace alignment. The foundation is comprised of blue shales of such depth, density and extent as to afford a uniform and satisfactory foundation bearing material for the entire structure. The hydraulic characteristics of the forebay channel at this site are especially favorable and a considerable saving in excavation quantities over that of the other sites is effected.

Foundation - In order to reduce seepage and uplift pressure on the base of the intake-powerhouse structure, and to assure the stability of this structure, a cutoff grout curtain will be constructed near the upstream face. In addition, consolidation grouting operations will be carried out under the structure to fill any voids or fissures that may be found in the foundation.

A system of deep relief wells will be provided immediately downstream from the grout curtain. These wells will drain water from the sandstone layers. A second deep relief well system, comparable to that under the intake, will be provided on the downstream side of the powerhouse. These two systems will work together to reduce uplift pressures under the entire structure. In addition, a drain system under the draft tube slab will be installed to give local relief of uplift pressures when the draft tube is unwatered.

General Arrangement - The general arrangement features a powerhouse combined with an intake. This over-all structure is divided by transverse construction joints into three operating units and one assembly bay. Two of the operating units and the assembly bay are to be carried to completion in the initial phase of construction. The third unit at the north end is left in the "block-out" condition, to be completed at a later date. The exact date when the third unit should be installed will depend on the rate of increase of load. The principal powerhouse data are as follows:

Intake deck	El 127.0
Intake slab invert	El 34.0
Transformer deck	El 86.0
Office Floor	El 67.5
Generator and control room floor	El 49.0
Turbine floor	El 37.0
Center line of distributor (tentative)	El 12.0
Reservoir maximum water surface	El 119.0
Reservoir normal high water level	El 108.0
Average reservoir operating level	El 93.6
Normal tail water surface at mean tide for 5,000 cfs discharge	El 14.5
Normal tail water surface at mean tide for 10,000 cfs discharge	El 16.9
Flood tail water surface for 300,000 cfs discharge	El 47.0
Maximum designed flood tail water surface for 525,000 cfs discharge	El 67.5
Ultimate generating capacity (3 units)	120,000 kw
Initial installation capacity (2 units)	80,000 kw

Forebay - The forebay channel, leading from the reservoir to the forebay and intake structure of the power plant, is an important feature. The channel alignment chosen results in the least possible excavation quantity.

A reinforced concrete lining with sealed joints extends 100 feet upstream of the intake structure. Beyond this an impervious blanket extending an additional 250 feet along the bottom and sideslopes of the channel is provided. Together, the concrete lining and the impervious blanket will lower the percolation gradient under the powerhouse and reduce underseepage.

Unit Bay Arrangement - Each of the three unit blocks measures 70 feet by 198 feet, the latter in the direction of flow. The upstream portion of each unit is the intake containing the trashracks, intake gates, emergency stoplog slots and the water passage from the face of the intake to the scrollcase. The control bay and service rooms are between the intake and generator room. The substructure of the downstream portion of each unit houses the turbine, and contains the draft tube and galleries. All water passages and channels, as well as the scrollcase itself, are constructed of reinforced concrete.

The intake structure and enough of the substructure to permit ready completion of Unit No. 3 "in the dry" is provided. Blockouts in the first stage concrete will permit proper placing of future equipment and concrete. The water entrance from the reservoir will be blocked by a set of concrete stoplogs inserted in the emergency gate slots. Water will be allowed to enter the draft tube and pit. Inspection gallery entrances are to be closed with temporary concrete walls.

The superstructure is of conventional reinforced concrete construction with a steel truss-supported roof. Crane rails are supported on wall corbels. A temporary end wall, designed for easy removal, will protect the generator room at the north end of Unit No. 2.

Turbines, Generators, and Auxiliary Equipment - The 55,000 hp kaplan-type turbines have been selected to answer a wide range of requirements imposed by present and future power demand and the wide fluctuation of operating heads. These turbines, in which the blades automatically adjust to load and head conditions, provide high efficiency for varying gate openings and therefore are ideally suited to the load and head variations of the Karnafuli Project. The speed of each turbine will be controlled by a separate actuator-type governor.

The hydraulic turbines are direct-connected by a vertical shaft to 40,000 kw (50,000 kva), 50 cycle generators. The generator will be supported on a reinforced concrete foundation built up from the turbine foundation block.

Assembly Bay - The assembly bay is located at the south end of the three unit bays. Some of its spatial functions are to provide for the unloading, assembly, and storage areas for major plant equipment at the time of initial installation; space for future installations and repairs; housing of the machine shop, pump room, oil purification equipment and oil storage; a place for transformer service and repair; and an ideal observation platform for visitors.

Control Bay and Service Room - The control bay and service rooms occupy three decks and are located between the intake and generator rooms. The location was selected to provide shortest possible cable lengths from the generators.

Transformers and associated equipment are located on the top deck, El 86.0. Directly below are the following rooms: fan room, water treatment room, station service room, office and miscellaneous utility rooms. The third deck consists of a pump room, the main control room, and compressor, battery and electrical shop rooms.

Station Services - Equipment will be installed to provide the following services to the power plant: heating, ventilation and air conditioning, lighting, treated water, fire portection, insulating and lubricating oil systems, compressed air and CO_2 systems, plumbing and drainage. Emergency power will be supplied by a 100 kw diesel-generator set.

Equipment and Material Handling - The facilities for receiving and transporting equipment and machinery to the power plant consist of a wharf, roadways and rail lines.

The general location of the wharf facilities is central for the project features, and the immediate location possesses the advantage of being favorably situated with respect to handling shipments for the powerhouse area. A floating platform back of mooring piles is provided for barge unloading. Heavy shipments will be handled by an electrically powered stiffleg derrick and lifted to the elevation of the storage area. Powerhouse equipment will be placed on a special rail car for movement to the assembly bay or transformer deck.

The lifting equipment at the power plant consists of an intake gantry crane, powerhouse bridge crane and a gantry crane on the tailrace deck. The intake crane is provided to handle stoplogs, trashracks and trash rakes. Heavy pieces of equipment will be handled in the powerhouse by a bridge crane which has two primary lifting hooks with a total capacity of 250 tons and two secondary hooks with a capacity of 15 tons each. The gantry crane on the tailrace deck will handle the draft tube bulkheads.

13.09 FUTURE POWER PLANT

As previously stated the initial project will include two units with space for a third unit to be installed some five to ten years in the future when the power demand requires. The chief value of the third unit as explained in Chapter XII is to increase the capability (kw) of the plant for meeting peak demands. Experience in the United States has shown the advisability and economic advantage of using hydro power for peaking purposes when the hydro units are interconnected into a large hydro-thermal system. It may be many years before the demand and consumption of power in East Pakistan will make it desirable to use the Karnafuli Power for peaking purposes. However when in the future such a large load develops it may be economical to operate additional generating units. Space has been allotted to the project layout for the future construction of a second power plant.

The selection of units should be made based on operating conditions as disclosed by experience in operating the initial units and by power requirements as they develop. It does not appear economically desirable to increase the capital cost and interest charges of the initial project by providing for these future units in the present construction.

13.10 SWITCHYARD

The switching scheme has been designed on the basis of the unit system consisting of a generator and main power transformer bank operated as an electrical unit, with the generator-transformer units and high-tension feeder circuits connected through high-voltage oil circuit breakers to a common high-tension bus. All major equipment required, except the line circuit breakers, will be located outdoors on the transformer deck of the powerhouse at El 86.0.

The line circuit breakers, with associated disconnecting switches and outdoor carrier-current telephone equipment, will be located on leveled ground at El 140.0 approximately 200 feet north of the powerhouse, with major equipment and structures mounted on suitable concrete foundations or pads. A ground mat of bare copper cable will be provided below the graveled surfacing in the switchyard. Initially only one high-tension line oil circuit breaker will be required, but the switchyard will be of sufficient size for a future line oil circuit breaker necessary for an additional transmission circuit. Space will also be provided on the transformer deck for a future third main transformer bank, associated high-voltage oil circuit breaker and equipment for installation with future Generator No. 3, for use when additional generating capacity becomes necessary.

Single-phase power transformers are used in preference to three-phase units to overcome transportation problems which would be inherent in the larger units. Each transformer bank will consist of three single-phase power transformers of the oil-immersed, self-cooled type with provisions for future addition of forced-air cooling fans. The transformer bank kva capacity will be capable of continuously handling 115 percent of generator nameplate rating with the addition of the cooling fans. One spare transformer will be provided for replacement use. Each transformer will be provided with wheels for moving the transformer on the tracks provided in the powerhouse. Connection between the generator and transformers will be made by insulated power cable routed through suitable ducts between the transformer bay and the generator terminal equipment room.

High-voltage circuit breakers of the oil type will be used for switching the generator-transformer units and transmission line feeders. Each pole of the circuit breaker will be encased in a steel tank, arranged for three-phase group operation, and will be capable of interrupting the maximum short-circuit kva available.

-127-

Disconnect switches will be of the single-pole, air-break type, mounted on suitable steel structures and arranged for manual three-phase group operation from the floor level. High conductivity electrical copper or aluminum will be used for all bus work and electrical connections, which will be spaced and supported to provide adequate clearance from grounded parts. Structures in the switchyard will be of steel, protected against corrosion and designed with ample strength and rigidity to accommodate the outgoing transmission conductor.

13.11 TRANSMISSION AND SWITCHING STATION FACILITIES

The project requires a transmission line linking the switchyard at the Karnafuli Project with switching stations in the Chittagong and Dacca areas. These features are not a part of this contract. As required for a proper economic analysis, general requirements and costs for these features have been developed in Chapter VII and Appendix B.

CHAPTER XIV

ESTIMATES OF QUANTITIES AND COSTS

14.01 GENERAL

The quantities and costs for the major construction items as listed in this section are those required to complete the Karnafuli Project as shown on the Drawings, Volume III. Although the listings given are for the principal items only, all incidental items have been allowed for in the costs. For a detail list of construction items see Appendix E.

Work completed to date includes the diversion channel, upstream cofferdam, preliminary boring investigations, existing camp facilities, and construction materials and equipment on hand. Expenditures up to July 1954 have been included as a separate item with interest added from the time of expenditure to the end of the construction period.

14.02 SCHEDULE OF WORK

The construction schedule shown in Exhibit 27 presents a workable construction program. The dam construction naturally divides itself into three seasons work with the left portion of the dam embankment being constructed in the first two dry seasons and the final right bank closure section being placed during the third dry season. During the last phase the river will be diverted through the diversion tunnel. The remaining features and work items are coordinated with the dam construction so they are completed and ready by the time the reservoir fills. The recommended construction schedule calls for completion of the project in 1958.

14.03 QUANTITIES

The quantities are based on the "Drawings" in Volume III and are subject to variation with changes in foundation conditions.

SUMMARY OF PRINCIPAL QUANTITIES

	Quantities
Main Dam and Saddle Dams	
Excavation	295,000 cu yd
Embankment	2,831,000 cu yd
Riprap	566,000 sq ft
Diversion and Outlet Tunnel	
Tunnel Excavation	11,440 cu yd
Channel Excavation	323,000 cu yd
Tunnel Concrete	4,465 cu yd
Reinforcing Steel	80,000 lb
Gates and Metal Work	228,500 lb
Spillway	
Excavation	2,500,000 cu yd
Concrete	93,565 cu yd
Reinforcing Steel	5,840,000 lb
Gates and Metal Work	2,465,870 lb
Navigation Locks	
Excavation	650,000 cu yd
Concrete	42,200 cu yd
Reinforcing Steel	4,500,000 lb
Gates and Metal Work	1,653,000 lb
Powerhouse and Switchyard	
Excavation	1,118,000 cu yd
Backfill	84,000 cu yd
Concrete	138,075 cu yd
Reinforcing Steel	8,478,000 lb
Gates and Metal Work	3,265,000 lb
Power Generating Equipment	80,000 kw

14.04 COSTS

The Consulting Engineers consider it proper to adopt a very conservative approach in preparing the Engineers Estimate of project costs on which the economic evaluation of the project is made. Substantial allowances have been made which in the opinion of the Consulting Engineers should be adequate to cover construction contingencies, contractors fee, and engineering contingencies. Inclusion of these allowances has been made in order to determine the capital expenditures which should not be expected to be exceeded under present construction conditions assuming construction efficiencies equal to good United States practice. The result of including these allowances has been to substantially increase the estimated cost of the Karnafuli Project. In addition some changes and betterments in the design, also on the side of conservatism, have been made which add to the project costs. Similar conservatism has been applied to the estimates of cost for the transmission system.

On this basis the capital costs have increased considerably over those considered in the advance draft of the Report on Electrical Development of East Pakistan submitted on December 15, 1954 which contained a lower allowance for contingencies.

The Engineer's estimate of the construction costs are based on the final design quantities as shown in Appendix E. Due consideration was given to the speed of construction essential for a project of this magnitude and to the work that has been completed to date. Interest during construction, import duties and taxes, contractor's contingencies, contractor's fee and engineering contingencies have been included in the costs. It has been assumed that the efficiency of operations and performance of the work will be in accordance with best United States practices.

COST ESTIMATE

Item	Total Cost Millions of Dollars
a. Karnafuli Project	
Money Already Spent [1]	10.203
Land Compensation [2]	4.910
Main Dam	7.338
Tunnel	1.470
Spillway	11.793
Navigation Locks	7.495
Power Plant	25.473
Engineering and Administration	4.199
Sub-totals	72.881
Minus Salvage Value of Construction Equipment	-0.750
TOTAL CAPITAL COSTS - KARNAFULI PROJECT	72.131
b. Transmission Lines and Receiving Stations:	
Transmission Lines	7.749
Receiving Stations and Synchronous Condenser	3.612
TOTAL CAPITAL COST - TRANSMISSION FACILITIES	11.361

[1] Effective July 1954.
[2] Includes the cost of lands and properties in the Karnafuli reservoir and site area, clearance of the reservoir area and re-alignment of roads and utilities as estimated by the Government of Pakistan.

CHAPTER XV

SUMMARY OF BENEFITS

15.01 POWER BENEFITS

The tangible benefit of the power production of the Karnafuli hydro system with thermal support is equal to the cost of supplying equivalent power by the next most economical alternate which is thermal power. This is conservatively estimated to be $8,328,000 in 1965. (See Section 7.02)

The economy of East Pakistan will for many years to come be based on agriculture. The rising economic level of the people of East Pakistan will intensify the present strong demand for imported consumer goods requiring foreign exchange. Conservation of foreign exchange is accordingly of prime importance to the economy of Pakistan.

The Karnafuli hydro system with thermal support will save, in the year 1965, $2,461,000 in foreign exchange over the cost of equivalent all-thermal generation. This is a net saving to the economy of Pakistan after deducting the costs of interest and sinking fund amortization for the Karnafuli Project with navigation locks, supporting thermal plant and transmission system.

Construction of the Karnafuli Project will further assist in the economic development of East Pakistan by providing a much needed opportunity for Pakistan's engineers and workmen to obtain the experience and skills of working on a heavy construction project using modern methods and equipment. A body of trained and experienced men will be available to undertake further heavy construction in East Pakistan such as much needed irrigation, drainage, highway, and railroad projects.

15.02 FORESTRY

As described in Appendix G the construction of the Karnafuli Project will make practicable the expansion of the timber industry in East Pakistan. Extensive stands of heavy timber can be reached by the Karnafuli Reservoir which winds through a thousand square miles or virgin forest. Commercial timber can be cut in the now inaccessible Kasalong Forest Area and readily moved to the lake. This timber can then be transported on barges to industrial plants on the river or to the Port of Chittagong. The annual benefits from the lumber industry are estimated as $1,212,000 in 1960 and the same amount in 1965.

15.03 FISH INDUSTRY

The demand for palatable fish in East Pakistan has always greatly exceeded the supply. If Karnafuli Reservoir is kept stocked with fish, concessions for commercial fishing can be sold. It is estimated that the annual net revenue from fishing concessions will amount to $379,000 in 1965.

15.04 FLOOD CONTROL

The storage capacity above the maximum normal pool level of Karnafuli Reservoir is sufficient to contain any flood of actual record with outflow rates not exceeding safe channel capacity. The annual benefit from flood control, determined from the estimated average annual damage from observed floods, is $164,000. (See Chapter X)

15.05 NAVIGATION

The construction of Karnafuli Dam will provide four basic improvements to navigation that are now greatly needed. The most important is the establishment of direct water transportation between Chittagong and a thousand square miles or more of potentially productive forest land that is now practically inaccessible. Hardly less important is the trapping of all silt from sources above Kaptai, which will stabilize the channels in the lower river and permit the maintenance of a deep-water ship channel from the Port of Chittagong to the ocean. Of third importance is the conversion of the upper reach of the main river into a pool and the maintenance of a flow below the dam that will provide depths for fully loaded boats and barges at all times. The elimination of the freshets is by no means unimportant. They now interfere with the rafting of bamboo, shift the river channels, and at the same time make the use of training spurs impracticable.

It is not practicable to make estimates of the profits to be realized from the transportation of forest products, or the benefit of increased trade in the Port of Chittagong, nor of the economic value to the nation of the commercial development of the upper Karnafuli Basin.

The estimated annual direct benefits from navigation are as follows:

Item	Annual Benefit in Dollars[1] 1960	1965
Navigation Lock Tolls	$190,000[2]	$ 208,000[2]
River Navigation Improvement	15,000	15,000
Chittagong Port	0	845,000
Total Annual Navigation Benefits	$205,000	$1,068,000

(1) Assuming Karnafuli Project completion in 1958.

(2) Interpolated from Section 11.08.

15.06 AGRICULTURE

Although agriculture will be greatly benefited by the establishment of industrial plants for the production of fertilizer, preservation of foods, and utilization of agricultural products as raw materials, the direct agricultural benefits from the Karnafuli Project will be those arising from the use of electric power for purposes of drainage and irrigation. The amount of Karnafuli power that will be allocated to land reclamation and the extent of its distribution are matters of future government policy. It is therefore impossible at this time to make a reliable estimate of the annual benefit to agriculture. (See Appendix F)

15.07 GENERAL INDUSTRIAL EXPANSION

There has been no enterprise in East Pakistan comparable to the Karnafuli Project, to serve as a yardstick for estimating the industrial benefits. However, a material growth of the mechanical industries will benefit the foreign exchange and economic welfare of the country to a degree that can hardly be overestimated. There are three principal ways in which the Karnafuli Project will stimulate industry. First, the availability of low-cost electric power will encourage the construction of processing and manufacturing plants. Second, an abundance of raw materials from the forests will be made available by the lake waterways. Third, plant sites on the lake and river will be connected by excellent water transportation with headwater points and with the Port of Chittagong.

15.08 SUMMARY AND COST-BENEFIT RATIO

The estimated annual tangible benefits arising from the Karnafuli Project, are summarized below:

TOTAL ANNUAL BENEFITS

Source	Benefit in Dollars 1960	Benefit in Dollars 1965
Electric Power	$6,051,000	$ 8,328,000
Forestry	1,212,000	1,212,000
Fish Industry	0	379,000
Navigation	205,000	1,068,000
Flood Control	164,000	164,000
Total Annual Benefits	$7,632,000	$11,151,000

The total gross annual benefits and the total annual costs of the hydro system with thermal support and transmission system together with the gross cost-benefit ratios for typical years are listed in the following table. The annual costs are detailed in Appendix B.

COST-BENEFIT RATIOS

Year	Annual Costs Dollars	Annual Gross Benefits Dollars	Cost-Benefit Ratio
1960	5,680,000	7,632,000	1.34
1965	5,680,000	11,151,000	1.96

The above attractive cost-benefit ratios prove the Karnafuli Project to be an economically sound development. The cost-benefit ratio is 1.96 in 1965 and will increase in subsequent years.

There will be a substantial benefit in the saving of foreign exchange. For the year 1965 the saving in foreign exchange is estimated to be $2,461,000 and increasing thereafter. The completion of the Karnafuli Project will doubtless be of substantial benefit to the economy of East Pakistan and it may be expected there will be many intangible benefits not evaluated herein.

Signed at San Francisco, California, March 21, 1955

FOR INTERNATIONAL ENGINEERING COMPANY, INC.

J. P. Hawke

J. P. Hawke, Project Engineer

T. Mundal

T. Mundal, Chief Engineer

C P Dunn

C. P. Dunn, President

EXHIBITS

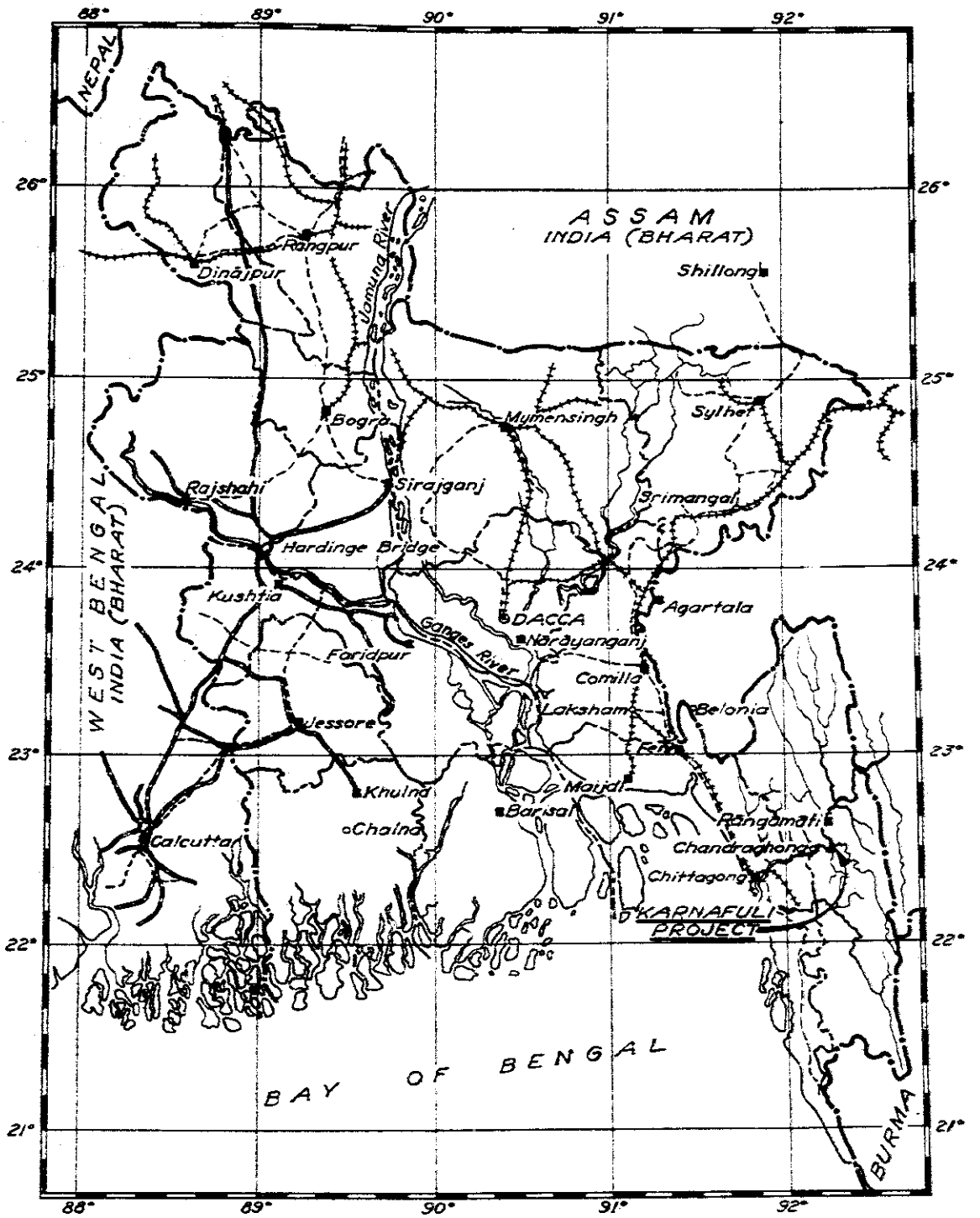
LIST OF EXHIBITS

Exhibit Number	Title	Drawing Number
1	Location Map	BW-10-201
2	Transmission Stage I H. T. Distribution Dacca and Chittagong Area	BW-04-246
3	Transmission Stage II	BW-04-247
4	Power Demand and Annual Energy Consumption for Dacca-Chittagong-Comilla Areas	BW-04-248
5	Forecast Annual Energy Consumption for Dacca-Chittagong-Comilla Areas	BW-04-249
6	Reservoir Area	BW-10-202
7	Map of Watershed	BW-04-210
8	Rainfall Map of East Pakistan	BW-04-240
9	Average Rainfall in East Pakistan by Months	BW-04-241
10	Hydrographs of Daily Flow Rangamati 1935-1941	BW-10-301
11	Hydrographs of Daily Flow Rangamati 1942-1948	BW-10-302
12	Hydrographs of Daily Flow Rangamati 1949-1954	BW-10-303
13	Hydrographs of Direct Runoff at Rangamati, and Unitgraphs	BW-04-242
14	Relation of Excess Rainfall and Unitgraph Lag at Rangamati	BW-04-243
15	Karnafuli River Dimensionless and Evaluated Unitgraphs	BW-04-244

Exhibit Number	Title	Drawing Number
16	Spillway Design Flood Inflow - Outflow Hydrographs	BW-04-245
17	Reservoir Flood Routing Studies	BW-04-250
18	Area, Capacity, Discharge and Tail water curves	BW-10-304
19	General Layout	BW-10-901
20	Main Dam and Saddle Dam General Plan and Sections	BW-12-401
21	Main Dam and Saddle Dam Sections	BW-12-402
22	Diversion and Outlet Tunnel Alignment, Profile and Sections	BW-32-201
23	Spillway General Plan and Sections	BW-13-301
24	Navigation Locks General Plan and Sections	BW-61-301
25	Power Plant Site Plan	BW-42-201
26	Powerhouse Transverse Section Through Units	BW-42-210
27	Construction Schedule	BW-85-201

Appendix F

F-1	Proposed Land Reclamation Area	BW-04-216
F-2	Land Use Classification	BW-04-217
F-3	General Layout of Unit Area	BW-04-218
F-4	Earthwork Installations in Unit Area	BW-04-219



LEGEND:
Boundry, International
Boundry, Province and District
Capital of country
Headquarters of district or subdivision
Other towns
Railway, Broad gauge
Railway, Other gauge
Roads

Scale 0 30 60 Miles

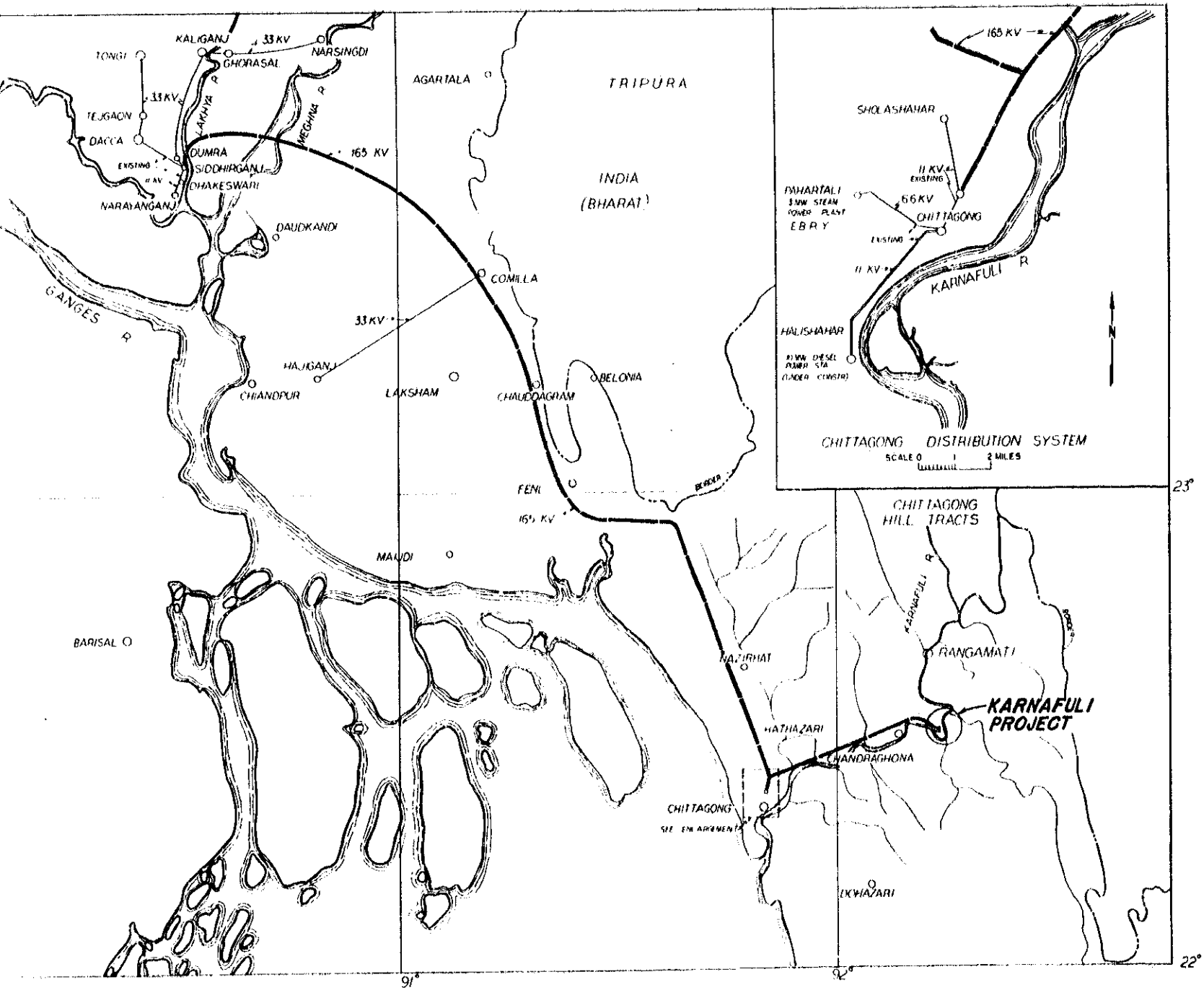
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

LOCATION MAP

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED —	CHK'D. J.F.T.	SUBMITTED
DRAWN J. R. F.	INSP.	RECOMMENDED
TRACED		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-10-201

EXHIBIT 2



GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

TRANSMISSION STAGE I

H.T. DISTRIBUTION

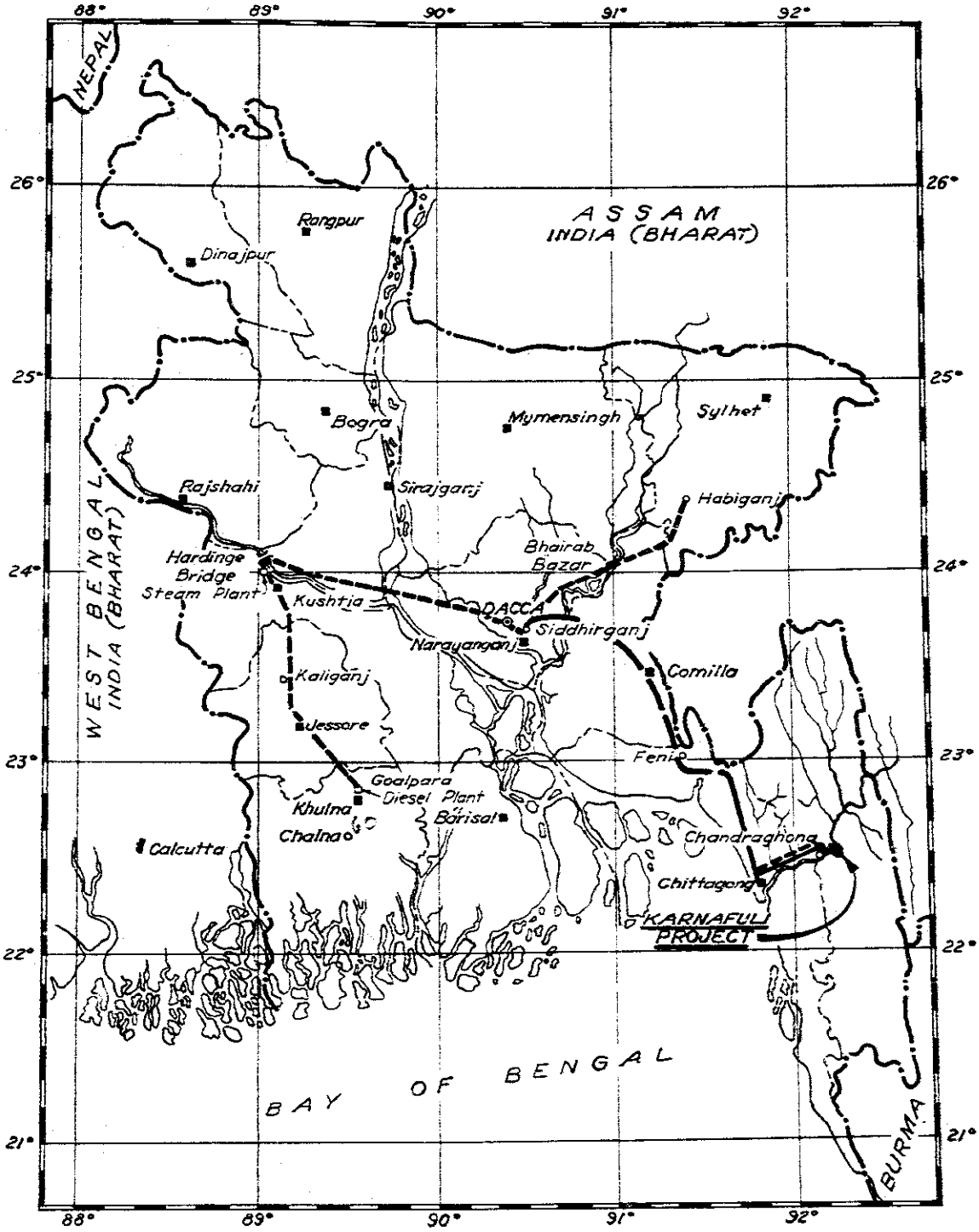
DACCA AND CHITTAGONG AREA

INTERNATIONAL ENGINEERING CO., INC.

SAN FRANCISCO, CAL.

DATE MARCH 1959

BW-04-246



Scale 0 30 60 Miles

LEGEND:

- Boundary, International
- Boundary, Province and District
- Capital of Province
- Headquarters of district or subdivision
- Other towns
- 165 KV Transmission Line 1st Phase of Construction
- 165 KV Transmission Line 2nd Phase of Construction

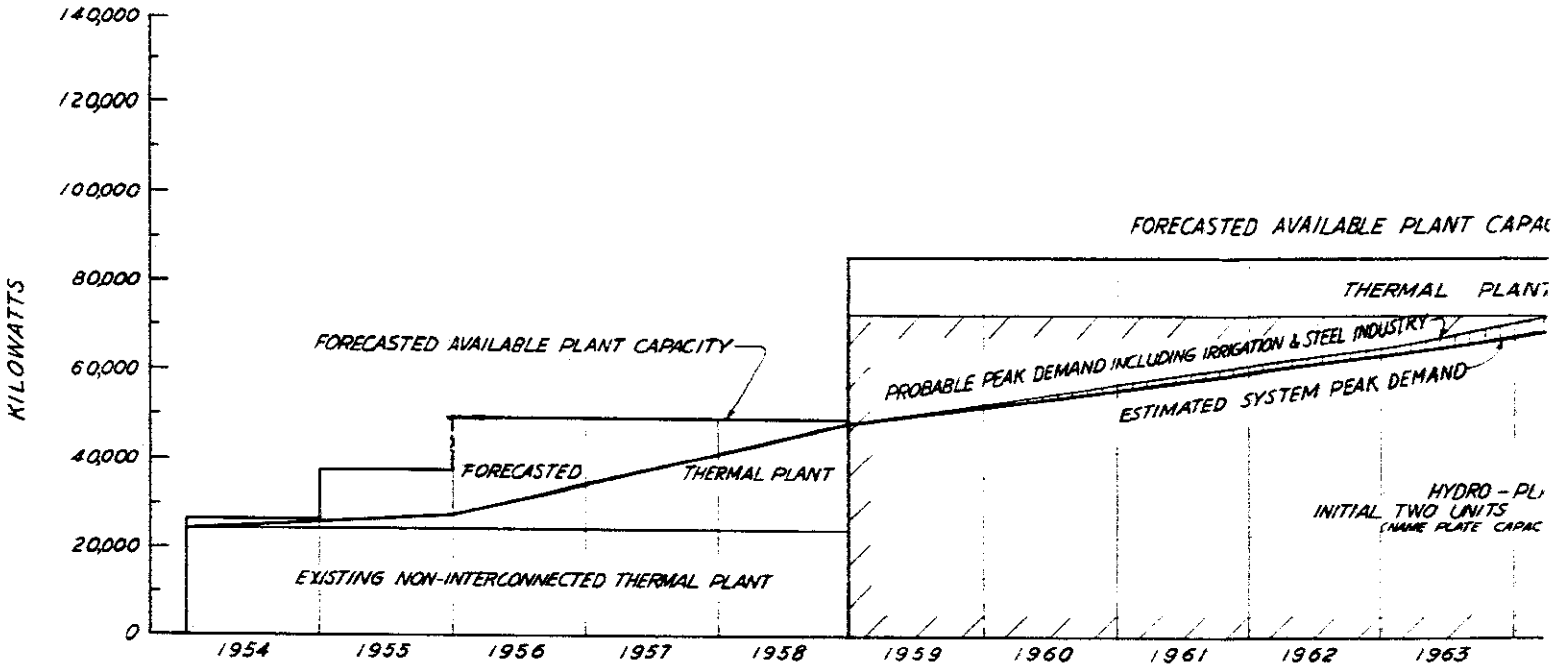
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

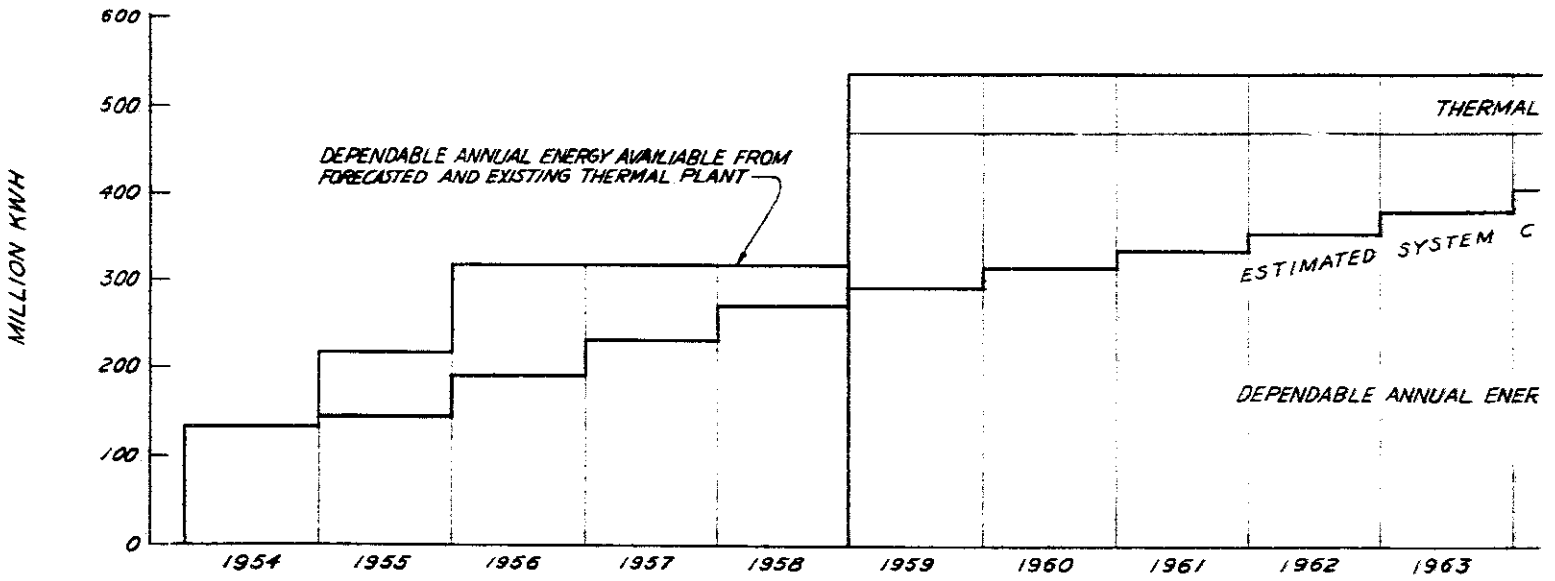
TRANSMISSION STAGE II

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED I.E.C.	CHK'D. C.B.K.	SUBMITTED
DRAWN J.R.F.	INSP.	RECOMMENDED
TRACED		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-247

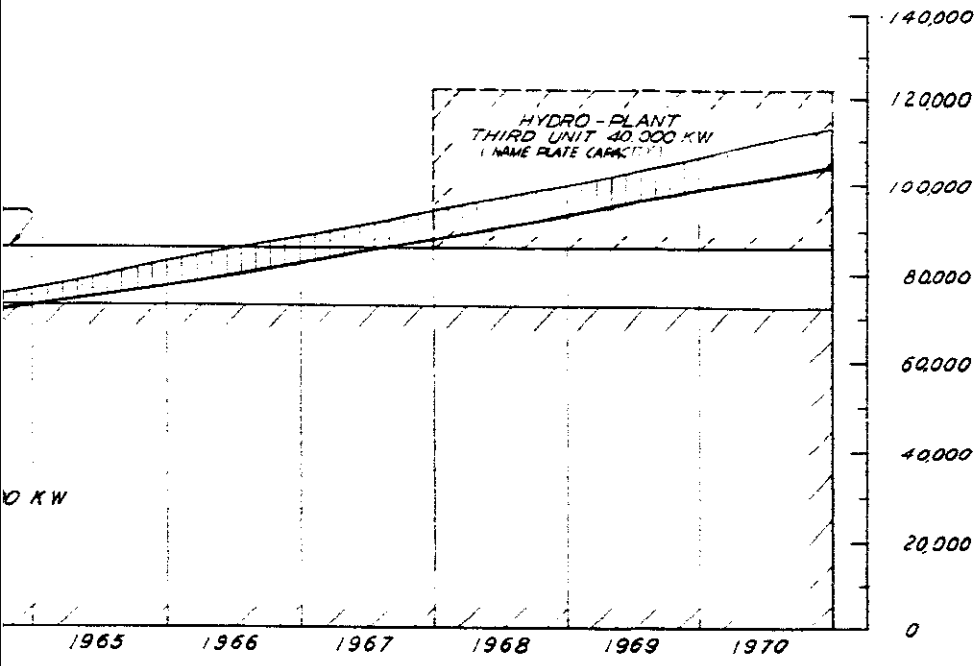


POWER



ENERGY

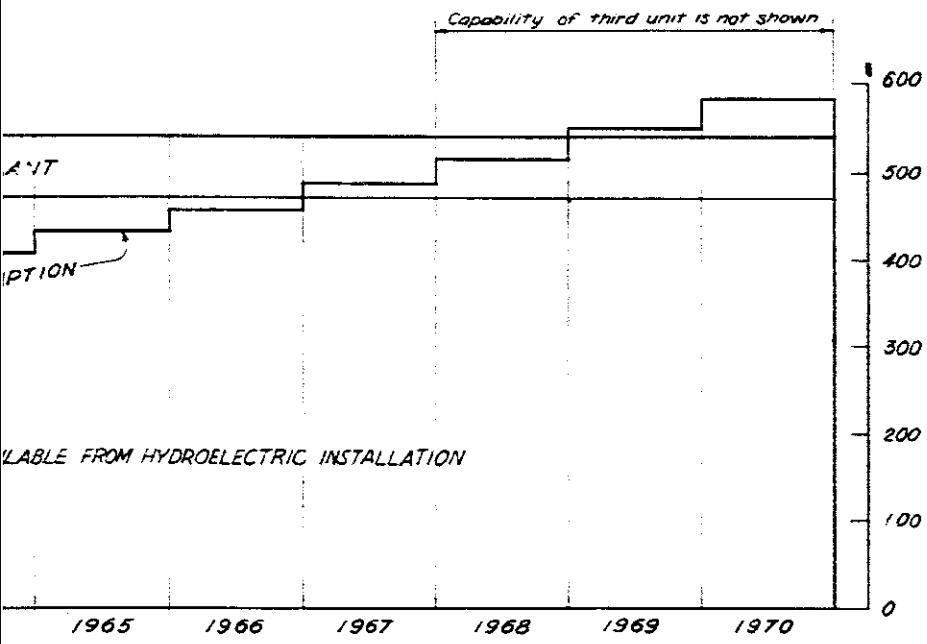
143



NOTE

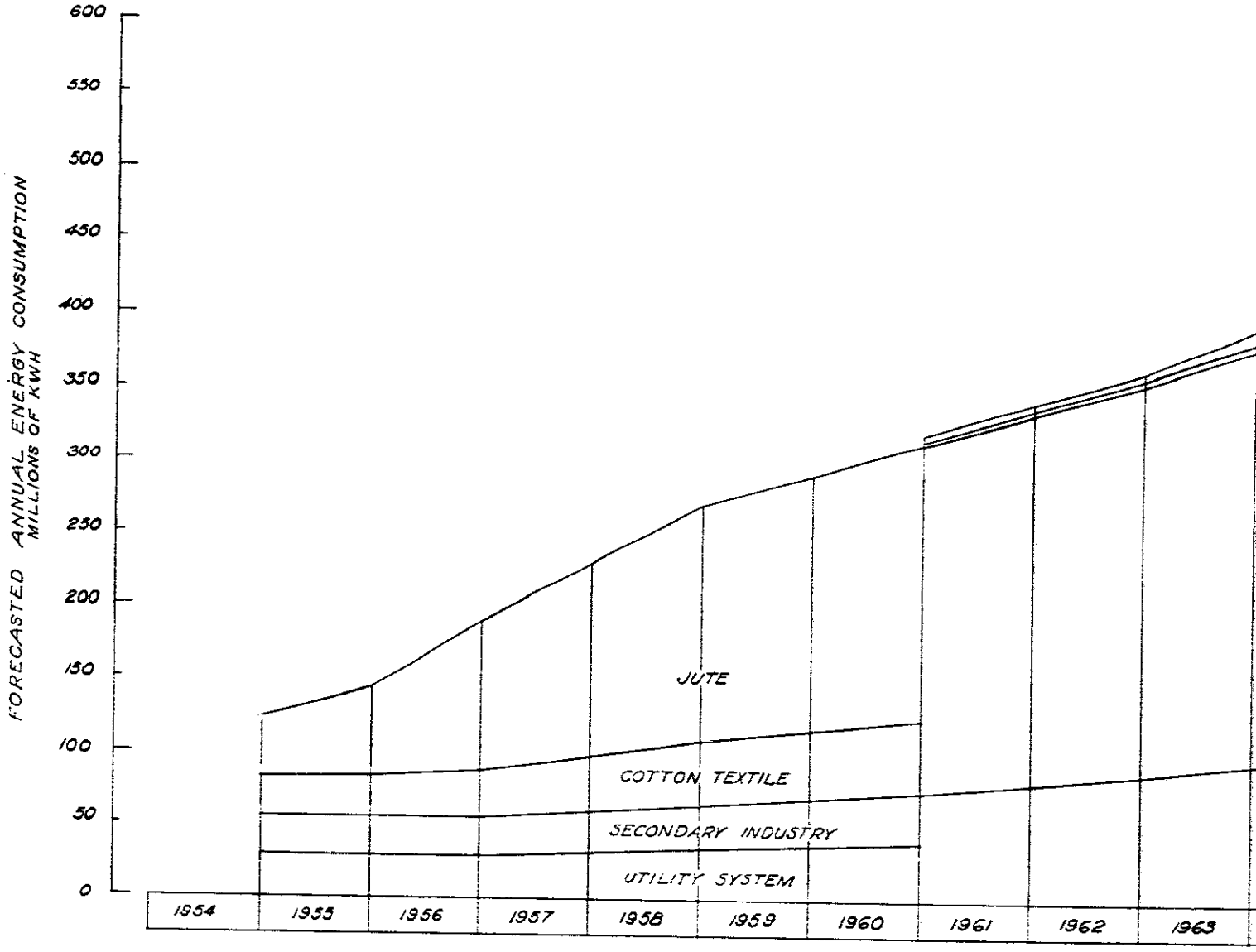
1. Thermal plant after 1958 consists of useable plant from existing non-interconnected plant and sufficient additional new thermal plant to total 15,000 kw. Remaining thermal plant retired or removed to other areas of demand. Selection to be made on basis of engineering inspection when hydro plant becomes available.

