POSSIBLE IMPLICATIONS FOR THE ENVIRONMENT OF THE PROPOSED ALTO SINÚ HYDROELECTRIC PROJECT, COLOMBIA

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RIN Contributions to Research on
Conservation of Natural Resources

No 1982 - 2

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CONTENTS pg

1 PURPOSE OF THE STUDY

The Alto Sinú Project involves the construction of two reservoirs (Urra I and Urra II) for the production of hydroelectricity on the upper Sinú river in Colombia. Gomez, Cajiao y Asociados. Ltda., consulting engineers in Columbia are preparing the necessary studies for the project. Early in March 1982, the Research Institute for Nature Management was requested by Haskoning bv, consulting engineers and architects, Nijmegen, The Netherlands to assess the possible implications for the environment of the proposed Alto Sinú Hydroelectricity Project. Drs. P. Leentvaar who has had experience with a similar project, the Brokopondo Project on the Surinam River in Surinam went to Colombia in March to carry out this study.

On arrival in Bogota, Gomez, Cajiao y Asociados Cia Ltda presented him with his task which was to provide answers to the following questions:

1 Should we clear the reservoir? If so, to what extent? What effect could regrowth have?

2 Which would be the best clearing method? What would be the effect of burning?

3 What percentage of the total biomass is decomposable under water?

4 What could be expected with respect to water quality? would the reservoirs stratify thermally? If so, how permanent would the stratification be? What could be the thickness of the epilimnion? What are the physical--chemical characteristics of this upper stratum in relation to the hypolimnion?

5 From a water quality point of view, would it be advisable to build fish passageways for the migratory species? Would the probable water quality interfere with this remedial measure?

6 Could a fisheries resource be developed in the reservoirs? What measures would have to be implemented?

7 What could be the effect of water weed growth? Should any special measures be taken?

2 SUMMARY OF THE ACTIVITIES OF THE MISSION AND SOURCES OF FURTHER INFORMATION

On arrival in Bogota the mission was briefed by Dr. Camilo Garzon, the environmental engineer of Gomez, Cajiao y Associados cia Ltda on the Alto Sinú Hydroelectric Project. Aerial photographs of the area and other relevant data were provided. On the 11 March a one-day visit was made to the area. The journey began at the city of Medellin. During the flight over the upper Sinú river system, a general impression was obtained of the river system itself and of the vegetation. Samples of plankton were taken from the rivers near the future dam sites.

Data collected by Mr. Germân Garvis, a biologist from the Universidad Nacional Bogotâ on the flora and fauna of the Sinú area was made available. From interviews with the fishermen, Mr. Garvis has collected data on catches and migratory habits of fish in the river system. He also presented photographs showing the presence of water hyacinth, duckweed and also species of Typha. These plants were not visible from the air as they were hidden by the trees. In addition dr. Garzon provided data on the chemical composition of the water.

The upper Sinú area has already been declared a national park. After construction of the dams, it has been suggested that the area be reserved for the use of the Indian population. Discussions were also held with dr. Jorge Hernadez-Camacho of the Instituto Nacional Desarrolo Resorces Naturalis in Bogotâ in this regard.

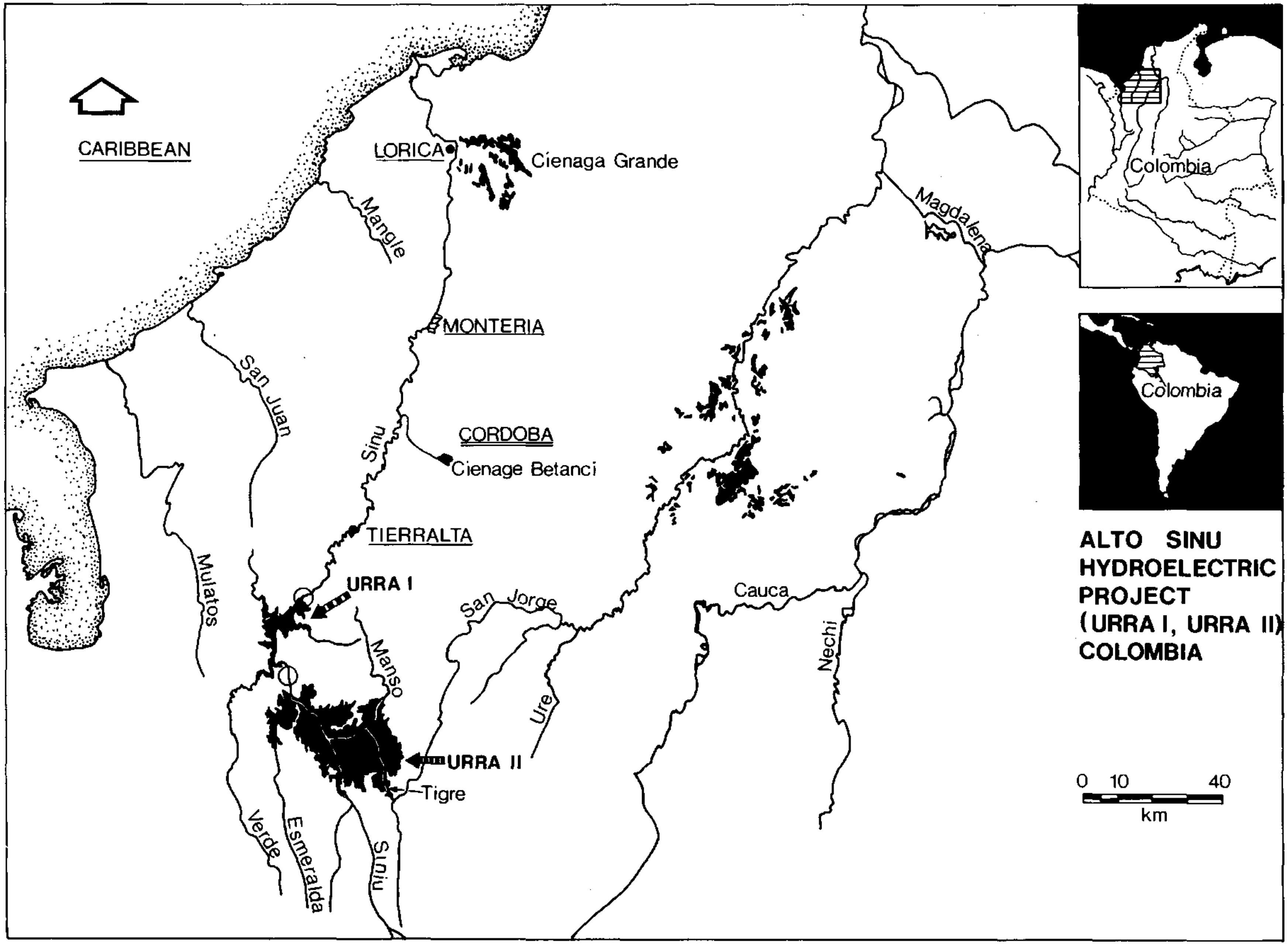
Additional data were also obtained from:

Gomez, Cajiao y Asociades, Bogotâ & Dames and Moore, Washington DC, 1981
Draft Final Report Environmental Assessment of the Alto Sinú Hydroelectric Project.
Colombia (Urra I and Urra II) Vol. I & II.

Estudos Technicos LTDA, Bogotâ, 1982
Clearing Report Corelco. Urra II Project
Reservoir Clearing, cost estimates.

Ministerio de Mines y Energia, 1981
Informe Technico Centrales Urra I, Urra II y desviacion del Rio San Jorge.
Corp. Electrico de la Costa Atlantica (Corelco)
Barranquilla, Colombia.

FIG 1


CARIBBEAN
LORICA
Cienaga Grande
Mangle
MONTERIA
San Juan
Sinu
CORDOBA
Cienage Betanci
TIERRALTA
Mulatos
URRA I
Manso
URRA II
Tigre
Verde
Esmeralda
Siniu
San Jorge
Ure
Cauca
Nechi
Magdalena
Colombia
Colombia
ALTO SINU HYDROELECTRIC PROJECT (URRA I, URRA II) COLOMBIA
0 10 40
km

3 DESCRIPTION OF THE SINU RIVER SYSTEM

In order to increase production of hydroelectricity in Colombia, plans have been made for the construction of two reservoirs in the Upper Sinú river. As a result of the Alto Sinú Hydroelectric Porject, a total of about 600 km^2 of tropical rainforest will be inundated. This includes about 67 km^2 in the proposed Urra I reservoir and about 540 km^2 in the proposed Urra II reservoir (see Fig. 1). As very little is known about the hydrology and biological life in the Sinú river system, an attempt has been made to provide a general description of the area based on the information available.

3.1 General description of the rivers

The Sinú river rises in the northern Colombian Andes and flows northwards into the Caribbean sea. Its is approximately 250 km long and its main tributaries are the Esmeralda, Manso, Tigre and Verde. These rivers flow through an extensive area of tropical rainforest. The area around the upper Tigre is swampy. In the upper reaches of the rivers the valleys are steep and the water flows very fast. As already mentioned the area is covered with tropical rainforest but as observed from the air, here and there the vegetation has been cleared by the Indians for the cultivation of banana. Very few people live in the area, only isolated huts were observed. While the Indians cut and burn the forest, their activities are limited to a few hectares and do not contribute significantly to erosian in the upper Sinú area. The lower Sinú, below the proposed reservoirs, flows through flat open country which is used for grazing and agriculture. The river meanders over an alluvial flood plain with many ox-bow lakes and shallow eutrophic cienagas (marshy lagoons), such as the Betanci and Grande. These cienagas are connected to the river by small creeks, and during the wet season the water rises in the cienagas. There is a gradation in the salinity of the river water from the mouth of the river as far as Lorica. Where the rain-forest has been cleared in the Sinú there is evidence of erosian and successions of secondary forest. Further towards the mouth of the river the landscape is savannah with many marshy and swampy areas.
The discharge of the Sinú and its tributaries varies not only from river to river but also from place to place within the same river. Large suspended loads of sediment are carried by the Sinú, Esmeralda and Verde rivers and

deposited in various parts of the rivers. As a result the turbidity of the water is high, and the colour of the water is greyish-green. The water is similar to White Andean water. The Tigre and Manso rivers which rise in the swampy area carry more detritus and are coloured brown by the iron and humic substances. This water is referred to as Brown water. At the confluence of the Sinú and Manso and also at the confluence of the Sinú and Esmeralda a sharp division between the two colours is clearly visible from the air. However this difference in colour soon disappears in the main stream of the Sinú.

