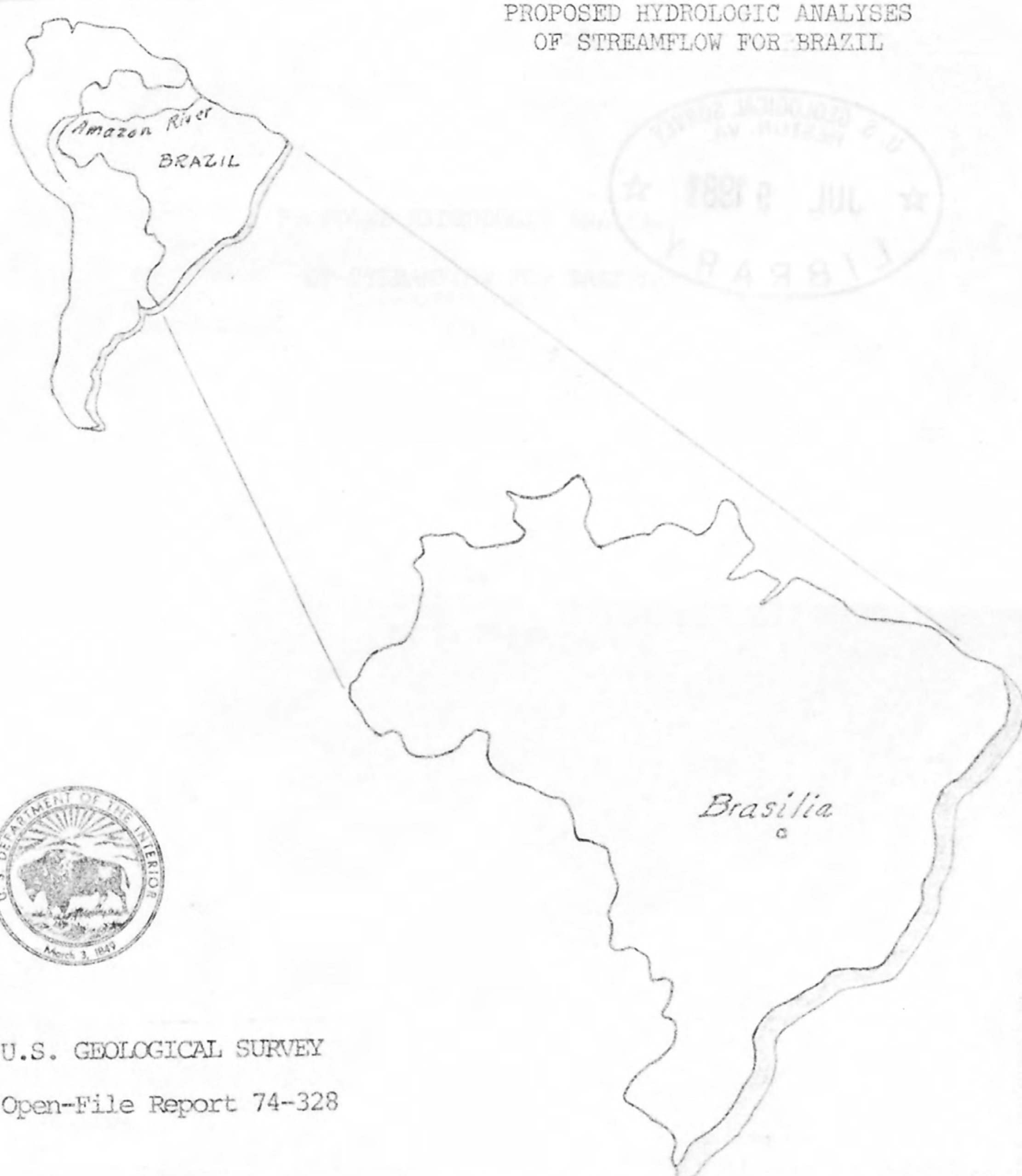
PROPOSED HYDROLOGIC ANALYSES OF STREAMFLOW FOR BRAZIL



U.S. GEOLOGICAL SURVEY

Open-File Report 74-328

Prepared in cooperation with
The Brazilian Ministry of Mines and Energy,
National Department of Water and Electrical Energy
under the auspices of the
United States Agency for International Development

