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HYDROELECTRIC RESOURCES IN LATIN AMERICA: THEIR MEASUREMENT AND UTILIZATION

Report submitted by the Economic Commission for Latin America - Energy and Water Resources Programme

NOTE: This text is provisional and is subject to changes of substance and style.

FOREWORD

The present study contains a preliminary and brief review of Latin America's hydroelectric resources, with special reference to the amount of knowledge available on them, their approximate magnitude and the part they play in supplying the region's energy requirements.

It is pointed out, in the analysis of the third aspect in the Introduction, that Latin American hydroelectric production is growing at a steady pace and that its share in the consumption of commercial energy - which is already nearly 15 per cent - is increasing, in common with the averages for the world and its main regions. Latin America's contribution to total electric power production is slightly more than 50 per cent and is expected to expand, whereas the world average is a little over 30 per cent and is on the decline.

In chapter I of the present paper it is stressed that the Latin American countries need to evaluate their water resources and plan their utilization with a view te obtaining the greatest possible benefit, in keeping with the experience already acquired in the integrated multi-purpose development of numerous river basins.

For this purpose, the salient concepts on hydroelectric potential are reviewed; the difficulties deriving from the use of this potential are pointed out and the particular potentials recommended that would be most suitable at the present stage of development in Latin America and the current position of water resources research there. The corresponding methods of evaluation are also described.

Generally speaking, a calculation should be made of the so-called theoretical potentials which, while constituting ceilings that are unattainable in practice, require a minimum amount of information and enable potentials for economic use to be estimated within fairly narrow limits by means of empiric coefficients.

As the irregularity of stream flow has a strong influence on the economic aspect of water resources development, a very useful coefficient, which has been recommended by the Economic Commission for Europe, is suggested for general programming studies.

/In chapter

In chapter II, up-to-date calculations of hydroelectric potentials in Latin America are given, together with the concepts in current usage and a broad outline of their application.

With respect to theoretical potentials, the assessments made by the United States Geological Survey (the sole source that covers research throughout the world) are reported; the criteria adopted were fairly uniform but the data vary in accuracy and scope. The calculation based on average stream flow attributes 23 per cent of world hydroelectric potential to Latin America, and there are no comparative data in the region against which the figures can be checked.

Conversely, in the field of economic potential, individual country assessments are available and have been compiled by the Economic Commission for Latin America. They differ considerably in method and principle. According to their data, the minimum economic potential of the region is 150 million Kw.

The data on the economic potentials of selected river basins shows that the geographical distribution of these basins is irregular.

It is clear that what is lacking is a systematic evaluation based on the same criterion in every country of the region.

For purposes of illustration, an analysis is made of the variation in the stream flow of selected Venezuelan and Chilean rivers and, in the case of Argentina, a very tentative curve is constructed for this factor, in application of the calculation mentioned in chapter I.

An examination is then made of the extent to which hydroelectric resources have been used in Latin America (in the proportion of about 4 per cent of the economic potentials), from which it emerges that the low percentage denotes the abundant nature of the resources rather than any lack of interest in their development.

Chapter II concludes by an account of some general features of existing hydroelectric works and explores the possibility of establishing new plants in the next few years, which would accentuate the sustained upward trend of growth registered so far.

/In chapter

In chapter III, the facilities for research on Latin America's water resources are studied, and stress is laid on the importance of flow and rainfall measurements (continuous statistical series covering an adequate number of years) for the proper execution of hydraulic works.

Most of the analysis is devoted to ascertaining the number of rain gauges and flowmeters in service in the different countries and important river basins, the span of the records in years is noted and the coverage indices calculated (number of stations per 10,000 square kilometres by average years of registration).

Consideration is then given to the detailed plans showing contour lines that are available, since they are another essential item of information for the evaluation of theoretical potentials. It appears that, despite the shortage of facilities for investigating hydraulic resources in Latin America, it would be possible to make a co-ordinated, systematic and integrated evaluation of hydroelectric potentials.

Lastly, a list is given of the organizations that are responsible for taking hydrological measurements in each country, together with observations on the coordination of the work, centralization and the publication of data.

No analysis is made in this study of the unit costs of hydroelectric installation and production in Latin American countries, as they form the subject of a special secretariat paper.

INTRODUCTION

The participation of hydraulic energy in total world production of commercial and electric energy

An analysis of the part played by water resources in supplying commercial energy during the last twenty years, and of their contribution to electricity production in the principal regions of the world – especially Latin America –, paves the way for an objective appraisal of the importance of their present role and an estimate of future prospects.

Table 1 shows that, in all the regions indicated, hydroelectric production increased in the last twenty years, usually far outpacing commercial energy but lagging behind total electricity production, as will be seen in greater detail later. Without dwelling on aspects which are dealt with at length in another ECLA study,[1/] mention should be made of the rapid rate at which commercial and hydraulic energy are developing in Latin America.

While the consumption of commercial energy in 1959 amounted to 2,750 million tons of petroleum equivalent for the whole world, at a cumulative annual rate of growth of 5.5 per cent – the average for the last decade –, demand in Latin America reached 84 million tons with a growth rate of 7.6 per cent. In the United States and Western Europe, demand was 937 and 556 million tons of petroleum equivalent respectively, and expanded annually at the rates of 3.5 and 3.8 per cent.

During the same two decades, the use of hydraulic energy to cover the above-mentioned requirements increased not only in absolute but also in relative terms, as may be seen from table 2.

Nevertheless, owing to the very unequal way in which the rates progressed in the regions indicated, the percentage contribution of hydraulic energy also changed in different degrees. It was highest – nearly 29 per cent – for the group of countries composed by Australia,

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1/ Present status and recent development of electric energy in Latin America (ST/ECLA/CONF.7/L.1.01).

/Table 1

Table 1

CUMULATIVE ANNUAL RATES OF GROWTH OF HYDROELECTRICITY, TOTAL ELECTRICITY AND COMMERCIAL ENERGY,a/ 1937-58

(Percentage)

	Commercial energy	Total electricity	Hydro-electricity
Latin America	6.3	8.2	7.7
Western Europe	1.9	6.0	5.6
Eastern Europe	5.2	8.4	10.0
United States	3.0	9.0	5.9
Other developed countries b/	3.7	5.9	5.5
Rest of the world	7.6	9.0	6.1
World total	3.6	7.5	6.0

Source: ECLA, on the basis of direct information for Latin America, and on United Nations, Statistical Papers, Series J. 1/3 for other regions and countries.

a/ Commercial energy comprises petroleum - including natural gas and its derivatives, mineral coal and hydroelectricity. Hydroelectricity has been evaluated by the amount of petroleum (at 10 700 kCal/kg) that would be needed to produce the same amount of electricity, due account being taken of the average yields of thermoelectric plants. For further details see Present status and recent development of electric energy in Latin America, op.cit.

b/ Australia, Canada, Japan, New Zealand and the Union of South Africa.

/Table 2

Table 2

PARTICIPATION OF HYDROELECTRICITY IN COMMERCIAL ENERGY CONSUMPTION

(Percentage)

	1937	1949	1955	1958
Latin America	13.5	13.6	12.7	14.0
Western Europe	7.6	9.7	11.6	13.4
Eastern Europe	1.6	1.4	2.3	3.4
United States	4.1	5.4	5.3	6.2
Other developed countries a/	24.0	26.6	27.4	28.8
Rest of the world	5.3	7.0	3.0	3.3
World total	6.6	7.5	8.0	8.9

Source: ECLA, on the basis of direct information for Latin America, and on United Nations, Statistical Papers, Series J. 1/3 for other regions and countries.

/Canada, Japan,

Canada, Japan, New Zealand and the Union of South Africa, and at lowest - 3.3 per cent - for the less-developed countries, excluding those of Latin America.

Apart from the former group of countries, in which hydraulic energy supplies more than a quarter of the commercial energy required to satisfy consumption, its contribution is greatest in Latin America and Western Europe, where it amounts to an eighth of the total.

The relative reduction in the part played by hydroelectric power in Latin America in 1955, which is observable from tables 2 and 3, was mainly due to the fact that the public utility systems in Brazil, in spite of having several hydraulic units in process of installation at Peixotos, Cubatao, Nilo Peçanha and Salto Grande, did not enter operation until 1956.

The share of hydraulic energy in world electricty production may be studied in table 3, which covers the same regions and years as table 2.

In contrast to the trend of events observed in the production of commercial energy, hydraulic energy is, on the whole, taking an increasingly small part in total electricity production in spite of its steady increase in absolute terms. This contraction is due to the more rapid development of electricity in recent decades which, from constituting 17 per cent of world commercial energy consumption in 1937, expanded to 22 per cent in 1949 and to about 35 per cent in 1958, without any apparent pause in its upward climb.[2/]

The only regions where hydroelectric power increased its participation in electricity production during the last two decades were Eastern Europe (mainly because of progress in the USSR) and, to a lesser extent, Latin America.

Together with the group of highly-developed countries consisting of Australia, Canada, Japan, New Zealand and the Union of South Africa, the Latin American region and Eastern Europe used water resources more extensively in their total electricity production (in proportions of 70, 52 and 41 per cent respectively), while the world average was 32 per cent.

2/ Present status and recent development of electric energy in Latin America, op cit.

/Table 3...

Table 3

PARTICIPATION OF HYDROELECTRICITY IN TOTAL ELECTRICITY PRODUCTION a/

(Percentage)

	1937	1949	1955	1958
Latin America	50.9	52.1	49.8	52.0
Western Europe	44.5	41.9	41.0	41.3
Eastern Europe	11.5	9.7	11.2	15.8
United States	37.0	30.8	19.0	20.2
Other developed countries b/	74.3	77.6	71.5	69.6
Rest of the world	46.2	51.4	23.0	26.3
World total	42.8	38.8	30.5	31.8

Source: ECLA, on the basis of direct information for Latin America, and on United Nations, Statistical Papers, Series J. 1/3 for other regions and countries.

a/ Comprising production for public consumption and production by private services for their own use.

b/ Australia, Canada, Japan, New Zealand and the Union of South Africa.

/A summary

A summary of world hydroelectric production, which reveals the accelerated development of hydraulic resources in the world and in Latin America in particular, is given in table 4 in absolute terms.

Nevertheless, it may be said that Latin America has barely started to tap its hydraulic potential. The first confirmation of this statement comes from table 5, which shows the amount of hydroelectric power that was produced per unit of area in 1958.[3/]

When the table is analysed, it is interesting to note that the Latin America and other less developed countries account for only 1.5 and 0.4 mWh/km^2, while the world average is 4.5, and the respective figures for Western and Eastern Europe are 21.1 and 13.8 mWh/km^2. It is undeniable that hydraulic potential varies considerably from one basin to another, in accordance with topography, precipitation, evapo-transpiration and underground infiltration, but even without going into these aspects in detail, it may safely be stated that in no case are they sufficiently adverse in Latin America as a whole as to give rise to potentials that are equal to only a third part of the world average, which is the state of development in Latin America today.

On the contrary, and despite the fact that the investigations made so far in this field have been on a small scale, it may be accepted that the potential per unit of area is considerably higher than the world average as it stands at present. Hence, it is obvious that development of hydraulic energy in Latin America is exceptionally low, although this source plays an important part in electricity production.

Of the different guises in which water will help in the economic development of the region, not the least important will be its role in the production of electric energy. On the ome hand, the growth of demand

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3/ It should be remembered that available head and flow are the prime factors determining potential in each hydroelectric plant. The former is a function of the topographic conditions and the latter of a number of elements, such as precipitation, evaporation, underground infiltration, and the extension of the catchment area up to the point under consideration. For this reason, it is customary, in evaluating potential and hydroelectric uses, to relate them to the unit of area.

/Table 4

Table 4

HYDROELECTRICITY PRODUCTION AND AVERAGE RATES OF ANNUAL GROWTH

	Production (millions of mWh)				Rates of growth (percentage)		
	1937	1949	1955	1958	1937/1949	1949/1955	1955/1958
Latin America	6.3	13.6	21.1	29.8	6.6	7.6	12.1
Western Europe	62.3	92.1	159.7	197.1	3.3	9.6	7.4
Eastern Europe	7.0	11.0	27.3	51.7	3.9	16.5	23.7
United States	44.0	90.0	120.4	147.0	6.1	5.0	6.9
Other developed countries a/	51.0	85.2	131.4	158.1	4.4	7.5	6.6
Rest of the world	6.2	12.8	11.4	21.7	6.3	-1.8	19.0
World total	176.8	304.7	471.3	605.4	3.4	7.6	8.6

Source: ECLA, on the basis of direct information for Latin America, and on United Nations, Statistical Papers, Series J. 1/3 for other regions and countries.

a/ Australia, Canada, Japan, New Zealand and the Union of South Africa.

/Table 5

Table 5

HYDROELECTRICITY PRODUCTION PER UNIT OF AREA, 1958

	Millions of mWh	Millions of square kilometres	kWh/km2
Latin America	29.8	20.38	1 460
Western Europe	197.1	9.36	21 050
Eastern Europe	51.7	3.74	13 810
United States	147.0	23.42	6 280
Other developed countries a/	158.1	19.54	8 100
Rest of the world	21.7	58.93	370
World total	605.4	135.37	4 470

Source: ECLA, on the basis of direct information for Latin America, and on United Nations, Statistical Papers, Series J. 1/3 for other regions and countries.

a/ Australia, Canada, Japan, New Zealand and the Union of South Africa.

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for this form of energy, which is expected to increase at a rate of between 7 to 12 per cent annually (doubling or trebling in 10 years' time) according to the country in question,[4/] and, on the other, the wealth of hydraulic potential, on which little is known as yet, will provide a sound economic basis for multi-purpose river development.

For this reason, it is becoming increasingly necessary to make a proper evaluation of the inherent possibilities of the Latin American river and lake systems.

The general review of facilities for investigating water resources from the standpoint of stream flow, which comprises the last chapter and was specially undertaken for the purposes of the study on hydroelectric potentials, is wholly valid and can be used as a basis for other analyses, including that of multiple-purpose development.

4/ Evaluation of future demand in Latin America (ST/ECLA/CONF.7/L.1.11).

/Chapter I

Chapter I

HYDRO-ELECTRIC RESOURCES: CONCEPTS AND METHODS OF EVALUATION

1. General considerations

Water is in limited supply on every continent and is of vital importance to mankind. It must therefore be used in the best interests of the community as a whole. While this becomes more essential everywhere as time goes on, it may even be a critical factor in some areas and seriously curtail their prospects of economic development.

The experience gained in many parts of the world with respect to the multiple-purpose development of rivers and basins and the evolution of the many theories on the subject have clarified a number of problems arising from optimum use of water.

The Latin-American countries, with their vast territories and untapped water resources, thus have the opportunity to plan their development in the light of this fact, and they must do so.

The following characteristics of a body of water must be determined before it can be equitably distributed among consumers and used to the best advantage: on the one hand, the volume, quality, geographical distribution and rate of flow (within a hydrological year and from one year to another) and, on the other hand, the amount required for various purposes (drinking water, irrigation, power production, industry, navigation) as well as the benefits to be derived from regulating increases in the flow of water.

It should be borne in mind that hydro-electric potential does not only depend upon the volume of water available in the time unit; it also implies that changes in elevation must be considered as well as the rate of stream flow. Hence, the hydro-electric potential is proportional to the product of these two factors.

It should also be noted that the operation of a hydro-electric plant as a source of energy depends as much on the demand for electricity within the network or system to which it is attached as it does on the volume of water available in the basin on which it is located to supply all the water requirements for which it is intended. Hence, its method of operation

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should combine the requirements of the various sectors in the best possible way. Specific cases arising in practice may cover a wide range, from a river primarily used for electric power generation to one where such production is merely the lesser of several uses to which the water is put. In most cases the design and administration of a hydro-electric works will provide both for electric power production and the use of the water for other purposes, although the order of priority will not be the same.

It is therefore essential that the organs responsible for the development of electricity services and those concerned with planning the multiple-purpose use of water resources should work in close co-operation for the benefit of the community as a whole. Experience nevertheless shows that authorities often give high priority and adequate funds for investigation of a specific development which can be completed within a short period of time. They are less inclined to invest in general research aimed at planning the overall development of a basin or region, particularly those involving long-term measurements. These specific projects often fail to achieve their purpose simply because data is lacking which might have been obtained had more time been taken over them, as advocated here.

Data essential to the planning of specific hydro-electric projects should be divided into two types: information which can be obtained in a relatively short period of time provided the necessary staff and technical equipment (topographical maps, geological surveys, soil mechanics, etc.) are available and the hydrological and hydro-meteorological data requiring several years of uninterrupted observations. With regard to the latter, it generally takes from twenty to thirty years before mean statistical values are obtained which can be considered reliable for future use as mean average values applicable to a specific area.[1/] It should be pointed out, however, that in many cases much less time is required, provided there are adequate correlations by which statistics on stream flow can be extended within a tolerable margin of error and,

1/ See: ECAFE, Flood Control Series, No. 7, Multiple Purpose River Basin Development, Part I, Manual of River Basin Planning and ECAFE Methods of Assessment of Hydro-Electric Potentials. I & NR/Sub.1/HPWP/1.

/secondly, if

secondly, if the economic loss resulting from this lack of absolute accuracy is less than the loss suffered by the community if a particular hydro-electric project were not carried out.

Generally speaking, overall development planning for an entire basin, involving as it does many experts in various fields and diversified research, must proceed slowly in view of the size of the investment required and the benefits to be derived.

In any case, a good knowledge of the geographical distribution of water resources and their specific features, including a knowledge of the hydro-electric potential, is clearly a basic requisite for river basin development planning. Full knowledge of a country's hydro-electric resources facilitates proper power development programming, the selection of the most suitable sites for electric power plants of different types (hydro-electric and thermal) and their relative role within each network, including the lines of inter-connection and transmission. Similarly, if hydro-electric power can be produced at sufficiently low cost, a valuable basic element will have been provided for the location of certain chemical and metallurgical industries which require a large supply of electric power.

2. Definitions of hydro-electric potentials

The United Nations specialized agencies, and particularly the Economic Commission for Europe and the Economic Commission for Asia and the Far East, have carried out studies for the purpose of laying down rules governing the uniform evaluation of hydraulic potentials at various levels, based on available data. Only thus can valid international or inter-regional comparisons be made.[2/]

The present position, while already discussed at length, is summarized below simply for the purpose of clarifying and emphasizing some practical

2/ See: Economic Commission for Europe, Hydro-electric potential in Europe and its gross, technical and economic limits (E/ECE/EP/131), Economic Commission for Asia and the Far East, Report of the working party on assessment of hydroelectric potential to the sub-committee on electric power (E/CN.11/I & NR/Sub.1/2) and Methods of Assessment of Hydro-Electric Potentials (I & NR/Sub.1/HPNP/1).

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aspects of immediate interest to the area. At the same time, a few specific suggestions are offered.

Two definitions of potentials are of particular interest to overall hydro-electric evaluations:

(a) The theoretical potential (sometimes called the gross potential) fully measures the resources of a hypothetical annual production of energy of a basin or river system in their natural state, that is to say without any alterations produced by works built to generate that energy. It is considered that all water at an elevation above sea level is susceptible of producing electric power, with a 100 per cent output.

(b) The exploitable potential (also called "technical potential" or "practical potential") measures resources by existing power plants and those capable of being installed at a given moment by conventional technical methods for this type of structure or with present techniques, setting a ceiling to the cost of installed kW. The concept of technically exploitable potential may seem very vague if no cost limit is set. In fact, if any construction is considered physically realizable (excluding the cost factor) the exploitable potential, or potential that can technically be achieved, is close to the theoretical potential.

It should be pointed out that the theoretical potential, as defined earlier, is an unalterable characteristic of each basin and is completely independent of the attitude of man,[3/] unlike the evaluations linked to development, either technical or economically achievable.

Theoretical potential should be divided into two parts:

(i) The gross run-off potential which measures the theoretical annual output of energy (or respective mean potential) by unit of area (kWh/km^2 or kW/km^2) corresponding to the water of a basin or region, neglecting the losses of water, and measured by each unit of surface with its altitude above sea level in its initial run-off.

3/ Not including changes in the rain pattern which may be produced by the method of "artificial rainfall" (increase in moisture nuclei by such agents as vapours of silver iodide). It should be pointed out that the evaluation of this potential must disregard the transfer of water from one basin to another.

Rain water falling on an area, it should be remembered, is divided into three parts which follow one of the three processes set out below:

1. Evaporation or transpiration from vegetation;
2. Surface run-off;
3. Infiltration with underground run-off.

The gross surface potential of a basin should preferably be estimated by "surface run-off" provided that there is adequate hydrological data or enough general information on which to base an adequate indirect assessment of the run-off coefficient (relation of volume of run-off to volume of precipitation).

If this cannot be done, the volume of precipitation (excluding losses) can be used to calculate the gross potential.

As very different results are achieved, depending upon the method used (by using the first method the estimated potential may be anywhere from 20 to 80 per cent of the figure obtained by the second method), every estimate of this type of potential should include: (a) the uniform application of one method for the entire project; (b) a clear indication of the method used, together with the specific values. (For more details, consult the UN, ECE and ECAFE documents referred to).

(ii) The gross river potential - on river beds - which measures the mean potential (or annual energy) along the course of each waterway and thus gives the kW (or annual kWh) for the whole river or for each unit of length.

The criticism levelled at theoretical potentials, namely that they are of no practical value because they only constitute unattainable upper limits, is valid if the problem is only considered from that point of view. However, once this fact has been recognized, they nevertheless serve some purpose in the overall approach to the problem. In fact, such limits should be considered unchangeable yardsticks against which actual progress achieved in a country or region can be measured. The same practical purpose can be served by the theoretical limit of thermo-dynamic efficiency (also unattainable) in the steam cycle.

Similarly, within the exploitable or technical potential a fraction is usually separated under the name of economic potential to define the

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potential that can be used on a short or medium term basis within the framework of the general economic development of the country concerned. In relation to the technically exploitable potential, the economic potential excludes that part of the development or portion of annual production which, in the event of insoluble conflicts with other water uses, do not have any priority over them when an integral analysis is made. It also excludes those incapable of supplying the same category of power (load factor, reliability of service, etc.) at a cost equal or less than that obtainable from other sources of electric power.4/

In addition to hydrological and topographical data (to which theoretical potentials are limited) the concept of exploitable potential requires detailed information on geological conformation (including background data on soil mechanics). Moreover, economic potential calls for research into the characteristic features of each particular case as it relates to the most proper use of water resources for the community and provision of its power requirements at minimum cost.

3. Difficulties in methods of evaluation

Estimates of the hydro-electric potential of river basins and countries, linked always to development sites considered economically exploitable, have for some time now been made in various parts of the world.

