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HYDROLOGIC INVESTIGATIONS IN THE ARAGUAIA-TOCANTINS RIVER BASIN (BRAZIL)

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HYDROLOGIC INVESTIGATIONS IN THE ARAGUAIA-TOCANTINS RIVER BASIN (BRAZIL)

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ABSTRACT

The Araguaia-Tocantins River basin system of central and northern Brazil drains an area of about 770,000 square kilometers and has the potential for supporting large-scale developments. During a short visit to the headquarters of the Interstate Commission for the Araguaia-Tocantins Valley and to several stream-gaging stations in June 1964, the author reviewed the status of the streamflow and meteorological data-collection programs in relation to the pressing needs of development project studies.

To provide data for areal and project-site studies and for main-stream sites, an initial network of 33 stream gaging stations was proposed, including the 7 stations then in operation. Suggestions were made in regard to operations staffing and equipment. Organizational responsibilities for operations were found to be divided uncertainly.

The Brazilian Meteorological Service had 15 synoptic stations in operation in and near the basin, some in need of reconditioning. Plans were at hand for the addition of 15 sites to the synoptic network and for limited data collection at 27 other sites. The author proposed collection of precipitation data at about 50 other locations to achieve a more representative areal distribution. Temperature, evaporation, and upper-air data sites were suggested to enhance the prospective hydrometeorological studies.

HYDROLOGIC INVESTIGATIONS IN THE ARAGUAIA-TOCANTINS RIVER BASIN [BRAZIL]

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by Leonard J. Snell

Introduction

The purpose of the visit to the headquarters of CIVAT (The Interstate Commission for the Araguaia-Tocantins Valley) was to review with CIVAT personnel the existing hydrologic program in the basin and to suggest a program to meet the needs of the studies for proposed large-scale developments in the basin.

The Commission was organized in 1962 and is composed of representatives from the States of Pará, Maranhão, Mato Grosso, Goiás, and the Federal District. The Commission visualizes the development of improved agriculture, large quantities of possible hydroelectric power, improvement of navigation, drainage of extensive marshy areas for agricultural use, and increased mining and industrial production in that large, relatively sparsely settled region. The basis for much of the development is the use and control of the water of the Araguaia and Tocantins Rivers and their tributaries, the discharge of which below Marabá, is estimated to be about 6000 m^3/s (210,000 cfs) or 190 billion cubic meters (150 million acre-feet) annually, which makes the Tocantins River one of the worlds largest and, at the present time, largely undeveloped.

Geography

The Araguaia-Tocantins River basin includes an area of about 770,000 square kilometers (300,000 sq miles) between latitudes 2° and 18° S. and longitudes 46° and 55° W. The length from the source of the Araguaia River, west of Goiânia, to the Bay of Marajo, at Belem, is more than 2200 kilometers (1500 miles). The valley averages about 500 kilometers (300 miles) in width above the confluence of the Araguaia and Tocantins Rivers near Marabá, about 500 kilometers from the mouth.

Topographically the area is generally relatively flat in the northern half with gently rolling to rugged hills in the higher regions; streams contain a large number of falls and rapids which range up to 20 meters in fall. Most of the area lies between 200 and 600 meters in elevation although in the extreme upstream areas the elevations exceed 1200 meters; the lowest 200 kilometers however are mostly braided tidal flats. The extensive marshy area of some 50,000 square kilometers along the Araguaia River at an elevation of nearly 300 meters is a distinct feature and is an area which may become good agricultural land if provided with drainage and flood control measures. [See Figure 5.]

Native vegetation and cover varies from relatively barren and grassy on extensive areas of thin soil cover in the uplands to the tropical rain forests in the lower reaches. In most of the basin the soils appear to be mainly recent alluvial deposits, but with massive outcroppings of rock formations which result in the numerous rapids and falls and are the apparent cause of the barriers to drainage such as on the Araguaia River.

The climate of the basin is tropical but varies from the tropical humid to almost temperate at higher elevations. A low pressure area in the interior of Brazil in summer when the sun's rays are most direct brings air masses from the northeast which result in high humidity and precipitation. In winter the air movements are largely from the east. Precipitation is almost all during the summer period and averages from 1500 to 2000 mm over most of the basin, but more than 2500 mm north of Marabá. There is practically no precipitation in June, July and August. The maximum observed precipitation in 24 hours in the basin was 125 mm at Belem on Mar. 13, 1931. (See Figure 1.)

Mean annual temperatures average from about 24°C to 26°C throughout the basin although daily and annual ranges vary considerably. In the lower part of the basin, where the humid tropical climate appears, the mean daily temperature varies less than 2°C, with the daily range about 9°C; the temperatures in the higher southern regions have daily and seasonal ranges even exceeding 20°C, with temperatures at places near freezing in winter and up to 40°C in summer. (See Figure 2.)

Relative humidity averages about 85% in the lower part of the basin to 65% in the southern regions.

Hydrologic Information

The enormous area under consideration, which is larger than many countries of the world, would require very extensive networks of streamflow, meteorological, and climatological stations if the development, population, and other factors required or permitted. In fact, most developed countries would have a total of more than a thousand rainfall stations and more than 300 streamflow stations in an area of that size. However, because of the sparseness of population, the absence of industry and agriculture to benefit from such data, and the difficulty of transportation and communications in much of the basin, very little data has been obtained in the past. Even at the present time it is probable that only the most necessary and the most reliable stations of the various networks should be undertaken. Data should first be obtained which will meet the greatest need in the planning of the developments now proposed and for some good general hydrologic data in the basin; the networks may then expand and fill gaps as sites become accessible and as personnel and equipment become available.

A French consulting organization, SCET (Societé Centrale pour L'Equipment du Territoire), has made a detailed soils and hydrologic study of the Alto Araguaia area and will submit a report (prepared in France) to CIVAT in July 1964. The group made reconnaissance trips throughout the basin, largely by air, to view vegetation, possible dam sites, and gaging station sites, and related information. They plan to prepare a suggested hydrological plan for the entire basin in addition to the individual "basin Studies" of Alto Araguaia, Farinha, and Alto Paraná River basins to which their studies were mainly oriented.

The network of streamflow station should consider the requirements for planning for the following water-use or water-control works:

- Hydroelectric power
- Irrigation
- Flood control
- Drainage
- Navigation
- Industrial and municipal use

Streamflow discharge data is required for the determination of the capacity and production of power at hydroelectric projects and the determination of spillway capacities. For irrigation studies or planning the data is needed to determine the amount of land which may be irrigated as well as for reservoir and spillway capacities. Flood control is based on the capacity of a channel to carry the water, the capacity of storage reservoirs to regulate the flow, and of their spillway capacities. The study of drainage requires knowledge of the inflow and outflow of water in the problem area. Navigation studies require discharge data throughout the reaches to be studied in order to learn the steps to be taken to improve depth of channel, or velocity, or other problems in certain reaches. For industrial and municipal requirements the amount and the quality of water need to be known.

In conjunction with river discharge and stage data it is necessary to know other characteristics of the rivers. The sediment discharge should be studied at important reservoir sites for the determination of silt storage requirements since silting of a reservoir will reduce the active capacity; sediment discharge data, and especially the heavier bed-load movement, is needed to study the formation and changes in sand and gravel bars in a river which would affect navigation. Sediment deposition on irrigated lands may be a benefit or a detriment depending on the type and quantity of sediments and of the soils irrigated.

The chemical quality of water should be known in the various parts of the basin to understand its effect on crops if used for irrigation, and for industrial or other use. Only occasional analyses of water samples would be necessary for such studies.