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROPOSED HYDROLOGIC ANALYSES OF STREAMFLOW FOR BRAZIL

by

H. C. Riggs

Open-File Report 74-328

May 1974

Reston, Virginia

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROPOSED HYDROLOGIC ANALYSES OF STREAMFLOW FOR BRAZIL

by

H. C. Riggs

Open-File Report 74-328

May 1974

Reston, Virginia

Contents

Introduction

The objective of my assignment was to recommend what hydrologic analyses might be made using the records of stream discharge soon to be available at the gaging stations in Brazil. To attain this objective I (1) examined the streamflow records in part of the Rio Jacui basin in the state of Rio Grande do Sul for quality, length of record, and density of areal coverage; (2) looked at the available topographic maps; (3) spent one day in the field visiting gaging stations and observing general hydrologic conditions and (4) examined an isohyetal map of Brazil. The assignment was accomplished May 6-24, 1974.

Streamflow records generally are collected for use in planning and design of structures that utilize water or that require protection from water. Streamflow records are also used in operating powerplants, in forecasting floods and droughts, and in defining the effects of changes in a basin on the streamflow characteristics.

Most of those uses require analyses of gaging station records. For planning and design, flow characteristics such as annual mean flows, flood-peak frequency curves, low-flow frequency curves and draft-storage frequency curves are commonly needed.

If a gaging station record is available at the site where a project is to be constructed, the analyses of that record may provide the needed information, but streamflow information is needed at many sites where no gage record has been obtained. To meet this need some method of transferring flow characteristics to ungaged sites is needed. The most common method relates a flow characteristic to basin characteristics.

Although the principal purpose of hydrologic analyses is to furnish information for utilizing streamflow, these analyses may also indicate deficiencies in hydrologic data and the need for alternative types of analyses with the corresponding data requirements. Thus, hydrologic analyses will provide information both for utilization of streamflow and to improve the data collection and analytic procedures in order to further improve the reliability of the flow characteristics.

A large amount of streamflow data will soon be available for analysis in Brazil. The results of analyses of those data should be of great value in planning the further development of the resources of Brazil; their use should substantially reduce the studies required for individual projects.

The assistance and cooperation of Don C. Perkins, Senior Hydrologist, U.S. Geological Survey, (USGS); Dr. Eduardo de Castro Ferreira Pinto, Projeto Hidrologia, Departamento Nacional de Águas e Energia Elétrica (DNAEE), Rio; Dr. Roberto Moreira Coimbra, Acting District Chief, DNAEE, Porto Alegre; Dr. Delio Fernandes, DNAEE, Goiânia; and the staff at Porto Alegre is greatly appreciated. Without their help I would not have been able to interpret the data, understand the hydrology and hydraulics, and get a basis for the needs for streamflow information.

Examination of Data

I spent May 7 - 15, 1974, in the DNAEE office in Porto Alegre. During that time I examined the gaging station records in the Rio Jacui basin upstream from Rio Taquari, visited some gaging stations, and lectured on hydrologic analyses to the professional hydrologists of DNAEE.

In the basin there are 20 gaging stations for which stage records and discharge measurements are available at the DNAEE office. These stage records had been evaluated and obvious erroneous parts eliminated or corrected. Results of discharge measurements were already listed, and for some stations the rating curves had been prepared. Because the basic data were collected by various agencies over a period of about 40 years, and because discharge measurements were (and are) not computed by the "hidrometristas", it was not feasible for me to follow every step in the discharge computation process. However, the available material and discussions with the hydrologists gave me an adequate basis for evaluating the reliability of the individual streamflow records.