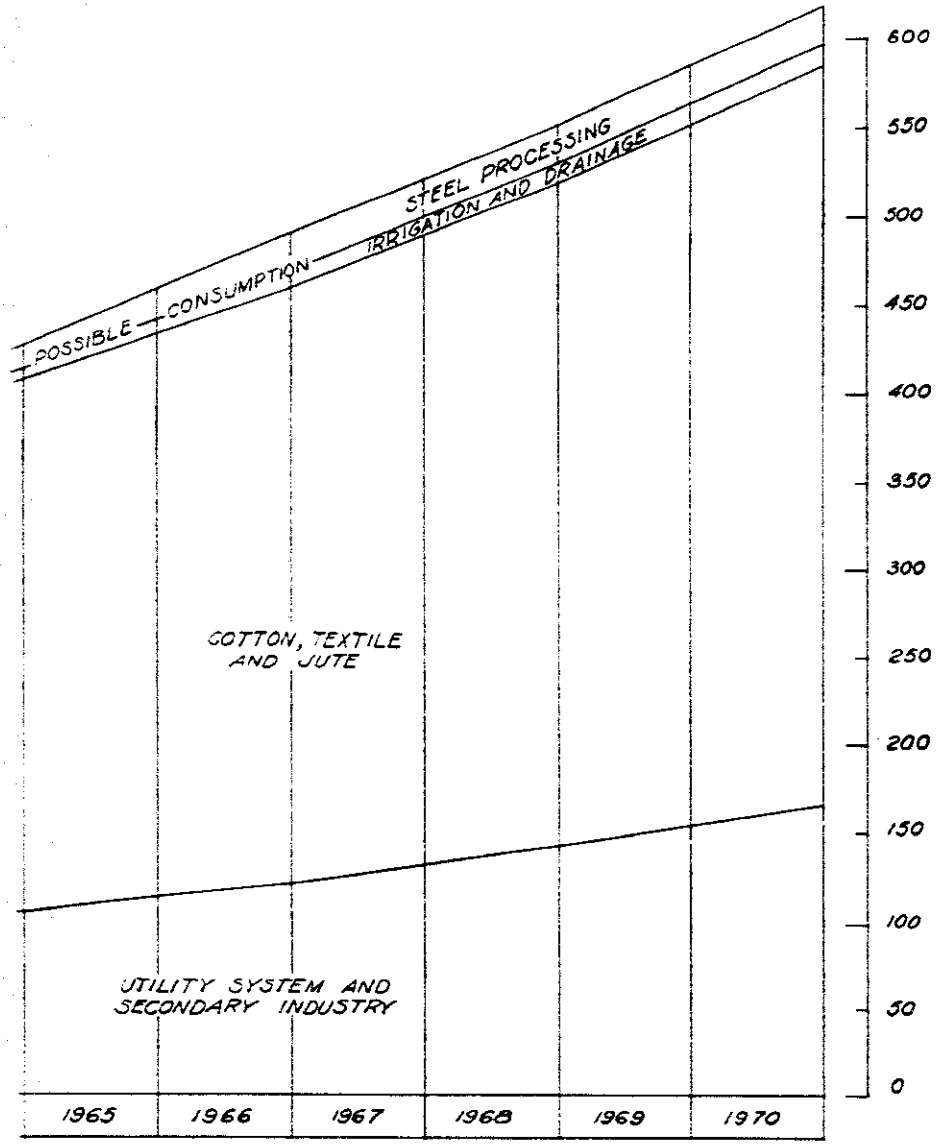
2. Available plant capacity is considered to be 90 % of name plate capacity.



GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT POWER DEMAND AND ANNUAL ENERGY CONSUMPTION FOR DACCA-CHITTAGONG-COMILLA AREAS		
INTERNATIONAL ENGINEERING CO., INC.		
DESIGNED L.E. DRAWN	CHECK F.F.S. REP.	SUBMITTED RECOMMENDED APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-248

143A


FORECASTED ANNUAL ENERGY CONSUMPTION
MILLIONS OF KWH
600
550
500
450
400
350
300
250
200
150
100
50
0
JUTE
COTTON TEXTILE
SECONDARY INDUSTRY
UTILITY SYSTEM
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963



GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

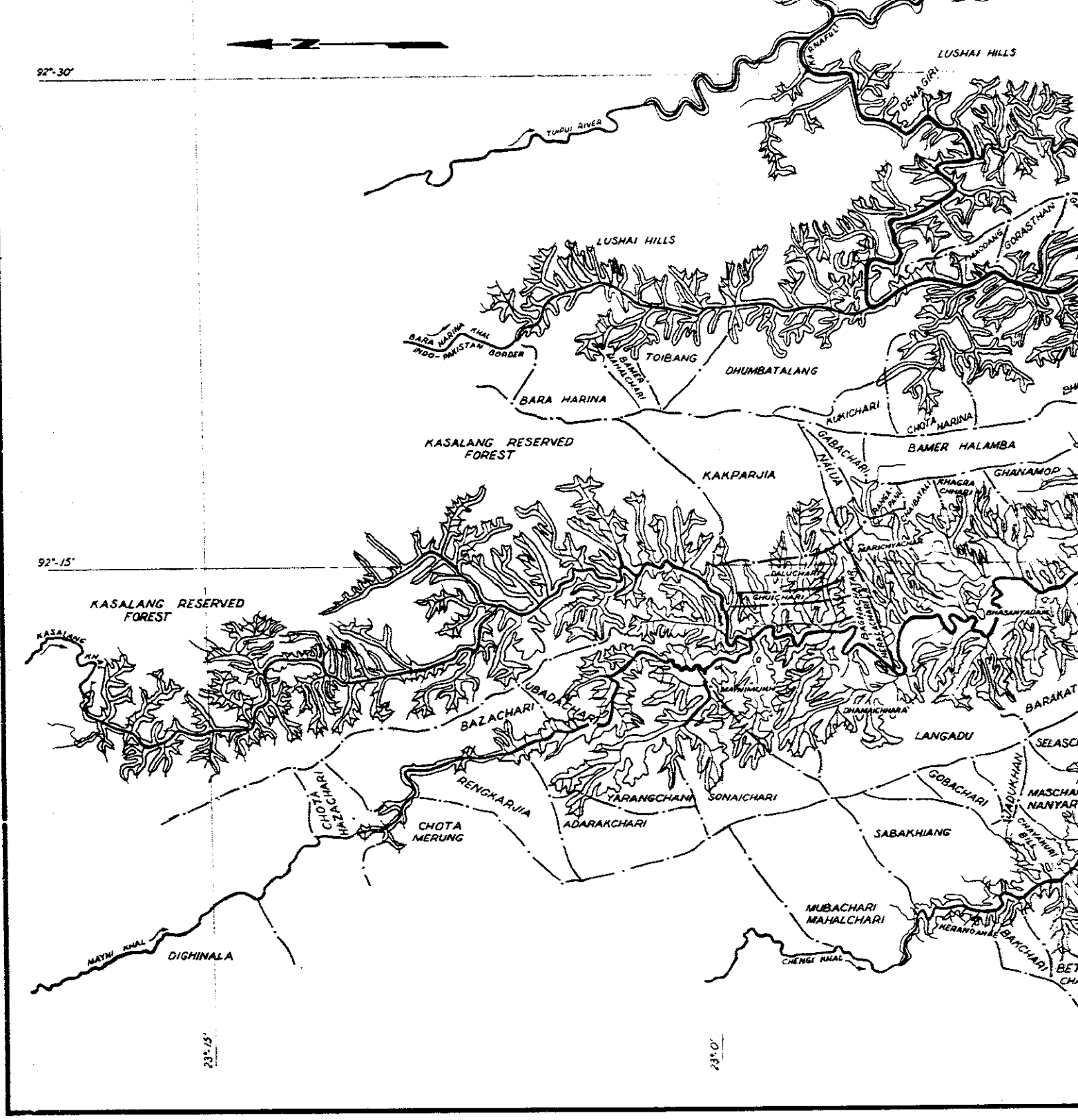
KARNAFULI PROJECT

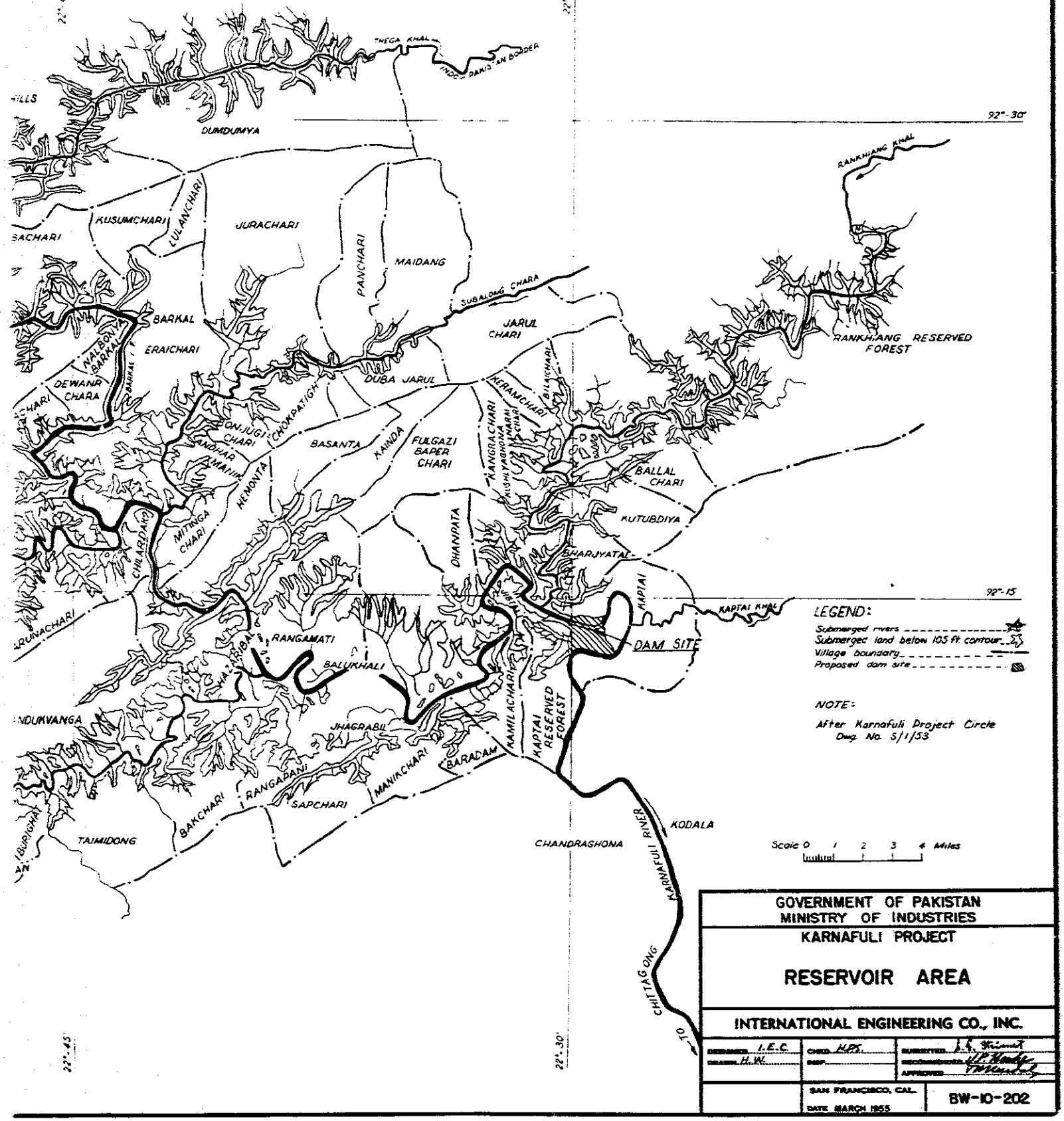
FORECAST ANNUAL ENERGY CONSUMPTION FOR DACCA-CHITTAGONG-COMILLA AREAS

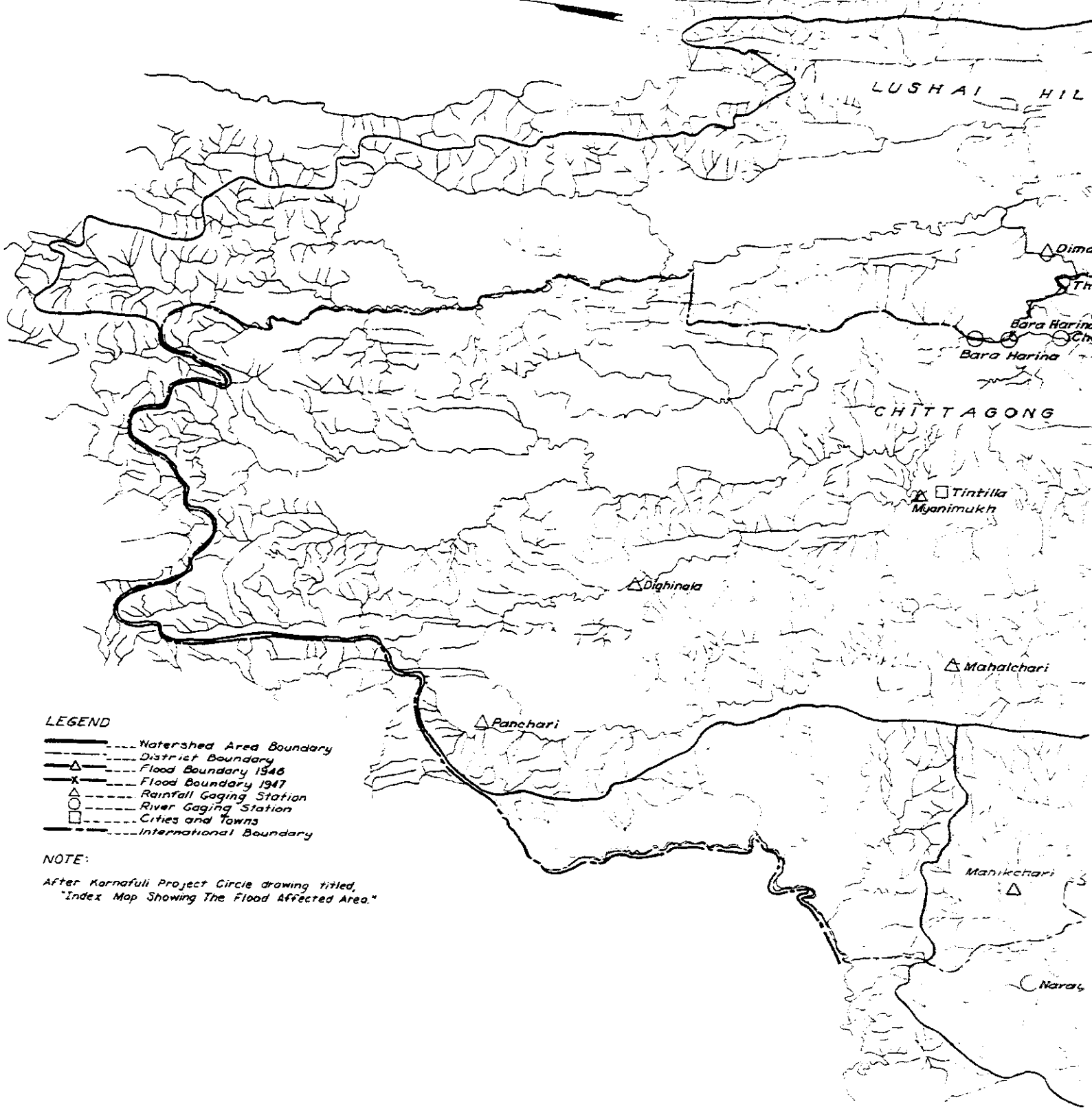
INTERNATIONAL ENGINEERING CO., INC.

DESIGNED I. E.	CHKD. P. F. S.	SUBMITTED
DRAWN RVB	SHEP.	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-249

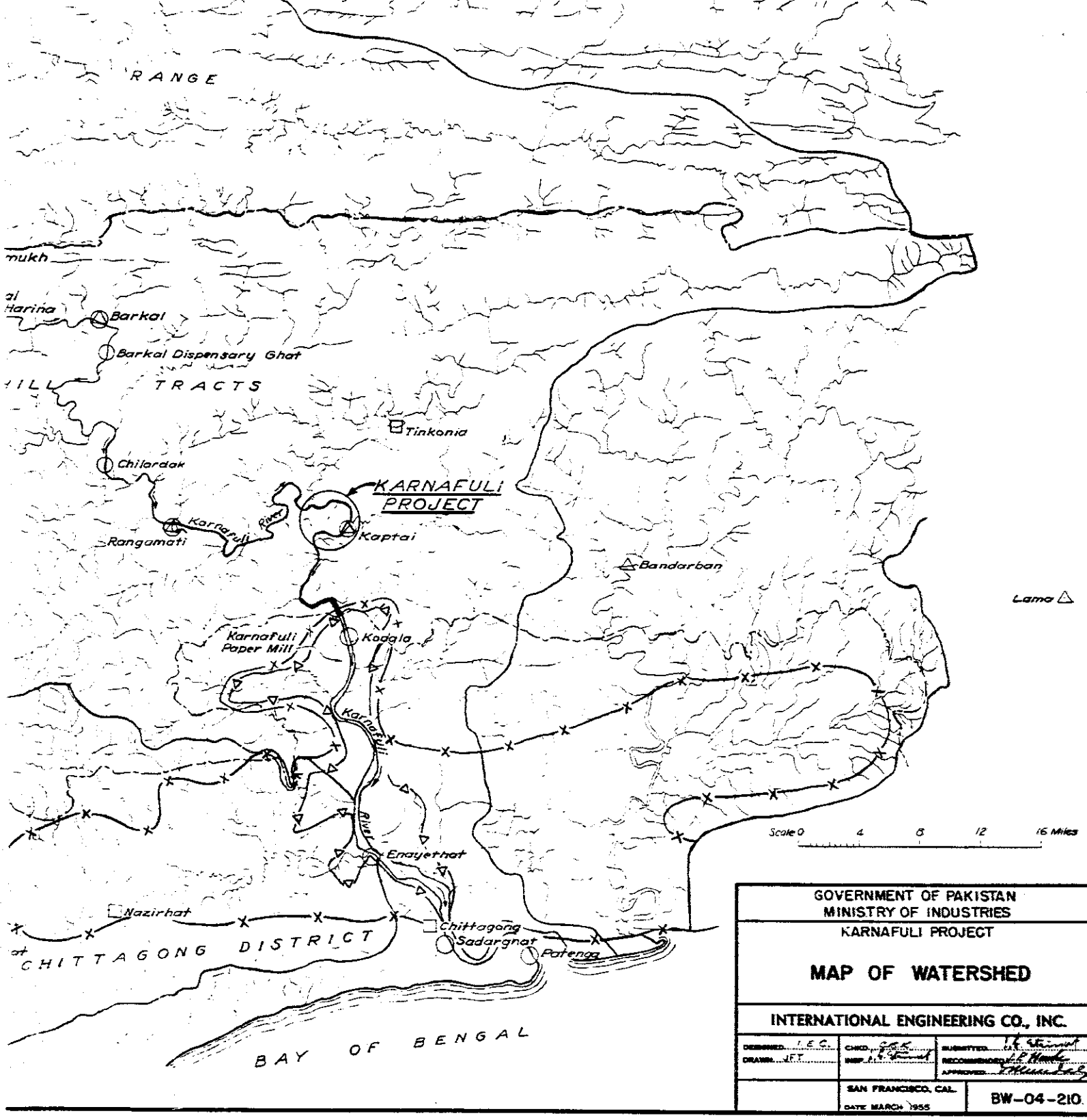
144A


N
92°-30'
92°-15'
23°-15'
23°-0'
LUSHAI HILLS
DEMAGIRI
TIPUI RIVER
LUSHAI HILLS
BARA HARINA KHAL
INDO-PAKISTAN BORDER
BAMER MAHALCHARI
TOIBANG
DHUMBATALANG
BARA HARINA
KUKICHARI
CHOTA HARINA
BAMER HALAMBA
KASALANG RESERVED FOREST
KAKPARJIA
GABACHARI
NALUA
GHANAMOP
KHAGRA CHHARI
KASALANG RESERVED FOREST
KASALANG
BAZACHARI
LUBADACHARI
LANGADU
BARAKAT
SELASC
GOBACHARI
MASCHA
NANYAR
CHOTA HAZACHARI
RENGKARJIA
CHOTA MERUNG
YARANGCHANI
SONAICHARI
ADARAKCHARI
SABAKHIANG
MUBACHARI MAHALCHARI
KERANDANAE
BAKCHARI
CHENGI KHAL
MAYNI KHAL
DIGHINALA


THEGA KHAL
INDO-PAKISTAN BORDER
DUMDUMYA
92°-30'
RANKHIANG KHAL
KUSUMCHARI
LULANCHARI
JURACHARI
PANCHARI
MAIDANG
SUBALONG CHARA
JARUL CHARI
BARKAL
NALBONIYA BARKAL
ERAICHARI
DEWANR CHARA
DUBA JARUL
KERAMCHARI
BILAICHARI
RANKHIANG RESERVED FOREST
CHOKPATIGH
BASANTA
KAINDA
FULGAZI BAPER CHARI
KANGIRACHARI
KUSHYAGHONA
BALLAL CHARI
KUTUBDIYA
HEMONTA
MITINGA CHARI
CHILARDANG
DHANPATA
BHARJYATAL
KAPTAI
92°-15
KAPTAI KHAL
DAM SITE
RANGAMATI
BALUKHALI
KAMILACHARI
KAPTAI RESERVED FOREST
JHAGRABIL
BARADAM
MANICHARI
SAPCHARI
RANGAPANI
BAKCHARI
TAIMIDONG
CHANDRAGHONA
KARNAFULI RIVER
KODALA
CHITTAGONG
TO
22°-45'
22°-30'
LEGEND:
Submerged rivers
Submerged land below 105 ft. contour
Village boundary
Proposed dam site
NOTE:
After Karnafuli Project Circle Dwg. No. S/1/53
Scale 0 1 2 3 4 Miles
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT
RESERVOIR AREA
INTERNATIONAL ENGINEERING CO., INC.
DESIGNED I.E.C.
DRAWN H.W.
CHKD. H.P.S.
SUBMITTED
RECOMMENDED
APPROVED
SAN FRANCISCO, CAL.
DATE MARCH 1955
BW-10-202


LUSHAI HIL
Bara Harina
CHITTAGONG
Tintilla
Myanimukh
Dighinala
Mahalchari
Panchari
Manikchari
LEGEND
Watershed Area Boundary
District Boundary
Flood Boundary 1946
Flood Boundary 1947
Rainfall Gaging Station
River Gaging Station
Cities and Towns
International Boundary
NOTE:
After Karnafuli Project Circle drawing titled, "Index Map Showing The Flood Affected Area."

-146



GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

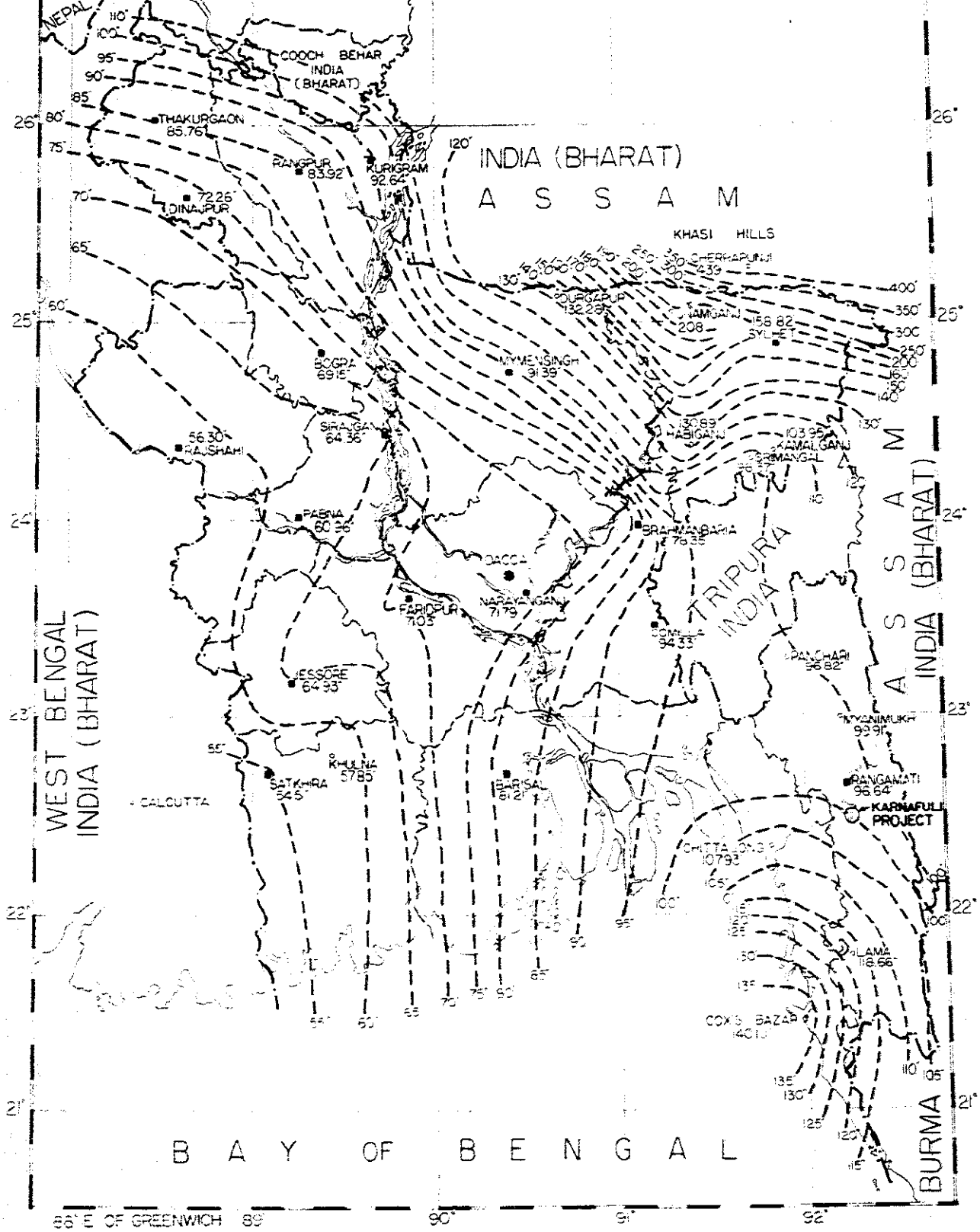
MAP OF WATERSHED

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED I.E.C. CHKD. J.E.C. SUBMITTED
DRAWN J.F.T. INSP. RECOMMENDED
APPROVED

SAN FRANCISCO, CAL.
DATE MARCH 1955

BW-04-210.



NOTE
ISOHYETALS ARE BASED ON AVERAGE ANNUAL RAINFALL IN INCHES.

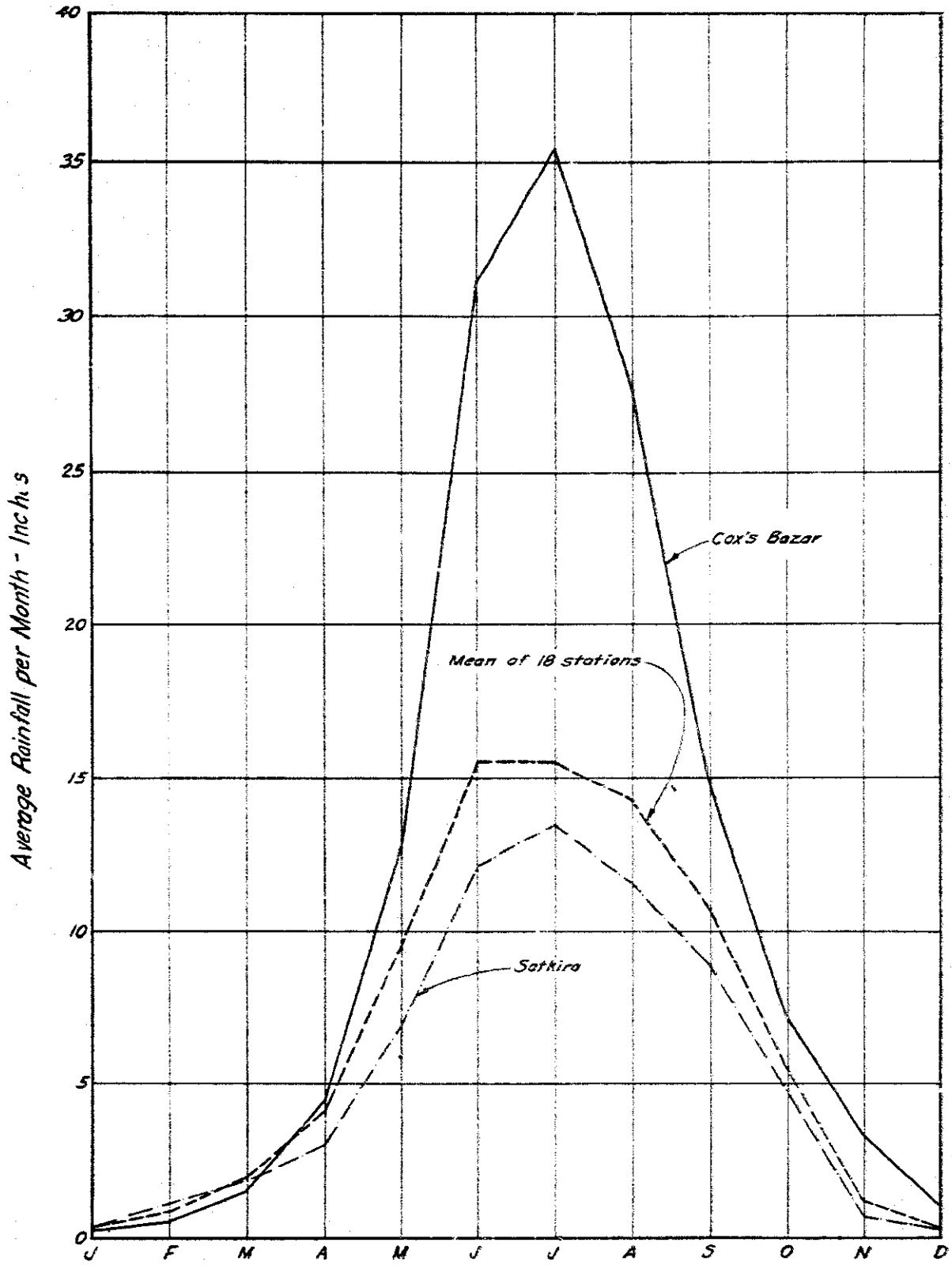
LEGEND
BOUNDARY, INTERNATIONAL
PROVINCE AND DISTRICT
HEADQUARTERS OF DISTRICT OR SUBDIVN
ISOHYETAL LINES

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

RAINFALL MAP OF EAST PAKISTAN

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED E.E.F. DRAWN H.W.	CHKD E.E.F. INSP	SUBMITTED RECOMMENDED APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-240



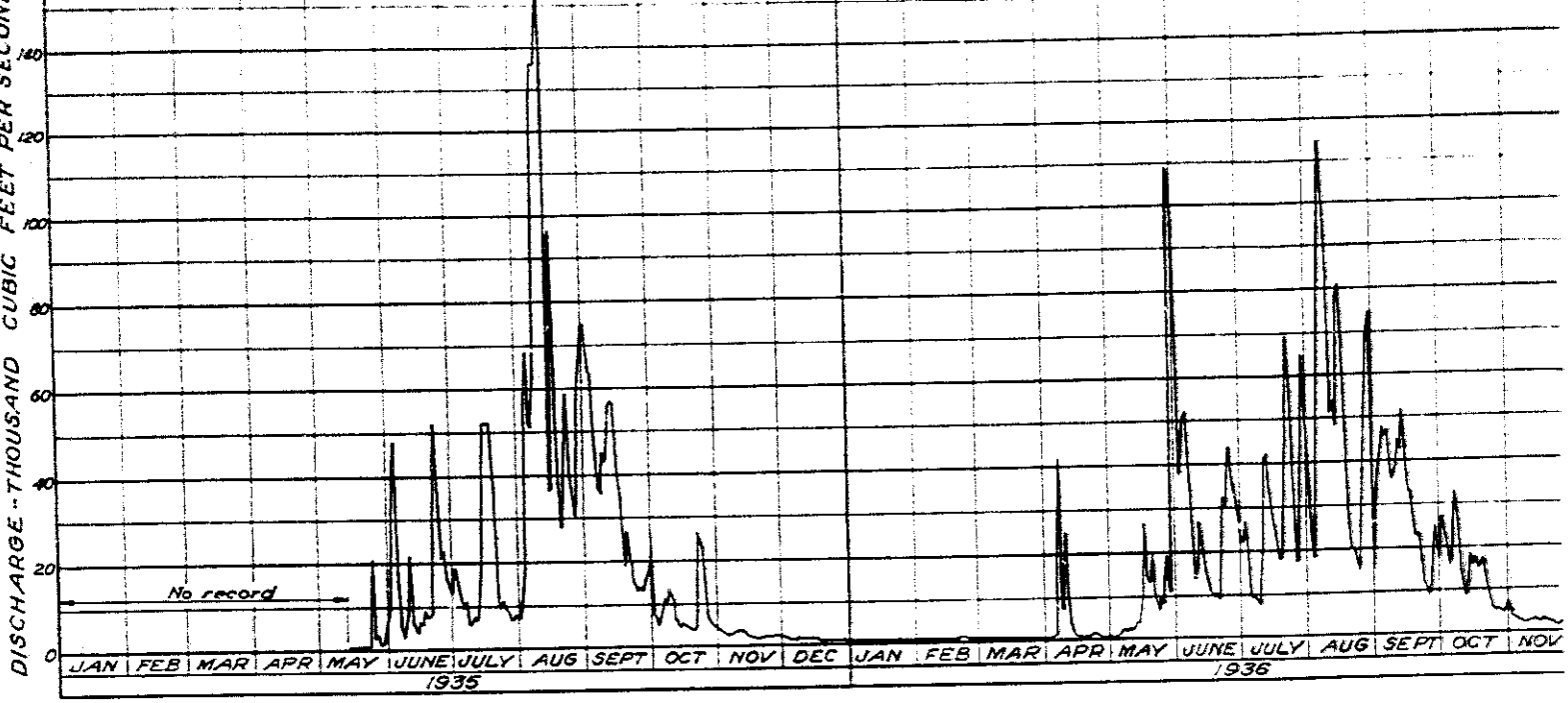
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

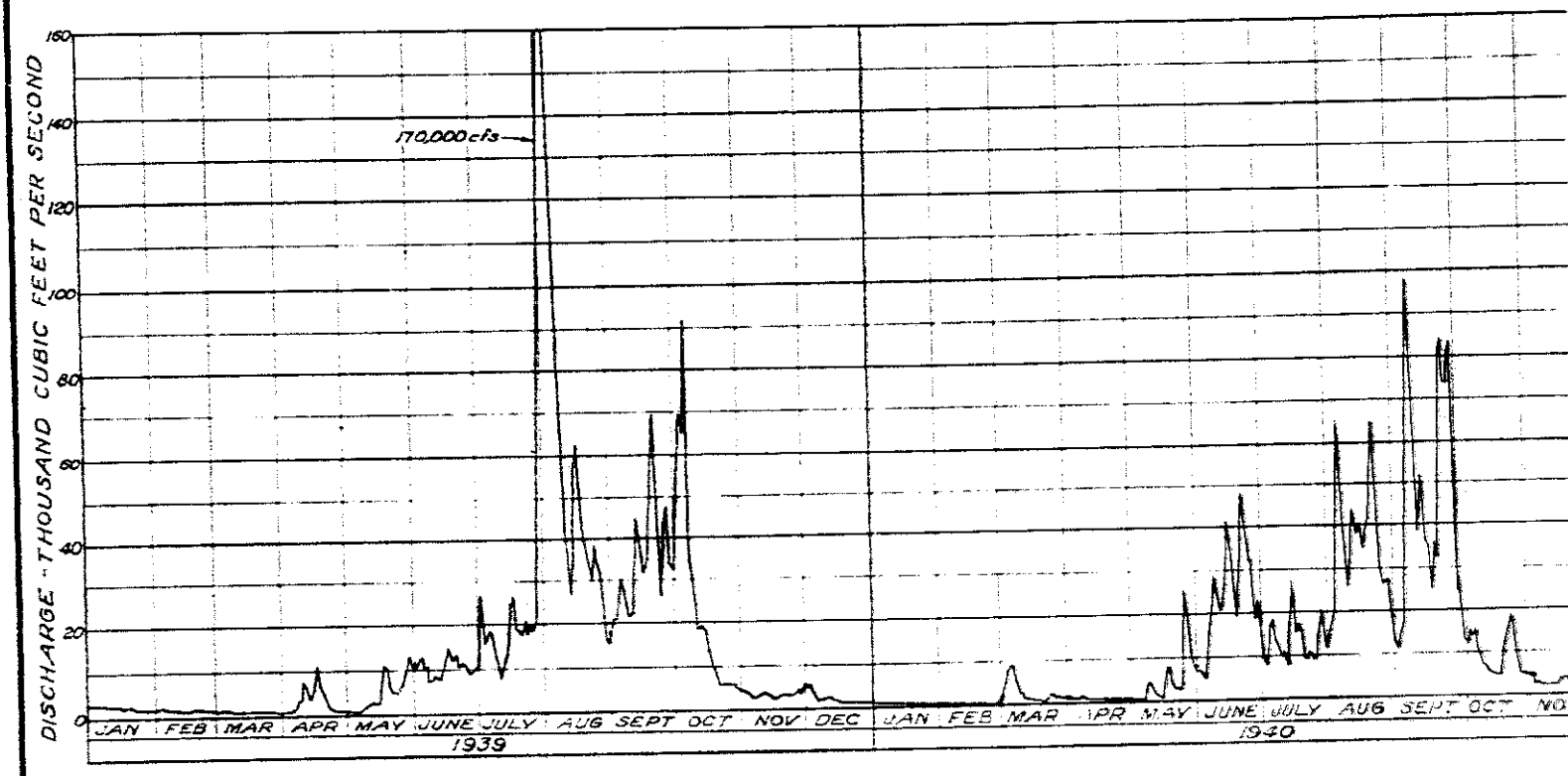
KARNAFULI PROJECT

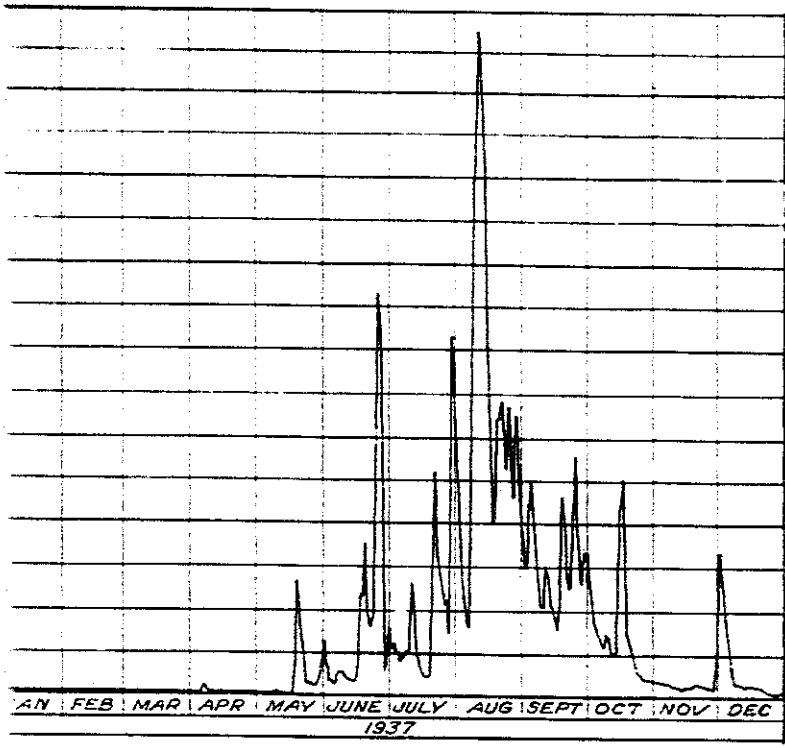
AVERAGE RAINFALL IN EAST PAKISTAN BY MONTHS

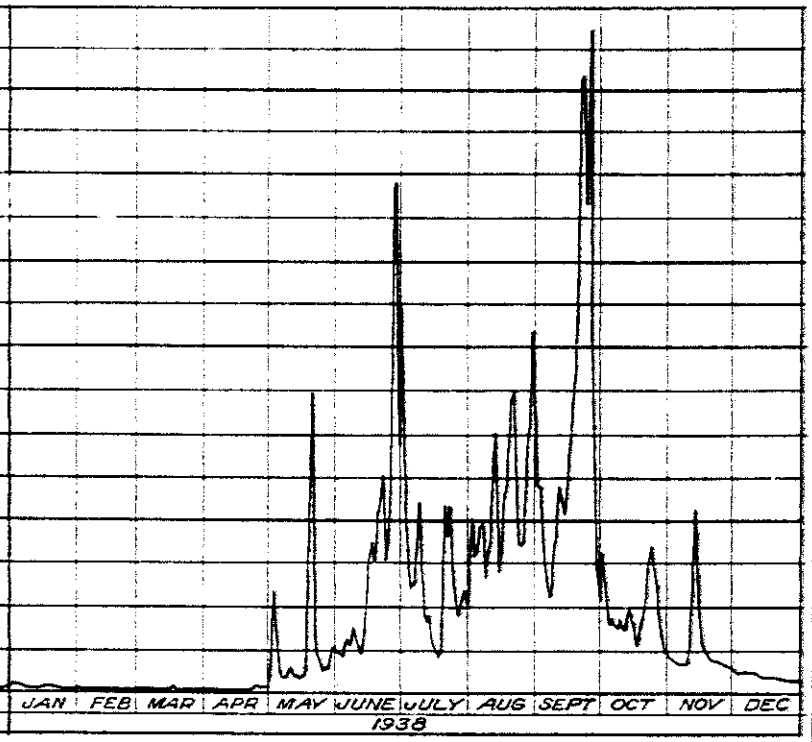
INTERNATIONAL ENGINEERING CO., INC.

