

## REGIONAL DISTRIBUTION OF RIVERS AND STREAMS IN SOUTH AMERICA

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### Summary

The continent of South America with the adjoining islands occupies an area equal to 17.9 million km<sup>2</sup>. In the north, the continent borders Central America. Eighty-five percent of the mainland area belongs to the Atlantic Ocean basin and 7% to the Pacific Ocean basin. Land that does not have river runoff to the oceans occupies the rest of the mainland area. About 14% of the area of South America is located in the northern hemisphere. More than 80% of the mainland area is in the equatorial and tropical geographical belts. South America has three of the largest rivers of the world: the Amazon, Orinoco and La Plata. The runoff of rivers flowing from the mainland to the

Atlantic Ocean including the basins of the Caribbean Sea are eight times as great as the water resources of the Pacific Ocean slope. The water resources of the inner runoff areas are equal to 56 km<sup>3</sup> a year.

Four natural-economic regions are delineated on the basis of formation conditions and the value of water resources, economic development and the extent of water use: Northern, Western, Eastern and Central. Since the 1950s, the water resources of the Atlantic Slope of South America have shown a tendency to increase. For the continent in general, low water content years are most frequently followed by average water content years and these are generally followed by low or average water content years. The high water content years have a tendency to maintain their water content in the following year. No synchronicity is observed in the oscillations of water volumes flowing to the Pacific and Atlantic Oceans.

Current water withdrawal and water consumption on the continent are 166 and 97.7 km<sup>3</sup> per year, respectively. Due to constant population increase over the period 1950 to 1995, there was a decrease of water availability per person in the Northern, Eastern, Western and Central regions, of 71, 69, 66 and 55%, respectively. By 2025, water availability is expected to decrease again by 1.6 times in the Northern region and by 1.5 times in the other regions, in average water content years.

## 1. Introduction

The continent of South America is located in the western hemisphere between 12°25' N (Pt. Gallinas on Guajira Peninsula) and 53°54'S (Cape Froward), 81°20'W (Pt Parinas) and 34°46'W (Cape Cabo Branco). The area of the continent with the adjoining islands (Terra del Fuego, Chilean archipelago, Falkland Islands, Galapagos Islands and other smaller islands) comprises 17.9 million km<sup>2</sup>.

The continent is characterized by a large solar heat influx and high moistening. There are 13 countries on the continent: Argentina, Brazil, Bolivia, Venezuela, Guyana, Guiana, Columbia, Paraguay, Peru, Surinam, Uruguay, Chile and Ecuador. The population of the continent is greater than 315 million of people. The average population density comprises 18 people per km<sup>2</sup>.

South America is surrounded on almost all sides by vast water space. It is washed by water of the Atlantic Ocean from the east and the Pacific Ocean from the west. In the south, the Drake Passage separates it from Antarctica and in the north, the Caribbean Sea from the Greater Antilles. A narrow Isthmus of Panama connects South America with Central America.

The hydrological network of South America is mainly connected with the World Ocean. The inner drainless areas occupy only a small part of the continent. They include:

- 1) Vast territory encompassing the Pampas (steppes of the right-hand bank of the Parana River situated approximately from the Rio Salado River in the north to the Rio Colorado River in the south and from 64°W to the Atlantic Ocean coast south of the La Plata);

- 2) The areas of Pre-Cordilleras and Pampas Sierras. The total area of the territories under consideration is greater than 1 million km<sup>2</sup>;
- 3) Semi-desert territory in the northeast of Patagonia between the Rio Negro and Chubut with an area of slightly greater than 130 000 km<sup>2</sup>;
- 4) Altiplano Plateau with an area of more than 220 000 km<sup>2</sup> located between the marginal ranges of Cordillera Occidental and Oriental.