At this time, discharge records are not available for these stations. My evaluation of the reliability of discharge records that will be computed is based on the available stage records and rating curves either already defined or plotted by me. In general the upper ends of rating curves are poorly defined. Hydrologists have spent considerable time extending ratings above the defined portion by various methods, but little effort is justified because no information on the channel characteristics or the station control is available in the office; and the field work is being done by Companhia de Pesquisa de Recursos Minerais (CPRM), not by DNAEE.

The following station records were examined:

85 - 460 Rio Vacacai at Santa Brígida

Stage record 1928-71 but with many gaps. Few discharge measurements except in 1971. Rating not stable. It is questionable whether a discharge record should be computed here.

85 - 470 Rio Vacacai at Pte. São Gabriel

Stage record and measurements since 1967. Rating fair except for minimum flows.

85 - 480 Rio Vacacai at Passo do Rocha

Record since 1970. Rating poor.

85 - 520 Rio dos Corvos at P. Barca do Pavão

Record since 1971. Tentative rating looks pretty good. Small range in stage because of swamps upstream.

85 - 580 Rio Vacacai at Passo do Verde

Record since 1967; Medium and higher part of rating good; low end of rating poor.

85 - 600 Rio Vacacai at Passo das Tunas

Record since 1942. Rating OK at upper end; extension not great.

85 - 620 Arroio São Sepé at Pulquéria

Stage record 1947-65. Measurements made only in 1947 and 1949 (except for 1 in 1964) define a fairly good rating.

85 - 630 Arroio São Sepé at Passo São Sepé

Stage records since 1940, but those from 1965-68 seem questionable. High-water rating good. Discharges during rises are smaller here than at Pulquéria, which is upstream. Apparently floods at Pulquéria are attenuated by channel storage downstream.

85 - 380 Rio Jacuizinho at Passo Estrela

Stage record since 1953. Rating good except at lower end.

85 - 440 Rio Jacui at Ponte Jacui

Stage record 1927-54 except for some months. Most of the 21 measurements were made in 1940. Rating probably adequate for defining annual flood and annual means for period of stage record.

85 - 650 Rio Jacui at Cachoeira

Stage record 1934-53. During 1940-52, nineteen measurements were made. Discharge record should be fairly good 1934-53.

85 - 850 Rio Pardinho at Santa Cruz-Montante

Stage record and discharge measurements since 1964. Rating good.

85 - 850001 Rio Pardinho at Santa Cruz-Jusante

Stage record began in 1939 but parts are questionable. Discharge 1940-43 and 1950-54 should be usable. Upper end of rating good. Discharge records for the two stations at Santa Cruz may be combined because they are not concurrent and the stations are close together.

85 - 890 Rio Pardo at Ponte do Rio Pardo

Stage record and discharge measurements since 1964, but rating is very poor because of backwater from Rio Jacui. Use of stage record on Rio Jacui (85-900) to define a stage-fall rating was only partly successful. The fall between the two stations is probably negligible at times.

85 - 900 Rio Jacui at Rio Pardo Montante

Stage record since 1964. Rating looks good.

85 - 080 Rio Jacui at Espomoso

Stage record 1942-70. Measurements made until 1959. Rating well defined but upper end has long extension.

85 - 120 Rio Jacui at Passo Bela Vista

Stage record 1940-70. Measurements made 1940-56. Excellent rating with little high-water extension needed.

85 - 140 Arroio Grande at Ponte Arroio Ibirubá

Stage record covers 1943-59 but with many months missing. Many measurements; my plot indicates a good rating with an acceptable high-water extension.

85 - 200 Rio Jacui-Mirim at Passo do Lagoão

Stage records 1942-67. Good rating based on 119 measurements 1941-57.

85 - 400 Rio Jacui at Dona Francisca

Stage record 1940-73. Rating good; upper end extended from 7 to 13 meters.