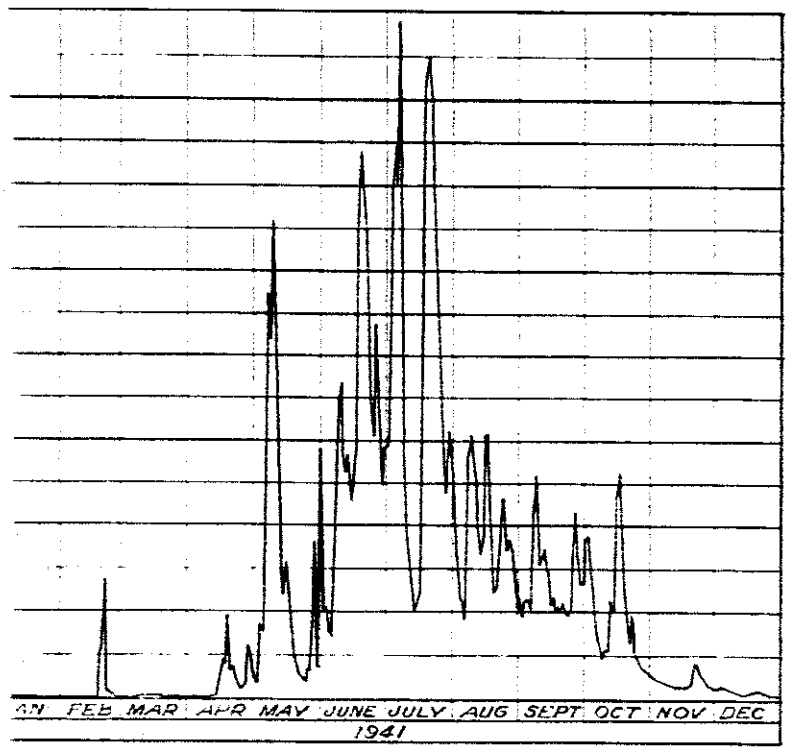
DESIGNED I.E.C. DRAWN H.W.	CHKD C.B.K. INSP	SUBM. RECM. APPD.
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-241


DISCHARGE - THOUSAND CUBIC FEET PER SECOND
0
20
40
60
80
100
120
140
No record
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1935
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1936


DISCHARGE - THOUSAND CUBIC FEET PER SECOND
0
20
40
60
80
100
120
140
160
170,000 cfs
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1939
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1940







NOTES:
Hydrographs of Daily Flow were determined from data supplied by Government of Pakistan.

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

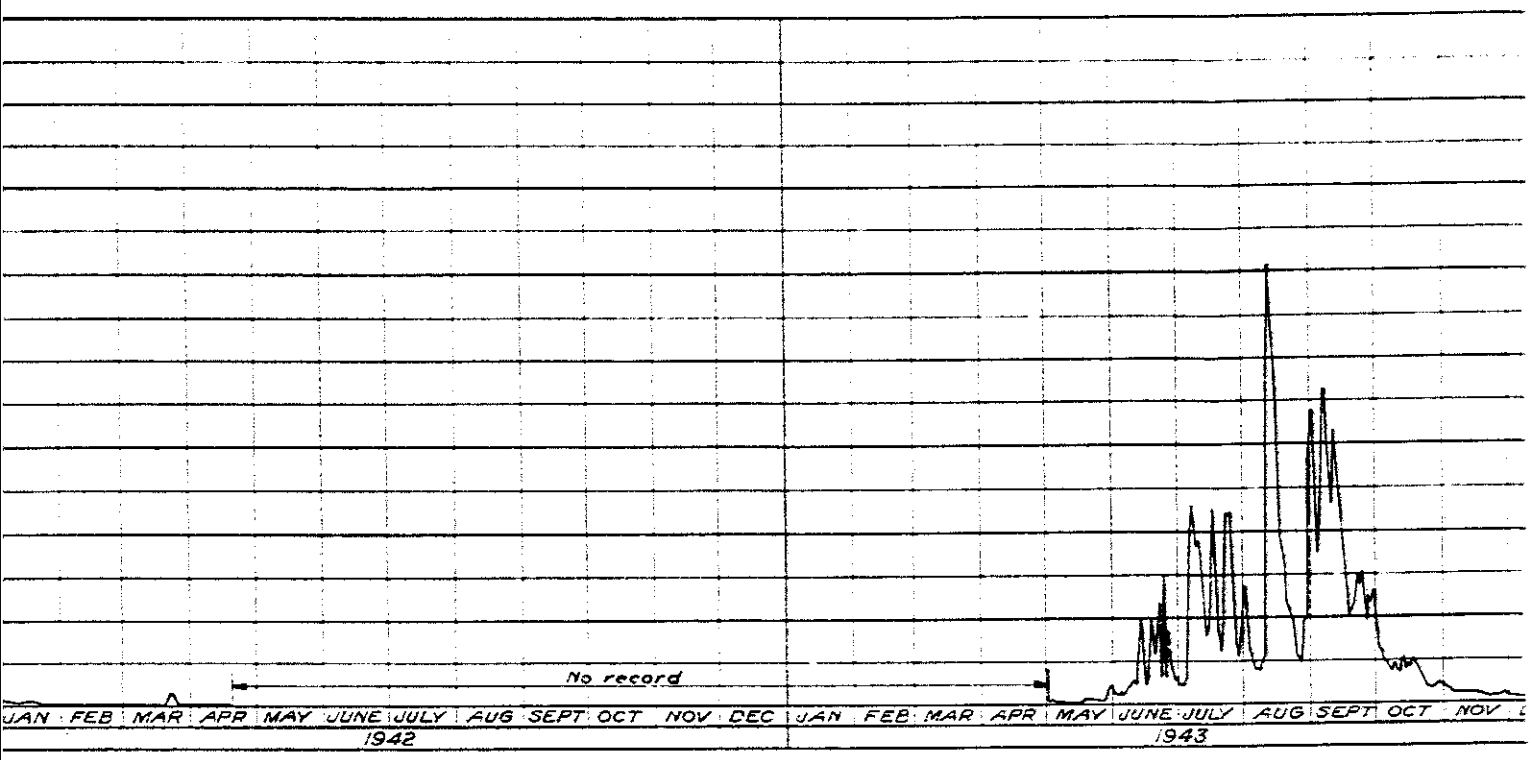
KARNAFULI PROJECT

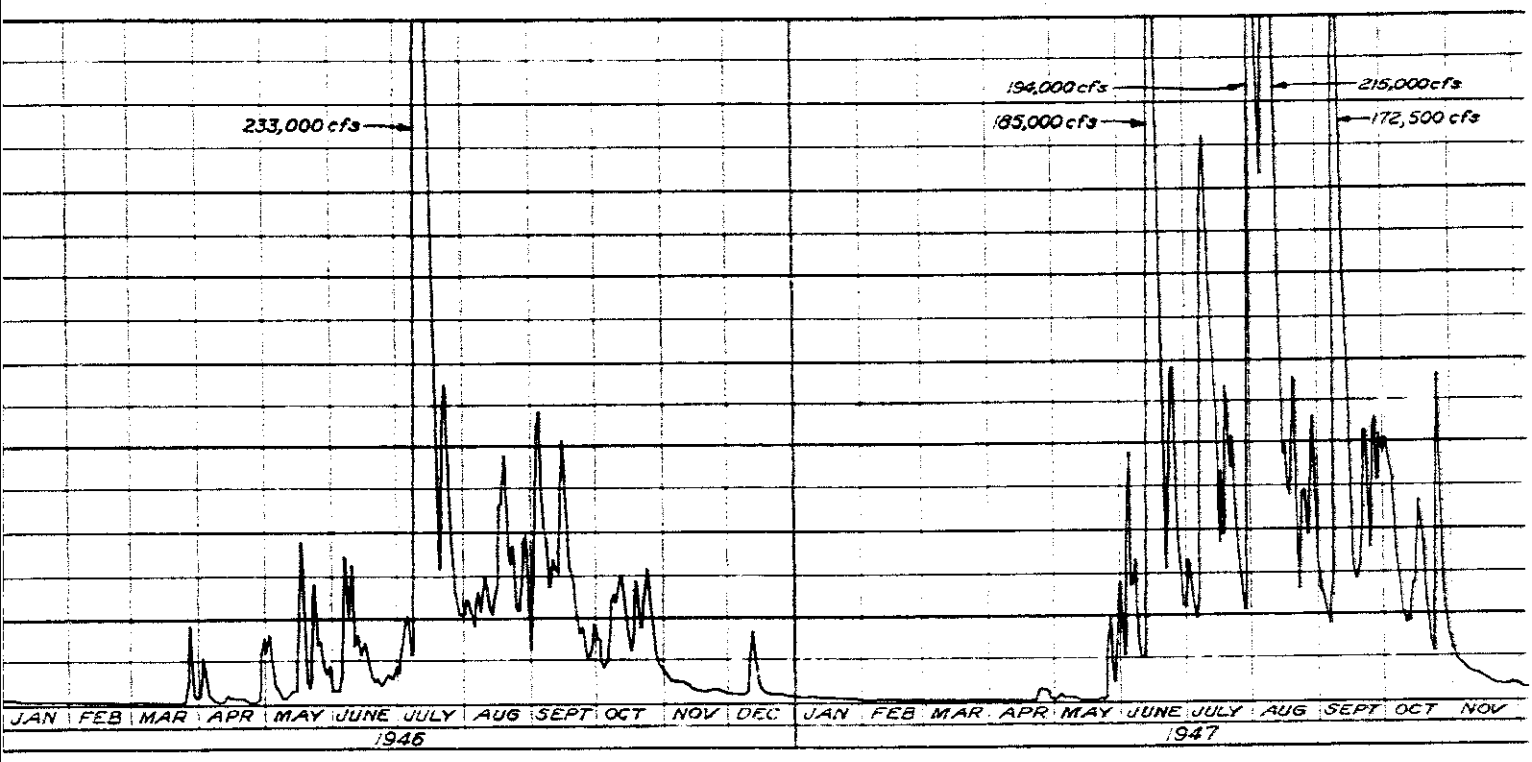
HYDROGRAPHS OF DAILY FLOW RANGAMATI 1935 - 1941

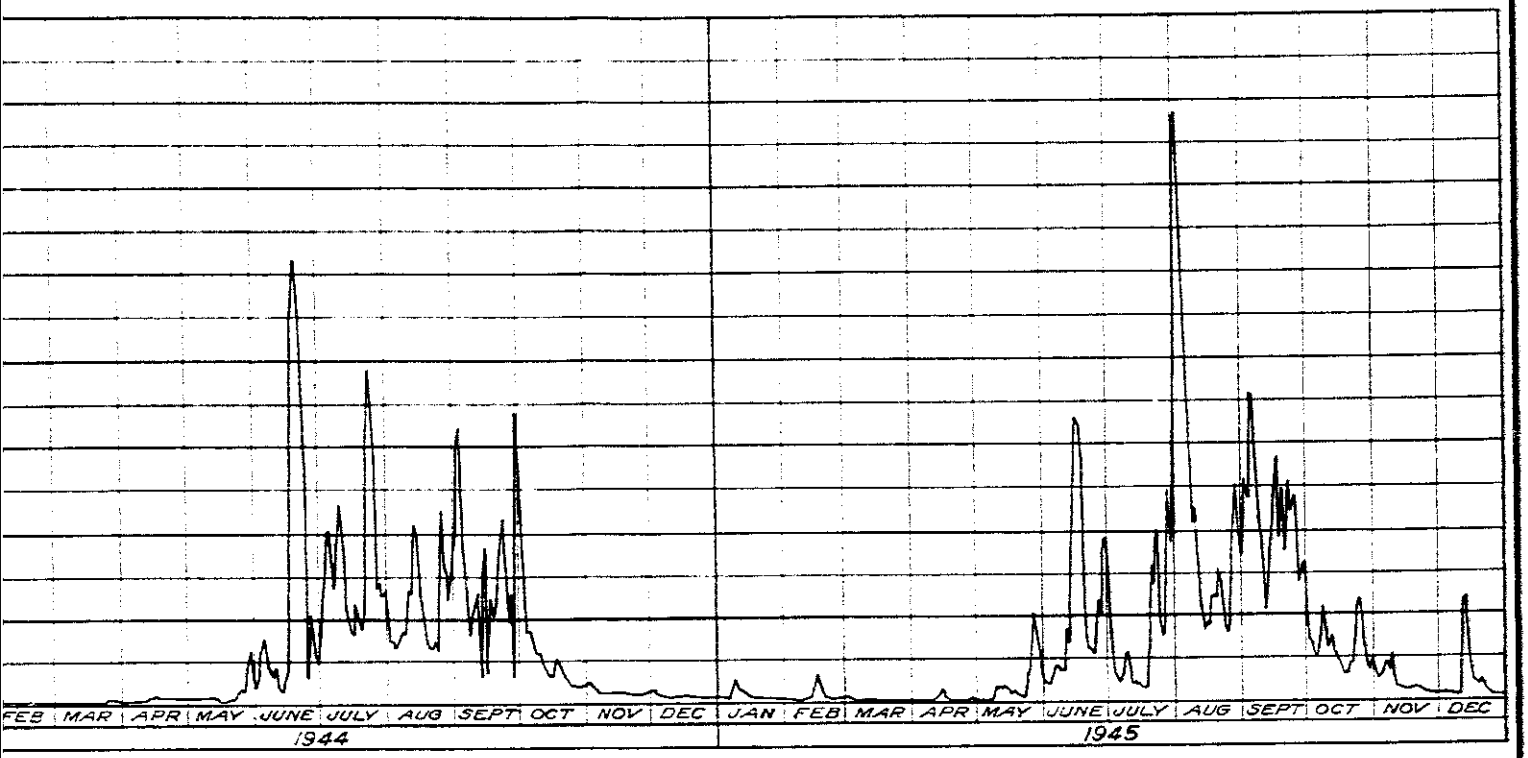
INTERNATIONAL ENGINEERING CO., INC.

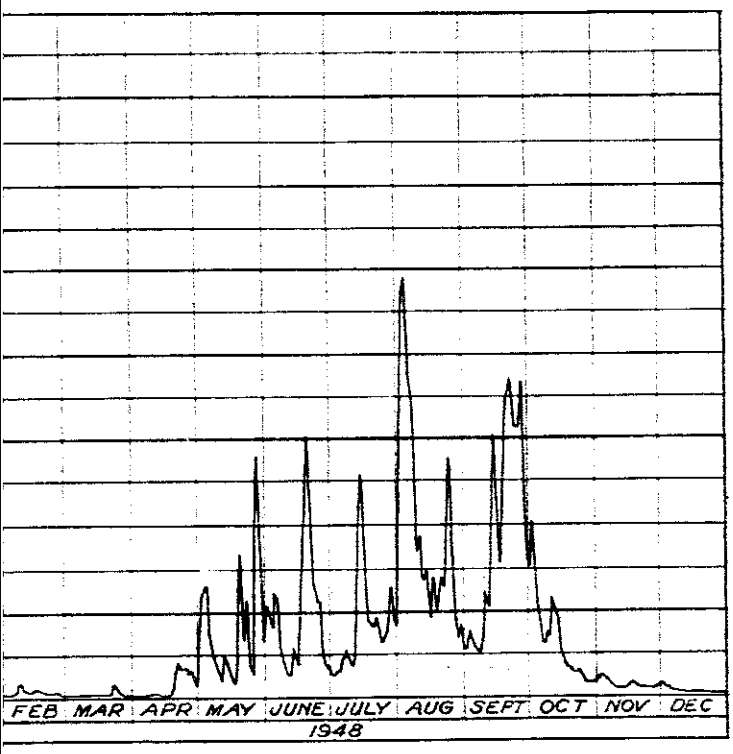
DESIGNED I.E.C.	CHKD. J.F.T.	SUBMITTED
DRAWN J.R.F.	REV.	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-10-301

-149


No record
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1942
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1943


233,000 cfs
194,000 cfs
185,000 cfs
215,000 cfs
172,500 cfs
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1946
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1947





NOTES:
See Dwg BW-10-301

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

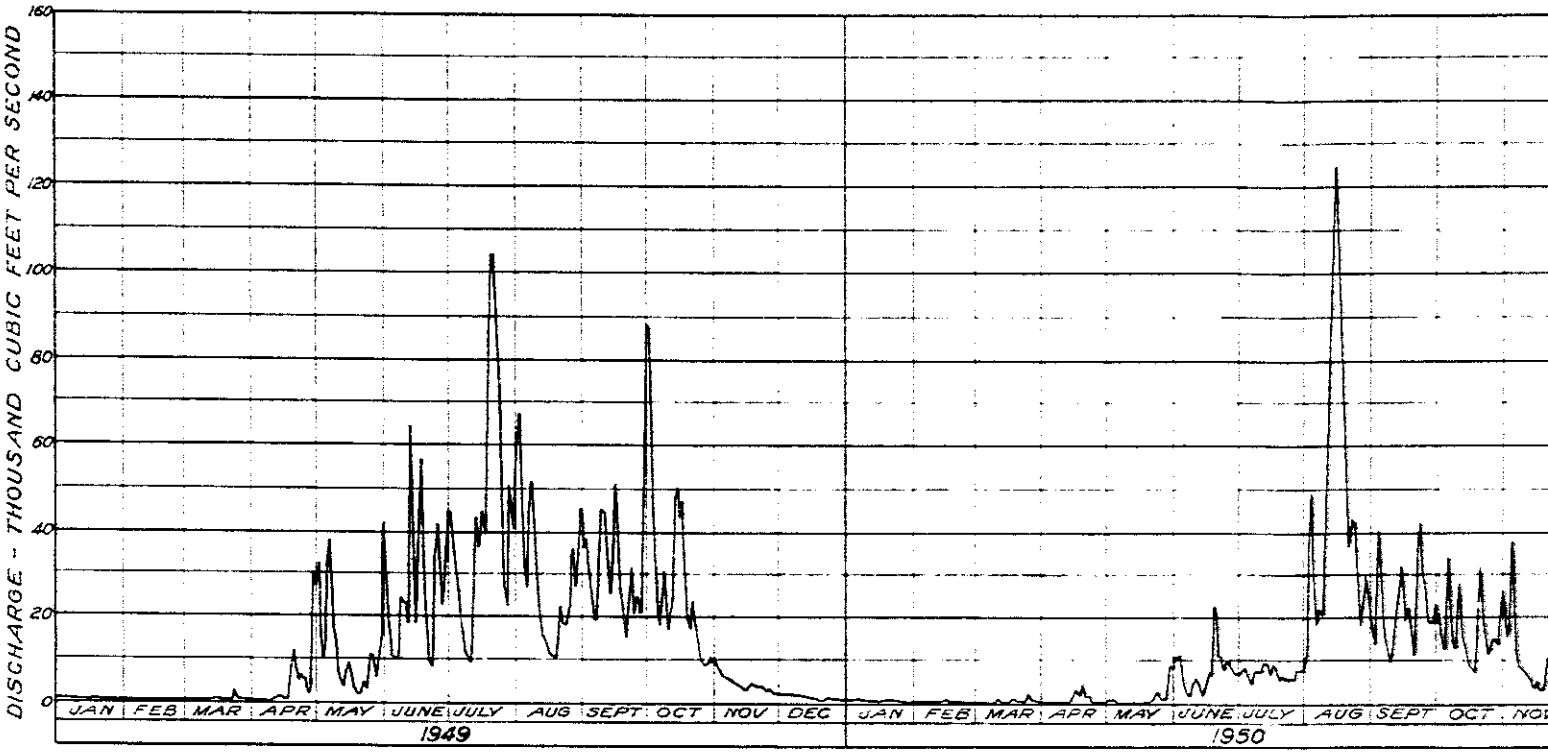
HYDROGRAPHS OF DAILY FLOW
RANGAMATI
1942 - 1948

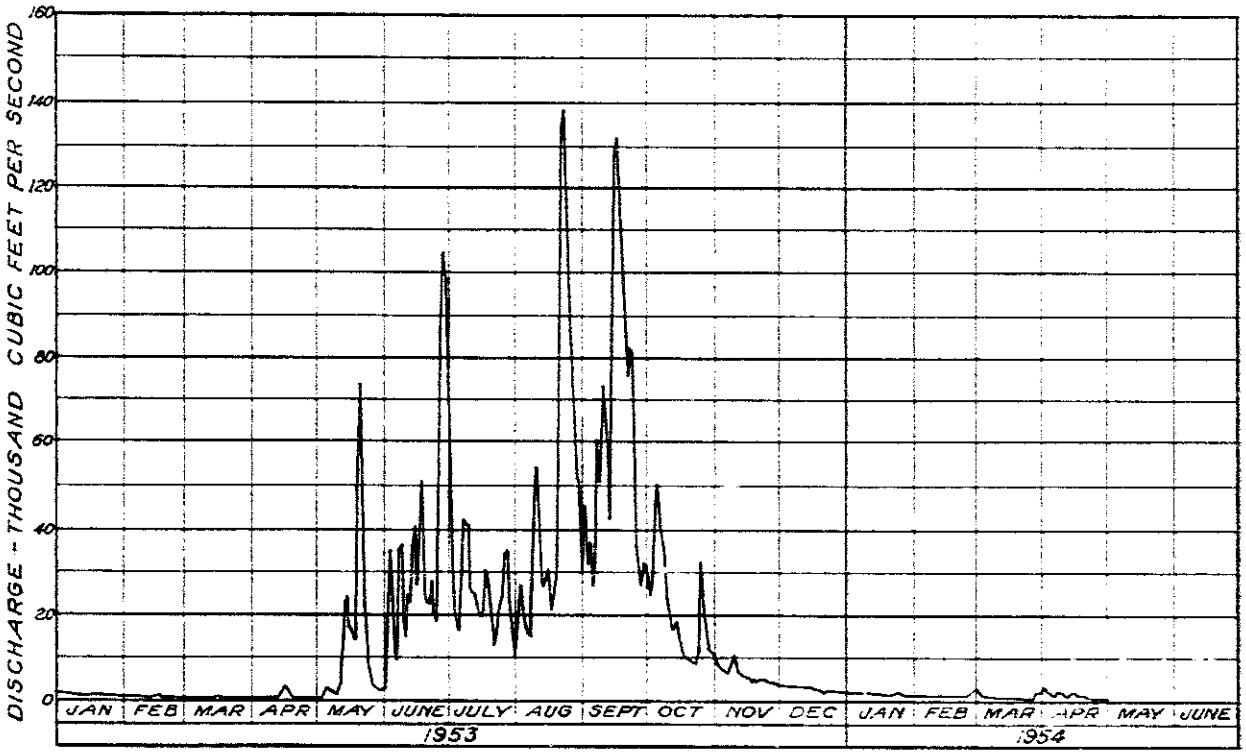
INTERNATIONAL ENGINEERING CO., INC.

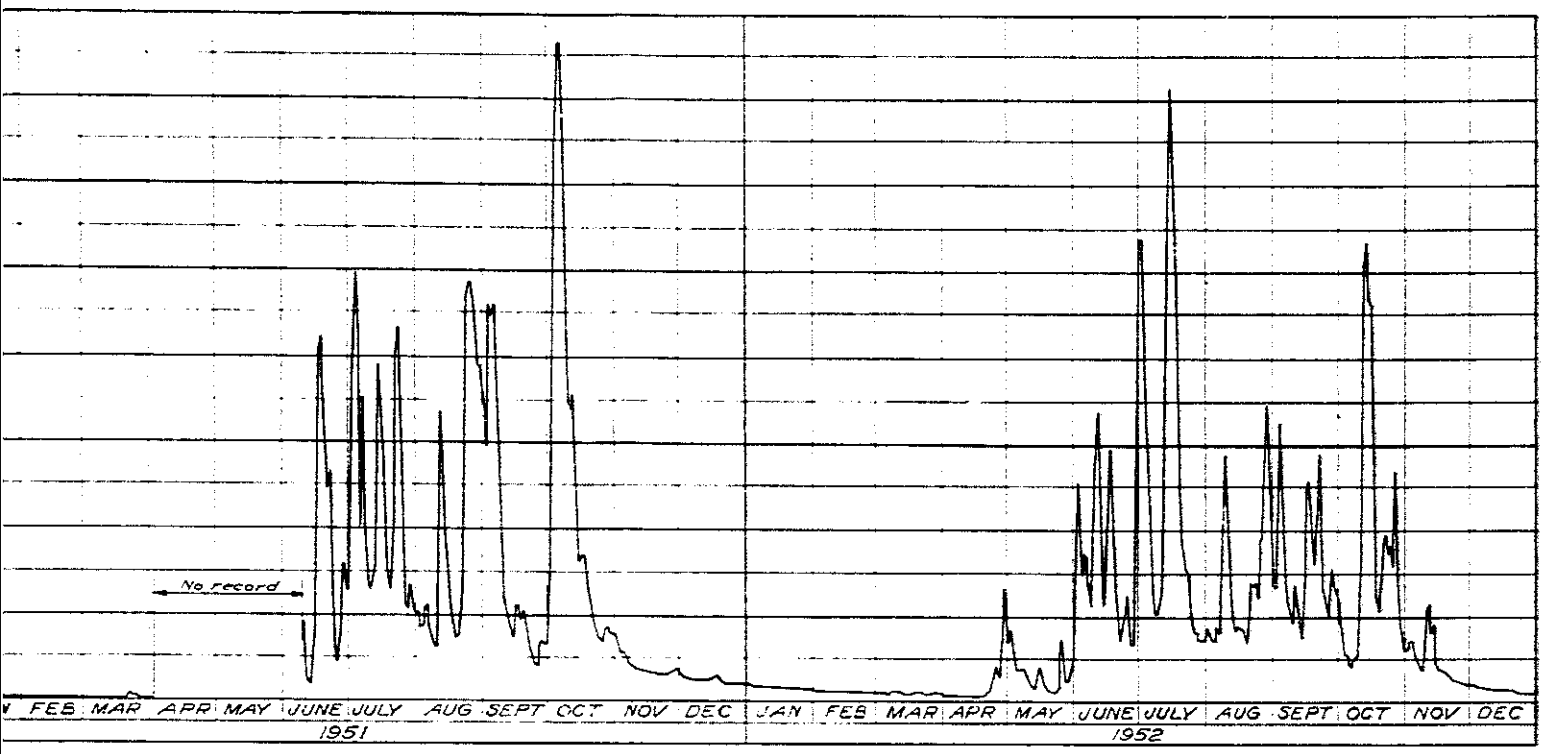
DESIGNED I.E.C. CHKD J.F.T. SUBMITTED
DRAWN J.R.F. INSP. RECOMMENDED
APPROVED

SAN FRANCISCO, CAL.
DATE MARCH 1955

BW-10-302


DISCHARGE - THOUSAND CUBIC FEET PER SECOND
160
140
120
100
80
60
40
20
0
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1949
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1950


DISCHARGE - THOUSAND CUBIC FEET PER SECOND
160
140
120
100
80
60
40
20
0
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1953
JAN FEB MAR APR MAY JUNE
1954



NOTES:
See Dwg BW-10-301

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

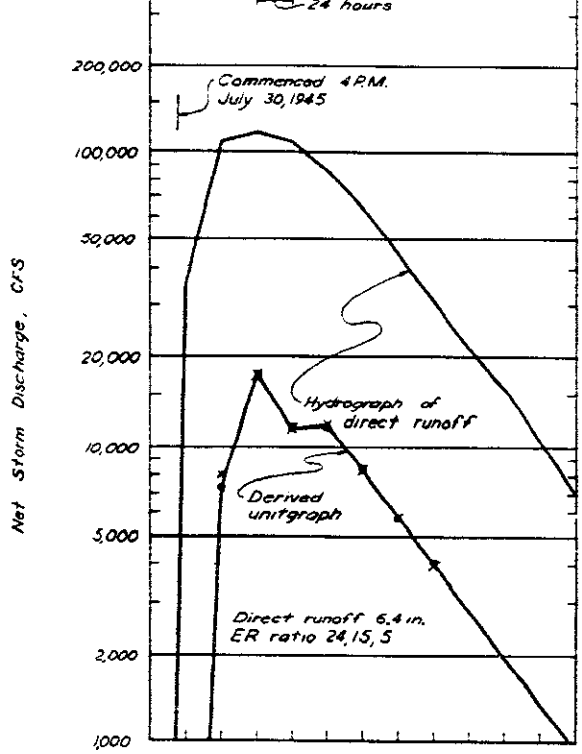
KARNAFULI PROJECT

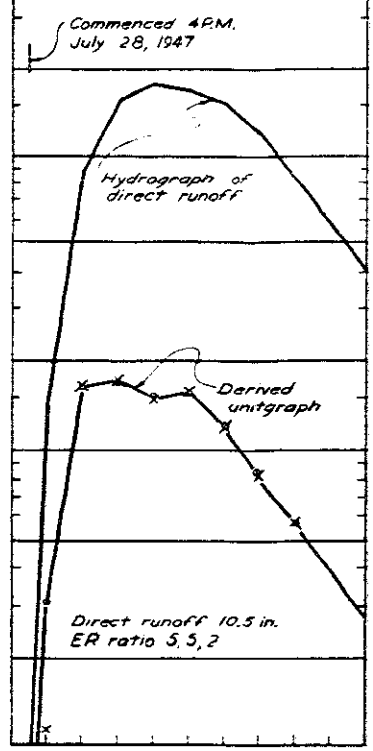
HYDROGRAPHS OF DAILY FLOW
RANGAMATI
1949 – 1954

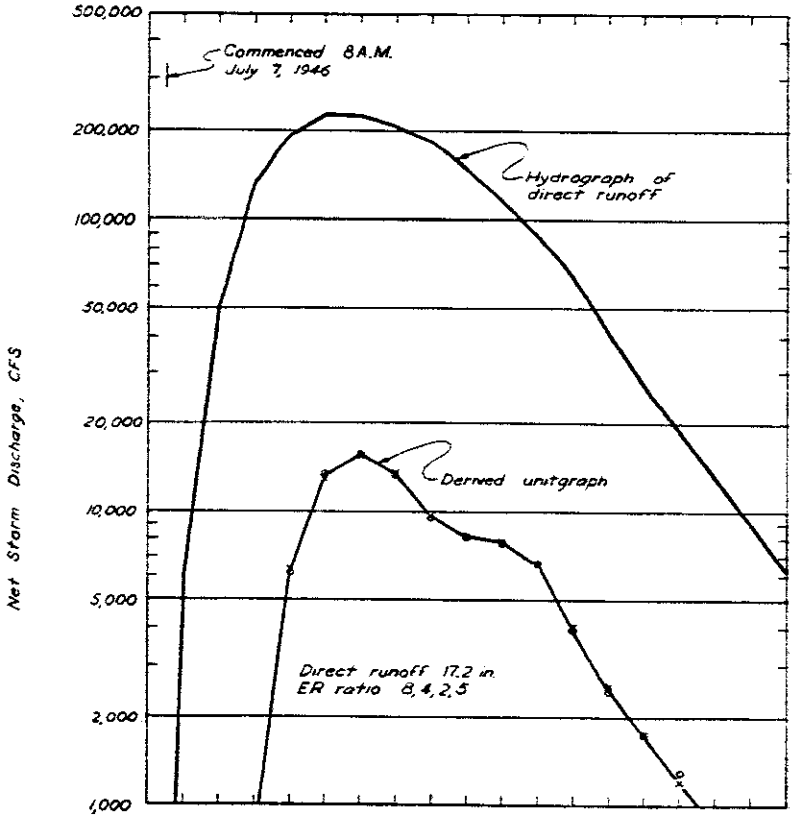
INTERNATIONAL ENGINEERING CO., INC.

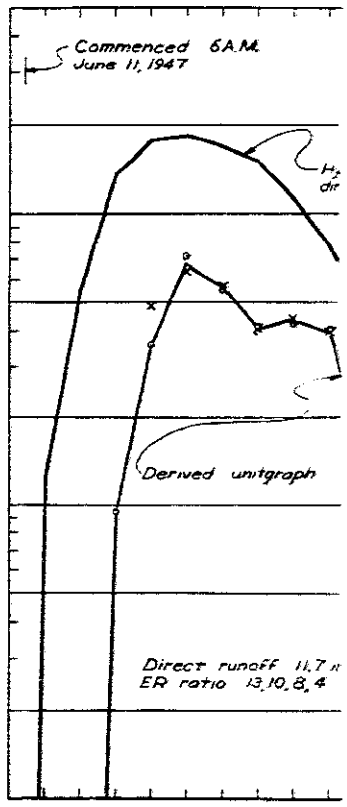
DESIGNED I.E.C. DRAWN R.F.	CHKD. J.F.T. SHEP.	SUBMITTED RECOMMENDED APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-10-303

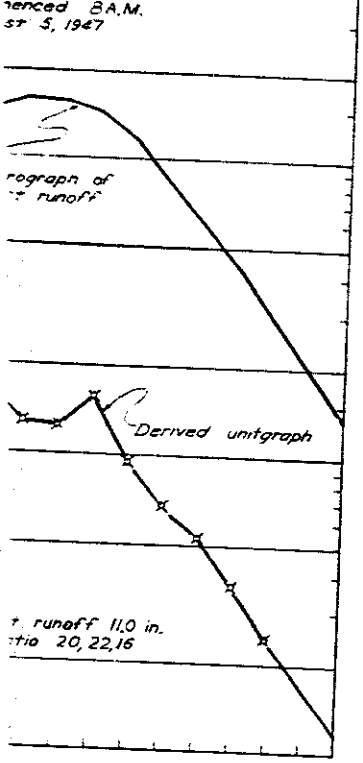
1517

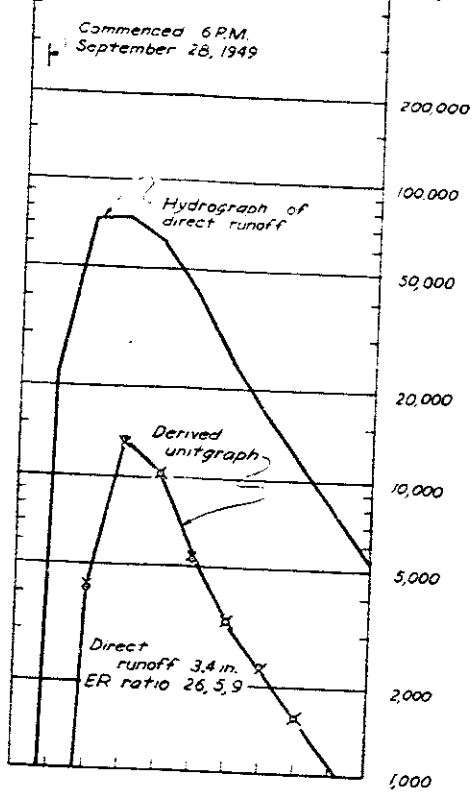

24 hours
Commenced 4 P.M.
July 30, 1945
Hydrograph of direct runoff
Derived unitgraph
Direct runoff 6.4 in.
ER ratio 24, 15, 5
Net Storm Discharge, CFS
200,000
100,000
50,000
20,000
10,000
5,000
2,000
1,000

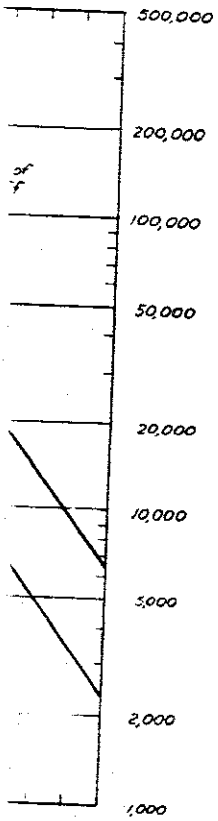

Commenced 4 P.M.
July 28, 1947
Hydrograph of direct runoff
Derived unitgraph
Direct runoff 10.5 in.
ER ratio 5, 5, 2


Commenced 8 A.M.
July 7, 1946
Hydrograph of direct runoff
Derived unitgraph
Direct runoff 17.2 in.
ER ratio 8, 4, 2, 5
Net Storm Discharge, CFS
500,000
200,000
100,000
50,000
20,000
10,000
5,000
2,000
1,000


Commenced 6 A.M.
June 11, 1947
Derived unitgraph
ER ratio 13, 10, 8, 4







LEGEND :

Time scale, days 0 1 2 3 4 5

Unitgraphs :
Forward run
Reversed run

NOTES :

The ER ratio gives the relative proportions of the successive daily increments of excess rainfall, corresponding to the derived unitgraph. The values are not in standard units of depth.

The unitgraph ordinates express relative proportions only. They are not in standard units of discharge.