3.2 Chemical composition of the water

The data provided by dr. Camilo Garzon, Gomez, Cajiao y Asociados indicates that the water in the Sinú river system is rich in nutrients. Although the water temperature is about 24°C, the mean average air temperature is about 27.5°C. The concentrations of chemicals in the water vary with the discharge of the rivers in the wet and the dry seasons. Table 1 gives the concentrations of various substances in the water derived from samples taken during a 7-month period (July 1981 - January 1982) in the wet season. From Table 1, it can be seen that the quantity of suspended material in the water is high and as a result the turbidity of the water is also high. This is especially the case near the town of Monteria and in the tidal zone near la Doctrina. The water is well oxygenated and the values recorded show concentrations at about the level of saturation. From analyses of samples taken at a number of stations, it would appear that the biological oxygen demand (BOD_5) is low, varying between 1 and 3 mg/l. The rivers, therefore, carry small amounts of easily decomposable organic matter in spite of the large quantities of suspended material. Pollution of the water measured in terms of coli counts is high compared to the standards for non-polluted waters. While the reason for the high coli counts may be obvious in the stretches of the rivers near the towns, the reasons for the high coli counts in the upper Sinú and its tributaries are not so obvious.

The total electrolytes, measured as conductivity, is relatively high compared to other rivers flowing on laterite soils. The pH is also relatively high, about neutral in the upper Sinú and above 7 in the lower Sinú, also depending on river discharge. Conductivity is highest in the Cienaga Grande. The brackish water on the river side of the cienaga may account for the high conductivity, while on the other side of the cienaga, the fluctuation between flooding in the wet season and drying up in dry season may have an effect on the concentration of minerals in solution.

Concentrations of phosphate and nitrogen in the upper Sinú are high, which is typical of most Andean rivers. This may be related to leaching out of the subsoil and not to the leaching out of the primary tropical rainforest bordering the rivers.

Further, from Table 1 it can be determined that the water contains low concentrations of alkalis and that the concentration of sulphates are also low. The iron content is high and the water in some of the upper tributaries is coloured deep red-brown from the iron, but becomes greyish-green, when the tributaries join the Sinú. The iron concentration in the lower Sinú is higher than in the upper Sinú. This may be related in some way to the greater load of suspended material and fluctuations in river discharge.

In summary, the chemical quality of the water in the Sinú river system can be described as fertile Andean White Water, which in the lower course of the river gives rise to eutrophication.

3.3 Biological aspects of the rivers

The development of algae and submerged vegetation is limited because of the fast flowing water and/or because of the high turbidity. Filamental algae (Stigeoclonium) have been observed growing on submerged rocks where the water is clear. In the lower Sinú and the cienagas there is practically no orthophosphate but the total phosphate is higher than in the upper Sinú. As the flow of water is slower in the lower Sinú and stagnant in the cienagas, conditions are favourable for the growth of phytoplankton.
Orthophosphate may accumalate in the algae and the algae biomass may give rise to greater turbidity. In the cienagas, nutrients may well be taken up by the swamp vegetation and by submerged and floating plants which is reflected by the lower turbidity. In the samples of plankton taken from the Sinú and Esmeralda rivers, considerable quantities of detritus and sand particles were found but no zooplankton and very few phytoplankton. The diatom Fragilaria ulna var. ungarica, a tropical species, was present in all samples. Other diatoms found in the samples were Surirella tenera and Amphipleura, and Girosygma. Green algae such as filamentous Spirogyra, Mougeotia and Oedogonium were found mainly in samples from the Sinú. This may indicate that the water upstream may be connected to stagnant and swampy water yet further upstream. Closterium moniliferum and Cosmarium sp. were

TABLE I

Physical, chemical and bacteriological analyses of water samples taken from various sites on the Sinú River, Colombia, 1981/1982, mean of 7 months *

Sampling station	1	2	3	4	5	6	7	8	9	10	11	
Turbidity	47	142	150	75,4	136	117	159	233	178	46	83	
pH	7.5	7.4	7.2	7.7	7.5	7.3	7.3	7.4	7.4	7.8	7.4	
Alkalinity, total	29	51	38	47	43	44	45	46	61	102	42	mg/l $CaCO_3$
Conductivity	-	100	90	110	115	100	80	80	80	480	130	mmho/cm-25°C
Chlorid	3	3.4	3.3	3.7	3.1	2.0	4.8	8	4	60	5	mg/l
Oxygen	8.1	8.3	8.2	8.8	8.5	6.6	7.3	8.9	-	-	-	mg/l (t=± 24°C)
Nitrate	0.59	0.48	0.47	0.53	0.60	0.60	0.83	0.52	0.67	0.65	0.67	mg/l N
Phosphate, total	0.18	0.21	0.21	0.18	0.39	0.27	0.80	0.45	0.54	0.82	0.20	mg/l P
Phosphate, ortho	0.15	0.17	0.14	0.10	0.17	0.01	0	0	0	0.05	0	mg/l P
Iron, total	1.15	4.04	3.73	0.98	2.30	7.48	16.02	10.68	27.6	6	7	mg/l Fe
Sulphate	5	6.3	6.4	9	9.4	10	8	14	-	-	-	mg/l S
Total susp. mat.	19	401	264	92.9	202	147	832	832	620	526	212	mg/l
Coliforms	930	930	1800	-	3350	2400	24000	-	-	-	-	MPN/100cc

Location of sites:

1 = Upper Sinú, 100 m upstream from the confluence with the Esmeralda
2 = Esmeralda, 100 m upstream from the confluence with the Sinú
3 = Sinú, at Urra II - Mira 12
4 = Verde, 100 m upstream from the confluence with the Sinú
5 = Sinú, at Urra I - Mira 56
6 = Lower Sinú at Las Palomas, Nuevo river
7 = Lower Sinú at Monteria
8 = Lower Sinú at la Doctrina - Estacion limnimétrica
9 = Cienaga Grande at San Sebastian
10 = Cienaga Grande at Chima - Estacion Limnimétrica
11 = Cienaga Betanci at Maracayo - Estacion Limnimétrica

* Data provided by Gomez, Cajiao y Asociados Ltda, Bogota

the only species of Desmids found and a few threads of fungi were also found. As far as it is possible to draw conclusions from the plankton samples, it would appear that typical acid-oligotrophic species are not present in the water. The swift flowing water prevents the growth of plankton in the main streams.

Very little is known about the presence of macrophytes in the upper Sinú. Mr. Germán Garvis has observed water hyacinth (Eichhornia sp.) and water fern (Salvinia sp.) in pools of water in the rainforest away from the rivers. These water plants could be transported into the rivers during the wet season when the water level is high. In the lower course of the Sinú, especially in the cienagas there is luxurious growth of floating plants. These plants were not visible in the upper Sinú from the air nor were they observed during a boat trip on the river. Virtually nothing is known of the aquatic macrofauna. Mr. Garvis has found no evidence of snails in the Sinú river. This is in accordance with the fact that there are no records of bilharzia in the area.

3.4 Fish species

More data are available on the fish which live in the Sinú river system. Approximately 148 species of fish have been recorded as living in the Sinú and its tributaries. Marine and estuarine species entering the Sinú from the Caribbean include sharks, rays and also tarpons. The most common fresh water species are Characoids and Silurioidea (catfish). The 8 species known to be endemic to the Sinú are:
Brycon fowleri
Brycon moorei sinuensis
Brycon americus icelus
Gephyrocharax sinuensis
Hemibrycon velox
Pimelodella reyesi
Saccoderma robustum
Trachycorystes insignis badeli
The most important commercial species in the Sinú is the bocachico (Prochilodus reticulatus magdalenae). Bocachico spawn in the river during the wet season when the water level rises and return to the cienagas after spawning. The eggs and larvae are transported downstream during the high water.
The fish feed on detritus. As dams are to built on the upper Sinú, more data on fish, especially their migratory habits, are urgently required.

4 COMPARISON OF THE EFFECTS OF THE BROKOPONDO PROJECT ON THE ENVIRONMENT AND THE POSSIBLE EFFECTS OF THE ALTO SINÚ PROJECT

In order to assess the impact of the inundation on the environment, it is worthwhile comparing the proposed Urra I and Urra II reservoirs with other man-made lakes in tropical rainforest areas, especially the Brokopondo reservoir on the Surinam river, which covers an area of about 1500 km^2. These are, however, a number of environmental aspects which are different and which should be kept in mind when making such comparisons.

4.1 General characteristics of the rivers

The soils in the Brokopondo reservoir are derived from old eroded hard rock and laterite and as a result the rivers and creeks are poor in minerals and nutrients. Many types of trees in the forest therefore are nitrogen-fixing. The environment is typically oligotrophic.

The rivers to be included in the Alto Sinú Project carry large amounts of sediment which are visible in the colour of the water and which results in high conductivity (about 100 µS and above) depending of the rainfall. This White Water is typical of Andean rivers. During and after rain the rivers in Surinam are flushed and suspended matter is carried downstream. The water is comparable to pure rain water. The colour of the water remains brown because of humic substance originating from the forest floor which are dissolved in it. Iron and silica are added to the water from the subsoil. Eroded material probably contributes most to the chemical composition of the water of the Sinú river, and humic substances may only be of minor importance. As a result the pH of the river water is relatively high. From analyses of the water it can be assumed that the environment of the river is meso--eutrophic in character, but insufficient data are available on plankton and macrofauna to confirm this.

4.2 Rapids

From an aerial survey carried out during the dry season, it appears that in comparison with Brokopondo river, there are very few rapids in the Sinú river. These rapids contain typical rock flora such as Podostemonaceae, which were not observed in the Sinú, but which are also typical in the rapids of Amazonian brown and black waters. As a result of permanent inundation of the rapids, these plants have no longer been observed in the Brokopondo reservoir. In the Sinú this may happen also. It may well be that fish, such as

Plecostomus, and other organisms, which occur only in rapids, will also disappear after inundation.

4.3 Silt

The rivers in Surinam carry very little silt containing humic debris and plankton. In the dry season the water between the rapids is more of less stagnant and plankton develops, however, as a biomass it is negligible. The silt sediment is also negligible. Plankton does not develop in the upper Sinú because the rivers carry too much silt. Even in the dry season the flow of the Sinú is fast and there is insufficient light for plankton to develop. The plankton present in the river has most probably developed in the tributaries and ox-bows. However, this may not be of importance as most of the planton are erratic benthic species original from the bottom. The silt carried by the tributaries will be deposited at the entrance to the future lake and may well form a delta region.

4.4 Nutrients in the water

In Surinam and also in the Amazon, the nutrient cycle in the tropical forest is a closed cycle. The nutrients in the soil and mineralized humic substances are taken up swift by the roots of trees. As a result the waters of the rivers contain few nutrients such as phosphorus and nitrogen. The soils are not leached. In the Sinú region, the waters of the rivers contain relatively large amounts of phosphorus and nitrogen. As the present tropical rain forest is similar to that in other tropical regions, it is clear that the existing phosphorus and nitrogen are leached out of the subsoil. This is related to the alluvial soils and the alluvial tropical rainforest growing on them. It was observed during a boat journey on the Sinú that the forest along the banks was more diverse in species than that along the rivers in Surinam especially the lower layers of the forest. This may be because the soils are more fertile in comparison to Surinam.