The great abundance of surface water in the basin which at present is not being utilized appears to indicate that large scale ground water use would be a future development. However, in certain areas it may be desirable to consider pumping of underground water for intensive use and, also, such pumping might be carried on in presently marshy areas for the dual purpose of drainage and irrigation.

Meteorological data are needed to better understand the climate of the area since meteorological stations are now so few . Rainfall and temperature, especially should be known and evaporation, humidity, and other data also be available for study. Good rainfall data can provide information for correlation studies. However, since the data for individual rainfall stations vary considerably it is necessary that a large number be established.

In the use of correlation studies to produce data for an area where data is not available it must be realized that correlation is merely a tool by which to try to make an educated estimate. There must be reliable data as a base from which to begin and such data should cover a large enough period of years and of area to be representative. Correlation based on streamflow is less erratic than rainfall data since runoff data tends to integrate the several factors in a basin, such as rainfall, evaporation and transpiration, geology, and topography which influense runoff.

Hydrological investigations in an area the size of the Araguaia-Tocantins basin is a very large program and it will be many years before all desirable data can be obtained, and much will probably never be obtained. A start needs to be made and from there the investigations may expand as funds, personnel, and equipment allow.

Hydrological Data

There have been very little data obtained in the Araguaia-Tocantins basin. The Meteorological Service of the Ministry of Agriculture has operated observation stations at a number of places but data has been incomplete and intermittant, probably because of insufficient supervision, maintenance, repair, or replacement of equipment. Streamflow data are even more scarce. Prior to mid-1961 when CELG (Centrais Eletricais de Goiás) began streamflow investigations through HIDROSERVICE, an engineering and consulting firm, the only data consisted of gage readings at several points on the Tocantins River by CEORTA (Comissão dos Estudos de Obras dos Rios Tocantins e Araguaia). That organization is now included in the Department of Rivers and Harbors, which also has a hydrology section for its hydrological studies. Because of the need for data, CIVAT has begun investigations and operate one discharge station at the present time.

It is unfortunate that lack of foresight by the engineering and scientific professions, by governmental agencies in general, and the Divisão das Aguas has permitted so great a river basin to have gone so long without at least a few streamflow discharge stations since Rio Tocantins is actually one of the largest rivers in the world. However, since back data are not available it is most desirable to begin runoff investigations as soon as possible to meet immediate needs for basin planning and for the long range study of the regime of the basin so as to evaluate over succeeding decades the effect of man-made changes through water use and control as well as to study possible long-range climatic changes in the area.

A good streamflow network is desirable to meet all needs both present and future, including individural project planning (which, however, many engineers seem to believe is the only purpose of data), runoff from the various parts of the basin for future studies and planning, and long-range index stations on the main stem of the rivers and on tributaries to learn the long-range changes in the system. As so little has been done to date the desirable program is large, however, since costs always are a limiting factor, the program should begin modestly with the most urgently needed stations and those most easily operated given the first priority.

Rainfall is mostly during the summer months and streamflow, accordingly, is greatest during the December-February period. To avoid the difficulties in comparison and correlation of data during high discharge periods it is suggested that the water-year basis be used covering the period October 1 to September 30. Streams are generally at, or near, their low points in the basin at that time so that annual or seasonal data are more easily compared.

Discharge measurements by HIDROSERVICE are by usual U.S. methods,- that is, the 0.2 and 0.8 depth method for velocity measurement, but with the "mean-section" method for their computation. At the one discharge station operated by CIVAT the discharge is measured by obtaining vertical velocity curves at each of about a dozen sections and computed by partly graphical methods. If CIVAT is to operate stations it is recommended that the 0.2 and 0.8 depth velocity method be used, with 20, or more, sections, and that the "mid-section" method of discharge computation be used, since it will speed up the field work slightly and reduce the computation of the measurement to a small fraction of the time it now takes.

CIVAT has not yet made daily discharge computations but HIDROSERVICE, like the Divisão das Aguas, computes daily discharge from the equation of the stage-discharge relation curve. The "rating table" method as used in the U.S. is a more easy method of computation and seems more flexible in that shifting control adjustments are easily made; also, the application of discharge may be done by most employees after any shift adjustments are determined by an engineer or technician.

Existing Streamflow Data and Program

Data available and stations operated at the present time (June 1964) are as given below. The accuracy and reliability of the data is probably good to fair except that high dishharge data is scarce and changes of gages at some locations may make even the short periods of record difficult to review. Aaso, a large number of discharge measurements were made during each infrequent visit to a station and many were made either on the same day or at the same stage during the visit.

Rio Tocantins at São Felis, Goiás

Lat 13°33'S., long 48°06'W., near São Felix dam site, 400 m downstream from Rio São Felix. Drainage area, 56,500 sq km. Station established by HIDROSERVICE for CELG September 1961. Gage heights available from September 1961 to December 1962 and probably to present. Sixty-four discharge measurements made from September 1961 to November 1963, but were made in five or six groups so not well distributed. Highest discharge measurement, 1190 m^3/s at 4.08 m gage height on Feb. 9, 1963; maximum daily gage height, 8.20 m, Dec. 23, 1962. No gage readings Dec. 1-20, 1962, when higher stage probably occurred. Data appears reliable.

Rio Tocantins at Porto Nacional, Goiás

Lat 10°42'S., long 48°25'W., at city of Porto Nacional. Drainage area, 173,200 sq km.. About 13 years of gage readings are available according to CIVAT. The French group, SCET, is reviewing the data in France so all data is not available at CIVAT. A total of 353 discharge measurements were made during the period March 1949 to June 1954 by CEORTA, all of which are under 4,000 m^3/s. Gage heights for some discharge measurements are confusing as 1 and 2 meter discrepancies are frequent (pbobably because gage sections were not properly marked) but errors can probably be corrected and the discharge computed.

Hidroservice established a station September 1961 about 80 meters from old CEORTA gage and also constructed a pontoon raft and ferry cable from which to make discharge measurements. Gage readings were begun by Hidroservice September 1961 and 19 discharge measurements were made during December 1963 and January 1964. Highest discharge measurements were 3,160 m^3/s at 6.40 meters gage height on Jan. 15 and 16, 1964; maximum mean daily gage height since 1961 is 9.84 m on Dec. 18, 1962. The new station may provide data for computation of old gage data if gage elevations can be compared.

Rio Tocantins at Carolina, Ma.

Lat 07°22'S., long 47°27'W.; on right bank at city of Carolina. Drainage area, 274,800 sq km. Station established by Hidroservice September 1961. Gage readings available since establishment. No discharge measurements. Highest mean daily gage height for period is 8.19 m on Dec. 24, 1962. In a Hidroservice report the maximum known stage is given as 15.2 meters.

Rio Ribeiro Lageado at Lageado, Go.

Lat 09°51'S., long 48°14'W., 500 meters below a falls and 18 kilometers upstream from Rio Tocantins. Established by Hidroservice for CELG in September 1961. Gage readings are available to date. Nine discharge measurements were made in September 1961 and 10 made in January 1964; measurements range from 7.3 m^3/s at gage height 1.30 to 24.7 m^3/s at 3.02 meters. Daily discharge has been computed by Hidroservice. The station appears to have been changed during the short period of record but remained in the vicinity of the falls.

Rio Farinha near Fazenda Nova, Ma.

Lat 07°02'S, long 47°00'W; two kilometers above falls, about six kms ~~above mouth of Rio Farinha~~ downstream from Rch do Mato, about 65 kms upstream from Rio Tocantins, and 65 kms northeast of Carolina. Drainage area, about 3,000 sq km. Station established July 1961 by Hidroservice for CELG. Gage readings are available since July 1961 and daily discharge computed by Hidroservice based on 15 discharge measurements made in July and September 1961 and Februarey 1962. Additional measrements have probably been obtained. Measurement No. 14, made Feb. 17, 1962, is 70.1 m^3/s at gage height of 2.41 meters.