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

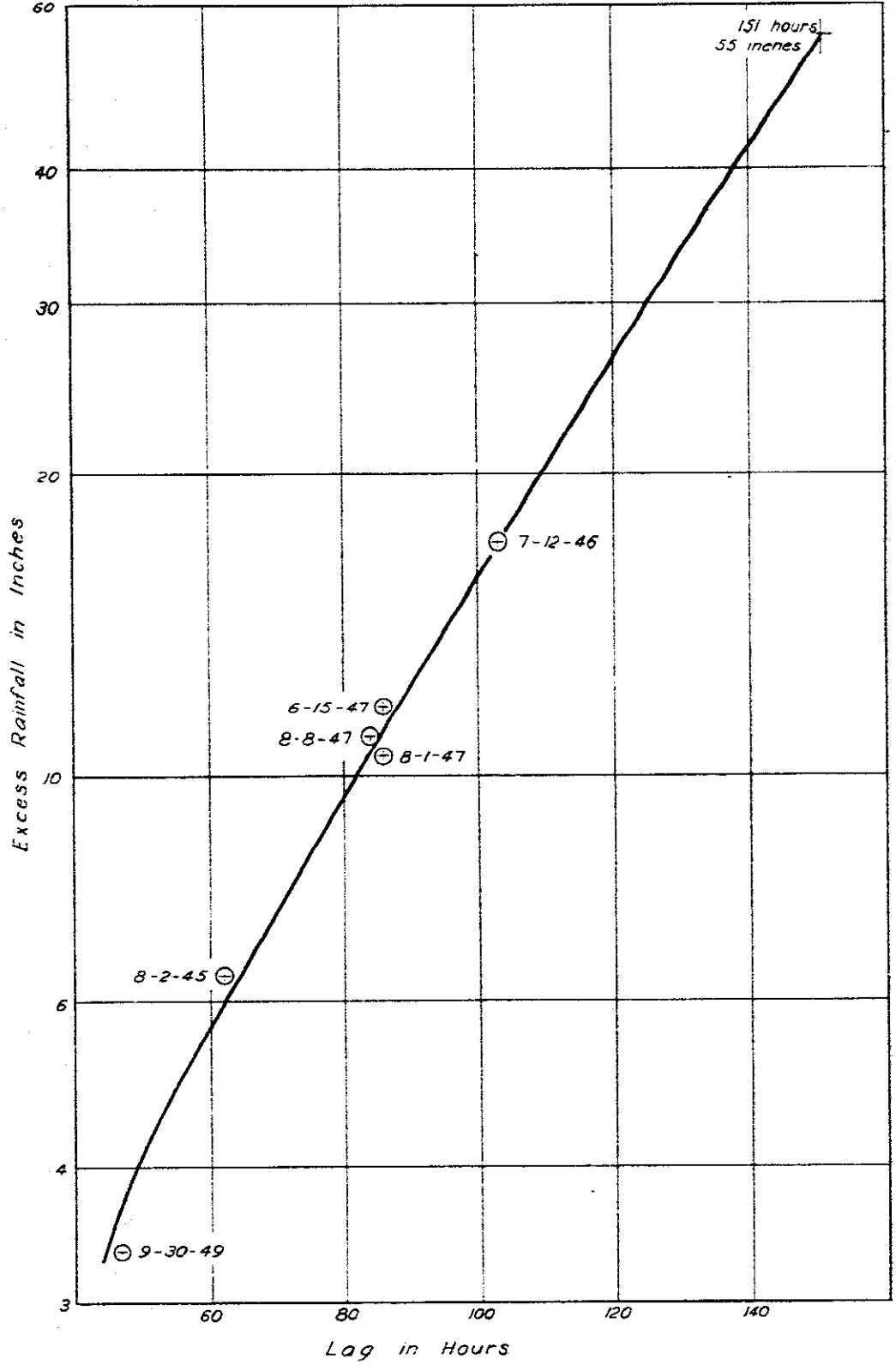
KARNAFULI PROJECT

HYDROGRAPHS OF DIRECT RUNOFF AT RANGAMATI, AND UNITGRAPHS

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED I.E.C.	CHKD. C.B.K.	SUBMITTED I.E.C.
DRAWN H.W.	INSP.	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL.	BW-04-242
	DATE MARCH 1955	

152A



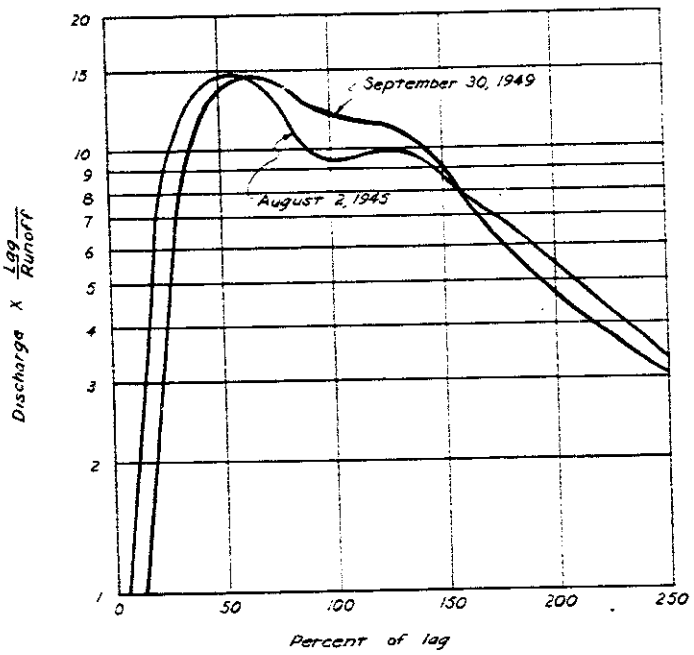
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

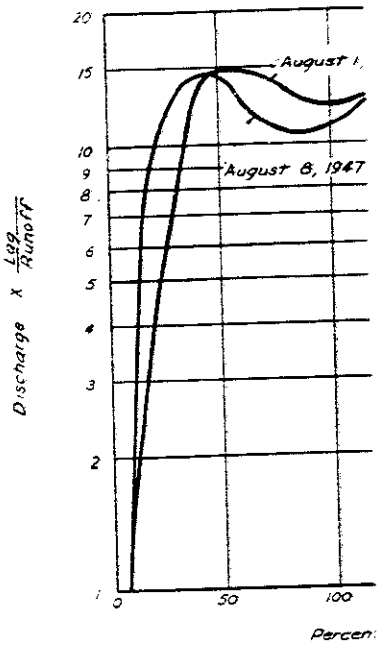
RELATION OF EXCESS RAINFALL AND UNITGRAPH LAG AT RANGAMATI

INTERNATIONAL ENGINEERING CO., INC.

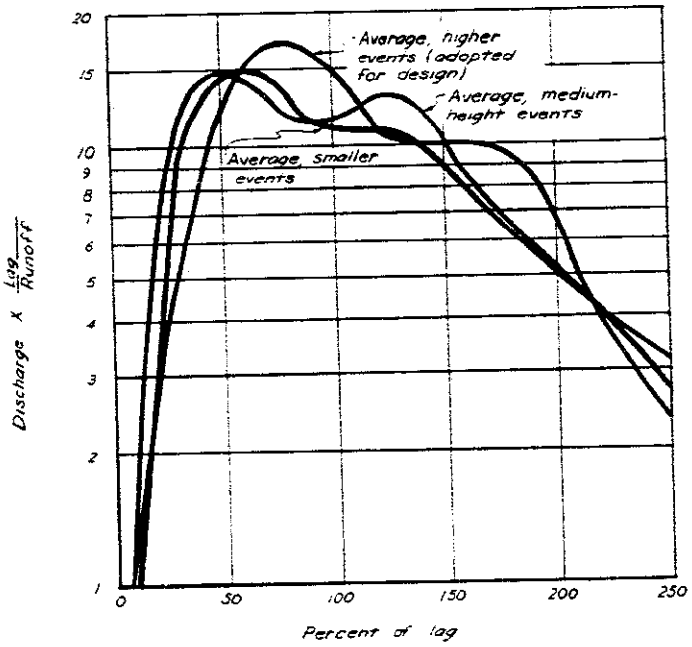
DESIGNED I.E.C.	CHK'D. C.B.K.	SUBMITTED
DRAWN H.W.	INSP.	RECOMMENDED
TRACED		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-243



COMPARISON OF SMALLER EVENTS
(Figure A)

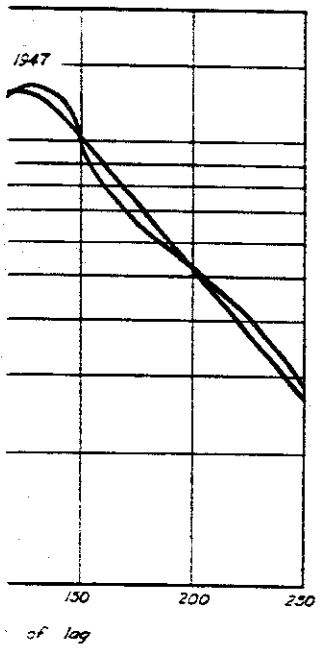


COMPARISON OF ME
(Figur

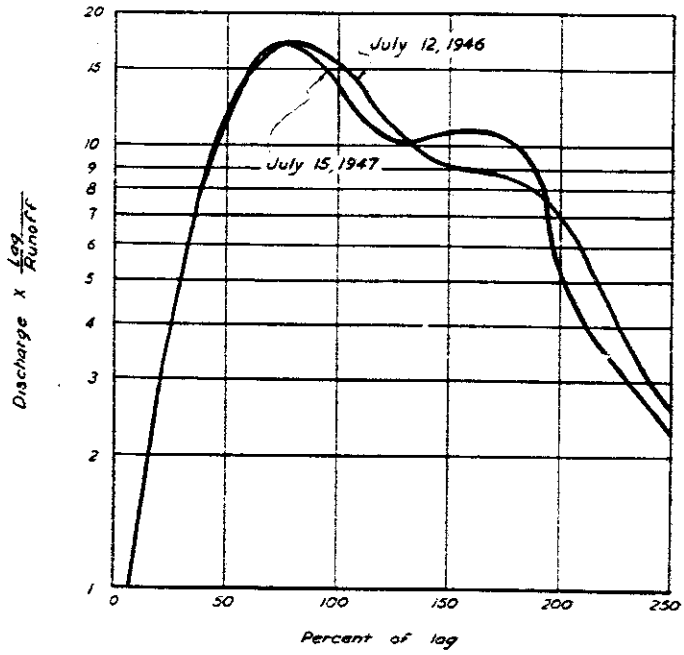


COMPARISON OF GROUP AVERAGES
(Figure D)

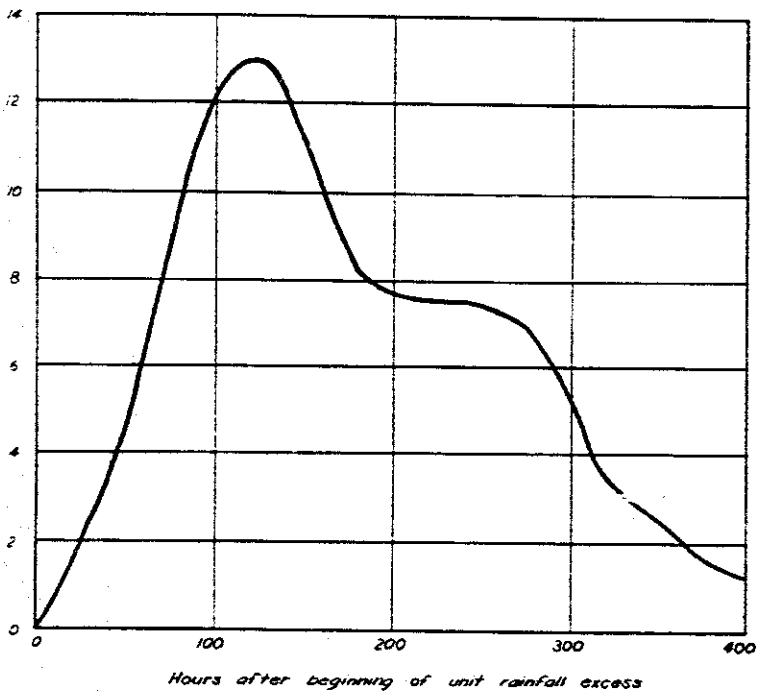
Thousands of CFS per inch of excess



DIUM-HEIGHT EVENTS
+ B)

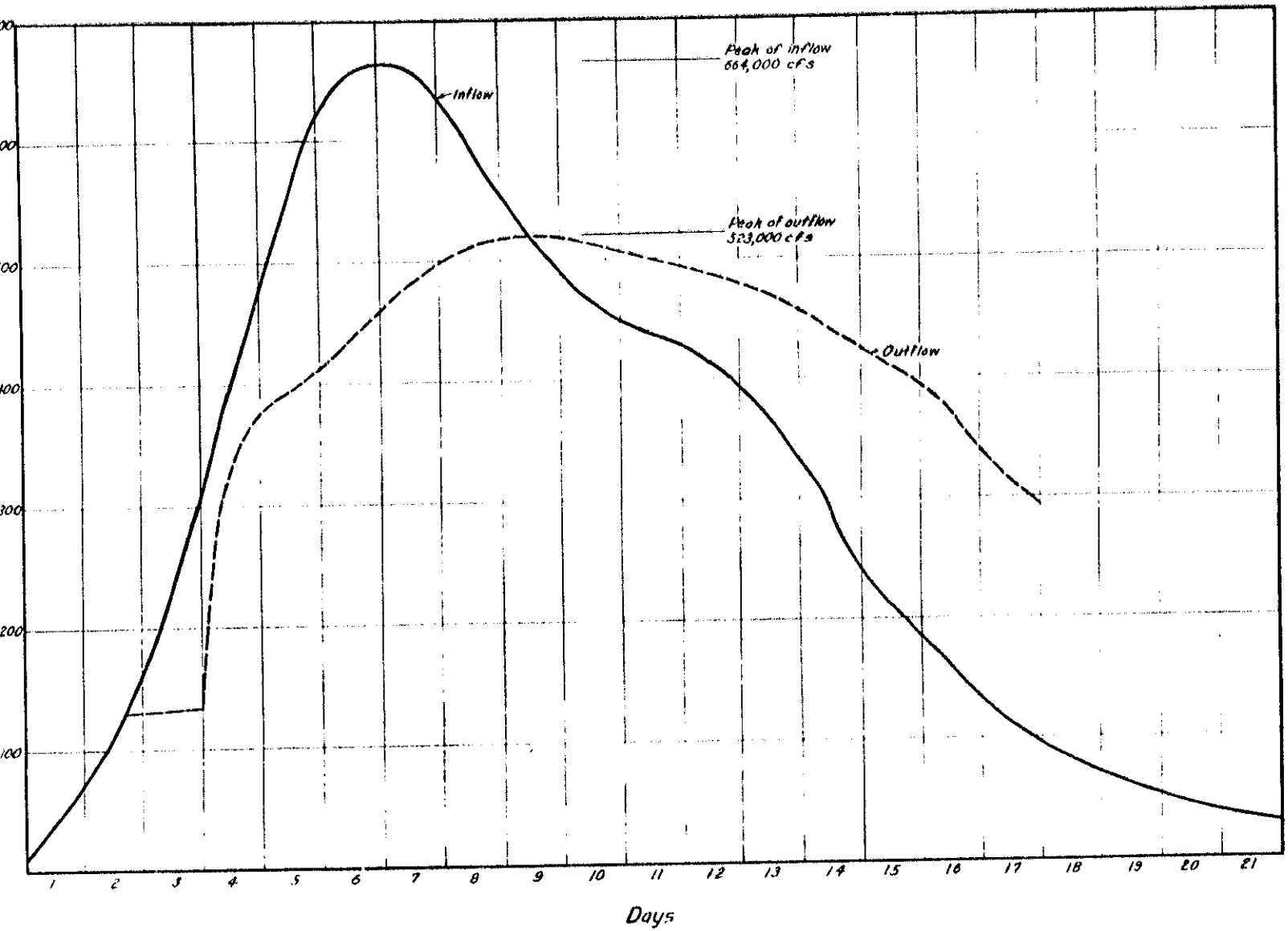


COMPARISON OF HIGHER EVENTS
(Figure C)



EVALUATED UNITGRAPH
KARNAFULI RIVER AT DAM SITE
(Figure E)

GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT KARNAFULI RIVER DIMENSIONLESS AND EVALUATED UNITGRAPHS		
INTERNATIONAL ENGINEERING CO., INC.		
DESIGNED I.E.C DRAWN H.W	CHKD. C.B.K CHIEF	SUBMITTED RECOMMENDED APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-244



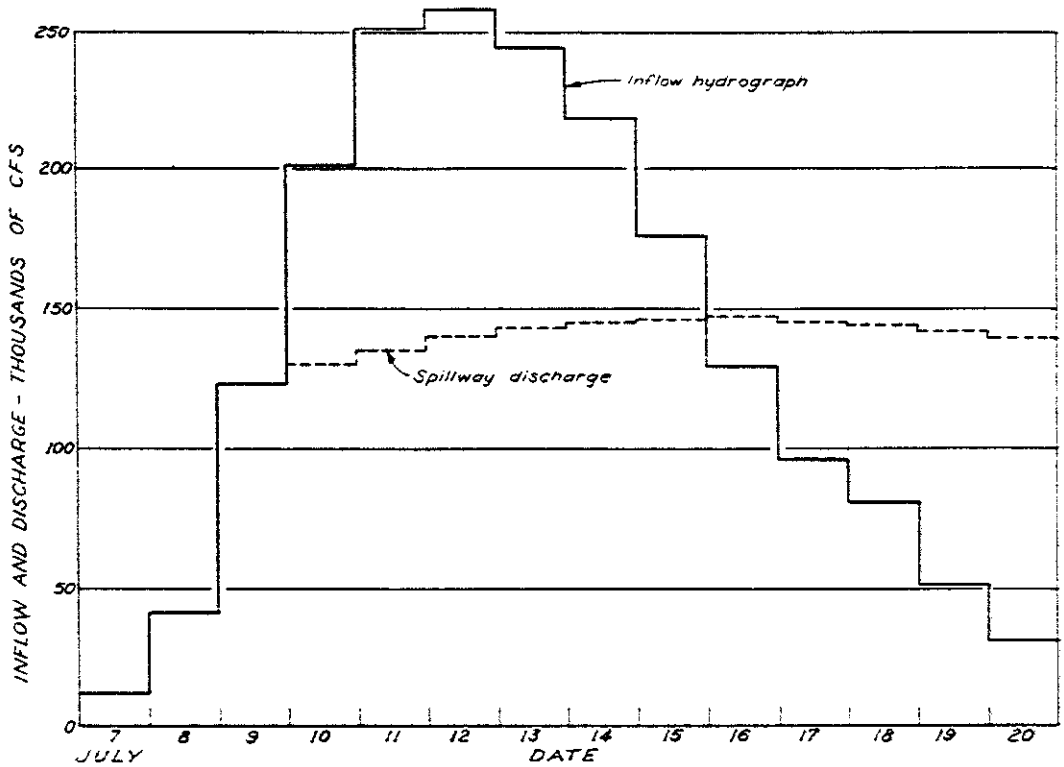
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

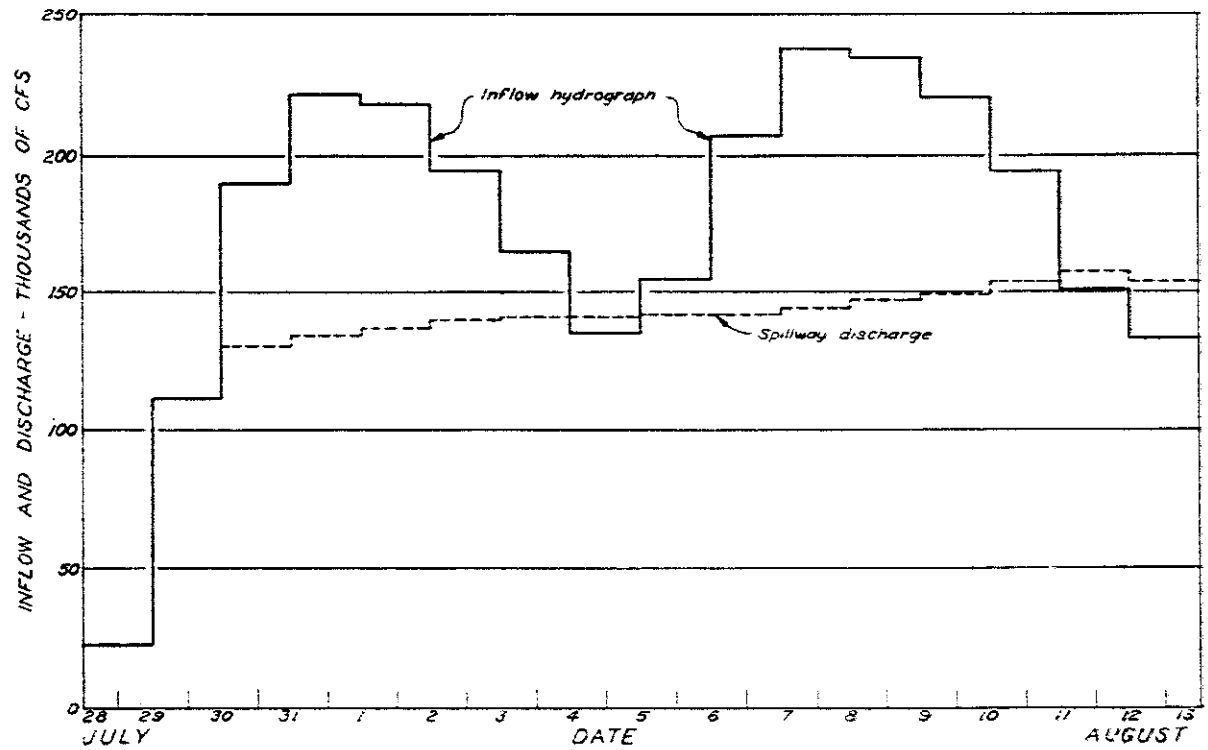
SPILLWAY DESIGN FLOOD
INFLOW-OUTFLOW HYDROGRAPHS

INTERNATIONAL ENGINEERING CO., INC.
SAN FRANCISCO, CALIF.

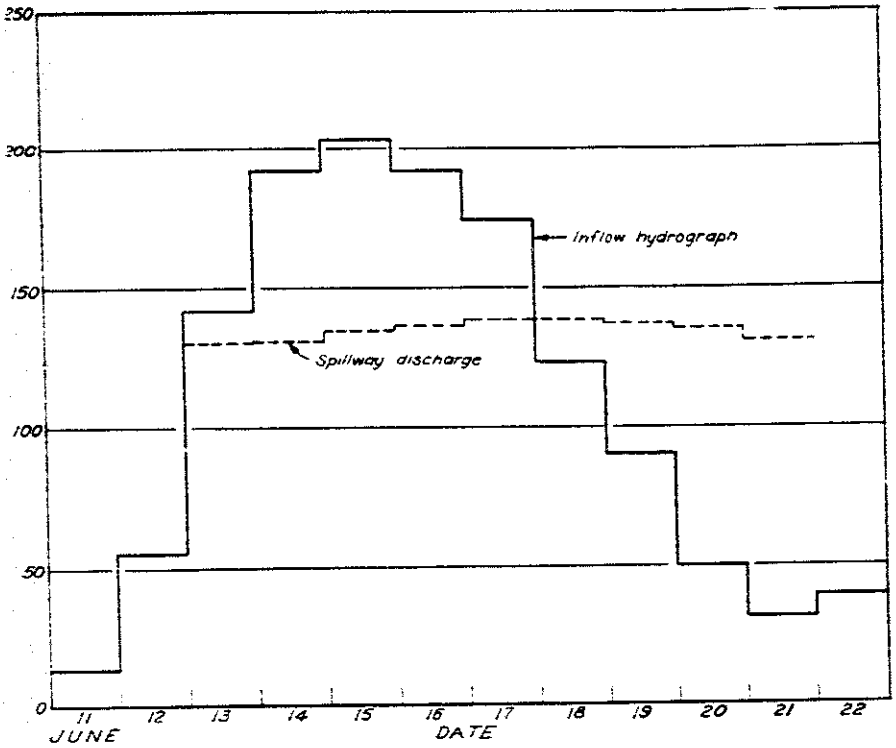
DR. H.K.	RECOMMENDED J.P. Hawker	APPROVED V. Mundel
CK. P.L.S.		
DATE MARCH 1955		BW-04-245



FLOOD ROUTING FOR FLOOD OF JULY 1946



FLOOD ROUTING FOR FLOOD OF JULY AND AUGUST 1947



FLOOD ROUTING FOR FLOOD OF JUNE 1947

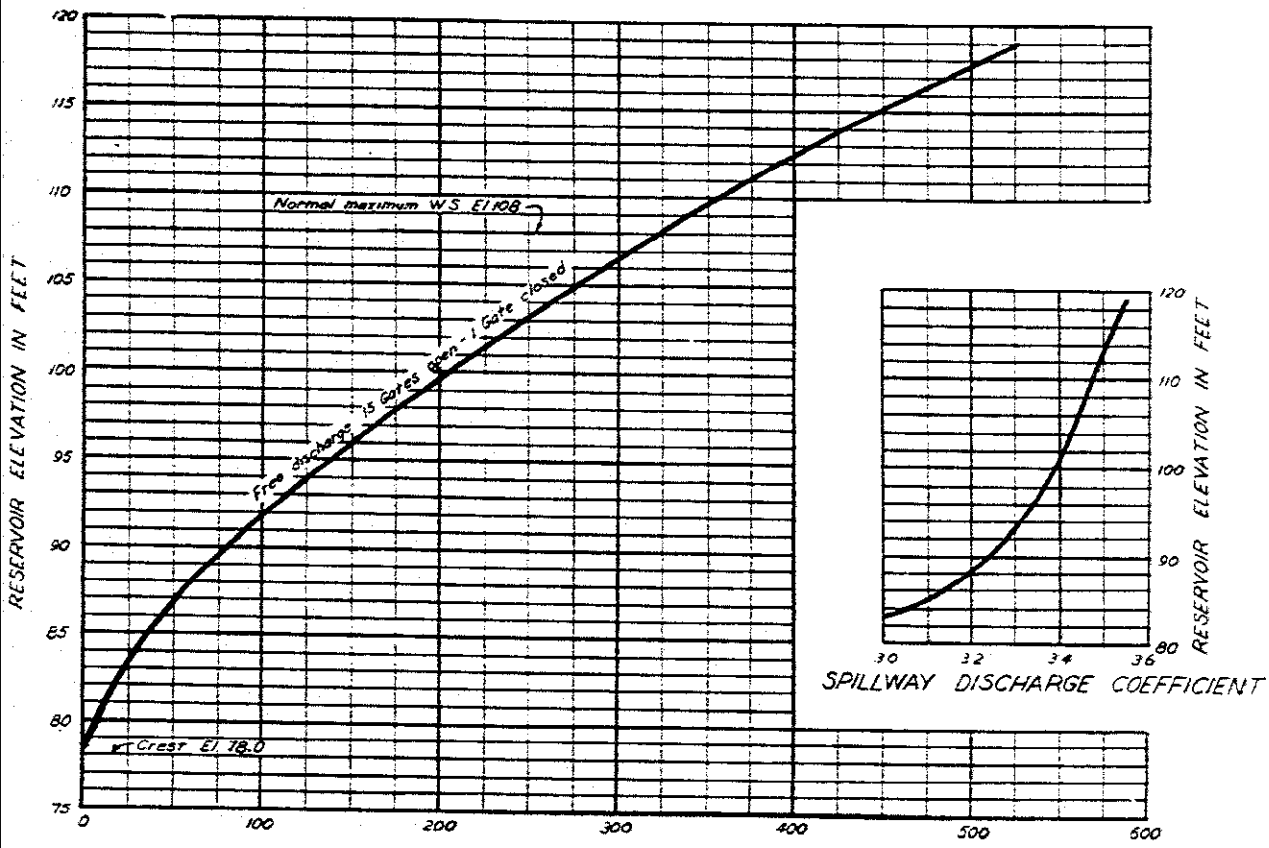
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

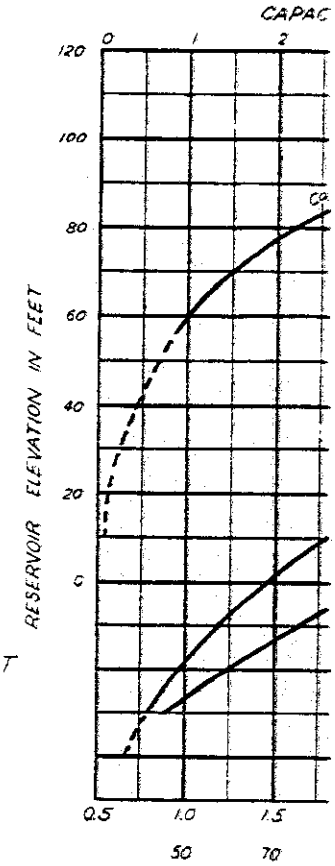
KARNAFULI PROJECT

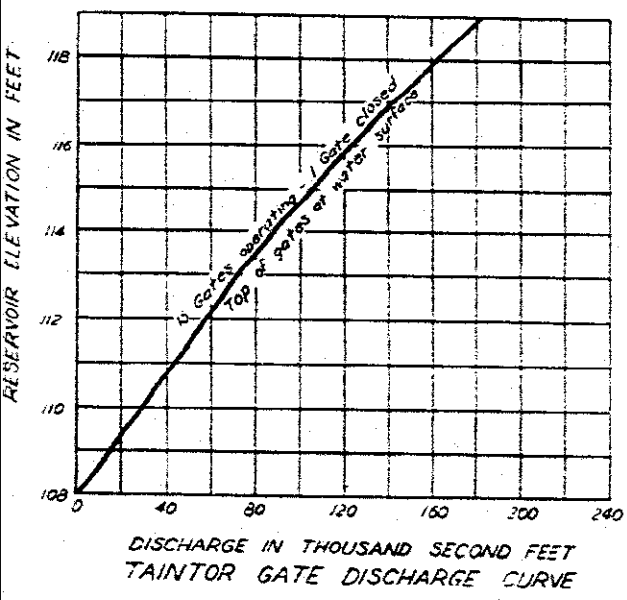
RESERVOIR FLOOD ROUTING STUDIES

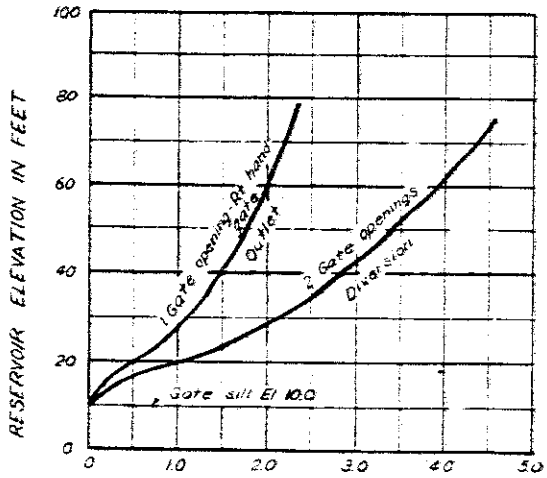
INTERNATIONAL ENGINEERING CO., INC.

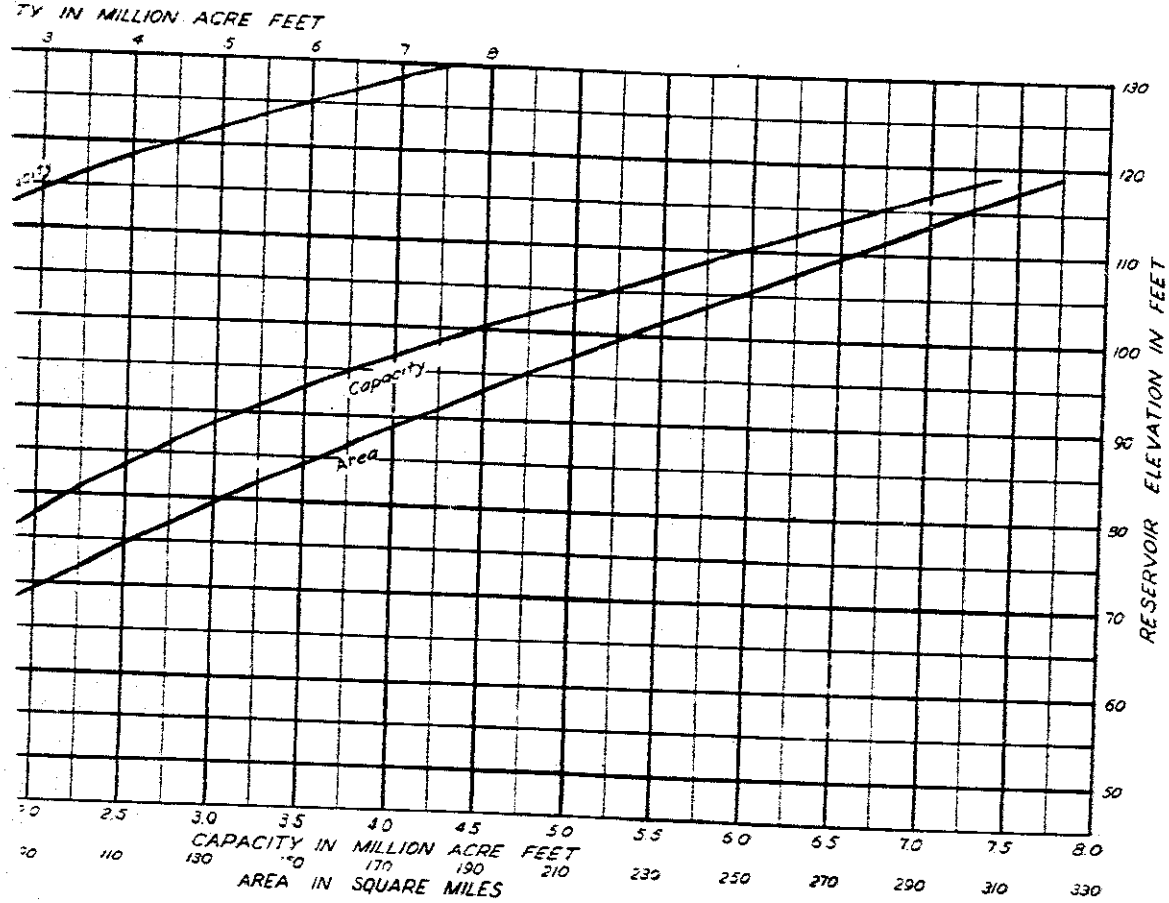
DESIGNED I.E.C. DRAWN H.W.	CHKD. P.F.S.	SUBMITTED
		RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-04-250


RESERVOIR ELEVATION IN FEET
Normal maximum W.S. El 108
Free discharge - 15 Gates open - 1 Gate closed
Crest El. 78.0
DISCHARGE IN THOUSAND SECOND FEET
SPILLWAY DISCHARGE CURVE
SPILLWAY DISCHARGE COEFFICIENT


CAPAC
RESERVOIR ELEVATION IN FEET


RESERVOIR ELEVATION IN FEET
15 Gates operating - 1 Gate closed
Top of gates at water surface
DISCHARGE IN THOUSAND SECOND FEET
TAINTOR GATE DISCHARGE CURVE


RESERVOIR ELEVATION IN FEET
1 Gate opening - Rt. hand gate
Outlet
2 Gate openings
Diversion
Gate sill El 10.0
DISCHARGE IN THOUSAND SECOND FEET
DIVERSION AND OUTLET
DISCHARGE CURVES
Two 6'-0" x 7'-6" slide gates



ESERVOIR AREA AND CAPACITY CURVES

NOTES:

Area-Capacity curves computed from survey of Pakistan topographic maps sheets 1 to 125 inclusive with elevation corrections supplied by Mr Azeemuddain.

Elevations based on P.W.D. Datum.

Tail water rating curve was computed from the best available data and is subject to fluctuations due to the regime of the river.

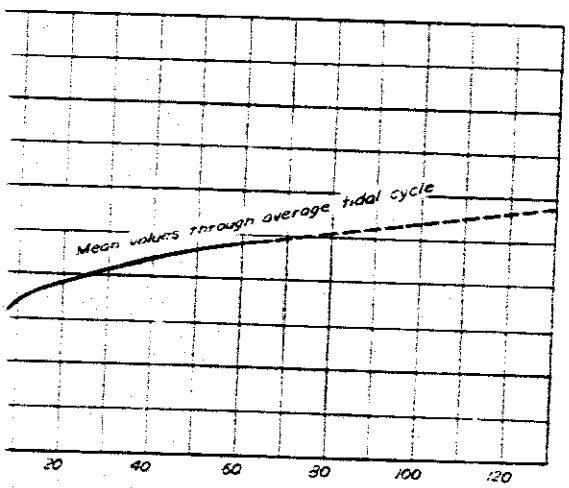
Crest discharges computed assuming:

$$Q = CL_eH^{3/2}$$

where: C = Computed coefficient varying with approach conditions and with H.

L_e = Computed effective length between piers.

H = Height of energy gradient above crest.



TAIL WATER RATING CURVE
(Guys at Chowdhury Chara)
(Power Plant Site)

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

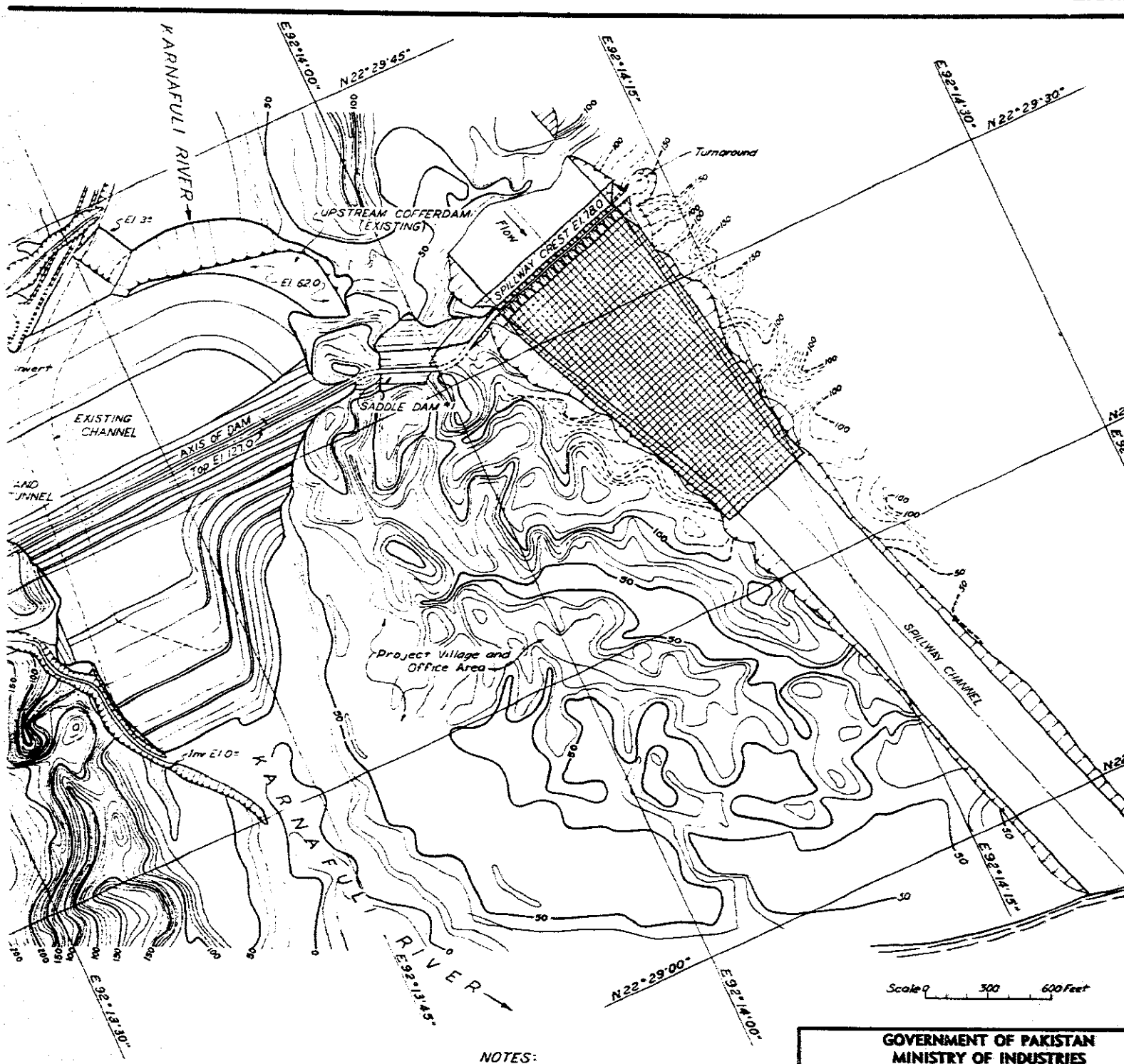
AREA, CAPACITY, DISCHARGE AND TAILWATER CURVES

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED J.E.	CHKD. C.E.I.	SUBMITTED
DRAWN H.W.	SUPP.	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-10-304

E 92°13'00"
E 92°13'15"
N 22°30'00"
E 92°13'30"
SADDLE DAM #2
NAVIGATION LOCKS
KARNAFULI
SADDLE DAM #3
SWITCHYARD
FOREBAY CHANNEL
PROPOSED SITE OF FUTURE POWER PLANT (Saddle dam to be removed when power plant is constructed)
N 22°29'45"
POWERHOUSE (Units 1, 2 & 3) (Chowdhury Chara)
Wharf
RIVER
N 22°29'30"
E 92°13'00"
Road
N 22°29'15"
E 92°13'15"

158'



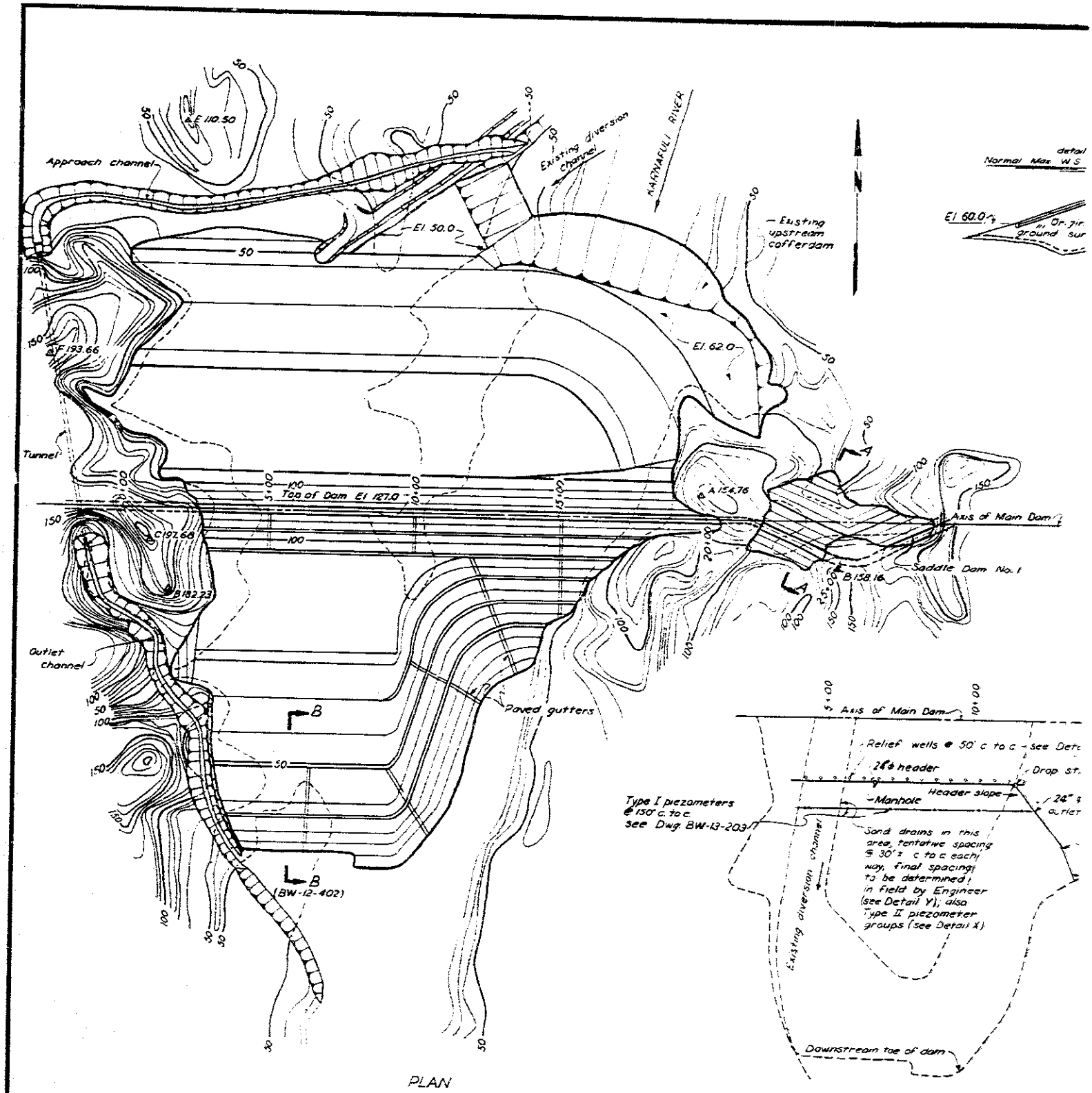
NOTES:
Elevations are based on PWD datum.
Topography from Karnafuli Project Circle drawing titled, "Contour Plan Showing Triangulation Points and Control Lines of Structures" dated Nov. 26, 1954.
Roads shown with dotted lines are not a part of this contract and are to be located in the field.

