

INSTITUTO COLOMBIANO DE INVESTIGACIONES CIENTÍFICAS

UNIVERSIDAD DE COLOMBIA

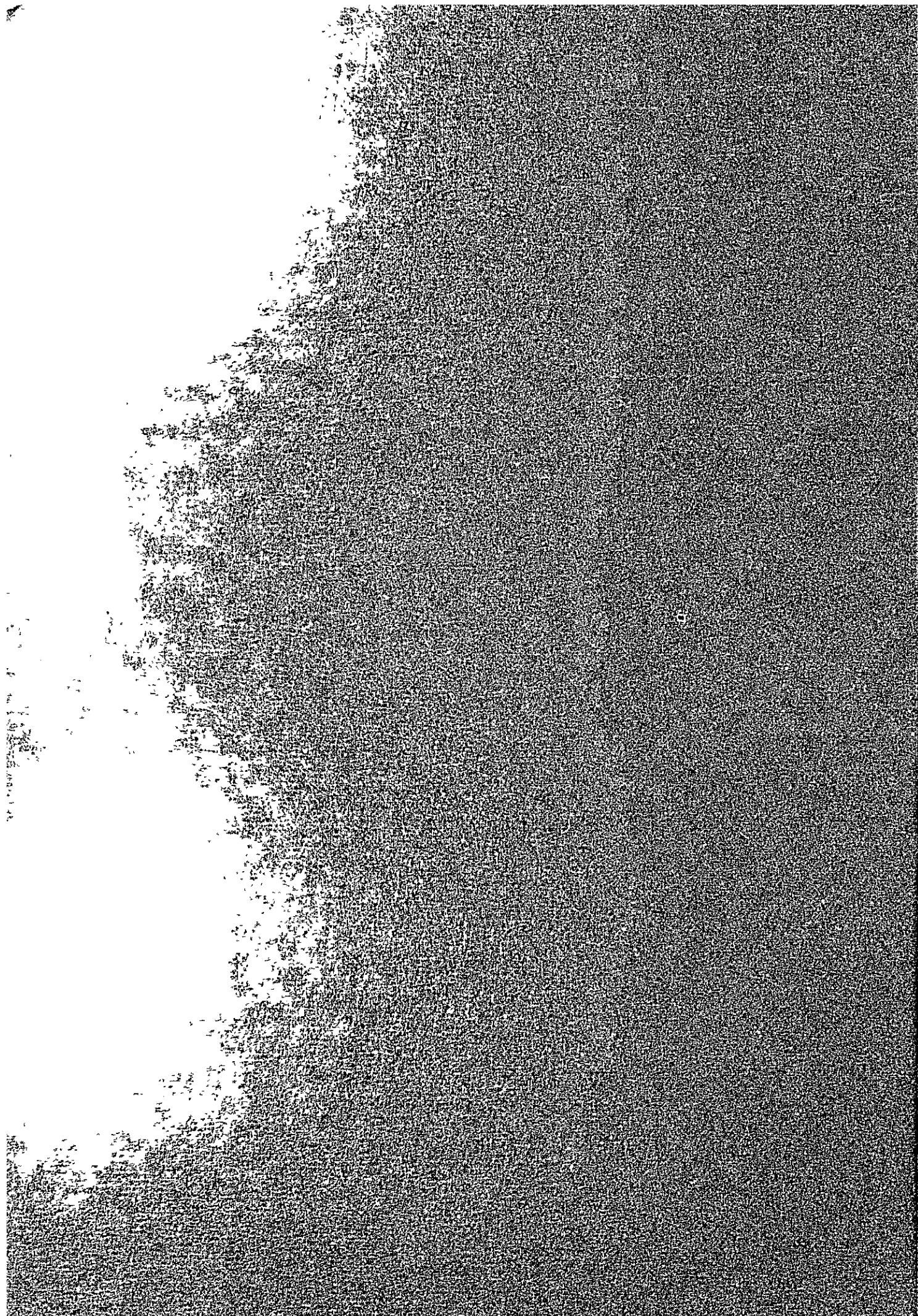
ANNUAL REPORT

INSTITUTO COLOMBIANO DE INVESTIGACIONES CIENTÍFICAS
UNIVERSIDAD DE COLOMBIA

MARCH 1968

INSTITUTO COLOMBIANO DE INVESTIGACIONES CIENTÍFICAS

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INSTITUTO COLOMBIANO DE ENERGIA

THE REPUBLIC OF COLOMBIA

**MASTER PLAN REPORT
ON
RIO ATRATO HYDROELECTRIC
POWER PROJECT**

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MARCH 1982

JAPAN INTERNATIONAL COOPERATION AGENCY

| 国際協力事業団 | |
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PREFACE

In response to the request of the Government of the Republic of Colombia, the Government of Japan decided to conduct a survey on the Atrato Hydroelectric Power Development Project and entrusted the survey to the Japan International Cooperation Agency (JICA). The JICA sent to Colombia a survey team headed by Mr. Kokichi Yoshizawa from July 11 to August 9, 1981.

The team exchanged views with the officials concerned of the Government of Colombia and conducted a field survey in the Atrato area. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of Colombia for their close cooperation extended to the team.