Rio Mosquito, in Municipio Campos Belos, Go.

Lat 12°50'S, long 46°26'W, 30 meters from wooden bridge and 50 meters above a rapids, about 12 kms south of Vila Manha, and 24 kms upstream from Rio Palma (a tributary of Rio Tocantins). Drainage area, about 330 sq km. Station was established in September 1961 by Hidroservice for CELG. A second station was established at the same time at a site 18 kms above Rio Palma. Five discharge measurements were made at the upper site and two at the lower site in September 1961. Although no data is in the files of CIVAT or CELG, gage readings at one, or both, sites are probably available since establishment.

Rio Araguaia near Alto Araguaia, Mato Grosso.

Lat. 17°05'S, long 53°03'W, on right bank (Goiás) about 200 meters upstream from falls (about 20 meters), 10 kms downstream from Rio Babilonia, and 25 kms downstream and northeast of Alto Araguaia and Sta Rita Araguaia situated on left and right banks, respectively, of the river on highway BR 31. Drainage area, 4750 sq km. Altitude, about 760 meters. Station established Nov. 14, 1963, by CIVAT for possible hydro electric project at falls. Auxiliary staff gages installed at boat measureing section about one kilometer upstream. CIVAT has made six discharge measurements to date and gage readings are available since establishment. Flow is said to be very uniform with a minimum discharge of about 50 m^3/s throughout the dry season.

One discharge measurement was made of Rio Tocantins at Marabá in October 1963. Discharge was 1500 m^3/s; stage was referred to a reference mark at top of concrete steps at street level of Marabá. Flow of Rio Itacaiunas at rapids about 2 kms upstream from mouth was estimated as about 5 m^3/s.

Suggested Streamflow Station Network

The seven gaging stations mentioned above are a start in a network which should be expanded in an orderly, well-planned program. All of the present stations except those on Rio Tocantins at Porto Nacional and Carolina are "project-type" stations since they have been established to provide data for a certain project; in this case proposed or probable hydroelectric developments. The stations at

Porto Nacional and Carolina are main stem stations which will provide data on Rio Tocantins for both navigation studies and for long-range inventory and regime studies in the basin. The Porto Nacional records should be computed and compiled in order to make that 13-year record available for planning purposes and possible correlation with other points in the basin. Since water-use and control in the basin is negligible at the present time all stations provide data which indicate the natural runoff for their respective drainage areas. As the stations are mainly for hydroelectric projects they should continue to provide natural discharge data after the projects are completed as the only change from natural flow conditions would be the regulatory effect if a reservoir is used, shorrt-period hourly or daily variations in discharge caused by power requirements, bank storage effects, and perhaps increased evaporation if reservoirs are large. Stations upstream or downstream from such projects should therefore be continued if at all possible or practicable after a project has been completed so as to provide continuous data at such sites for project operation and for correlation with nearby streams.

Gaging stations may be classed as "project", "areal index", "river management", and "river inventory" type, or as "primary" and "secondary", depending on what the purpose of a gaging station is. The cost and the work involved to obtain good, reliable streamflow data require that the purpose of a station be known before its establishment and, also, that the length of time that it is expected to be operated be considered. Streamflow records for a long, continuous period are most desirable as such records supply data on which to estimate future variations in the stream as well as to provide a good base, or index, from which shorter periods at other stations may be extended by correlation methods. All types of stations are therefore needed in a station network and certain stations should be chosen as primary index stations to be operated indefinitely to provide such a base for correlation and for long-range regime studies. If the long period of gage height record at the Rio Tocantins at Pôrto Nacional can be transformed into discharge records it should be one of the stations to be operated indefinitely.

Until actual locations have been seen so that it is known that conditions at a site are suitable for a gaging station, the exact locations of stations cannot be definitely planned. Some day if, and when, the Araguaia-Tocantins basin is developed and water use is such that it might become a scarce commodity, the number of streamflow stations could exceed 300 in the basin. However, in view of the early stage of development, of the inaccessibility of so much of the area, and the costs involved, it is suggested that a network be started which will provide for early planning needs and then expand the network as conditions permit.

The element of funds is probably the most critical and CIVAT, CELG, SPVEA, and the Divisão das Aguas should plan on how the program is to proceed, and who should do the work. Perhaps the Divisão das Aguas can operate the stations with some funds supplied by other agencies. Since CELG has found it necessary to utilize a commercial firm to obtain streamflow data it appears that the Divisão das Aguas, which it would seem should actually operate all stations in Brazil, is unable to provide the personnel and equipment to do the work. Also, CIVAT has found it necessary to begin its own investigations. Although there should be no objectio to the production of streamflow data by a commercial firm, the fact that data should be collected for indefinite, long periods of years for long-range scientific and river regime or climatic studies as well as for immediate planning, the overall program appears best suited to a large governmental agency such as the Divisão das Aguas, and that the commercial firms are best suited for individual project studies. However, if the agency which should, apparently, be responsible for the program cannot properly do the job as required, it does become necessary for other agencies to obtain the data as they see necessary so that the lack of data does not jeopardize development planning. No recommendations are therefore made as to operation, computation and compilation except that if the Divisão das Aguas is unable to do the work that CELG and CIVAT should obtain the data as conditions permit. Data should, however, be turned over to a central agency for publication regardless of how many agencies perform the work so that the data will become available to all interested agencies.

Gaging stations are needed for planning of hydroelectric developments, and five of the present seven stations are for that purpose. Other possible hydroelectric development foreseen by CIVAT are on Rio Itacaiunas near Marabá and on Rio Tocantins at Itaboca, at the large rapids in the lower reach of the river. Streamflow stations should be established which will assist in the consideration of those sites. Other main stream and tributary data should be obtained for additional probable development.

Navigation studies require discharge data although stage data only may be needed at most such stations during later years. The Rio Tocantins stations at São Félix, Pôrto Nacional, and Carolina may be used in that study. Other main stem stations should be established to provide further information.

Irrigation is practiced on only a small scale at the present time but the benefits are probably known when crops can be grown throughout the dry season. Streamflow stations should be established above or below an area that may be an irrigation area.

Drainage, expecially along the Rio Araguaia, may make large areas of marshy lands suitable for agriculture. Streamflow stations above and below such problem areas will provide data on which drainage problems may be studied.

Municipal and industrial water use is not a problem as yet, however, data on tributary streams will be useful for such studies as well as for areal runoff studies.

Highways are not yet extensive but discharge data could provide flood frequency and magnitude data to assist in the selection of bridge and culvert sizes after a few years when more and much more costly construction may be necessary.

In view of the above the following is suggested as a beginning network based on the present gaging stations, probable development needs, accessibility, and of stations desirable to provide data for runoff correlation studies, for the next two or three year period. The listing is not in order of priority and conditions not known at the present time may change the locations. A fact to be considered is that accessibility is very important and good, reliable records near a proposed development are much more valuable than questionable, unreliable data attempted to be obtained at a project site. See Figure 3 for map showing locations.