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

GENERAL LAYOUT

INTERNATIONAL ENGINEERING CO., IN

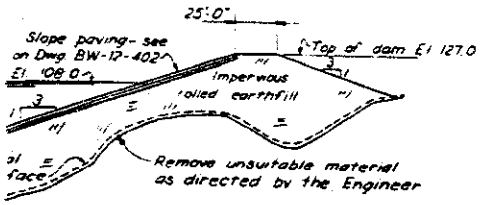
DESIGNED I.E.C.	CHKD. C.E.K.	SUBMITTED
DRAWN R.S.P.	SUPERVISED	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL.	BW-10-9
	DATE MARCH 1955	



PLAN

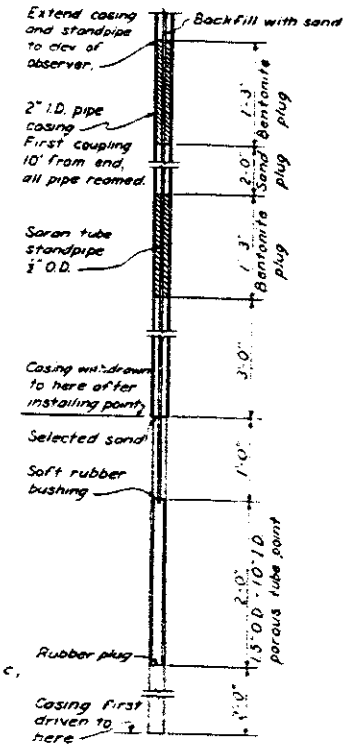
PLAN OF FOUNDATION DRAINAGE SYSTEM

159'

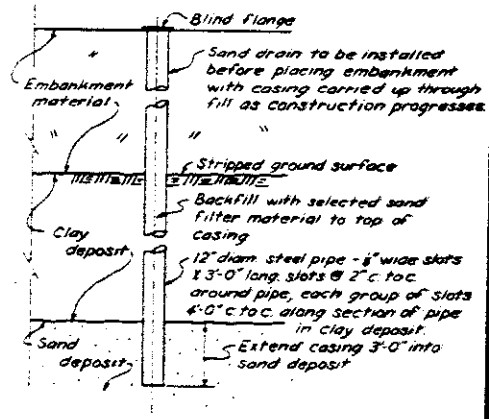


SECTION A-A
TYPICAL SADDLE DAM SECTION
Scale 0 50 Feet

Note:
Type II piezometer to be installed in groups of three; at center of brown clay formation and at top and center of blue clay formation. Tentative spacing of piezometers in each group is 30'± c to c, with groups @ 150'± c to c. Each piezometer to be midway between sand drains.



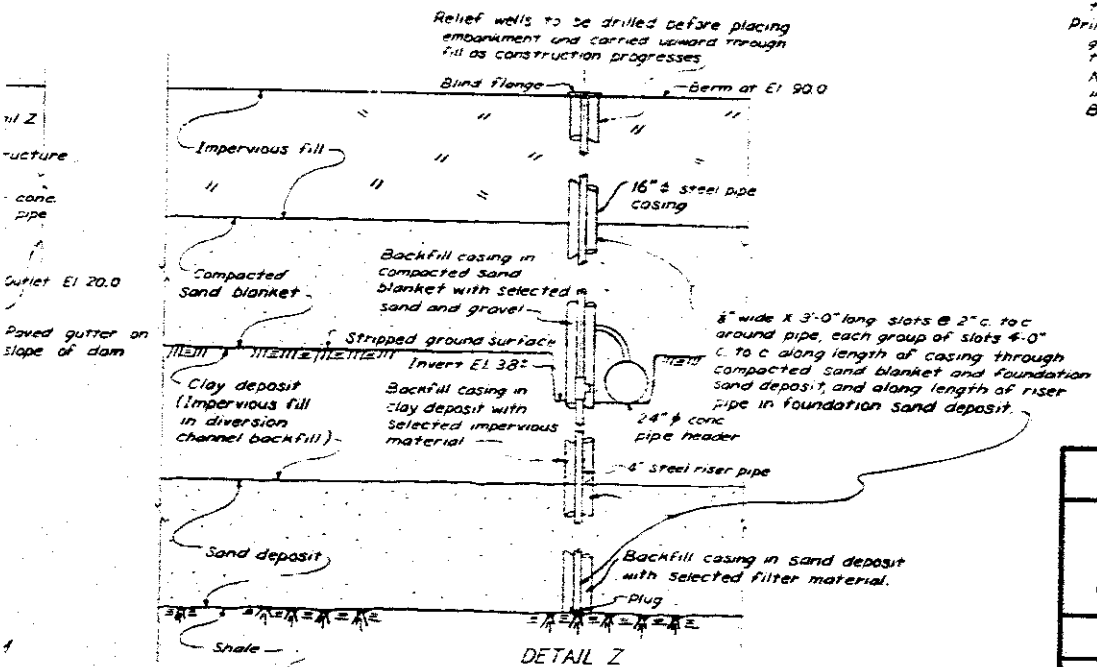
DETAIL X
TYPE II PIEZOMETER
Scale 0 1 Foot



DETAIL Y
TYPICAL SAND DRAIN
Scale 0 4 Feet

NOTES:

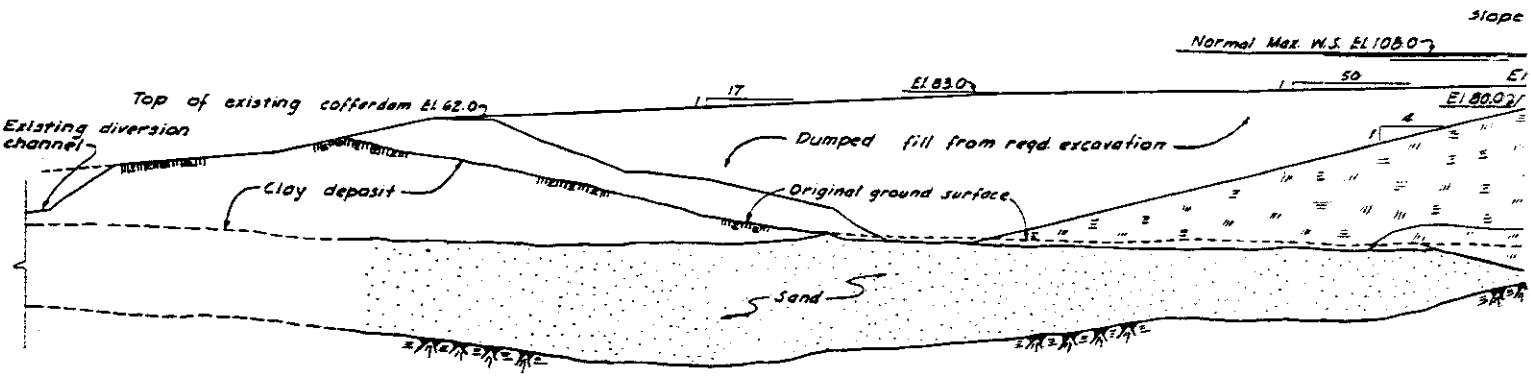
Elevations shown are based on P.W.D. datum.
Topography from Karnafuli Project Circle Dwg titled, "Contour Plan Showing Triangulation Points and Control Lines of Structures" dated Nov 26, 1954.
Points marked thus "Δ 8182.23" are triangulation points with elevation.
Sections and details shown are based on best present information & d indicate the general classes of work to be performed. Final detailed construction drawings will be prepared by the Engineer based on detailed investigations of conditions prior to and during embankment construction.
Actual foundation lines may vary from those shown on the drawings.
Top of dam elevation shown is the final elevation after consolidation. Detailed construction drawings, prepared by the Engineer, will indicate the additional height to which the embankment will be constructed to provide for future consolidation.
Primary grout holes @ 40'± c to c, secondary grout holes midway between primary holes, tertiary grout holes at intermediate spacings. Necessity for tertiary holes to be determined in the field by the Engineer. See Drawing BW-12-402 for grout curtain location.

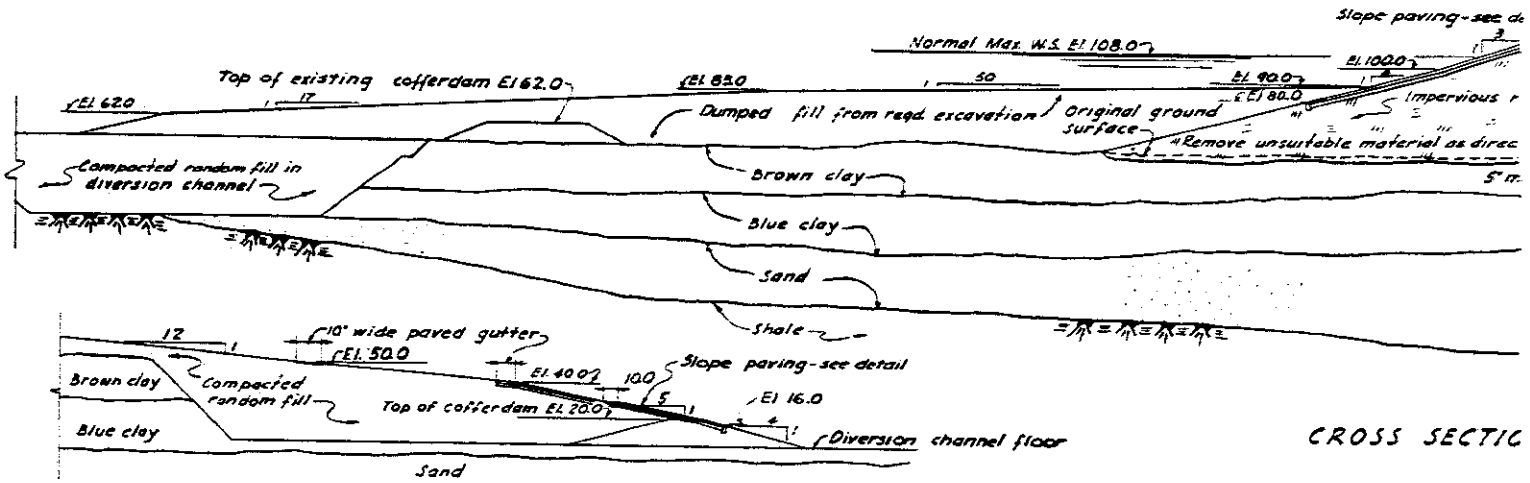


DETAIL Z
TYPICAL RELIEF WELL
Scale 0 4 Feet

Scale 0 200 400 Feet
Excepr as noted

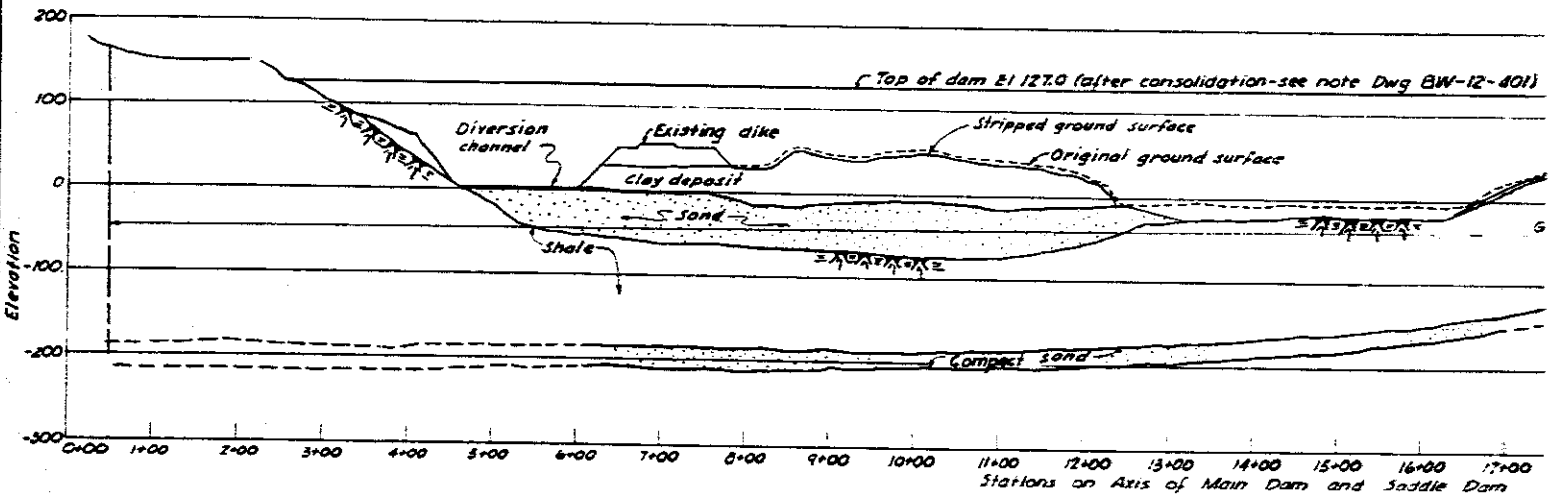
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT
MAIN DAM AND SADDLE DAM
GENERAL PLAN AND SECTIONS
INTERNATIONAL ENGINEERING CO., INC.
DESIGNED SMA KLT CHKD. SMA SUBMITTED
DRAWN H.W. SUP. RECOMMENDED APPROVED
SAN FRANCISCO, CAL.
DATE MARCH 1955
BW-12-401



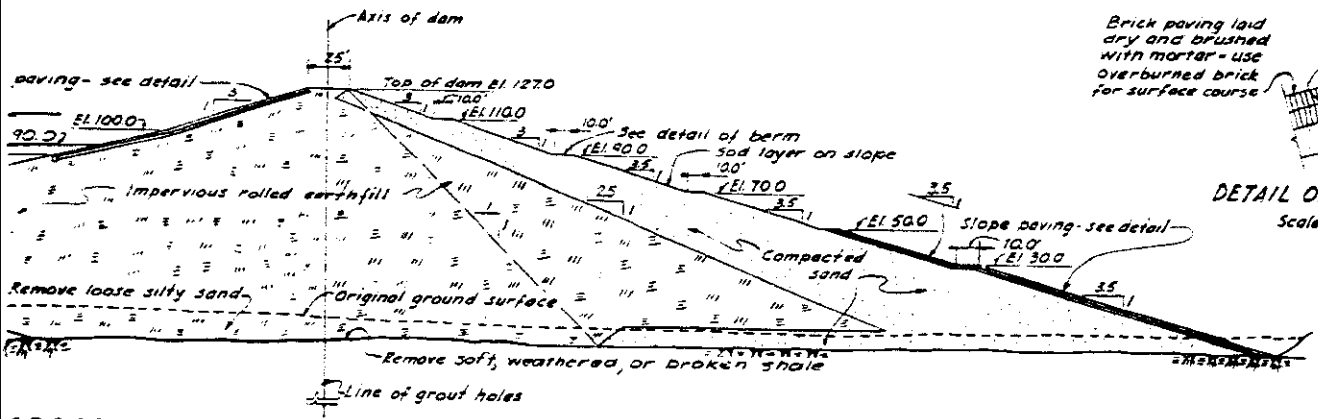


CROSS SECTIC

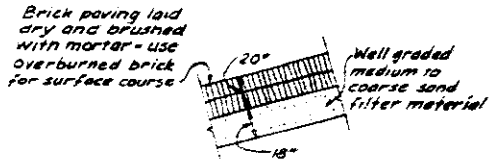
SECTION B-B
(See Dwg BW-12-401)



PROFILE ON AXIS OF MAIN DAM AND SADDLE DA

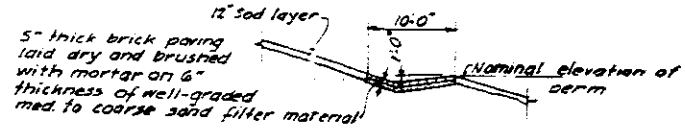


CROSS SECTION AT STATION 14+00



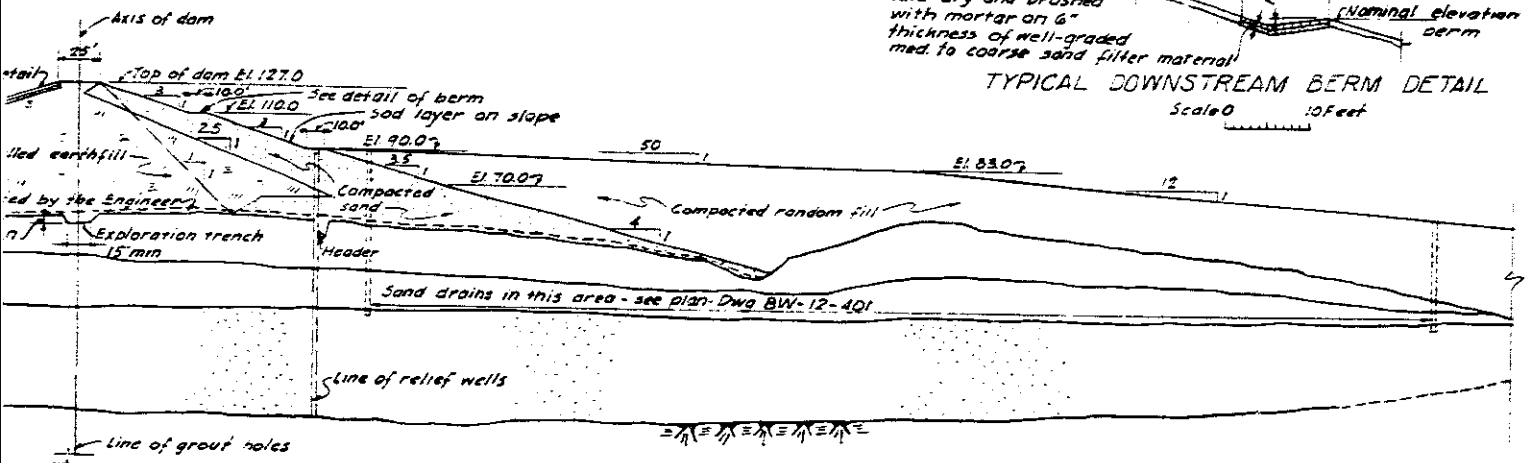
DETAIL OF SLOPE PAVING

Scale 0 4 Feet

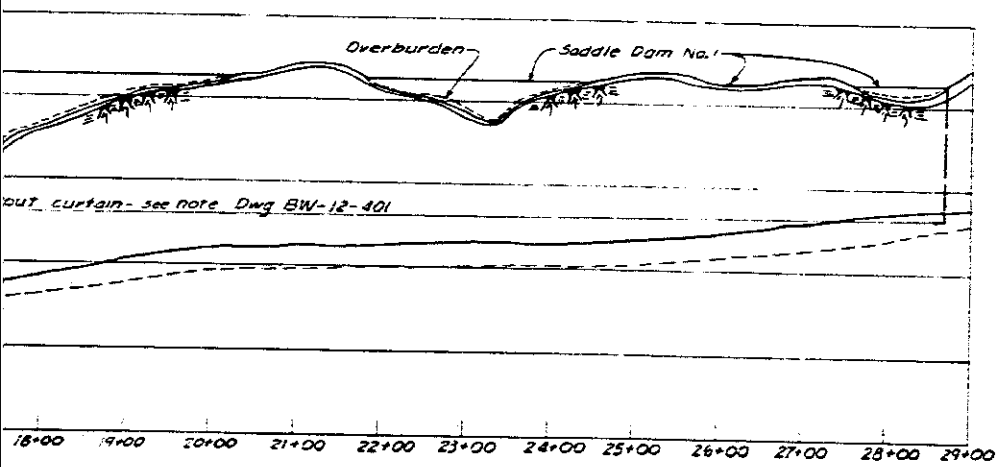


TYPICAL DOWNSTREAM BERM DETAIL

Scale 0 10 Feet



N AT STATION 9+00



A LOOKING UPSTREAM

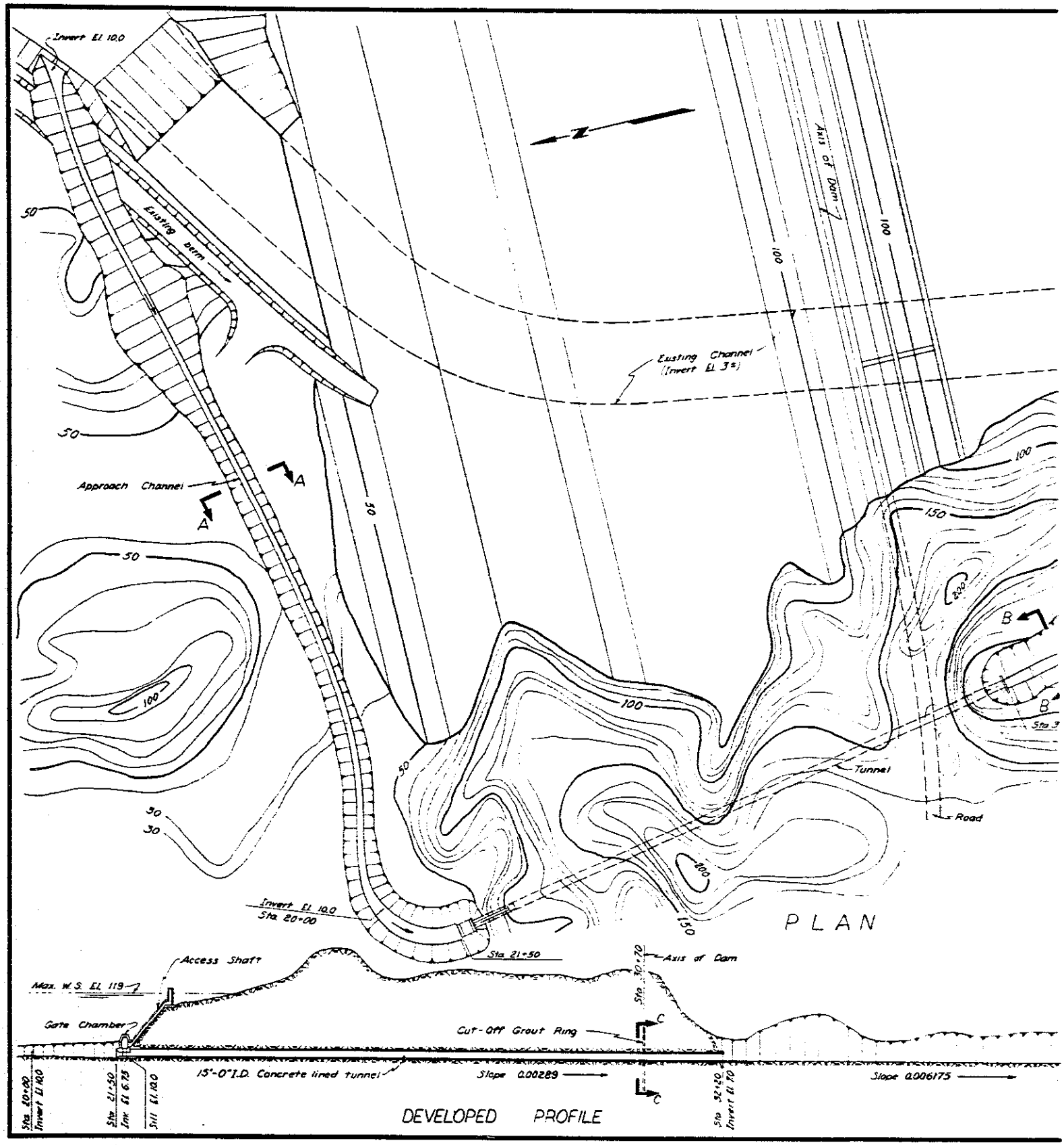
For general notes see Dwg BW-12-401

Scale 0 50 100 Feet

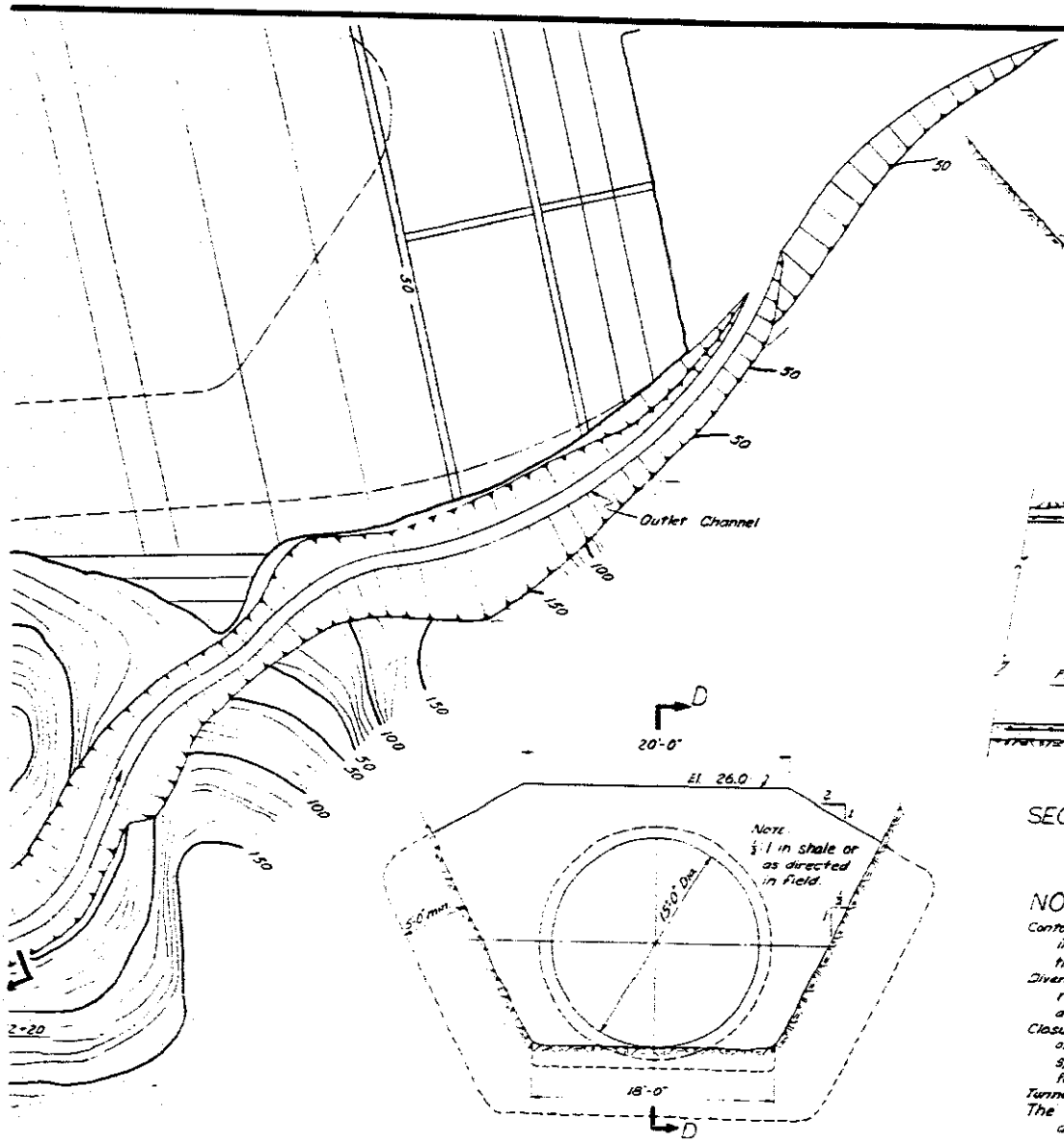
Except as noted

GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES	
KARNAFULI PROJECT	
MAIN DAM AND SADDLE DAM SECTIONS	
INTERNATIONAL ENGINEERING CO., INC.	
DESIGNED SMA-VIT CHKD. S.M.A. SUBMITTED DRAWN M.M.D. SUP. RECOMMENDED APPROVED	
SAN FRANCISCO, CAL. DATE MARCH 1955	BW-12-402

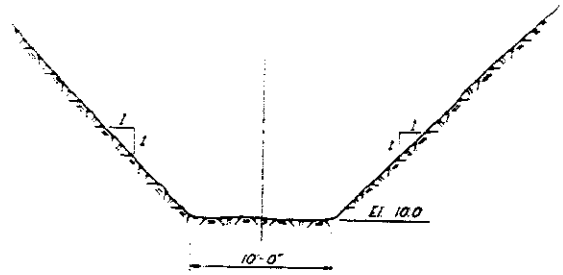
160A


Invert El. 10.0
Existing berm
Axis of Dam
Existing Channel (Invert El. 3±)
Approach Channel
A
B
Tunnel
Road
Invert El. 10.0
Sta. 20+00
PLAN
Access Shaft
Max. W.S. El. 119
Gate Chamber
Sta. 21+50
Sta. 30+70
Axis of Dam
Cut-Off Grout Ring
C
15'-0" I.D. Concrete lined tunnel
Slope 0.00289
Slope 0.006175
Sta. 20+00 Invert El. 10.0
Sta. 21+50 Inv. El. 6.75
Sill El. 10.0
Sta. 32+50 Invert El. 7.0
DEVELOPED PROFILE

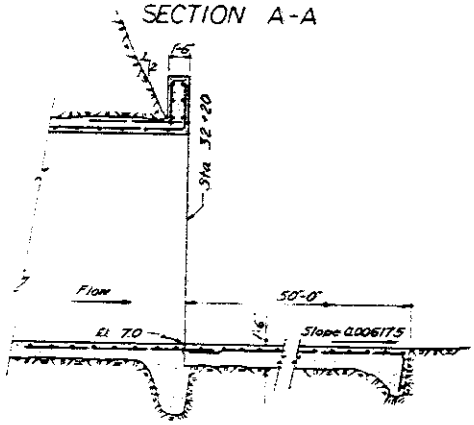
161'



SECTION B-B



SECTION A-A



SECTION D-D

NOTES:

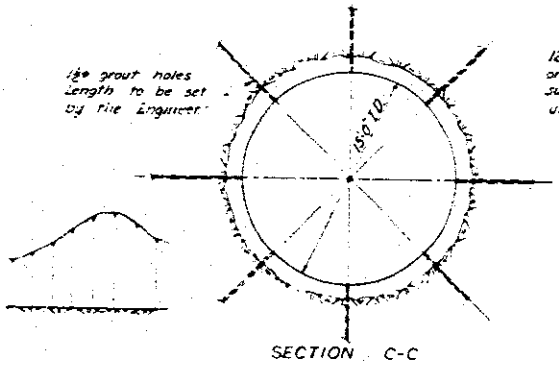
Contours shown are based on preliminary field information. Final alignment may vary from that shown.

Diversion studies were based on the 18½ year runoff record (June 1935 to April 1954) available.

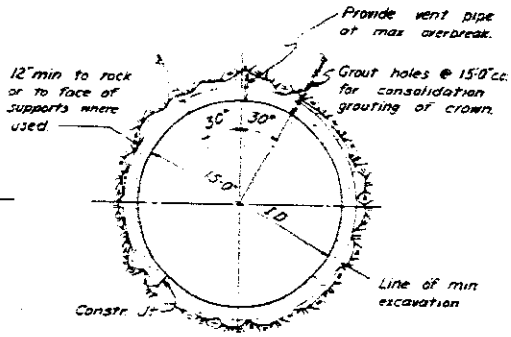
Closure is assumed to begin in the middle of November and the dam to be raised above spillway crest level by the end of the following May.

Tunnel was designed as a free flow tunnel.

The Engineer will determine the extent of all grout holes upon field investigation.



SECTION C-C
(Cut-Off Grout Ring)



TYPICAL TUNNEL SECTION

Scale 0 6 12 Feet
Sections

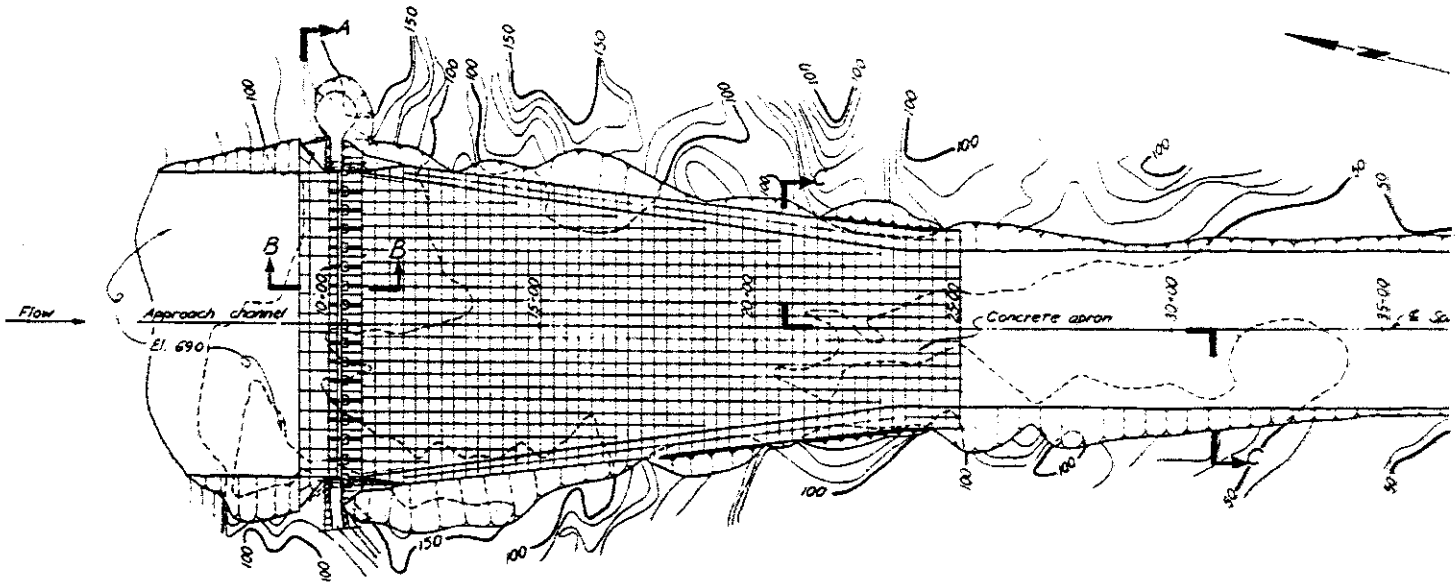
Scale 0 100 200 Feet
Plan and Profile

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

DIVERSION & OUTLET TUNNEL ALIGNMENT, PROFILE & SECTIONS

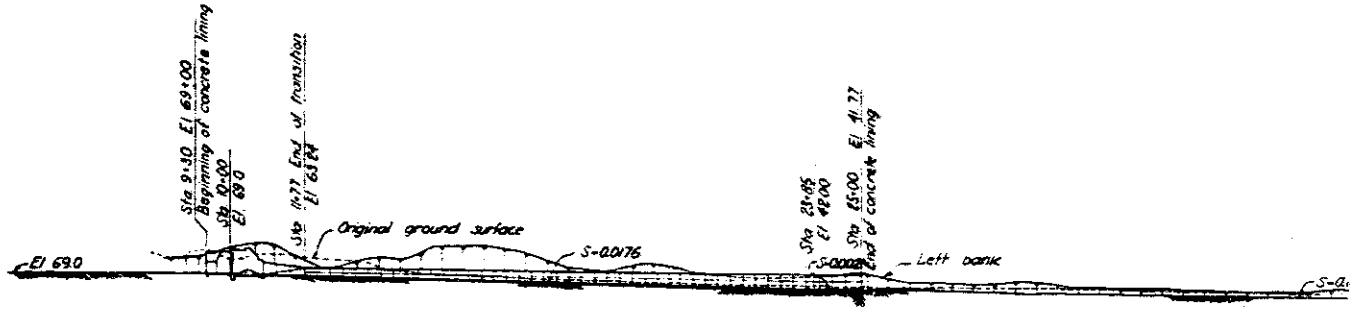
INTERNATIONAL ENGINEERING CO., INC.

DESIGNED M.G.	CHECK A.J.C.	SUBMITTED
DRAWN	REV. L.F. N.D.	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-32-201



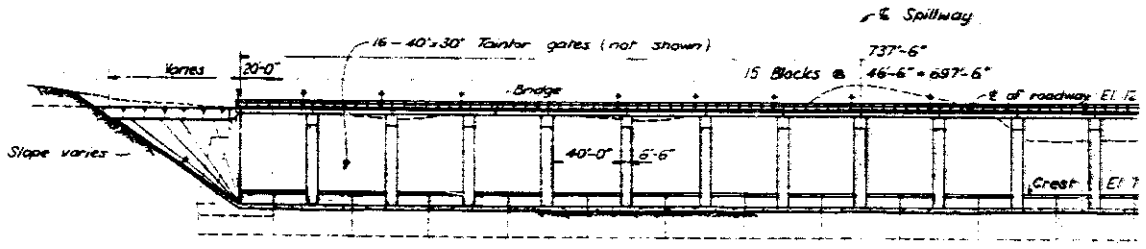
PLAN

Scale 0 200 Feet



SECTION ON CENTER LINE

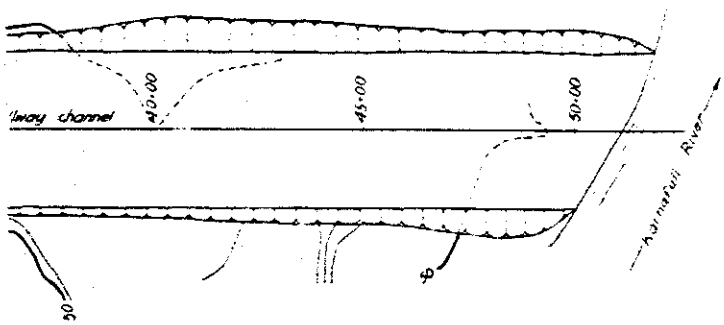
Scale 0 200 Feet

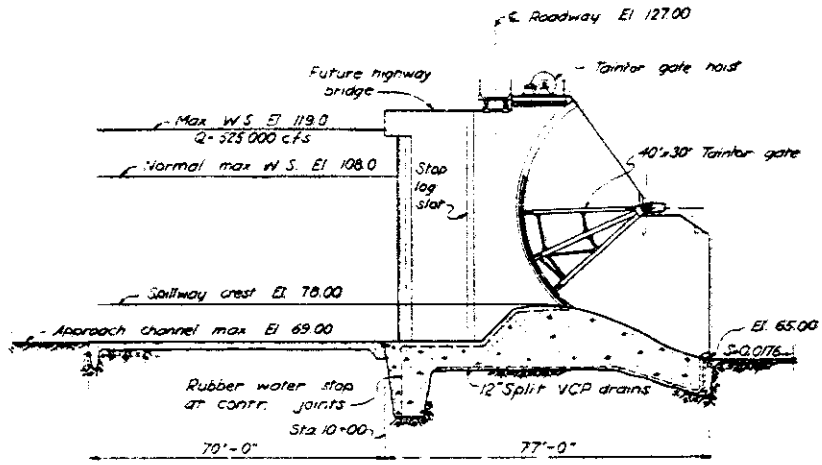


ELEVATION A-A

Scale 0 50 Feet

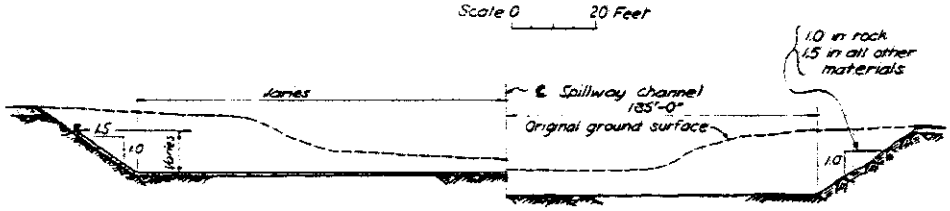
162





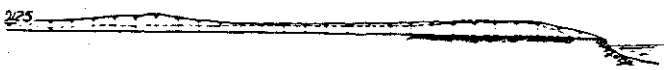
SECTIONAL ELEVATION B - B

Scale 0 20 Feet



SECTION C-C

Scale 0 50 Feet



NOTES:

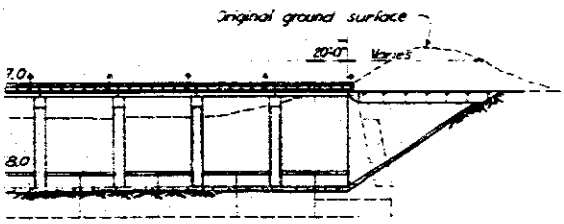
The Engineer will verify by hydraulic model tests the spillway details prior to the preparation of the necessary construction drawings.

Actual required excavation may vary from profile and assumed excavation lines shown.

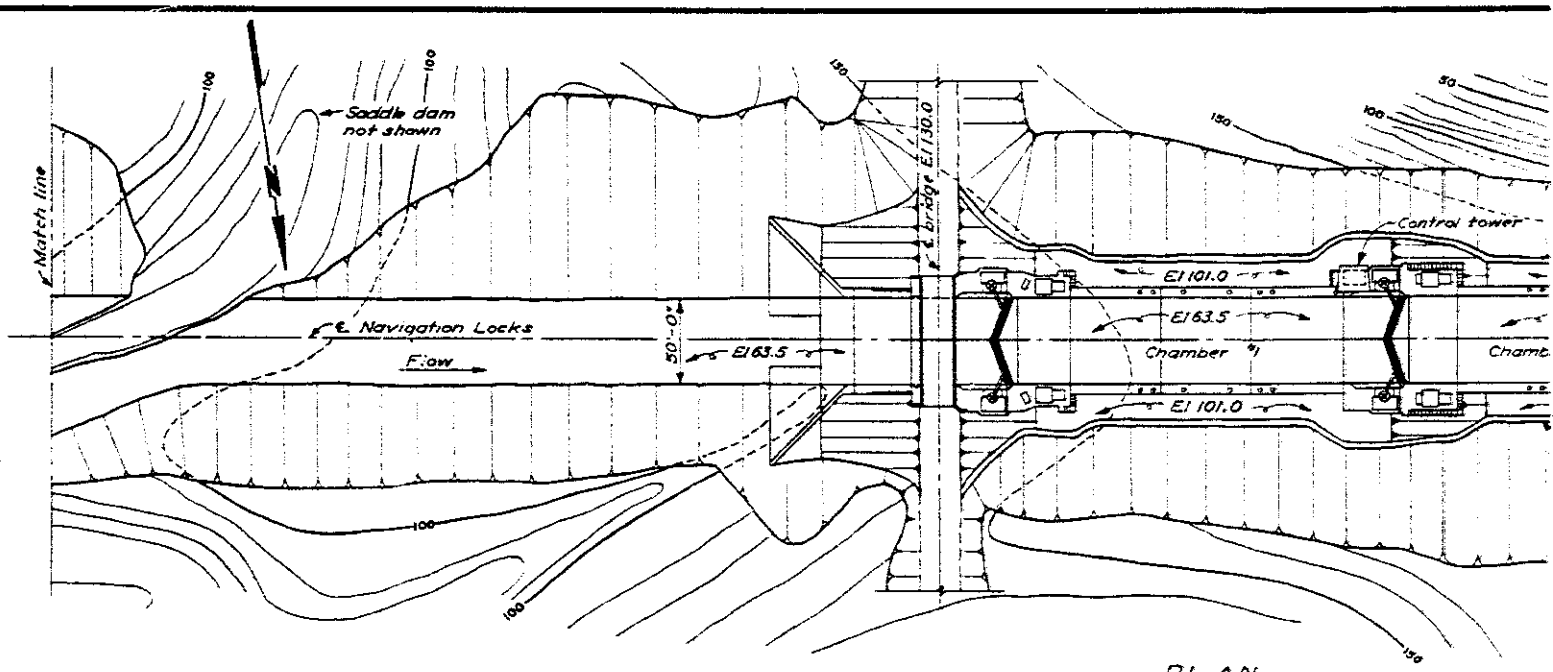
Contours shown were traced from Karnafuli Project Circle drawing titled, "Plan Showing the Net Level Sheet of Spillway Left Bank" dated Oct. 13, 1954.

Retaining walls, where required for protection of existing structures near the spillway channel, shall be constructed as directed by the Engineer.