Tokyo. March. 1982



Keisuke Arita
President
Japan International Cooperation
Agency

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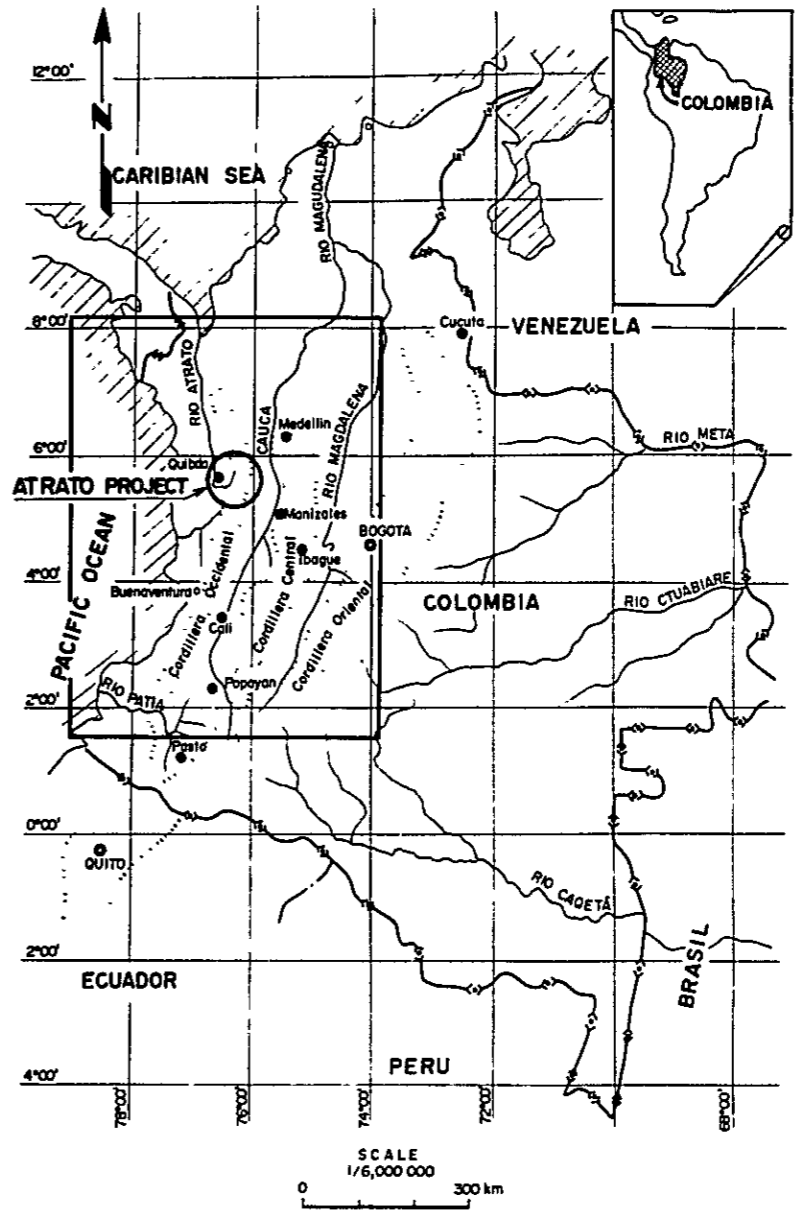
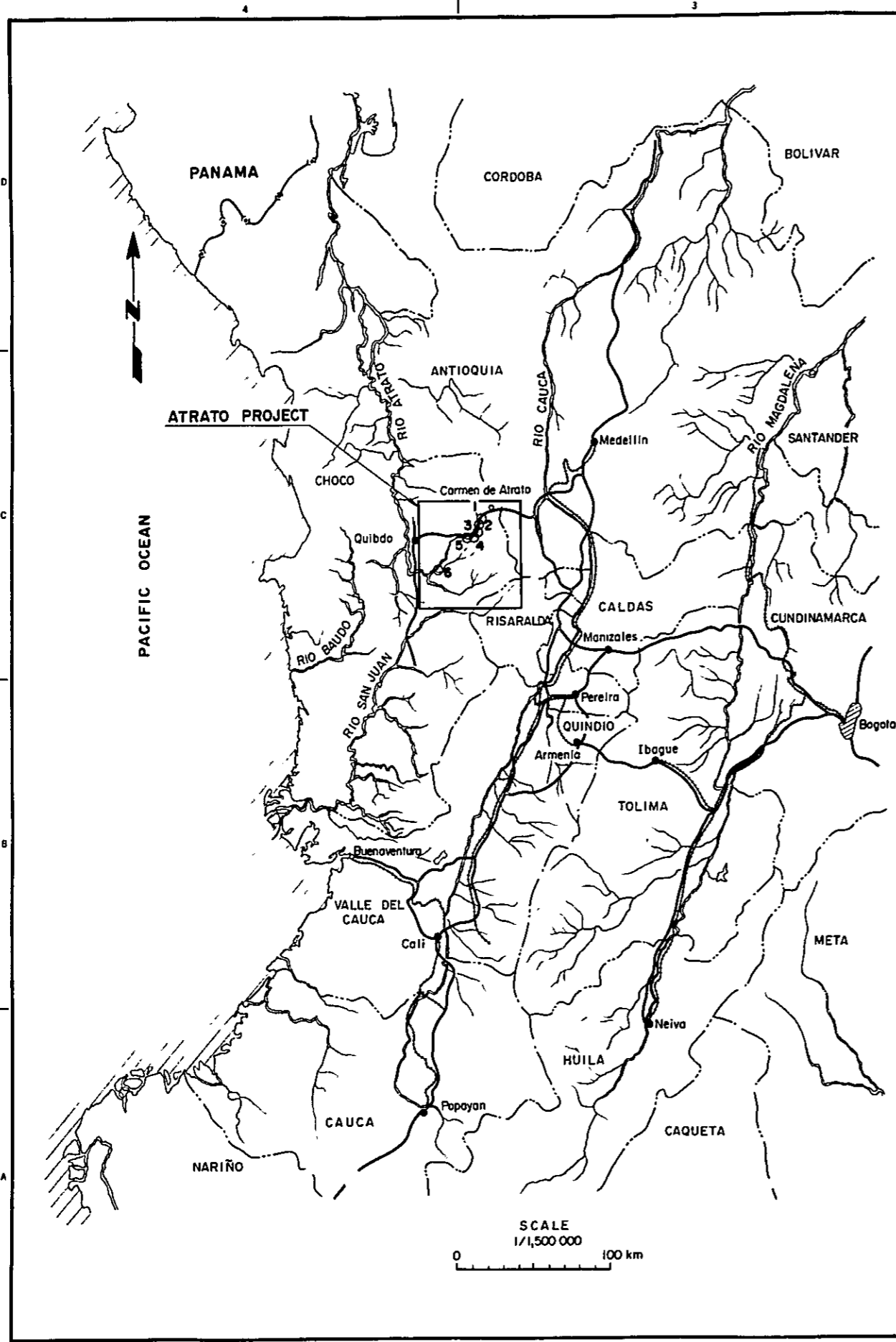
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- LEGEND**
- Boundary Line of Country
 - - - Boundary Line of Department
 - Road
 - Railway
 - Capital City of Department

| | |
|---|-------------|
| JAPAN INTERNATIONAL COOPERATION AGENCY | |
| INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA | |
| ATRATO PROJECT | |
| KEY AND LOCATION MAP | |
| ELECTRIC POWER DEVELOPMENT Co. LTD TOKYO JAPAN | |
| D.R. | SUBMITTED |
| T.R. | RECOMMENDED |
| C.K. | APPROVED |

| LOCATION | DATE | DESCRIPTION | BY |
|----------|------|-------------|----|
| REVISION | | | |

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1 SHEET NO OF

CHAPTER 1 INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 Background of the Study

In September 1980, the Government of the Republic of Colombia requested the Government of Japan for technical cooperation and assistance in studying an electric power development scheme for the upstream basin of the Rio Atrato in Colombia. The Government of Japan immediately directed the Japan International Cooperation Agency (JICA) to make a study, and JICA in March 1981 dispatched a preliminary survey team consisting of five persons headed by Mr. Michio Takahashi, Civil Engineer, to Colombia to carry out a study. The survey team conferred with the Departamento Nacional de Planificacion (DNP) and Instituto Colombiano de Energia Electrica (ICEL), the agencies concerned with the Colombian side, regarding the method of proceeding with the study of the scheme for electric power development on the Rio Atrato, and based on the matters concurred in, an agreement to the effect that the scheme would be implemented with the technical cooperation of the Government of Japan was prepared and signed.