Note.- 1 Main stream inventory station
2 Areal index station
3 Project-type station

Name and location	Type of station
Rio Tocantins at São Félix, Go.	1,3
Rio Tocantins at Pôrto Nacional, Go.	1,3
Rio Tocantins at Carolina, Ma.	1,3
Ribeiro Lageado at Faz. Lageado, Ma.	2,3
Rio Farinha near Faz. Nova, Ma.	2,3
Rio Mosquito, in municipio Campos Belos, Go.	2,3
Rio Araquia near Alto Araguaia, Mt and Go line	2,3

(The above are existing stations)(1964)

Below confluence of Araguaia and Tocantins

Rio Tocantins at Marabá, Pa.	1,3
Rio Itacaiunas near Marabá, Pa.	2,3

Tocantins basin

Rio Tocantins at Tocantinópolis, Ma.	1,3
Rio Tocantins at Pedro Afonso, Go.	1,3
Rio das Balsas near Ponte Alta do Norte, Go.	2
Rio Perdida at Tres Pedras, Go.	2
Rio Palma near Paraná, Go.	2
Rio Paraná near Monte Alegre de Goiás, Go.	2
Rio Paraná at Urutagua, Go.	1
Rio das Almas at Ceres, Go.	1
Rio Santa Teresa near Peixe, Go.	2
Rio Marnahão above Rio das Alsmas, near Niquelandia	2
Rio Sereno near Piacá, Ma.	2
Rio Manuael Alves Grande near Piacá, Ma.	2

Araguaia basin

Rio Araguaia at Xambioá, or Araguatins, Go.	1
Rio Araguaia at Araguacema, Go. (or Conc. do Araguaia)	1
Rio Cixas Mirim near Bandeirante, Go.	2
Rio Araguaia at Santa Isabel (Ilha do Bananal), Go.	1,3
Rio Araguaia at Bandeirante, Go.	1,3
Rio Araguaia at Aruana, Go.	1,3
Rio Mortes near Xavantina, Mt.	2
Rio Araguaia at Aragarças, Go.	1
Rio Vermelho below Goiás, Go.	2
Rio das Garças near General Carneiro, Mt.	2
Rio Claro near Mal Floriano, Go.	2

(In addition to the suggested regular gaging stations, it may be also necessary to establish gages for river stage only observations at critical points on the Araguaia and Tocantins main stems and to make special discharge measuremnts at other critical points where complete records are not needed.)

The locations of the above stations have been based mostly on inspection of topographic maps, location of regular airline service, and roads, so are based largely on accessibility. The writer has not seen most of the basin having been only to some of the upper Araguaia and upper Tocantins streams in the region west and north of Goiânia, and in the Marabá to Jatabá area; however, the Rio Balsas and Rio Parnaíba in Maranhão are known and some conditions may be similar. The local conditions at some of the suggested sites may not be desirable for a gaging station so that an alternate location might be preferable since river conditions should be such as to produce acceptable data, an observer must be available, and the site must be accessible for discharge measurements.

The thirty-three stations suggested would be a beginning of streamflow information desirable for areal runoff studies, project studies, main river discharge data for navigation and drainage studies, as well as data for knowledge of the long time behavior of rivers in the basin. Data at other sites may be more urgent or desirable as CIVAT and CELG plans develop and and should supersede some of the above as necessary.

Since the streamflow data program is just beginning the suggested program will probably take two or more years to implement. Staff gages are sufficiently accurate for gage heights on large streams, but automatic water-stage recorders are preferable on the more rapidly changing streams. Boat measurements are probably necessary on most streams as bridges are usually not available and stream widths and bank heights may not be such as to make a cableway practical, even though cableway measurements are usually considered more accurate than boat measurements. A station such as Rio Araguaia near Alto

Araguaia is well adapted for a cableway and a 3/4-inch cable erected on usual A-frame supports, or even attached to large trees and then anchored to the base of other trees, would improve measuring conditions and avoid the necessity of using four or more men to obtain measurements.

The suggested network would require about four or five field crews, including the stations now covered by contract. Two crews would be needed as early as possible and the other two added as the network expands. Training of personnel in the field work and in office computations will be necessary if CIVAT undertakes to operate the network. Training will be necessary in the making of discharge measurements, installation and operation of water-stage recorders and of cableways, sediment sampling, routine operation and maintenance, and training in improved practices as well as in the computation and compilation of data. Computations will probably be done in the central office. Field training is is best done in the field by actually doing the work. Vehicles and boats will have to be rented locally in towns accessible only by air.

Major equipment needed for a network such as the above, and considering four or five crews, is as given below. The items and names are as used in U.S. practice, and the costs are estimated in U.S. [1964] dollars. The symbol (°) indicates all or part of the item would be locally furnished.

	Quantity	Cost
(°) Pickup trucks, 4-wheel drive	3	$5000
Boats, aluminum	3	800
Rubber rafts	6	200
Outboard motors	3	800
Current meters, Price type AA	6	800
Sounding Reels, type A (USGS)	5	1000
" " , type B "	4	1200
Boat booms	3	700
Water-stage recorders	5	2000
Bridge cranes	2	600
Hand-lines, complete	5	200
Wading rods	6	200
Sounding weights, 15-pound	5	200
" " , 30-pound	5	200
" " , 50-pound	5	300
" " , 100-pound	5	400
" " , 150-pound	4	400
" " , 200-pound	2	300
Tag-lines, 100-meter	5	200
" " , 150-meter	5	300
Boat tag-lines, 300-meter	4	300
Reels, for boat tag-lines	4	200
Stop-watches, 60-second	10	100
(°) Level, surveyors	2	500
(°) Level rods	2	100

Hand levels	5	100
Cableway equipment	5	1000
Sediment samplers, integrating, point, and bottom type	5	1700
Depth sounder, recording	1	1500
" " , non-recording	1	200
(°) Miscellaneous minor equipment for water-stage recorders, etc.		2000
(°) Office equipment and forms, etc.		1000
Books and publications		400
Total		25,900
Locally procured		8,000
Imported		17,900
Freight, plus 30%		5,400
		$23,300

Meteorological Network

Few records of climatic data are available in the basin and much is intermittent or incomplete. The Meteorological Service of the Ministry of Agriculture has operated the existing network and is entering into an agreement with CIVAT for the reconditioning of existing stations and expansion of the network. That program is expected to be started immediately and be well accomplished as to reconditioning within the next eight months.

Rainfall and temperature data are the most important and, fortunately, the easiest to obtain as far as costs and services of an observer are concerned. Such stations should be located throughout the basin at all towns or places where reliable observers may be found.

Evaporation data is needed for agricultural studies, especially, but also for the study of loss of water through evaporation in reservoirs, in the extensive marshy areas, and in other investigations. Humidity, wind, solar radiation, soil temperatures, and upper air conditions are also desirable and should be obtained as funds and observer availability permit, although on a limited scale compared to the rainfall and the temperature data.

Existing Network

The existing network, as given in CIVAT files and correspondence with the Meteorological Service, is as follows:

State of Goiás

At Goiás : Synoptic station No. 83,374, established 1912.
Equipment: Barograph
Dry and wet thermometer
Max and Min thermometer
Wind
Rainfall
Observation: No. shelter. Functioned irregularly in 1911, 1916, 1920, 1930, and 1947. No data for 1917, 1918, 1937, 1945.

At Pirinópolis: Synoptic station No. 83,376, established 1914.
Equipment: Same as for Goiás with addition of barometer, thermograph, hygrograph, evaporimeter (Piche), heliograph, and recording rain gage.
Observations: Functioned irregularly in 1913, 1929, 1933, 1954, 1956.

At Formosa: Synoptic station No. 83,379, established 1915. Lat 15°32'S., long 47°18'W.; altitude, 912.0 m.
Equipment: same as Pirinopolis plus anemometer.
Observations: Evaporation data (probably pan) and solar data not being furnished. Station functioned irregularly in 1912 and 1960.