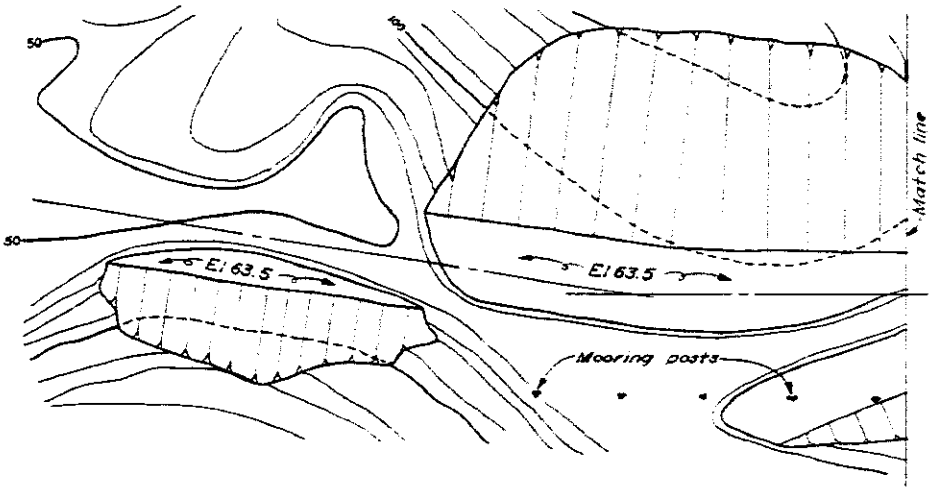
Scales as noted

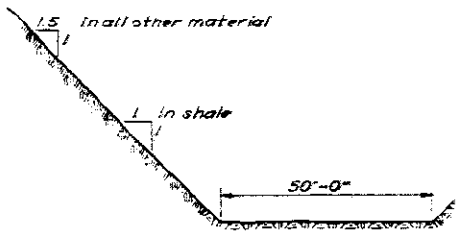


GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT SPILLWAY GENERAL PLAN AND SECTIONS		
INTERNATIONAL ENGINEERING CO., INC.		
DESIGNED S.M.A. DRAWN VIT-HW	CHKD. C.E.E. SUP. HR. LP	SUBMITTED J.E. Stewart RECOMMENDED U.P. Mady APPROVED Williams
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-13-301



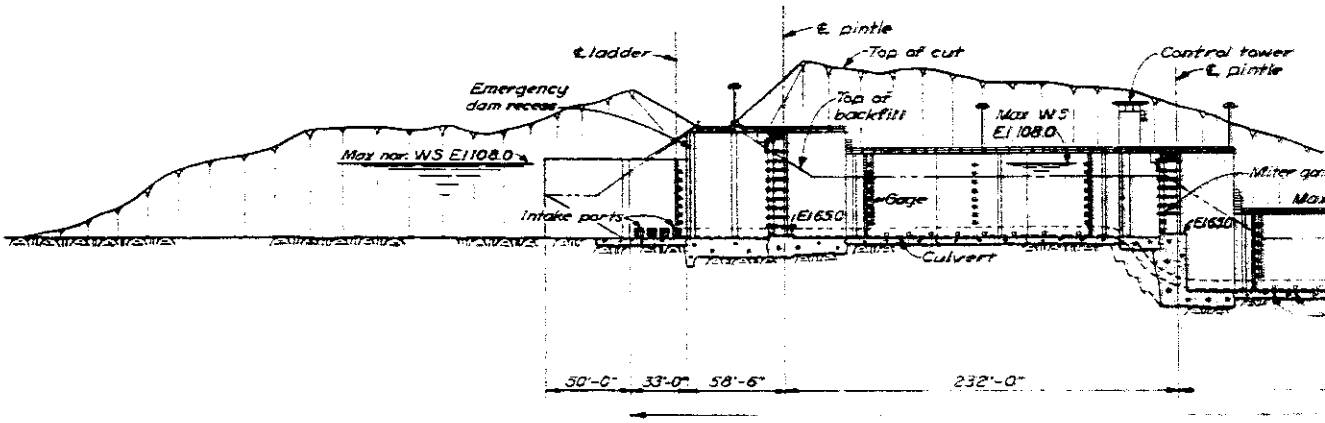
PLAN



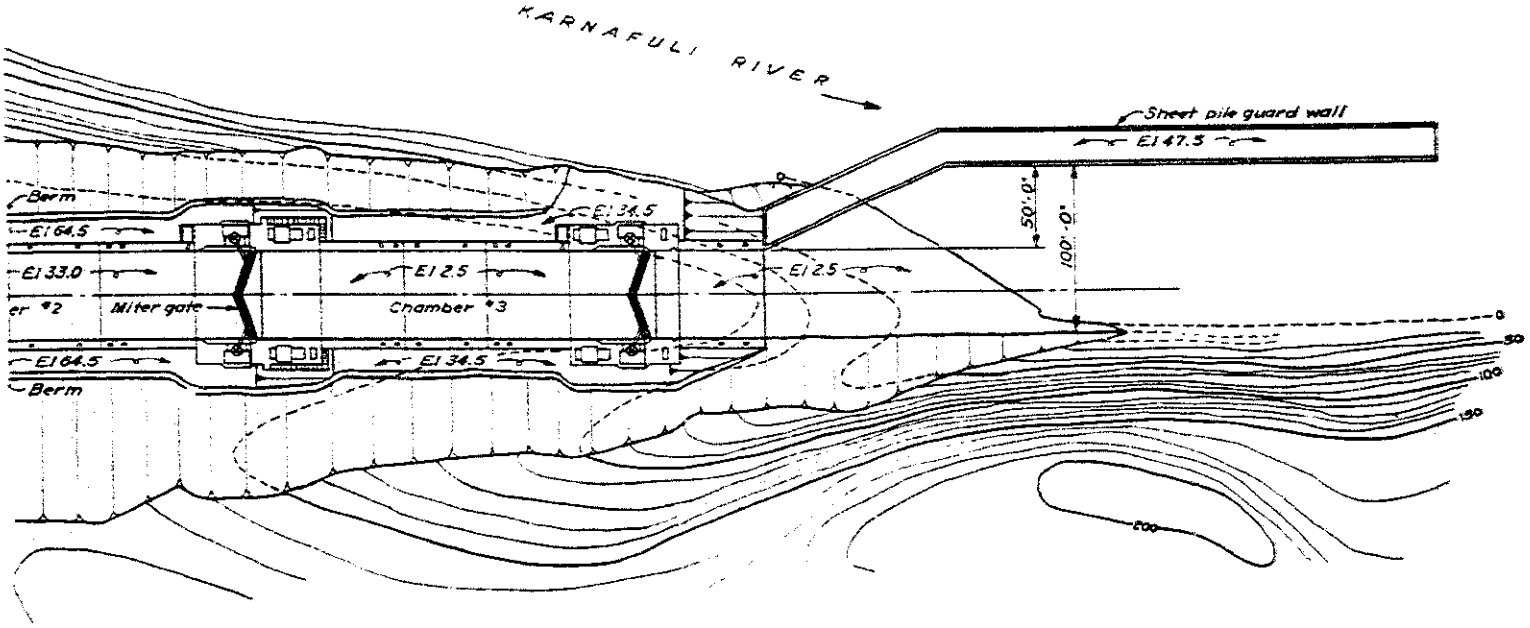


TYPICAL APPROACH CHAN

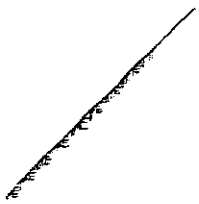
Scale 0 20 Feet



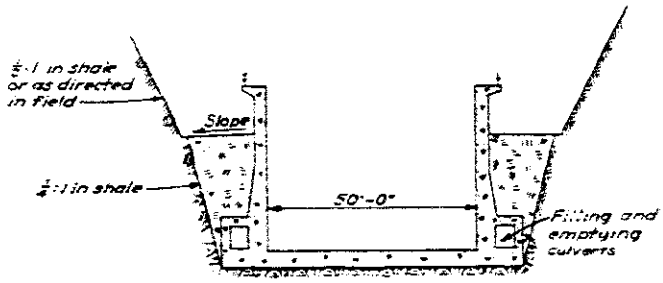
ELEVATION ON ℄ NAVIGATION LO



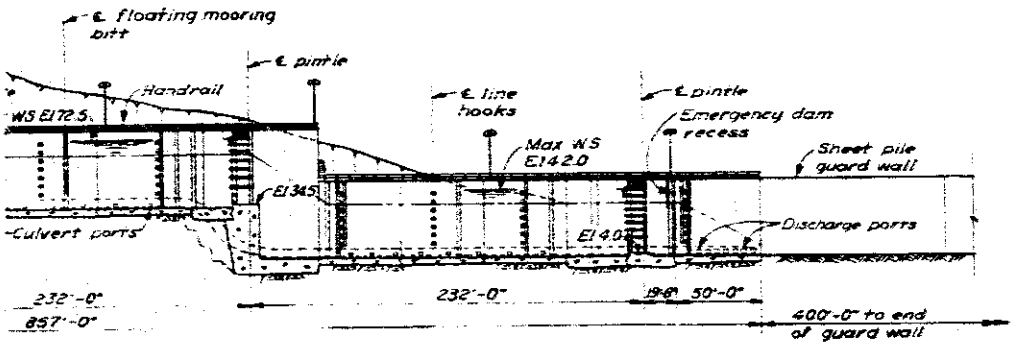
NOTES:
Contours shown were traced from Karnafuli Project Circle drawing titled "Contour Plan Showing Triangulation Points and Control Lines of Structures" dated Nov. 26, 1954.



NEL SECTION



TYPICAL LOCK SECTION
Scale 0 20 Feet

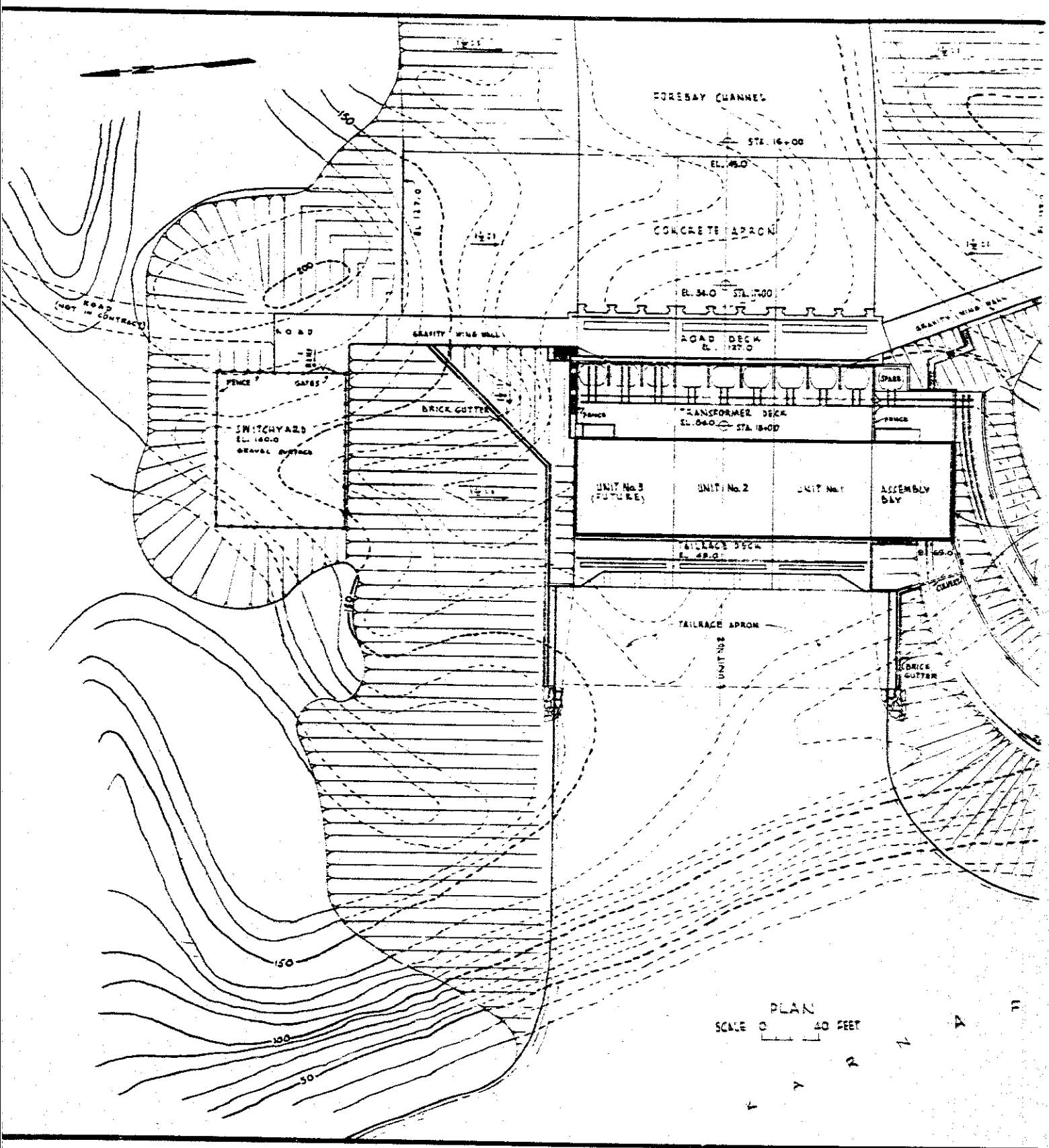


CKS

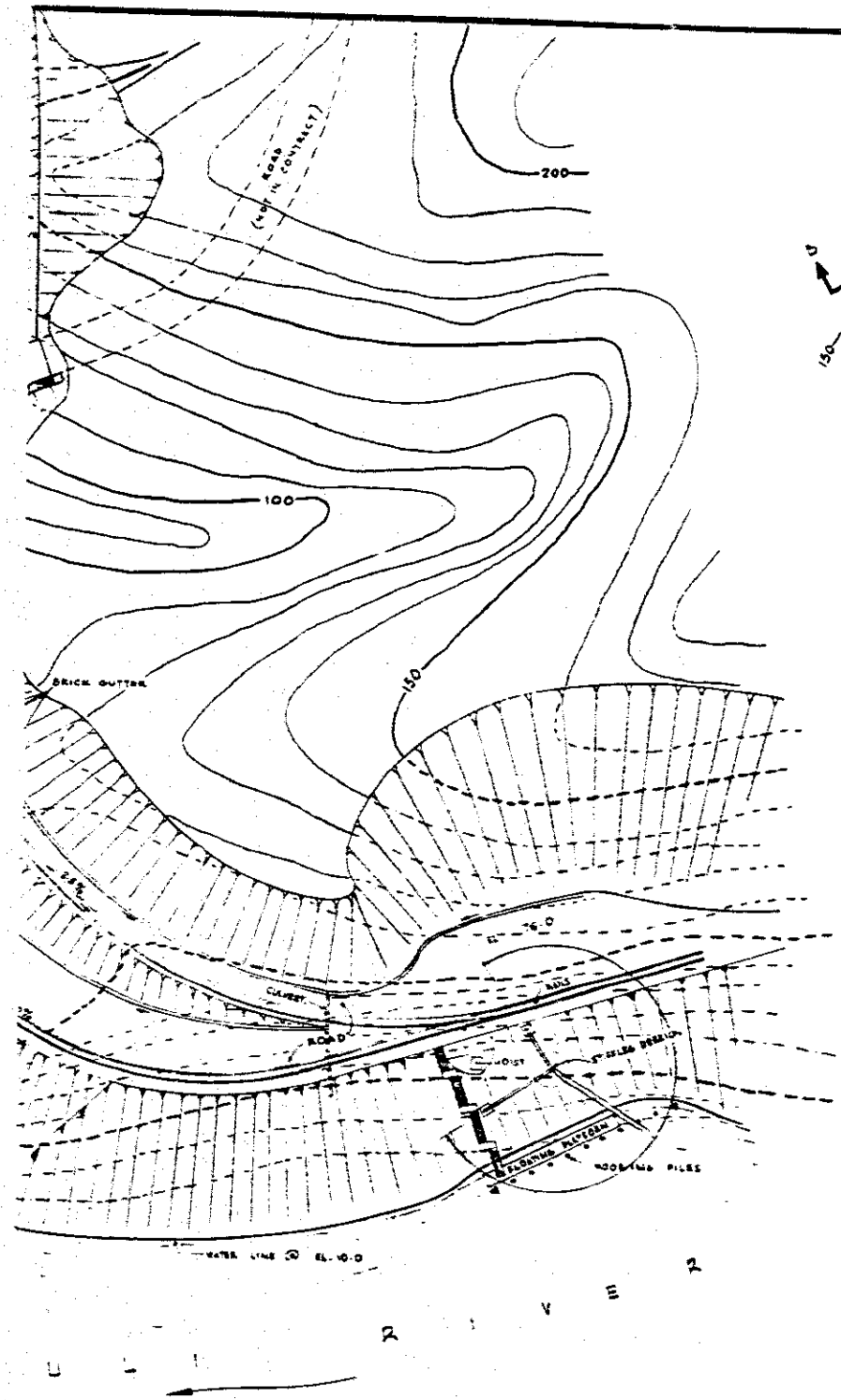
Scale 0 50 100 Feet
Except as noted

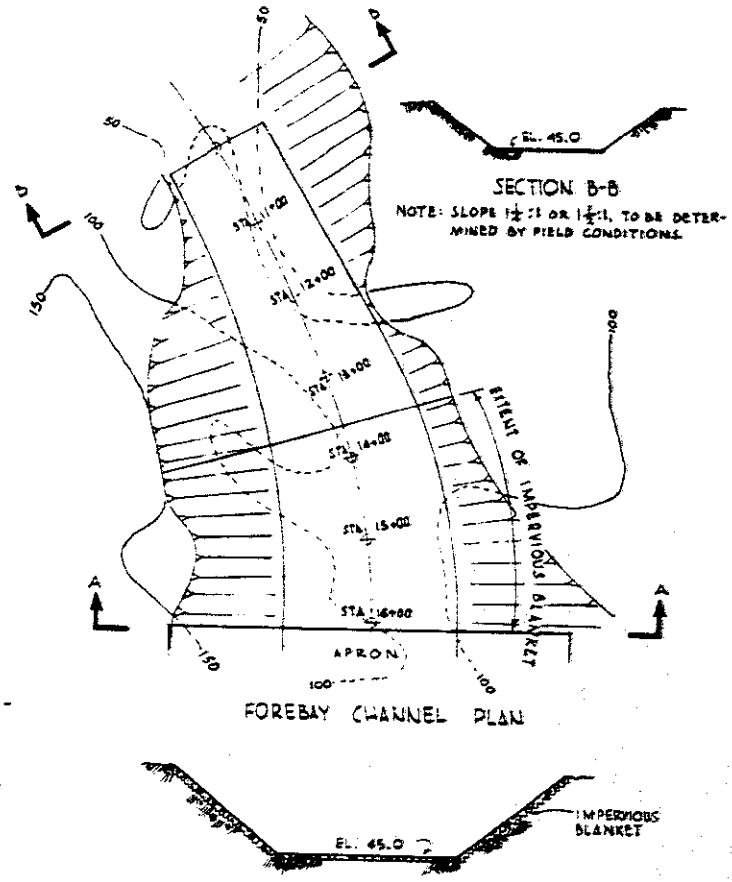
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT
NAVIGATION LOCKS GENERAL PLAN AND SECTIONS
INTERNATIONAL ENGINEERING CO., INC.

DESIGNED P.F.S.	CHKD. C.A.C.	SUBMITTED
DRAWN J.N.F.	REVIEWED	RECOMMENDED
		APPROVED
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW-61-301


FORESAY CHANNEL
STA. 16+00
EL. 48.0
CONCRETE APRON
EL. 34.0
STA. 17+00
ROAD (NOT IN CONTRACT)
ROAD
GRAVITY WING WALL
ROAD DECK
EL. 127.0
FENCE
GATES
SWITCHYARD
EL. 160.0
GRAVEL SURFACE
BRICK GUTTER
TRANSFORMER DECK
EL. 86.0
STA. 18+00
SPARE
UNIT No. 3 (FUTURE)
UNIT No. 2
UNIT No. 1
ASSEMBLY BAY
TAILRACE DECK
EL. 48.0
TAILRACE APRON
UNIT No. 3
BRICK GUTTER
150
100
50
PLAN
SCALE 0 40 FEET

164



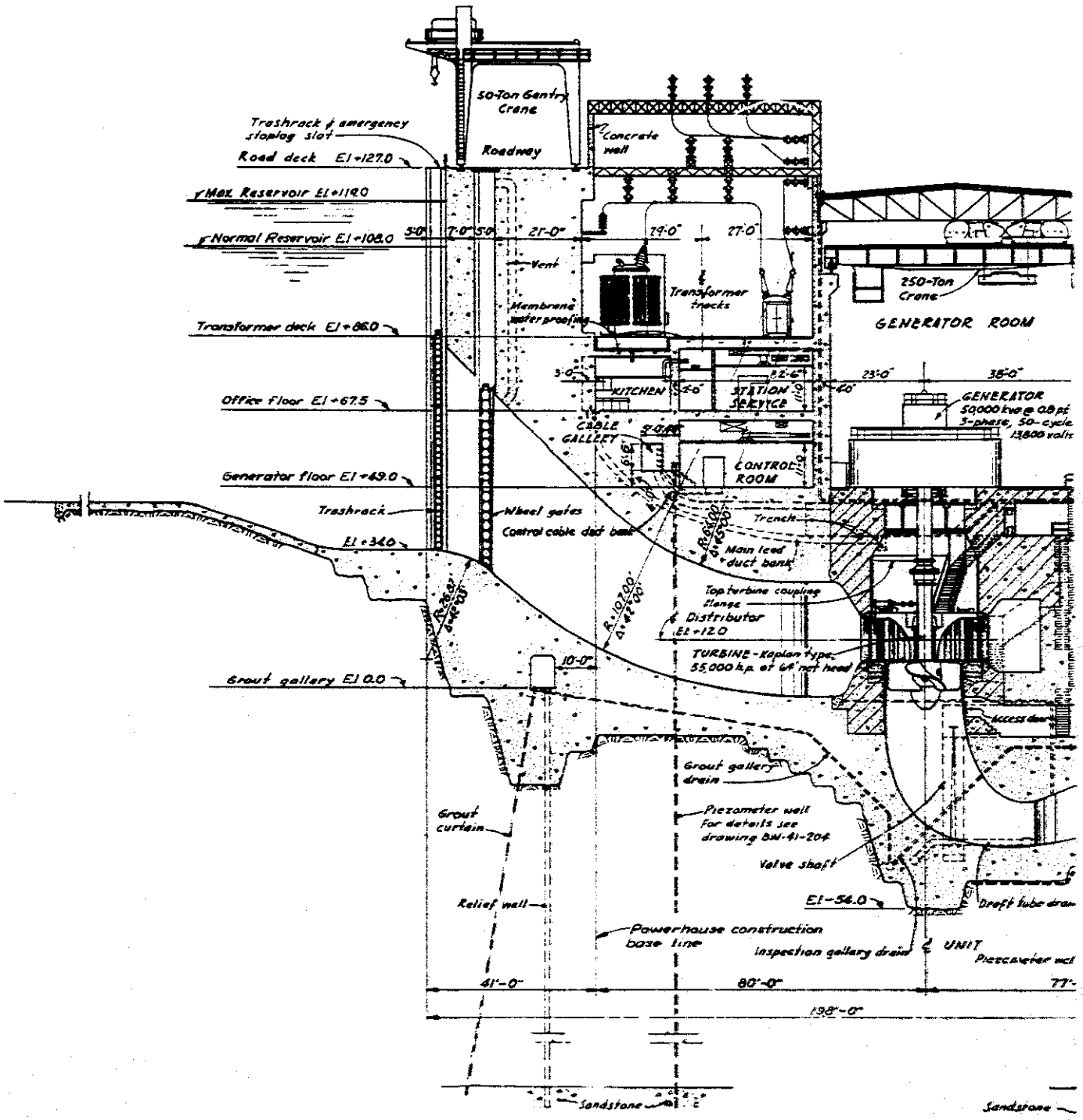


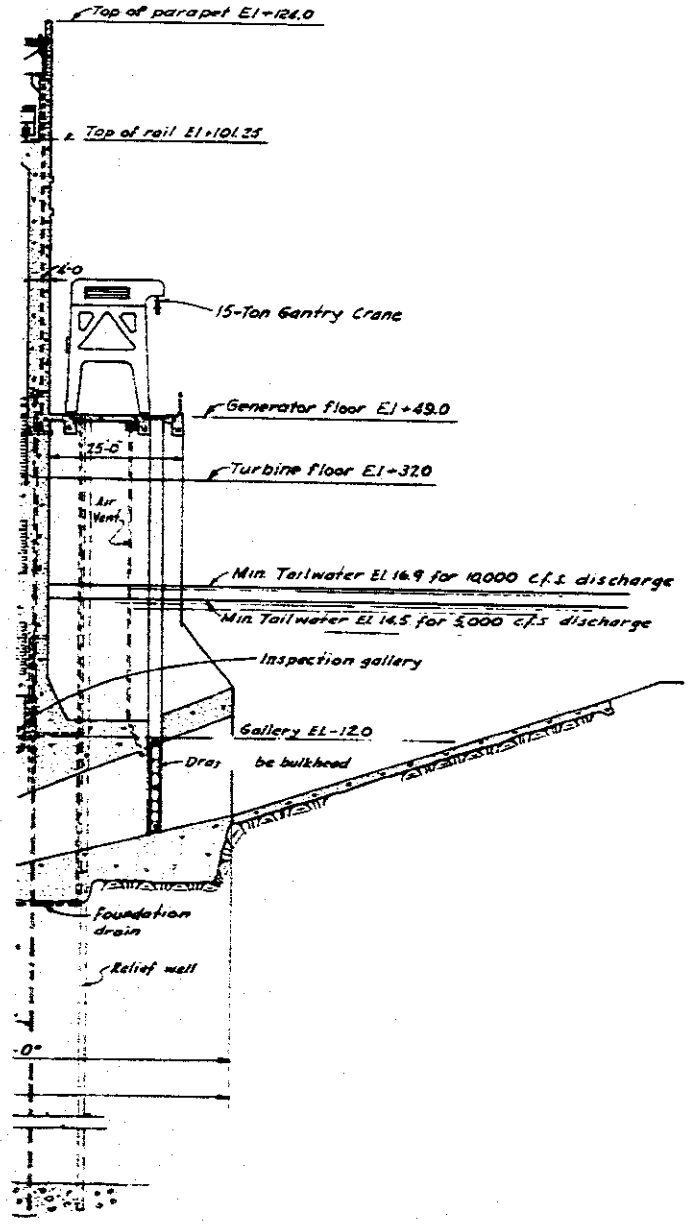
NOTES
For general notes see Dwg BW-42-206
Elevations shown are based on P.W.D. datum.
Topography from Karnafuli project circle drawing titled "Contour plan showing triangulation points and control lines of structures" dated Nov. 26, 1954

Scale as noted

This drawing supercedes drawing No. BW 10.010

GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT **POWERPLANT** **SITE PLAN**		
INTERNATIONAL ENGINEERING CO., INC.		
DESIGNED T.E. DRAWN S.Y.W.	CHKD. C.W.W. REV. L.F. E.E.	SUBMITTED Y. Lambrakis RECOMMENDED [illegible] APPROVED [illegible]
	SAN FRANCISCO, CAL. DATE MARCH 1955	BW - 42 - 201


50-Ton Gantry Crane
Trashrack & emergency stoplog slot
Road deck El +127.0
Roadway
Concrete wall
Max. Reservoir El +119.0
Normal Reservoir El +108.0
Vent
Transformer tracks
Membrane waterproofing
250-Ton Crane
GENERATOR ROOM
Transformer deck El +86.0
Office floor El +67.5
KITCHEN
STATION SERVICE
CABLE GALLERY
CONTROL ROOM
GENERATOR 50,000 kva @ 0.8 pf 3-phase, 50-cycle 13,800 volts
Generator floor El +49.0
Trashrack
Wheel gates
Control cable duct bank
Trench
Main lead duct bank
El +34.0
Top turbine coupling flange
Distributor El +12.0
TURBINE - Kaplan type, 55,000 h.p. at 64' net head
Grout gallery El 0.0
Access door
Grout gallery drain
Grout curtain
Piezometer well For details see drawing Bal-41-204
Valve shaft
Relief wall
El -56.0
Draft tube drain
Powerhouse construction base line
Inspection gallery drain
UNIT
Piezometer well
41'-0"
80'-0"
77'-
198'-0"
Sandstone
Sandstone



LEGEND:
First Stage Concrete
Second Stage Concrete
5" Brick Partitions

NOTE:
For general notes see Dwg. BW-42-206

Scale 0 16 32 Feet

GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES

KARNAFULI PROJECT

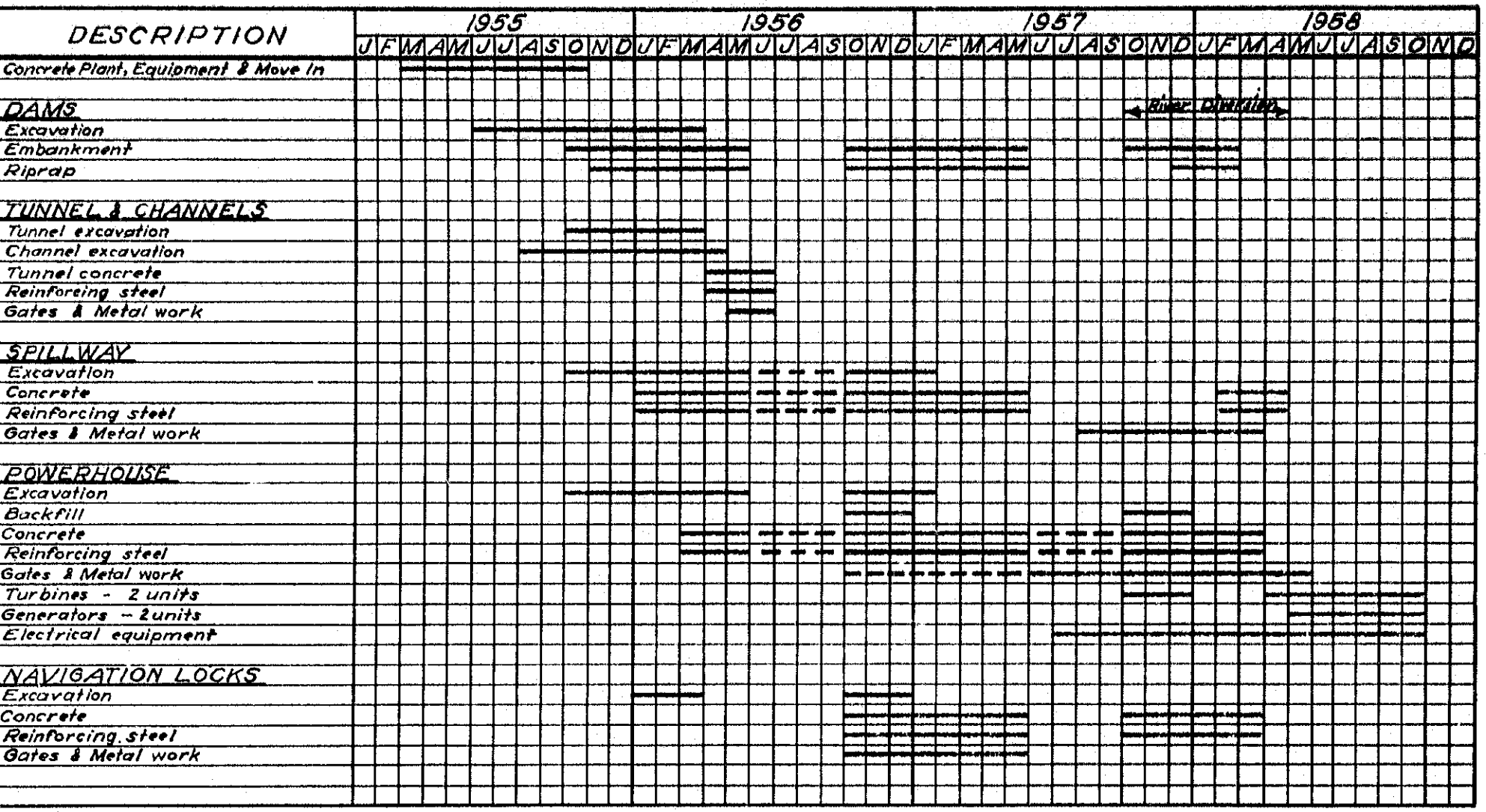
POWERHOUSE TRANSVERSE SECTION THROUGH UNITS

INTERNATIONAL ENGINEERING CO., INC.

DESIGNED N.N.D. DRAWN N.N.D. CHKD. C.W.W. INDEX LF CS

SAN FRANCISCO, CAL. DATE MARCH 1956

BW - 42 - 210



GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT

CONSTRUCTION SCHEDULE

INTERNATIONAL ENGINEERING CO., INC.
SAN FRANCISCO, CALIF.

DR. J.R.F.	RECOMMENDED	APPROVED
CK. P.F.S.	J.P. Hooker	

DATE: MARCH 1955 | BW-83-201

APPENDIXES

APPENDIX A

CAPITAL AND ANNUAL COSTS - SCHEME I
ALL-THERMAL SYSTEM

A.01 GENERAL

In this appendix the capital costs are shown and the annual costs are determined on the sinking fund depreciation basis for Scheme I - Non-Interconnected All-Thermal System as described in Chapter VII. This system comprises a total of 75,000 kw of thermal plant located at Dacca and Chittagong with necessary switching stations but without transmission lines or distribution system.

A.02 CAPITAL COSTS

For purposes of economic comparisons the capital costs have been estimated for steam plants complete with switching stations on the basis of cost per kilowatt of installed capacity. To reduce the difficult operation and maintenance problems involved, low pressure steam plants have been adopted for this study.

The capital costs include the cost of construction, interest during construction, import duties, taxes and contractor's fee.

Capital Cost per Kilowatt of Installed Capacity

Item	Foreign Currency	Pakistan Currency	Total
Plant and Equipment including Switching Structure Packed for Export and including Interest during Manufacture	$142	$ -	$142
Freight and Custom Duty	-	41	41
Foundations and Buildings	8	2	10
Oil Handling and Storage Facilities	8	2	10
Engineering and Start Up	10	4	14
Erection	8	2	10
Land	-	2	2
Totals	$176	$ 53	$229

Total Capital Costs - It has been determined that in 1960 an installed capacity of 75,000 kw will be required which provides for spare capacity as will be necessary for maintenance.

Total Capital Cost (Foreign)	=	75,000	x	176	=	$13,200,000
Total Capital Cost (Pakistan)	=	75,000	x	53	=	3,975,000
TOTAL CAPITAL COST IN 1960						$17,175,000

In 1965 an installed capacity of 105,000 kw will be required.

Total Capital Cost (Foreign)	=	105,000	x	176	=	$18,480,000
Total Capital Cost (Pakistan)	=	105,000	x	53	=	5,565,000
TOTAL CAPITAL COST IN 1965						$24,045,000

A.03 ANNUAL COSTS

The following costs represent the annual costs for the all-thermal system. The annual costs consist of interest, sinking fund, operation, maintenance and fuel costs.

The total annual cost in 1960 for Scheme I is $6,051,000 of which $4,058,000 is in foreign currency and $1,993,000 is in Pakistan currency. This cost is made up of the following items, the detailed computations of which are presented later in this appendix.

Summary of Annual Costs for 1960

	Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
Interest	0.660	0.139	0.799
Sinking Fund	0.399	0.141	0.540
Operation	0.197	0.197	0.394
Maintenance	0.110	0.110	0.220
Fuel - Dacca	2.177	1.310	3.487
Fuel - Chittagong	0.515	0.096	0.611
Totals (In millions)	4.058	1.993	6.051

The total annual cost in 1965 for Scheme I is $8,328,000 of which $5,595,000 is in foreign currency and $2,733,000 is in Pakistan currency.

Summary of Annual Costs for 1965

Item	Cost in Millions of Dollars: Foreign Currency	Pakistan Currency	Total
Interest	0.924	0.195	1.119
Sinking Fund	0.559	0.197	0.756
Operation	0.276	0.276	0.552
Maintenance	0.150	0.150	0.300
Fuel - Dacca	2.958	1.780	4.738
Fuel - Chittagong	0.728	0.135	0.863
Totals (In millions)	5.595	2.733	8.328

The above costs were determined as follows:

a. Interest - Interest rates of 5% for foreign currency and 3-1/2% for Pakistan currency have been used.

Interest in Millions of Dollars

For 1960:

Capital Cost (Foreign)	x	i	=	13.200	x	.05	=	0.660
Capital Cost (Pakistan)	x	i	=	3.975	x	.035	=	0.139
				Total				0.799 Millions

For 1965:

Capital Cost (Foreign)	x	i	=	18.480	x	.05	=	0.924
Capital Cost (Pakistan)	x	i	=	5.565	x	.035	=	0.195
				Total				1.119 Millions

b. Sinking Fund - The useful life of the thermal plant has been assumed to be 20 years. Interest rates for determining the sinking fund are the same as for annual interest.

170

For 1960:

Capital Cost (Foreign)	x	f	=	13.200	x	.03024	=	0.399	
Capital Cost (Pakistan)	x	f	=	3.975	x	.03536	=	0.141	
					Total			0.540	Millions

For 1965:

Capital Cost (Foreign)	x	f	=	18.480	x	.03024	=	0.559	
Capital Cost (Pakistan)	x	f	=	5.565	x	.03536	=	0.197	
					Total			0.756	Millions

c. Operation - An operation cost of $5.25 per kw of installed capacity has been used. This is in accordance with the Federal Power Commission data on costs, corrected to the 1954 level by application of an index, for steam plants having units of 10,000-15,000 kw each and using steam pressure of 600 psi. It is not feasible to definitely establish the ratio of Pakistan and foreign currencies. For purposes of this report division is assumed to be equal.

Operation Cost in Millions of Dollars

For 1960:

75,000 kw	x	$5.25	x	.5	=	0.197	Foreign
75,000 kw	x	$5.25	x	.5	=	0.197	Pakistan
		Total				0.394	Millions

For 1965:

105,000 kw	x	$5.25	x	.5	=	0.276	Foreign
105,000 kw	x	$5.25	x	.5	=	0.276	Pakistan
		Total				0.552	Millions

d. Maintenance - An average maintenance cost of $677.00 per million kwh generated has been used. This is also computed in accordance with the Federal Power Commission data for similar plants. The proportion of foreign and Pakistan currencies are assumed equal.

Maintenance Cost in Millions of Dollars

For 1960:

324.00 Mkwh	x	$677.00/Mkwh	x	.5	=	0.110	Foreign
324.00 Mkwh	x	$677.00/Mkwh	x	.5	=	0.110	Pakistan
		Total				0.220	Millions

For 1965:

443.60 Mkwh	x	$677.00/Mkwh	x	.5	=	0.150	Foreign
443.60 Mkwh	x	$677.00/Mkwh	x	.5	=	0.150	Pakistan
		Total				0.300	Millions

e. Fuel - A modern efficient steam plant, operating at 1,400 psi steam, using oil as fuel and operating on base load with a high load factor will consume approximately 10,000 to 12,000 Btu per kwh of energy output. However, plants having the capacity and steam conditions under consideration and being operated at low load factors require more Btu per kwh output. For the purpose of this study it has been assumed that the heat rate is 14,400 Btu per kwh output. The net calorific value of fuel oil furnished by oil companies operating in the area of East Pakistan is of the order of 18.500 Btu per pound. In this report fuel consumption is assumed to be 0.78 pounds of oil per kwh of output.

The present selling price of fuel oil at Chittagong as quoted by Burma Shell Oil Co. is $28.308 per long ton. Included in this cost is import duty of $2.516 and sales tax of $1.928 per long ton. This cost is the present price at Chittagong whereas the future price and the location of the hypothetical power plant can only be conjectured. However, present trends indicate that industry will locate in the Dacca and Chittagong areas and it is assumed that a steam plant would be located in the area of demand. The cost of fuel is equivalent to $9,855 per million kwh generated of which $8,310 is in foreign currency and $1,545 is in Pakistan currency.

The present selling price of fuel oil at Dacca including import duty, sales tax, and the freight from Chittagong to Dacca is $38.220 per long ton or total cost of $13,310 per million kwh output at Dacca of which $8,310 is in foreign currency and $5,000 is in Pakistan currency.

Fuel Cost in Millions of Dollars

For 1960:							
Dacca -	262.0 Mkwh	x	$8,310.00/Mkwh	=	2.177	Foreign
	262.0 Mkwh	x	$5,000.00/Mkwh	=	1.310	Pakistan
			Total		3.487	Millions
Chittagong -	62.0 Mkwh	x	$8,310.00/Mkwh	=	0.515	Foreign
	62.0 Mkwh	x	$1,545.00/Mkwh	=	0.096	Pakistan
			Total		0.611	Millions
For 1965:						
Dacca -	356.0 Mkwh	x	$8,310.00/Mkwh	=	2.958	Foreign
	356.0 Mkwh	x	$5,000.00/Mkwh	=	1.780	Pakistan
			Total		4.738	Millions
Chittagong -	87.6 Mkwh	x	$8,310.00/Mkwh	=	0.728	Foreign
	87.6 Mkwh	x	$1,545.00/Mkwh	=	0.135	Pakistan
			Total		0.863	Millions

A.04 BASIS OF COMPUTATIONS

In this section the sinking fund factors and interest factors required for the economic analyses of Appendixes A, B and C have been computed.

The sinking fund depreciation factors are derived for facilities having useful lives of 20, 25, 35 and 50 years. These are based on interest rates of 5% for foreign currency and 3-1/2% for Pakistan currency. Interest factors were at the same rates.

Computations are also presented for the interest and amortization factors used in the operation and debt service analysis in Appendix D. Annual interest and amortization are based on repayment of interest and principal in 20 equal annual payments for foreign currency and in 50 equal annual payments for Pakistan currency with interest rates, compounded semi-annually, of 5% for foreign currency and 3-1/2% for Pakistan currency. However, in the case of the 15,000 kw thermal plant, a useful life of 20 years was estimated and the Pakistan currency was accordingly amortized in 20 years.

SUMMARY OF INTEREST FACTORS USED IN APPENDIXES A, B, C AND D

Annual Interest:

Sinking Fund Depreciation Basis -	i = .05	Foreign
	i = .035	Pakistan
Amortization Basis -	i = .050625	Foreign
	i = .035306	Pakistan

Sinking Fund:

20 year period -	F = .03024	Foreign
	F = .03536	Pakistan
25 year period -	F = .02095	Foreign
35 year period -	F = .01107	Foreign
	F = .01500	Pakistan
50 year period -	F = .00478	Foreign
	F = .00763	Pakistan

Amortization:

20 year period -	F = .03004	Foreign
	F = .03524	Pakistan
50 year period -	F = .007563	Pakistan

The preceeding factors may be computed as follows:

Annual Cost Factors - Sinking Fund Basis

Annual Interest:

For Foreign currency $i = 5\%$

For Pakistan currency $i = 3.5\%$

Sinking Fund:

Both currencies - Factor $= \dfrac{i}{(1 + i)^n - 1}$ where i = interest rate, n = number of annual periods

Example:

$n = 25$

$i = 5\%$

$$F = \frac{0.05}{(1.05)^{25} - 1} = \frac{0.05}{3.386 - 1} = \frac{0.05}{2.386} = 0.02095$$

Annual Expenditure Factors - Amortization Basis

Annual Interest:

Both currencies $F = \dfrac{i(4 + i)}{4}$ where i = interest rate, F = annual factor based on interest compounded semi-annually

Example:

$i = 5\%$

$$F = \frac{0.05(4 + 0.05)}{4} = \frac{0.05(4.05)}{4} = 0.050625$$

Amortization:

Both currencies $F = (2.0 + 0.5i)\left(\dfrac{i}{2(1 + 0.5i)^{2n} - 2}\right)$

Example:

$n = 20$

$i = 5\%$

where i = interest rate, F = annual factor based on interest compounded semi-annually, n = number of annual periods

$$F = \left[2.0 + 0.5(.05)\right]\left(\frac{0.05}{2\left[1 + 0.5(.05)\right]^{40} - 2}\right)$$

$$= 2.025\left(\frac{0.025}{1.6851}\right) = 0.03004$$

APPENDIX B

CAPITAL AND ANNUAL COSTS - SCHEME II

HYDRO SYSTEM WITH THERMAL SUPPORT

B.01 GENERAL

In this appendix the capital costs are shown and the annual costs are determined on the sinking fund depreciation basis for Scheme II - Hydro System with Thermal Support as described in Chapter VII. This system comprises the Karnafuli Project, transmission lines and receiving stations and a 15,000 kw thermal plant, but without distribution system.