If the results of separate estimates on the same country or river system are compared, they will be found to differ widely, the most recent

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4/ The cost of hydro-electric power, when used for multiple purposes, obviously must be determined after a judicious distribution of investment among the several consumers. It is equally obvious that in each specific case the delay before the plant begins to operate and the foreign exchange investment are factors which must be borne in mind.

/estimates being

estimates being frequently the highest.[5] The explanation for these anomalies may be briefly summed up in the following main points:

1. Lack of hydrological and geomorphological data.
2. Lack of uniform evaluation criteria.
3. Evolution of construction techniques and methods.

Proper investigation of a river or lake system calls for the establishment of measurement units along the main waterways and the installation of flowmeter and hydro-meteorological stations by which the flow at key points can be measured over a period of years. The statistical series relating to basic pluviometer stations must at least provide measurements covering a period of several decades, with a minimum of 15 years for the flowmeters in order to establish a correlation with the former by which the statistical series can be extended to 20 or more years (preferably over 30) before the final plans for hydro-electric development are carried out. The difficulty

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5/ There are numerous cases in Latin America, among which the following may be mentioned:

(i) Argentina, with estimates of 6.5, 7, 11, 13 and 20 million kW within a period of not more than ten years (Guillermo A. Mazza, paper submitted at the Madrid Sectional Meeting of the World Power Conference held on 9 June 1960).

(ii) Colombia, with an estimated power potential of slightly over 4 million kW up to 1954. Very broad estimates on the subject made by Electricité de France and Gibbs & Hill Inc. (1955) now place the figure at 40 million kW.

(iii) Venezuela, with a potential previously estimated at 3.2 million kW up to 1955, is now considered to have a potential of 16 million kW following studies and research carried out mainly on the Caroní River.

The following cases can be mentioned for Europe:

(i) Switzerland, with estimates of 15, 20 and 27 million mWh in 1914, 1934 and 1946 respectively, for annual technically exploitable energy.

(ii) Sweden, with 40, 50 and 80 million mWh in 1938, 1952 and 1955, also for technically exploitable power. (E/ECE/EP/131) Hydro-electric Potential in Europe and its Gross, Technical and Economic Limits, and A. J. Dilloway "Comparative Study of Hydro-electrical Resources as Exemplified by European Experience - paper submitted to the World Power Conference - 9 June 1960).

/of obtaining

of obtaining the above statistics will be more clearly appreciated if it is pointed out that very often a high percentage of the hydrometrical stations required have to be maintained over a period of years in remote areas difficult to reach. In Latin America the sites must range from high mountain zones to wooded areas with a tropical climate.

On the other hand, changes in elevation along rivers are difficult to measure mainly because of their inaccessibility, there being few roads over which they can be reached. However, general estimates of hydro-electric potential can now be made and civil engineering projects planned by means of aerophotogrammetry, which has become an efficient and rapid method of obtaining the necessary preliminary data, except perhaps in very densely wooded areas.

It should be pointed out that the data provided by the type of investigation mentioned above merely covers "volume of flow" and "head", to the product of which the theoretical potential of a waterway is proportionally related; it does not provide other information which is essential to the definition of the exploitable or economic potential of a site, such as data relating to geological characteristics, soil mechanics, volume of flow regulation, the complementary or conflicting nature of the development with other uses of water, etc.

Determination of hydro-electric potentials in Latin America has not only suffered from lack of basic hydrological and topographical data but also from lack of uniformity in the definitions and procedures used in different countries and even within the same country. Estimates have been made with respect to the same rivers or river systems, based on the same background information, which have produced vastly different results depending upon the expert or institution entrusted with the survey.[6/]

It is therefore essential that the countries in the region should agree on specific definitions of potential so that uniform estimates at various levels can be achieved on the basis of the data available. Only a very few countries in the area have adopted the relevant recommendations

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6/ For instance, the potential of Lake Titicaca has been estimated at anywhere from under 1 million kW to over 2.5 million kW.

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of the World Power Conference and even in those countries the recommendations have not always been carried out.

The widespread practice in the region of evaluating potentials solely on the bases of sites "considered to be economically exploitable" has, it should be pointed out, created specific difficulties even though it has been applied on the basis of uniform criteria.

In fact, the personal factors which affect the overall concept of every project in determining its possible use introduce an element of extreme variability which must be reduced to the minimum. Moreover, improved techniques and construction methods, inter alia, may in time substantially modify the economic aspect of projects so that some, considered unjustified in the past, may be recommended as feasible in the future.

Since a study of the "economic electric exploitability" of water resources should include not only electric power but the other uses to which the water can be put, harmonic plans should be formulated for its multiple use on the basis of general economic considerations which lessen the viable and categorical nature of the estimates of the potential in question. There should be, among other things, standard criteria for determining the priority of a group of structures within the overall development plan.

In practice, it is difficult to lay down a rigid method by which systematic determination of economic potentials on a 10 or 15 year basis can be effected. The conditions affecting the economic character of a project are linked to a number of unpredictable factors such as the volume and structure of demand; the availability and price of other competing sources of electric power production; characteristics of the consumer pattern to be met not only as a result of demand growth but also of the type and economic features of the plants built prior to the development project under consideration; the complementary or conflicting nature of the project with other uses of water and criteria for the distribution of investments made in multiple-purpose projects; development of construction techniques and costs; time required for a project to "ripen", etc. Even the rates of interest, which vary, have

/a substantial

a substantial effect on changes in the cost of electricity from a single source since, under present average conditions, capital costs represent up to 85 per cent of the cost of power in a hydro-electric plant as against only 40 per cent for a thermal plant.

Moreover, its general application is hardly feasible in Latin America at present because so much data and background information of different types is needed which require time and specialized staff and equipment.

In short, for developing countries such as those in Latin America it is essential that the study of a particular river development project under construction should include an evaluation of the hydro-electric potential limited to the economically exploitable "quantum" (together with criteria for the optimum utilization of water). However, evaluations on a larger scale for purposes of planning, which should be carried out as rapidly as material conditions in each country will allow, call for the adoption of simpler, more expeditious, concepts and criteria.

4. Suggested methods of evaluation

(a) Gross runoff potential

The method of determining the gross runoff potential requires the division of the region or country under study into small sub-basins for which information is available on stream flow, with statistics covering a long period (not less than twenty years) or, if the period covered is only some twelve or fifteen years, with statistics that can be extended by covariation with rainfall, subject to prior verification of a satisfactory correlation.

In brief, the theoretical runoff potential in millions of kWh a year is given by formula (1), assuming full utilization and a 100 per cent yield.

$$Ps = \frac{V \times H}{367} \quad (1)$$ 7/

7/ Given the known formula P(kW) = 9.8 x Q x H, which expresses the output of a fall of water in kW in function of the flow Q (cubic metres per second) and height H (metres), with an ideal yield of 100 per cent, the formula can be found for the annual power in kWh:

$$Ps = 9.8 \times H \frac{V}{31.5} \times \frac{8,760}{10^6}$$

where the new numerical coefficients are:

8,760 = number of hours in the year
31.5 = number of seconds in the year, in millions.

Here V is the volume of annual runoff in millions of cubic metres (average for a period of years as described above) originating exclusively in precipitation in the sub-basin in question, and H is the average height of the sub-basin above sea level in metres. The addition of these values gives the hydroelectric potential in a region or a country.

Dividing the potential, thus calculated, of each sub-basin by its area in square kilometres gives the specific value of its potential in kWh/km^2.

If the value of the specific potential of the sub-basin is marked at its geometric centre on a map, and the process is repeated on a larger scale (national or regional) covering the whole area, equipotential lines can be interpolated.

In such countries as those of Latin America, where hydrological information is limited, the main problem is that of the means of determining the value of V, and in some cases of H, for each sub-basin.

In this connexion, the best method of establishing V in the absence of direct hydrological information is by use of runoff data deduced from rainfall data but checked against actual flow data recorded at a stream-gauging station. (Details are given in the Annex, section 1.)

In countries with rivers that cross the frontier it is necessary in determining the national potential to reduce the potential of the basins concerned, since the average elevation of each micro-basin is reduced by being calculated not from sea level but from the elevation at the point where the river into which it flows crosses the frontier.

Land-locked lakes in which underground filtration and evaporation balance the flow of the affluents (enclosed basins) are a special case. Automatic application of the principle of evaluating the hydro-electric potential as linked to the area of the basin of its first runoff, with 100 per cent utilization of the slope to the sea, would exclude any exceptions, although nature itself limits the slope by the level of the lowest point in the basin. A typical example in Latin America is the Lake Titicaca-Desaguadero River-Lake Poopó system, where a high proportion of the potential can be exploited on the basis of the potential

/head above

head above sea level, by substantial reduction of evaporation[8/], and as a result of other favourable features such as altitude, geographic situation, topography, and so forth.

Examples of a diametrically opposite situation are to be found in the case of enclosed basins in Mexico in the States of Chihuahua, Durango and Coahuila, where it would appear logical in view of natural features very different from those described above to regard the potential as limited by the level of the lakes concerned.

For the sake of uniformity it would be advisable in every case to give the theoretical surface potential in relation to sea level, with a specific separate indication of the potential that should be discounted because of the difference in elevation between the surface of undrained land-locked lakes and sea level.

(b) Gross river potential

The recommended method for calculating the gross river potential, which is also a constant intrinsic characteristic of the river system of a country or region, is as follows:[9/] each river or water course in the area is divided into sections bounded by the points of confluence of successive tributaries; however, for practical reasons these sections should not exceed 10 kilometres in length.

For each section the potential is calculated by the formula:

$$P_L = 9.8 \times Qm \times H \qquad (2)$$

Here P_L is the average potential in kW; Qm is the average flow at each end of the section ($Qm = \frac{Q_A + Q_B}{2}$); and H is the difference in elevation between the water level at each end, in metres.

8/ It would clearly be possible from the strictly technical point of view to reduce evaporation by lowering the level of Lake Titicaca by construction of a drainage system that would reduce the area of that lake and of Lake Poopó, with a consequent reduction of the volume of water evaporated.

9/ This method is that used in France to evaluate hydro-electric potential by Electricité de France (see United Nations, Hydro-electric potential in Europe and its gross, technical and economic limits (E/ECE/EP/131)).

/Repeating the

Repeating the same procedure for all sections of the river and its tributaries and adding the results gives the gross river potential of the whole basin, country or region.

However, this method is not usually employed in the upper reaches of the tributaries or the lower reaches of the river (near the mouth), those stretches being excluded from the point where the potentials are lower than 15-20 kW per kilometre. In Latin America the higher limit could be adopted.

To calculate the annual energy that corresponds to the gross river potential given in kW, it is sufficient to multiply the latter by 8,760 (number of hours in the year) to get the number of kWh.

The river potential can conveniently be marked on a map by drawing lines of different thicknesses following the river, varying according to a given scale with the potential per unit length obtained in kW per kilometre for each section.

The graphic representation of this potential and the advantages it provides are given in the Annex, section 2.

(c) Exploitable or technical potential

The best method of evaluating this potential, and the only direct method, is to draw up detailed schemes for the regulation and utilization of the waters of the river or river system in question. By this method it can be clearly established what will be the geographical location, quantity, seasonal characteristics and hydrologic dependability of the power in proposed electric power plants, in addition to the probable proportion of base and peak energy that can be expected. The difficulty of this method is obvious: even for a single moderately large basin it could require much time and considerable funds. Nevertheless, this is the method that should be adopted for the final plan for the multiple-purpose development of a basin.

In general evaluations for planning purposes, the recommended alternative to direct determination of the exploitable potential, both because it is simple to apply and because it is no less reliable than other indirect methods, is to obtain it as a fraction of the gross river potential by analogy with other basins or river systems that have been studied in

/detail and

detail and have similar geographical and physical features, as indicated in the following section.

5. Comparison between the two types of potential

Although the two theoretical potentials referred to give ceilings that are unattainable in practice (and that do not agree), the gross river potential is closer than the runoff potential to technical and economic potentials. Moreover the gross river potential has the great advantage of indicating on the maps representing it the physical location of the rivers and which sections have a high potential, thus pinpointing the places that should be studied in greater detail (by geological prospecting, soil mechanics investigations and studies of regulation and of other complementary or conflicting uses of the water, etc.) in order to compile the information required for an economic study. Maps of runoff potential, on the other hand, link the potential to the source of the water without necessarily indicating possible sites for the production of electric power.

The information required to give the runoff potential, however, is simpler than in the case of the gross river potential, and thus easier to obtain in countries where there are large under-developed areas about which there is a lack of information, as in the Latin American countries.

Experience in more developed countries in various parts of the world shows that generally speaking the relationship between the theoretical potentials under discussion and the economic potentials, which in the last analysis are what matter, fall within a fairly narrow range of values. In a number of European countries with a high level of hydro-electric production it has been shown in the last decade that the exploitable potential as a whole is from 20 to 25 per cent of the gross runoff potential, with wider local variations.[10/] In the ECE paper referred to it is stated that

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10/ In Sweden the proportion is exceptionally high, being 40 per cent. In view of Sweden's highly favourable runoff conditions and geological conformation, this is probably an upper limit. See A. J. Dilloway, United Nations, "Comparative study of hydro-electric resources as exemplified by European experience" (paper presented at the Madrid Sectional Meeting of the World Power Conference, July 1960).

a study of eight European countries showed the ratio between the real economic potential and the gross runoff potential to be between 0.17 and 0.20.

The results of some other studies,[11/] however, show that the ratio between the real economic potential and the gross river potential is roughly between 0.33 and 0.40.

Here lies the main interest for under-developed areas and countries in determining their theoretical potentials, since even with relatively simple hydrological and geomorphological investigations, and without great expenditure of time, they can estimate the upper and lower limits that will establish the approximate hydro-electric potential for economic use.

ECE is preparing a map at a scale of 1:2,500,000 with the theoretical runoff potential covering the greater part of the countries of Europe with lines of equal hydro-electric power per surface unit.[12/]

This map will make it possible to revise the relations between the runoff potential and the technical and economic potentials for some river systems and countries, by making use of information available for those where a greater part of the water resources have already been developed and where a full investigation has been conducted for the areas where the water resources still remain to be developed. This information will be of great value for the countries of Latin America and for other under-developed areas.

Some countries that have reliable hydrologic and geomorphologic information have in practice omitted the evaluation of the theoretical potentials in order to concentrate their investigations directly on the technical and economic potentials. This is the type of work being undertaken by the

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11/ ECAFE study op. cit., which includes references to V. M. Yevdjevic and O. Marjanovic, Power resources of Yugoslavia (Belgrade, 1956), Vol. 1, and to United Nations, Determination of hydro-electric potential in the USSR (ECE, Committee on Electric Power, Working Paper No. 46, 13 February 1956).

12/ The line of least potential drawn on this map is that representing 0.25 kWh per square metre, and the other lines represent successive multiplication by two (0.5, 1.0, 2.0, etc.) up to the line showing 6 kWh per square metre in the central zone of the Alps. See A. J. Dilloway, op. cit.

Federal Power Commission[13/], and to some extent the Geological Survey[14/] in the United States.

6. Irregularity of stream flow in the rivers

It has already been seen that the proposed theoretical potentials (runoff and river) are concerned by definition with the average annual stream flow and takes no account of the changes that actually occur in the course of time, both from year to year and during the course of a single hydrologic year (seasonal variations). However, it will be readily appreciated that the irregularity of the stream flow of a river is a factor that appreciably affects that part of the potential that can be economically developed in relation to the theoretical potential.

The study of any particular hydro-electric project normally includes detailed technical analysis of the duration of natural flow and the installations required to regulate it in order to obtain, on economic terms, the optimum use of the resource, but, as previously indicated, such analysis is of little practical value in investigations relating to general planning and programming of the use of the water resources of an area or a country. Hence for some time an index has been sought that would make it possible to draw maps showing the territorial distribution of the runoff irregularity of rivers, and a number of proposals on these lines have been made in different countries at different times. The most appropriate seems to be that selected by ECE to indicate irregularity during the course of the hydrologic year.[15/]

13/ See Frank L. Weaver, "Hydro potentialities as indicated by Federal Power Commission" (paper presented at the Twenty-First Annual Meeting, American Power Conference, Chicago, April 1959).

14/ See Developed and potential water power of the United States and other countries of the world (op. cit.).

15/ See United Nations, Specifications for construction of an index of stream-flow irregularity (E/ECE/EP/205), which should be consulted for more general information, since the present study does no more than examine briefly some relevant aspects of the question.

/For a

For a given year, the formula is:

$$Cri = \frac{Vi}{Wi},$$

where Cri is the coefficient (index), Vi is the storage capacity required for full regulation of runoff for that year, and Wi is the volume of runoff for the year.

The mean value of coefficient Cr for a set of observations covering n years can be obtained merely by taking the average of the values for Cri.

For the sake of simplification, in preliminary studies a coefficient Cr can be used that corresponds to a fictitious year, for which the figure for each month is the arithmetic mean of the flow figures for the month concerned. The same method can be used to arrive at final conclusions, provided that the Cr value used is multiplied by a correction factor greater than 1, but the advantage of this procedure is open to question, since the correction factor has to be calculated separately in each instance.

There is little or no correlation between the values of Cr and the size of the catchment area concerned, a fact which justifies the drawing of maps showing this coefficient as basic background information for planning activities, together with estimates of hydro-electric potentials. In calculating this coefficient special care must be taken not to include lakes or reservoirs, as the resulting distortion would be so great as to invalidate the map concerned. In order to draw lines of interpolation joining points where Cr has the same value, the Cr value should be entered on the map at the centre of the basin or sub-basin concerned. Care should also be taken to avoid drawing these lines across mountain ranges or extensive depressions.

It should not be overlooked that a run-of-river plant designed for an average river stream flow of Qm will produce an average of:

$$kWh = (1 - Cr) \times 9.81 \times 8{,}760 \times Qm \times H$$

with a yield of 100 per cent. For normal yields, the value of 9.81 should be replaced by another of the order of 8.3.

/Chapter II

Chapter II

LATIN AMERICAN HYDROELECTRIC POTENTIAL

1. Concepts and current estimates

Generally speaking, knowledge of hydroelectric potential in the Latin American countries is in its infancy, as will be seen from the analysis of the method and concepts used and of current research facilities. The biggest handicaps to an estimation of the region's total potential on the basis of the direct information available are the lack of uniformity in the evaluation criteria and the meagre explanations that accompany the calculations supplied by each country.

(a) Estimates prepared by the United States Geological Survey

The paper on "Developed and potential water power of the United States and other countries of the World December 1954"[1/] estimated hydroelectric potentials at the end of 1954 from two different standpoints.

The first, based on ordinary minimum flow (flow available 95 per cent of the time) attributes to Latin America as a whole a potential of 57 million kW (12 per cent) out of the figure of nearly 480 million estimated for the whole world.

The second, based on mean flow, attributes to the region as a whole 520 million kW, out of the estimated world total of almost 2,270 million kW (see table 6).

The most important points elucidated by the above-mentioned study with respect to its method of execution refer mainly to potentials estimated on the basis of ordinary minimum flow, and are as follows:

Developed and undeveloped sites are considered on the basis of 100 per cent efficiency;

The regulatory effect of storage reservoirs has been disregarded, except in those sites where they are already operating;

The estimates for the United States, Canada and Europe are based on known sites;

1/ Lloyd L. Young, Geological Survey Circular 367, United States Department of the Interior, Geological Survey 1954 (reprinted 1958). This is the only source that covers the whole world.

/For the

For the Asian countries (except Japan), Africa and South America (except Brazil)[2], the estimates are based principally on rainfall and topography and consequently are not as dependable.

These few indications suffice to give a fairly good idea of the general criterion adopted by the author of the paper, which was brought into line with the relevant recommendations by the World Power Conference.

The estimate of potentials on the basis of ordinary minimum flow corresponds, except for a few amendments of minor importance, to that given in the same paper for 1952.[3]

The comments which may be made on this type of estimate in relation to countries with large under-developed areas and little information (as in Latin America) relate mainly to the concept of ordinary minimum flow and endeavour to assimilate it to that of flow available 95 per cent of the time.

(i) The determination of ordinary minimum flow from data that are predominantly on rainfall is much more difficult than the mere determination of mean flow, which was done in the other evaluation made in the same document and in the definitions of theoretical potential that have been examined earlier. There is no doubt that the accuracy with which this type of flow has been estimated differs considerably from one country to another, and this has militated against the uniformity that is to be aimed at in such evaluations.

(ii) The estimate of potentials for Q 95 per cent automatically places the countries that already have big reservoirs (taken into account in the evaluation) on a different level from those that have none, since a regulated flow is generally greatly preferable to the natural run-off available 95 per cent of the time. The over-estimation of potential in countries already possessing storage plants would disappear with the adoption of the concept of mean flow.

2/ It coincides with the official estimate made in 1951 by the Divisao de Aguas do Departamento Nacional da Produçao Mineral.

3/ Prepared by Benjamin E. Jones and Lloyd L. Young. It should be noted that this was the only survey of international scope undertaken up to 1954 and its findings were included in such publications as Schurr and Marschak, Economic aspects of atomic power; Palmer C. Putman, Energy in the future; and Energy in Latin America, United Nations Publications, Sales No: 1957.II.G.2.

/Hence, the

Hence, the evaluation that will play the most important part hereafter will be that based on mean flow in the Geological Survey Circular, which comes very close to the definition of theoretical linear potential. The only discrepancy between the two would seem to be the fact that the former was limited to "known sites" in the more developed countries.

Table 6, which was prepared from data given in the reference paper, enables a comparison to be made between Latin America and other regions of the world.

From column 2, it appears that Latin America's hydroelectric resources are equal to the sum of the same resources in Europe (including the USSR total) and in the United States. They also constitute more than 22 per cent of the world potential.

The penultimate column shows an average of about 25 kW/km^2 for the region, which exceeds both the world average (16.7 kW/km^2) and those of the other regions and groups of countries considered, with the sole exception of Western Europe, for which the average is 30 kW/km^2. The other group of less developed countries, Eastern Europe and the United States, follow in descending order with approximately 17, 12 and 11 kW/km^2. In pointing out that the evaluation was limited to "known sites" in the case of Canada, the United States and nearly all the European countries, the document raises the question of whether Latin America's potential has not been over-estimated, in comparison with the figures for the other regions on which little information is available.

The last column of the table contains a per capita evaluation of the same potential, in which the figure for Latin America, also because of the region's low population density, is almost 2,700 Watts; this is more than three times the world average of 800 Watts and far exceeds the averages of the other regions and countries in question. The areas that come closest to one another are the group of countries formed by Canada, Japan, New Zealand and the Union of South Africa, with 980 Watts per capita, and Eastern Europe (including the USSR total), with 950 Watts per capita. The United States and Western Europe appear with only 490 and 350 Watts per capita respectively.