At Pôrto Nacional: Synoptic station No. 83,064; established 1916; Lat 10°31'S., long 48°43'W.; altitude, 237.19 m.
Equipment: Same as Pirinopolis, except probably an evaporation pan.
Observations: Due to lack of observers there have been no evaporation and solar data. Station functioned irregularly in 1915, 1925, 1938, 1944, 1946, 49, 50.

At Taquatinga: Synoptic station No. 83,235; established 1917.
Equipment: Barometer
Wet and dry thermometers
Max and min thermometers
Wind
Observations: No shelter. No observations in 1919. Irregular observations in 1918, 1925, 1929-31, 52, 53, 60.

At Pedro Afonso: Station now closed but observations made 1936 to 1959, with irregularities in 1936, 38, 41, 42. Station had barometer, wet and dry thermometer, max and min thermometers, rain and wind gages.

At Paraná: Station No. 83,231. Record indicates that only barometer and wind gage, but other equipment may be on hand.

State of Maranhão

At Imperatriz: Synoptic station No. 82,564; established 1914.
Equipment: Wet and dry thermometers
Max and min thermometers
Rain gage
Wind

Observations: No shelter. No observations 1936, 1937; Irregular data in 1935, 1938, 1939, 1951.

At Carolina: Synoptic station No. 82,765; established 1917.
Equipment; Barometer
Thermometer
Rain gage
Wind
Observations: No shelter. Irregular operation in 1924, 1925, 1951, 1957, 1959, 1960.

State of Pará:

At Belem: Synoptic station No. 82,191; established 1923.
Equipment: Barometer, Barograph, Wet and dry thermometers, Hygrograph, Evaporimeter, Heliograph, Anemometer, Rain gage, Recording rain gage, Shelter
Observations: Irregular operation 1926, 1927, 1930, 1932, 1936, 1938, 1951, 1953-58.

At Conceição do Araguaia: Synoptic station No. 82,861; established 1915.
Equipment: Barometer
Wet and dry thermometer
Max and min thermometer
Wind

Observations: Irregular operation 1917, 1918, 1930, 1936, 1938-44, 1952, 1957, 1959. No data 1924-29.

State of Mato Grosso

At Presidente Mutinho: Synoptic station No. 83,365; established, 1924. Lat 10°31'S, long 48°43'W; altitude, 552.0 meters.
Equipment: Barograph, Barometer, Wet and dry thermometers, Max and min thermometers, Heliograph, Wind

Observations: No shelter. No observations 1946-49. Irregular operation in 1958.

At Xavantina: Station closed. No information.

Stations outside, but near, the basin:

At Goiânia: Synoptic station No. 83,423; established 1937. Lat 16°41'S, long 49°17'W. Altitude, 729.49 m.
Equipment: Full equipment, including theodolite.

Observations: Probably complete except aerological data.

At Brasilia: Synoptic station No. 83,377.
Equipment: As in Goiânia, but no theodolite.

At Cuibá: Synoptic station No. 83,361; established 1912.
Equipment: Complete, including recording equipment.

[Proposed Plan of Cooperation]

The proposed plan of cooperation between CIVAT and the Meteorological Service proposes the reconditioning of, or the establishment of, meteorological station at locations as follows, which include those mentioned above:

Belém, Pa.	Jacundá, Pa.
Igarapé-miri, Pa.	Marabá, Pa.
Cametá, Pa.	Xambioá, Go.
Baião, Pa.	Conceição do Araguaia, Pa.
Tucurui, Pa.	Imperatriz, Ma.
Carolina, Ma.	Riachão, Ma.
Tocantinópolis, Go.	Montes Altos, Ma.
Grajeu, Ma.	Pedro Afonso, Go.
Miracema, Go.	Pôrto Nacional, Go.
Ponte Alta do Norte, Go.	Novo Acôrdo, Go.
Lizarda, Go.	Peixe, Go.
Gurupi, Go.	Porangatu, Go.
São Miguel do Araguaia, Go.	Santa Isabel (Ilha do Bananal), Go.
Dianópolis, Go.	Natividade, Go.
Paraná, Go.	Cavalcante, Go.
Nova Roma, Go.	São Domingos, Go.
Combinado Agro-Urbano de Arraias, Go.	Taguatinga, Go.
	São Felex, Go.
Niquelándia, Go.	São João d'Aliança, Go.
Veadeiros, Go.	Aruanã, Go.
Aragarças, Go.	Caiapônia, Go.
Israelândia, Go.	Brazília,
Formosa, Go.	Pirinópolis, Go.
Anápolis, Go.	Cristalina, Go.
Goiânia, Go.	Pires do Rio, Go.
Morringos, Go.	Goiás, Go.
Ceres, Go.	Cuiaba, Mt.
Poxoréu, Mt.	Alto Araguaia, Mt.
Mineiros, Go.	Paraíso, Go.

The complete plan of CIVAT and the Meteorological Service for equipping the above stations is not known, however, in view of the costs involved and the problem of observers, it is probable that only elementary equipment would be provided at most stations and that stations may be up-graded as conditions permit.

The existing stations to be reconditioned are mainly in the east and south and will serve as a good base from which to expand and improve the network since those stations are equipped for most of the necessary observations. Other locations to fill gaps in the network and which appear desirable for fairly complete data, including rainfall, temperature, humidity, wind speed and direction, with evaporation pans, heliographs, and barometric data at a few, are:

Tucurui	Marabá
Xamboia	Araguacema
Novo Acordo	Peixe
São Felix	Alto Araguaia
Uruacu	Aruanã
Xavantina	Aragarças
Natividade	Santa Isabel (Ilha do Bananal)
São Miguel do Araguaia	

A few other locations in the middle Rio Araguaia region should be established if observers are available, since that area is said to be well suited for raising rice.

[Suggested Additions to The Network]

In addition to the 15 stations to be continued and reconditioned, and the other 15 stations suggested above to be added to the synoptic network, it is suggested that stations for rainfall and temperature data, or rainfall data only be established in at least 70 other locations throughout the basin as indicated approximately in Figure 4. The locations indicated are:

In Pará: Cametá, Juroma, Jacundá, Baião, Gameira, Luis Gonçalves

In Maranhão: Riachão, Monte Alegre, Frades, Caboceiringa (on Rio Farinha)

In Goiás:

Araguatins	Aldeia do Correinha
Tocantinopolis	Tres Pedras
Porangatu	Piaca
Miracema	Ponte Alta do Norte
Lizard	Gurupi
Porangatu	Dianopolis
Cavalcante	São Domingos
Urbano de Arraias	Niquêlandia
São J. d'Aliança	Veadeiros
Caiaponia	Cristalina
Parauna	Ceres
Mineiros	Crixas
Iporo	Aurolandia
Mal Floriano	Novo America
São Bentinho	Iticaja
Tres Pedra	Lizarda
Pedra de Anchar	Damianopolis
Conc. de Norte	Arraias
Monte Alegre de Goiás	Posse
	Trombas
Urutagua	Bandeirante
Sãn Miguel do Araguaia	Piedade
	Guaré
Cristalandia	Dueré
Canoana	

In Mato Grosso:	Col. Ponca	Araguaina
	Guiritinga	Tesouro (or Gen. Carneiro)
	Col Moru	Santa Terisina

The 64 locations listed are at towns or places found on maps and are indicated by open circles in Figure 4. Six other desirable locations are indicated with a circle and question mark since place names were not given. The locations include nearly all locations included in the CIVAT plan plus about 50 additional. It should be possible to establish such stations between the more complete stations to fill in those area. Even so, the area per rainfall station will be more than 7500 square kilometers and, a hundred or more rainfall stations should be added as good locations are found,- perhaps at fazendas between the suggested towns. Also, some of the stations to be established by SUDENE in the State of Maranhão should be of value.