Other information needed for hydrologic analysis in the basin includes topographic and rainfall data. Map coverage in Rio Grande do Sul ranges from excellent to adequate for defining topographic characteristics of drainage basins. Comparable coverage is said to be available in most of eastern Brazil.

An isohyetal map of annual precipitation in Brazil, based on records for 1914-38, is available. A similar map, based on records for 1941-70 for the state of São Paulo, is published. Rainfall records are available to make detailed isohyetal maps of many of the other states, but this will be a time-consuming job.

Recommendations for Analyses

As soon as discharge records are available at gaging stations the following types of analyses are recommended:

1. Computation of mean flow at gaging stations. For short records, adjust the computed mean to that for a longer period on the basis of long records at nearby gaging stations, by the method described by Riggs (1969 p. 108)

2. Prepare frequency curves of annual mean flows at stations having 10 or more years of record. The frequency curves should show the probabilities or recurrence intervals of experiencing means less than the curve value. Graphical analysis will be adequate. See Riggs (1968, p. 8)

3. Prepare frequency curves of annual floods at gaging stations having 10 or more years of record. This will require first an estimate of the maximum stage each year obtained by (1) plotting the twice-daily gage height readings for a few days before and after the annual maximum flood, (2) sketching in the probable gage-height graph, and (3) reading the maximum stage from that graph. The maximum stage is entered in the rating curve or table to get the maximum peak discharge for the year.

   The annual floods are used to define a flood-peak frequency curve as described by Riggs (1968, p. 7 - 9). Graphical analysis is adequate, is quicker, and is as reliable as mathematical fitting of a specific statistical distribution.

4. Relate flow characteristics to basin characteristics as described in the following section.

Relating Flow Characteristics to Basin Characteristics

Flow characteristics to be studied are (1) mean flow of record, (2) annual mean flows at selected recurrence intervals from the frequency curves of annual means, and (3) annual flood peaks at selected recurrence intervals from the flood frequency curves.

The general procedures are described by Riggs (1973). Only a few basin parameters should be used; the selection should be based on ease of definition and probable importance in describing the difference in flow characteristics among basins.

Drainage area and annual precipitation may describe most of the variation in mean flow and in annual mean flow at selected recurrence intervals. An index of basin storage may be necessary in some regions.

Flood peaks at 10-year, 25-year, and 50-year recurrence intervals should be related separately to drainage area, using data for a state or other large region that appears to be hydrologically homogeneous. The graphical method of multiple regression is recommended for these exploratory analyses. See Riggs (1968a, p. 22-25 and Riggs 1973, p. 5).

Examination of the data and of the basins for points which deviate greatly from the relation with drainage area should lead to identification of other basin characteristics that will help describe the vatiability among basins. Precipitation, channel slope, and basin storage may be useful variables, but defining indexes of any of these in advance is recommended only if it appears that it will be useful.

If a characteristic has a small variability over a region it will not help to describe the differences in flow characteristics among regions.

The size of region used in a single analysis may have to be defined subjectively on the basis of hydrologic knowledge and on plotting of data. Some basin characteristics such as geology can not be described by a number, but the effect may be minimized by limiting the analysis to a region in which the effects due to geology have little range. A region should not be small, however. A minimum of 20 or 30 stations should be included except where streamflow data are sparse.

A relation between a flow characteristic and basin characteristics will not apply in some basins. For example, flood peaks on Arroio São Sepé decrease with an increase in drainage area between Pulqueria and Passo São Sepé; this condition can not be described by a simple regression model and a few parameters. For such streams, other methods of transferring flow characteristics are needed.

Transfer of flow characteristics along the main channel of a stream gaged at several points may be done quite reliably from a graph on which the various flow characteristics are plotted against distance along the channel. This method is generally more accurate than regression on basin characteristics where the records on the main stream are long; it is recommended for the Rio Jacui which is gaged at 6 points above Rio Taquari (in Rio Grande do Sul).