4.5 Floating water plants

The development of floating water plants such as water hyacinth and water ferns is generally regarded as a problem in many tropical waters. In Surinam only a few m^2 of water hyacinth was found in secluded places upstream in the rivers. Water hyacinth was observed also in many areas in the lower reaches of the rivers near the tidal region. This may also be the case in the lower Sinú and the cienaga Grande and Betanci. Upstream the flow is too fast and the variation in water level between the dry and wet season is so great that the plant does not develop. As soon as the water in the Brokopondo reservoir stagnated water hyacinth spread widely, firstly in the area bordering the former river banks for several kilometres and then as islands around the dead trees protruded above the water. It was finally controlled at considerable expense by aerial spraying of 2 - 4 D. As far as is known, the plant is at present only to be found at the inflow of the Surinam river to the lake but must be closely observed for further development. Several other water plants also developed, Utricularia (a carnivorous species), duckweeds, and a species of floating water fern but later disappeared without the use of control measures. As the water is too deep for the development of submerged species such as Cabomba, these plants did not appear even in the shallow waters near the shores of the lake. Conditions in the Brokopondo reservoir were not favourable to the development of submerged water plants with roots. It is not known which species of water plants occur in the Sinú. An areal survey of the rivers has indicated a swampy region and several ox-bows in the upper Tigre area where water plants could possible be present. These should be able to spread after inundation of the area. There was no evidence of water hyacinth or other floating plants but this survey was done during the dry season and the swamp had dried up. A few herons were observed which indicates that fish are almost certainly present in the swampy area. Even observations made when walking along the river bank did not provide evidence that water hyacinth of other plants were in the water. Water plants such as Typha and Montrichardia which are found in the middle and lower courses of the Surinam rivers were not observed on the Sinú. However, water hyacinth and aquatic plants have been observed by mr. German Galvis in the Alto Sinú area. In comparison with the Brokopondo situation, where there is little or no growth of submerged water plants, it is possible that plants such as Hydrilla or Althernantheria will grow on the Sinú. In general the conditions for the development of roots are more favourable in this area than in the Brokopondo area because the water contains more nutrients, more light can penetrate once the sediment has settled and plants can root in the subsoil in the shallow parts of the lake.

During the first year of impoundment, large mats of filamentous algae may well develop in the Sinú reservoir as developed in the Brokopondo reservoir. The algae were activated by the high level of illumination, nutrients and dissolved organic matter, especially in secluded places between trees in the bays. Stigeoclonium has been observed attached to rocks in the Sinú. The bocachico feed on this algae. Area of high oversaturation of oxygen are produced in these mats of thread algae while the immediately surrounding area is depleted of oxygen. These mats and also floating duckweeds disappear after heavy rain as a result of the mechanical action of the rain. During the wet season regrowth of the algae is hindered because of the overcast conditions and as a result large amounts of phosphorus and nitorgen are transmitted to the water. These amounts are, however, very small when compared to the amounts of nutrients and dissolved organic matter produced by decaying forest leaves at the same time.

Thread algae will also develop on dead trees and other substrate where sufficient light can penetrate the water. In addition worms, crustaceans and insects will develop among the algae threads as a food for fish in the reservoir.

4.6 Influence of man

Before inundation there were several villages along the Surinam river with a total of about 1400 bush negroes, who were resettled after inundation of the region. The influence of these people on the quality of the water was negligible as they considered the river to be sacred. As they cultivated the land inland from the river their activities also had little effect on the quality of the water. In the lower Sinú the land is used for cultivation and grazing. Pollution of the water, measured in terms of coli counts is reasonably high, especially near the towns. The coli counts were also relatively high in water samples taken from the upper Sinú. This may be caused by pollution in some of the upper tributaries of the Sinú where the land is used for cultivation and grazing cattle. In the upper Sinú region there are few inhabitants and little of the area is cultivated. It is recommended that attention be given to the quality of the water of the proposed reservoirs, because of polluted water flowing into the reservoirs from upstream tributaries.

4.7 Inundated trees

Generally, soon after inundation the brown canopy of inundated dead highland forest can be observed in the lake. This forest is bordered by the still green canopies of forests along the former river course as the latter are adapted to regular inundation during wet season. Soon, however, these trees also die and loose their leaves. Sunlight can then penetrate the water surface and also more wind can strike the surface. In the Brokopondo reservoir, the softwoods were the first trees to break down. The trunks of trees were observed submerged or floating in the water. Many trunks were blown to wind sheltered places. The softwoods were also attacked by insects and the wood bleached by the sun. The trunks of the hardwoods remained above the water but deprived of the smaller branches. Even though the trunks are being continually eroded by the mechanical action of the water and by the process of oxydation. The trunks of hardwoods can still be seen just under the surface of the water in lake Gatun in Panama, which was impounded in 1914. However, these trunks hamper navigation and water circulation. The bleached trees in the Brokopondo Reservoir provide a sinister image. The only visible living creatures are spiders; there is no bird life. The unattractive scenery of these dead trees may be sufficient reason for the removal.

The contribution of the trunks of remaining trees to the nutrients in the water may be considered to be of little significance during the first phase after inundation compared to contribution made by the mineralization of leaves. Thus after the leaves of the drowned forest have rotted the trunks of hardwoods may contribute very little to the quality of the water in the future Sinú reservoirs which will be largely determined by the bottom layers of the reservoirs and by the inflowing water from the rivers.

4.8 Effect of the quality of the water on plant life

Whether the trees are removed or not, the lake will go through a saprobic phase, during which the dead organic matter will be mineralized. This has occurred in the Brokopondo reservoir. After impoundment, the original community of river plankton changed and most species sank to the bottom because the water stagnated. Other species such as green algae and desmids produced oxygen in the photic layers, and also rotifers and crustacears flourished. When the lake filled up this green wave could be followed moving from the dam in the direction of the influent rivers. Later, when the water level stabilized, the plankton community also stabilized, indicating that the first vigorous oxygen consuming- and oxygen producing phase, characteristic of the saprobic surface layers, had come to an end. This occurred in the Brokopondo reservoir after about 8 years. As the volume of each of the proposed Sinú reservoirs will be smaller than of the Brokopondo reservoir biologically these reservoirs will stabilize sooner. However, the effect of the saprobic processes, which end in a phase of eutrophy or oligotrophy after mineralization of the saprobic substances, will not be the same as in the Brokopondo reservoir. As already mentioned, the natural character of the water in the lake will be already eutrophic in terms of the concentrations of nutrients (Phosphorus and nitrogen). As a result of the activity of plankton organisms in the surface layers, the lake will go through a phase in which the concentration of nutrients is higher than can be expected under natural circumstances. The concentration of anorganic nutrients will temporarily excessively high. This can be defined as a hypertrophic phase and means that certain elements of green phytoplankton organisms will develop in large numbers, producing high oversaturation of oxygen during daylight while at night oxygen depletion will not occure nor will undersaturation. In a later phase, when there is an equilibrium between inflowing concentrations, autochthonic nutrients balance and outflow, a more normal meso-eutrophic situation may develop. In contrast to the situation in the Brokopondo reservoir, the characteristic components of plankton in each phase will probably not consist of desmids, which depend on lime-poor acid oligotrophic environment. Species adapted to disturbance will develop and there will be no desmids in the hypertrophic phase apart from green algae and probably also diatoms and blue-green algae. Development of biomass in the surface layers is not independent on the processes going on at lower levels in the water. There may be some mixing of the various layers in the reservoirs, which may cause death of plankton and also fish. In the Brokopondo reservoir during the saprobic phase many fish died and fish were also observed in the early morning coming to the surface for air. This was no longer observed when the level of the lake rose, probably because the fish could escape into the tributaries which feed into the lake. Catches of fishes in the tributaries by the bush negroes were very good at this time. Below the dam all fish died, but later fish migrated from unaffected creeks. To what extent this will occur in the lower Sinú will depend largely of the quality of the water after filling the lake. The facts that the lower Sinú is much longer than the lower Surinam and that there are no ox-bows and cienagas in the Surinam must also be taken into consideration. This will probably mean that the water will improve in quality before it reaches the lower course. Thus, in contrast to the Surinam river, there may be only a small stretch of the Sinú river in which the water is of poor quality, and which may disappear before the fresh water tidal zone is reached.

4.9 Effect of inundation on fish life

Fish are abundant in the Surinam river in spite of the oligotrophic character of the water. Most species are carnivorous although a few live on insects, fruits and organic debris which fall into the water. The main species are Characidae and Silurioidea (catfish) and Serrasalmidae (pireng). Little is known about the biology of many of the species. No measures were taken to prevent the dam becoming a barrier to the migration of fish. The diversity of species in the reservoir compared to the diversity of species found in the river decreased. Two species, Chichla ocellaris and Serrasalmus rhombeus, however, became abundant. Many species of fish have been recorded in the Sinú river system, of which 8 species are endemic. The bocachico (Prochilodus reticulatus magdalenae) which is the fish eaten mostly by the local people enters the Sinú river in the dry season in order to spawn in the tributaries. During wet season the floating eggs and fish larvae are transported down the river and reenter the cienagas. The quality of the water after the construction of the dam will clearly influence the behaviour pattern of the bocachico. For this it is important to remember that fish, in general, are conservative in the choice of migratory routes to spawning places. However, it is not known to what extent the tiver course is used by the bocachico. Regardless of the quality of the water, it may well be that the remaining river course below the dam will be sufficient for their needs. Isolated populations of fish present in the Manso river may enter the future Sinú river reservoir and spawn in the influent rivers of the lake. The dorada (Brycon moori sinuensis) is an example of a predator species which lives in the deeper waters of the cienagas and spawns in the river in the dry season. Its migration is more restricted than that of the bocachico. In order to maintain both these species communication between the cienagas and the river should be allowed to remain open at least during migration periods. The migration of the Tarpon which also occur in the Surinam river is probably not hindered by the dam. Fish migrate from the sea into the Surinam river, but not as far as the dam and this will probably also be the case with the Sinú river which is longer. The construction of the dam will also endanger other species of fish in the Sinú river system. Apart from the results of the analysis of stomach contents no data are available on the food habits of fish. It is recommended that benthic organisms in the river are analyzed in this regard.