Since the network is to be established with the cooperation of the Meteorological Service, it is expected that their standardised equipment will be used. No comments are therefore made in that regard since standardization is a desirable aspect as long as such equipment furnishes reliable data. Evaporation stations, however, should include evaporation pans even though Piche evaporimeters are used, since the coefficients applicable are often doubtful.

Upper air data is very scarce in Brazil and it is probable that even at Brasilia and Belém the equipment may not be in use. Such data would be of value at a number of locations so that weather patterns may be studied. The cost of pilot balloon stations is relatively high but should be considered for a few places such as Goiânia, Porto Nacional, Carolina, Maraba, and other locations where airport personnel could operate the equipment.

Figure 4 indicates the location of existing stations of the Meteorological Service and those suggested by the writer.

Evaporation stations should be at at least 12 locations, which could be some of the synoptic stations. Those stations should be equipped with Type-A evaporation pans even though Piche evaporimeters are used. Twelve suggested locations for the evaporation station network are:

Marabá	Sta Isabel (Ilha de Bananal)
Imperatriz	Paraná
Carolina	São Felix
São Miguel	Presidente Murtinho
Goiás	Conceição de Araguaia
Uruacu	Porto Nacional

Conclusion

The discussion, comments, suggestions, and recommendations made herein have been based on sketchy personal acquaintance with the basin and have been based mostly on available maps and information, substantiated by a few visits to parts of the area. The suggested program will require further study as it is implemented since better locations of stations may be likely than those suggested. The accessibility and the availability of observers will have to receive as much consideration as the actual station conditions in many cases, which may cause data to be more difficult to work with in some instances.

This preliminary study is therefore prepared to give an idea of the size of the problem, the availability of data at present, and suggestions and recommendations to begin an extensive program. If the studies and developments in the entire Araguaia-Tocantins basin should materialize, whatever information gathered at the earliest date will be very useful.

The excellent cooperation from CIVAT personnel is greatly appreciated and their interest in furthering the development of the basin is to be commended. The field trips during the past two-weeks visit to CIVAT headquarters and area were valuable as well as educational to me. And, if the hydrologic investigations program as discussed above may not be as complete as might be desired, it is hoped that it may be a step toward good planning, for the planning of water-use projects and developments on the scale envisioned in the Aragaia-Tocantins basin should be based on reliable hydrologic information. It seems well, therefore, to begin an orderly study of the availablility and distribution of water since that is without a doubt the greatest natural, replenishable resource in the basin.

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Some notes from field trips in June 1964 to the Alto Araguaia area, to Rio das Almas, Rio Marnhao, and Rio Tocantins in the vicinity of Ceres and Uruacu, and the October 1963 trip to Rio Tocantins at Marabá, are attached for further information.

L. J. Snell
June 14, 1964

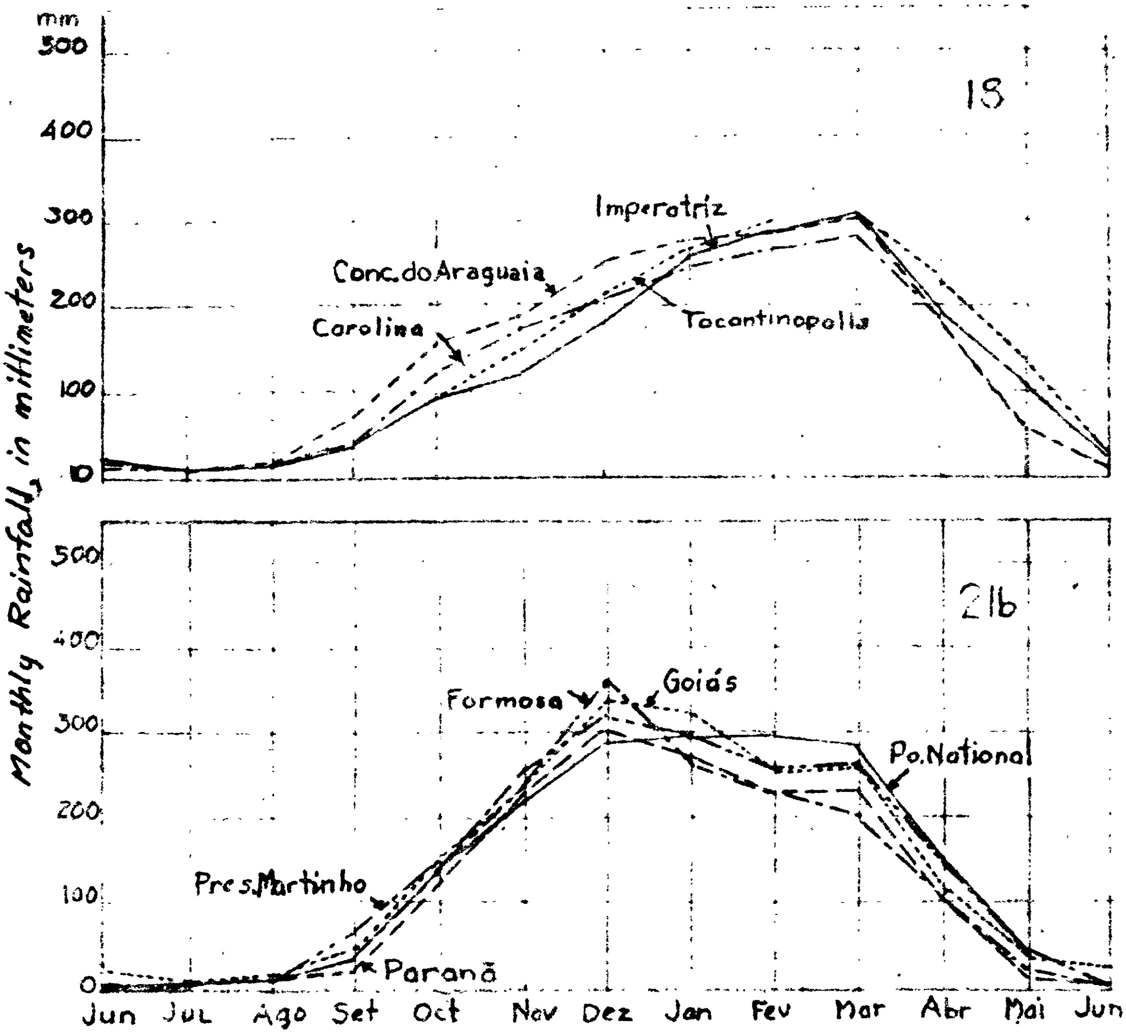
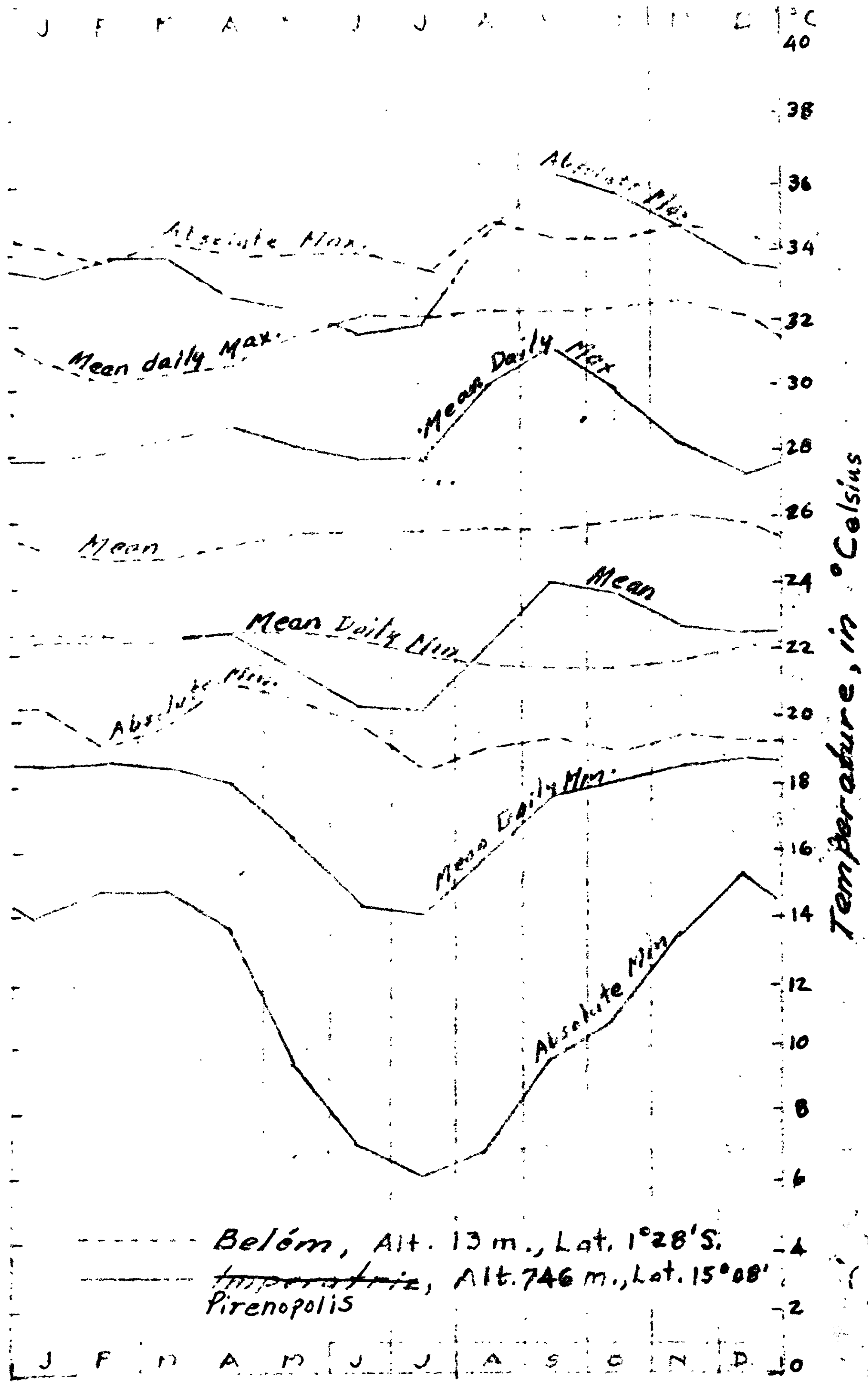