/Table 6

Table 6

HYDROELECTRIC POTENTIAL IN LATIN AMERICA AND THE WORLD

	Based on ordinary minimum flow (thousands of kW)	Based on mean flow		
		Total (thousands of kW)	Per km^2 (kW/km^2)	Per cápita (W/per cápita)
Latin America	57 398	520 024	25.50	2 700
Western Europe	32 356	111 382	29.78	350
Eastern Europe a/	61 138	288 414	12.31	950
United States	26 864	85 376	10.91	490
Other developed countries b/	40 517	133 952	6.86	980
Rest of the world	259 561	1 126 959	16.61	670
World total	477 834	2 266 107	16.74	800

Source: ECLA, on the basis of data presented in United States Department of the Interior, Geological Survey Circular 367, with respect to hydroelectric potentials; and United Nations, Statistical Yearbook 1958 for territorial areas and population.

a/ Including the total for the USSR.

b/ Australia, Canada, Japan, New Zealand and the Union of South Africa.

/Lastly, the

Lastly, the table confirms the previous observation, made, for the sake of comparison, on the determination of potentials solely on the basis of the flow Q 95 per cent in that the estimates for countries already possessing large storage plants are also too high. Whereas, in fact, the Q 95 per cent potential in Latin American and other less developed countries is only 11 and 23 per cent of the mean flow potential, in the United States, in the group of developed countries consisting of Australia, Canada, Japan, New Zealand and the Union of South Africa and in Western Europe, it amounts to 31.5, 30 and 29 per cent respectively. It should not be forgotten, of course, that the degree of regularity of the rainfall régimes also has a direct bearing on these results.

(b) National estimates

The following observations may be made on the information which the ECLA secretariat has compiled on the basis of the estimates of potential prepared in every Latin American country:

(i) Some countries have no data on potential nor have they undertaken any research on the subject;

(ii) In other countries, the data differ considerably according to their source, and explanations of the concepts and methods used are either non-existent or else so concise as to be impossible to classify;

(iii) The data are often limited to a few basins only or to the best-known areas within each country;

(iv) Lastly, a few countries have already made overall studies on their hydroelectric resources, and are currently engaged upon a more systematic survey, improving and expanding their hydrometeorological and hydrological networks.

An initial selection was made, from all the background information available, of those estimates which, because of the reliability of the source and related considerations, could form part of a general scheme with some possibility of classification - however remote - despite the fact that lack of uniformity and consistency were the salient characterisitcs revealed by the evaluation methods in many of the figures presented (see table 7).

/Table 7

Table 7

LATIN AMERICA: HYDROELECTRIC POTENTIALS

(Official and private estimates in each country)

Country	Year of estimate	Potential (millions of kW)	Source of information	Remarks
Argentina	1934	20.0	Adolfo Niebuhr, La electrificación en la República Argentina	Estimate of utilizable potential based on precipitation and differences of elevation in national territory.
	1958	12.5	Water and Energy. Reply to questionnaire.	Power stations in operation and economically - utilizable sites during next development period. Capcity of generating units. a/
Bolivia	1959	2.7	Department of Water and Electricity.	Power stations in operation and economically utilizable sites. Capacity of generating units.
Brazil	...	16.4	Official estimate (see General Carlos Berenhauser Jr. (ECLA/TAO), O Problema da Energía Elétrica no Brasil 1959.	Q (95 per cent) corresponds to the norms of the World Power Conference.
	...	30.0	Estimate by competent agencies. (See General Carlos Berenhauser, Jr., op.cit., and the Joint Brazil-United States Economic Development Commission, Relatorio sobre Energía Elétrica no Brasil	Power stations in operation and economically - utilizable sites. Flow regulation and inter-valley exchanges. Capacity of generating units.
Colombia	1960	7.6	Institute of Water Utilization and Electricity Development. Reply to questionnaire	Some economically - utilizable sites (Q 50 per cent), with 85 per cent yield. Capacity of generating units.
	1954	40.0	National electrification plan (Gibbs & Hill, Inc., and Electricité de France)	Estimate for whole country. Capacity of generating units. Annual plant factor 0.57
Costa Rica	1959	1.5	Costa Rican Electricity Institute, Investigación de recursos hidroeléctricos (CCE/SC.5/I/DT.8)	Economic potential. Capacity of generating units (?)
Cuba	1954	-	Agricultural Development Bank. Preliminary reconnaissance of 19 rivers and 2 swamps.	The estimated potencial is less than 0.1 million kW.
Chile	1952	10.6 b/	ENDESA, Plan de electrificación del país.	Linear potential for Q (95 per cent). Norms of the World Power Conference.
	1952	23.6 b/	ENDESA, Plan de electrificación del país.	Linear potential for Q (50 per cent).

/Table 7 (cont.)

Table 7 (cont'nd 1)

Country	Year of estimate	Potential (millions of kW)	Source of information	Remarks
Chile	1952	26.6 b/	ENDESA, Plan de electrificación del país.	Linear potential for Q (mean)= gross river potential
	1952	20.9 b/	ENDESA, Plan de electrificación del país.	Economic potential
Ecuador	1958	2.0	R. Schröder, Study of water resources in Ecuador joint ECLA/BTAO/WMO study in draft form; Mr. J. Rittershaussen (BTAO)	Power stations in operation and economically - utilizable sites. Capacity of generating units.
El Salvador	1959	0.91	Atilio García Prieto, La investigación de recursos hidráulicos (CCE/SC.5/I/DT.12)	Economic potential of some sites studied. c/ Capacity of generating units. Annual plant factor 0.5.
Guatemala	1959	0.15	Department of National Electrification, Directorate of Public Works, Investigación de los recursos hidroeléctricos (CCE/SC.5/I/DT/4)	Economic potential of some sites studied. d/ Capacity of generating units. Annual plant factor 0.5
Honduras	1959	0.4	Julio A. Lang, Investigación preliminar y parcial de los recursos hidroeléctricos (CCE/SC.5/I/DT.18)	Economic potential of some sites studied. e/ Capacity of units to be installed.
Mexico	1939	4.7	Ministry of Agriculture and Development, Catálogo General de Aprovechamiento de Aguas Nacionales para Generación de Fuerza Motriz	Potential of 2 604 known sites. The reference seems to be to Q 95 per cent
	1948	5.7	Guzmán Cantú, Energía en México	Corresponding to the fundamentals of the above appraisal
	1948	21.0	Guzmán Cantú, Energía en México	Described as "practical". It seems to be based on conditions similar to those of "exploitable" potential.
	1953	11.0	C. Lara Beautell, La Industria de energía electrica	This seems to refer to plants in operation and to economically-utilizable sites in a forthcoming development period. Capacity. of generating units
Nicaragua	1959	0.33	National Electric Power Commission, Ministry of Development and Public Works, Plan de electrificación nacional e investigación de los recursos hidroeléctricos (CCE/SC.5/I/DT.1 & DT.15)	Economic potential of some sites studied. f/ Capacity of generating units. Annual plant factor 0.5

/Table 7 (cont.)

Table 7 (cont'nd 2)

Country	Year of estimate	Potential (millions of kW)	Source of information	Remarks
Panama	1959	0.9	Economic Development Institute, Proyecto de recursos hidráulicos y electrificación del S.C.I.F.E., 1960	Economic potential of some sites studied. Capacity of generating units.
Paraguay	1954	3.1	H. Foster-Smith (TAO). Information for 1960	Q 95 per cent. No further data available
Peru	1949	25.0	Pablo Boner, El problema de la energía eléctrica (Reports of the Society of Engineers)	This seems to refer to "exploitable" potential
	1956	10.0	Swiss-Peruvian Consultative Economic Council, L'industrie électrique au Pérou	The potential dealt with may perhaps be compared with minimum economic potential
	1959	6.5	Jorge Grieve, Potencial hidroeléctrico del Perú (Forum on energy problems)	Power stations in operation and known sites that are likely to be economically utilizable.g/ Capacity of generating units
	1959	15.0	Jorge Grieve, Potencial hidroeléctrico del Perú (Forum on energy problems)	Gross river potential
Uruguay	1959	1.2	José L. Buzzetti, El potencial hidroeléctrico en nuestro país; Elvio Sacco, Política energética en el Uruguay	Economic potential with regulated flow. Capacity of generating units. Annual plant factor 0.51h/.
Venezuela	1959	16.0	R. Schröder, Study of water resources in Venezuela, a joint ECLA/TAO/WMO study in draft form	Economic potential of some sites studied. Capacity of generating units.i/
Surinam	1959	1.5	Bokopondo Bureau, Government of Surinam, Appraisal survey of Hydroelectric power resources in Surinam, 1959	Economic potential of main rivers

a/ Only 700 000 kW, i.e. half the international utilization, are considered in the case of the River Uruguay (Salto Grande).

b/ Including 0.6 million kW - half the international resources shared with Argentina.

c/ Rivers: Lempa Grande de San Miguel, Paz, Goascorán, Jiboa, Cuscumacayán, Mirazalcos and La Cabrera.

d/ Corresponding to Lakes Amatitlán, Atitlán and Ayarza and to the Rivers Samalá, Aguacapa, Cahabón, Yocotán, Negro of Chixoy and Chilasco.

e/ Corresponding to Rivers Ulúa, Patuca, Choluteca and to Lake Yojoa-River Lindo.

f/ Corresponding to Rivers Tuma, Viejo, Matagalpa, Coco and Grande de Matagalpa.

g/ Half of the Lake Titicaca International Project was considered, i.e. 1.2 million kW.

h/ Only 700.000 kW, i.e. half the international utilization, are considered in the case of the Rivers Uruguay (Salto Grande).

i/ Fourteen million kW are linked up with the total utilization of the River Caroní.

/An analysis

An analysis of table 7 shows that the most common evaluation concept is undoubtedly installable economic capacity, in known localities or sites. The pertinent method involves, as already explained, the regulation of stream flow, the estimation of the load factor (characteristic of consumption), the inclusion of a reserve (mechanical and electric) and possibly the transfer of water from one valley to another, all factors that vary in accordance with the purpose for which they are intended, personal ability in development programming and in the choosing of the right economic criteria to assess the priority of electricity production vis-à-vis that of other water uses (in the event of conflicts over multiple water utilization), and the availability of technical and building facilities at the time the estimate is being made.

In spite of these observations, which rule out the possibility of a close comparison between national hydroelectric resources in the absence of a standard concept of economic potential, provisional estimates have been made in table 8 on the basis of national surveys and studies, although some of these do not provide more than partial coverage. Map II-1 is included on the same provisional basis.

2. Geographical distribution

Out of an approximate total of 150 million economically installable kW in Latin America (see again table 8), more than 70 per cent is concentrated in four countries - Colombia, Brazil, Chile and Venezuela - which have 40, 30, 21 and 16 million kW respectively. They are followed by Argentina, Mexico and Peru, which, with 12.5, 11 and 6.5 million kW, constitute 20 per cent of the total for Latin America.

The distribution of this potential per unit of area is also fairly uneven. El Salvador, Colombia, Costa Rica and Chile would seem to be the best endowned, with 45, 35.2, 29.5 and 28.3 kW/km^2, followed by Venezuela with 20.6 kW/km^2. Then come Panama, Paraguay, Ecuador and Uruguay, but with much lower figures of 11.8, 7.6, 7.4, and 6.5 kW/km^2 respectively.

Moreover, in relation to their current population levels, the countries that are best provided with water resources for electricity production are Venezuela, Colombia, Chile and Paraguay, with 2,990, 2,940, 2,910 and 1,850 Watts per capita respectively.

/Table 8

Table 8

LATIN AMERICA: HYDROELECTRIC POTENTIAL

(Estimates of economic utilization, 1960)a/

Country	Millions of kW	Resources per capita and per square kilometre	
		W/per capita	kW/km²
Argentina	12.5	615	4.5
Bolivia	2.7	814	2.5
Brazil	30.0	477	3.5
Chile	21.0	2 910	28.3
Colombia	40.0	2 940	35.2
Costa Rica	1.5	1 430	29.5
Cuba	-	-	-
Dominican Republic	...	...	...
Ecuador	2.0	498	7.4
El Salvador	0.9	373	45.0
Guatemala	0.2	56	1.9
Haiti	...	...	...
Honduras	0.4	220	3.6
Mexico	11.0	340	5.6
Nicaragua	0.4	292	2.7
Panama b/	0.9	856	11.8
Paraguay	3.1	1 850	7.6
Peru	6.5	647	5.1
Uruguay	1.2	438	6.5
Venezuela	16.0	2 990	20.6
British Guiana	...	...	...
West Indies	...	...	...
Surinam	1.5	6 200	10.5
Regional total c/	151.8	814	7.6

Source: ECLA, on the basis of direct information, and United Nations, Statistical Yearbook 1958 for territorial areas.

a/ National estimates. They correspond to the sum of the capacities of established plants and those of plants that can be economically set up in known localities or sites.

b/ Including the Canal Zone.

c/ Excluding countries for which information is not available.

/Map II-1

As national estimates do not afford any possibility of building up a complete picture of homogeneous hydroelectric potentials, at another level, table 9 presents the figures estimated by the United States Geological Survey in 1954 by countries, with particular reference to the evaluation based on mean Q. According to this table, the best-endowed countries would seem to be Brazil, Colombia, Peru and Venezuela, with 176.6, 73.6, 40.5 and 36.8 millions kW respectively, followed by Mexico (33.1) Argentina (29.4) and Ecuador (25.8).

When the same potential is measured by unit of area, the countries best provided for would seem to be the West Indies, Costa Rica, Ecuador, Guatemala and British Guiana, with 177.9, 115.7, 97.9, 81.1 and 68.5 kW/km^2, followed consecutively by Colombia (64.7), El Salvador (55.2), Honduras (52.5), Surinam (51.8) and Venezuela (40.3).

The last column of table 9 shows that Surinam, British Guiana, Bolivia, Ecuador and Venezuela are richest in hydroelectric resources in relation to their current population levels, with 30.6, 27.4, 6.7, 6.4, and 5.8 kW *per capita* respectively.

No direct inter-country comparison can be made between the estimates of the United States Geological Survey and the overall group of national assessments. In the first place, the national estimates are governed by theoretical concepts that are at difference levels; secondly, as explained before, varying criteria and methods were used and different territorial areas were covered. Thirdly, the coverage of the basic data employed must have been very irregular - at least in certain areas - since the exceptional case of Chile, for which the estimate of economic potential exceeds that of theoretical potential, is otherwise inexplicable. Elsewhere, on the other hand, the estimate of theoretical potential is several times larger than that of economic potential; in Ecuador, for instance it is more than ten times as big. However, for Latin America as a whole (after compensation of errors), the relation of 0.29 between the two potentials seems to be reasonable provided that due account is taken of the fact that errors by omission undoubtedly predominate in national estimates.

The distribution of economic potential in each country is also very unequal. This is revealed in table 10, which gives the estimated potential of an economic development of selected basins, according to each country's surveys (see again map II-1).

/Table 9

Table 9

LATIN AMERICA: HYDROELECTRIC POTENTIAL

Country	Based on ordinary minimum flow (thousands of kW)	Based on mean flow		
		Total (thousands of kW)	Per km² (kW/km²)	Per capita (kW/per capita
Argentina	3 974	29 440	10.60	1.45
Bolivia	2 650	22 080	20.10	6.72
Brazil	14 720	176 640	20.70	2.81
Chile	5 152	18 400	24.80	2.52
Colombia	3 974	73 600	64.65	5.44
Costa Rica	1 030	5 888	115.67	5.47
Cuba	-	-	-	-
Dominican Republic	-	-	-	-
Ecuador	1 472	25 760	97.90	6.44
El Salvador	221	1 104	55.20	0.46
Guatemala	1 546	8 832	81.10	2.47
Haiti	-	-	-	-
Honduras	1 030	5 888	52.50	3.21
Mexico	6 256	33 120	16.80	1.02
Nicaragua	810	4 416	29.80	3.17
Panama	515	2 944	38.80	2.80
Paraguay	2 061	7 360	18.10	4.42
Peru	4 710	40 480	31.50	3.96
Uruguay	294	2 208	11.80	0.82
Venezuela	3 165	36 800	40.30	5.82
British Guiana	2 650	14 720	68.50	27.36
West Indies	368	2 944	177.90	2.80
Surinam	800	7 400	51.80	30.60
Regional total	57 398	520 024	25.50	2.70

Source: ECLA, on the basis of data from the United States Department of the Interior, Geological Survey Circular 367, with respect to hydroelectric potentials, and direct information for territorial areas and population.

/Table 10

Table 10

LATIN AMERICA: HYDROELECTRIC POTENTIALS, 1960

(Estimated economic potential of selected basins)

Country, basins or sub-basins	Potential	
	Million of kW	Percentage of country total
Argentina a/		
Tunuyán-Diamante-Atuel systems	1.38	11.0
Río Negro	2.33	18.6
Córdoba system	0.28	2.2
Bolivia b/		
Upper Beni (Bala)	1.00	37.0
Rivers Corani-Espíritu Santo	0.15	5.6
Brazil		
River San Francisco c/	3.10	10.3
Río Grande d/	7.00	23.3
Rivers Paranapanema and Tieté	2.50	8.3
River Paraná	7.00	23.3
Chile e/		
River Maule	1.55	7.4
River Bío-Bío	2.38	11.4
River Maipo	0.61	2.9
Colombia		
River Bogotá f/	1.00	2.5
River Cauca (as far as Buga, including the Cauca Dagda project)	1.6	4.0
Costa Rica g/		
River Reventazón	0.57	38.0
River Grande Tárcoles	0.16	10.7
Cuba		
Dominican Republic	...	
Ecuador h/		
River Mira	0.15	7.5
River Esmeralda	0.16	8.0
El Salvador i/		
River Lempa	0.84	92.3
Guatemala		
Haiti		
Honduras j/		
Lake Yojoa - Río Lindo	0.17	42.0

Table 10 (cont'nd 1)

Country, basins or sub-basins	Potential: Millions of kW	Potential: Percentage of country total
Mexico		
River Balsas k/	1.0	9.1
Rivers Lerma-Chapala-Santiago l/	1.83	16.6
River Papaloapán m/	0.50	4.5
Nicaragua n/		
Rivers Tuma-Matagalpa-Viejo	0.13	32.5
Panama o/		
River Chiriquí	0.2	22.2
Paraguay p/		
River Acaray-Monday	0.35	11.3
Peru q/		
Río Santa	1.00	15.4
Uruguay r/		
Río Negro	0.49	40.8
Venezuela s/		
River Caroní	14.0	87.5
British Guiana	...	
West Indies	...	
Surinam		
River Surinam t/	0.2	13.3

a/ Water and Electric Energy. Economically-utilizable potential, study by G.A. Mazza, 1958.
b/ Department of Water and Electricity.
c/ San Francisco Valley Commission, A Valorização do Vale do Sao Francisco, 1957. (Regulated by the Tres Marías reservoir.)
d/ Brazilian National Committee, World Power Conference, Electric power in Brazil 1960, (regulated by the Furnas reservoir.) The capacity of this basin differs from that assigned to it in the country estimate. Some estimates place the river potential as high as 10 million kW.
e/ Plan de electrificacion del país, op. cit. Economic potential.
f/ Data supplied by the Costa Rican Electricity Institute.
h/ Estimate by J. Rittershaussen (TAO).
i/ La investigación de recursos hidráulicos, op. cit.
j/ Investigación preliminar y parcial de los recursos hidroeléctricos, op. cit.
k/ Estimate based on power stations in operation and established projects.
l/ C. Lara Beautell, La industria de energía eléctrica. Economic potential.
m/ Papaloapán Commission, Department of Hydraulic Resources, Economía del Papaloapán.
n/ Plan de electrificación nacional e investigación de los recursos hidroeléctricos, op. cit.
o/ Proyecto de recursos hidráulicos y electrificación del SCIFE, op. cit.
p/ Direct information Supplied by the National Electricity Administration.
q/ S. Antúnez de Mayolo, Plan de instalaciones hydroeléctricas de la Corporación Peruana del Santa en el Valle del Río Santa en el Perú, 1949.
r/ El potencial hidroeléctrico en nuestro país, op. cit.
s/ Study of water resources in Venezuela, op. cit. Economic potential.
t/ Appraisal survey of hydroelectric power resources in Surinam, op. cit

/It is

It is interesting to note that, in some cases, high proportions of the country's total estimated potential are concentrated in one or two rivers only. The real phenomenon of irregularity in geographical distribution in undoubtedly understated in table 10 in the case of a number of countries because of the way in which the potentials were estimated, and its extent is increasing in proportion to the improvement in the facilities for investigating resources. As many of the basins chosen are those which have been most thoroughly studied (with, of course, a few exceptions), the potentials assigned to them are closer to the real figures than those forming part of the total country appraisal, which are relatively underestimated. In addition, the lack of uniformity in certain data justifies a sample demonstration of special cases of inconsistency, such as that of the River Grande in Brazil(Sao Paulo-Minas Gerais) whose potential, in the table, has been more recently estimated and is higher than that attributed to it in the country assessment. Projects exist for power plants in the basin of the River Balsas in Mexico, which, added to the plants already in operation, will produce approximately 1 million kW, and will exceed by 300 per cent the estimate made for that basin in the assessment of total Mexican potential.

Nevertheless, it is worthy of consideration that in El Salvador, the River Lampa, in Venezuela, the Caroní, in Honduras, Lake Yojoa-River Lindo, in Uruguay, the Negro, in Bolivia, the Alto Beni and in Nicaragua, the Tuma, Matagalpa and Viejo, appear to comprise more than 90, 85, 40, 40, 35 and 30 per cent of their respective national hydroelectric potentials. Fairly high concentrations of this resource are also to be found in other countries, as may be seen from table 10. Sometimes, as in the case of the Rivers Tunuyán, Diamante, Atuel and Negro in Argentina, a big potential is concentrated in an area that is relatively remote from the principal centres of electricity consumption.

3. Irregularities of stream flow by countries

There is no information to indicate that extensive regional maps or studies have been undertaken on the irregularities of stream flow in Latin America.

/In order

In order to obtain some idea of the degree of overall stream flow irregularity in each country, particularly for purposes of comparison, the relation between the potentials estimated by the United States Geological Survey on the basis of ordinary minimum flow and on that of mean flow should be studied. Due consideration should be given to the fact that the storage works set up so far are generally unimportant as far as nation-wide regulation is concerned; the most significant work in this respect having been done by Argentina, Brazil and Mexico.4/ The relevant figures are given in table 11.

Chile and Paraguay appear to have the most regular stream flows, the most irregular being found in Brazil, Colombia, Ecuador and Venezuela. The near-uniformity of the irregularities recorded for Mexico and the other Central American countries contrasts with the situation in the remaining countries of the region, and seems to bear out the author's own observation that Latin American estimates are more inaccurate than those for developed areas because of the scarcity of basic data. In view of the difficulty of determining ordinary minimum flow from data that deal almost exclusively with rainfall, as stated before, it seems only reasonable to place less dependence on estimates of potential that are based on Q 95 per cent.