4.10 Clearance of the vegetation and the quality of the water

As in Brokopondo reservoir the water in the future Alto Sinú reservoir will become stratified and the quality of the water will be affected and this in turn will affect the basin as an environment for aquatic organisms. There is

no doubt that optimal management and use of a man-made lake could be achieved if all obstacles under water which may restrict the circulation of water were removed before the basin is filled. However, from experience it is impossible, especially in the large tropical reservoirs, to obtain a smooth profile at the bottom of a lake adequate for good water circulation and oxygenation of the water. Oxygenation of the water is largely dependent on the chemical and biological quality of the water to be impounded.
In comparison with the situation in the Brokopondo reservoir, there is more time before the dam will be in operation (1988) to consider the effect of the dam on the environment. This means that more time is available for the preparation of inventories of the little known flora and fauna in the area. In addition, more time will be available for either total or partial clearance of the vegetation should this be required. As has already been mentioned, total clearance would be preferable for most aspects such as the quality of the water, fisheries, navigation. In the Brokopondo reservoir and also the new Kabalebo project total clearance has also been considered. For the Brokopondo project it was concluded that the costs of clearing the area were far too high and only the economically valuable trees were removed. These were relatively few in comparison to those left. With the Kabalebo project, proposals have been made to remove the economically valuable trees only. There have also been discussion about the effect of clearfelling the area. It is not certain what will happen if areas along the Kabalebo rivers are completely cleared of trees. It could be expected that the denuded soils will be washed away during the heavy rain and this will affect the quality of the water downstream. It also is thought that after impoundment, the fluctuations of the water level would be so great that considerable surfaces of the soil would become temporarily dry. On the other hand, any regrowth in vegetation before the rise in the water level would also have an effect on the quality of the water. As yet no decision has been made. The same problem exists with the Alto Sinú Project. It may well be possible to remove the trees. Consideration must also be given in the Urra I and in the Esmeralda section of Urra II to the erosion of the soil by heavy rain. However, as opposed to the Surinam situation on the river, the soil here is alluvial and more fertile, and as a result regrowth of vegetation will occur before the dam is finished, which will reduce erosion. After impoundment, the variation in water level will be only about 50 cm* which will not greatly affect

* the yearly fluctuation may reach 20 - 30 m.

the river bank. Therefore if the soil is favourable to regrowth, this section could be cleared, assuming that fluctuations of water level after impoundment are not extreme. In the authors opinion, regrowth of vegetation on the laterite soils in the Brokopondo area was very slow after clearfelling of the trees. It took several years before some regrowth of vegetation occurred. This is also known to be the case on the laterite soils of the Amazon forest, where removal of the forest is irreversible and gives rise to severe erosion.

Thus in the Sinú area, regrowth of vegetation on the laterite soils may also occur very slowly. If this is the case, then clearfelling of areas of laterite soil may be feasible. On the other hand, the trees could be allowed to remain and then it should be accepted that after impoundment there will be a relatively long period when the quality of the water (saproby-hypertrophy) will be poor. This will be followed by a period in which the rotting ceases and the predominant environmental characteristics of the lake will reach equilibrium. This will occur wether or not the trees remain and will make no difference to the quality of the water. The Brokopondo reservoir has lost its saprobic-hypertrophic character and finally, with the dead trees still under the water, the quality of the water has reached equilibrium with the oligotrophic character of the surrounding forest and the influent oligotrophic river and creeks. This equilibrium has taken decades to achieve, however the effect of stratification has not been taken into consideration here.

4.11 Ultimate quality of the water in the reservoirs

It has already been mentioned, as with many tropical lakes, the Sinú reservoirs will be thermally stratified. The dynamics of this depend on heat adsorption at the surface layers during the day and cooling at night, and the action of the wind to mix the various layers. In the tropics the diurnal cycle extends depth of about 3 to 4 meters, depending on several factors such as air temperature, water colour, daily variation in temperature. While in more temperate areas wind is effective in mixing the various layers, there is often little wind in tropical rainforest areas. When a lake is situated in a wind sheltered position the thermoclime will not extend deep into the water. The depth of the thermocline depends on the duration of the wind action and the extend of the surface area of the lake affected by the wind action. Thus if the wind blows constantly over the entire length of a lake the thermocline will extend deep into the water and a deep epiliminon will form; on the other hand, if the wind blows only over a small area of the lake, the thermocline will not extend deep into the water. The shape of the basin also affects the rate of which the thermocline is formed. Once the thermocline has formed, reaeration of the hypolimnic water will be hampered by covering of the superficial layers. Oxygen will be depleted in the hypolimnion in waters rich in nutrients. This is caused not only by dead plankton organisms and excrements settling down in the deeper layers, but also by decomposable organic matter on the bottom and by the oxygen demand of the bottom layer itself. In Amazonian oligotrophic lakes, the sediment in the hypolimnion consists of a mineralized ooze of diatomsilicates and sponge needles. This is brought about by the high temperature in the hypolimnion. The organic matter will be mineralized on its way to the bottom. This also may happen in the relatively deep waters of the Urra I and II reservoirs 60 and 150m depth respectively near the dam. However the (eutrophic) plankton biomass will not be mineralized totally after sedimentation as the oxygen capacity of the hypolimnion will not be sufficient for that. In Urra I, the short retention time of the water may reduce the extent of oxygen depletion because oxygenated water from elsewhere will be added to the hypolimnion. In this regard, it may be useful to clear the vegetation along the Esmeralda section of Urra II in order to improve the flow of water through Urra I and Esmeralda river.

Apart from this mechanism of oxygen consumption by dead plankton, in humic rich Amazonian and Surinam rivers other oxygen - consuming mechanisms come into action as soon the water stagnates. In the flowing river water is aeriated from top to bottom but soon after stagnation most of the oxygen is probably absorbed by dissolved humic substances. The vigorous consumption of oxygen in this type of water, therefore, is not totally due to decaying organic matter of dead plankton because under natural conditions the total amounts are usually very low. It is difficult to predict how this process will develop in the Sinú reservoir, as nothing is known of the plankton biomass which may develop and of the amount of dissolved humic substances which could be expected. As the water will be eutrophic it should be expected that plankton will cause considerable oxygen depletion in the hypolimion resulting in an anaerobic hypolimnion. This has occurred in the Brokopondo reservoir but as the result of other processes.

Thus in conclusion, the quality of the water in the Urra reservoirs should be compared to eutrophic lakes in tropical areas and not compared to tropical oligotrophic lakes such as Brokopondo reservoir.

5 ANSWERS TO SPECIFIC QUESTIONS POSED BY GOMEZ, CAJIAO Y ASOCIADOS LTDA

5.1 Should we clear the reservoir? If so to what extent? What effect could regrowth have?

The question of clearing the areas for the reservoir has already been discussed (chapter 4.10). In summary, the following points are made.

a. There are a considerable number of years in which to organize the actual clearing of the area.

b. The reservoirs and the lower Sinú will pass through a phase of saprobity and hypertrophy, which could be reduced in proportion to the amount of biomass removed.

c. After the various environmental factors have reached a state of equilibrium, the quality of the water will be the same whether the biomass has been removed or not. It is estimated that this state of equilibrium will take about 10 years to achieve.

d. Removal of trees in the deep parts of the lake will not provide sufficient light for the growth of submerged water plants, nor will the removal of these trees allow for sufficient oxygen at the bottom of the lake to favour colonization of bottom fauna and related fish fauna even if there is temporary depletion of oxygen.

e. Standing trees under water are obstacles to water circulation. Any movement or flow of water will follow the former river courses to the dam site. Water will stagnate in all other parts of the flooded area including shallow bays.

f. Trees emerging from the water will be bleached by the sun and attacked by insects and will break down finally at the waterline. This will be especially the case with softwoods, but, many hardwoods will remain for centuries even under water. In Brokopondo and Gatun reservoirs, the remaining trees hamper navigation and the development of fisheries and have made recreational activities on the reservoirs unattractive.

g. Trees under water may become a substrate for the growth of algae where the light can penetrate the water. Trees may also become a substrate for other fish food, such as worms and crustaceans.

h. After leaching out, the tree trunks will not significantly influence the quality of the water, but trees will contribute to the stagnation of water which in turn will contribute to the depletion of oxygen.

Thus, it would appear that the only positive reason for not clearing the trees in the area of the proposed reservoirs is that they may form a substrate for the growth of algae. However, assuming that most trees will eventually sink to the bottom of the reservoir, this does not seem to be sufficient reason for allowing them to remain. All other factors mentioned above are in favour of clearing the trees from the sites of the reservoirs. While the saprobic phase in the reservoirs could be minimized by removing as much as possible of the vegetation, the amount of vegetation to be removed is largely determined by the cost and physical exertion involved. Although the benefit of clearing the vegetation will be countered to some extent by the effect of regrowth before inundation occurs, this will be far less than if the original forest is allowed to remain. The degree of regrowth depends on the fertility of the soil. On lateritic soils, deforestation is irreversible and regrowth of vegetation will be very slow as has been the experience at Brokopondo. Further, as erosion is likely to occur more rapidly on soils without vegetation, it is recommended that areas of lateritic soils are selected for clearance. At present insufficient data are available on the location and extent of lateric soils in the Sinú basin.
A further reason for restricting the clearance of trees is the effect this will have on the hydrology. To ensure a good flow of water through Urra I, trees on the site of the reservoir should be removed and also along the section of the Esmeralda to be flooded. Extreme fluctuations in water level in the reservoir should be avoided (see Chapter 4.10). Finally, if the trees are not removed, it must be accepted that the reservoir and also the river downstream from the dam will pass through a phase of saprobity. Damage which may occur downstream must be weighed against the long-term benefit of the hydroelectric project.

5.2 Which would be the best clearing method? What would be the effect of burning ??

In relation to cost aspects the Clearing Report Corelco, Urra II Project (1982) prepared by Estudios Technicos:

1. cut/remove trees $>$10 cm diameter and $>$2 m high with road construction;
2. cut/remove all trees and shrubs, trees $>$3 m high no road construction;
3. cut/remove all trees and shrubs, trees $>$3 m high and burn at the spot;
4. cut/remove all commercial timber $>$ 40 cm diameter;
5. cut/remove all trees $>$ 40 cm diameter, burn at the spot.

From the point of view of ecological management, the first two proposals appear to be the best. However, when consideration is given to the cost of clearing the area, the second proposal of felling all trees and shrubs $>$ 3 m without the construction of roads appears to be preferable. Burning the trees on the spot, as put forward in the remaining proposals, is not recommended. Ash will not improve the quality of the water. It will be necessary to transport the felled trees and shrubs to a site downstream from the proposed reservoir for burning.

In addition, it should be mentioned that rainforest does not burn easily, and burnt stumps and even tree trunks will remain. Thus burning the felled vegetation will be less effective than cutting and removing it. Burning was not considered to be feasible on the site of the Brokopondo reservoir. One advantage of burning may be that the remaining trunks and stumps will not be subject to the process of rotting as the organic matter will be mineralized in the proces of burning. The secondary effect, however, will be eutrophication as the minerals give rise to secondary production of biomass in the water. This will affect the quality of the water after inundation, as secondary decay of organic matter will give rise to saprobity. This may be less than if the vegetation is not burnt.

5.3 What percentage of the total vegetative biomass is decomposable under water?

It is not possible accurately to predict what percentage of the biomass is decomposable under water without adequate data on the various aspects of the forest. Thus, as insufficient data are available on the rainforest in the Sinú area, this question can only be answered in general terms.
After the drowning of a forest, the easily biodegradable substances from leave cells produce a high biological oxygen demand (B.O.D.). Humic substances also contribute to this. The wood of trees and shrubs decays slowly. While the trunks of softwoods are subject to slow decay, the hardwoods are even more resistent.