In accordance with this agreement, JICA, in July 1981, dispatched a First Survey Mission composed of six persons headed by Mr. Kokichi Yoshizawa, Civil Engineer, for discussion of concrete survey implementation plans, compilation of the matters agreed upon in the form of an Inception Report, field investigations for the purpose of preparing a master plan on electric power development at the upstream basin of the Rio Atrato, and collection of related data.

The First Survey Mission, immediately after returning to Japan, commenced studies based on the data obtained in Colombia, and in March 1982 completed the preparation of this "Master Plan Report on Rio Atrato Hydroelectric Power Project" which is hereby submitted to the Republic of Colombia.

1.2 Object and Scope of Report

1.2.1 Object

The object of this Report is to formulate the master plan for hydroelectric power development at the upstream basin of the Rio Atrato, compile the results of the study, and to select the project site on which a feasibility study should be conducted by the Second Survey Mission.

1.2.2 Scope

The Project area made the object of the present survey and study was the upstream basin of the Rio Atrato, which moreover, was limited to the mainstream part. The reason for this was that it was impossible to enter the areas other than along the public road or the areas accessible by boat.

As another reason, the scope was limited to the mainstream since one object was to carry forward the studies of project sites at the upstream part of the Rio Atrato taken up when the DNP conducted an investigation of hydroelectric power resources in 1980. However, even though simply termed the upstream part of the Rio Atrato, just the part from the upstream El Siete site to the downstream-most El Lloro site is a distance of as much as 120 km. Furthermore, it is a stream where the elevation difference of 1,415 m in river bed height from 1,460 m to 45 m can be utilized for power generation with six projects planned in this part. All six of these projects were made objects of this study.

1.3 Investigations and Studies

1.3.1 Field Investigations

The field survey of the First Survey Mission was made for a period of approximately one month from July 11 to August 9, 1981, and the members of the First Survey Mission were the six specialists in fields connected with electric power listed below.

| <u>Position</u> | <u>Name</u> | <u>Specialty</u> | <u>Affiliation</u> |
|-----------------|-------------------|---------------------------|--------------------|
| Chief | Kokichi Yoshizawa | Civil Engineering | EPDC |
| Member | Toshio Morooka | Economics | JICA |
| " | Masayuki Seino | Civil Engineering | EPDC |
| " | Teruo Hagiwara | Electrical Engineering | EPDC |
| " | Hideo Ishii | Geology | EPDC |
| " | Tohru Takagi | Civil Engineering | EPDC |

The schedule followed by the First Survey Mission was that shown in the table below.

Table 1-2-1 Survey Schedule

| No. | Date | Journey | Activities | Stay |
|-----|-----------------|------------------------|---|---------------|
| | <u>Jul. '81</u> | | | |
| 1 | 11 | Tokyo → New York | Travel | New York |
| 2 | 12 | New York → Bogota | Travel | Bogota |
| 3 | 13 | | Visiting the Japanese Embassy, DNP and ICEL | Bogota |
| 4 | 14 | | Meeting with ICEL | Bogota |
| 5 | 15 | Bogota → Medellín | Data collection and meeting with ISA | Medellin |
| 6 | 16 | Medellin → Quibdo | Data collection | Quibdo |
| 7 | 17 | | Field survey at El Lloro site | Quibdo |
| 8 | 18 | | Field survey at El Lloro site | Quibdo |
| 9 | 19 | Quibdo → Medellín | Travel | Medellin |
| 10 | 20 | | Data collection at ISA | Medellin |
| 11 | 21 | | Data collection at ISA | Medellin |
| 12 | 22 | Medellin → Carmen | Travel field survey at El Dieciocho site | Medellin |
| 13 | 23 | | Field survey at El Dieciocho site | Carmen |
| 14 | 24 | | Field survey at El Dieciocho site | Carmen |
| 15 | 25 | | Field survey at El Dieciocho site | Carmen |
| 16 | 26 | | Field survey at El Dieciocho site | Carmen |
| 17 | 27 | | Field survey at El Once site | Carmen |
| 18 | 28 | | Field survey at El Siete site | Carmen |
| 19 | 29 | | Field survey at El Siete site | Carmen |
| 20 | 30 | Carmen → Medellín | Field survey at El Siete site | Carmen |
| 21 | 31 | | Data collection at ISA | Medellin |
| | | | Data collection at ISA | Medellin |
| | <u>Aug. '81</u> | | | |
| 22 | 1 | Medellin → Bogota | Travel | Bogota |
| 23 | 2 | | Data arrangement | Bogota |
| 24 | 3 | | Data collection | Bogota |
| 25 | 4 | | Data collection and meeting with ICEL | Bogota |
| 26 | 5 | | Data collection | Bogota |
| 27 | 6 | | Visiting ICEL and the Japanese Embassy | Bogota |
| 28 | 7 | Bogota → San Francisco | Travel | Bogota |
| 29 | 8 | San Francisco → | Crossing the date line | San Francisco |
| 30 | 9 | Tokyo | Travel | in flight |

The First Survey Mission, besides investigating the outlines of the various project sites, topographies, river run-off, and geological conditions during the above survey period, performed simple topographical surveying with instrument which had been brought along. Further, data necessary for the study were collected in Colombia.

1.3.2 Studies

Back in Tokyo, based on the data obtained in Colombia, the First Survey Mission, for the 6 month period from August 1981 to January 1982, carried out the study consisting of formulation of a master plan of electric power development for the upstream part of the Rio Atrato, preparation of topographical maps, performance of hydrological analyses, examination of geology, estimation of energy production, computation of construction costs at a rough estimate, and contemplation of economics of projects.

In this study, the First Survey Mission was forced to expend considerable effort in preparation of topographical maps (scales: 1/25,000, 1/10,000) and analyses of hydrology. The reasons were the incomplete states of topographical maps and hydrological data, and the first order of study was to compile sufficient basic data.

Preparation of topographical maps was done applying aerial photographs and radar imagery, and was ordered from specialist firm. However, since the existing aerial photographs had not been taken with the purpose of mapping, the accuracy was poor. Nevertheless, the data from simple surveying performed in the field by the First Survey Mission were added to improve the maps to a degree that master plan formulation could be done.

Meanwhile, with regard to hydrological data, the situation was that they were not compiled and stored even at Instituto Colombiano de Hidrologia Meteorologia y Adecuacion de Tierras (HIMAT), so that the First Survey Mission visited the individual gaging stations in the field, and water level records copied from observation ledgers were used to prepare the hydrological rating curves in Tokyo based on the data of the only run-off velocity measurements made in September 1981. Run-off of the existing gaging stations were then calculated from these hydrological rating curves.

The First Survey Mission made analyses and studies in accordance with the above basic data in order to prepare this Report. Mr. Kokichi Yoshizawa, the chief of the mission, visited ICEL for two weeks from February 1 to 15, 1982 to explain the results of study and to make final adjustments.

It should be added here that Ing. Eugenio Peña Barrera, a civil engineer of ICEL, visited Japan to participate in analyses and studies during the process of preparation of this Report, staying in Japan for approximately 45 days.