Analyses of Lower Priority

1. Low-flow frequency characteristics cannot be defined accurately from the gaging-station records I examined, because the lower ends of most rating curves are poorly defined.

2. Draft-storage-frequency analyses can be made easily when the daily discharges are in computer storage. Such analyses probably should be restricted at present to regions where there are specific needs.

3. Flow-duration data can be easily obtained from the computer file of daily discharges, but flow-duration curves are of little value.

Uses for Results of Analyses

To provide information to the public:

The principal use will be to estimate flow characteristics at ungaged sites. This capability should be of great value in planning the development of the water resources of Brazil. Therefore, the results should be published so they will be readily available as needed.

To improve the hydrologic work:

In addition to presenting streamflow information in a form useful to planners and designers, the examination of streamflow records and the study of flow characteristics in relation to basin characteristics will lead to a better understanding of the hydrology. Specific findings may include: (1) identification of streams to which standard methods of analysis do not apply, (2) identification of gaging station records that appear questionable, and (3) evaluation of the adequacy of the gaging station coverage with respect to range in drainage area sizes.

These findings should be used to improve the program of data collection and analysis by use of alternative methods of transferring streamflow characteristics in space (with their different data requirements), methods for improving the operation of gaging stations, and modification of the data-collection network.

Alternative Methods of Transferring Streamflow Characteristics in Space

Mean flow can be estimated at an ungaged site if monthly measurements of discharge are made at the site. The method is described by Riggs (1969). Applicability of this method to various regions of Brazil can be tested by using gaging-station records.

Channel width has been shown to be a useful index of flood characteristics in some regions of the United States. This relation should be explored for Brazilian streams when flood-frequency curves are available. If suitable relations can be developed, their use would permit quick estimates of flood-peak characteristics along channels where regression on basin characteristics does not give usable results, and where streamflow records are too short to define frequency curves. A summary of Wahl (written communication, 1974) describes significant procedures and applications.

A Recommendation for Improving the Operation of Gaging Stations

Based on my examination of streamflow data in Rio Jacuí basin, the biggest problem is to define the upper end of the stage-discharge relation. A point high up on the rating could be obtained by a slope-area survey and computation of the peak discharge following a large flood---but large floods are infrequent, and slope-area measurements are costly.

A simpler method of estimating the discharge at a high stage has been proposed by Riggs (written communication, 1974). The discharge through a reach at a given stage is computed from the average cross-sectional area and the water-surface slope at that stage. The relation, based on data given by Barnes (1967), is

$$\log Q_s = .53 + 1.295 \log A_s + .316 \log S$$

where Q_s is discharge in m^3/sec, A_s is cross-sectional area in m^2 (average area of 3 cross sections), and S is slope (dimensionless) of the water surface through the channel reach. Standard error of the regression is about 20 percent. The Manning roughness coeficient is not needed in the relation,because it is closely related to channel slope in natural channels. The relation has not been verified by data other than those used in its derivation.

The information needed to apply the relation to a site is (1) three measured cross sections of the stream over a reach of at least 4 or 5 channel widths, and (2) the measured water-surface slope at the time of the survey. The stage for which a discharge is to be computed is then selected and the measured slope drawn through this point to define the upper limits of the measured cross sections. The areas of the cross sections are then computed and averaged for entry into the equation along with the slope.

This application of the method assumes that the water-surface slope at a low or medium stage is the same as the slope at a high stage, an assumption that should be valid for fairly uniform stream reaches.

The method applies only to streams in one channel (no appreciable overbank flow), and the relation is based on discharges that nearly filled their channels.

Application of the relation to Brazil could be checked at a few stations by making a high discharge measurement and at the same time measuring a couple of additional cross sections and the water-surface slope. The discharge computed by the formula using the average of the measured cross sectional areas and the measured water-surface slope would then be compared with the measured discharge.

If the relation is verified in Brazil, then it should be used at gaging stations where the rating curves must be extended far beyond the discharge measurements and where it is difficult to make current-meter measurements of large floods. Better definition of the water-surface slope in the vicinity of the gage could be obtained by use of crest-stage gages at each end of each of the three cross sections.