The process of decaying is anaerobic in the hypolimnion, and aerobic in the epilimnion. Most of the decaying process takes place in the hypolimnion. Mineralization occurs at the high temperatures and is intense and quick. Bacterial action is slow in acid waters. There are no extensive peat formations in tropical rainforest areas, and the humic layers are thin. In comparison with the Brokopondo reservoir, the acidity in the Sinú reservoir

may be not as high and as a result decomposition may be quicker.
As the leaves of shrubs and trees will form the greatest part of decomposable matter, removal of leaves before inundation would be preferable.
This has been done in smaller reservoirs in temperate regions where the vegetation is not as dense as the Sinú area. However, here it is not a practical consideration as it would be impossible to remove the crowns of the trees and transport them to an area some distance away from the proposed reservoirs.

5.4 What could be expected with respect to water quality? Would the reservoirs stratify thermally? If so, how permanent would the stratification be? What would be the tickness of the epilimnion? What are the physical - chemical characteristics of this upper stratum in relation to the hypolimnion?

In comparison to the Surinam rivers, the water in the Sinú and its tributaries contains higher concentrations of solids and a number of elements, especially phosphate and nitrats, and the total electrolytes measured as conductivity is 4 or 5 times greater. This is typical of the White Waters of the Andes. The water in the rivers of the lower Amazon basin and the Guyana Shield is more acid and very low in electrolytes. Thus, impoundment of the water of the Sinú will produce other chemical effects than have been observed in Brokopondo reservoir. The water in the Sinú reservoirs will be more eutrophic, and the biota will be affected by this. It is necessary to have a hydrological balance. The quality of the water is determined by the discharge of inflowing rivers and by the effective difference between precipitation and evaporation over the total surface area of the lake. Rain may dilute the epilimnion and thus reduce the level of eutrophy in the lake.
Stratification occurs in both tropical lakes and lakes in temperate regions. In tropical areas because temperature is high only a few degrees variation in temperature can cause great differences in density of the water. The difference in temperature between the epilimnion and hypolimnion will be only a few degrees. The temperature of the upper Sinú has been estimated to be about 24-26°C, and the temperature in the Sinú reservoirs may be about 30°C. It is also to be expected that the water of the Sinú will become more transparant as sediments settle after stagnation. Less heat may be absorbed from the sun than in the Brokopondo reservoir as the water there is brown in colour because of the humic content.
The depth of the epilimnion will depend on the amount of radiation, intake

and outlet of water, and wind. At the time of filling, the Brokopondo reservoir was permanently stratified to a depth of about 5 m. After the reservoir was filled stratification only occured in the dry season, and because of the winds in the wet season destratification occurred. This destratification or mixing up must also be considered in relation to the gradually warming up of the deep hypolimnion water. As a result, there is less difference in temperature between epilimnion and hypolimnion, and thus less energy is required for mixing the layers by the wind. It may be expected that the same sequence of events will occur in the Sinú reservoirs.

In the Sinú area, dry season is short (December-April) and is followed by a long wet season. The average yearly air temperature is rather constant at about 27.5°C, but the diurnal variation in temperature can be as much as 10°C. This will affect the thermocline. In dry season mixing of the layers will depend on the intervals between rain showers accompanied by wind action.

The diurnal variation in air temperature will affect the density distribution of vertical layers, which may extend to a greater depth than in the Brokopondo reservoir. It is advisable to compare the thermocline in existing reservoirs in the Andean region of Colombia. It can be assumed that the Sinú reservoirs will be eutrophic and that a rich phytoplankton will develop in the epilimnion, which will produce oxygen oversaturations. After destratification, the oxygen will be mixed in the deeper layers. This will also occur continiously because the inflowing water from the rivers will be well oxygenated. The pH in the epilimnion will vary daily as a result of the assimilatory activity of phytoplankton and may be as high as 9 or 10, while the pH of the hypolimnion will be about 7 or below.The depth and shape of the two proposed reservoirs are such that depth of the thermocline in each may well extend to 15 metres. The actual depth of the thermocline will also depend on wind action and currents. Urra I will be very deep (about 60 m) and will be V-shaped. This may favour the development of a permanent and thick hypolimnion as occurs in deep lake with relatively small surface areas. The chemical concentrations of electrolytes in the hypolimnion will increase towards the bottom. In addition, chemicals from the soil and sediments will go in solution. The chemical concentrations will not influence the thermal stratification. In the epilimnion, the primary producents will use the nutrients in the water, and as a result the levels of phosphate and nitrogen will probably lower than at present in the upper reaches of the Sinú and its tributaries. On the other hand, the total biomass of plankton will be greater compared to the rivers. Thus it will be advisable to locate the intake of water in the epilimnic layer, in order to avoid discharge of anaerobic water with high amounts of nutrients in the lower Sinú.

5.5 <u>From a water quality point of view, would it be advisable to built fish passage ways for the migratory species? Would the probable water quality interfere with this remedial measure?</u>

There are many species of fish in the Sinú river and its tributaries. In general, the presence of fish is a useful indicator of the quality of the water. It is also of direct interest to man for food and also for commercial and recreational purposes. Thus, it is important to find out as much as possible about the biology and behaviour of the important species. Draft Final Report (1981) prepared by Dames & Moore reviews the species present and special attention is given to their migratory behaviour. Reference is made to data collected by Mr. German Galvis, Universidad Nacional Bogotá, from interviews with fishermen.

It is not possible to answer the question whether fish passageways should be constructed in the dams, because insufficient information is available on the migratory behaviour of fish and the exact location of spawning places. It has been recorded that bocachico spawn on rocky substrate anywhere in the Sinú. They do not appear to select special places for spawning and yet they migrate for spawning in the Sinú as far as the are around Tierralta. If this is the case, then there is no need to construct passageways in the dam for this population of bocachico. Other species and populations may spawn in the upper reaches of the Sinú, but at present little is known of their migratory behaviour. It has also been reported that a population of bocachico spawns in the upper Manso. Thus it would seem that the construction of the dams will not present an obstacle to the migratory pattern of some fish. It also means that fish will be able to migrate into the future reservoirs and colonize it.

Fish in the future reservoirs will most probably be restricted to the epilimnic layers. This means that only pelagic species will live in the open water of the lake, while species which live on the bottom only will be found in a restricted area along the shores of the reservoirs. Before fish passage ways are constructed near the dam, the quality of the water must be considered. Release of hypolimnic water from the reservoir into the lower Sinú could be another obstacle. It is possible that the quality of the water not only in the reservoir but also below the dam will be such that fish will not migrate to the dam. This will depend to some extend on the management of the gates in respect to the amount and quality of water discharged from the reservoir.

On the other hand, it is well known that fish in search of spawning places are very active and the quality of the water is of little consequence to them. Thus, they may well use the passageways into the dam even if quality of the water is not optimal. Insufficient data are available on the factors governing the quality of the water, especially oxygen levels, to adequately assess to what extend the quality would interfere with the use made of fish passageways by migrating fish. Further, it is not possible to give a definitive answer to the question of the construction of fish passageways because the migratory patterns of fish living in the rivers are not known. Some species go through their entire life cycle above the dam. Perhaps it may be feasible to trap fish in the river below the dam and transport them in containers to the lake for spawning. The young fish could then be transported passively through the spillways. On the other hand, the reservoirs could be artificial stocked with fish.

5.6 Could a fishery resource be developed in the reservoir? What measures would have to be implemented?

In the Sinú reservoirs, a natural fish stock will develop after the reservoirs have passed through the phase of saproby and hypertrophy. It is worthwhile citing the sequence of events which occured in the Volta reservoirs in North-west Africa. Some years after filling, large catches of fish were obttained from the lake which attracted many fishermen, but some years later catches declined thus depriving fishermen of their livelihood. Studies were undertaken to find ways of improving the situation. It was found that in the first few years after filling the hypertrophic situation in the water provided abundant food for fish. Later, when natural equilibrium had been reached on a lower trophic level the number of fish decreased. It is most probable that the same sequence of events will occur in the Sinú reservoirs. It appears that fisheries could be developed in the Sinú reservoirs, however the opinion of a fisheries expert should also be obtained on this matter. The reservoirs will need to be adapted to the requirements of the fish species and to methods of fishing. More data are required on the life cycles and migratory patterns of species.

If the trees are to remain under water, it may well be advisable to clear fish lanes for net fishing. Electric fishing and use of poison will not be hindered by the trees. These methods should be considered on their merits.

5.7 What could be the effect of water weed growth? Should any special measures be taken?

As far as is known, floating water plants such as the water hyacinth have not been observed in the Sinú. If present, it is possible that these plants could cover large areas of the water surface of the reservoirs after stagnation of the water. The covering mat of plants will insulate the underlying water from the air and as a result oxygen depletion will occur. Many insects larvae, fish larvae, snails and crustaceans will live in and between the plants. In addition, fish, frogs and snakes will also live on the plants. Such a community of the floating plants would be beneficial to life in the lake, but growth must be restricted to islands and should not extend to closed fields, which is an aspect of undesirable hypertrophy. Thus the optimum growth of floating plants would be such that it is possible to navigate anywhere on the reservoir without being hampered by these plants.

If the development of floating plants is vigorous, control measures should be undertaken. The plants could be harvested and used as manure, or burnt some distance away from the reservoirs. In addition, biological control by means of herbivorous fish and the introduction of insects could be investigated. It was recommended that floating water hyacinth upstream from the Brokopondo reservoir should be removed. This could have been done easily by the methods mentioned above. Unfortunately, this was not done and the vigorous growth of water hyacinth was finally brought under control at considerable expense. It is also necessary to control the growth of floating plants because of the problem of disease. These plants are potential breeding places for the larvae of malaria mosquitoes and also snails which are a source of schistosomiasis parasites. Malaria control can be achieved by promoting fish which live on the larvae. Even though snails and schistosomiasis have not been recorded in the area, special attention should be paid to the presence of snail species in future inventories of flora and fauna. It may well be, that just as in Brokopondo area the snail vector is not present because the environment is unsuitable (acid, lime-poor water). In addition, as with the Brokopondo reservoir, these reservoirs are situated inland and few people live along the shores.

Little is known about the species of submerged water plants in the Sinú area. The usefulness and control of such plants is similar to floating plants.

It has already been mentioned that these submerged plants will only root in shallow water. In order to remove them it will be necessary to cut the plants under water. This can be done with the aid of mowing boats if trees do not obstruct.

The presence of water plants in the Sinú area has not been investigated. It may be expected that these plants are present in the Tigre area and are most likely to spread into the reservoirs. This will also probably be the case with other organisms and plankton which live in stagnant water. After impoundment, these species will replace the community which lives in the flowing water.