Fig. 1. Average Monthly Precipitation
Period 1914-38
[at selected sites in Brazil]
(From ATLAS PLUVIOMETRIC do BRASIL)
Boletin No. 3

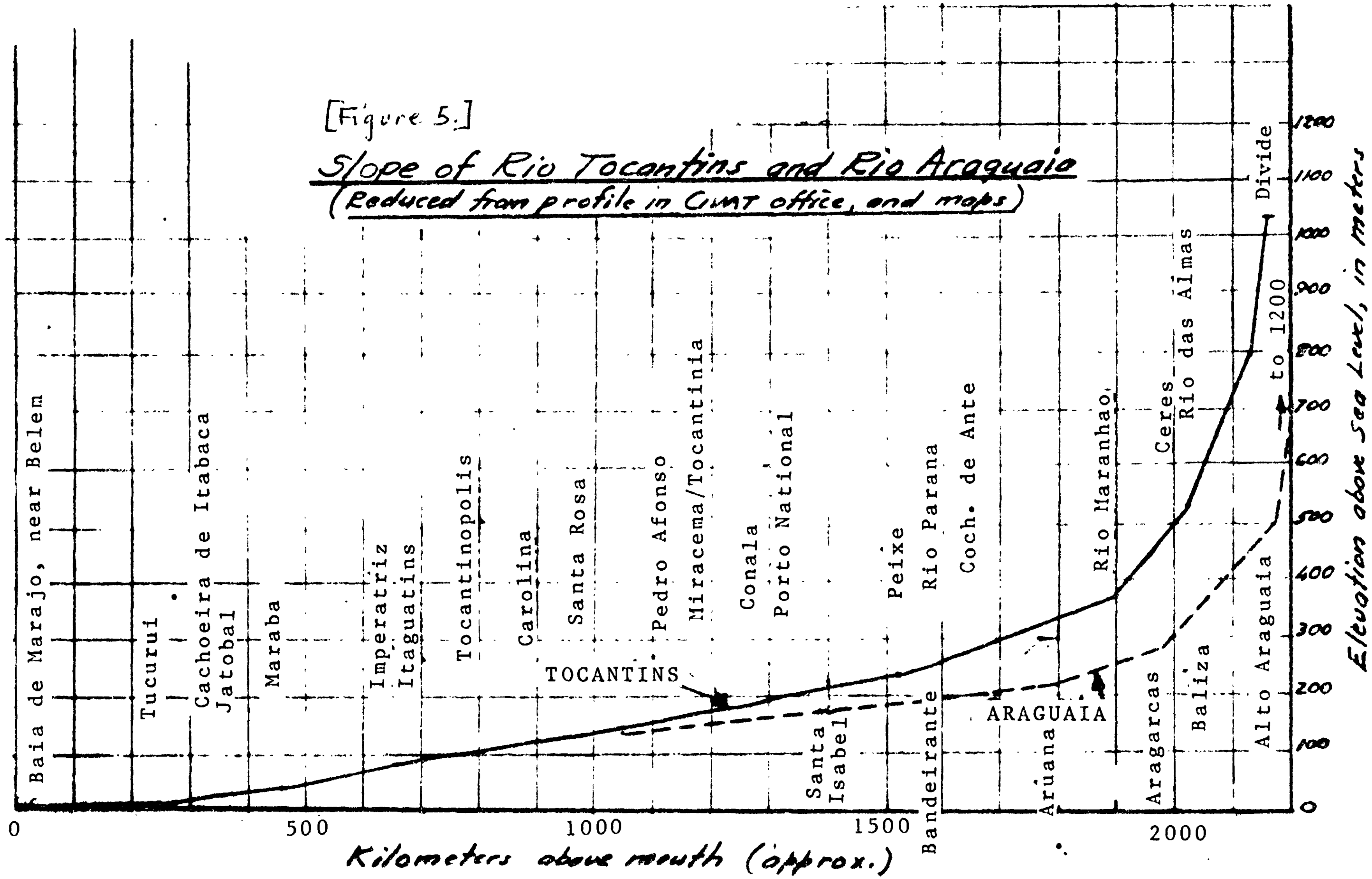


TEMPERATURES IN REGIONS NEAR [Araguaia-Tocantins] BASIN EXTREMITIES

Fig. 2

page 24 follows

[Figure 5.]



Slope of Rio Tocantins and Rio Araguaia
(Reduced from profile in CIMT office, and maps)

[ANNEX 1]

TRIP TO ALTO ARAGUAIA [BRAZIL]

June 3 - Departed Goiânia at 7:30 a.m. with Engr. Erton Carvalho of CIVAT.
1964 Arrived Alto Araguaia (540 kms) at 5:10 p.m.

Crossed Rio Verde and Rio Claro flowing south to Rio Paranaíba. Good locations for discharge stations, with good flow and clear water; but outside basin now under study. Rio Babilônia, tributary to Rio Araguaia, also had good flow.