B.02 CAPITAL COSTS

Capital Cost of Karnafuli Project - Initial Development (3 Unit Powerhouse with 2 Units Installed) - These costs include construction cost, interest during construction, import duties and taxes, contractor's contingencies, contractor's fee and engineering contingencies. Money already spent is included as a separate item with interest added from time of expenditure to the end of the project construction period.

	Capital Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
Money Already Spent (To August 1954)	-	10.203	10.203
Land Compensation	-	4.910	4.910
Main Dam	4.262	3.076	7.338
Tunnel	0.853	0.617	1.470
Spillway	6.850	4.943	11.793
Navigation Locks	4.354	3.141	7.495
Power Plant	14.792	10.681	25.473
Engineering and Administration	2.850	1.349	4.199
SUB-TOTALS (In millions)	33.961	38.920	72.881
Minus Salvage Value of Construction Equipment (decrease)		-0.750	-0.750
TOTAL CAPITAL COSTS (In millions)	33.961	38.170	72.131

Capital Cost of Transmission Lines and Receiving Stations - These costs are for 187 miles of 165 kv transmission line from Karnafuli to Chittagong to Dacca; receiving stations at Chittagong, Siddhirganj and Comilla; and a synchronous condenser at Dacca. Construction cost, import duties and taxes, interest during construction, cost of lands, and contractor's fee and contingencies have been included.

Transmission Line and Receiving Stations	Capital Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
187 miles, 165 kv Transmission Line	5.259	2.490	7.749
Receiving Stations			
Chittagong 37,500 kva	0.855	0.270	1.125
Siddhirganj 75,000 kva	1.261	0.398	1.659
Comilla 6,000 kva	0.274	0.086	0.360
Synchronous Condenser	0.367	0.101	0.468
TOTALS (In millions)	8.016	3.345	11.361

Capital Cost of 15,000 kw Thermal Plant - These costs are for a 15,000 kw Thermal Plant at Dacca which will be required to support the Karnafuli Power Plant. Construction cost, import duties and taxes, interest during construction, contractor's fee and cost of lands have been included.

Item	Capital Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Total Capital Cost of 15,000 kw Plant	2.640	0.795	3.435

B.03 ANNUAL COSTS

For the purpose of computing the annual costs, interest is charged at 5% on foreign currency and 3-1/2% on Pakistan currency. The sinking fund is based upon investment at 5% for foreign currency and 3-1/2% for Pakistan currency for the following life expectancies:

Dam and Appurtenant Works	50 years
Hydro Power Plant Machinery and Equipment	25 years
Transmission System	35 years
Receiving Stations	35 years
Thermal Plant	20 years

This is in accord with the practices of the Federal Power Commission (F.P.C.) of the U.S. Government.

Operation and maintenance for hydro power is charged at $2.70 per kw of installed capacity, which is the cost reported to F.P C. by operators in the United States corrected to the 1954 cost index.

The total annual cost for Scheme II is $5,680,000 of which $3,134,000 is in foreign currency and $2,546,000 is in Pakistan currency. This cost is made up of the following items, the detailed computations of which are presented later in this appendix:

Summary of Annual Costs - Scheme II

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Karnafuli Project:			
Interest	1.698	1.336	3.034
Sinking Fund	0.290	0.307	0.597
Operation and Maintenance	0.109	0.394	0.503
SUB-TOTALS (In millions)	2.097	2.037	4.134
Transmission Lines and Receiving Stations:			
Interest	0.401	0.117	0.518
Sinking Fund	0.089	0.050	0.139
Operation and Maintenance	0.037	0.087	0.124
SUB-TOTALS (In millions)	0.527	0.254	0.781
15,000 kw Thermal Plant:			
Interest	0.132	0.028	0.160
Sinking Fund	0.080	0.028	0.108
Operation and Maintenance	0.049	0.049	0.098
Fuel	0.249	0.150	0.399
SUB-TOTALS (In millions)	0.510	0.255	0.765
TOTAL ANNUAL COSTS (In millions)	3.134	2.546	5.680

The above figures have been computed as follows, using factors shown in Section A.04, Appendix A.

a. Annual Interest

Item										Interest in Millions of Dollars	
Karnafuli Project:											
Capital Cost (Foreign)	x	i	=	33.961	x	.05		=		1.698	
Capital Cost (Pakistan)	x	i	=	38.170	x	.035		=		1.336	
							Total			3.034	Millions
Transmission Lines and Receiving Stations:											
Capital Cost (Foreign)	x	i	=	8.016	x	.05		=		0.401	
Capital Cost (Pakistan)	x	i	=	3.345	x	.035		=		0.117	
							Total			0.518	Millions
15,000 kw Thermal Plant:											
Capital Cost (Foreign)	x	i	=	2.640	x	.05		=		0.132	
Capital Cost (Pakistan)	x	i	=	0.795	x	.035		=		0.028	
							Total			0.160	Millions

b. Sinking Fund

Item										Sinking Fund in Millions of Dollars	
Karnafuli Project:											
Power Plant Mechanical and Electrical Equip (25 year life):											
Total Capital Cost			=	8.743 millions							
Capital Cost (Foreign)			=	8.743 (90%)					=	7.869	
Capital Cost (Pakistan)			=	8.743 (10%)					=	0.874	
Capital Cost (Foreign)	x	f	=	7.869	x	0.02095			=	0.165	
Capital Cost (Pakistan)	x	f	=	0.874	x	0.02567			=	0.022	
Dam and Civil Works (50 year life):											
Capital Cost (Foreign)	x	f	=	26.085	x	0.00478			=	0.125	
Capital Cost (Pakistan)	x	f	=	37.296	x	0.00763			=	0.285	
							Sub-total (Foreign)			0.290	
							Sub-total (Pakistan)			0.307	
							Total			0.597	Millions
Transmission Lines and Receiving Stations (35 year life):											
Capital Cost (Foreign)	x	f	=	8.016	x	.01107			=	0.089	
Capital Cost (Pakistan)	x	f	=	3.345	x	.015			=	0.050	
							Total			0.139	Millions
15,000 kw Thermal Plant (20 year life):											
Capital Cost (Foreign)	x	f	=	2.640	x	0.03024			=	0.080	
Capital Cost (Pakistan)	x	f	=	0.795	x	0.03536			=	0.028	
							Total			0.108	Millions

c. Operation and Maintenance

Item				Expenditure in Millions of Dollars	
Karnafuli Project:					
Power Plant	80,000 kw	x	$ 2.70/kw	= 0.216	
Navigation Locks	7.495	x	1%	= 0.075	
Other	20.601	x	0.35%	= 0.072	
			Total (Millions)	0.363	
30% estimated to be foreign				= 0.109	Foreign
70% estimated to be Pakistan				= 0.254	
Administration	28.096	x	0.5% (Pakistan)	= 0.140	
				0.394	Pakistan
Transmission Lines and Receiving Stations:					
Transmission Lines	187 miles	x	$ 380.00/mi	= 0.071	
Receiving Stations	118,500 kva	x	$ 0.45/kva	= 0.053	
			Total (Millions)	0.124	
30% estimated to be foreign				= 0.037	Foreign
70% estimated to be Pakistan				= 0.087	Pakistan

15,000 kw Thermal Plant:

It is estimated that the Thermal Plant will generate 30 million kilowatt hours per year.

Item			Cost in Millions of Dollars	
Maintenance	=	30 x $ 677.00/kwh	= 0.020	
Operation	=	15,000 x $ 5.25/kw	= 0.078	
Total Operation and Maintenance			= 0.098	Millions
Operation and Maintenance (Foreign)	=	0.098 x 0.50	= 0.049	
Operation and Maintenance (Pakistan)	=	0.098 x 0.50	= 0.049	
		Total	0.098	Millions
Fuel (Foreign)	=	30 x $ 8,310/Mkwh	= 0.249	
Fuel (Pakistan)	=	30 x $ 5,000/Mkwh	= 0.150	
		Total	0.399	Millions

179

APPENDIX C

CAPITAL AND ANNUAL COSTS - SCHEME IIa

HYDRO SYSTEM WITH THERMAL SUPPORT

NAVIGATION LOCKS ELIMINATED

C.01 GENERAL

Scheme IIa is similar to Scheme II (Appendix B) except that overland transfer of river shipping past the dam has been substituted for the navigation locks. The project otherwise includes transmission lines, receiving stations and a 15,000 kw thermal plant as in Scheme II, but without distribution system.

C.02 CAPITAL COSTS

Capital Cost of Karnafuli Project - Initial Development (3 Unit Powerhouse with 2 Units Installed).

	Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
Total Capital Cost With Navigation Locks	33.961	38.170	72.131
Minus Cost of Navigation Locks	- 4.354	- 3.141	- 7.495
	29.607	35.029	64.636
Capital Cost of Overland Transfer of Shipping	0.750	0.250	1.000
Total Capital Cost with Overland Transfer of Shipping (In millions)	30.357	35.279	65.636

Capital Cost of Transmission Lines and Receiving Stations.

	Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
Total Capital Cost	8.016	3.345	11.361

Capital Cost of 15,000 kw Thermal Plant

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Total Capital Cost of 15,000 kw Plant	2.640	0.795	3.435

C.03 ANNUAL COSTS

The total annual cost for Scheme IIa is $5,310,000 of which $2,945,000 is in foreign currency and $2,365,000 is in Pakistan currency. Interest rates, life expectancies and operating costs of the various features, except the overland transfer of shipping, are as stated in Appendix B of this report.

Summary of Annual Costs - Scheme IIa

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Karnafuli Project:			
Interest	1.518	1.235	2.753
Sinking Fund	0.292	0.285	0.577
Operation and Maintenance	0.098	0.336	0.434
Sub-totals	1.908	1.856	3.764
Transmission Lines and Receiving Stations:			
Interest	0.401	0.117	0.518
Sinking Fund	0.089	0.050	0.139
Operation and Maintenance	0.037	0.087	0.124
Sub-totals	0.527	0.254	0.781
15,000 kw Thermal Plant:			
Interest	0.132	0.028	0.160
Sinking Fund	0.080	0.028	0.108
Operation and Maintenance	0.049	0.049	0.098
Fuel	0.249	0.150	0.399
Sub-totals	0.510	0.255	0.765
TOTAL ANNUAL COSTS (In millions)	2.945	2.365	5.310

The above costs were determined as follows, using factors computed in Section A.04 of Appendix A:

a. Annual Interest

Item										Interest in Millions of Dollars
Karnafuli Project:										
Capital Cost (Foreign)	x	i	=	30.357	x	.05	=	1.518		
Capital Cost (Pakistan)	x	i	=	35.279	x	.035	=	1.235		
						Total	=	2.753	Millions	
Transmission Lines and Receiving Stations:										
Capital Cost (Foreign)	x	i	=	8.016	x	.05	=	0.401		
Capital Cost (Pakistan)	x	i	=	3.345	x	.035	=	0.117		
						Total	=	0.518	Millions	
15,000 kw Thermal Plant:										
Capital Cost (Foreign)	x	i	=	2.640	x	.05	=	0.132		
Capital Cost (Pakistan)	x	i	=	0.795	x	.035	=	0.028		
						Total	=	0.160	Millions	

b. Sinking Fund

Item										Sinking Fund in Millions of Dollars
Karnafuli Project:										
Power Plant Mechanical and Electrical Equipment (25 year life):										
Capital Cost (Foreign)	x	f	=	7.869	x	.02095	=	0.165		
Capital Cost (Pakistan)	x	f	=	0.874	x	.02567	=	0.022		
Overland Transfer of Shipping (20 year for Foreign, 50 year for Pakistan):										
Capital Cost (Foreign)	x	f	=	0.750	x	.03024	=	0.023		
Capital Cost (Pakistan)	x	f	=	0.250	x	.00763	=	0.002		
Dam and Civil Works (50 year life):										
Capital Cost (Foreign)	x	f	=	21.738	x	.00478	=	0.104		
Capital Cost (Pakistan)	x	f	=	34.155	x	.00763	=	0.261		
						Total Foreign	=	0.292		
						Total Pakistan	=	0.285		
						Total	=	0.577	Millions	
Transmission Lines and Receiving Stations (35 year life):										
Capital Cost (Foreign)	x	f	=	8.016	x	0.01107	=	0.089		
Capital Cost (Pakistan)	x	f	=	3.345	x	0.01500	=	0.050		
						Total	=	0.139	Millions	
15,000 kw Thermal Plant (20 year life):										
Capital Cost (Foreign)	x	f	=	2.640	x	0.03024	=	0.080		
Capital Cost (Pakistan)	x	f	=	0.795	x	0.03536	=	0.028		
						Total	=	0.108	Millions	

157

c. Operation and Maintenance

Item					Expenditure in Millions of Dollars	
Karnafuli Project:						
Power Plant	80,000 kw	x	$ 2.70/kw	=	0.216	
Overland Transfer of Shipping	342,600 tons	x	$ 0.11/ton	=	0.038	
Dam and Civil Works	20.601	x	0.35%	=	0.072	
		Total (Millions)		=	0.326	
30% estimated to be foreign =	0.326	x	0.30	=	0.098	Foreign
70% estimated to be Pakistan =	0.326	x	0.70	=	0.228	
Administrative	21.601	x	0.5% (Pakistan)	=	0.108	
					0.336	Pakistan
Transmission Lines and Receiving Stations:						
Transmission Lines	187 miles	x	$ 380.00/mi	=	0.071	
Receiving Stations	118,500 kva	x	$ 0.45/kva	=	0.053	
		Total (Millions)		=	0.124	
30% estimated to be foreign				=	0.037	Foreign
70% estimated to be Pakistan				=	0.087	Pakistan

15,000 kw Thermal Plant:

It is estimated that the Thermal Plant will generate 30 million kilowatt hours per year. The annual costs are the same as those shown in Appendix B, section B.03.

Operation and Maintenance (Foreign)	=	0.049		
Operation and Maintenance (Pakistan)	=	0.049		
Total	=	0.098	Millions	
Fuel (Foreign)	=	0.249		
Fuel (Pakistan)	=	0.150		
Total	=	0.399	Millions	

APPENDIX D

OPERATION AND DEBT SERVICE

KARNAFULI HYDRO-THERMAL UTILITY SYSTEM

D.01 GENERAL

In this appendix the annual expenditures for operation and debt service are determined for a complete hydro-thermal electric utility system in the Chittagong and Dacca areas. This system comprises the Karnafuli Project, transmission lines and receiving stations, distribution system and 15,000 kw thermal plant. This system differs from that of Scheme II in that it includes the cost of a distribution system required to reach the major consumers served by the initial development. The repayment period for the foreign currency loan is generally less than the useful life of the installation, hence the annual expenditures for debt service computed on an amortization basis are greater than the depreciation allowance computed for Scheme II in Appendix B. However, at the end of the repayment period, which is 20 years for foreign currency and 50 years for Pakistan currency, the expenditures for debt service will cease and operation expenditures only will continue for the remaining useful life of the installations.

The thermal plant costs and annual expenditures have been calculated on the same basis as those for Scheme I in Appendix A.

It is assumed that the existing distribution system and the thermal plant which is to be retired have been amortized, and consequently the costs of these features are not included in the total cost of the Karnafuli development. Conversely, however, it is assumed that the 15,000 kw thermal plant at Dacca, which is to be retained, is a new plant which has not been amortized and for which interest, amortization and operating costs must be charged. These costs have been assumed to be those of a steam plant as herinafter described.

D.02 CAPITAL COSTS

Capital Cost of Karnafuli Project - Initial Development (3 Unit Powerhouse with 2 Units Installed) - These costs include construction cost, interest during construction, import duties, taxes, contractor's contingencies, contractor's fee and engineering contingencies for the Karnafuli Project complete with navigation locks. Money already spent is included as a separate item with interest added from time of expenditure to the end of the project construction period.

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Total Capital Costs	33.961	38.170	72.131

Capital Cost of Transmission Lines and Receiving Stations - These costs are for 187 miles of 165 kv transmission line from Karnafuli to Chittagong to Dacca; receiving stations at Chittagong, Siddhirganj and Comilla; and a synchronous condenser at Dacca. Construction cost, import duties, taxes, interest during construction, cost of lands, and contractor's fee and contingencies have been included.

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Total Capital Costs	8.016	3.345	11.361

Capital Cost of Distribution System - In order that the distribution of energy may be carried out with a minimum capital investment, it is desirable to provide distribution only to major consumers in the initial development.

Considering the extent and voltage of the existing installations and the locations selected for the future basic industries, it is recommended that the distribution system for the initial development should operate at 33 kv and be confined to the vicinity of Dacca and Comilla connecting the loads in these areas to central receiving stations. Exhibit 2 shows the existing high voltage distribution system and the recommended new 33 kv feeder system. It is estimated that a total of 84 miles of single circuit 33 kv distribution line would be required.

In conjunction with the distribution system there would be step-down substations at local load centers to transform energy to 3.3 kv and 230/400 volts. It is estimated 5,000 kva substations at Dumra, Tejgaon, Tongi, Kaliganj, Ghorasal, Narsingdi, and Hajiganj would be required in addition to existing installations. It is considered that substations in the Chittagong area have sufficient capacity to serve the initial development.

In order that energy may be made available to the smaller industries and to enable those industries which have private plants to be connected to the distribution system without excessive cost, low voltage (3,300 and 230/440 volt) distribution lines will be required. The design of the installa-

tion cannot be carried out until the final location of industry is determined. However, the Engineers have estimated that approximately 40 miles of low voltage distribution system will be required and recommend that it should be overhead open wire construction. The following costs are for a distribution system as described above. Construction cost, interest during construction, import duties, taxes, contractor's fee and cost of lands have been included.

	Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
84 miles of 33 kv line	0.513	0.313	0.826
7 Substations, 5,000 kva each	0.673	0.343	1.016
40 miles low voltage system	0.212	0.138	0.350
Totals (In millions)	1.398	0.794	2.192

Capital Cost of 15,000 kw Thermal Plant - These costs are for a 15,000 kw Thermal Plant at Dacca which will be required to support the Karnafuli Power Plant. Construction cost, import duties and taxes, interest during construction, contractor's fee and cost of lands have been included.

	Cost in Millions of Dollars		
Item	Foreign Currency	Pakistan Currency	Total
Total Capital Cost of 15,000 kw Plant	2.640	0.795	3.435

D.03 ANNUAL EXPENDITURES

These costs represent the annual expenditures for operation and debt service that will be required to operate a complete electric utility system consisting of Karnafuli hydro with 15,000 kw thermal support and the necessary transmission lines, receiving stations and distribution system. The total annual expenditure is $6,741,000 of which $4,167,000 is in foreign currency and $2,574,000 in Pakistan currency. The annual expenditures consist of interest, debt service, operation, maintenance, and fuel for the thermal plant.

Summary of Annual Expenditures

Item	Cost in Millions of Dollars		
	Foreign Currency	Pakistan Currency	Total
Karnafuli Project:			
Interest	1.719	1.348	3.067
Amortization	1.021	0.289	1.310
Operation and Maintenance	0.109	0.394	0.503
Sub-totals	2.849	2.031	4.880
Transmission Lines and Receiving Stations:			
Interest	0.406	0.118	0.524
Amortization	0.241	0.025	0.266
Operation and Maintenance	0.037	0.087	0.124
Sub-totals	0.684	0.230	0.914
Distribution System:			
Interest	0.071	0.028	0.099
Amortization	0.042	0.006	0.048
Operation and Maintenance	0.010	0.024	0.034
Sub-totals	0.123	0.058	0.181
15,000 kw Thermal Plant:			
Interest	0.134	0.028	0.162
Amortization	0.079	0.028	0.107
Operation and Maintenance	0.049	0.049	0.098
Fuel	0.249	0.150	0.399
Sub-totals	0.511	0.255	0.766
TOTAL ANNUAL EXPENDITURES (In millions)	4.167	2.574	6.741

The above expenditures were determined as follows, using factors computed in Section A.04, Appendix A.

a. Annual Interest - For the purpose of these computations interest rates of 5% compounded semi-annually for foreign currency and 3-1/2% compounded semi-annually for Pakistan currency were used.

Item									Interest in Millions of Dollars	
Karnafuli Project:										
Capital Cost (Foreign)	x	i	=	33.961	x	.050625	=		1.719	
Capital Cost (Pakistan)	x	i	=	38.170	x	.035306	=		1.348	
						Total			3.067	Millions
Transmission Lines and Receiving Stations:										
Capital Cost (Foreign)	x	i	=	8.016	x	.050625	=		0.406	
Capital Cost (Pakistan)	x	i	=	3.345	x	.035306	=		0.118	
						Total			0.524	Millions
Distribution System:										
Capital Cost (Foreign)	x	i	=	1.398	x	.050625	=		0.071	
Capital Cost (Pakistan)	x	i	=	0.794	x	.035306	=		0.028	
						Total			0.099	Millions
15,000 kw Thermal Plant:										
Capital Cost (Foreign)	x	i	=	2.640	x	.050625	=		0.134	
Capital Cost (Pakistan)	x	i	=	0.795	x	.035306	=		0.028	
						Total			0.162	Millions

b. Annual Amortization - For the purpose of these computations the annual amortization for the Karnafuli Project, transmission lines and receiving stations and distribution system is based upon investment at 5% compounded semi-annually for 20 years for foreign currency and 3-1/2% compounded semi-annually for 50 years for Pakistan currency. For the 15,000 kw thermal plant the amortization is based on a period of 20 years using interest rates as mentioned above.

Item									Amortization in Millions of Dollars	
Karnafuli Project:										
Capital Cost (Foreign)	x	f	=	33.961	x	.03004	=		1.021	
Capital Cost (Pakistan)	x	f	=	38.170	x	.007563	=		0.289	
						Total			1.310	Millions
Transmission Lines and Receiving Stations:										
Capital Cost (Foreign)	x	f	=	8.016	x	.03004	=		0.241	
Capital Cost (Pakistan)	x	f	=	3.345	x	.007563	=		0.025	
						Total			0.266	Millions
Distribution System:										
Capital Cost (Foreign)	x	f	=	1.398	x	.03004	=		0.042	
Capital Cost (Pakistan)	x	f	=	0.794	x	.007563	=		0.006	
						Total			0.048	Millions
15,000 kw Thermal Plant:										
Capital Cost (Foreign)	x	f	=	2.640	x	.03004	=		0.079	
Capital Cost (Pakistan)	x	f	=	0.795	x	.03524	=		0.028	
						Total			0.107	Millions

Item			Expenditure in Millions of Dollars
Karnafuli Project:			
Power Plant	80,000 kw x	$ 2.70 /kw	= 0.216
Navigation Locks	7.495 x	1%	= 0.075
Other	20.601 x	0.35%	= 0.072
		Total (Millions)	0.363
30% estimated to be foreign			= 0.109 Foreign
70% estimated to be Pakistan			= 0.254
Administration	28.096 x	0.5% (Pakistan)	= 0.140
		Total (Millions)	0.394 Pakistan
Transmission Lines and Receiving Stations:			
Transmission Lines	187 miles x	$ 380.00/mi	= 0.071
Receiving Stations	118,500 kva x	$ 0.45/kva	= 0.053
		Total	0.124 Millions
30% estimated to be foreign			= 0.037 Foreign
70% estimated to be Pakistan			= 0.087 Pakistan
Distribution System:			
Substations	35,000 kva x	$ 0.54/kva	= 0.019
Lines	124 miles x	$ 120.00/mi	= 0.015
		Total	0.034 Millions
30% estimated to be foreign			= 0.010 Foreign
70% estimated to be Pakistan			= 0.024 Pakistan

15,000 kw Thermal Plant:

It is estimated that the thermal plant will generate 30 million kilowatt hours per year. The annual costs are the same as those shown in Appendix B, Section B.03.

Operation and Maintenance (Foreign)		= 0.049
Operation and Maintenance (Pakistan)		= 0.049
	Total	0.098 Millions
Fuel (Foreign)		= 0.249
Fuel (Pakistan)		= 0.150
	Total	0.399 Millions

APPENDIX E

PROJECT QUANTITIES

The following detailed list of quantities contains the items of work covered by the engineering specifications and drawings included in Volumes II and III of this report.

PROJECT QUANTITIES - MAIN DAM AND SADDLE DAMS

Item No.	Item	Quantity
D-1	Clearing & grubbing	500 ac
D-2	Unwatering	LS
D-3	Stripping borrow pits	430,000 cu yd
D-4	Excavation, common, for foundation of dam above river level	85,000 cu yd
D-5	Excavation, common, for foundation of dam in original stream bed	210,000 cu yd
D-6	Foundation preparation	356,000 sq yd
D-7	Rolled earth fill in embankment of main dam and saddle dike	2,831,000 cu yd
D-8	Random fill for blankets including cofferdams	1,470,000 cu yd
D-9	Dumping spillway and powerhouse excavation in designated areas	1,470,000 cu yd
D-10	Filter under slope protection	27,000 cu yd
D-11	Slope protection on U/S & D/S slopes (brick)	566,000 sq ft
D-12	Sodding D/S slope	32,000 sq yd
D-13	Drill 12" diam holes & install sand drains	23,800 lin ft
D-14a	Brick gutters, trench, for D/S slope	9,200 lin ft
D-14b	Laying brick, gutters	180 M

PROJECT QUANTITIES - MAIN DAM (contd)

Item No.	Item	Quantity
D-15	Drill 16" diam relief wells & install casings 30-130' deep	2,450 lin ft
D-16	Furnish & install 24" concrete pipe header for relief wells	1,200 lin ft
D-17	Furnish & install concrete drop structures for relief well header	3 ea
D-18	Drilling grout holes, 0-350'	30,500 lin ft
D-19	Pressure grouting	30,500 cu ft
D-20	Furnish & install 4" diam steel riser pipe for relief wells	2,450 lin ft

191

PROJECT QUANTITIES - DIVERSION & OUTLET TUNNEL

Item No.	Item	Quantity
T-1	Clearing & grubbing	10 ac
T-2	Unwatering	LS
T-3	Excavation, unclassified, approach & outlet channels	323,000 cu yd
T-4	Excavation, unclassified, access shaft	1,000 cu yd
T-5	Excavation, unclassified, tunnel (9" overbreak included)	10,440 cu yd
T-6	Concrete, intake structure, including access shaft & house	825 cu yd
T-7	Concrete, tunnel lining, including 9" overbreak	3,640 cu yd
T-8	Reinforcing steel	80,000 lb
T-9	Furnish & install 6'-0" x 7'-6" bonnet-type slide gates, manual operation, for outlet tunnel	210,000 lb
T-10	Furnish & install 4'-0" x 9'-0" trashrack for outlet tunnel	18,500 lb
T-11	Furnish & install electrical system for tunnel inlet	740 lb

PROJECT QUANTITIES - SPILLWAY

Item No.	Item	Quantity
S-1	Clearing & grubbing	20 ac
S-2	Unwatering	LS
S-3	Excavation, overburden and sand	1,420,000 cu yd
S-4	Excavation, shale	1,080,000 cu yd
S-5	Foundation preparation, shale	111,100 sq yd
S-6	Embankment	22,000 cu yd
S-7	Selected backfill	10,000 cu yd
S-8	Sand & gravel under spillway apron	20,000 cu yd
S-9	Drilling holes for anchor bars & grouting bars in place	93,000 lin ft
S-10	Drilling grout holes, 0-75'	2,200 lin ft
S-10a	Drilling grout holes, 0-20'	2,000 lin ft
S-11	Pressure grouting	4,000 cu ft
S-12	Concrete in spillway piers	12,600 cu yd
S-13	Concrete in spillway weir	25,000 cu yd
S-14	Concrete in spillway apron & chute	47,500 cu yd
S-15	Concrete in spillway transition & abutments	8,200 cu yd
S-16	Concrete in roadway bridge deck	130 cu yd
S-17	Concrete, prestressed, in roadway bridge beams	135 cu yd
S-18	Furnish & install reinforcing steel	5,840,000 lb
S-19	12" split-tile drains	1,700 lin ft
S-20	12" tile drains	7,400 lin ft
S-21	10" tile drains	8,000 lin ft
S-22	8" tile drains	7,700 lin ft

PROJECT QUANTITIES - SPILLWAY (contd)

Item No.	Item	Quantity
S-23	6" tile drains	7,200 lin ft
S-24	4" tile drains	30,300 lin ft
S-25	Handrail	27,870 lb
S-26	Rubber waterstop	4,000 lin ft
S-27	Prestressing steel	8,000 lb
S-28	12" cast-iron pipe	500 lin ft
S - A	Drill 16" diam relief wells & install casings, 30-100'	1,500 lin ft
S - B	Furnish & install 4" steel pipe for relief wells	2,000 lin ft
S-29	Supply & install 40'-0" x 30'-0" taintor gates for spillway	1,440,000 lb
S-30	Supply & install spillway taintor gate hoists	480,000 lb
S-31	Supply & install embedded metal for taintor gates	518,000 lb
S-32	Furnish & install auxiliary electrical equipment	3,940 lb
S-33	Furnish & install lighting system	740 lb
S-34	Furnish & install electrical wiring	1,765 lb
S-35	Furnish & install electrical conduits	4,620 lb
S-36	Furnish & install grounding system	1,300 lb
S-37	Furnish & install aerial line from powerhouse, including high line equipment and transformers	69,410 lb
S-37A	Furnish & install feeder to village	10,900 lb

PROJECT QUANTITIES - NAVIGATION LOCKS

Item No.	Item	Quantity
L-1	Clearing & grubbing	10 ac
L-2	Cofferdam & unwatering	LS
L-3a	Excavation, overburden & sand	250,000 cu yd
L-3b	Excavation, shale	400,000 cu yd
L-4	Backfill, selected	35,000 cu yd
L-5	Concrete in lock walls (excluding gate blocks)	9,000 cu yd
L-6	Concrete in gate blocks	16,000 cu yd
L-7	Concrete in lock floors	16,500 cu yd
L-8	Reinforced concrete in bridge, valve pits, culverts, ports, etc.	700 cu yd
L-9	Furnish & install reinforcing steel	4,500,000 lb
L-10	Sheet piling for permanent guide walls	1,500,000 lb
L-11a	Furnish & install drains behind walls & under floor - 10" Ø	2,000 lin ft
L-11b	Furnish & install drains behind walls & under floor - 4" Ø	2,500 lin ft
L-12	Furnish & install rubber waterstops	5,000 lin ft
L-13	Furnish & install navigation lock gates	700,000 lb
L-14	Furnish & install navigation lock gate operating mechanism	240,000 lb
L-15	Furnish & install towing equipment	120,000 lb
L-16	Furnish & install segmental valves	80,000 lb
L-17	Furnish & install segmental valve operating mechanism	160,000 lb
L-18	Furnish & install navigation lock gate bulkhead	200,000 lb
L-19	Furnish & install segmental valve bulkhead	5,000 lb

PROJECT QUANTITIES - NAVIGATION LOCKS (contd)

Item No.	Item	Quantity
L-20	Furnish & install embedded metal including miscellaneous & floating mooring bits	124,000 lb
L-21	Furnish & install slot filler	24,000 lb
L-22	Furnish & install 75 kw engine driven generator	1 ea
L-23	Furnish & install auxiliary electrical equipment	3,290 lb
L-24	Furnish & install lighting system	28,820 lb
L-25	Furnish & install electrical wiring	5,555 lb
L-26	Furnish & install electrical conduits	24,435 lb
L-27	Furnish & install grounding system	1,825 lb
L-28	Furnish & install aerial line from powerhouse including high line equipment & transformers	30,410 lb

PROJECT QUANTITIES - POWERHOUSE

Item No.	Item	Quantity
P-1	Clearing & grubbing	8 ac
P-2	Unwatering	LS
P-3	Excavation, powerhouse tailrace & switchyard	655,200 cu yd
P-4	Excavation, canal, forebay, road & jetty	463,000 cu yd
P-5	Backfill, compacted impervious blanket in canal	21,000 cu yd
P-6	Backfill with impervious material	8,000 cu yd
P-7	Backfill, common	55,000 cu yd
P-8	Riprap in tailrace	1,000 cu yd
P-A	Gravel for drainage	126 cu yd
P-9	Concrete, powerhouse substructure	101,035 cu yd
P-10	Concrete, powerhouse superstructure	9,460 cu yd
P-11	Concrete, mass gravity walls	21,000 cu yd
P-12	Concrete, switchyard, miscellaneous	1,100 cu yd
P-13	Concrete, canal lining & tailrace retaining walls	5,480 cu yd
P-14	Reinforcing steel	8,478,000 lb
P-15	Omitted	-
P-16	Furnish & install 8" concrete drainage pipe	1,000 lin ft
P-B	Furnish & install 6" concrete drainage pipe	400 lin ft
P-17	Supply & install grout pipe, fittings & drains	23,550 lb
P-C	Furnish & install relief well casing (16" x 1/4" steel tubing) including drilling 16" Ø hole	1,925 lin ft

PROJECT QUANTITIES - POWERHOUSE (contd)

Item No.	Item	Quantity
P-D	Furnish & install 4" diam steel riser pipe in relief well casing	3,180 lin ft
P-E	Drilling grout holes	2,000 lin ft
P-F	Pressure grouting	4,000 cu ft
P-G	Drill holes for anchor bolts	8,650 lin ft
P-H	Furnish & install anchor bolts	23,000 lb
P-18	Furnish & install rubber waterstop	
a	3-bulb type	1,640 lin ft
b	2-bulb type	2,630 lin ft
P-19	Furnish & install metal waterstop	
	copper, 20-oz	4,490 lin ft
	steel plate	18,740 lin ft
P-20	Furnish & install doors, frames & hardware	Job
	Single doors (31) 450 sq ft	
	Double doors (6) 296 sq ft	
	Fire doors (2) 416 sq ft	
	Roll-up doors (1) 430 sq ft	
	1,592 sq ft	
P-21	Furnish & install glazed metal windows	980 sq ft
P-22	Furnish & install metal toilet partition (290 sq ft)	290 sq ft
P-23	Furnish & install brick masonry partitions	890 sq yd
P-24	Plaster on brick masonry	1,415 sq yd
P-25	Cement floor finishing, outside troweling	2,900 sq yd
P-26	Cement floor finishing, inside troweling and hardener	3,750 sq yd
P-27	Furnish & install ceramic tile floors	650 sq ft
P-28	Furnish & install ceramic tile walls	2,250 sq ft

PROJECT QUANTITIES - POWERHOUSE (contd)

Item No.	Item	Quantity
P-I	Furnish & install ceramic tile base	2,400 lin ft
P-29	Furnish & install metal acoustical tile ceiling	6,200 sq ft
P-30	Furnish & install roofing (5-ply)	19,000 sq ft
P-31	Furnish & install flashing & miscellaneous sheet metal work	Job
P-32	Furnish & install membrane waterproofing (5-ply)	11,500 sq ft
P-33	Carpentry & millwork	Job
P-34	Painting interior walls & ceilings	10,100 sq yd
P-35	Painting equipment	Job
P-36	Furnish & install pipe handrails	12,000 lb
P-J	Furnish & install steel guardrails (flex-beam)	40,000 lb
P-37	Furnish & install structural roof steel	212,000 lb
P-38	Furnish & install powerhouse draft bulkhead for intake structure	232,000 lb
P-39	Furnish & install embedded metal for intake structure (including dogging devices)	684,000 lb
P-40	Furnish & install railroad rails	118,000 lb
P-41	Furnish & install crane rails	78,000 lb
P-42	Furnish & install miscellaneous metal & gratings	180,000 lb
P-43	Furnish & install 16' x 48' fixed wheel gate for powerhouse intake	420,000 lb
P-44	Furnish & install trashracks & rake for powerhouse intake	152,000 lb
P-45	Furnish & install stoplogs for power-house intake	225,000 lb

PROJECT QUANTITIES - POWERHOUSE (contd)

Item No.	Item	Quantity
P-46	Furnish & install lifting beam for trashracks, wheel gates & stoplogs	2,000 lb
P-47	Furnish & install 50-ton Gantry crane for intake structure	150,000 lb
P-48	Furnish & install 20-ton Gantry crane for powerhouse afterbay	70,000 lb
P-49	Furnish & install 250-ton powerhouse overhead bridge crane (2 trolleys)	450,000 lb
P-50	Furnish & install 70-ton stiffleg derrick for unloading dock	117,000 lb
P-51	Furnish & install 55,000 hp Kaplan type turbine with actuator type governor	2,200,000 lb
P-52	Furnish & install insulating & lubricating oil system	4,226 lb
P-53	Furnish & install compressed air & CO_2 system	17,142 lb
P-54	Furnish & install plumbing & drainage system	66,576 lb
P-55	Furnish & install treated water system	11,429 lb
P-56	Furnish & install raw water & fire protection system	121,400 lb
P-57	Furnish & install water still & accessories	270 lb
P-58	Furnish & install machine shop equipment	14,790 lb
P-59	Furnish & install 80-ton capacity low-bed flat car	66,000 lb
P-60	Furnish & install piezometer piping (OMIT)	-
P-61	Furnish & install head & tail water gauges	10,445 lb
P-62	Furnish & install heating, ventilating & air conditioning system	19,982 lb

PROJECT QUANTITIES - POWERHOUSE (contd)

Item No.	Item	Quantity
P-63	Furnish & install 40,000 kw generator	2 ea
P-64	Furnish & install 100 kw engine driven generator (8,775 lb)	1 ea
P-65	Furnish & install generator auxiliary equipment	2 sets 24,190 lb
P-66	Furnish & install generator main leads	3,000 ft 23,930 lb
P-67	Furnish & install 16,667 kva main power transformer	7 ea
P-68	Furnish & install oil circuit breakers	128,200 lb
P-68a	Furnish & install switches, insulators, bus bars & switchyard auxiliaries	58,470 lb
P-69	Furnish & install main control board	6,505 lb
P-70	Furnish & install station service switchgear	34,265 lb
P-71	Furnish & install auxiliary switchgear	6,690 lb
P-72	Furnish & install station battery & charger	8,665 lb
P-73	Furnish & install carrier current telephone equipment	1 set 11,715 lb
P-74	Furnish & install telephone system	LS 4,100 lb
P-75	Furnish & install powerhouse & switchyard lighting system	19,850 lb
P-76	Furnish & install wiring in powerhouse & switchyard	25,945 lb
P-77	Furnish & install electrical conduits in powerhouse & switchyard	41,050 lb

PROJECT QUANTITIES - POWERHOUSE (contd)

Item No.	Item	Quantity
P-78	Furnish & install grounding system	6,370 lb
P-79	Furnish & install switchyard equipment foundations	60 cu yd
P-80	Furnish & install structural steel in switchyard	100,000 lb
P-81	Testing & making plant operative	Job

APPENDIX F

AGRICULTURE AND LAND RECLAMATION

F.01 AGRICULTURE AND LAND RECLAMATION

There is a great need in East Pakistan for land reclamation projects and for improved agricultural practices. The majority of the land reclamation schemes require pumping plants. Electric power when it becomes available from reliable and economical central stations will greatly aid in this development. Much work remains to be done in the detailed planning of the reclamation schemes and in establishing improved agricultural practices. The execution of those schemes will require substantial capital outlay. The availability of Karnafuli hydroelectric power will greatly encourage the development of land reclamation in East Pakistan.

The estimates of construction costs for irrigation and drainage projects quoted herein have been prepared by the Irrigation Department, Government of East Pakistan and are based on the use of hand labor. The valuation of crops and the cost of agricultural production has been obtained from Governmental sources in East Pakistan and is based on hand cultivation of small plots. It is very difficult to arrive at a proper evaluation of the actual costs of such hand labor when applied to either construction or agriculture.

F.02 AGRICULTURE - GENERAL

East Pakistan is predominantly an agricultural country and in spite of the program for industrialization that is now being pursued, its economy is likely to remain predominantly agricultural for a long time to come. The prosperity of Pakistan, therefore, depends to a large extent upon the success of the country's program for agricultural development. Present crops include a number of cereals, pulses, vegetables, spices, oilseeds, fruits, fibers, sugar, and tobacco, providing food for the ever-increasing population and also raw materials for consumption in the newly established industries as well as for export to foreign countries. The methods of agriculture employed, the qualities and varieties of crops produced, the methods of processing adopted, and the marketing practices used in the country are major problems which, if properly handled, will improve the standard of agriculture and increase the economic returns.

Agriculture in East Pakistan has a basic need; to increase the total production of crops by improving the yield per acre and expanding crop acreage. The total production can be increased by more extensive and intensive cultivation, and by corrective measures to prevent damage to

standing crops and by reducing loss in storage. The yields per acre of many of the major crops are among the lowest in the world. The yield of rice, for example is but one-third of the yield in Egypt and Japan and only one-fourth that of Italy. The yields per acre can be vastly increased by the adoption of more scientific agricultural methods that would include the use of improved seeds, better manure and fertilizers, improved cropping systems, modern farm implements and increased facilities for irrigation and drainage.

F.03 LAND CLASSIFICATION

For the purpose of classification and evaluation, the agricultural land may be divided into four classes:

Class I Land - Land that is above flood level and receives water only from rains and irrigation, if available. This is referred to as "highland"

Class II Land - Land that receives flooding to an extent beneficial to crop raising. This is called "mediumland"

Class III Land - Land that remains submerged under flood water for a considerable part of the year but can be improved by adequate drainage methods. This land is called "lowland", and in some parts of the country is referred to as "haor" areas

Class IV Land - Land that remains submerged under flood water almost all the year around and cannot be improved by ordinary drainage methods. This land is called "swampland".

During the dry season, Classes I, II and III land are all irrigable, provided the proper facilities are available. If correct irrigation methods are applied, a greater variety of crops can be grown and the yield per acre of each crop can be increased. Irrigation water would have to be pumped, which appears feasible provided that power can be supplied at reasonable cost.

Class III land can be reclaimed during the wet or flooding season by an adequate system of drains and pumps, which would also require a source of power.

F.04 SOILS

The agricultural soils of East Pakistan are of secondary origin, i.e., they are formed from transported alluvium. The major river systems that have built up these vast alluvial areas are the Ganges, Brahmaputra and the Meghna together with smaller systems that drain the upland sections of the eastern portions of the country.

Most of the soils are considered immature since they do not have any profile development. This is due mainly to the fact that the soil character is constantly being altered by the activities of the rivers that are directly or indirectly responsible for their deposit.

Most of the surface textures are medium and heavy, classed as silt loams, clay loams and clays. There are some areas of light textured or sandy soils, which are usually found along the riverbanks.