Another aspect of growth of water plants, especially floating plants, will be the effect on evapotranspiration. In comparison to the evaporation from a free-water surface, evaporation is much higher. It may become a significant factor in the water balance and management of the reservoirs. The amount of evaporation depends on temperature of the air, humidity and wind action, and has to be measured on the spot.

In conclusion, no special measures are required at present other than care and vigilance for the occurrence and introduction of species. An inventory of species is required.

Appendix I	Alto Sinú Hydroelectric Project (Dutch)
Appendix II	Description of the Hydroelectric Project (Spanish)
Appendix III	Physical, chemical and bacteriological characteristics of the Sinú river and its tributaries.

APPENDIX 1 ALTO SINÚ HYDROELECTRIC PROJECT Bezoek van 6-20 maart 1982,
Bogota, P. Leentvaar

Bij mijn bezoek aan het ingenieursbureau Gomez, Cajiao y As. te Bogota, Colombia werden mij de beschikbare gegevens van het project ter beschikking gesteld met de opdracht een report te schrijven over de implicaties van de bouw van de reservoirs (Urra I en II) op het milieu, zulks naar ervaringen opgedaan bij het Brokopondo project. Verder werden mij 7 vragen voorgelegd over deze problematiek ter beantwoording.

De gegevens die mij ter beschikking werden gesteld bestonden uit twee lijvige delen van het Draft Final Report Environmental Assessment of the Altu Sinú Hydroelectric Report van Dames & Moore, Washington; het technisch report: Centrales Urra 1, Urra II y desviacion del Rio San Jorge van de Corperacion Electrico de la Costa Atlantica (die eigenaar is van het project); het clearing report Corelco 1982 en chemische gegevens over 1981 van 11 monsterpunten van de Sinurivier. Ook stonden luchtfoto's van het gebied ter beschikking, terwijl op 11 maart met een helicopter over het gebied werd gevlogen. In verband met de veiligheid was er geen gelegenheid zelf excursies te organiseren.

Het is de bedoeling in dit verslag enkele aanvullende opmerkingen te vermelden, die niet in mijn report ter sprake komen.

In het Draft Final Report wordt in 6 secties ingegaan op technische gegevens, flora an fauna van het gebied, seismografie, hydrologie, prognose van het effect op de omgeving vóór, tijdens en na constructie van de reservoirs; dierenreddingsactie (John Walsh); de invloed op de benedenloop van de Sinú e.d. Wat me opviel in dit report is dat veel werd geinterpreteerd naar de Brokopondo situatie, terwijl we hier te maken hebben met de zgn White Waters van de Andes die anders zijn dan de Brown Waters van Suriname en Amazone. Ook bleek men vrijwel geen gegevens te hebben over de flora en fauna van het gebied, maar werd een opsomming gegeven van diersoorten en bomen die algemeen in tropische regenwouden te vinden zijn. Conclusies stonden daarom nogal op losse schroeven. Het Draft Final Report is nog niet in de publiciteit gegeven. Ik kreeg een copie van section 3: Baseline Environment mee. Van het technische report kreeg ik alleen Capitulo II, Description del Proyecto mee. Het Clearing Report van Corelco kreeg ik ter inzage. Aangezien in mijn report de cases 1 t/m 5 worden genoemd laat ik deze cases hieronder volgen.

Clearing Report Corelca - cases for clearing:

1 cut/remove trees > 10 cm diameter and > 2 m high with road construction
2 cut/remove all trees and shrubs, trees > 3 m high no road construction
3 cut/remove all trees and shrubs, trees > 3 m high and burn at the spot
4 cut/remove all commercial timber > 40 cm diameter
5 cut/remove all trees > 40 cm diameter, burn at the spot

In mijn report wordt hier verder op ingegaan.

Het "doorspitten" van de diverse rapporten en de besprekingen met de milieu-ingenieur Camilo Garzon kostte een week tijd. Daarna werd een week tijd besteed aan het schrijven van mijn report. Op 11 maart werd 1 dag met een helicopter boven het Sinugebied gevlogen om een indruk te krijgen van flora en fauna. De Sinu rivier heeft in de bovenloop een aantal zijtakken: de Rio Verde, Manso, Esmeralda en Tigre. (zie bijgevoegde kaartjes). De Rio San Jorge stroomt naar het stroomgebied van de Rio Magdalena, maar zal worden afgeleid naar het stuwmeer. Opvallend was dat de Sinu een grijsgroene kleur had terwijl de andere meer bruinachtig water voerden. Hier en daar zag men hutten van indianen met grondjes bananen. Waterhyacinth of waterplanten werden niet gezien. Wel bleek dat een deel van het gebied, bij de oorsprong van de Tigre een lage vegetatie had, met hier en daar wat bomen. In dit moerassige gebied zag ik bruine reigers. Bij het kampement op de samen vloeiing van Rio Sinu en Esmeralda, werd van beide rivieren een planktonmonster genomen, waarin zich behalve veel detritus en erosiemateriaal een enkele diatomee bevond. Andere monsters werden genomen bij de toekomstige dam van Urra I en Urra II in de Sinu, dat weinig verschilde. Het bos langs de oevers vertoonde meer variatie in boomsoorten en ondergroei dan dat van de regio Brokopondo. Er werd een groep zwarte gieren waaronder een zwart-rood-witte gezien en er waren holen van krabben langs de oever. In het gebied waren weinig stroomversnellingen. Ik maakte ± 100 dia's vanuit de lucht.

Een bioloog van de Universiteit van Bogota bleek part time te werken voor Gomez. Hij had vissers langs de Sinu geinterviewd over de vangsten en migratie van vis. Met deze bioloog, German Garvis, kon ik van gedachte wisselen over de problematiek. Hij toonde foto's van de Sinu waarop duidelijk Eichhornia crassipes, Lemnaceae en Typha te zien waren. Deze kwamen voor in geisoleerde poelen verscholen onder de bomen. Indianen kappen balsa en andere bomen en planten bananen. De grond is zo vruchtbaar dat in 2 jaar balsa een stamdikte van 40 cm bereikt.

Tenslotte bracht ik een bezoek aan Jorge Hernández - Camacho van INDERENA (Instituto Nacional Desarrolo Resources Naturalis) te Bogota. Aan hem vroeg ik hoe het kon dat in een gebied dat tot nationaal park was verklaard een stuwmeerproject kon worden uitgevoerd. Op deze naieve vraag kreeg ik geen duidelijk antwoord. De overheid kan hier weinig aan doen en de waterkrachtcentrale is van nationale betekenis. Wat er voor flora en fauna in het gebied voorkwam was hem ook niet bekend, maar er zullen zeker endemen zijn, terwijl het gebied in een zone ligt waar de invloed van de centraal Amerikaanse flora en fauna en die van Zuid-Amerika elkaar ontmoeten. Gevraagd naar het voorkomen van slakken in verband met bilharzia (dat in Colombia niet voorkomt) legde hij verband met het voorkomen van krokodillen. Deze eten de slakken (Ampullaria, Pomacea). Uitroeien van de krokodillen heeft in Argentinie op het ogenblik geleid tot een explosie van Fasciola hepatica bij runderen, doordat de besmette slakken zijn toegenomen, die door de runderen belikt worden om het slijm. Met Hernandez werd afgesproken contact te onderhouden en uitwisseling van publicaties met het RIN te onderhouden. INDERENA tracht de bevolking met voorlichting begrip voor de natuur bij te brengen. Zo zag ik bv op de airport van Bogota een permanente stand van IDERENA met aquaria en lectuur.

APPENDIX II DESCRIPTION OF THE ALTO SINÚ HYDROELECTRIC PROJECT (SPANISH)

CAPITULO II

DESCRIPCION DEL PROYECTO

La presentación resumida de los principales componentes del Proyecto Hidroeléctrico del Alto Sinú tiene como objetivo permitir al lector interesado en los aspectos ambientales una visión completa del problema. Por lo tanto, la descripción que a continuación se hace no pretende ser exhaustiva sino sintética y complementaria.

El proyecto, uno de los desarrollos más grandes del país, actualmente se encuentra en etapa de diseño de las obras civiles principales y del equipo electromecánico y en etapa de construcción en lo relacionado con las vías de acceso. Comprende tres partes principales : La Central de Urrá I, la Central de Urrá II y la Desviación del Río San Jorge al embalse de Urrá II.

A. LOCALIZACION GEOGRAFICA

El proyecto del Alto Sinú está localizado al sur del Departamento de Córdoba, cerca de los límites con Antioquia (ver Figuras II-1 y II-2).

Urrá I es la central ubicada más aguas abajo y por esta razón es la que tiene mejores accesos actualmente. Se localiza en la Angostura de Urrá, unos 30 km al sur de la población de Tierralta y unos 9 km aguas abajo del caserío de Tucurá.

La Angostura de Urrá es una zona montañosa, cortada por el río Sinú en una longitud de 8 km, aproximadamente. Esta zona montañosa en sus dos extremos está limitada por dos valles aluviales, de los cuales el valle inferior es muy amplio y corresponde al Bajo Sinú. La cadena de montañas cruza el río normalmente, o sea que se extiende en el sentido Este-Oeste y tiene una altura de 250 metros sobre el nivel del mar. La topografía en la Angostura de Urrá es montañosa, con numerosas cañadas, no presenta escarpes abruptos, las divisorias de aguas son estrechas, el río no tiene playas notables en este trayecto y el cañón tiene forma de V amplia, con pendientes relativamente suaves.

Aguas arriba de la Angostura de Urrá se presenta una serie de valles estrechos hasta la desembocadura del Río Verde. A partir de este sitio, la topografía se vuelve cada vez más abrupta y en la desembocadura del Río Esmeralda al Río Sinú éste corre por un cañón estrecho. Esta fue la zona escogida para la ubicación del proyecto Urrá II.

El valle de los ríos Sinú, Manso y Tigre, que forma el embalse de

Urrá II, está separado del valle del Río San Jorge por un filo discontinuo de la serranía San Jerónimo, llamado Alto del Carmen, con cota máxima de 1 200 m sobre el nivel del mar.

El Río San Jorge, en la zona, corre por un valle en forma de V con pendientes moderadas, que se amplía a un valle aluvial plano, el cual continúa hasta su desembocadura en el Río Magdalena. El valle marca la zona límite para la ubicación de una presa de desviación, la cual se ubicó 1 km aguas abajo de la desembocadura del Río Mutatá, a unos 80 km aguas arriba de la población de Pica-Pica.

El filo divisorio entre los dos valles presenta una depresión natural, con cota mínima aproximada de 325, que permite desviar el San Jorge a Urrá II por canal abierto en las cotas altas o por túnel en las bajas.

B. CARACTERISTICAS DEL PROYECTO

Los datos generales del proyecto se encuentran resumidos en el Cuadro II-1 y su programa de construcción en la Figura II-3. El perfil esquemático del proyecto se ilustra en la Figura II-4 y a continuación se presentan las características principales de la Central de Urrá I, la Central de Urrá II, la Desviación del San Jorge y los Campamentos de Construcción.