The equatorial and monsoon-trade wind circulation predominates over the continent. South America is located in six climatic belts: equatorial, northern and southern sub-equatorial, tropical, subtropical and temperate, with almost 84% of the mainland territory situated in the first four belts, 12% in the subtropical and 4% in the temperate belt.

## **2. Factors determining the development of the hydrographic network and the hydrological regime of rivers during the present period**

### **2.1. Relief**

The relief of South America in the east of the continent is plain-plateau. The uplifts of the South American platform are represented by the Guiana, Brazilian and Patagonia Highlands. From the east, the highlands are contoured by narrow and broken bands of coastal plains.

The Guiana Highlands rise towards their center (Pico da Neblina, 3100 m), the Brazilian from northwest to southeast (Pico da Bandeira, 2890 m) and Patagonia from east to west (to 2200 m). The Guiana and Brazilian Highlands present gently undulating plains with a height of 1500 to 1700 m. Within their boundaries, there are cone-shaped peaks and mountain ranges as well as sandstone uplands. The troughs and depressions of the Brazilian Highlands are expressed in the relief by the accumulative plains or lava plateaus.

The powerful folded system of the Andes extends from the north and the south of the continent. This system is subdivided into the North, Central and South Andes. The North Andes extending to 5°S is distinguished by alternating high folded-block ridges and deep depressions. In Ecuador, it is comprised of the Cordilleras Oriental and Occidental with the depression between them filled with the products of volcanic activity (Chimborazo, Cotopaxi and other volcanoes). Three main systems of Cordilleras are identified in Columbia (Oriental, Central and Occidental) divided by the basins of the Magdalena and Cauca Rivers. The largest Sub-Caribbean and Sub-Pacific lowlands are located in the north and the west of the continent.

The Central Andes is located south of the North Andes, up to 27–28°S. They are characterized by inner highlands rising to 3800 – 4800 m above sea level surrounded by marginal ridges. The southern part—the Central Andes upland—is the widest segment of the Andes. Its main component is the Puna highland with the ancient lacustrine Altiplano Plateau in the southwest and several block ridges in the east and south.

In the northern part of the South Andes, up to 41°30' S, the double Main Cordillera is expressed in the relief, to which the massifs of Pre-Cordilleras adjoin in the east. In the southernmost segment of the Andes—Patagonia Andes—the Cordillera de la Coast merges with the archipelago of islands, and in the Longitudinal Plain, into the system of straits, flooded troughs (fjords) of the Patagonia Cordillera.

Between the Andes and the uplands, there are lowlands and plains:

- Orinoco lowland;
- Amazon lowland;
- Plains and lowlands of Paraguay – Parana;
- La Plata lowland.

Relief has a large influence on climate and the formation of the river system of South America, which is mainly connected with the World Ocean. The inner runoff zones occupy a relatively insignificant areas.

## 2.2. Climate

The main factors determining the formation of climate are as follows:

- Geographical location of the continent;
- Orography structure;
- Cold oceanic currents directed from south to north along the western and eastern coasts.

The location of South America, predominantly at low latitudes, governs a large solar heat influx. The radiation balance, almost everywhere on the continent, is 45 to 70 W/m<sup>2</sup> a year. Only in Patagonia, it decreases to 20 to 30 W/m<sup>2</sup> a year. North of the south tropics, the average monthly air temperatures vary predominantly between 20 and 28° C (with a maximum of 49 °C in Gran Chaco) decreasing in summer (January) to 10 °C in Patagonia, and in winter (in July) to 12 – 16 °C in the Brazilian Highlands, to 6 – 10 °C in Pampa, and to 1 °C, in the extreme south. In the tropical part of the continent, the mean monthly air temperature varies from 20 to 24 °C. In the Amazon Basin, it is practically constant at 24 °C.