Practically all of the agricultural soils are in need of fertilizers. The United States Government through the Foreign Operations Administration has supplied Pakistan with shipments of ammonium sulfate. Fifteen thousand tons have been sent to East Pakistan and good results were obtained wherever proper use of it was made. The Government of Pakistan is building an ammonium sulfate plant at Daud Khel in the Province of Punjab, scheduled for completion in 1956. It is expected that this new industry will produce 50,000 tons of ammonium sulfate per year. The practice of applying organic fertilizer (animal manure) is not widespread, and the growing of green manure crops as another source of organic fertilizer is very limited.

Soil surveying in East Pakistan is in its infancy. Only one of the Province's seventeen districts, the Dacca District, has a completed soil survey. It is planned to cover the remaining districts as rapidly as time and facilities permit.

F.05 CROPS

There are about 45 food and cash crops grown in East Pakistan. They are grouped under five headings which are designated as food grains, fibers, pulses, oilseeds and miscellaneous crops.

a. Food grains include rice, wheat, barley, maize, and millets. Rice is the most important of all of the food grains.

b. Fibers include jute, cotton, sun-hemp, and rhea. Jute is by far the most important and is the nation's chief source of foreign exchange.

c. Pulses form an important part of the diet of East Pakistan. These are cooked separately, or together, or in a combination with vegetables, rice or meat. The principal pulses grown in the country are gram, lentils, mash, mung, pigeon pea, cowpea, soya bean and chickling vetch.

d. A great number of oilseeds are produced in East Pakistan. The major ones include the following: rapeseed, mustard, cottonseed, sesamum, linseed and groundnut.

205

e. Miscellaneous crops include sugarcane, tea, tobacco, vegetables, spices, fruits, fodders, betelnuts and coconuts.

Of all the crops grown, rice (paddy) is the major food crop, and jute is the principal cash crop. The rice crop of East Pakistan is highly variably with a large number of varieties grown each year. These are listed as follows:

a. Highland aus - Sown in April and May and harvested in August and September. It is purely dependent on rains and is broadcast at the earliest opportunity. In some places however, the crop is grown under transplanted conditions. It is generally followed by winter crops of mustard, pulses, vegetables, etc.

b. Lowland aus - Sown broadcast in the lowlands in February and March and harvested in June to September

c. Deepwater aman - Sown in lowlands in February and March and harvested in November and December when the flood water recedes. In the medium deep areas this paddy is grown mixed with lowland aus and harvested separately as they ripen

d. Transplanted aman - This crop is transplanted from seedbeds in the months of July and August in mediumlands and harvested in November and December

e. Boro paddy - Sown in the seedbed in November and transplanted in December and January on the lowest areas of all, which usually do not dry up in the winter. It is harvested during March and April.

Jute is usually sown in the mediumlands during the months of March and April and harvested in July and August. It is estimated that between 70 and 80 percent of the world's production of jute comes from East Pakistan.

F.06 CULTURAL PRACTICES

Plowing - The methods of plowing are similar to those seen in many other parts of the Orient. Wooden plows with steel shares are used, which are pulled by water buffalo or bullocks. The wooden plow has the advantage of being light and inexpensive, however, it is inefficient and should be modernized in the interest of better and faster plowing. This would increase the yield per acre and at the same time, more land could be plowed and planted, materially increasing the total agricultural production.

Harrowing - The harrow used by the Pakistani farmer is made of three bamboo splints. It is used for breaking clods, collecting weeds, packing the soil, and covering seed after broadcasting. It does a fairly good job if the soil condition is right.

Seeding - No drills or planters are used for sowing, the seeds being broadcast by hand. The transplanted rice seedlings are set out by hand in the flooded fields.

Cultivating - Cultivation is done almost exclusively by hand. The tool used is similar to a hoe and consists of a flat iron with a sharp edge attached to a wooden handle.

Harvesting - Harvesting is done with sickles. It is common practice for neighborhood groups to harvest the fields together, rather than for each farmer to harvest his own land. Mechanical harvesters are virtually unknown.

Threshing and Winnowing - Grains are threshed by treading with bullocks, and winnowed by throwing the troden debris into the wind.

F.07 LAND USE

According to the Directorate of Agriculture, land use in East Pakistan may be classified into four broad categories: net cropped area, "current fallow" cultivated land, cultivable waste land, and area not available for cultivation. Exhibit F-2 shows the land use classification by districts in East Pakistan. Based upon the figures shown, the total area of the country is approximately 34.6 million acres of which 19.3 million are net cropped, 2.6 million are in current fallow, 2.7 million are in cultivable wasteland, and the balance, or 10.0 million acres, is area not available for cultivation which consists of forest area, permanent swamps, rivers, urban areas, etc. It must be borne in mind that these figures were established several years ago and have never been revised. It is estimated that there has been a general increase in the net-cropped area of about 1.2 million acres and corresponding decreases in the acreages of the current fallow area and cultivable wasteland.

There is a large potential for land reclamation in the first three categories. As soon as drainage and irrigation projects are installed, large portions of the current fallow area and cultivable waste land can be brought under continuous cultivation. In addition, a larger portion of the net-cropped area can be double cropped and, in some cases triple cropped. It is also possible that portions of the area not available for cultivation, such as permanent swamps, can be reclaimed.

F.08 LAND TENURE

The land tenure system in East Pakistan has always been quite complex. The year 1793 marked the beginning of the present system. In that year, "Permanent Settlement" was declared which meant that hereditary proprietary rights were conferred permanently on the revenue collectors who thus became "zaminders" or owners of the land. The only condition to which they were subjected was that they pay a fixed amount of revenue to the government.

The zaminders distributed the land among the cultivators who fell into two classes: "raiyats" and "under-raiyats". The raiyats became land users who had the rights of use and transfer and they often sublet their lands to the under-raiyats, either permanently or temporarily. The under-raiyats shared proportionate amounts of the produce with the raiyats for the use of the lands. The zaminders were authorized to collect the cash rents (actually it is a sort of land tax) from the raiyats at regular rates and paid the government a fixed assessment. Since the peasant or cultivator had the right of inheritance, the lands have gradually become fragmented into smaller and smaller sizes.

The land tenure system has thus produced two major ill effects: the landlord has had little or no interest in the land other than the receipt of rent, while the tenant who didn't really own the land was interested only in deriving maximum benefit from the present use of the land and cared little for the future. Furthermore, the fragmentation of the land has resulted in uneconomic holdings which are becoming unsuited for the use of improved agricultural practices.

The State Acquisition and Tenancy Act, enacted in 1950, will ultimately reconstitute the entire land tenure system in East Pakistan. Some of the salient features of this legislature are: the Government assumes the right of ownership, replacing the zaminders who will receive compensation for their former holdings; the agricultural lands will be re-distributed on a more equitable basis; tenants will pay rentals directly to the government; the practice of sub-letting land will be abolished; and all agricultural tenants will have permanent, heritable and transferable rights in their lands. This is very significant legislation and will have far-reaching effects upon the agricultural economy of the country. However, the full implementation of the act will require a long period of time and during the interim the old land tenure system will remain in effect.

Crop acreages - Crop acreages for 1954 are estimated as follows:

Crop	Acreage (expressed in millions of acres)
Rice (paddy)	17.8
Jute	0.8
Rape and mustard seeds	0.4
Sugarcane	0.2
Tobacco	0.1
Other cereals, fibers, pulses, oilseeds, spices, tea and vegetables	1.2
Total crop acreage	20.5

Size of agricultural holdings - The sizes of agricultural holdings are:

1. 46.0% of the farm families have less than 2 acres each
2. 11.2% of the families have 2 to 3 acres
3. 9.4% of the families have 3 to 4 acres
4. 8.0% of the families have 4 to 5 acres
5. 17.0% of the families have 5 to 10 acres
6. 8.4% of the families have above 10 acres.

(The average number of members per farm family is five.)

Land values - The values of agricultural land in East Pakistan are extremely variable and are dependent upon several factors, particularly the proximity to market, susceptibility to periodic flooding, and demand for land. In the Chittagong area, where the land is close to market, above the flood level, and the demand for it is high, its value will reach $750 per acre. In the "haor" areas of the Mymensingh and Sylhet Districts where the markets are further removed, the land is periodically flooded, and the demand for it is less; the values range around $150 per acre. Land in the same districts that is closer to market, above flooding, and in more demand is valued at $450 per acre. Land values in the Jessore District are reported to be less, and are quoted at $60 per acre.

F.10 GENERAL - LAND RECLAMATION

East Pakistan is in the peculiar position of receiving too much water during part of the year and too little water the rest of the year. This is due to the uneven distribution of the annual rainfall, 86% of which falls during the period of four or five months, May to September. This is the monsoon season, when the rains are frequent and torrential. It is estimated that about 50% of the country is submerged to varying depths during this period. The problem of providing adequate drainage systems to reduce crop damage in these flooded areas is very acute.

Following the monsoon season the lands dry up quickly, thus affording little opportunity for growing a second crop. The possibility of triple cropping is even more remote. This situation can be corrected only by irrigation.

It is possible to isolate certain flooded areas by means of embankments and resort to drainage pumping to remove the excess water. At the same time, it is also practicable to utilize the same pumping system for irrigating these areas during the dry season. Land reclamation carried out in this manner would increase the total crop production and the yields per acre of the various crops grown.

After consultation with numerous officials of the Irrigation Branch, Communication, Building and Irrigation Department, Government of East Pakistan, 25 possible land reclamation areas were selected for study. They are situated in five of the easternmost districts of the Province: Mymensingh, Sylhet, Dacca, Tippera and Chittagong. Exhibit F-1 lists the areas by number in the respective districts and the table on the following page gives the description and location, gross acreages, and net acreages benefited by reclamation. These latter figures were obtained by applying a 20% deduction to the gross acreages. It is estimated that this deduction would be sufficient to cover homestead and village areas, non-irrigable lands, bils, waterways, etc., all of which would be excluded in determining the net acreages to be benefited by reclamation.

DESCRIPTION & LOCATION, GROSS ACREAGES, & NET ACREAGES BENEFITED BY RECLAMATION OF PROPOSED AREAS

No. of Area	Description and Location	Gross Acreage	Net Acreage Benefited by Reclamation
	Mymensingh District		
1	Haor Area in P.S.[1] Mohanganj, Madan, Kahliajuri, Itna, Karimganj, Nikli, Astragram, Bajitpur and Bhairab Bazar	384,000	307,200
17	Area in P.S. Durgapur	9,600	7,680
18	Area in P.S. Haluaghat	7,680	6,144
19	Area in P.S. Nokla and Nalitabari	4,480	3,584
20	Area in P.S. Basail	2,560	2,048
	Mymensingh District TOTAL.....	408,320	326,656
	Sylhet District		
2	Areas in P.S. Golapganj, Beanibazar, Jakiganj and Kanairghat	23,680	18,944
3	Dumaria Haor in P.S. Fenchuganj, Golapganj, and Sadar Sylhet	11,520	9,216
4	Muria Haor in P.S. Beanibazar	12,800	10,240
5	Bara Haor in P.S. Kanairghat	19,200	15,360
6	Haor Areas in P.S. Chhatak	6,400	5,120
7	Muktarpore Haor in P.S. Balaganj	6,400	5,120
8	Fringes of Hakaluki Haor in P.S. Fenchuganj, Golapganj, Barlekha, and Kulaura	19,200	15,360
9	Hail Haor in P.S. Srimangal and Maulavi Bazar	13,440	10,752
10	Mokar Haor in P.S. Baniyachung and Nabiganj	12,800	10,240

[1] P.S.- (Police Station)

TABLE (continued)

No. of Area	Description and Location	Gross Acreage	Net Acreage Benefited by Reclamation
11	Area in P. S.[1] Ajmiriganj and Bahiyachung	12,800	10,240
23	Area in P. S. Kanairghat	2,560	2,048
24	Area in P. S. Jagannathpur	12,800	10,240
25	Sanir Haor in P. S. Tahirpur	5,120	4,096
	Sylhet District TOTAL	158,720	126,976
	Dacca District		
21	Area in P. S. Jaydebpur, Kaliganj and Sripur	11,520	9,216
22	Area in P. S. Sabhar	5,760	4,608
	Dacca District TOTAL	17,280	13,824
	Tippera District		
12	Area in P. S. Brahmanbaria north of Akhaura	9,600	7,680
13	Area in P. S. Muradnager, Homna and Daudkandi	10,240	8,192
14	Area in P. S. Chauddagram and Laksham	7,680	6,144
15	Area along banks of Dakatia River in P. S. Hajiganj and Laksham	6,400	5,120
	Tippera District TOTAL.....	33,920	27,136
	Chittagong District		
16	Areas in Halda, Karnafuli and Sangu River basins in P. S. Fatikchhari, Sitakund, Rauzan, Hathazari, Rangunia, Panchlais, Boalkhali, Patia, and Anwara	256,000	204,800
	Chittagong District TOTAL.....	256,000	204,800
	TOTAL GROSS ACREAGE (All Districts)	874,240	
	TOTAL NET ACREAGE BENEFITED BY RECLAMATION (All Districts)		699,392

[1] P.S. - (Police Station)

F.11 TYPICAL LAYOUT FOR A RECLAMATION UNIT

In order to make agricultural and economic appraisals of the proposed land reclamation projects, a typical unit area was first selected for a hypothetical study in which the land was assumed to be reclaimed by pumping. The unit is in P. S. Itna, Mymensingh District, on the east bank of Dhanu River, and is a part of the haor zone designated as "Area No. 1" (see Exhibit F-3). The gross area of the unit is 26 square miles or 16,640 acres, and the net area that would be benefited by reclamation amounts to 13,312 acres.

It is assumed in this study that the unit is completely enclosed within suitable dikes and that reversible-flow pumps have been installed to pump water either into, or out of, the area.

A portion of the available rainfall required for the crops of the area within this embankment during the monsoon season will be retained and the balance pumped out during the rains, while during the dry season, water will be pumped from the Dhanu River into the area for irrigation. The fill material required for the construction of the embankment would be taken from a continuous borrow pit, which serves the double purpose of a drainage and irrigation canal. In addition, one main canal and two distributaries are required for irrigation and drainage purposes. The farm distribution systems are adapted to these installations. The pumping station is assumed to be located on the crest of the embankment near the lake, as is shown in Exhibit F-3, which also shows the general layout of the works described above.

It is estimated that the total annual rainfall in this area averages 120 inches. About 20 inches will be lost through evaporation and percolation, 40 inches will be required for crop production, and the balance or 60 inches will be pumped out. The pumps will work 20 hours per day with an average total lift of 4.5 feet during the rainy season and 14 feet in the dry season.

The discharge required for the drainage pumping for a period of 4 months is 420 cfs, which requires 346 horsepower or 258 kilowatts. The discharge required for the irrigation pumping, assuming a duty of 125 acres per cfs, is 108 cfs which requires 274 horsepower or 204 kilowatts.

F.12 ESTIMATE OF CONSTRUCTION QUANTITIES AND COSTS FOR A UNIT AREA

There are four major earthwork installations in the proposed reclamation work in the unit area. They include the continuous embankment and borrow pit channel, considered as one; main canal, and two distributaries leading off the main canal. Exhibit F-4 shows the cross-sectional

views of these installations. In addition, there are the pumping station, transmission line, and sub-station installations. Estimates of the principal quantities and costs for each of these installations are given below:

Estimate of Principal Quantities

Continuous embankment and borrow pit channel	
Excavation and embankment	957,700 cu yds
Dressing and turfing	171,500 sq yds
Main canal	
Excavation	88,900 cu yds
Distributary No. 1	
Excavation	21,500 cu yds
Distributary No. 2	
Excavation	5,900 cu yds
Pumping station. transmission line and sub-station	258 kw

Estimates of Costs For
A Net Area of 13,312 Acres

Item	Cost – Dollars		
	Foreign	Local	Total
Continuous embankment and borrow pit canal including facilities, land acquisition, structures, engineering and supervision	$ 0	$271,200	$271,200
Main canal including land acquisition, structures, engineering and supervision	0	17,000	17,000
Distributary No. 1, including land acquisition, engineering and supervision	0	4,400	4,400
Distributary No. 2, including land acquisition, engineering and supervision	0	1,400	1,400
Minor channel work	0	3,000	3,000
Pumping station, transmission line and sub-station	72,900	55,800	128,700
TOTALS	$72,900	$352,800	$425,700

The capital cost is approximately $32 per acre.

F.13 EXTRAPOLATION OF CONSTRUCTION COSTS AND POWER REQUIREMENT TO TOTAL AREA

The unit area that was selected for analysis is considered fairly representative of conditions in all of the areas proposed for reclamation (see Exhibit F-3). The capital cost of $32 per acre can be extrapolated to the total net acreage, 699,392 acres, that can be benefited by reclamation. This amounts to a total capital outlay of $22,400,000.

The maximum power demand at the pumps for the total net acreage, is estimated at 13,500 kw.

F.14 PRESENT AND POTENTIAL PRODUCTION OF LAND

Based on the 1949-50 agricultural year, which is described as a year with average yields, the yields per acre of the major agricultural crops without irrigation are listed below:

Crop	Actual Yield in Metric Tons Per Acre
Winter or aman paddy (clean)	0.400
Autumn or aus paddy (clean)	0.272
Summer or boro paddy (clean)	0.440
Jute (fiber)	0.628
Sugarcane (gur)	1.400
Pulses	0.280
Oilseeds	0.176
Cereals	0.248
Spices	0.240
Tobacco	0.348

These yields can be increased in several ways, among which are irrigation and fertilization. Recent experiments conducted in the Kushtia District by technicians of the Food and Agricultural Organization, United Nations, have shown the following comparative results:

Without irrigation	100 (base)
With irrigation	150
With irrigation and fertilization on lowland	200
With irrigation and fertilization on highland ...	300

Presumably these increases in yields were obtained under optimum conditions, but they do illustrate the beneficial effects of irrigation and fertilization on crop yields. For the purposes of this report, the following percentage increases in yields per acre of the same crops under irrigation are assumed, together with the expected yields.

Crop	Percentage Increase	Expected Yield in Metric Tons Per Acre
Winter or aman paddy (clean)	11.5%	0.446
Autumn or aus paddy (clean)	15.0%	0.313
Summer or boro paddy (clean)	15.0%	0.506
Jute (fiber)	17.5%	0.738
Sugarcane (gur)	125.0%	3.150
Pulses	35.0%	0.378
Oilseeds	35.0%	0.238
Cereals	35.0%	0.335
Spices	35.0%	0.324
Tobacco	35.0%	0.470

Although aman paddy, aus paddy and jute are crops that are grown during the monsoon season, there are occasional periods of drought when supplementary irrigation is required to maintain crop production. Sugarcane at present can only be grown for about 11 months because of the dry winter season, but with irrigation it can be grown to a full maturity in 15 to 18 months.

It must be assumed that the increased yields under irrigation will be accompanied by better farming practices such as deep plowing, crop rotation, green manuring, improved seed varieties and equipment necessary for irrigation farming. The soils are generally too hard for plowing from January to April. Even if a light irrigation is available only once during this period, an ordinary pair of bullocks could plow deeper, — from 4 to 6 inches instead of 2 to 4 inches as at present. Crop rotations are essential for the maintenance of soil fertility and the improvement of soil tilth. Green manure crops, such as cowpea, mash kalai, and fodder crops as sources of feed for the draft animals should be included in the rotation systems.

The application of inorganic and organic fertilizers is an important factor in increasing crop yields. However, the inorganic fertilizers, such as sulphate of ammonia and ammonium phosphate, are quite expensive and beyond the means of the average cultivator. Unfortunately, too much of the organic fertilizer in the form of animal manure is used as fuel, and too little is applied to the land. It is therefore necessary to make up the shortage of manure by some easy and economical method such as composting.

A method has been devised for producing compost from all sorts of vegetative refuse but it has not yet received widespread acceptance. Until commercial fertilizers become reasonably priced and the use of organic fertilizer becomes an accepted practice, the effect of fertilization on further increasing crop yields cannot be fully realized.

F.15 VALUES OF PRESENT AND POTENTIAL CROPS

The present crop in the unit area is boro paddy. The total annual yield is 1,952 tons from 4,437 acres for a total gross return of $142,000 at present day prices. The cost of production is estimated at $25 per ton for a total cost of $48,800. Thus, the total net return is $93,200 or $21 per acre.

The crops that would be grown after the installation of the reclamation project are aman and boro paddy, as a double crop. The annual yields of these crops under irrigation are expected to be 6,000 tons of aman paddy and 6,700 tons of boro paddy for a combined total annual yield of 12,700 tons from 13,312 acres. The total gross returns are $491,000 for the aman crop and $488,000 for the boro crop, making a combined total gross return of $979,000. The cost of production for these crops under irrigation is estimated at $33 per ton. Thus, the total cost of production for these crops is $419,000 exclusive of the water charges. The charges for irrigation water must be sufficient to meet the annual costs of the irrigation system plus a surplus with which to meet contingencies such as fluctuations in foreign exchange and to finance extensions of the project. In order to satisfy this requirement, it is necessary to assess $3.30 per crop acre or a total annual water charge of $88,000. Thus, the annual net return to the farmers will be $472,000, or approximately $35 per acre. Since the cost investment for the project is $32 per acre, it appears that the project is economically sound.

F.16 POWER RATES

An energy charge of $0.02 per kilowatt hour plus a maximum demand charge of $2.12 per kilowatt per month have been assumed in determining the total annual cost of the project.

F.17 SUMMARY OF COSTS AND BENEFITS FOR A UNIT AREA

The capital cost of a unit area project, including earthwork, pumping station, transmission line, substation, bridges, land, facilities, engineering and unforeseen items is estimated at $426,000 or $32 per acre of irrigated land. The total annual cost which includes such items as interest, amortization, operation and maintenance, and administration is estimated

at $79,000. The annual water revenue is estimated at $88,000 so that the project can be expected to yield to the Government a net return of $9,000 or a return on the capital outlay of about two percent. The present crop production in the area is estimated at 1,952 tons and the value of $142,000. After reclamation, the crop production will be increased to 12,700 tons with an estimated value of $979,000. Therefore, the annual value of the increased crop production is $837,000, or $63 per acre. The net return to the farmers is $35 per acre.

Indirect benefits that will result from reclamation include betterment of diet, improvement of health conditions, augmenting of internal trade, and the increase in employment and public revenues.

All of the basic data used for the computations and results in the foregoing sections were secured from East Pakistan sources.

F.18 FACTORS GOVERNING THE SUCCESS OF LAND RECLAMATION

Land reclamation projects in East Pakistan that involve drainage and irrigation will directly or indirectly affect land use, cropping systems, and the management of individual farms. After the projects have been successfully developed, it can be expected that double cropping will increase, good rotation systems will be introduced to maintain soil fertility, and land tenure conditions will be improved to better the relations between the landlords and tenants.

In order that the land reclamation projects may be successful, a few of the governing factors are listed below:

Agricultural Education - One of the major problems facing the agriculture of East Pakistan today is the establishment of a comprehensive agricultural education system to bring modern agricultural methods to the farmers. The structure of an organization to carry on this work has already been established, the pattern being somewhat similar to that of the Agricultural Extension Service in the United States. The introduction of land reclamation in areas where farmers have had no experience in draining and irrigating land requires many practices with which the farmers are not now familiar. It is necessary, therefore, that the Government provide a thorough agricultural education program through its rural extension agencies. This program should place special emphasis upon such practices as the proper maintenance of drainage systems, land leveling, layout of farm irrigation systems, and proper application of irrigation water. In addition, the farmers will need assistance on kinds and varieties of crops to grow, rotation systems, cultural practices, and the application of fertilizers, organic as well as inorganic.

One method for implementing such a program would be to establish demonstration farms in or near the areas where the reclamation projects are to be installed. These farms should secure the cooperation of responsible farmers in these areas who will try out the new practices that are being introduced. Special efforts should be made to provide these farms with the necessary drainage and irrigation facilities to test the practices, even before final completion of the projects. The farms could be used to train extension workers in the new techniques and they, in turn, could educate the other farmers in the areas affected by the projects.

The agricultural education program can be further implemented by coordinating it with the educational programs of the Village Aid Training Centers that are sponsored jointly by the Foreign Operations Administration of the USA and the Government of Pakistan.

Marketing and Processing Facilities - The increase both in crop acreage and yield per acre that will result from the land reclamation projects will increase the need for marketing and processing facilities.

Many agricultural products are perishable or semi-perishable and available for only a short season. It may become necessary to establish small industries such as canneries and cold storage facilities to preserve these products. More crushing machines for the preliminary processing of sugarcane and oilseeds will also be needed. These and other types of locally needed machines can be provided through cooperative societies.

Land Tenure - It is important that the present relationship between landlords and tenants be maintained at levels that will give the landlord a fair return on his investment and the tenant an assurance of security and an adequate share of produce in relation to his labor. Unless these levels are maintained, there will be no incentive for either party to increase agricultural production or to improve the productive power of the land. As soon as the provisions of the State Acquisition and Tenancy Act (1950) become fully effective, the State will become the landlord and the land tenure system will undergo some rather radical changes. It is expected that this legislation will do much to stabilize and improve the situation. A healthy land tenure system is a requisite for successful land reclamation.

F.19 RECOMMENDED PRE-CONSTRUCTION INVESTIGATIONS AND SURVEYS

It is recommended that certain essential investigations and surveys be conducted previous to the construction of any of the land reclamation projects. These should be carried out in a two-phase operation.

The first phase should be of a preliminary or reconnaissance nature and in sufficient detail to serve as a basis for determining whether or not construction should proceed. It should include the following items:

a. Engineering Surveys and Analyses

1. Analyses of river discharge and siltation data including not only the available information but also whatever additional data are needed

2. Analyses of data on tidal action in relation to salinity

3. Survey of available and potential sources of power, including allowable power rates

4. Preliminary surveys of irrigation and drainage systems, and required embankments

5. Preliminary designs of pumping stations

b. Land and Water Use Studies

1. Reconnaissance soil survey and land classification with particular reference to irrigability

2. Determination of cropping systems that will be suitable for irrigated lands, including an appraisal of increased production resulting from irrigation

3. Determination of water requirements for the various crops to be grown

4. Investigation of existing water rights

5. Investigation of present methods of payment for water, and ability to pay for future use

c. Economic Analyses

1. Preliminary cost and benefit analyses

If decisions to proceed with the project construction are reached on the basis of findings in the first phase, the second phase of the investigations should be undertaken. This latter phase should, of necessity, be of a detailed nature and should include the following items:

a. Engineering Surveys, Plans and Cost Estimates

1. Detailed surveys of all proposed irrigation and drainage canals, distribution systems, embankments and transmission lines

2. Detailed plans, specifications and cost estimates for all earthworks and structures including weirs, sluices, bridges, etc

3. Detailed plans, specifications and cost estimates for pumping stations

b. Land and Water Use Studies

1. Detailed soil surveys and land classification for irrigability purposes

2. Final and complete plans for cropping systems, including the amount of irrigation water to be applied, number of irrigations, etc

3. Estimates of power requirements for pumping

4. Detailed farm management studies to determine the most suitable organization of farm enterprises

5. Detailed studies of the project land for subdividing into units to which the most efficient water deliveries can be made

c. Economic Analyses

1. Final cost and benefit analyses

Many of the studies and investigations listed above should be of a continuing nature. Hydrologic information, for example, must be obtained over a long period of time. The same is true for information on fertilization, crop adaptation, water requirements of crops, and agricultural statistics. Reliable and useful information on these and other pertinent subjects can be obtained only by long-term experimentation and research.

LEGEND:

Boundry line, International
" " , District
Areas where power pumping can be utilized for drainage & irrigation

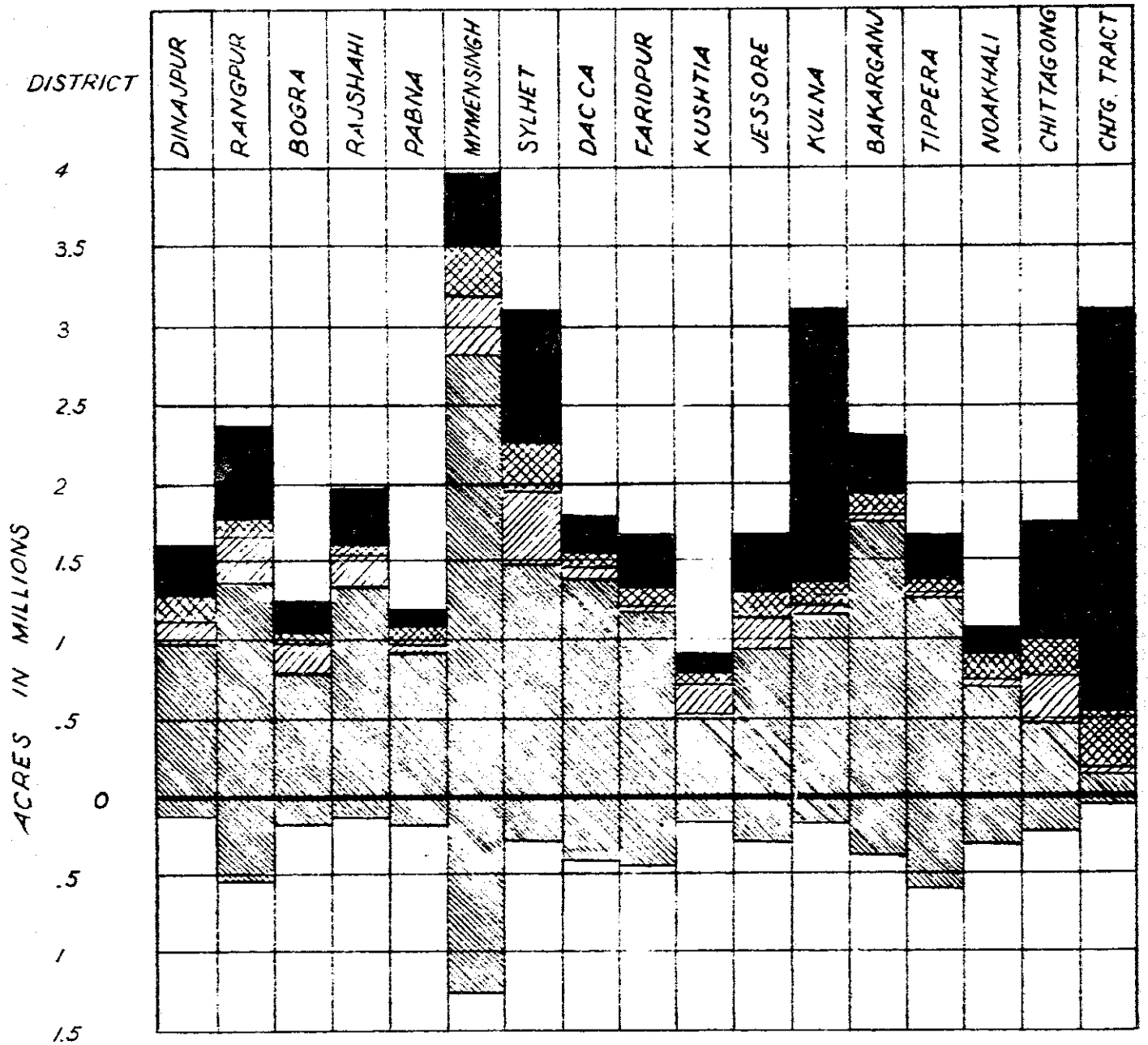
NOTE:

For reference numbers See TABLE I

After South Eastern Circle drawing titled, "Areas Where Power Pump Can Be Utilized For Drainage And Irrigation."

GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT PROPOSED LAND RECLAMATION AREA		
INTERNATIONAL ENGINEERING CO., INC. SAN FRANCISCO, CALIF.		
DR. H.W. CK. C.B.K.	RECOMMENDED JPH-HWB	APPROVED
DATE		BW-04-216

LAND USE CLASSIFICATION BY DISTRICTS IN E. PAKISTAN



LEGEND:

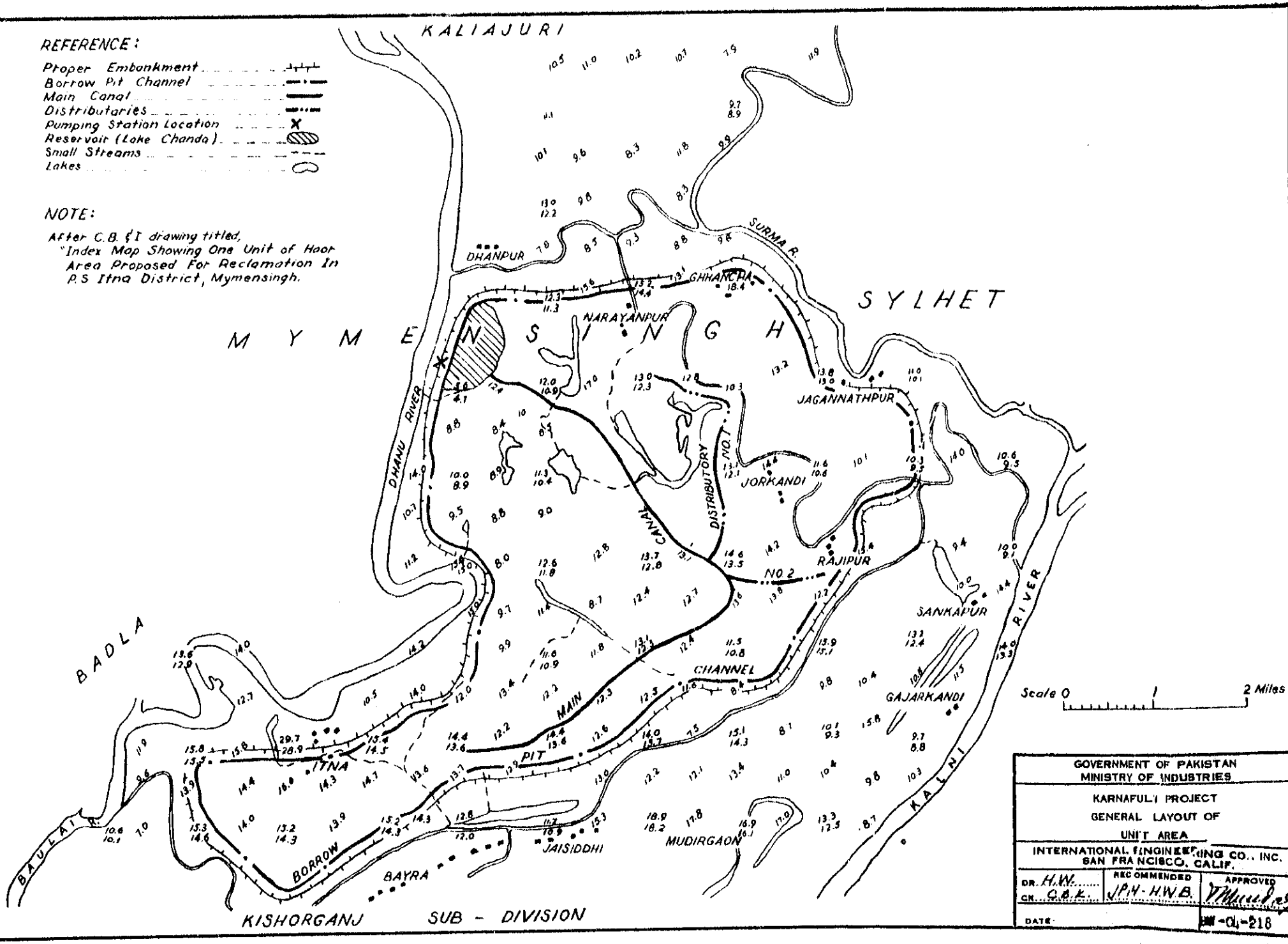
- Not available for cultivation
- Cultivable waste land
- Current fallow cultivated land
- Net cropped area
- Area cropped more than once

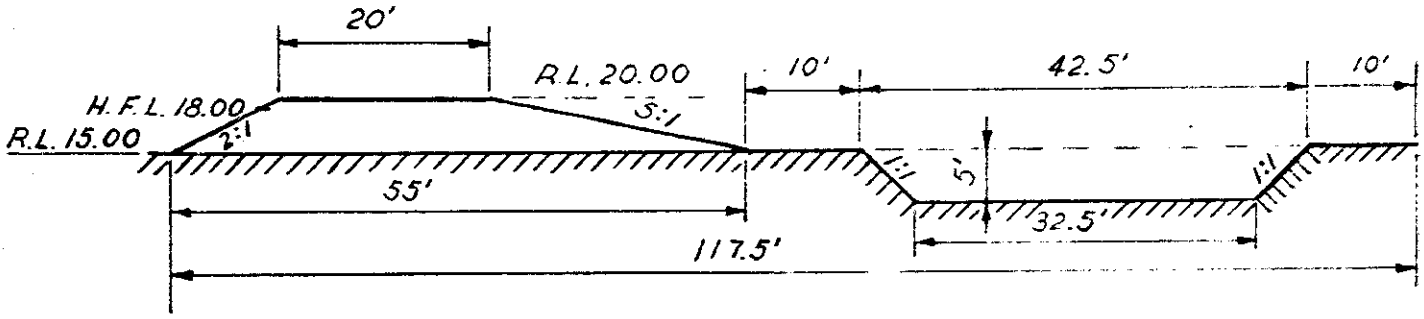
NOTE:

After Directorate of Agriculture drawing titled, "Land Use Classification By Districts In East Bengal"

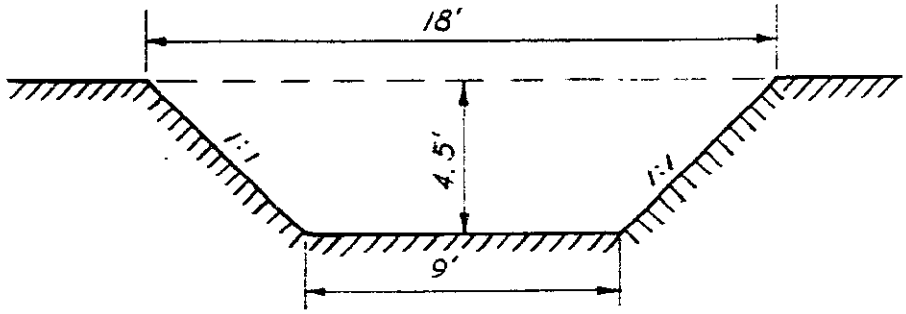
GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT LAND USE CLASSIFICATION		
INTERNATIONAL ENGINEERING CO., INC. SAN FRANCISCO, CALIF.		
DR. H.W. CK. C.B.K.	RECOMMENDED JPH-H.W.B.	APPROVED
DATE:		BW-04-217

EXHIBIT F-3

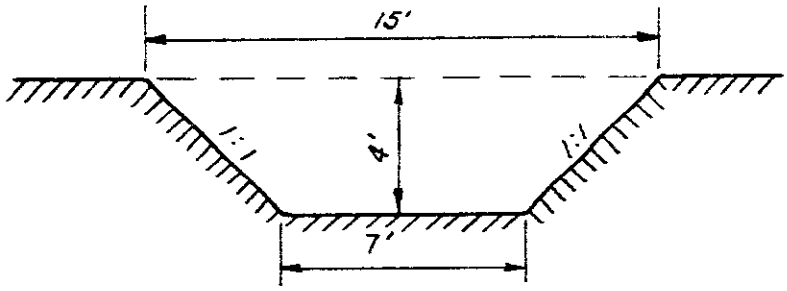

REFERENCE:
Proper Embankment
Borrow Pit Channel
Main Canal
Distributaries
Pumping Station Location
Reservoir (Lake Chanda)
Small Streams
Lakes
NOTE:
After C.B. & I drawing titled, "Index Map Showing One Unit of Haor Area Proposed For Reclamation In P.S Itna District, Mymensingh.
KALIAJURI
SURMA R.
SYLHET
MYMENSINGH
DHANPUR
GHHANCHA
NARAYANPUR
JAGANNATHPUR
DHANU RIVER
DISTRIBUTORY NO. 1
JORKANDI
CANAL
RAJIPUR
NO 2
SANKAPUR
BADLA
CHANNEL
MAIN
GAJARKANDI
Scale 0 1 2 Miles
ITNA
PIT
KALNI RIVER
BAULAI R.
BORROW
BAYRA
JAISIDDHI
MUDIRGAON
KISHORGANJ SUB - DIVISION
GOVERNMENT OF PAKISTAN
MINISTRY OF INDUSTRIES
KARNAFULI PROJECT
GENERAL LAYOUT OF
UNIT AREA
INTERNATIONAL ENGINEERING CO., INC.
SAN FRANCISCO, CALIF.
DR. H.W.
CK. G.B.K.
RECOMMENDED
JPH-H.W.B.
APPROVED
DATE
-04-218



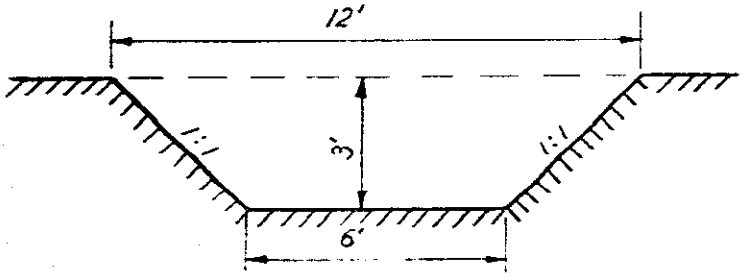
Cross Section of Embankment and Borrow Pit Channel



Cross Section of Main Canal



Cross Section of Distributory No. 1 of Main Canal



Cross Section of Distributory No. 2 of Main Canal

GOVERNMENT OF PAKISTAN MINISTRY OF INDUSTRIES		
KARNAFULI PROJECT EARTHWORK INSTALLATIONS IN UNIT AREA		
INTERNATIONAL ENGINEERING CO., INC. SAN FRANCISCO, CALIF.		
DR. H.W. CK. C.E.K.	RECOMMENDED JPH H.W.B.	APPROVED [illegible]
DATE: MARCH 1955		BW-04-219

APPENDIX G

FORESTRY
RESOURCES AND PRESENT DEVELOPMENT

The Kasalong Reserved Forest located within the Chittagong Hill Tracts contains valuable stands of merchantable timber (gurjun) suitable for dimension lumber and heavy timbers. These forests at present are virtually inaccessible for large scale logging operations and as a result timber is now scarce and expensive in East Pakistan. Construction of the Karnafuli Project will make practicable large scale commercial logging. The reservoir will provide a reliable, navigable waterway for transportation and make accessible large areas along its extensive perimeter.

Extraction of sp-gurjun is expected to reach 40,000 tons annually in 1965. This will be made possible by introducing modern logging, shop and communication equipment which has been furnished by the Foreign Operations Administration (FOA) of the U. S. Government.

The estimated value of the increased annual production of 40,000 tons of gurjun timber is $1,212,000 after deducting extraction costs. Since this production is possible only by construction of the Karnafuli reservoir this may be taken as the benefit for the year 1965.

In addition to the above benefit there will be a benefit to the bamboo operations which, although substantial, is difficult to evaluate. The recent operations of the Karnafuli Paper Mill have utilized the bamboo along the banks of the Karnafuli River and as time goes on it will be necessary to go further inland to secure bamboo which must be carried to the river bank. Construction of the Karnafuli Reservoir will greatly expand the perimeter convenient to the waters edge and will facilitate these operations. At present, bamboo rafts are navigated down the Karnafuli River with very considerable difficulty and the Karnafuli Reservoir will provide a waterway which will permit efficient navigation.