In any case it is obvious that more information is required on rainfall and stream flow and that the existing data should be processed more satisfactorily, by means of a systematic research on hydroelectric potentials.

Whenever studies evaluating hydroelectric potential by countries or basins are carried out, the relevant maps should also be prepared on flow irregularities during the hydrological year under consideration.

Flow coefficients have been calculated for a rather limited number of rivers in the studies by the ECLA/BTAO/WMO Water Resources Survey Group on Chile and Venezuela.5/

In the case of Chile, it was thought worthwhile to make a quantitative evaluation of the variation in irregularity of the rivers flowing from north to south. Its qualitative aspects are already well-known, because of both

4/ This estimate is based on a different concept from that of the recommended coefficient of irregularity C_r.

5/ Los recursos hidráulicos de Chile (E/CN.12/501/Add.1), and Water Resources in Venezuela, a summary of which is contained in document E/CN.12/562.

/Table 11

Table 11

LATIN AMERICA: RELATION BETWEEN POTENTIALS BASED ON ORDINARY MINIMUM FLOW AND POTENTIALS BASED ON MEAN FLOW

Argentina	0.14	Mexico	0.19
Bolivia	0.12	Nicaragua	0.18
Brazil	0.08	Panama	0.18
Chile	0.28	Paraguay	0.28
Colombia	0.05	Peru	0.12
Costa Rica	0.18	Uruguay	0.13
Ecuador	0.06	Venezuela	0.09
El Salvador	0.20	British Guiana	0.18
Guatemala	0.18	West Indies	0.13
Honduras	0.18		

/the longitudinal

the longitudinal variation in the rainfall régime and the accumulative action of snow in the Cordillera as a storer of large volumes of water which varies according to latitude.

The coefficients for the different rivers were calculated at what may be regarded as transitional points between the Cordillera of the Andes proper and the flat area or longitudinal valley. The results are given in table 12.

In the case of Venezuela, it was also important to show in quantitative terms the marked irregularity of flow of its rivers (with the exception of the Motatán), which seriously affects their utilization and reflects the seasonal distribution of rainfall; the Guarinco, for example, which registers the highest coefficient, has a wet season of only 5 months (see table 13).

By way of a sample of the methodology used, a map of Argentina was very provisionally constructed on the basis of the index cited (see map II-2).

In the Cordillera, owing to the regulatory action of the snow on the high summits, curves with a low index of irregularity are recorded, especially between 26 and 32 degrees of latitude. This phenomenon probably extends farther south, but the map does not show it for the simple reason that very few of the data required for tracing the relevant curves were available. Around the Rivers Paraná and Uruguay, the low irregularity coefficient curves mainly reflect the regularizing influence of the magnitude and diversification of the river systems in the tributary basins concerned (particularly in Brazilian and Paraguayan territory), and also, although on a lesser scale, the uniformity of the rainfall régimes in the areas lying between the two rivers and in the provinces of Santa Fe and El Chaco.

Conversely, for the Jujuy, Salta, Tucumán and other neighbouring areas curves with a high index of irregularity are registered, in consequence of fluvial characteristics which vary during the course of the hydrological year, of undiversified tributary characteristics and of the absence of regularizing lakes.

/Table 12

Table 12

CHILE: DEGREE OF IRREGULARITY IN THE FLOW OF SELECTED RIVERS IN A HYDROLOGICAL YEAR

River	River gauge	Latitude (approximate)	Cr
Carmen (Huasco)	Ramadillas	28° 47'	0.10
Claro (Elqui)	Rivadavia	30°	0.11
Choapa	Cuneumén	31° 55'	0.34
Maipo	La Obra	33° 35'	0.25
Tinguiririca (Rapel)	Bajo Briones	34° 58'	0.24
Achibueno (Maule)	Los Peñones	35° 58'	0.23
Maule	Afluentes de Laguna de La Invernada	34° 48'	0.20
Laja (Bío-Bío)	Afluentes del Lago Laja	37° 22'	0.18
Allipén (Toltén)	Los Laureles	38° 57'	0.16
Pilmaiquén (Bueno)	El Salto	40° 37'	0.15
Maullín	Llanquihue	41° 13'	0.10
Puelo	Carrera de Basilio	41° 37'	0.09

Source: Los recursos hidráulicos de Chile, op. cit.

/Table 13

Table 13

VENEZUELA: IRREGULARITY COEFFICIENTS OF THE RIVERS IN THE LLANOS AND THE RIVER MOTATAN

River	Station	Approximate irregularity coefficient a/
Guárico	Puente Carretera el Sombrero	0.445
Pao	Paso La Balsa	0.360
Tinaco	Puente Carretera Tinaco-El Pao	0.382
Tirgua	Paso Viboral	0.206
Cojedes	Puente Carretera San Calor-Acarigua	0.234
Agua Blanca	Puente Carretera San Calor-Acarigua	0.275
Acarigua	Puente Carretera Acarigua-Guanare	0.313
Guadie	Puente Carretera Acarigua-Guanare	0.321
Baconó	Peña Larga	0.249
Masparro	Puente Carretera Guanare-Barinas	0.273
Santo Domingo	El Curay	0.247
Uribante	Puente Colgante	0.230
Motatán		0.13

Source: Ministry of Public Works, Resumen de Datos Hidrométricos 1940-59 (Summary of Hydrometric Data 1940-59), Caracas, 1960 (taken from the ECLA/TAO/WMO study, in draft form, on the water resources of Venezuela.

a/ Calculated on the basis of the mean hydrological year and of monthly mean figures only.

/Map II-2

4. Present development

Table 14 enables a comparison to be drawn, although only approximately, between the proportions of hydroelectric resources developed by different regions, on the basis adopted for the construction of the table.

The table indicates that Latin America has developed only a very small proportion of its potential, since the percentage in question would amount to no more than one fifth of the world average and to about one thirty-seventh and one thirtieth of the relative utilization figures for Western Europe and the United States.

An analysis of the degree of development by countries, <u>on the basis of the estimated economic potential</u>, appears in table 15.

For the region as a whole, the utilization referred to above is seen to be a little over 4 per cent. The countries showing the highest relative development figures are Guatemala, Uruguay, Mexico and Brazil, with 15.0, 10.7, 10.5 and 9.5 per cent respectively.

Guatemala appears with a high percentage, not because it has developed its resources to an exceptional extent in relation to other countries, but because the rated potential would seem to be under-estimated inasmuch as only part of the country's river system has been taken into account. Obviously, in general terms, all the Latin American countries are still a very long way from utilizing their hydroelectric resources in the same proportion as other more developed countries. In the United States, the proportion of utilization in 1958, calculated on bases similar to those adopted here, was almost 24 per cent.[6/] Similarly, for Switzerland, France and Austria the corresponding proportions were, in the same year, 17.7, 14.6 and 8.5 per cent respectively.[7/]

6/ Select Committee on National Water Resources, United States Senate, <u>Water Resources Activities in the United States</u>, Print No.10 (estimates prepared by the Federal Power Commission).

7/ Information supplied by ECLA, on the basis of data given in <u>The electric power situation in Europe in 1958-59 and its prospects</u> (ST/ECE/EP/2) and <u>Hydroelectric potential in Europe and its gross, technical and economic limits</u> (E/ECE/EP/131).

/Table 14

Table 14

INSTALLED HYDROELECTRIC CAPACITY IN 1958 IN RELATION TO POTENTIAL RESOURCES - MEAN Q

	Millions of kW	Percentage of potential
Latin America	6.22	1.2
United States	30.10	35.3
Western Europe	50.26	45.1
Eastern Europe	12.45	4.3
Other developed countries	29.90	22.3
Rest of the world	9.11	0.8
World	138.04	6.1

Source: ECLA, on the basis of data supplied by United States Department of the Interior, Geological Survey Circular 367, with respect to hydroelectric potentials; direct information for installed capacity in Latin America; and United Nations, Statistical Yearbook 1958, for the rest of the world.

/Table 15

Table 15

LATIN AMERICA: a/ UTILIZATION OF HYDROELECTRIC POTENTIAL IN 1958 b/

Country	Installed hydroelectric capacity	
	Thousands of kW	Percentage of estimated economic potential
Argentina	278	2.2
Bolivia	89	3.3
Brazil	2 850	9.5
Chile	521	2.5
Colombia	490	1.2
Costa Rica	77	5.1
Cuba	4	...
Dominican Republic	-	-
Ecuador	36	1.8
El Salvador	56	6.7
Guatemala	26	15.0
Haiti	-	-
Honduras	4	1.0
Mexico	1 159	10.5
Nicaragua	1	0.3
Panama c/	52	5.8
Paraguay	-	-
Peru	401	6.2
Uruguay	128	10.7
Venezuela	35	0.3
British Guiana	-	-
Surinam	-	-
West Indies	13	...
Regional total a/	6 220	4.1

Source: ECLA, on the basis of direct information and miscellaneous publications.

a/ Excluding in the second column, the Dominican Republic, Haiti, British Guiana and the West Indies, for want of data on economic potentials.

b/ Information up to 31 December 1958 only was used, for the sake of uniformity with other studies. Between 1959 and 1960, the completion of certain works, such as those at the Central Macagua I in Venezuela, raised installed hydraulic capacity to 335 kW as at 31 December 1960. On that date, relative utilization in Venezuela stood at 2.1 per cent.

c/ Including the Canal Zone.

/Nevertheless, if

Nevertheless, if the resources situated near the large population centres or the areas of most intensive industrial activity in each country are studied individually, it becomes evident that there are some which are already fairly well developed, especially in comparison with the corresponding national averages. Among the cases for which information is available, special mention may be made of the Río Grande de Tárcoles (Costa Rica), with nearly 40 per cent of its potential now utilized, the Córdoba system (Argentina), with over 35 per cent, the Papaloapán (Mexico), with 31 per cent, the Río Negro (Uruguay), with more than 25 per cent (1958)[8] and the Maipo (Chile), with almost 20 per cent (see table 16).

Of the estimated potential of the Rivers Bogotá (Colombia), Lerma-Chapala-Santiago (Mexico) and Esmeraldas (Ecuador), 13, 11 and 10 per cent respectively is utilized.

In Brazil, a high proportion of the Rivers Paraíba and Tieté is already being utilized. The former has an installed capacity of 664 mW and the latter of 876 mW.

5. Development characteristics

Approximately 40 per cent of the aggregate capacity of those hydro-electric power plants for the public service which were in operation in Latin America in 1958 and on which data are available was contributed by plants of the run-of-river type, and the rest by hydro storage plants (see table 17). The proportion of power produced by the former was 36 per cent. In most countries - the exceptions being Argentina, Brazil, Colombia, Mexico, Peru, Uruguay and, on a smaller scale, El Salvador which in the year in question had a larger proportion of hydroelectric capacity in a storage reservoir -, run-of-river hydro plants were predominant. In fact, for many years the general tendency was to develop hydraulic resources of the Cordillera type - small flows and relatively high heads, without regulation. Plants were projected for minimum river flows frequently available for more than 95 per cent of the time. This is the type of plant for which

8/ When the Baygorria power station is brought into service in the near future (1960), over 45 per cent of this river's potential will be utilized.

/Table 16

Cuadro 16

LATIN AMERICA: UTILIZATION OF HYDROELECTRIC POTENTIAL IN THE CASE OF SELECTED RIVER BASINS (1958)

Country	Basin or Sub-basin	Installed hydroelectric capacity	
		Thousands of kW	Percentage of estimated economic potential of the basin
Argentina:	Tunuyán-Diamante-Atuel	74	5.4
	Río Negro	12	0.5
	Córdoba System	100	35.7
Bolivia	River Corani	-	
Brazil	River San Francisco	198	6.4
	River Jacuí	77	...
	Río Grande	105	1.5
	River Uruguay	7	...
	River Paraíva	664	...
	River Tieté	876	...
Chile	River Maule	102	6.6
	River Bío-Bío	87	3.7
	River Maipo	118	19.7
Colombia	River Bogotá	128	12.8
	River Cauca (as far as Bugá)	18	1.1
Costa Rica	River Reventazón	5	0.9
	River Grande de Tárceles	62	38.8
Cuba			
Dominican Republic		-	-
Ecuador	River Mira	3	2.0
	River Esmeraldas	16	10.0
El Salvador	River Lempa	45	5.4
Guatemala	River Michatoga	12	...
Haiti			
Honduras	Yojoa-Río Lindo	-	-
Mexico	River Balsas	449	...
	Lerma-Chapala-Santiago	201	11.0
	Papaloapán	154 a/	30.8
Nicaragua	Río Viejo	-	-
Panama	River Chiriquí	6	3.0
Paraguay			
Peru	Río Santa	52	5.2
Uruguay	Río Negro	128	26.1
Venezuela	River Caroni	35	0.3
British Guiana		-	-
Surinam	River Surinam	-	-
West Indies		-	-

Source: ECLA, on the basis of direct information and miscellaneous publications.

a/ Between 1958 and 1959.

/investment requirements

investment requirements are proportionally smallest, but it implies very low percentages of development of natural resources. Later, in response to the simultaneous pressure of increased demand for electricity and of agricultural and drinking-water requirements, large regulation works began to be constructed with a view to more rational, and usually multiple-purpose, water utilization. At the present time, in almost all the countries of the region, the idea is gaining ground that no hydraulic project should be put into execution without prior study of the optimum use of water in the widest interests of the public, due consideration being simultaneously given to the needs and possibilities for irrigation, drinking-water, flood control, navigation, etc., with the production of electric energy, generally speaking, as the economic-financial basis for any and every programme.

Argentina, Brazil, Chile, Colombia, Mexico and Uruguay in particular afford good examples of this policy. There can be no doubt that the contribution of hydro storage plants to the production of hydroelectricity will gradually increase in all the Latin American countries, along with the concurrent tendency to make more use of them for producing energy during peak-load hours (low plant factor) in systems fed simultaneously by thermal electric plants and by different types of hydraulic plants (in so far as other water uses permit), as is the case in the majority of the more highly developed countries.

In an extensive system fed by power stations of different types, it is desirable that the base load be served as far as possible by the run-of-river hydro plants (or by nuclear plants where these exist), with some help - as a rule significant - from thermal power plants (those with the highest yields) and/or a few of the hydro storage plants. The upper part of the load curve is assigned to a considerable proportion (or all) of these last, with the support of gas turbines (where these exist). The intermediate section - reduced to a minimum by the operation of the types of plant enumerated - is allocated to the thermal plants with lower yields. In every case, of course, there are many factors that must be considered in this regard. For example, the other uses to which the water is simultaneously put (irrigation, navigation, etc.) may make it necessary to manage the reservoirs on lines

/Table 17

Table 17

LATIN AMERICA: CAPACITY AND PRODUCTION OF HYDROELECTRIC POWER STATIONS FOR THE PUBLIC SERVICE, 1958

Country	Run-of-river plants a/		Storage plants		Storage capacity b/
	Capacity (thousands of kW)	Energy (millions of kWh)	Capacity (thousands of kW)	Energy (millions of kWh)	(millions of kWh)
Argentina	58	119 c/	202	546 c/	484
Bolivia	52	195	18	43	29
Brazil d/	922	1 799	1 580	11 897	3 360
Chile	219	1 005	191	891	515 e/
Colombia	195	787 c/	258	1 143 c/	75
Costa Rica	73	274	-	-	-
Cuba	3	...	-	-	-
Dominican Republic	-	-	-	-	-
Ecuador	31	130	-	-	-
El Salvador	11	54	45	149	38
Guatemala	26	106	-	-	-
Haiti	-	-	-	-	-
Honduras	4	11	-	-	-
Mexico	401	1 482	706 f/	2 674	3 170
Nicaragua	1	3	-	-	-
Panama g/	6	14	-	-	-
Paraguay	-	-	-	-	-
Peru	68	165	145 h/	633 h/	159
Uruguay	-	-	128	760	600
Venezuela	35	138	-	-	-
British Guiana	...	...	...	...	...
Surinam	...	...	...	...	...
West Indies	13	85	...	...	...
Regional total (excluding countries for which no data are given)	2 118	4 568	3 273	18 736	8 430

Source: ECLA, on the basis of direct information and miscellaneous publications.

a/ Without reservoirs.

b/ The kWh capacity of each storage plant was evaluated on the basis of the sum of the heads of all hydraulic power stations further down-stream operating in series.

c/ Estimated energy.

d/ The folowing are the power stations with an appreciable degree of regulation tion which are taken into account: Nilo Pecanha, Fontes, Cubatao, Itupararanga, Peixoto, Bugres, Canastra, Salto Grande, Americana and Itutinga. When the Tres Marías power station and reservoir (River San Francisco) enter operation, the capacity added will be 520 MW and the energy capacity stored will increase by 4 000 million kWh, including the head of the Paulo Alfonso Power Station.

e/ The useful storage capacity of the Abanico Power Station was in process of expansion.

f/ Hydroelectric plants belonging to the Miguel Alemán System, The Temascal (Papaloapán) Power Station, the Necaxa System, Lerma and La Boquilla.

g/ Excluding the Panama Canal Company's power station for want of production data.

h/ Power stations connected with the natural reservoirs in the upper basin of the Sta.Eulalia. (Part of the dischange utilized is run-of-river, from different from those dictated by energy considerations alone. Again, run-of-river hydro plants with little regulation are common, and should be operated so as to distribute their capacity between base-load and peak-load etc.

Today it can be asserted that all the plants of any importance now being constructed, projected and programmed in Latin America include regulation works.

As far as can be judged from the available data, reservoir capacity throughout the region (in 1958) amounted to approximately 36 per cent of the energy produced by the hydro power plants and about 45 per cent of that produced by hydro storage plants.[9/]

Brazil (Sao Paulo-Cubato, Río de Janeiro-Fontes and Nilo Peçanha-Peixoto Systems), Mexico (Miguel Alemán System), Uruguay (Río Negro), Argentina (Córdoba and Mendoza Systems) and Chile (Abanico and Cipreses Systems) are the countries whose storage capacity is proportionally biggest in relation to the energy produced (1958 figures) by the power plants concerned.

Utilization of public service installations in 1958 can be studied, by countries, in table 18 (second column). In countries where the share of hydroelectricity in total installed capacity is large, combined utilization figures of more than 4,500 hours are frequently met with, and the average for Latin America exceeds 4,600 hours. The region's most important electricity systems (but for a few exceptions, outstanding among which are Buenos Aires, Caracas, Havana, Guayaquil and Asunción) operate with hydro base power plants whose installed capacity is generally characterized by a high degree of hydrologic reliability. In smaller systems the base load is often served by run-of-river hydro plants, diesel groups being available to cover the increase in demand at peak load hours and to meet emergencies.

The low utilization of Argentina's hydro power plants is partly attributable to the peak role assigned to some of the hydro storage plants, and partly reflects the lack of supplementary works at specific power

9/ See table 17, note b/.

/Table 18

Table 18

LATIN AMERICA: DEVELOPMENT OF INSTALLED HYDROELECTRIC CAPACITY FOR THE PUBLIC SERVICE, BY PROGRAMMES

Country	1958		1965	1970	Annual rate of increase of capacity	
	Capacity (thousands of kW)	Annual utilization (hours)	Capacity (thousands of kW)	Capacity (thousands of kW)	1958-65	1958-70
Argentina	260	2 558	728	2 578	15.8	21.0
Bolivia	70	3 400	130	...	9.2	...
Brazil	(2 525)	5 424	5 792	...	12.6	...
Chile	410	4 624	985	1 489	13.3	11.3
Colombia	453	4 260	1 141	1 799	14.1	12.2
Costa Rica	73	3 753	135	...	9.1	
Cuba	-	-	...	...	...	
Dominican Republic	-	-	...	...		
Ecuador	31	4 194	101	...	18.3	
El Salvador	56	3 625	96	...	8.0	
Guatemala	26	4 077	98	...	20.8	
Haiti	-	-	...	...		
Honduras	4	2 750	...	...		
Mexico	1 107	3 754	2 556 a/	...	14.9	
Nicaragua	1	3 000	...	...		
Panama b/	6	2 350	...	...		
Paraguay	-	-	...	...		
Peru	213	3 746	859	1 419	22.0	17.1
Uruguay	128	5 938	233	933	8.9	18.0
Venezuela	35	3 943	350	4 350	39.[illegible]	49.5
British Guiana	-	-	...	...		
Surinam	-	-	16 c/	...		
Tobago and Trinidad	13	6 538	...	...		
Regional total (excluding the countries for which no data are given)	5 405	4 640	13 220	12 568	13.6	19.4

Source: ECLA, on the basis of direct information and miscellaneous publications.

a/ Up to 1964. Compañía Federal de Electricidad (C.F.E.) programme.

b/ Excluding the Panama Canal Company's power stations, for want of production data.

c/ The figure given represents the maximum capacity freely available for the public service at the 150 mW power station which is being constructed by the Surinam Aluminium Company (SURALCO) under an agreement with the Queen of the Netherlands represented by the Government of Surinam.

/plants in

plants in the provinces of Mendoza and Córdoba.[10/]

Unfortunately, the information available is insufficient for an analysis of plants in service or under construction in respect of degree or type of regulation (daily, weekly, seasonal, annual etc), head, age of installations, etc.

The foregoing remarks relate solely to hydro power plants for the public service. In the case of self-generation or, in other words, private supply services, thermal power plants generally predominate (petroleum, sugar, manufacturing and miscellaneous industries, etc), although there are countries where substantial use is made of hydraulic plants in the mining of metals (Peru, Bolivia). The proportion of total self-generation represented by hydroelectric production is approximately 35 per cent.

6. Developments projected

Several countries have official programmes for the expansion of the public service systems; in others, the leading enterprises have drawn up their own development programmes. In both cases there are some divergencies between the goals established and the progress actually achieved in the various works projected for different dates. The relevant data, unadjusted, constituted the basis for the last four columns of table 18, which presents projections of hydroelectric capacity for the public service for the years 1965 and 1970, together with the corresponding annual rates of cumulative growth for the periods 1958-65 and 1958-70.

The 13 countries for which data up to 1965 are available will probably install, in the aggregate, 7.8 million hydroelectric kW during the period 1958-65, which gives a cumulative annual rate of 13.6 per cent. Similarly, the programmes of the 6 countries for which data up to 1970 are to hand represent, in the aggregate, the installation of 11.1 million kW during the period 1958-70. This implies a cumulative annual growth rate of 19.4 per cent. Both estimates clearly reveal the importance of hydroelectric development in the region during the next few years. Up to 1965, the

10/ For Los Molinos I, which has an average of only 2,600 hours of utilization, the construction of the Anizácate dyke is under study. Similarly, a compensating reservoir would seem to be needed at the San Roque dyke power plant.