PROGRAMA DE CONSTRUCCION
ALTO SINU

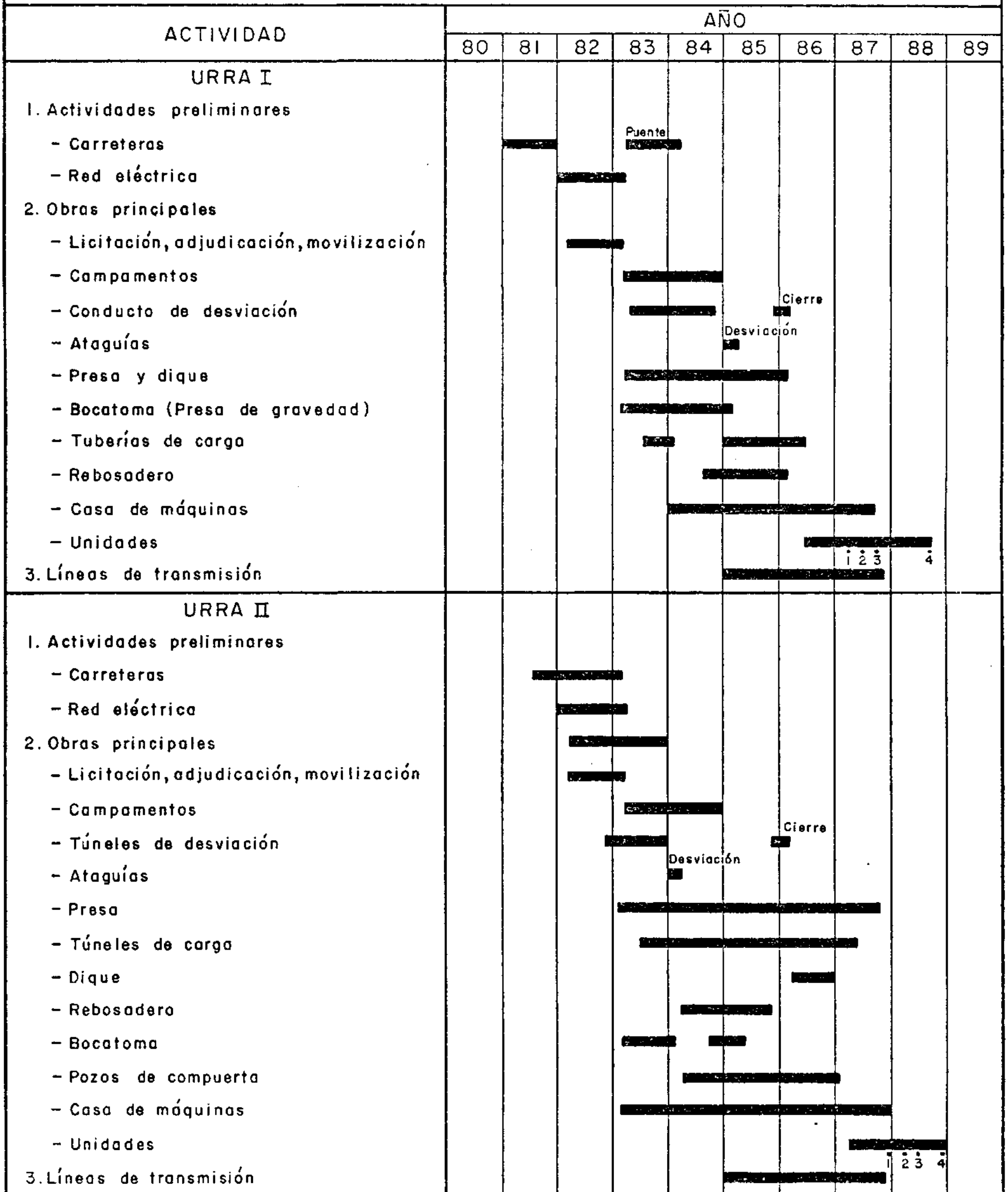


FIGURA: II-3

CUADRO II-1

CARACTERISTICAS PRINCIPALES

		PROYECTO URRA I	PROYECTO URRA II
DATOS GENERALES	Caudal de Diseño	713 m3/s	721 m3/s
	Salto Bruto Máximo	58 m	147 m
	Capacidad Instalada	340 MW	860 MW
	Capacidad Confiable	220 MW	560 MW
	Energía Firme	1 600 GW-H/año	3 400 GW-H/año
DATOS HIDROLOGICOS	Area de la Hoya Hidrográfica.	4 600 km2	2 600 km2
	Precipitación Media	2 500 mm a 3 500	2 500 mm a 4 300 mm
	Caudal Medio del Río.	352 m3/s	256 m3/s
	Creciente Máxima Probable con UrráII	5 250 m3/s	9 100 m3/s
EMBALSE	Area	62 km2	540 km2
	Volumen Total	1 500 Mm3	28 800 Mm3
	Volumen útil	1 000 Mm3	14 800 Mm3
	Nivel Máximo	Cota 123.5	Cota 270
	Nivel Mínimo	Cota 107.0	Cota 240
DESVIACION	Tipo	Conducto	Túnel
	Capacidad	675 m3/s	320 m3/s por túnel
	Longitud del Conducto.	344 m	279 m
	Dimensiones	7.10 x 4.50 m	6.00 m herradura
	Altura de la Ataguía	25 m	35.0 m
REBOSADERO	Capacidad	1 600 m3/s	1 000 m3/s
	Tipo	Flujo Libre sin Compuertas.	Flujo Libre sin Compuertas.
PRESA	Tipo	Gravas con Núcleo de Gravas Sucias	Conglomerado Terciario con Enrocado de Protección
	Altura Máxima	73 m	160 m
	Volumen	6 Mm3	22.5 Mm3
	Cota Cresta	136.0	275.0
CASA DE MAQUINAS	Tipo	Superficial	Superficial
	Pérdida Máxima de Carga	1.30 m	0.70
	Turbinas	4 tipo Francis de eje Vertical de 85 MW	4 Tipo Francis de 215 MW
	Generadores	4 de 90 MVA	4 de 235 MVA
CONDUCTOS DE CARGA	Tipo	Conducto	Túnel
	Longitud	140 m	410 m
	Diámetro Interior	6.5 m	5.5 - 6.5 m

1. La Central de Urrá I

Las obras principales del proyecto comprenden los conductos de desviación, la presa y el dique auxiliar, el vertedero, las obras de captación y conducción y la casa de máquinas (ver Figura II-5).

Las obras de desviación se construirán en la margen derecha del río y constan de los canales y estructuras de entrada y salida y de un conducto doble, de sección rectangular. Estas obras tendrán la capacidad suficiente para evacuar la mayor creciente que pueda presentarse una vez en 50 años, que sería de 2 600 m3/s. Los conductos son de 7.10 m x 4.50 m, y uno de los dos se taponará con concreto al finalizar la desviación. En el otro se instalarán, dentro de una cámara en forma de domo construída bajo la presa, dos compuertas deslizantes, una de ellas para operación y la otra de guarda, para habilitar el conducto como descarga de fondo del embalse. Se permite entonces un llenado controlado del embalse inmediatamente después del cierre de la desviación y se garantiza un caudal mínimo necesario en el río aguas abajo del proyecto, cuando no se esté generando (ver Figura II-6).

La presa se construirá al final de la Angostura de Urrá I en el sitio denominado Mano Vieja y estará conformada por un terraplén de 73 m de altura máxima y una longitud de 600 m; su ancho de corona será de 12 m y su volumen se ha estimado en 3.5 millones de metros cúbicos incluyendo la ataguía de aguas arriba. El material para su construcción se obtendrá de la zona de préstamo No. 5, que corresponde a terrazas aluviales antiguas del Río Sinú, las cuales se encuentran localizadas en la margen izquierda, 2 km aguas abajo del sitio de presa.

En la margen derecha y a continuación de la presa, se construirá un dique de altura máxima de 46 m y con una longitud de 430 m y un volumen de 2.5 millones de metros cúbicos.

El proyecto tendrá un rebosadero sin control, ubicado en la margen derecha con una capacidad que cumple con las condiciones impuestas por la creciente máxima probable, la cual tiene un pico de entrada de 5 250 m3/s.

La captación de las aguas se hará por medio de bocatomas independientes para cada una de las cuatro turbinas (ver Figura II-7).

La casa de máquinas será una estructura superficial de concreto, de tipo convencional, construída en la margen derecha del Río Sinú, a corta distancia aguas abajo de la presa. El agua proveniente de las turbinas descargará al río, a través de un canal de descarga a flujo libre.

Las cuatro unidades de generación serán de eje vertical y estarán constituídas cada una por una turbina tipo Francis, diseñada para generar 85 000 kW con una caída bruta nominal de 57.5 m, acoplada directamente a un generador de corriente alterna de tipo convencional. Por lo tanto, la capacidad instalada de la central en eje de turbinas será de 340 MW.

2. La Central de Urrá II

Las obras principales del proyecto, según se muestra en la Figura II-8, comprenden las obras de desviación, la presa y varios diques, el vertedero, las obras de captación y conducción, la casa de máquinas y obras anexas.

Las obras de desviación se construirán en la margen derecha del río y constan de las estructuras de entrada y salida y de dos túneles. Estas obras tendrán una capacidad de descarga capaz de evacuar una creciente máxima de entrada de 1 800 m3/seg que se presentaría una vez en 50 años dejando a salvo la cresta de la ataguía, cota 160.00 m s.n.m. El diámetro interior del tubo es de 6.00 y la sección es en herradura.

Uno de los túneles se taponará con concreto, al final de la desviación. En el otro se instalarán, dentro de una cámara subterránea construída para el efecto, dos pares de compuertas deslizantes, 2 de operación y 2 de servicio. Se habilita así el túnel como descarga de fondo y se facilita el llenado controlado del embalse al mismo tiempo que garantiza la descarga necesaria, cuando las máquinas de generación no estén operando.

La presa se construirá 5.3 km aguas abajo de la desembocadura del Río Esmeralda en el Sinú y 30 km aguas arriba del proyecto Urrá I. La altura máxima será de 175 m, con una longitud en la cresta de 1 700 m, su ancho de corona será de 12 m y su volumen estimado será del orden de 22 millones de metros cúbicos. Los materiales para su construcción provendrán de las zonas de préstamo No. 1 y 2, localizadas 3 km al suroeste y 4 km al noroeste del sitio de presa, respectivamente.

La captación de las aguas se hará a través de cuatro túneles independientes con rejas coladeras. El caudal de diseño para cada conducto es de 180 m3/seg (ver Figura II-9).

La casa de máquinas será superficial, de tipo convencional, construída a corta distancia aguas abajo de la presa en la margen derecha del Río Sinú. En ella se alojarán los grupos turbo-generadores con sus equipos auxiliares y la respectiva sala de montaje.