1.4 Data Used for Study

Much data were obtained in the Colombia for the study, and those used in the study in Tokyo are the following:

- Topographical maps (scale: 1/100,000) (Published by Instituto de Geografico "Agustin Codazzi"): Used for outline of Upstream Rio Atrato Basin, estimation of catchment areas of projects.
- Precipitation observation data (period: 22 years) (HIMAT): Used for estimation of run-offs and analyses of flood discharges.
- Water level measurements at gaging stations (HIMAT): Used for run-off analyses.
- Annual reports of ICEL, ISA: Used for comprehending electric power situation in general.
- Hydroelectric power resources survey report prepared by DNP: Used for general outline map of geology.
- Aerial photographs (Instituto de Geografico): Used for preparing 1/25,000 scale topographical maps.
- Long-range power development program prepared by ISA: Used for study of long-range program.

Besides the above, matters regarding which explanations were provided by ICEL and ISA were referred to in proceeding with the studies.



CHAPTER 2 CONCLUSION AND RECOMMENDATION



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Fig. 2-1-1 SCHEDULE OF EL SIETE No.1, No.2 PROJECT

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CHAPTER 2. CONCLUSIONS AND RECOMMENDATIONS

The first Survey Mission carried out studies, including field investigations, on an electric power development master plan for the upstream part of the Rio Atrato over a 7-month period from July 1981 to January 1982. As a result, the conclusions and recommendations below were arrived at.

2.1 Conclusions

The conclusions drawn in the current study will be described by item below, the essential points of the conclusions being as follows:

The upstream Rio Atrato, when developed for electric power, will comprise a project which is of superior nature among the numerous projects planned in Colombia when seen from technical and economic standpoints. The scale of development will be 1,120 MW in total, and by expediting this development program it will be possible to stabilize the electric power supply of Colombia, and also contribute to economic development of the country.

Electric power development of the upstream part of the Rio Atrato will consist of the six projects of El Siete No. 1; 160 MW, El Siete No. 2; 124 MW, El Once; 176 MW, El Dieciocho No. 1; 252 MW, El Dieciocho No. 2; 261 MW, and El Lloro; 147 MW.

Of these, El Siete No. 1 and No. 2 (combined output 284 MW) involve few technical problems, are economically superior, and can be developed at an early time. These two projects should be followed by development of El Dieciocho No. 1 and No. 2 (combined output 513 MW).

The conclusions reached in the present study are described below.

(1) Location of Project Area

The Rio Atrato is a river having the third largest scale among rivers in Colombia, which flows northward through the middle of Departamento de Choco in the northwest part of the country. The upstream part of this river is located approximately 100 km southwest of the major city of Medellin. The river rises at the western slope of the Cordillera Occidental, and the upstream stretch flows westward at a steep gradient. This upstream part was the object of the study for the power development master plan reported here.

The only villages in the area are Carmen de Atrato, Siete and Dieciocho, all of which are small villages. At the middle stream part there is the city of Quibdo (population approximately 30,000) which is the capital city of Departamento de Choco. As indicated in this manner, Departamento de Choco is an undeveloped region, and the project area is located in this department. Nevertheless, there is a public road from Medellin to Quibdo which runs along the upstream part of the Rio Atrato so that this is a relatively developed district even for Departamento de Choco, and it is possible to reach Carmen de Atrato Village from Medellin in 4.5 hours by car. Therefore, field investigations of the project area is made possible by public road, as is hydroelectric development also.

(2) Topography

Topographical maps by which the topographical condition of the Upstream Rio Atrato Basin can be grasped are not available at present, and the purpose of study cannot be achieved with the existing topographical map (scale: 1/1,500,000). Meanwhile, there are maps of scale 1/100,000 published by the Instituto but elevation contour lines are not illustrated and it is not possible to learn anything about the topographical condition.

Consequently, the aerial photographs covering the El Siete No. 1, El Siete No. 2 and El Once project area and the radar images covering El Dieciocho No. 1 and El Dieciocho No. 2

Since it was not possible to achieve accuracy of the plan with only these existing data and topographical maps, the Mission prepared new aerial topographical maps of 1/25,000 scale in Tokyo based on data of simplified surveying carried out during the survey period.

These new topographical maps can be adopted for the planning of study of this project, and they showed that it is necessary to modify the past schemes of the upstream Rio Atrato completely, especially the schemes about the dam and waterway type development of namely El Siete and El Dieciocho projects.

Although these topographical maps can be applied to formulation of a master plan for the power generation scheme, they are not adequate for a feasibility study. Therefore, it is necessary to be newly performed the aerial photographic surveying works along with leveling providing the signals at the ground surface.

(3) Run-off Durations at Project Sites

The existing gaging stations in the upstream basin of the Rio Atrato from which the run-off duration in project sites can be estimated are only the four of El Siete, Puente de Sanchez, Los Arayanes and El Lloro. These gaging stations, except for Puente de Sanchez, were newly installed in 1980 or 1981 by HIMAT, and since the period of gaging are extremely short, they cannot be applied to studies of power generation projects.

The only gaging station that can be used is Puente de Sanchez Gaging Station installed in 1975 and having run-off gaging records of an approximately 6-year period. The records of this gaging station can be applied to the El Siete No. 1 and No. 2 projects. For the other projects of El Once, El Dieciocho No. 1, El Dieciocho No. 2 and El Lloro, run-off analyses cannot be made applying the abovementioned gaging stations. Accordingly, for the present study, the estimated run-off of the project sites were calculated with considering the run-off coefficients from the precipitation data of precipitation observation stations in this area.

As a result, the annual average discharges at the various project sites are as shown in table 2-1-1.

Table 2-1-1 Annual Discharge at the Project Sites

| Project | Unit: m ³ /s | | | | |
|-------------------|-------------------------|---------|---------|--|---------|
| | Run-off discharge | | | Available discharge for power generation | |
| | Average | Maximum | Minimum | Lowest five discharge | Average |
| El Siete No.1 | 21.9 | 59.5 | 4.4 | 16.0 | 21.3 |
| El Siete No.2 | 35.3 | 111.3 | 8.5 | 25.6 | 33.7 |
| El Once | 89.0 | 333.8 | 18.9 | 64.5 | 85.2 |
| El Dieciocho No.1 | 94.8 | 357.6 | 19.9 | 68.5 | 90.6 |
| El Dieciocho No.2 | 114.9 | 427.3 | 25.4 | 83.2 | 110.2 |
| El Lloro | 292.4 | 844.0 | 87.6 | 213.3 | 287.1 |

Note: Lowest five discharge five days in a month. Average available discharge for lowest five days in a month.

(4) Development Forms

In formulation of a master plan for electric power development of the Upstream Rio Atrato Basin, as a result of studies taking into consideration topography, geology, river conditions, and run-off durations, the forms of dam and water way type and dam type are found to be applicable for this project area. The dam and waterway type would be applicable to the El Siete No. 1 and No. 2 projects and the El Dieciocho No. 1 and No. 2 projects. On the other hand, the dam type will be applicable to the El Once and El Lloro projects with heads obtained by dam.