/largest absolute

largest absolute increments would seem to be those planned by Brazil and Mexico,[11/] (3.27 and 1.45 million kW respectively), Colombia, Peru, Chile and Argentina following with 0.69, 0.64, 0.58 and 0.46 million kW respectively. Up to 1970, Venezuela and Argentina, which are projecting 4.3 and 2.3 million kW, are outstanding among the countries with known programmes.

The highest rates of growth registered in the period 1958-65, which easily exceed the regional average, are those recorded by Venezuela, Peru, Guatemala and Ecuador (39.0, 22.0, 20.8 and 18.3 per cent respectively). Also very significant are the corresponding figures for Argentina, Mexico,[12/] Colombia, Chile and Brazil (15.8, 14.9, 14.1, 13.3 and 12.6 per cent respectively).

For the period 1958-70, the most striking rates are those of 49.5 and 21.0 per cent estimated for Venezuela and Argentina.

Generally speaking, larger increments are contemplated for hydraulic capacity than for thermal capacity in almost all the Latin American countries.[13/]

11/ C.F.E. programmes only.

12/ Ibid.

13/ ECLA, Present status and recent development of electric energy in Latin America, op.cit.

Chapter III

ANALYSIS OF WATER RESOURCES RESEARCH MEDIA IN LATIN AMERICA

1. General considerations

In view of the fundamental importance of the various uses of water for the life and development of nations, it seems worth while to recall once more, however briefly, the vital significance attaching to research on water resources in all parts of the world.

It is common knowledge that an essential requisite for the study of any hydraulic project and for the designing of the constructions involved is the availability of the relevant hydrological information, which must fulfil two basic conditions; the data must be characterized firstly by accuracy and secondly by continuity over a sufficiently lengthy period.

Prevention of flood catastrophes and avoidance of the over-designing of structures (including the planning of electricity plant dimensions on too large a scale) which raises construction costs, as well as the more efficient operation of all hydraulic works, constitute the rewards that more than compensate for the proper collection, processing and analysis of hydrological and hydrometeorological statistics. Moreover, such work represents only a small fraction of the investment - usually substantial - required for hydraulic constructions.

Although the production of energy is not the primary purpose for which water is used, the magnitude of Latin America's hydroelectric resources - which can be divined, rather than assessed, from the statistics presented earlier - in conjunction with the outstanding contribution they already make to the supply of electricity in many countries, would alone suffice to justify a detailed analysis of the medium available for ascertaining the distribution and characteristics of water sources throughout the region, as a preliminary to any attempt at the integrated evaluation of such resources and the programming of their development.

The United Nations Economic and Social Council, in a resolution adopted on 24 August 1954, had recommended Governments and the appropriate specialized agencies to give particular attention to the assembly of hydrological data,[1] an activity which was undertaken by the United Nations Energy and Water Resources Programme.

ECLA, at its sixth session, in resolution 99(VI), recommended to the secretariat that it should evaluate such data with the aim of determining potential and optimum development of resources, and at the Commission's eighth session, in resolution 166(VIII), this recommendation was endorsed and reaffirmed. A joint ECLA/BTAO/WMO working group is making detailed country studies of water resources and their development.

Given the limitations inherent in such a study, the magnitude of the problem, which involves investigation of the quantity and quality of hydrological data in Latin America (number of stations and length of time covered by the records), is too great for anything but a general panoramic view of it to be obtained. Nevertheless, the following points may be brought out:

(a) In several countries a basis exists for making - or at least beginning to make - an evaluation of theoretical potentials (discussed in chapter I), in order to obtain more reliable data on the region's hydroelectric resources and their geographical distribution;

(b) Although various local shades of difference can be recognized within each country and from one country to another, the overall picture of the media for research on water resources is not very satisfactory;

(c) The importance of hydrological data for the projecting and operation of hydraulic works has not been fully grasped by the appropriate authorities, who apparently do not always give adequate support to the institutions responsible for such measurements;

(d) The fact that the shortage of data is greater in the case of river stages and flows than in that of rainfall suggests that for the moment evaluations must be primarily based on precipitation data. It also indicates that in the expansion of networks of hydrological and hydrometeorological stations priority should be given to those of the

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1/ United Nations Economic and Social Council, Official Records: Eighteenth Session. Resolutions (E/2654), resolution 533 (XVIII) (International co-operation with respect to water resource development).

/former which

former which offer possibilities of correlation, within a few years' time, with the precipitation stations already in operation, whose records of observations are continuous and cover a long period.

In the following paragraphs the situation in Latin America will be rapidly reviewed, although with the proviso that the lack of basic information in certain countries and the availability of only partial data in others may have resulted in the accidental inclusion of some figures which are not strictly in line with the facts. The numerical data given below should therefore be regarded merely as a first approximation to the analysis of the problem at regional level.

2. Number of pluviometres, flow metres and evaporimetres, by countries

Of all the observations recorded in the field of hydrology, those relating to the measurement of precipitation are (together with volume of flow measurements) the most fundamentally important and, at the same time, the most widespread. The establishment of precipitation/run-off relationships makes it possible, when information on stream flow variations in a watercourse is inadequate, to estimate these on the basis of precipitation data, which, except in a very few cases, constitute the longest statistical series available in hydrology.

Several factors affect a country's ideal minimum density requirements in respect of rain gauges, the most important being the irregularity of the surface distribution of rainfall, topographical characteristics and the purpose which the observations are intended to serve.

Consequently, the area that a rain gauge can representatively cover varies widely; however, figures ranging from 100 to 1,000 km^2 per rain gauge may be considered, on an average, to reflect satisfactory station densities for many purposes in various parts of the world.[2/] The highest densities correspond to mountainous districts where rainfall is more unevenly distributed than in the plains.

2/ See ECAFE, Proceedings of the third regional technical conference on water resources development in Asia and the Far East: Flood Control Series No. 13, United Nations Publications, Sales No.: 59.II.F.2, Bangkok, 1958.

/As regards

As regards stream flow gauging stations, it may be considered desirable for there to be one at the confluence of every important tributary with the main water course, as well as at tappings feeding existing works and at sites where the construction of new plant is contemplated. Despite the foregoing suggestion that the ideal number of stream flow metres for a given basin is a function of the number of confluences of major water courses, by analogy with precipitation stations (although their significance is not the same) comparisons are often established on the basis of the average territorial area corresponding to each stream flow gauging station.[3/]

Notwithstanding the importance that is attributed to the determination of evaporation by experiment in order to establish water balances in a basin or area, the simple methods in use (such as the tank or Piche evaporimetre and the Livingstone atmometre) do not exactly measure the natural process of evaporation, and are therefore regarded as only relative indicators of the phenomenon they attempt to assess. Consequently, rules for determining the optimum number of evaporimetres for a specific territorial area have not yet been laid down.

Table 19 shows the total number of rain gauges, flow metres and evaporimetres in service in each of the Latin American countries. In the case of rain gauges and flow metres, the average area of mainland territory per instrument is also given. Together with rain gauges have been counted snow gauges, which are few in number and, according to the data available, are to be found only in a few localities high up in the Andean massif and, as a rule, far from the equator. The countries possessing the largest number are Argentina, which has 88, and Chile, which has 24. Only in 10 countries does the overall average figure for the area per rain gauge fall below 1,000 km^2. El Salvador, the Dominican Republic, Haiti, Uruguay and Costa Rica show the most

3/ See W. B. Langheim and W. G. Hoyt, Water Facts for the Nation's Future, New York, 1959, p. 63, for an account of variations in the United States from 6,500 km^2 per station in arid and sparsely populated States like Nevada to 1,700 km^2 per station in the more densely populated Eastern States, with their damper climate.

/satisfactory averages

satisfactory averages (210,234, 280,340 and 400 km^2 per rain gauge, respectively). Cuba, Panama, Guatemala, Argentina, Venezuela and Mexico are the other countries with averages of less than 1,000 km^2 per rain gauge. It may be noted that the countries of relatively small size which have a high population density and whose economies are heavily dependent upon tropical crops (coffee, cacao, sugar-cane, etc.) are among the best equipped in respect of precipitation stations per unit of territorial area. Conversely, Peru, Bolivia and Brazil are those registering the largest average area per rain gauge (10,100, 5,500 and 3,300 km^2, respectively). In the remaining countries averages exceeding 1,000 km^2 per rain gauge are found.[4/] Chile and Ecuador have each signed (1960) agreements with the United Nations Special Fund with a view to the expansion and improvement of their meteorological and hydrological networks on the basis of the studies carried out by the ECLA/TAO/WMS Water Resources Survey Group in these two countries. The relevant programmes are already being put into effect.

The data available are not sufficiently complete to allow of a detailed analysis of the proportion of rain recorders in the corresponding precipitation stations. According to the information to hand, the highest relationships would seem to be found in Panama, Colombia, El Salvador, Costa Rica and Brazil (42, 23, 20, 10 and 7 per cent respectively). The additional data supplied by the automatic recording devices (continuous time-precipitation relationships) and their greater reliability, together with the fact that rain recorders do not require constant supervision (and are therefore highly suitable for sites which are difficult of access or are cut off altogether at certain times of year) are so many more reasons for the use of an increasing proportion of these instruments in Latin America, despite their heavier cost.

4/ In Europe the average area <u>per meteorological station</u> is 192 km^2 and in the United States 1,536 km^2. See Rudolf Schroeder, <u>Study of water resources in Venezuela. Present state of hydrometeorology</u> (a joint ECLA/TAO/WMS study in draft form), which alludes to a quotation, in a report by Robert Grace, from H. Landsberg, <u>Physical Climatology</u>, Pennsylvania State College, 1941.

/Table 19

Table 19

LATIN AMERICA: NUMBER OF RAIN GAUGES, FLOW METERS AND EVAPORIMETERS IN SERVICE

Country	Year	Area of territory (km^2)	Density of population in 1958 (number of inhabitants per km^2)	Rain gauges: Number	Rain gauges: Average area per rain gauge	Flow meters: Number	Flow meters: Average area per flow meter	Evaporimeters
Argentina	(1959)	2 778 412	7	3 613	769	537a/	5 174	110
Bolivia	(1959)	1 098 581	3	200b/	5 493	67	16 397	1
Brazil	(1959)	8 513 844	7	2 577	3 304	1 287c/	6 615	...
Chile	(1959)	741 767	10	479	1 549	260	2 853	19
Colombia	(1959)	1 138 355	12	510d/	2 232	197d/	5 778	8
Costa Rica	(1958)	50 900	21	128	398	15	3 393	4
Cuba	(1958)	114 524	56	188e/	609	26e/	4 405	...
Dominican Republic	(1958)	48 734	57	208e/	234	10e/	4 873	...
Ecuador	(1958)	263 206	15	86f/	3 061	18g/	14 623	...
El Salvador	(1959)	20 000	122	95h/	211	41h/	488	8h/
Guatemala	(1958)	108 889	33	149e/	731	8e/	13 611	7
Haiti	(1958)	27 750	123	100e/	278	29e/	957	2
Honduras	(1958)	112 088	16	62d/	1 808	40d/	2 802	...
Mexico	(1958)	1 969 269	16	2 035i/	1 064	965i/	2 041	535
Nicaragua	(1958)	148 000	9	60j/	2 467	16j/	9 250	7
Panama (including the Canal Zone)	(1959)	75 902	14	112k/	678	47k/	1 615	6
Paraguay		406 752	4	...	...	...	...	
Peru	(1959)	1 285 215	8	127	10 100 l/	90	14 300	35
Uruguay	(1959)	186 926	14	547m/	342	...	...	... m/
Venezuela	(1959)	912 050	7	1 016n/	898	248n/	3 678	143
British Guiana		214 971	2	...	...	...	...	...
Surinam	(1959)	142 822	2	60o/	2 380	-	-	-
West Indies		16 552	146	...	...	...	...	...

Sources: ECLA, on the basis of direct official information (in the shape of replies to the relevant questionnaire) and miscellaneous publications (see notes on individual countries).

Note: The sources of information acknowledged in connexion with this first table on the present subject, as well as the years (shown in parenthesis) up to which data have been taken into account, are valid for the remaining tables. The areas adopted are those given in the United Nations Statistical Yearbook 1959.

a/ National Department of Port Facilities and Navigable Waterways (Dirección Nacional de Construcciones Portuarias y Vías Navegables), Agua y Energía Eléctrica (1959) and Anuario Hidrográfico 1948-50.

b/ R. Schröder, Sugerencias para la organización de un servicio meteorológico e hidrológico adecuado para las necesidades de Bolivia (1960), a joint ECLA/TAO/WMO study in course of preparation.

c/ Belonging mainly to the Water Department of the Ministry of Agriculture.

d/ Direct information supplemented with the data provided by the Pan American Institute of Geography and History of the Organization of American States, Estudios sobre Recursos Naturales en las Américas, México 1953, Vol. II, Project 29.

e/ Ibid.

f/ R. Schröder, Study of water resources in Ecuador. Present state of hydrometeorology (1959), a joint ECLA/TAO/WMO study in draft form. (Four stations in the Galápagos Islands are not included.)

g/ Charles G. Hawes, Report on water resources in Ecuador, a joint ECLA/TAO/WMO study in draft form (1959).

h/ Atilio García Prieto, La investigación de recursos hidráulicos en El Salvador (CCE/SC.5/I/DT.12).1959.

i/ Pan American Institute of Geography and History, op. cit., Vol. IV; Water Resources Department, Lerma-Chapala-Santiago Study Commission, Boletín Hidrológico No. 1; Ingeniería Hidráulica en México, February 1956; and Federal Electricity Commission, Boletín Hidrológico No. 2: Cuenca Río Balsas.

/Table 19 (cont.)

Table 19 (cont'nd)

j/ Pan American Institute of Geography and History, op. cit., Vol. I; National Energy Commission, Plan de Electrificación Nacional e Investigación de los Recursos Hidráulicos (CCE/SC.5/I/DT.1).

k/ Pan American Institute of Geography and History, op. cit., Vol. I; Inter-American Co-operative Economic Development Service (Servicio Cooperativo Interamericano de Fomento Económico - SCIFE), Proyecto de Recursos Hidráulicos y Electrificación, 1960.

l/ The average figure for eight southern departments is 4 486 km^2 per rain gauge (see data quoted from a report by Robert Grace in Study of water resources in Venezuela, op. cit.).

m/ State Electricity, Gas and Telephones (Usinas y Teléfonos del Estado - UTE), Memoria Descriptiva General del Río Negro y de las Obras Hidroeléctricas construídas, 1959.

n/ Ministry of Public Works, Resumen de Datos Hidrométricos 1940-59, and data supplied by the National Institute of Sanitary Engineering (Instituto Nacional de Obras Sanitarias - INOS).

o/ Bokopondo Bureau, Appraisal Survey of Hydroelectric Power Resources in Surinam.

/As regards

As regards flow meters (see table 19), El Salvador, Haiti, Panama, Mexico, Honduras and Chile are the best-equipped countries , the respective areas per unit being 490, 960, 1,620, 2,040, 2,800 and 2,850 km^2. Costa Rica, Venezuela, Cuba, the Dominican Republic and Argentina follow with 3,390, 3,680, 4,400, 4,870 and 5,170 km^2 per flow meter. The available data indicate that the largest areas per stream gauging station are found in Bolivia, Ecuador, Peru and Guatemala, where 16,400, 14,620, 14,300 and 13,610 km^2 per unit are registered.5/

The information to hand is insufficient for a precise analysis, by countries, of those hydrological stations which measure only river stages, with no possibility of the data obtained being converted into terms of stream flows through discharge curves already or about to be established. However, the statistics presented above relate only to stations designed for flow measurement purposes, except in the case of Argentina, where they include data referring to 200 stations operated by the National Department of Port Facilities and Navigable Waterways (<u>Dirección Nacional de Construcciones Portuarias y Vías Navegables</u>) solely for the registration of river stages for navigation

5/ Further light is shed on the subject by a comparison with the similar situation prevailing in some of the countries of Asia and the Far East in 1955, as indicated in the following table:

Country	Total area in km^2	Number of inhabitants per km^2	Number of km^2 per rain gauge	Number of km^2 per flow meter
Burma	677 950	29	3 660	...
Ceylon	65 610	131	137	224
India	3 288 375	116	934	6 450
Japan	369 813	241	83	138
Republic of Korea	93 634	230	2 340	1 610
Laos	237 000	6	59 300	47 500
Federation of Malaya	131 287	46	129	501
Pakistan	944 824	87	1 630	4 180
Philippines	299 404	74	1 450	1 310
Thailand	514 000	39	1 280	2 940

<u>Source</u>: ECAFE, <u>Proceedings of the third regional technical conference on water resources development in Asia and the Far East, op. cit.</u>

/purposes. The

purposes. The great majority of the flow meters consist of firm cross-stream sections (weirs, bridge corners, gauging frames and structures, aqueducts of reinforced concrete or mansonry, etc.) fitted with simple scales (limnimeters) for reading the level of the water. The flows in question are computed by means of empirical formulae established on the basis of direct gauging, or specific relationship in hydraulic models. The number of cases in which scales are being replaced by automatic recorders (limnigraphs), which have advantages similar to those already pointed out in the case of rain recorders, is increasing in the various countries, but the relative share of these instruments in the total is still not very high. Thus, it was possible to establish that in the countries listed they accounted for the following percentages: Costa Rica, 100; Colombia, 25; El Salvador, 17; Argentina, 13; and Ecuador, 6. In other countries, either data are lacking or the figures given are so low as to be of dubious value.

Where evaporation stations in operation are concerned, Mexico, Venezuela and Argentina are quite outstanding, with 535,143 and 110 respectively. The corresponding figures for Peru, Chile and Colombia are, respectively, 35,19 and 8. Bolivia, Costa Rica, El Salvador, Guatemala, Haiti and Nicaragua also record observations of this type.

Although in some countries, such as Argentina, Brazil, Chile, Colombia and Mexico, sediment transportation is measured in certain watercourses, the information obtained was not sufficient for inclusion in the present study.

3. Number of rain gauges and flow meters, by selected basins and sub-basins

In each individual country, of course, rain gauges and flow meters are very unevenly distributed, as can be seen from a comparison of table 19 with table 20. The latter shows the situation in some of the basins and sub-basins which are most throughly studied in each country, with respect to the average area covered by each rain gauge and flow meter in operation.

/Table 20

Table 20

LATIN AMERICA: EXISTING EQUIPMENT IN SOME OF THE BASINS AND SUB-BASINS WHERE RESEARCH IS MOST SATISFACTORY, BY COUNTRIES

Country, basin or sub-basin	Total area (km²)	Rain gauges: Number	Rain gauges: Average area per rain gauge (km²)	Flow meters: Number	Flow meters: Average area per flow meter (km²)
Argentina					
Rio Negro	189 196	102	1 855	49	3 861
Cordoba System a/	70 873	237	299	29	2 444
Northern zone b/	170 000	320	531	79	2 152
Bolivia					
Lago Titicaca-Rio Desaguadero	43 400	32	1 356	4	10 850
Brazil					
River Doce	88 000	93	946	116 c/	759
River Paranaiba	219 000	24	9 125	57 c/	3 842
Rio Grande	147 000	165	891	166 c/	886
River Uruguay	169 000	114	1 482	118 c/	1 432
River San Francisco	614 000	476	1 290	178 c/	3 449
River Tieté	72 000	76	947	37 c/	1 900
Chile					
River Maipo	16 000	53	302	15	1 067
River Bío-Bío	26 960	48	562	19	1 419
Colombia					
River Cauca (as far as Manizales)	25 142	47	535	38	662
River Magdalena (as far as Honda)	56 903	127	448	69	825
Costa Rica					
River Grande de Târcoles	2 105	22	96	4	526
River Reventazón	2 105	27	78	5	421
Cuba					
River Hanabanilla	200	...	...	...	...
Dominican Republic					
River Yaque del Norte	7 000	...	...	7	1 000
Ecuador					
River Guaillabamba (inter-Andean zone)	4 000	3	1 333	2	2 000
River Ambi	1 100	3	367	1	1 100
El Salvador					
River Lempa (as far as "5 de Noviembre" power station)	6 540	40	164	21	311

/Table 20 (cont.)

Table 20 (cont'nd)

Country, basin or sub-basin	Total area (km^2)	Rain gauges: Number	Rain gauges: Average area per rain gauge (km^2)	Flow/meters: Number	Flow/meters: Average area per flow meter (km^2)
Guatemala					
Lake Amatitlán-River Michatoga	2 700	15	180	1	2 700
Lake Atitlán	560	4	140	-	-
Haiti					
...	...	...	...	...	...
Honduras					
River Ulúa	24 290	13	1 868	18	1 350
River Chamalecón	6 548	9	7 276	2	3 274
Mexico					
River Lerma-Chapala-Santiago	125 555	208	604	67	1 874
River Balsas	108 000	45	2 400	53	2 038
Nicaragua					
Lake Nicaragua and River San Juan	29 000	27	1 074	7	4 143
Panama					
River Chiriquí	1 700	7	243	6	283
River Santa María	3 300	11	300	6	550
Paraguay					
...	...	...	...	...	...
Peru					
River Rimac	3 630	4	908	5	726
River Mantaro (as far as Chinchihuasi tributary)	27 590	9	3 066	15	1 839
Uruguay					
Río Negro	69 175	...	...	12	5 765
Venezuela					
River Tuy	6 750	129	52	74	91
Lake Valencia	2 800	71	39	14	200
British Guiana					
...	...	...	...	...	...
Surinam					
...	...	...	...	...	...
West Indies					
...	...	...	...	...	...

Sources: See table 19.

a/ Including Rivers Primero, Segundo, Tercero, Cuarto and Carcarañá.

b/ Consisting of the upper basins (in Argentine territory) of the following rivers: Bermejo, as far as Elordi; Salado, as far as Suncho-Corral; and Dulce, as far as Santiago del Estero.

c/ Belonging mainly to the water Department of the Ministry of Agriculture.

d/ Area of the basin in Nicaragua territory.

/As regards

As regards rainfall measurements, for example, the position of Peru, Bolivia and Brazil is worth noting. Although for their territories as a whole the largest average areas per station are indicated, the figures for specific basins are a good deal more favourable. In the basins of the Rivers Rimac and Mantaro (as far as the Chinchihuasi tributary), in Peru, 908 and 3,066 km^2 per rain gauge are registered. The Titicaca—River Desaguadero basin, in Bolivia, shows 1,356 km^2 per rain gauge, and for the basins of the Rio Grande and the River Tieté, in Brazil, the corresponding figures are 891 and 947 km^2, respectively. Similar observations apply to the other countries in respect of both precipitation and stream flow measurement. The other highly enlightening aspect of table 20 is that relating to the experience afforded by the Latin American countries - as to the area - in terms of broad averages for which a rain gauge or flow meter seems sufficiently representative, in basins where hydraulic works are in operation, under construction or projected. In most of the basins studied the equipment ascertained to exist implies an area of less than 1,000 km^2 per rain gauge, and in the Cordillera and other mountainous districts (see Chile, Colombia and Ecuador) this figure is reduced to some 500 km^2 per rain gauge. As regards stream gauging (due allowance being made for the comparatively negligible significance attaching, as already pointed out, to indications of the area for which, on an average, one flow meter is considered adequate), between 500 and 2,000 km^2 per station might be mentioned as common. These statistics throw into relief the inadequacy of the media available for the collection of hydrological and hydrometeorological data in Latin America as a whole.