Area west of Rio Verde was quite dry and native vegetation sparse, but farming seemed to be increasing.

June 4 - Departed Alto Araguaia 7:30 a.m. About 30 kms to CIVAT gaging Station on Rio Araguaia, at 22 meter falls about 10 Kms downstream from Rio Babilônia. Staff gages about 200 meters upstream from falls; boat measurement location and auxiliary gages about one kilometer upstream. Surveys are being made in area for hydroelectric power development.

A discharge measurement was made, at 0,79 meter gage height (discharge is probably over 50 m3/s), with Amsler current meter on 4-meter rod, from dugout boat. River is about 60 m. wide, vertical bank to 3,0 meter gage height, and about 5 1/2 m. to top of banks. CIVAT discharge measurements are made by obtaining vertical velocity curve at each section and computed by plotting vertical velocity curves. Simpler 0.2 and 0.8 depth method with at least 20 verticals would be faster to measure and could be computed in 20 minutes. Also, measuring with rod from boat is harder work and not as good as with sounding weight and reel; Good cable-way location at measuring section; may even use trees for supports and anchers.

Road to gaging station from Alto Araguaia impossible in wet weather. Returned to Alto Araguaia and to Jataí, arrived Jataí 9 km.

June 5 - Departed Jataí 7:15 a.m.; arrived Goiânia 12:30 p.m.

TRIP TO RIO DAS ALMAS AND RIO MARANHÃO [BRAZIL]

June 8 - Left Goiânia at 12:30 p.m. to Rio das Almas at Ceres. Location
1964- appeared good for gaging station as channel is rocky and permanent. Gage could be about 150 meters upstream on left bank, from highway bridge. Measurements would need to be made by boat.

River narrows below city and location of gage may be preferable in the reach within 2 or 3 kilometers below city; also a cableway could be constructed for discharge measurements, but an observer may be a problem.

Old cable vehicle bridge is very overloaded, it appears, as some deck support irons are broken and need repair. About one meter sag in deck as heavy trucks cross. Bridge not suitable for discharge measurements.

Road (BR-14) is being rebuilt and to be asphalted between Anapolis and Ceres. Construction is progressing all the way to Uruacu and, also, east to Niquelandia. Broad valleys appear good agriculturally, but probably no market for products.

Hotel Araguaia in Uruacu is better than most small town hotels. Town is spread over 6 or 8 kilometers of road. Traffic to Uruacu was heaviest seen in area, and all cargo trucks. Arrived Uruacu at 8 p.m. Uruacu is in a "barbeira", or chagas, area but none seen; even one village is named Chagas.

June 9 - Left Uruacu at 7:30 a.m. Looked over Rio Tocantins 10 kms east of Uruacu, and about 3 kms below where Rio das Almas and Rio Maranhão join to form Rio Tocantins, for gaging stations site. Bridge is to be built (?) to replace ferry on new Uruacu to Niquelandia road; gaging station could be at, or near, bridge which is to be just below present ferry crossing. Estimated flow as about 300 m3/s. Area from Uruacu to Niquelandia is much like U.S. plains States with gently rolling hills, grassy flats, and occasional large flat areas; similar in parts of Rio das Almas basin. Soils very variable from silty to gravels. Vegetation sparse on well drained rises of ground and gravelly areas but rich in bottom lands.

On portion of new road constructed to Niquelandia the road had washed out at almost all water-course crossings for lack of culverts, or if culverts were installed were insufficient to carry the water.

Looked over sites for gaging station on Rio Maranhão at bridge on BR-95 between Niquelandia and Corumba. Discharge was estimated at about 80 m^3/s. River makes a sharp 180º bend at bridge in a massive rocky channel. Gages could be at upstream side of bridge attached to rock ledges and to circular piers but if water at higher stages is rough it is possible that the location might bot be desirable. Other locations could be around the bend about 200 meters downstream at a large pool and above a smaller rock constriction, which would be the control. Discharge measurements would have to be made about 200 meters, or more, upstream from bridge where channel is smoother, straighter, and wider above a gravel riffle. Gage could also be located there if water becomes too rough for good reading of gage at the other sites mentioned.

The Rio Maranhão area has very sparse vegetation except in narrow valleys. Soil is generally very thin; some hills as well as some road cuts indicate no soil cover whatever.

A large cement plant near Corumbá appeared not in operation.

[ANNEX 3]

SUMMARY OF INFORMATION ON THE MEASUREMENT OF
DISCHARGE OF RIO TOCANTINS AT MARABA, PARÁ, Oct. 26, 1963

The discharge measurement was made by the U.S. Geological Survey group which was in Brazil to measure the flow in the Amazon River. Although all persons were not needed for the Tocantins River measurement, the party consisted of Roy Oltman, Frank Ames, Luther Davis, and George Staeffler of USGS offices in the United States; L.J. Snell, USGS engineer assigned to USAID in Recife; Lt. Kieffer and Lt. Viveiros of the Brazilian Navy Hydrographic Office in Belém; and Harold Eissner, of the U.S. Consulate in Belem, who acted as interpreter.

Details about the river in the vicinity of Marabá and other information are given below.

Oct. 25: River within about 10 kms of Marabá was checked by boat and soundings to find location for measurements of discharge; depths of over 30 feet (10 meters) and low velocities downstream and rocky rapids immediately upstream from Marabá indicated that good measurement could only be made at Marabá. Rio Itacaiuna, which enters the Tocantins River at Maraba, was estimated as carrying about 175 cfs ($5m^3$) per second.

Oct. 26: Tocantins River discharge measured, in two channels, at Marabá from boat, using a 15-pound sounding weight, Price current meter, and hand-line, with distances determined by transit-stadia.

		Left channel	Right channel	Combined
Width	feet	1250	1700	2950
	meters	381	518	899
Area	square feet	9650	12,950	22,600
	m^2	818	1,097	1,915
Mean velocity	ft/sec	2.50	2.22	2.34
	m/sec	0.76	0.68	0.71
Maximum depth	ft	11.7	10.2	
	m	3.55	3.10	
Discharge	cfs	24,000	28,000	52,800
	m^3	683	813	1,496

Flow was smooth and uniform with a few weak boils; stream-bed was medium sand. Temperature of water was 88º F (31ºC) at 3 pm; 86ºF (30ºC) at 9 am. Electrical conductivity was 42 micromhos, indicating total hardness of about 30 ppm.

River stage was referred to a reference point on concrete retaining wall, 39.80 ft (12.13m) above water level. Flood mark of March 1957 flood was determined as 48.0 ft (14.6 m) above water level of Oct. 26, and 8.2 ft (2.5 m) above reference mark. The 1957 flood was about one meter deep in main part of town of Marabá but was exceeded by about two meters by flood of 1927, according to reports of local persons.

As it was reported that velocities were low during floods, it was estimated that flood flow of 1957 might be about 1 1/4 million cfs (36,000 m^3).

Oct. 27: Traveled by boat about 100 kms downstream from Marabá to the village on east side of Rio Tocantins opposite Jatobal. River is constricted by massive rock outcrop about 40 kms from Marabá, which cause the low velocities in that reach.

From the constriction to Jatobal, are several rapids with falls averaging about one meter. Time did not permit inspection of the reported 17 meter fall below Jatobal. The entire reach appeared poor for a streamflow station because of measuring conditions. Best measuring conditions are at Marabá, however, the sand streambed is subject to shifts. Gage could be above rapids, about 2 kms upstream.

Oct. 28: Met with the mayor of Marabá in morning and levels run from river to reference point and to the 1957 flood mark. Departed Marabá via VARIG and arrived Belém at 4:30 pm.