As for reservoir capacity to regulate the river run-off, in view of the river conditions it will be difficult to obtain a large reservoir with which seasonal regulation can be done at any one of the project sites, and it was decided that daily regulation systems should be applied to the development form.

The heads which can be obtained by dams and by water ways in each project are as shown in table 2-1-2.

Table 2-1-2 Head of Project

| Project | Head | | | Form of Development |
|-------------------|--------------|------------|-------------|-----------------------|
| | Total | by Dam | by Waterway | |
| El Siete No.1 | 490 | 55 | 435 | Dam and Waterway type |
| El Siete No.2 | 260 | 15 | 245 | Dam and Waterway type |
| El Once | 127 | 110 | 17 | Dam type |
| El Dieciocho No.1 | 175 | 80 | 95 | Dam and Waterway type |
| El Dieciocho No.2 | 150 | 45 | 105 | Dam and Waterway type |
| El Lloro | 30 | 30 | - | Dam type |
| Total | 1,232 | 335 | 897 | |

As the above results indicate, of the gross head of 1,232 m utilized for power generation, the head obtained by dams will be 335 m, 27% of the gross, while the head obtained by waterway will be 897 m, 73% so that the development form utilized most will be that of obtaining head by waterway.

The only project in which an underground powerhouse is to be adopted is El Dieciocho No. 2, power station 261 MW, with all of the others to have ground surface type (outdoor) power stations.

(5) Basic Development Scheme

In the upstream basin of the Rio Atrato which was the object of this study, the development schemes, El Siete No. 1; 160 MW, El Siete No. 2; 124 MW, El Once; 176 MW, El Dieciocho No. 1; 252 MW, El Dieciocho No. 2; 261 MW, and El Lloro project; 147 MW, a total 1,120 MW were set up.

The outlines of the projects are as shown in the table 2-1-3.

Table 2-1-3 Outline of the Projects

| Description | Unit | El Siete | El Siete | El Once | El Dieciocho | El Dieciocho | El Lloro | Total |
|---------------------------|----------------------|------------------|------------------|----------------|------------------|-------------------------|----------------|-------|
| | | No. 1 | No. 2 | No. 1 | No. 1 | No. 2 | No. 1 | |
| Type of Development | | Dam and waterway | Dam and waterway | Dam | Dam and waterway | Dam and waterway | Dam | |
| Maximum Output | MW | 160 | 124 | 176 | 252 | 261 | 147 | 1,120 |
| Maximum Discharge | m ³ /s | 40 | 60 | 170 | 180 | 220 | 600 | |
| Effective Head | m | 472 | 245 | 122 | 165 | 140 | 29 | |
| Annual Energy | GWh | 735 | 608 | 753 | 1,091 | 1,115 | 592 | 4,894 |
| Plant Factor | % | 52.4 | 56.0 | 48.8 | 49.4 | 48.8 | 45.9 | 49.9 |
| Hight of Dam | m | 55 | 15 | 110 | 80 | 45 | 30 | |
| Length of Headrace Tunnel | m | 3,300 | 6,500 | 600x2 | 4,500 | Playa Headrace 2,100 | - | |
| Length of Penstock line | m | 2,300 | 1,300 | 600x2 | 350x2 | 350x2 | - | |
| Length of Tailrace Tunnel | m | - | - | - | - | 4,900 | - | |
| Type of Powerhouse | | Ground Surface | Ground Surface | Ground Surface | Ground Surface | Under Ground Surface | Ground Surface | |
| Number of Unit | | 2 | 2 | 2 | 2 | 2 | 3 | |
| Construction Cost | 10 ⁶ US\$ | 139 | 114 | 347 | 347 | 287 | 263 | 1,497 |
| Construction Cost per kW | US\$ | 869 | 919 | 1,972 | 1,377 | 1,100 | 1,789 | 1,337 |
| Generating Cost per kWh | US\$ | 0.023 | 0.023 | 0.055 | 0.038 | 0.031 | 0.053 | 0.037 |
| Priority | | 1 | 2 | 6 | 4 | 3 | 5 | |

As indicated in the above table, when seen according to order of economic effectiveness, the projects which should be developed at an early time are the four of El Siete No. 1 and No. 2 (combined output 284 MW) and El Dieciocho No. 1 and No. 2 (combined output 513 MW). Of these four projects, El Siete No. 1 and No. 2 are superior economically to El Dieciocho No. 1 and No. 2.

The El Siete No. 1 and No. 2 projects are also one of the most advantageous projects being studied for development in Colombia after 1989. Accordingly, it may be concluded that the projects in the Upstream Rio Atrato Basin for which feasibility studies should be initiated ahead of others are El Siete No. 1 and No. 2 (combined output 284 MW).

As described in (2), in connection with the El Siete No. 1 and No. 2 projects, it will be comparatively easy to carry out the field survey about topographical maps and geological investigation, since the sites are located along a public road. Also, run-off records of Puente de Sanchez Gaging Station are available from 1975, so that discharge data in conditions over a period is sufficient to study for El Siete No. 1 and No. 2 project on which greater amount of basic data can be obtained than other projects.

The other projects will require at least 5 or 6 years more merely to compile the run-off data. Consequently, it will be around 1987 that feasibility studies can be started, assuming that only 5 years from now. Even in view of just this point, the projects which should be started first are El Siete No. 1 and No. 2. (See Chapter 3 for an outline of the projects.)

(6) Annual Energy Production

With the six projects mentioned in (5) above, it will be possible to produce 4,894 GWh of energy annually under the upstream Rio Atrato electric power development scheme. Even if only the four projects of El Siete No. 1 and No. 2 and El Dieciocho No. 1 and No. 2 out of the six were to be developed, 3,549 GWh of energy can be produced annually. This means that savings in petroleum of approximately 820,000 kl/yr will be possible. The monthly energy production amounts for the individual project sites are as indicated in total 2-1-4.