4. Length of records

The flow of water in a river may vary a great deal year by year, from one season of the year to another, and even at different times of day. Consequently, it is of the greatest importance that continuous records of the flow be available, and that they should cover a long period, so that the mean monthly, seasonal or annual discharges that may be counted upon for a project can be ascertained with the

/requisite degree

requisite degree of accuracy. Moreover, the peak and minimum discharges corresponding to periods of flood and of drought may constitute the decisive conditions for a project. For example, exceptionally high discharge figures, with frequencies as distant as 1 in 1,000 or 1 in 2,000 years, are sometimes used to determine spillway dimensions for certain dams. As the high and low extremes occur too irregularly for these peak and minimum discharges to be established by extrapolation, the loss of one such opportunity of recording them may mean that many years will pass before a similar situation recurs. It is for all these reasons that hydrological observations should be initiated long before the construction of works is begun.

Serious catastrophes arising from dam failures have had their origin in the under-estimating of maximum flood discharges through lack of continuity in hydrologic records or unduly short statistical series. Again, substantial losses are caused by over-designing of works and inefficient operation of projects, attributable to the same cause - inadequate hydrologic data whose chief deficiency is that the time covered by the records is too short. Latin America affords several examples of hydroelectric power stations constructed for over-estimated flows and therefore operating with low plant factors, while it must not be overlooked that the opposite situation also exists, and that the source is sometimes under-utilized because it would not be safe to turn the available discharge to account.

In various countries of the region hydrological stations can be found which were formerly installed as part of the permanent measurement network but have been closed down or dismantled before the completion of a hydrological period that can be regarded as representative or enables valid correlations to be established with other and longer series of rainfall or stream flow records, so that the initial effort and work have been wasted. Such situations are often due to lack of funds for these activities, because their importance hast not been fully grasped.

/When the

When the data for this study were being collected, there were instances in which information was obtainable only up to the early 1950's.6/ For the sake of uniformity with the majority of countries, for which data were available up to December 1958, the period of years covered by the records of the former group was prolonged on the hypothesis that the observations had been uninterrupted. This procedure meant that countries for which indirect and rather out-of-date information had been obtained, and which had installed rain gauges and flow meters two or three years prior to 1958, were probably credited with fewer sets of equipment than they actually possessed, but were not much affected as regards the length of their records.

Table 21 presents a break-down of stations by the number of years their records cover, for each country as a whole and for selected examples of the better-known basins. The table includes many estimates and must be regarded as highly provisional. Data on existing stocks and sites of rain gauges and flow meters were actually more complete than those relating to periods of operation and length of records. To round off the overall picture and calculate the coverage coefficient, estimates were made when these data were lacking, as far as possible on the basis of considerations relating to the creation of the institution owning the equipment or to the date of initiation of its activities (railway stations, airports, etc.), and in the remaining instances by the arbitrary assignment of lengths of series in relation to those known of in the same country.7/

6/ This was principally true of the Central American countries and the Antilles, in whose case the want of direct information was supplied mainly by recourse to the report of the Pan American Institute of Geography and History of the Organization of American States, Estudios sobre Recursos Naturales en las Américas, Vol. II, Project 29, Mexico, 1953.

7/ The classification into groups was based on the view that for the purposes of executing a final project of average importance records incorporating less than 5 years observations are inadequate. Records covering from 6 to 15 years might be used in certain special instances, but with reservations. Those in the 16-30 years group may be taken as satisfactory in most cases, and those of over 30 years, highly satisfactory.

/Table 21

Table 21

LATINA AMERICA: BREAKDOWN OF STATIONS BY LENGTH OF RECORDS (NUMBER OF YEARS COVERED)

Country, basins or sub-basins	Year	Throughout the country: Less than 5 years: Precipitation	Throughout the country: Less than 5 years: Flow	Throughout the country: 6 to 15 years: Precipitation	Throughout the country: 6 to 15 years: Flow	Throughout the country: 16 to 30 years: Precipitation	Throughout the country: 16 to 30 years: Flow	Throughout the country: More than 30 years: Precipitation	Throughout the country: More than 30 years: Flow	In some of the basins where research is most satisfactory: Less than 5 years: Precipitation	In some of the basins where research is most satisfactory: Less than 5 years: Flow	In some of the basins where research is most satisfactory: 6 to 15 years: Precipitation	In some of the basins where research is most satisfactory: 6 to 15 years: Flow	In some of the basins where research is most satisfactory: 16 to 30 years: Precipitation	In some of the basins where research is most satisfactory: 16 to 30 years: Flow	In some of the basins where research is most satisfactory: More than 30 years: Precipitation	In some of the basins where research is most satisfactory: More than 30 years: Flow
<u>Argentina</u>	(1959)	-	1	1 327a/	271a/	1 330a/	77	956	188								
Río Negro										-	-	97	28	39	5	26	16
Córdova System a/										-	1	85	5	91	16	61	7
Northern zone b/										-	-	115	59	121	15	84	5
<u>Bolivia</u>	(1959)	18	30	53	27	73a/	10	56a/	-								
Lake Titicaca-River Desaguadero										-	-	6	1	12	3	14	-
<u>Brasil</u>	(1959)	110	120	836a/	360	408	737	1 223a/	70								
River Doce										1	4	12	25	42	85	-	2
River Paranaiba										-	11	11	32	4	14	-	-
Río Grande										2	2	3	22	81	141	-	1
River Uruguay										33	19	7	23	13	76	-	-
River San Francisco										15	12	27	42	56	105	5	19
River Tieté										1	-	14	16	16	21	-	-
<u>Chile</u>	(1959)	61	72	230a/	110a/	92	68	96	10								
River Maipo										8	2	14	5	12	5	12	9
River Bio-Bio										4	9	6	1	8	6	13	3
<u>Colombia</u>	(1959)	282	132	122	49	79	14	27	1								
River Cauca (as far as Manizales)										10	15	27	22	7	1	3	-
River Magdalena (as far as Honda)										74	40	24	16	28	12	1	1
<u>Costa Rica</u>	(1958)	42	10	51	5	34	-	1	-								
River Grande de Tárcoles										10	3	7	1	4	-	1	-
River Reventazon										10	5	11	-	6	-	-	-
<u>Cuba</u>	(1958)	...	...	...	...	...	...	...	...								
River Hanabanilla										...	...	...	...	...	...	...	...
<u>Dominican Republic</u>			...	72	...	133	...	3	...								
River Yaque del Norte										...	...	...	...	...	...	...	...

Table 21 (cont'nd 1)

Country, basins or sub-basins		Throughout the country								In some of the basins where research is most satisfactory							
		Less than 5 years		6 to 15 years		16 to 30 years		More than 30 years		Less than 5 years		6 to 15 years		16 to 30 years		More than 30 years	
		Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow
Ecuador	(1958)	53a/	17	27	1	5	-	1	-								
River Guaillabamba (inter-Andean zone)										2	1	-	1	-	-	1	-
River Ambi										1	1	2	-	-	-	-	-
El Salvador	(1959)	34	40a/	24	1	15	-	22	-								
River Lempa (as far as "5 de Noviembre" power station)										12	20	10	1	9	-	9	-
Guatemala	(1958)	-	-	40	8	103	-	6	-								
Lake Amatitlán-River Michatoga										-	-	3	1	11	-	1	-
Lake Atitlán										-	-	-	-	3	-	1	-
Haiti		...	...	...	...	...	...	...	...								
...										...	...	...	...	...	...	...	...
Honduras	(1958)	18	40	38	-	5	-	1	-								
River Ulúa										4	18	9	-	-	-	-	-
River Chamalecón										-	2	4	-	4	-	1	-
Mexico	(1958)	170a/	90a/	754	451	520	359	407	65								
Rivers Lerma-Chapala-Santiago										2	10	87	20	95	33	24	4
River Balsas										29	21	16	28	-	3	-	1
Nicaragua	(1958)	25	14	8	-	21	-	6	2								
Lake Nicaragua and River San Juan										8	5	1	-	16	-	2	2
Panama	(1959)	37	36	28	4	18	-	29	7								
River Chiriquí										5	6	2	-	-	-	-	-
River Santa María										10	6	-	-	1	-	-	-
Paraguay		...	...	...	...	...	...	...	...								
...										...	...	...	...	...	...	...	...

Table 21 (cont'nd 2)

Country, basin or sub-basin		Throughout the country								In some of the basins where research is most satisfactory							
		Less than 5 years		6 to 15 years		16 to 30 years		More than 30 years		Less than 5 years		6 to 15 years		16 to 30 years		More than 30 years	
		Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow	Precipitation	Flow
Peru	(1959)	22	32	84	23a/	20	19	1	16								
River Rimac										-	-	2	1	2	1	-	3
River Mantaro										3	7	4	6	1	2	1	-
Uruguay	(1959)	...	-	...	5	...	1	...	6								
Río Negro										...	-	...	5	...	1	...	6
Venezuela	(1959)	221	202a/	570a/	30	186	16	39	-								
River Tuy										23	67	77	2	21	5	8	-
Lake Valencia										9	10	41	3	14	1	7	-
British Guiana																	
...																	
Surinam																	
...																	
West Indies																	

Sources: See table 19.

Note: In the case of those countries for which the only data available were supplied by the Pan American Insitute of Geography and History of the Organization of American States, Estudios sobre recursos naturales en las Américas, op. cit., Vol. II, it was estimated that the precipitation and stream gauging stations existing in 1953 and appearing in that publication were operating regularly in 1958.

a/ Including estimates.

b/ Consisting of the upper basins (in Argentine territory) of the following rivers: Bermejo, as far as elordi; Salado, as far as Suncho-Corral; and Dulce, as far as Santiago del Estero.

The length of rainfall records is often considerable (or relatively so), owing to the fact that many instruments were installed by private institutions at the time of their foundation for purposes closely linked to their main activities (railway companies when their construction works were begun, crop and stock farming enterprises, airlines, etc.).

The high proportion of precipitation stations with records covering many years in Brazil, Argentina, Mexico, Bolivia and Chile, for example, is worth noting, and so, on the other hand, is the extensive but more recent action taken by certain official agencies in countries like Colombia and Venezuela.

As regards stream gauging, Argentina, Brazil and Mexico can be seen to have begun recording observations on a large scale at an earlier date than the other countries of the region for which such data are available. Chile next, and then Colombia, afford evidence of more recently systematized activities on the part of the official bodies responsible for this work, and the same is true of the Central American countries.

A similar analysis in respect of certain selected basins confirms the disparities in levels of research as between one such basin and another within the same country, and even among different rivers in the same basin or from one reach of a river to another, according to their distance and accessibility from the main population centres.

5. Coverage coefficient

In order to assess the level of development of hydrological research in a given basin or territory, the coverage index for rainfall measurements and stream gauging simultaneously takes into account the density of observation stations and the age of the pertinent records, since these two elements play independent roles.

The index in question is determined by the product of two factors: the number of observation stations per 10,000 km^2 of the territory under study,[8/] and the average age, in years of the corresponding records.

8/ In the present study it was felt preferable to consider the number of stations per 10,000 km^2, instead of per 1,000 km^2 as in the ECAFE report referred to above, since the station density figure was too low in some countries.

/Table 22 enumerates

Table 22 enumerates these coefficients by countries, for both precipitation and stream gauging stations.

The countries in whose case this coefficient reflects the most thorough knowledge of precipitation conditions in their territory are El Salvador, Cuba, Argentina, Mexico, Panama, Costa Rica and Guatemala, the respective figures being as follows: 765, 393.6, 313, 299, 292, 268 and 260. Chile, Venezuela and Nicaragua would seem to occupy an intermediate position, with coefficients of 124,122 and 107 respectively, while Peru, Ecuador, Bolivia, Honduras, Colombia and Brazil present the lowest coefficients. Attention should be drawn, in connexion with the coefficient under study, to the importance acquired in some cases by rain gauge density and in others by the average age of the records; Argentina, Cuba and Mexico register an intermediate rain-gauge density and a high age of records, whereas El Salvador and Costa Rica show a high rain-gauge density and intermediate age or records, while for Nicaragua, Brazil and Bolivia the station density is low and the number of years covered by the records high.

Coverage coefficients for research on stream flows and river stages mark out Mexico, El Salvador, Argentina, Chile and Panama as the countries with the best knowledge of their territory in this respect, the relevant figures being 97 and 53, respectively, for the first two, and 45 for the three last-named. In Argentina's case, if only those stream gauging stations which are operated for purposes of flow measurement are taken into account, the coefficient drops to 16. Brazil, Uruguay, Venezuela, Nicaragua and Colombia appear in an intermediate position with 27, 22, 16, 14 and 12. The lowest coefficients are registered for Ecuador, Bolivia, Guatemala, Honduras, Costa Rica and Peru.

It should be noted that El Salvador shows the highest station density alongside, on the average, one of the shortest series of records; and, conversely, Argentina presents a low station density together with the greatest average length of records.

Maps of Latin America showing, in broad outline, the precipitation and stream gauging coverage coefficients for selected areas are presented below (see maps III-1 and III-2).

/Table 22

Table 22

LATIN AMERICA: COVERAGE COEFFICIENTS

Country	Precipitation records			Stream gauging records		
	Average length of records (i) a/	Number of stations per 10 000 km2 (ii)	Coefficient (i)x(ii)	Average length of records (iii) a/	Number of stations per 10 000 km2 (iv)	Coefficient (iii)x (iv)
Argentina	24.1	13.0	313.3	23.9	1.9	45.4
Bolivia	19.8	1.9	37.6	7.0	0.7	4.9
Brazil	26.6	3.0	79.8	17.9	1.5	26.9
Chile	19.0	6.5	123.5	10.8	4.2	45.4
Colombia	9.8	6.0	58.8	6.5	1.9	12.4
Costa Rica	10.1	26.5	267.7	3.8	2.9	11.0
Cuba	24.0	16.4	393.6	...	...	...
Dominican Republic	20.8	42.7	888.2	...	2.1	...
Ecuador	7.6	3.3	25.1	2.3	0.7	1.6
El Salvador	16.1	47.5	764.8	2.6	20.5	53.3
Guatemala	19.0	13.7	260.3	9.0	0.7	6.3
Haiti	...	36.0	...	...	10.5	...
Honduras	8.6	5.5	47.3	2.7	3.6	9.7
Mexico	26.0	11.5	299.0	10.4	9.3	96.7
Nicaragua	26.0	4.1	106.6	13.0	1.1	14.3
Panama b/	19.7	14.8	291.6	7.2	6.2	44.6
Paraguay	...	...	...	...	...	...
Peru	9.7	1.0	9.7	15.8	0.7	11.1
Uruguay c/	...	...	...	31.0	0.7	21.7
Venezuela	11.0	11.1	122.1	6.0	2.7	16.2
British Guiana	...	...	...	...	...	...
Surinam	...	...	...	...	...	...
Trinidad and Tobago	...	...	...	...	...	...

Sources: See table 19.

Note: In calculating coverage coefficients, stations that had been closed down were taken into account along with those in existence, when the information available permitted.

a/ In the case of stations for which no data on length of records were available, an estimated length was arbitrarily assigned on the basis of the average for other stations in the same country.

b/ Including the Canal Zone.

c/ The data available were confined exclusively to the stream gauging stations on the Rio Negro.

/Map III-1

In studying these maps certain special circumstances must be borne in mind.

There are arid zones in the continent where the absence, or a very low density, of precipitation and stream gauging stations is justified. This applies to vast tracts such as the high plateaux of Mexico and the Chihuahua desert, the peninsula of Lower California (especially in its extreme north-east), the arid belt along the coasts of Peru and northern Chile, the south-west of Bolivia and the north-west and south-east of Argentina. There are also smaller arid zones to the south of the Caribbean in Venezuela, Puerto Rico and Mexico (north-east Yucatán, besides Tehuantepec and the middle reaches of the River Balsas-Mexcala). A rather different state of affairs prevails in the "Polígono das Secas" (in north-eastern Brazil), where the rainfall is characterized not only by a relatively low mean volume, but also, in the main, by great irregularity. Consequently, precipitation and stream gauging research is of great importance here for regulatory purposes, with a view to irrigation works.

In the Amazonian jungle, vast unexplored areas and others that are scarcely inhabited show very low average population densities and therefore a great lack of precipitation and stream gauging stations (States and districts of Rio Branco, Amazonas, Pará, Mato Grosso, Acre and Guapré in Brazil, and the llanos of Colombia, Ecuador, Peru and Bolivia).

Lastly, in the study of stream gauging programmes, the importance of linking them up with those relating to precipitation measurement should not be forgotten, since flow statistics can as a rule be greatly improved upon by means of satisfactory correlations with rainfall data. The central zones of Mexico, Guatemala, Costa Rica, Argentina and El Salvador, and the north-east of Brazil, are examples of other areas where more comprehensive flow data than might be supposed from the corresponding coverage coefficients could be obtained for specific studies, on the basis of the available precipitation data.

/A comparison

A comparison with countries in other regions on the basis of coverage indices shows that as a whole the Latin American countries are ill-informed as to their water resources. For example, in the group of more developed countries for which complete data are available, Japan has coverage coefficients 5 and 4 times greater than the highest country figures registered in Latin American for precipitation measurement and stream gauging, respectively (El Salvador and Mexico).9/

6. Availatility of contour maps

It was not possible to establish, by countries, the availability of contour maps drawn to scales which would enable evaluation studies of integrated theoretical potentials to be carried out.10/

Geographical institutes attached to the armed forces of various countries prepare maps and charts both by aerophotogrammatic methods and by direct measurement, on scales which as a rule allow room for enough planimetrical and altimetrical detail (1:200,000; 1:250,000; 1;500,000; 1:100,000,000, etc.) to serve the purposes mentioned above. Possibly, therefore, large areas in different countries already have at their

9/ To facilitate further comparisons, a table with the pertinent coverage coefficients for selected countries in Asia and the Far East is inserted here.

Country	Precipitation measurement	Stream gauging	
		In general	Flow measurement only
Burma	77	...	...
Ceylon	2 840	400	820
India	535	32	18
Japan	3 900	...	380
Republic of Korea	77	81	27
Laos	1	8	-
Federation of Malaya	1 550	240	57
Pakistan	368	288	...
Philippines	104	38	37
Thailand	202	51	5

Source: ECAFE, Proceedings of the third regional technical conference on water resources development in Asia and the Far East, op. cit.

10/ 1: 500,000 and above. Every country has maps on a reduced scale with level curves such as, for instance, those used for aerial navigation which are on a scale of 1: 1,000,000.

/disposal a

disposal a sound cartographical basis on which at least to begin an integrated evaluation of their hydroelectric resources.

7. Institutions responsible for hydrological measurements

In almost all countries there exists a series of fiscal institutions, public corporations and private agencies concerned with hydrological (including hydrometeorological) observations and, in some cases, with the corresponding research.

The public institutions which finance and carry out activities of this type include, besides the national meteorological services, all those relating to agriculture, navigation and waterways, drinking-water and sewage and aviation, as well as electricity companies, railways, the armed forces, universities, etc.; while the private institutions comprise mainly electricity companies, those of an agricultural-industrial nature (coffee, banana, sugar companies, etc.), airlines and some mining enterprises.

Unfortunately, the advantage taken of the activities to which numerous institutions contribute is proportionally only very small, owing to the lack of uniformity, co-ordination and centralization of the observations recorded. A great many data benefit solely the company or institution taking the observations, and that only to a limited extent, while but a meagre proportion of them is published so as to place them within the reach of the various interested persons or institutions.

Co-ordination among the many institutions responsible in each country for hydrological observations is of particular importance for the following purposes:

(a) Satisfactory planning and distribution of stations so as to obviate duplication in some places and gaps in others;

(b) Standardization of instruments and methods so as to reduce costs and facilitate the comparison of findings; and

(c) Processing and publication of the observations recorded.

Thus, for the relatively small additional cost which such co-ordination would imply, the present yield from scattered and partly unrecognized activities could be greatly multiplied in many countries.

/It has

It has been suggested in several countries that a National Co-ordinating Committee should be set up with jurisdiction over all hydrological and meteorological activities. This Committee, in its turn, would form part of another national body empowered to co-ordinate all activities connected with the development of hydraulic resources.[11/]

Table 23 lists the main institutions in each country that are active in one way or another in the field of hydrology. More undoubtedly exist (particularly of a private nature) than the number given in the table.

There is some co-ordination of functions in Argentina, Bolivia, Chile, Colombia, Costa Rica, Mexico and Peru, but it varies in scope and degree. Ecuador has set up a Department of Meteorology and Hydrology (Dirección General de Meteorología e Hidrología) with jurisdiction over the whole republic.[12/]

Most countries have meteorological publications which also cover hydrometeorological observations to a certain extent.

In the field of fluviology, however, only Argentina, Brazil, Colombia, Panama, Peru and Mexico issue publications.

8. Staff and level of training

Governmental and semi-governmental hydrological services have developed at very varying rates in the different countries, and even within the same country notable disparities are to be observed among the organizations that take rainfall and flow measurements. The effective implementation of their activities is most frequently impeded by two factors whose influence is direct and immediate: Shortage of personnel and shortage of funds. With few exceptions, the people who work in this field are still paid at low rates in Latin America, although specialists in hydrology and hydrometeorology are hard to find there.

11/ Los recursos hidráulicos de Chile, op. cit., and Study of water resources in Ecuador, a joint ECLA/BTAO/WMO study in draft form.

12/ March 1960. This institution complies with the general recommendations made by the ECLA/TAO/WMO Water Resources Survey Group, which undertook a mission in Ecuador in 1959.