The equatorial and monsoon trade wind circulation predominates. At equatorial latitudes, due to the large heating of the mainland surface during the entire year, a constant rise of air masses occurs with formation of a low pressure area into which the trade air masses from the Atlantic rush. Most of South America is under the influence of the eastern moisture transfer from the Atlantic Ocean. The mountain ranges of the Andes do not let the air masses pass to the west, and restrict the influence of the Pacific Ocean, which extends only to a narrow band of the western coast and the adjoining mountain slopes. A small southern part of the continent located south of 40°S is influenced throughout the year by the western transport from the Pacific Ocean. The Pacific coast located between 5 and 28°S is under the influence throughout the year of the eastern periphery of the South-Pacific High. It is washed by the cold Peru Current preventing condensation and moisture fallout. This is why between 22° and 27°S, there

is the Atacama Desert. In July, the equatorial monsoon dominates in the north of South America, which is generated in the Amazon Basin spreading to the Orinoco lowland. Intense intra-mass convection governs the afternoon showers that are connected with cooling of air masses in the upper layers of the atmosphere. The moisture flux to the north of Columbia, Venezuela, Guyana and French Guiana originates from the cyclonic rains and humid northeast trade wind.

The combined effect of climatic factors and relief govern a large amount of atmospheric precipitation over a significant area of the continent. In Columbia, the amount of precipitation ranges from 2000 to 5000 mm a year. At high altitude, precipitation decreases. On the South Chilean coast, the abundant precipitation of 2000 to 5000 mm a year and greater is determined by the interaction of the western airflow from temperate latitudes and the Andes. Abundant precipitation also falls out in the Amazon Basin, at more than 2000 mm a year. In the coastal band between the mouths of the Orinoco and Amazon, as well as in the west of the Amazon Basin in the foothills of the Andes, precipitation exceeds 3000 mm a year. Two maxima of seasonal sums of precipitation are observed over much of the Amazon Basin in spring and in autumn according to the Sun's position at the zenith.

In the equatorial moistened zone of the continent, cases of precipitation anomalies related to the anomalies of circulation of air flows are observed. Depending on the location of the intra-tropical convergence zones, one can observe droughts alternating with abundant rains. This phenomenon is one of the reasons for the existence of arid areas near the equator in the northeast of Brazil and Venezuela where irregular precipitation does not exceed 1000 mm a year and in places, only 300 to 500 mm a year.

The moist parts the continent are in sharp contrast to the very arid areas situated in different areas. The Pacific Ocean coast located between 4°30' and 28°S is distinguished by extreme aridity with a very small amount of precipitation, less than 100 mm a year. In the coastal Atacama Desert, rain is exceptionally rare. Conversely, in the south of Chile, precipitation is very high (up to 5000 mm a year).

The most arid area of the Andes, the Central Andes upland extends between Patagonia and Atacama. Here, about 50 – 150 mm a year of precipitation falls out, and only in the east of this upland, precipitation increases to 250 – 500 mm a year.

Most of the precipitation over the entire area of South America falls during the hottest season, and this contributes to high evaporation from the surface of the continent at this time. The evaporation from the continent changes over a very wide range from a few mm a year in deserts to 1500 mm a year and more in the sub-equatorial moist areas.

### **2.3. Soils and vegetation**

In accordance with the geographical location of the continent, evergreen forests, open woods and shrubs grow on laterite soils. The most widespread are the plant formations of moist evergreen forests—hylea tropical forest—which occupies almost the entire Amazon lowland and the adjoining highlands slopes of the Andes and West Columbia and the eastern slopes of the Brazilian Highlands.

Altitudinal zonality is observed in the mountain tropical forest of the Andes. Up to a height of 1200 m above sea level, forests and soils are similar to tropical forests of the plain. Up to 1800 to 2200 m, tree-fern and bamboo prevail, and up to 3000 – 3200 m, foggy forests of bushy tress and shrubs. In the East Amazon, with increasing distance from the equator, a mixture of deciduous species appears, while in the north of Guiana and in the east of the Brazilian Highlands, it is replaced by forests in which some trees are deciduous and others are evergreen.