Table 2-1-4 Monthly Energy Production

| Project Month | El Siete | | El Dieciocho | | El Dieciocho | | Sub-total | El Once | El Lloro | Total |
|------------------|----------|-------|--------------|---------|--------------|-------|-----------|---------|----------|-------|
| | No. 1 | No. 2 | No. 1 | No. 2 | No. 1 | No. 2 | | | | |
| January | 48.4 | 41.5 | 77.4 | 79.1 | 246.4 | 53.2 | 41.8 | 341.4 | | |
| February | 38.4 | 32.5 | 59.2 | 60.7 | 190.8 | 40.8 | 31.8 | 263.4 | | |
| March | 43.7 | 35.0 | 60.7 | 62.0 | 201.4 | 41.9 | 33.8 | 277.1 | | |
| April | 61.0 | 50.4 | 89.6 | 90.9 | 291.9 | 61.8 | 46.5 | 400.2 | | |
| May | 70.1 | 58.8 | 106.3 | 108.1 | 343.3 | 73.3 | 55.7 | 472.3 | | |
| June | 69.8 | 54.4 | 91.9 | 94.0 | 310.1 | 63.5 | 51.9 | 425.5 | | |
| July | 62.7 | 48.9 | 80.8 | 83.0 | 275.4 | 55.9 | 48.1 | 379.4 | | |
| August | 65.1 | 52.1 | 89.8 | 92.5 | 299.5 | 62.0 | 54.8 | 416.3 | | |
| September | 62.7 | 53.1 | 96.9 | 99.3 | 312.0 | 66.8 | 54.1 | 432.9 | | |
| October | 78.3 | 66.7 | 123.9 | 126.0 | 394.9 | 85.4 | 62.5 | 542.8 | | |
| November | 74.0 | 62.2 | 114.2 | 116.2 | 366.6 | 78.7 | 58.1 | 503.4 | | |
| December | 60.6 | 52.7 | 100.6 | 103.0 | 316.9 | 69.3 | 52.6 | 438.8 | | |
| Total | 734.8 | 608.3 | 1,091.3 | 1,114.8 | 3,549.2 | 752.6 | 591.7 | 4,893.5 | | |

Unit: GWh

As seen from the above figures, the 3-month period from January to March corresponds to a dry season at the upstream basin of the Rio Atrato and the monthly energy production will be decreased, whereas April to December will be relatively wet season. This means that since the other existing hydroelectric power stations in Colombia will be in a period of dry season from July to September, the project sites along the Rio Atrato will conversely be in the wet season so that the energy produced on the Rio Atrato will not become secondary power and can be sold extremely effectively.

(7) Roughly Estimated Construction Cost

The construction costs estimated as of 1981 for the each project are as shown below. Construction funds totalling US\$253 million at a rough estimate will be required to develop El Siete No. 1 and No. 2 (combined output 284 MW). Adding El Dieciocho No. 1 and No. 2 for a maximum output totalling 797 MW, US\$887 million at a rough estimate will be required. The breakdown of construction costs divided for civil works, equipment, and others is as shown in table 2-1-5.

Table 2-1-5 Estimated Construction Cost

| Project | Civil Works | Elec. & Mech. Equipment | Unit: 10 ⁶ US\$ | |
|-------------------|-------------|----------------------------|----------------------------|-------|
| | | | Others | Total |
| El Siete No.1 | 81 | 18 | 40 | 139 |
| El Siete No.2 | 65 | 20 | 29 | 114 |
| El Dieciocho No.1 | 207 | 37 | 103 | 347 |
| El Dieciocho No.2 | 170 | 41 | 76 | 287 |
| Sub-Total | 523 | 116 | 248 | 887 |
| El Once | 212 | 32 | 103 | 347 |
| El Lloro | 138 | 53 | 72 | 263 |
| Total | 873 | 201 | 423 | 1,497 |

Note: Others are comprised compensation, Engineering fee, contingency and interest during construction period.

(8) Economics of Individual Projects

The construction costs per kW and generating costs per kWh (annual expense factor 12%) of the each project are obtained and compared in table 2-1-6.

Table 2-1-6 Economic Effect of Project

| Project | Maximum Output | Annual Energy Production | Roughly Estimated Construction Cost | Construction Cost per kW | Generating Cost per kWh |
|-------------------|----------------|--------------------------|-------------------------------------|--------------------------|-------------------------|
| | (MW) | (Gwh) | (10 ⁶ US\$) | (US\$/kW) | (US\$/kWh) |
| El Siete No.1 | 160 | 735 | 139 | 869 | 0.023 |
| El Siete No.2 | 120 | 608 | 114 | 919 | 0.023 |
| (1) Sub-Total | (284) | (1,343) | (253) | (894) | (0.023) |
| El Dieciocho No.1 | 252 | 1,091 | 347 | 1,377 | 0.038 |
| El Dieciocho No.2 | 261 | 1,115 | 287 | 1,100 | 0.031 |
| (2) Sub-Total | (513) | (2,206) | (634) | (1,238) | (0.034) |
| (3) El Once | 176 | 753 | 247 | 1,972 | 0.055 |
| (4) El Lloro | 147 | 592 | 263 | 1,789 | 0.053 |
| (1) ~ (4) Total | 1,120 | 4,894 | 1,397 | 1,337 | 0.037 |

According to the above figures, the construction cost per kW of the El Siete No. 1 and No. 2 projects combined is US\$891, while the generating cost is US\$0.023/kWh, so that the combined project will be of a high priority project and is not inferior to any other hydro-electric project presently being studied in Colombia. Accordingly, as described in (5), the El Siete No. 1 and No. 2 project should be started first among the project sites in the upstream basin of the Rio Atrato, and these are also projects for which feasibilities can be established.

The construction cost per kW of the El Dieciocho No. 1 and No. 2 projects combined is US\$1,236, while the generating cost is US\$0.034/kWh, and the economic effectiveness will be not A-grade. However, since the situation was one where planning could not be done using adequate data (run-off data, topographical maps, etc.), these two are projects for which the economics can be improved through investigations. According to the present plans, as may be comprehended from the breakdowns of construction costs, the proportion of dam cost will be large. The reason is that because the economics of the El Once project would be poor it was necessary to take into consideration adequate sedimentation capacity for El Dieciocho No. 1 Dam. Also, because the study of planning was done using incomplete topographical maps at present, the dam height was as much as 80 m, and the construction cost became high.

Both El Once and El Lloro projects are sites for dam type development, and because of the high cost of the dams, the economic effects will be poor. However, these have the possibilities of becoming economical in case fuel costs of oil-fired thermal power plants should rise in the future.