/Table 23

Table 23

LATIN AMERICA: INSTITUTIONS RESPONSIBLE FOR RAINFALL AND/OR FLOW MEASUREMENTS

Country	Governmental and semi-governmental	Private	Co-ordination of functions	Centralization and publication of data
Argentina	National Meteorological Services. National Department of Port Facilities and Navigable Waterways. Water and Electric Energy		The National Meteorological Service records observations made by all the officially-recognized rain gauges installed in the country administered by that Service, the Railways, and national provincial and private agencies.	Publications: Anuarios Hidrológicos de Agua y Energía Eléctrica. Anuarios Hidrológicos de Construcciones Portuarias y Vías Navegables. Estadísticas Climatológicas of the National Meteorological Service, which centralizes hydrometeorological information.
Bolivia	Department of Meteorology. Inter-American Agricultural Service. Bolivian Development Corporation. Department of State Railways. Lloyd Aéreo Boliviano. Universidad Mayor de San Andrés. Department of Irrigation.	Panagra. Bolivian Power Company, Ltd.	Department of Irrigation and Department of Meteorology.	...
Brazil	Ministry of Agriculture. National Department of Irrigation (Ministry of Communications and Public Works). Meterrological Service. Rio Grande do Sul Electric Power Commission. Vale do San Francisco commission. Department of water and Electricity of Sao Paulo and Paraná. Minas Gerais electric power stations.	Brazilian Technical Services Company. Brazilian electricity companies.	...	Publications: Anuarios Fluviométricos and Forças Hidráulicas del Ministerio da Agricultura.
Chile	Chilean Meteorological Office. Chilean Air Force. Department of Irrigation. Department of Sanitary works. National Electricity Company (ENDESA). Agrometeorological Service. Universities.	Braden Copper Company Panagra.	None. Information is, however, exchanged among a number of institutions.	None.

/Table 23 (cont.)

Table 23 (cont'ed 1)

Country	Governmental and semi-governmental	Private	Co-ordination of function	Centralization and publication of data
Colombia	Meteorological service. Ministry of Public Works. War Ministry. Agustín Codazzi Geographical Institute. Institute of Water Utilization and Electricity Development. Bogota water and Sewage Company. State enterprises of Medellín Colombian Airport Company. Valle del Cauca Corporation.	Bogota Electric Power Company. National Federation of Coffee-Growers. Geophysical Institute of the Colombia Andes.	The National Meteorological and Hydrological Committee co-ordinates activities throughout the country.	Partial centralization. Publications: Boletín del Instituto dd Aprovechamiento de Aguas. Miscellaneous reviews. Anales del Observatorio Meteorológico Nacional.
Costa Rica	National Meteorological Service. Costa Rican Electricity Institute (ICE). Inter-American Technical Service for Agricultural Co-operation.	National Light and Power Company. Inter-American Institute of Agronomics. Costa Rican Banana Company. Costa Rican Coal Company. Northern Railway Company. Panagra.	The Costa Rican Electricity Institute and the National Meteorological Service.	No centralization. Publication: Boletín Trimestral of the National Meteorological Service.
Cuba	National Observatory. River Hondo Development Commission.	Cuban Aviation Company. Observatories of the Jesuit Fathers.	...	... The Casa Blanca National Observatory has produced some publications.
Dominican Republic	Naval Meteorological Service. Section of Hydrology and Irrigation Planing (Department of Public Works and Irrigation). Santiago Town Council.	Grenada Company Barahona Company.	...	...
Ecuador	Department of Meteorology. Department of Civil Aviation. Ecuadorian Army and Air Force. Observatory.	Ecuadorian Banana Association. Anglo-Ecuadorian Oilfields.	Department of Meteorology and Hydrology (created in March 1960).	No centralization. Publications: Boletín Meteorológico de la Dirección General de Meteorología. Boletín Meteorológico de la Armada.

/Table 23 (cont.)

Table 23 (cont'd 2)

Country	Gobernmental and semi-governmental	Private	Co-ordination of functions	Centralisation and publication of data
Ecuador (cont'ed)	Executive Committee on Communications in the Province of Guayas. Inter-American Co-operative Service. National Irrigation Institution. Municipality of Ibarra.			Publications by the Observatory.
El Salvador	National Meteorological Service. Department of Meteorology (Ministry of Defence). National Agronomics Centre. Tropical Institute of Scientific Research (National University) Department of Agricultural Engineering (Ministry of Agriculture). River Lempa Hydroelectric Executive Committee.	International Central American Railways. El Salvadorian Railways. Santa Ana Electric Power Company. Sonsonate Electric Power Company. Panagra.	None.	No centralization. Publications: Anales del Observatorio Nacional Meteorológico. Boletín Meteorológico of the University of El Salvador. Revista de la Asociación de Cafeteros.
Guatemala	Ministry of Agriculture. Department of Public Works.	United Fruit Company.	...	...
Haiti	Ministry of Public Works.	Meteorological Observatory of San Marcial Seminary.	...	...
Honduras	Department of Irrigation. National Meteorological Service.	Tela Railroad Company.	None	...
Mexico	Mexican Meteorological Service. Department of Hydraulic Resources. Federal Electricity Commission.	...	Information is exchanged and there is some co-ordination among the principal institutions.	Publications: Bulletins dealing with hydrological questions are published by the Federal Electricity Commission, the Department of Hydraulic Resources and the National Irrigation Commission.
Nicaragua	National Electric Power Commission.	...	...	...

/Table 23 (cont.)

Table 23 (cont'ed 3)

Country	Governmental and semi-governmental	Private	Co-ordination of functions	Centralization and publication of data
Panama	Inter-American Co-operative Service for Economic Development (SCIFE).	Panama Canal Company (Section of Meteorology and Hydrology).	Information is exchanged between the two institutions named.	Publications by the Panama Canal Company and by the Department of Statistics and Censuses of the Republic of Panama
Paraguay	...	...	...	...
Peru	Department of Meteorology (Air Ministry). Meteorological Service (Ministry of Development). Meteorological Service (Ministry of Agriculture). Peruvian Civil Aviation Corporation. Inter-American Co-operative Service. Water and Irrigation Department (Ministry of Development). Department of Irrigation (Ministry of Agriculture). Peruana del Santa Corporation.	Private tobacco monopolies. Guano Administrative Company. Cerro de Pasco Corporation.	The Department of Meteorology administers and co-ordinates the observations throughout the country. With respect to flow measurements, it co-ordinates its activities with those of the Ministry of Development and Ministry of Agriculture.	The Department of Meteorology centralizes all meteorological information, and publishes the following: <u>Boletín Anual Meteorológico</u>. <u>Boletín Climatológico Mensual</u>. <u>Boletín Diario</u>. A publication on hydrological questions. A daily bulletin with general information.
Uruguay	Meteorological Service. Department of State Power Plants and Telephones (UTE).		...	The Meteorological Service centralizes information and publishes a <u>Boletín</u> and a <u>Revista Meteorológica</u>.
Venezuela	Ministry of Public Works. Ministry of Agriculture and Livestock. Venezuelan Development Corporation (Caroní). Ministry of Defence. National Institute of Sanitary Works.	Shell. Mene Grande Socony Vacuum Creole. Venezuelan Railways. Iron Mine Company of Venezuela.	None. Information is, however, exchanged among a few institutions	The Meteorological service centralizes a certain amount of information and publishes fortnightly bulletins and a yearbook.
British Guiana Guiana	...	...	...	...
West Indies	...	...	...	...
Surinam	...	...	...	...

/At the

At the lower, non-university, level of the observers, it is customary in a number of countries to employ for people who have other activities as well, and who make the observations and fill in the forms sent to them by the head offices simply to earn more money (although they do occasionally work free of charge).

The element of routine in the work of observation, the fact that it requires no special training, and the inadequate supervision exercised from above, sometimes lead to the gradual introduction of operational deficiencies and even to defects in the instruments, which may pass unperceived for a long time in the data-processing offices with the inevitable consequences.

Solely in the case of three countries could fairly complete and reliable information be obtained on the personnel engaged in hydrological and hydrometeorological activities, according to level of training, in the principal institutions (see table 24).

The sample shows that, in relative terms, the greatest shortage of specialized personnel is at the intermediate level, and of non-specialized persons at the level of those who have completed their secondary school studies.

/Table 24

Table 24

PERSONNEL ENGAGED IN HYDROLOGICAL AND HYDROMETEOROLOGICAL MEASUREMENTS AND STUDIES, BY LEVEL OF TRAINING

Country	Specialized University training		Non-University	
	Higher	Intermediate	Secondary studies	Primary studies
Argentina a/	16	7	30	397
Chile b/	9	26	52	286
Colombia c/	16	16	17	598

a/ Water and Electric Energy in hydrological studies only.

b/ Department of Irrigation, ENDESA and the Chilean Air Force, in hydrological and hydrometeorological studies.

c/ The Bogota Water and Sewage Company, the Valle del Cauca Corporation, Medellin State enterprises and the Institute of Water Utilization, in hydrological and hydrometeorological studies.

/ANNEX

A N N E X

1. Evaluation of the gross run-off potential on the basis of rainfall data checked by a stream-gauging station

Reference is made in section 4 of chapter I to the determination of the gross run-off potential of a region or a country; this is done by dividing the area into small sub-basins and using the hydrologic data provided by a stream-gauging station at the lowest point of each sub-basin. However, if this division involves areas greater than 400-500 square kilometres (a common situation in Latin America because of the lack of stream-gauging data) it is advisable to adopt the method indicated below, which involves a further sub-division into micro-areas by standard squaring (see figure I-A).[1/] Let A be the area in square kilometres of such a sub-basin, F the stream-gauging station, and $\underline{t}$ the length in kilometres of the side of a single square. The average elevation H of each square above sea level can be calculated from a map at a suitable scale (1:500,000 to 1: 1,000,000) showing contour lines. On the basis of extensive[2/] rainfall data in the form of isohyetal lines it is possible to obtain the hydraulic contribution of each square to the total run-off $\underline{Qm}$ of the sub-basin, either by calculating the average annual loss by evapo-transpiration for the whole area A,[3/] or by calculating this loss for each square ($\underline{t^2}$) by one of the available

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1/ This method was proposed by the ECE Committee on Electric Power: see United Nations, Hydro-electric Potential in Europe and its Gross, Technical and Economic Limits (E/ECE/EP/131).

2/ Ideally covering a period of 30 years.

3/ By one of the following formulas:

(i) $e_1 = \frac{\sum t^2 p - 31.536\ Qm}{A}$ (Height of the water in millimetres),

where $\underline{p}$ is the annual precipitation in millimetres for each square, and $31,536 \times 10^3$ is the number of seconds in the year

(ii) $e_2 = P - Qm$ (m^3/sec.), where

$P = \frac{\sum t^2 p}{31,536} = \frac{\sum V}{31,536}$ represents the average annual volume of rainfall on area A, expressed in cubic metres per second.

/empirical formulas

empirical formulas (Vermeule, Khosla, Justin, etc.) on the basis of such variables as elevation above sea level, average temperature, rainfall, etc. In the second case a final correction is required, in the form of a proportional modification of the contribution of each square so that the run-off measured at F shall be equal to the sum of the contribution of each square. When the flow has been finally estimated as the contribution of each square to the flow Qm, the potential Ps can be determined for each of the squares, and by addition for the whole basin.

2. Graphic representation of the gross river potential

Section 4 of chapter I gave a general outline of the method of evaluating the gross river potential. Further details are given below, together with the graphic representation.

Let the stretch of river concerned be AB (see figure I-B).

The average annual flow should be known at each of these points, by direct verification (or direct verification and covariation, on the basis indicated for determining the gross run-off potential) from a statistical series covering a period of not less than twenty years.

The elevation of the water level above sea level in metres at each point, H_A and H_B, must also be determined.

The maximum theoretical potential of the section concerned in kW is given by formula (2), which assumes a 100 per cent yield, and represents the upper limit of the total output of a group of hydraulic power plants in series:

$$P_L = 9.8 \frac{Q_A + Q_B}{2} (H_A - H_B) \qquad (2)$$ 4/

where Q_A and Q_B are the values for the average flow immediately downstream of A and upstream of B, respectively, expressed in cubic metres per second.

A graphic representation of this potential is given in figure I-B.

Using rectangular co-ordinates and a given scale, elevations H_A and H_B are drawn as ordinates and flows Q_A and Q_B as abscissae. The shaded area P represents the potential P_L at the appropriate scale.

4/ For the first section of the river the formula is reduced to:

$$P_L = \frac{9.8}{2} Q_B (H_A - H_B)$$

/Figure I-C

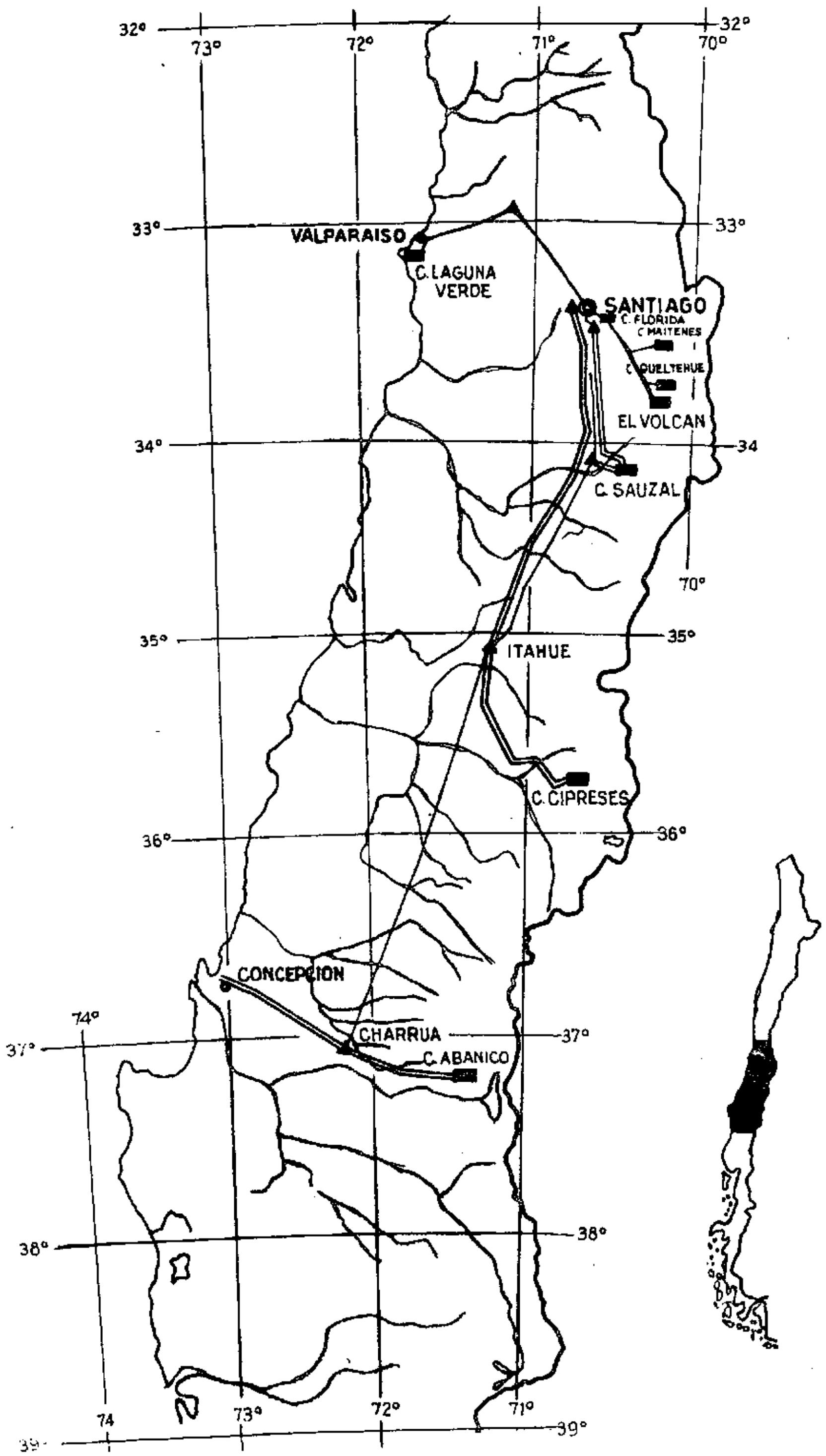
Figure I-C is a diagram representing the principal course of a river and two tributaries flowing into at points C and E. The second tributary has a small tributary of its own. It should be noted that a tributary consisting of a single stream is represented by a triangle such as B_1CB, whereas when a tributary has another stream flowing into it, the basic diagrams are superimposed to form geometric figures like that at D_1GD_2HED. Variations in shading make it possible to distinguish between the potentials of the various components. It should be noted that points of equal elevation (at the basis of the diagrams of the tributaries) such as B and C (and D and E in the other example) represent the same place on the course of the main river, and are given different letters only in order to indicate the river's flow including and excluding that of the tributary.

The potential of a river system between its source and any point X on its main stream can be easily determined by measuring on the appropriate diagram the area represented as above a horizontal line X-X drawn at the level of that point. Generally speaking the potential between any two points on a river is given by the area included between the horizontal lines drawn on the diagram to represent the elevations of the two points.

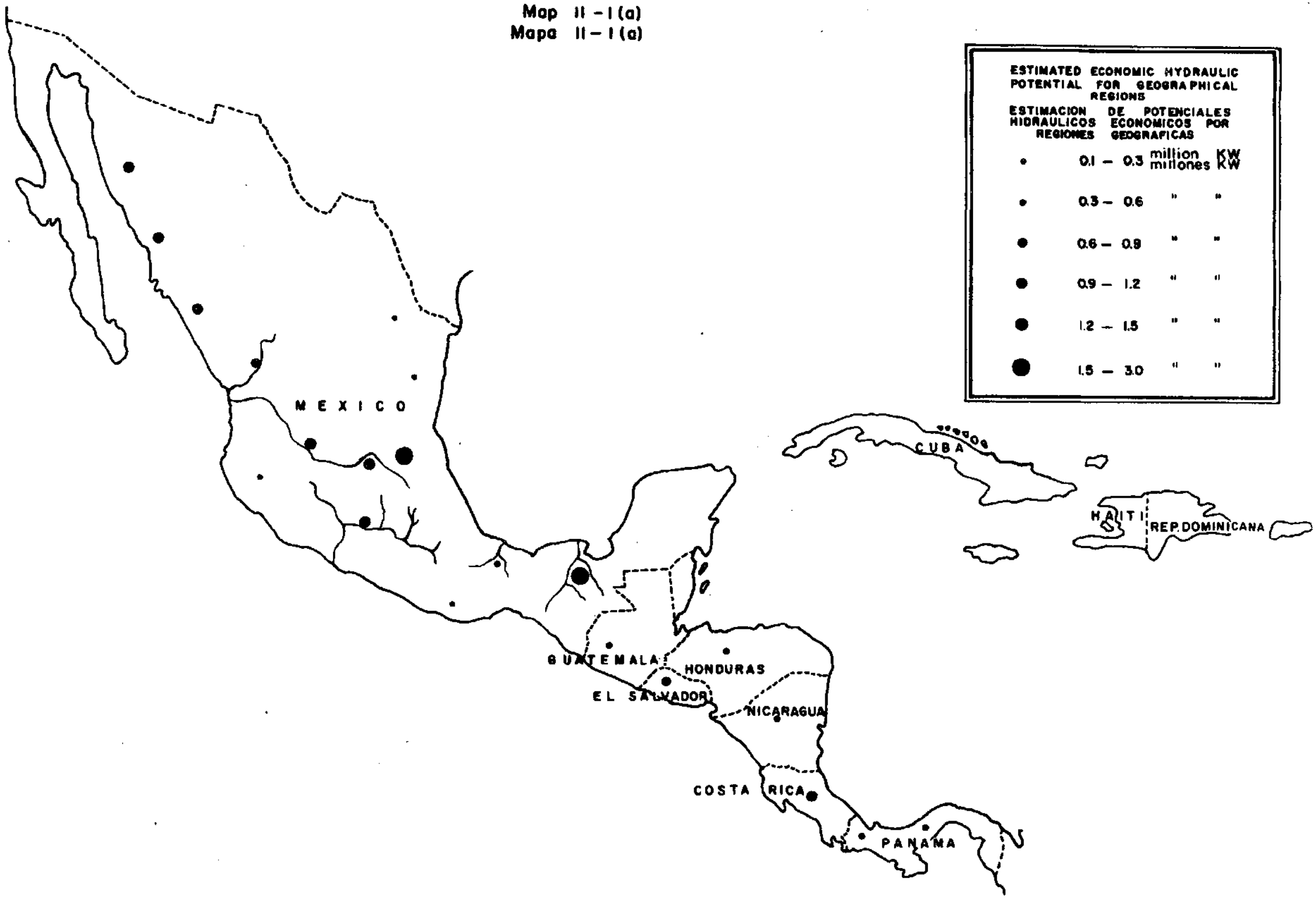
MAP I

MAPA I

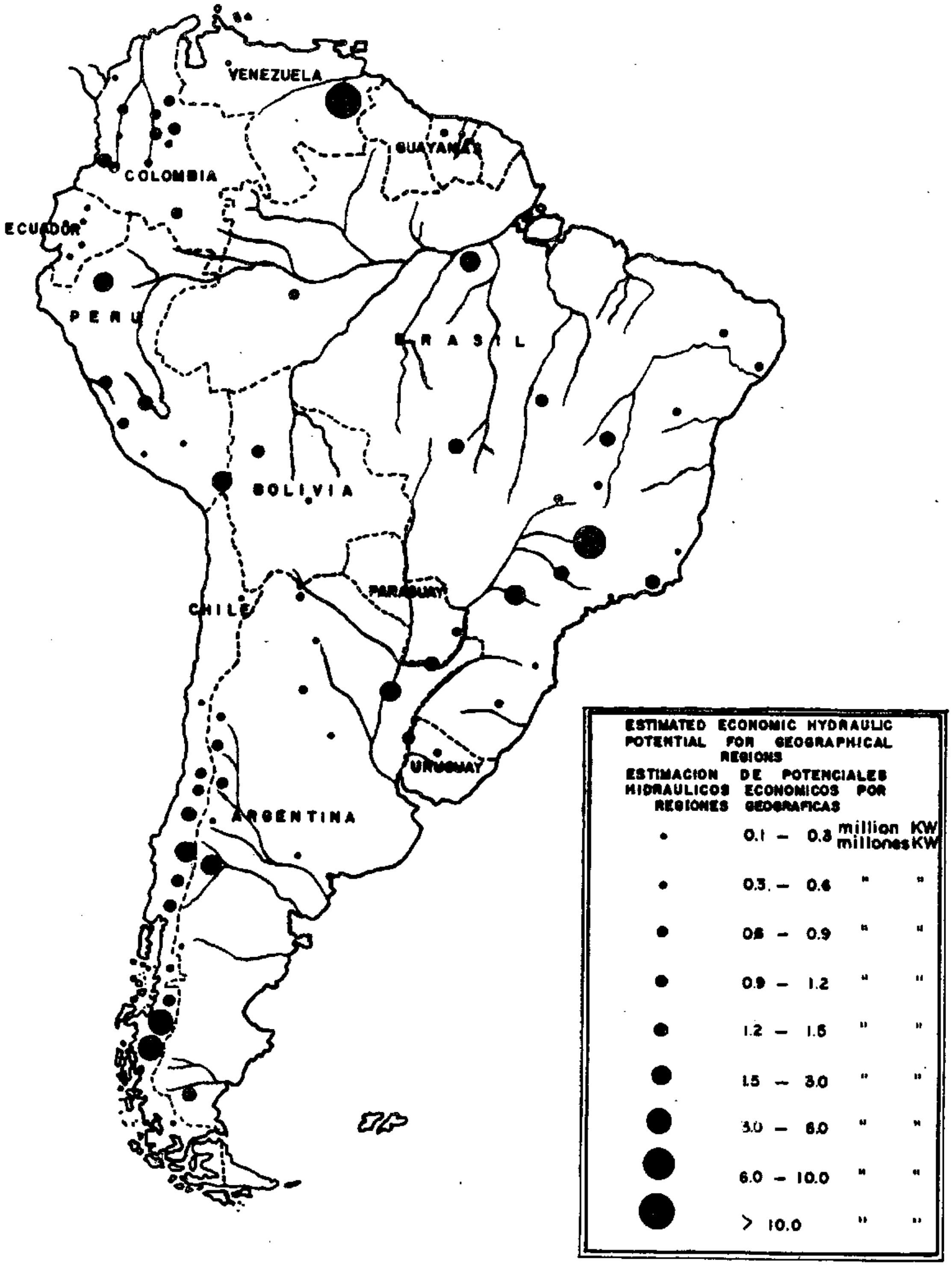
PLAN OF CHILE'S INTERCONNECTED SYSTEM
ESQUEMA DEL SISTEMA INTERCONECTADO CHILENO