Las cuatro unidades serán de eje vertical constituídas cada una por turbina Francis, diseñadas para generar 215 000 kW con una caída neta nominal de 155.0 m, acoplada directamente al generador. Por lo tanto la capacidad instalada de la central en eje de turbinas es de 860 MW. Los transformadores quedarán localizados detrás de la casa de máquinas a la altura de la plazoleta de acceso.

3. La Desviación del San Jorge

La desviación del Río San Jorge al Sinú, tal como se pudo estudiar hasta diciembre de 1979, cuando por problemas de orden público fue necesario suspender dichos estudios, presenta dos alternativas. Los estudios de acuerdo con el programa de trabajo se podrán continuar tan pronto esté construída la vía de acceso al sitio teniendo en cuenta que por el volumen de las obras el plazo de ejecución es menor que para las centrales de Urrá I y Urrá II.

La primera alternativa incluye una presa de aproximadamente 70 m de altura máxima, localizada 40 km aguas arriba de la población de Juan José; un túnel de desviación durante la construcción alrededor de la presa, de 8 m de diámetro con sección de herradura y con capacidad de 600 m3/seg; un rebosadero lateral a la presa, en canal a tajo abierto controlado con compuertas, con descarga al cauce del río y con capacidad máxima de 2 250 m3/seg; y un canal de derivación de sección trapezoidal con 10 m de base, que conducirá el caudal del Río San Jorge a Urrá II. La capacidad nominal de este canal es de 90 m3/seg, teniendo en cuenta que el caudal medio del río en el sitio de proyecto, es de 53 m3/seg.

Dentro de esta alternativa se puede tener un esquema opcional, con un canal que conectaría los embalses del Río San Jorge y de Urrá II, de sección trapezoidal, con 25 m de base, a través del cual se desviaría hacia Urrá II el caudal total del Río San Jorge, y que sería además el rebosadero del proyecto.

La segunda alternativa incluye presas de pequeña altura sobre el Río San Jorge y la quebrada Virrivirri, tributaria por la margen izquierda, para formar dos pequeños embalses. En esta alternativa se aprovecha el 75% del área de la hoya que se aprovecha en la primera alternativa, pues se pierde el aporte de la quebrada Cañaveral.

Los embalses creados se interconectan mediante un canal a tajo abierto, con capacidad para la creciente máxima probable, estimada en 1 800 m3/seg. El canal que interconecta el embalse de la quebra da Virrivirri con el de Urrá II, tiene la misma localización y es similar al descrito en el de la variante a la primera alternativa.

Se considera que esta última alternativa es la más recomendable, al nivel de conocimiento actual.

4. Campamentos de Construcción

Para la construcción de las presas de Urrá I y Urrá II se han localizado tres campamentos, uno principal situado en el valle de Crucito y dos satélites cercanos a los frentes de trabajo.

El campamento de Crucito está a una distancia de 25 km de la presa de Urrá I y a 15 km de Urrá II. Se encuentra localizado el valle de Crucito a una altura de 190 m.s.n.m. y con una temperatura media de 24° C. Allí se ha localizado un campamento unificado y permanente que atenderá al personal profesional y técnico de Urrá I y Urrá II, además del personal obrero de Urrá II, tanto de la Interventoría como del Contratista.

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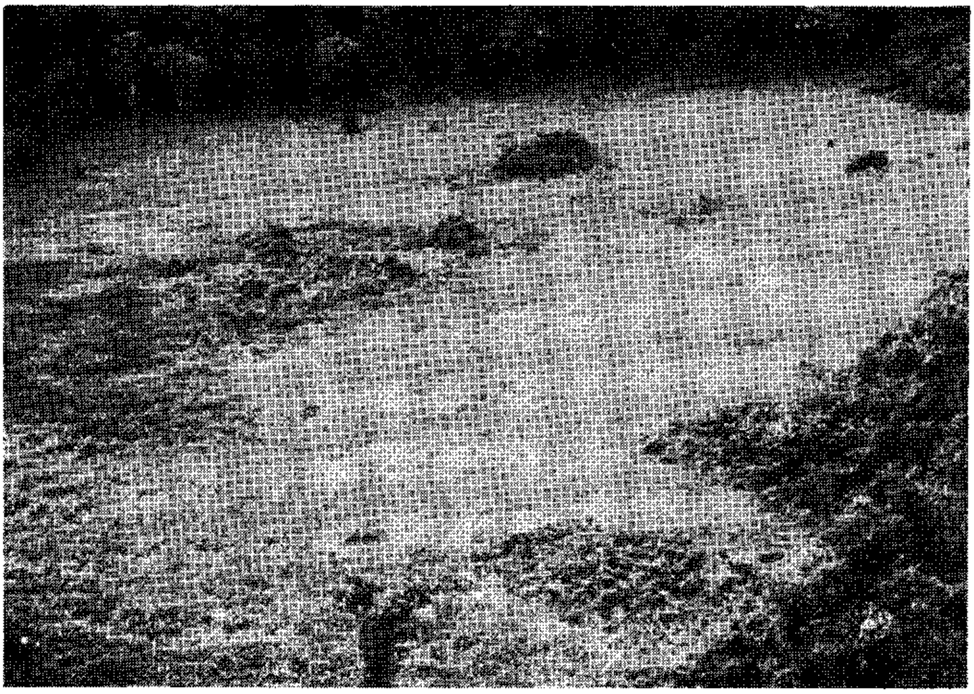
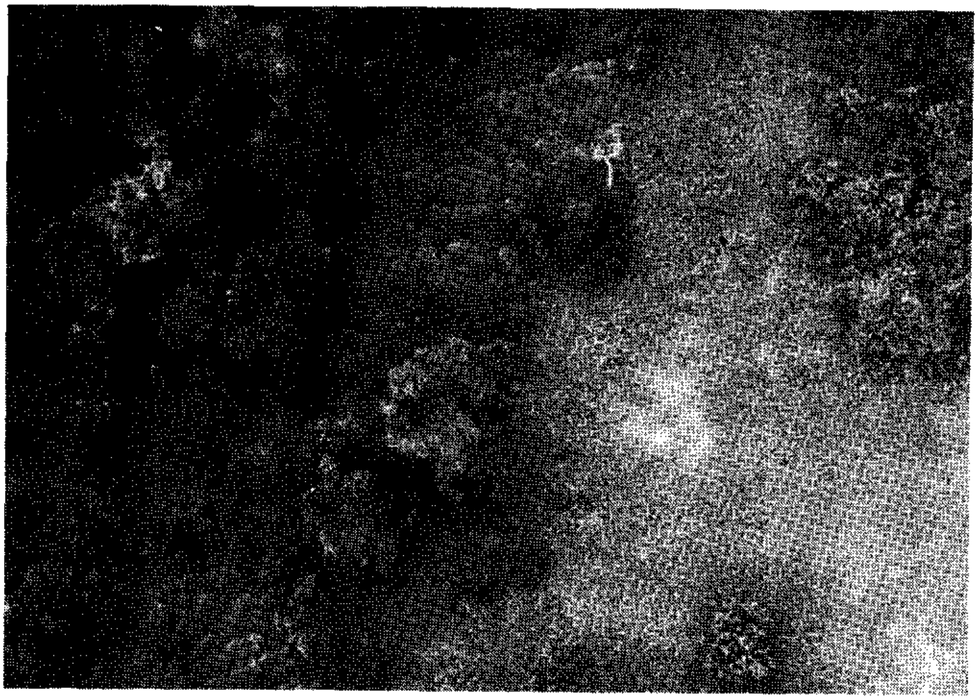
Oblique views of the tropical rain forest vegetation at the upper Sinú area. The vegetation in such areas has not yet been studied. The full species composition is therefore unknown. Tree species include probably *Cavanillesia plantanifolia* (cuipa), *Ceiba pentandra* (bonga).



Low oblique of the swamp vegetation (herbaceous, reedlike , with a few shrubs) covering parts of the upper Sinú river region (Tigre area) and its transition to the forest.

Meandering tributary of the Sinú in the forest.

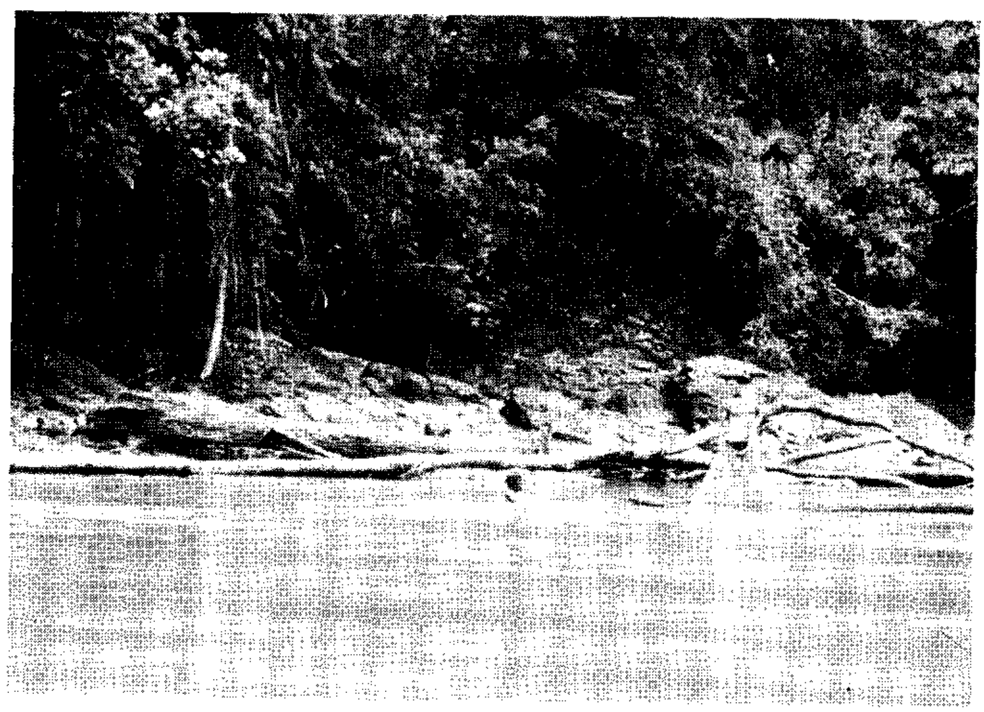


Virtually vertical aerial view of the vegetation at the Tigre area. Several distinct structural types can be distinguished, ranging from a dense (monospecific?) herbaceous cover (lower right) to species - and structurally rich forest at the higher places (upper left)

Aerial view (high oblique, tele-objective) of the vegetation at the Tigre area. In this swampy area the vegetation consists of a mosaic of dense, tall herbaceous (reedlike) vegetation and tall shrubs.

Confluence of the river Sinú (White Water) and the river Esmeralda (Brown Water). Note the differences in water colour, even visible at this black and white photograph.

Example of indian settlement (hut, cultivated plot and banana trees) as incidentally found along the river.



Natives fishing in the river Sinú.