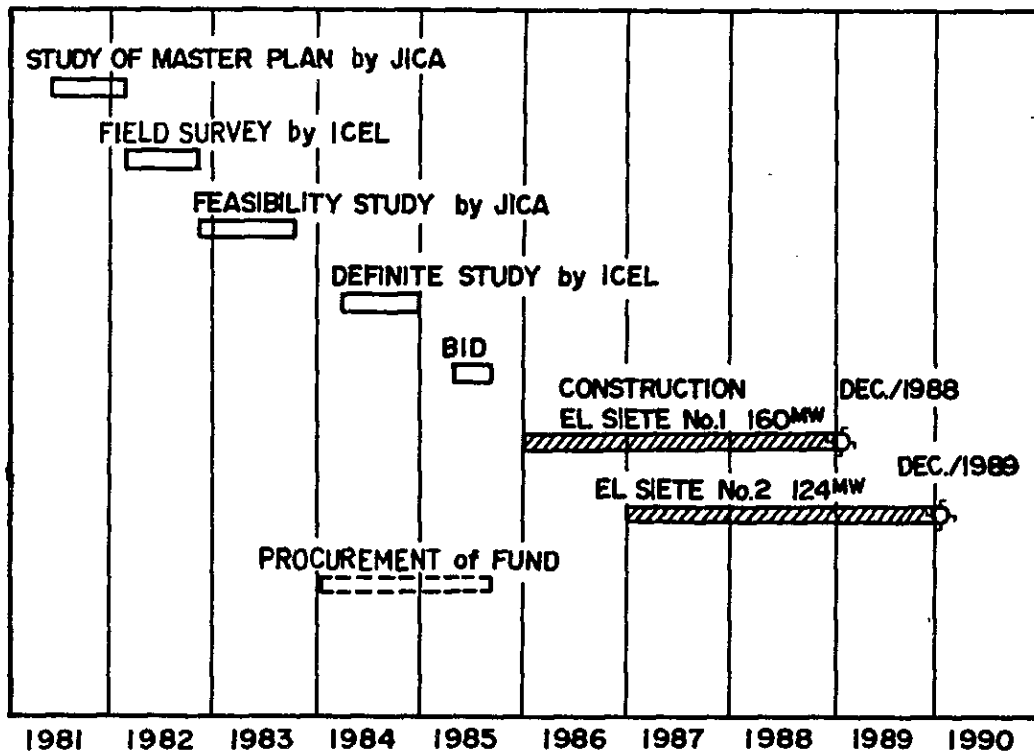
Regarding the El Once project, a plan to develop the mainstream Rio Atrato together with the Rio Grande as dam and waterway type is also conceivable, and this is a site which should be reexamined when more complete run-off data of the Rio Grande have become available in future.

As for the El Lloro project, the site is one where the development is inconceivable from other than as a dam type. Therefore, it is not possible to improve the economic effect over the plan studied now. Furthermore, the only means of traffic for the residents around the El Lloro damsite is boat navigation. Consequently, this project will have the drawback that operation of the power station will be restricted in order to maintain the downstream water level. This will further decrease the value of power generation, and is a factor impairing the economics.

(9) Years of Commencement of El Site No. 1 and No. 2 Projects

The schedules up to commencement were studied for the El Siete No. 1 and No. 2 project and the results are as shown in the chart below. The schedules show that in case the studies on the El Siete No. 1 and No. 2 project proceed favorably and it is possible to procure the funds of construction as scheduled below, El Siete No. 1; 160 MW, can start operation in December 1988, while El Siete No. 2; 124 MW, can be commissioned in December 1989. This means that there will be no problem in connection with the future schedule even if the El Siete No. 1 and No. 2 project are given first priority in selection of projects for 1989 and after.

Fig.2-1-1 SCHEDULE OF EL SIETE No.1, No.2 PROJECT



(10) Position of Rio Atrato Power Generation Scheme in Long-Range Electric Power Development Program of Colombia

The general situation of electric power supply and the middle-range electric power development program of Colombia at present are described in 4.2. According to 4.2, the projects which are to be commissioned by 1988 have already been decided, and those projects are either under construction or are undergoing preparations for construction. Consequently, new projects should be studied aiming for commencement in 1989 or later.

There are twelve sites (total output 12,284 MW) in Colombia for which studies have already been started as projects for commissioning in 1989 or later. (See 4.2.3)

These twelve projects are extremely good, but the economics of the El Siete No. 1 and No. 2 (284 MW) projects at the Rio Atrato are not inferior to them and conversely, when degree of ease of construction, supplemental capacity for existing hydroelectric stations in dry season, and good transporting situations for construction, etc. are considered, these two may be deemed as being superior.

on the other hand, the El Siete No. 1 and No. 2 project, as described in (9) above, can be developed at an early stage when the schedules are examined. Considered at the present time, it will be possible for El Siete No. 1 to go into operation in December 1988 and El Siete No. 2 in December 1989.

In view of the above, the El Siete No. 1 and No. 2 projects should be considered as leading contenders for the next middle-range program, and it is thought that they should be brought to the head of that program, in 1989.

(11) Items to be Investigated in Advance for Proceeding to Feasibility Study Level with El Siete No.1 and No. 2 Projects

In order to elevate the studies of the El Siete No. 1 and No. 2 projects, the most economical of the power generation schemes at the upstream basin of the Rio Atrato, to the feasibility level,

the field investigations below should be carried out in advance at an early stage.

- ° Aerial Photographic Surveying (Scale 1/25,000),
Photographing Area: 450 km², Mapping Area: 69 km²

Signal, bench marks, triangulation stations, etc. are to be installed on the ground before carrying out this surveying. The photographs are to cover the mapping area and the mapping area are to cover the project sites. (See Drawing-13)

- ° Topographic Surveying (Scale 1/2,000),
Surveying Area: 3.7 km

This surveying is to be done for the principal structures composing the El Siete No. 1 and No. 2 projects, in other words, areas covering the damsite, penstock, powerhouse, substation, etc.

In carrying out the surveying, the elevation of the bench mark (existing) of the Instituto Geografico at Siete Village (branching point of the road to Quibdo and Carmen de Atrato) is to be applied as a original elevation. The bench mark transferred from the origin is to be provided within the survey area.

- ° Topographic Surveying (Scale 1/5,000), Mapping Area: 1.0 km²

This surveying is for the purpose of obtaining a topographical map for the reservoir area of El Siete No. 1 Dam, and the mapping is to be done applying the previously-mentioned aerial photographs. In performing this mapping, it is necessary for the same datum points and bench marks to be used as for the previously-mentioned 1/25,000 topographical maps.

These topographical maps are to be used for studies such as calculation of reservoir storage capacity, investigations of objects to be submerged, analyses of backwater curves, planning of relocated roads, etc.

° Complete Equipping of Puente de Sanchez Gaging Station

This gaging station is of greatest importance to the study of the El Siete No. 1 and No. 2 projects, and under the present situation water level staff gages for daily observations are insufficient for times of dry season. The shortage of staff gages must be filled and corrected.

° Gaging Stations to be Newly Installed (Two Sites)

In order to improve the accuracies of run-off analyses in feasibility studies concerning the El Siete No. 1 and No. 2 projects, a gaging station should be newly provided in the vicinity of El Siete No. 2 Intake Damsite. It is desirable for this gaging station to be installed with gaging equipment furnished by JICA.

Meanwhile, in order to bring the El Dieciocho No. 2 project to the stage of a feasibility study, run-off gaging records for the Rio Playa are necessary. Therefore a new gaging station should be set up in Rio Playa by applying another gaging equipment furnished by JICA.

° Geological Investigation Works

In the present study, only a surface reconnaissance was performed to learn about the geologic condition, and it was not possible to study enough about the geology of the project site. Consequently, it is necessary for the following geological investigation works to be carried out in order to start on a feasibility study of El Siete No. 1 and No. 2 projects.

Boring Investigation Works

It is necessary for information on the depth of talus deposits covering the ground surface, depth of river-bed deposits, lithological character, rock type and existence of faults to be obtained.

Seen from the project scale, the work quantities below are necessary for the various sites in order to carry out the feasibility study.