Guides to Modifying the Data-Collection Program

Examination of a data-collection program should begin with a statement of objectives. What information is needed, or will be needed? Ordinarily the principal information needs are (1) streamflow characteristics at any site on any stream, and (2) current streamflow data at specific sites for project operation, forecasting, or other uses.

The extent to which the first of these objectives has been met can be determined by analyzing the available data. The first step in the analysis is to relate flow characteristics to basin characteristics. The results will be valuable for planning and design of projects as well as for showing deficiencies in certain regions and in coverage of streams in small basins.

Results of the analyses are merely a guide. The actual modification of the program must be somewhat subjective, must consider costs, priorities, and the differing accuracy needs of the various regions.

As general rule, a few gaging stations should be operated indefinitely, but the majority need not have more than about 20 years of record. Most gages in Brazil are on the main streams. Data should be collected on some small streams, but it may not be necessary to collect a continuous discharge record at all of these.

Where regression on basin characteristics is not suitable, analytical methods using a few data at each site should be incorporated in the program. Accuracy of the regression method ordinarily will not be improved by use of additional streamflow records or by obtaining longer records.

Regulated streams must be gaged if flow information is needed. Methods of transferring flow characteristics to ungaged streams do not apply to regulated streams.

Examination of the data-collection programs should be done periodically to confirm that proper data are being collected to make the selected analyses, and to find out if the types of analyses being used are appropriate to the type of data that are being or can be obtained. This examination should include evaluation of the quality of the gaging station records being collected.

Related Activities

Although not a part of my assignment, I was requested by hydrologists of DNAEE to describe hydrologic techniques.

In Porto Alegre, in one afternoon I described to the professional staff and to Délio Fernandes and Eduardo de Castro Ferreira Pinto, the conclusions of my review of streamflow records and other hydrologic information in the upper Jacuí basin. On another day I discussed (1) extension of streamflow records in time, (2) regional analysis, and (3) other methods of transferring streamflow characteristics in space.

In Rio, I lectured to the hydrologists of DNAEE one afternoon on use of rainfall in estimating streamflow and on other reconnaissance methods. The following afternoon I discussed network planning.

By request, I reviewed a regional analysis of flood-peak characteristics in the Rio Canoas basin. This is the first analysis of this type made by DNAEE. I furnished written comments and later discussed them with the analysts, Eduardo de Castro Ferreira Pinto and João Eduardo O. Rodrigues.

Summary

1. The objective of my assignment was to recommend what hydrologic analyses should be made as soon as discharge records are available.

2. I examined gaging stations records in upper Rio Jacuí basin in the Porto Alegre office of DNAEE, and visited some gaging stations.

3. I lectured 1 1/2 days to the professional staff at Porto Alegre.

4. In Rio, I prepared this report, lectured two half-days, and reviewed a regional flood-frequency analysis.

5. I recommend that regional analysis of mean streamflows and of flood-peak characteristics be started as soon as discharge records are available.

References

Barnes, Harry H. Jr., 1967, Roughness characteristics of natural channels: U.S. Geol. Survey Water-Supply Paper 1849, 213 p.

Riggs, H. C., 1968, Frequency Curves: U.S. Geol. Survey Techniques Water-Resources Inv., book 4, chap. A2, 15 p.

Riggs, H. C., 1968a, Some statistical tools in hydrology: U.S. Geol. Survey Techniques Water-Resources Inv., book 4, chap. A1, 39 p.

Riggs, H. C., 1969, Mean streamflow from discharge measurements: Internat. Assoc. of Sci. Hydrology Bull., vol. XIV, no. 4, Dec. 1969.

Riggs, H. C., 1973, Regional analyses of streamflow characteristics, U.S. Geol. Survey Techniques Water-Resources Inv., book 4, chap. B3, 15 p.