Map II-1(a)
Mapa II-1(a)

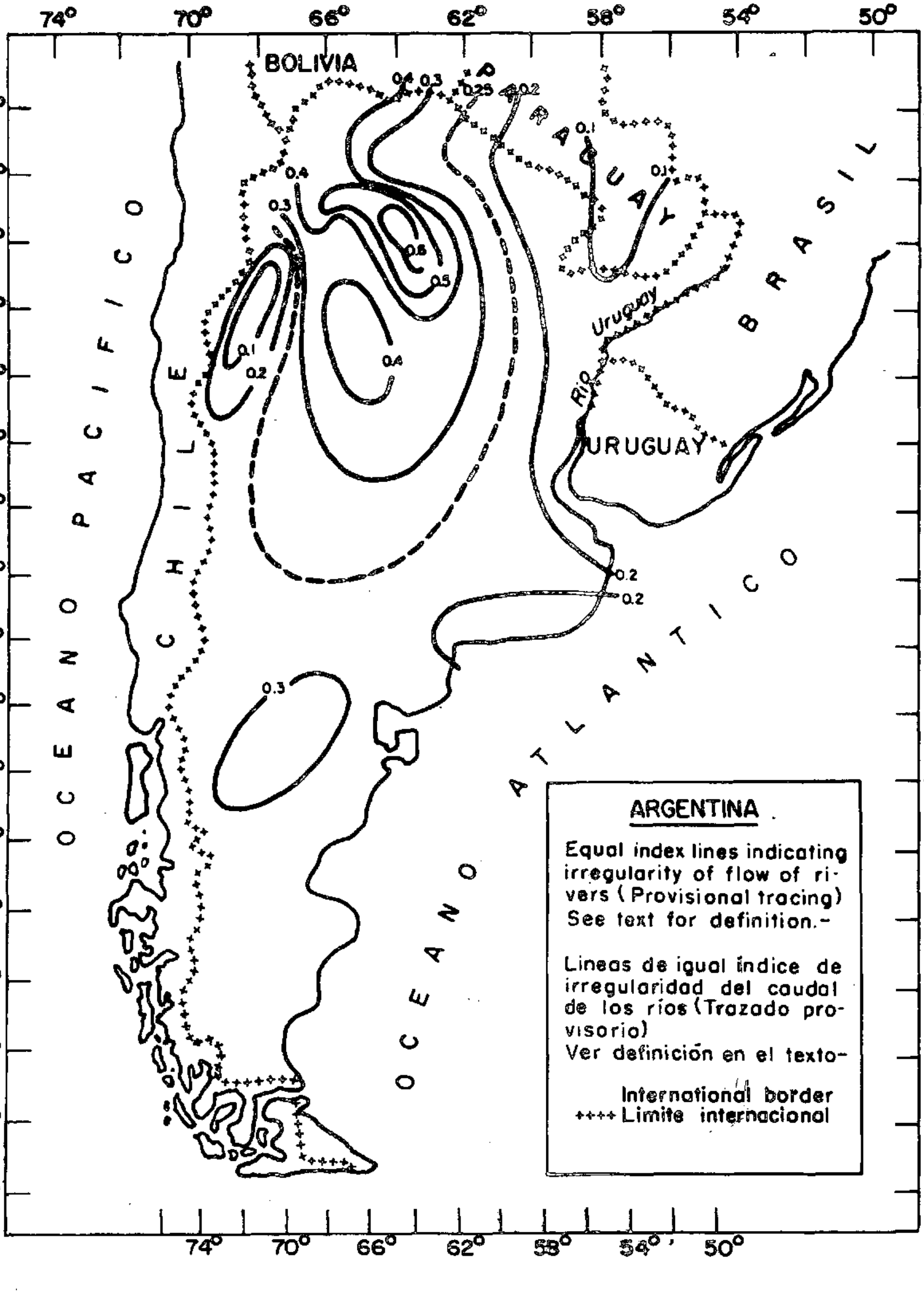


Map II-1(b)
Mapa II-1(b)



Map II-2

Mapa II-2



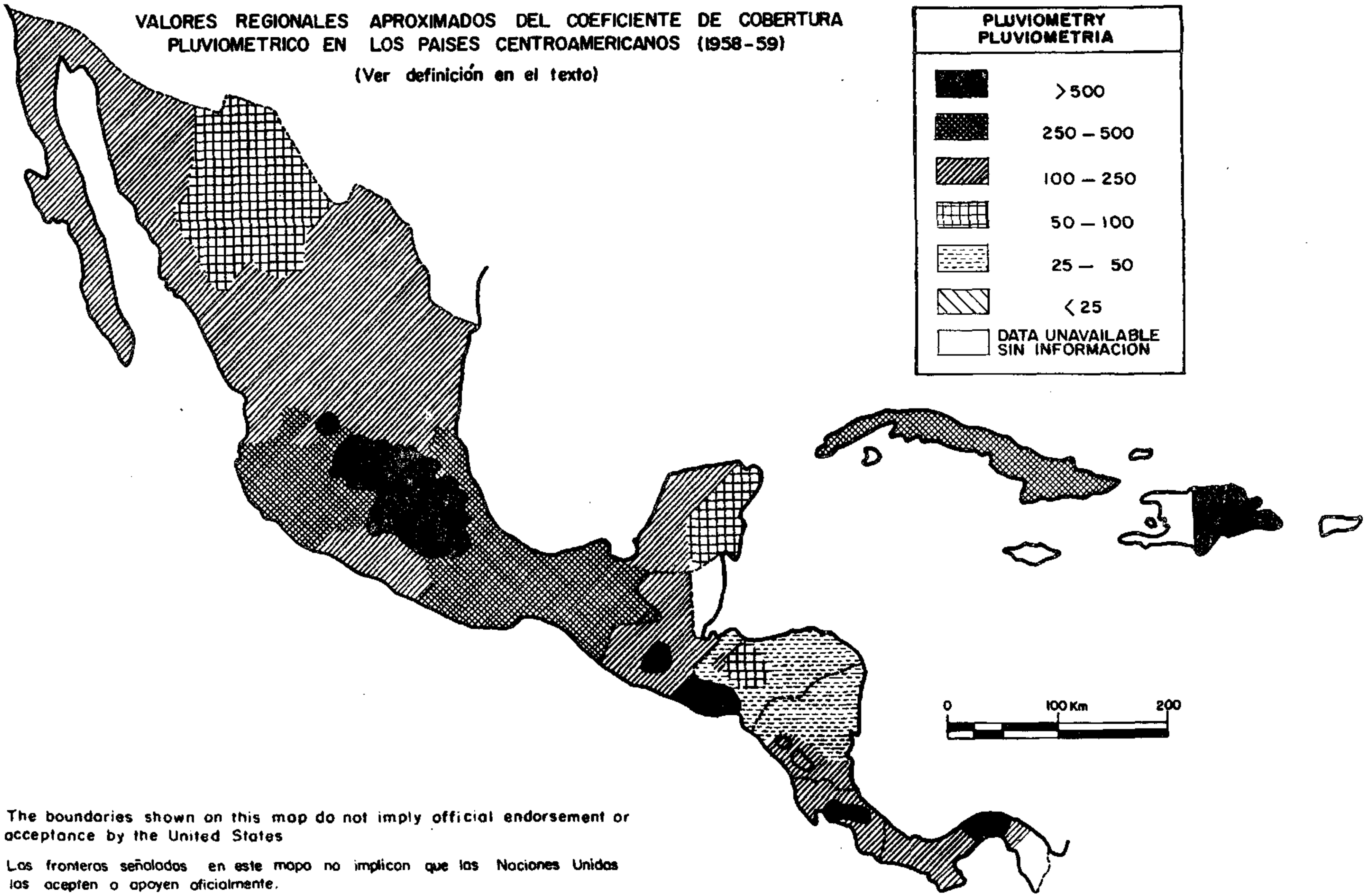
Mapa III - 1(a)

APPROXIMATE REGIONAL VALUES OF THE PLUVIOMETRIC COVERAGE COEFFICIENT IN CENTRAL AMERICA

(See text for definition)

VALORES REGIONALES APROXIMADOS DEL COEFICIENTE DE COBERTURA PLUVIOMETRICO EN LOS PAISES CENTROAMERICANOS (1958-59)

(Ver definición en el texto)



The boundaries shown on this map do not imply official endorsement or acceptance by the United States

Los fronteras señalados en este mapa no implican que las Naciones Unidas los acepten o apoyen oficialmente.

Map III - 1 (b)

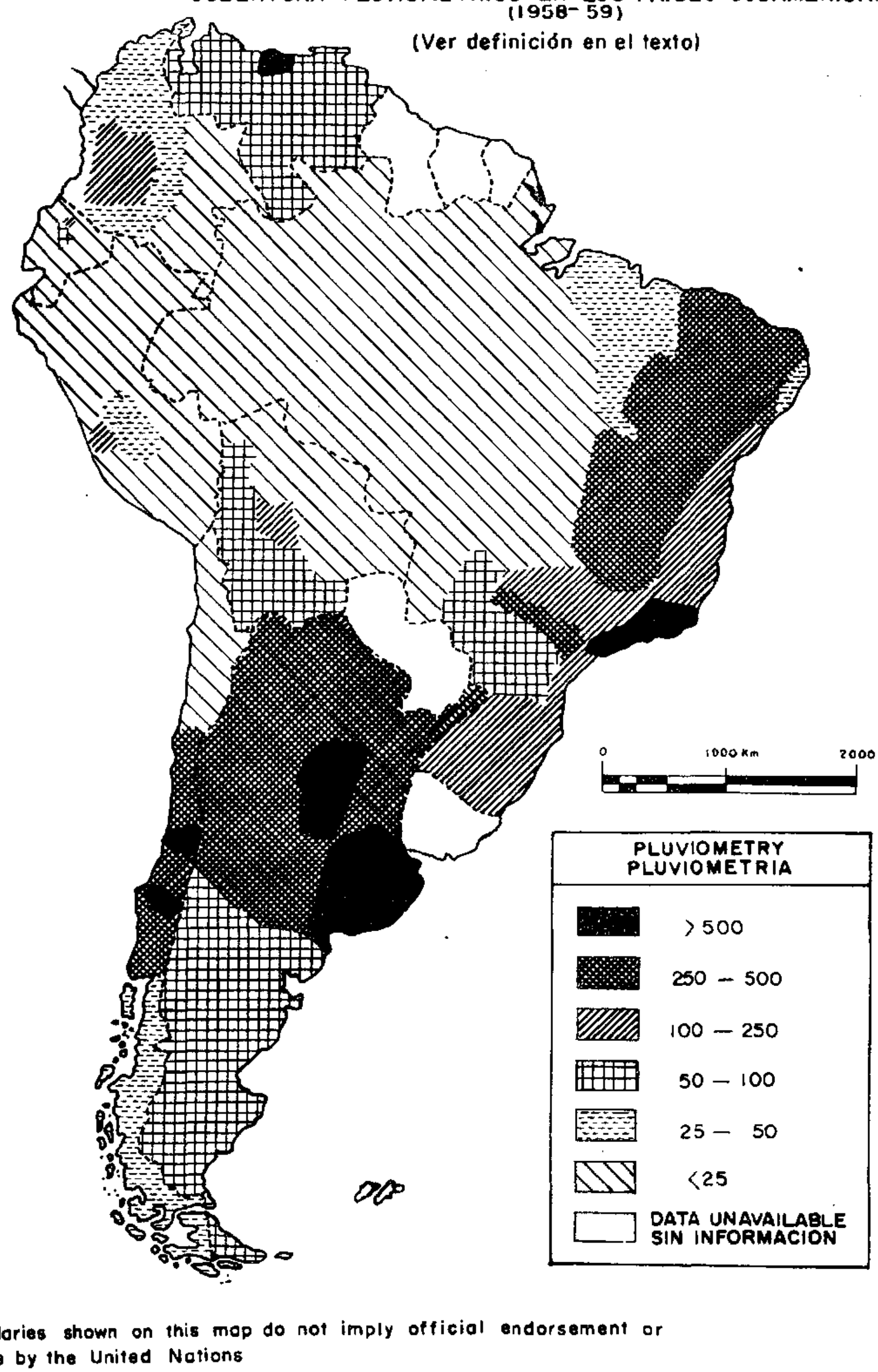
Mapa III - 1 (b)

APPROXIMATE REGIONAL VALUES OF THE PLUVIOMETRIC COVERAGE COEFFICIENT IN LATIN AMERICA

(See text for definition)

VALORES REGIONALES APROXIMADOS DEL COEFICIENTE DE COBERTURA PLUVIOMETRICO EN LOS PAISES SUDAMERICANOS (1958-59)

(Ver definición en el texto)



The boundaries shown on this map do not imply official endorsement or acceptance by the United Nations

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Map III- 2(a)
Mapa III- 2(a)

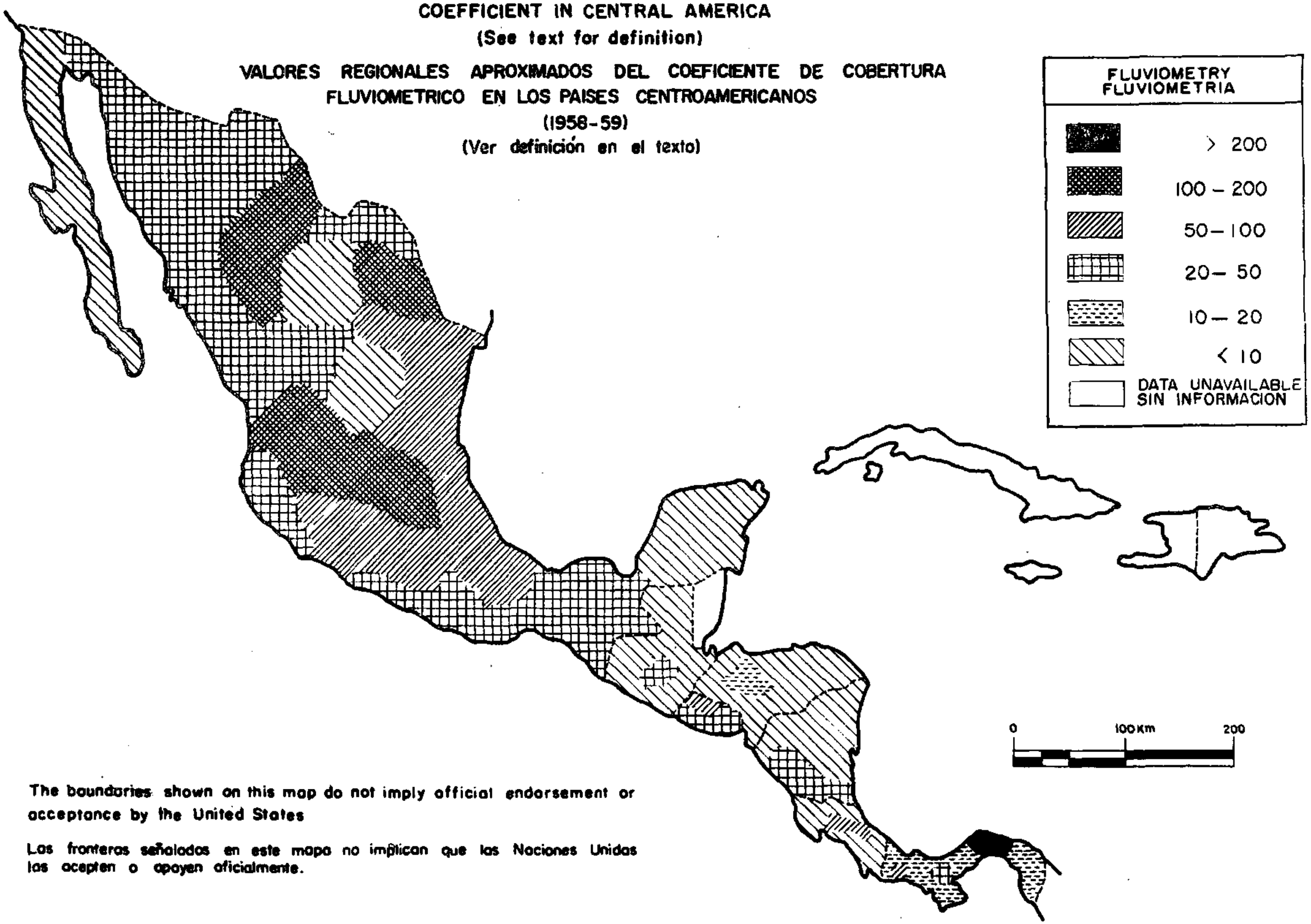
APPROXIMATE REGIONAL VALUES OF THE FLUVIOMETRIC COVERAGE COEFFICIENT IN CENTRAL AMERICA

(See text for definition)

VALORES REGIONALES APROXIMADOS DEL COEFICIENTE DE COBERTURA FLUVIOMETRICO EN LOS PAISES CENTROAMERICANOS

(1958-59)

(Ver definición en el texto)



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Map III-2 (b)

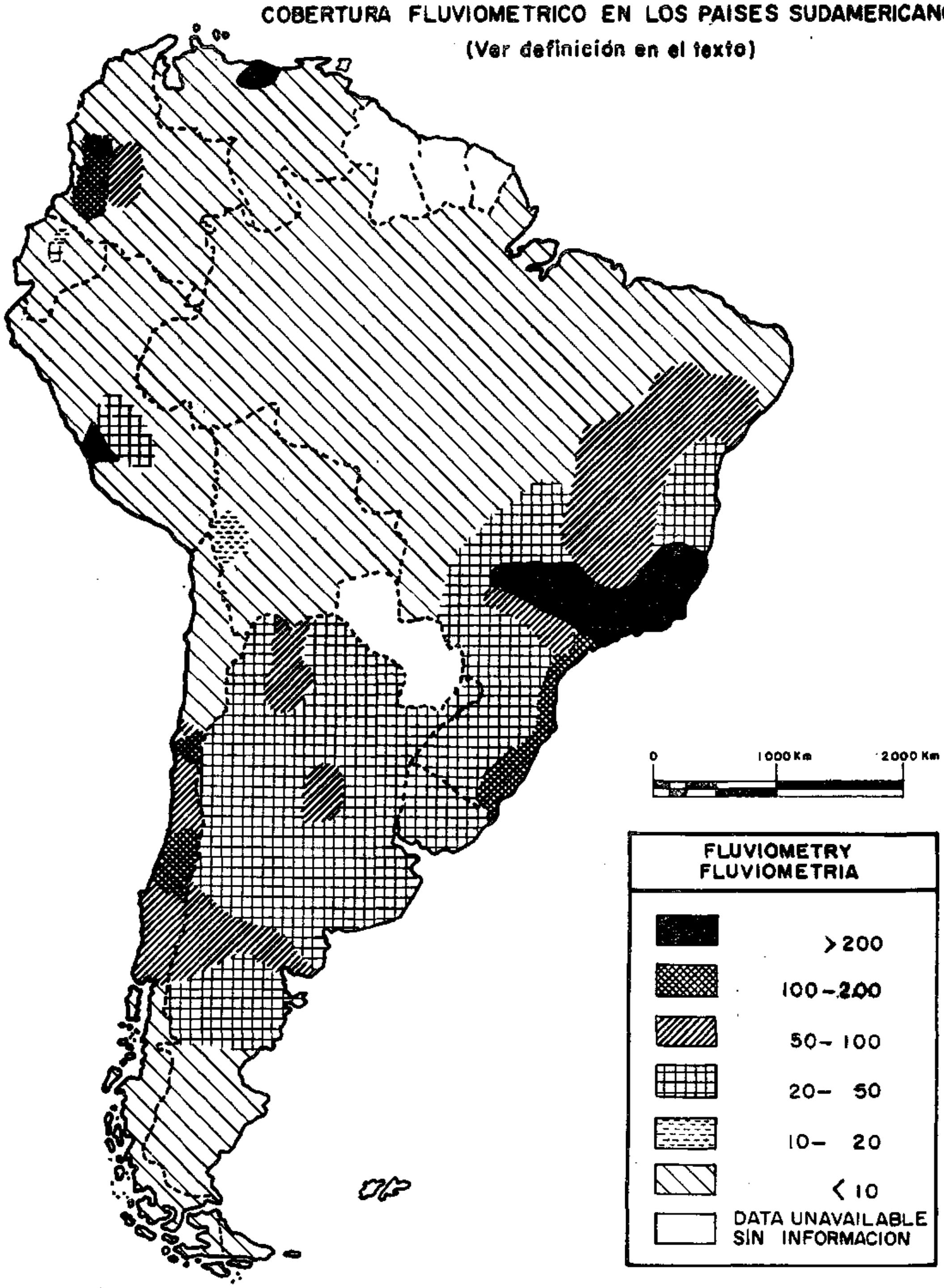
Mapa III-2 (b)

APPROXIMATE REGIONAL VALUES OF THE FLUVIOMETRIC COVERAGE COEFFICIENT IN LATIN AMERICA

(See text for definition)

VALORES REGIONALES APROXIMADOS DEL COEFICIENTE DE COBERTURA FLUVIOMETRICO EN LOS PAISES SUDAMERICANOS

(Ver definición en el texto)



The boundaries shown on this map do not imply official endorsement or acceptance by the United Nations

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FIGURE IVa
GRAFICO IVa

CONSUMPTION CURVES AND HOURLY COSTS IN THE INTERCONNECTED SYSTEM
CURVAS DE CONSUMOS Y COSTOS HORARIOS SISTEMA INTERCONECTADO

WORKING DAY
DIA DE TRABAJO