Table 2-1-8 Quantity of Boring Works

| Project | Boring Sites | Number of boring | Length of one boring (m) | Total length of boring (m) |
|---------------|--------------------------|------------------|--------------------------|----------------------------|
| El Siete No.1 | El Siete No.1 dam | 6 | 30 | 180 |
| | Penstock line | 4 | 20 | 80 |
| | Power house | 1 | 30 | 30 |
| | Sub-Total | 11 | | 290 |
| El Siete No.2 | El Siete No.2 Intake dam | 3 | 20 | 60 |
| | Penstock line | 3 | 20 | 60 |
| | Power house | 1 | 30 | 30 |
| | Sub-Total | 7 | | 150 |
| Total | | 18 | | 440 |

The various boring sites are shown in Drawings-14. These sites may be suitably changed in view of the conditions in the field.

Geologic Interpretation Using Aerial Photographs

Aerial photographs newly taken make possible the geological interpretations regarding existence of faults, the possibility of land-sliding, etc., and these works should be ordered from a specialist firm. For this purpose, it is necessary for the scope of aerial photography to cover the catchment area of projects.

Adit Investigation Works

The previously-mentioned boring investigations are inadequate for examining about the geologic conditions at the damsite. Accordingly, it is necessary to examine the directions of faults and joints, and lithological characters to be investigated employing pilot test adit investigation works in combination.

With regard to El Siete No. 1 Dam, adits of the number and lengths indicated below will be necessary.

| | |
|--------------------|---|
| Number of adits | : 2 |
| Length per adit | : 30 m and 40 m |
| Total length adits | : 70 m |
| Sites | : Right and left banks of El Siete No. 1 Dam (See Drawing-14) |

The observation works for concrete materials (see chapter 5. Drawing-15).

The above investigation works are to be carried out by a specialist firm on order from ICEL based on scope of works agreed upon between ICEL and JICA in February 1981. During the period of the investigation works, JICA will carry out the supervise works by dispatching the engineers to provide instructions for data collection and to manage the investigation works together with ICEL.

2.2 Recommendations

A study for formulation of a master plan on electric power development at the upstream Rio Atrato has just been made. As a result, it was possible to arrive at the conclusion that the El Siete No. 1 and No. 2 projects, 284 MW, are good economically and satisfied the condition that the execution of construction is very easy, and are worth starting the feasibility studies at an early time.

Based on this study the recommendations about how the El Siete No. 1 and No. 2 project and other projects in Rio Atrato should be handled are made concerning the items below.

(1) Lack of Run-off Data and Incompleteness of Data Arrangement

Run-off observations and arrangement and analyses of data are being carried out by HIMAT, and are not the responsibility of ICEL. There are run-off gaging stations at the sites along the Rio Atrato, but this number cannot be said at all to be adequate for development of the river. The operation and maintenance of these gaging station, which are important facilities providing precious data, are not thorough enough. For example, because repairs of parts damaged by flood were

inadequate, the result has been many unrecorded periods. Furthermore, since observations have been on water levels only and flow velocities have not been measured, the records are incomplete as run-off data. The cross section of the river at gaging station are changed every time in flood, and there are cases when the old water-level observation data become useless. Therefore, it is desirable and hoped that existing gaging stations will be made more complete and superior maintenance and repairs should be carried out.

(2) Preparation of Complete Topographical Maps

The complete topographical maps are necessary for study of development in all cases. To develop the area without topographical maps, it is necessary to prepare topographical maps first.

The upstream basin of the Rio Atrato is an area for which topographical maps are not complete. In order to proceed with a study, the preparation of complete topographical maps is of greatest importance. In the present study of the master plan, it was possible for the purpose to be attained through simplified mapping by the aerial photograph, but in order to further the examination to a feasibility study it is desirable for topographical maps to be fully provided.

(The scope of preparation of topographical maps concerning the El Siete No. 1 and No. 2 projects is as described in 2.1(11) and Drawing-13.)

When carrying out aerial photography of this area, an influencing factor is that there are rainy days throughout most of the year. Therefore, the selection of timing for carrying out the aerial photography is of greatest importance. This timing, seen from rainfall records would be during the dry season from January to March, and moreover, it would be effective to take the photographs in the mornings.

As for topographical surveying to be done on the ground, the work efficiency would be poor in the rainy season with mountaintops covered by clouds on most days, so that it is desirable for the surveying to be done concentrated in the dry season.

As indicated above, the aerial photography works will be possible only during rare occasions, so that it would be advantageous not to confine the photography to El Siete No. 1 and No. 2 projects, and photographing of the El Dieciocho No. 1 and No. 2 projects areas should be done at the same time. It should be remembered that so long as photographs are available, the mapping can be done when necessary in the future.

(3) Efforts to Procure the Funds for Field Investigation Works for Feasibility Study of El Siete No. 1 and No. 2 Projects

It is necessary for the field investigation works described in 2.1(11) to be carried out in order to elevate the El Siete No. 1 and No. 2 projects to the feasibility study level. It will be desirable for ICEL to procure the funds for such investigations and to make the efforts in order that the implementation of investigation works will not be impeded.

(4) Installation of New Gaging Stations

As described in 2.1(11), it is necessary to provide the two new facilities of El Siete No. 2 Intake Dam Gaging Station and Playa Gaging Station to raise the studies of the El Siete No. 1 and No. 2 projects and the El Dieciocho No. 1 and No. 2 projects to feasibility study levels.

It is desirable for these gaging stations to be constructed by ICEL at an early date, and advisable for these stations to be equipped with the water gages and precipitation gages furnished by JICA.

(5) Data to be Prepared by ICEL for the El Siete No. 1 and No. 2 Projects Feasibility Study

The data ICEL should prepare in order for a feasibility study to be made of the El Siete No. 1 and No. 2 projects are as follows:

- ° Measurements of gaging cross sections and flow velocities at the Puente de Sanchez Gaging Station to be made in 1982 (at least once every months).
- ° Actual power demands of the two years of 1981 and 1982. Also, power generating performance of each existing power station in the same period.

- Actual electricity rates and gross revenue from electricity sales.
 - Estimated single line diagram of current flow in entire Colombia's power system in 1989 year.
 - Situation of project progress had made in middle-range electric power development program of entire Colombia and explanations of changes made in the program.
- (6) Ordering of Field Investigation Works Concerning El Siete No. 1 and No. 2 Projects from Specialist Firm and Contractor

It is desirable for the field investigation works described in 2.1(11) to be ordered by ICEL at an early date, based on the Schedule of the Inception Report (June 1981).

- (7) Status of El Dieciocho No. 1 and No. 2 Projects

These projects should be pushed ahead to the feasibility study level in view of their economics. However, the time for the feasibility study would be around 1987 when run-off data from Los Arayanes Gaging Station and Playa Gaging Station, the latter newly to be installed, have become available in adequate form.

- (8) Status of El Once and El Lloro Projects

These projects, in view of their economics, are not ones that can be realized in the near future. However, run-off gaging work should be continued.