The sub-equatorial and tropical belts are characterized by savanna and open wood formations with gallery forests in the river valleys. The altitudinal zones of the East Andes in the sub-equatorial and tropical belts are mainly represented by evergreen forests, and in the highlands of Peru and in northern Bolivia, by high-mountainous steppes. The southern highlands of the Andes and the western macro-slopes in the tropics have semi-desert and desert types of soils and vegetation.

In the subtropical belt in the west, semi-deserts are replaced by summer dry sclerophyll forests and thickets. East of the Andes, in the northwest of Argentina, there are shrub semi-deserts. Subtropical and tropical swamps occupy vast areas in the upper Paraguay depression along its middle reach, in the interfluve and in the lowlands at convergences of many rivers.

The contrasts between vegetation and soils are very large in the west and in the east of the temperate belt. The islands and western slopes of the Patagonia Andes are covered by evergreen forests, the eastern slopes of the Andes by coniferous-deciduous forests and leeward Patagonia by arborescent grasses and umbels. In the north of the Terra del Fuego, there are steppes and in the extreme southeast, humid grassland and blanket bog.

In general, a combination of favorable natural conditions and predominantly abundant moistening of vast territories, and the extent of forest vegetation and swamps, is one of the main causes of formation of a dense and high river network across South America.

## **2.4. Economic activity**

### **2.4.1 Water reservoirs**

In addition to relief, climate, soils and vegetation, human economic activity has a significant influence on the development of the hydrographic network. Among the numerous factors of economic activity, of special importance is the construction of water reservoirs that are in fact components of the artificial hydrographic network. Currently, around 2000 water reservoirs are in use over the continent. Their total full volume comprises 750 km<sup>3</sup>. The total area of reservoirs is approximately equal to 60 000 km<sup>2</sup>.

The largest number of water reservoirs occur in Brazil. Their total full volume is greater than 450 km<sup>3</sup>. A much smaller number of reservoirs has been built in Argentina, their full volume exceeding 130 km<sup>3</sup>.

<b>Name of reservoir</b>	<b>Country</b>	<b>River Basin</b>	<b>Year of filling</b>	<b>Full volume (km<sup>3</sup>)</b>
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Guri	Venezuela	Caroni	1986	136.3
Serra Da Mesa	Brazil	Tocantins	1993	54.4
Serros Colorades	Argentina	Neuguen	1977	43.4
Tucuruí	Brazil	Tocantins	1984	43.0
Sobradinho	Brazil	Sao-Francisco	1979	34.2
Itaipu	Brazil, Paraguay	Parana	1982	29.0
Loma de la Lata	Argentina	Neuguen	1977	25.1
Ilia Solteira	Brazil	Parana	1974	21.2
Yacyreta	Argentina, Paraguay	Parana	1991	21.0
Furnas	Brazil	Grande	1965	20.9
El Chocon	Argentina	Limay	1975	20.2
Tres Marias	Brazil	Sao-Francisco	1960	19.2
Emborcacao	Brazil	Paranaiba	1982	17.6
Itumbiara	Brazil	Paranaiba	1980	17.0
Tres Irmaos	Brazil	Tiete	1990	13.8
Sao Simao	Brazil	Paranaiba	1978	12.5
Brocopondo	Surinam	Surinam	1971	12.4
Piedra del Aguila	Argentina	Limay	1993	11.3
Agua Vermeiha	Brazil	Grande	1979	11.0
Itaparica	Brazil	Sao-Francisco	1988	10.8

Table 1. Main information about the largest water reservoirs of South America.

The other countries have a significantly smaller stock of reservoirs. Information on the largest water reservoirs of South America is presented in Table 1.

Large and average size reservoirs were created predominantly in plain and highland conditions with only a few reservoirs constructed in the mountains. Most water reservoirs are involved in seasonal, weekly or daily runoff regulation. Along with large and average reservoirs where hydropower stations are built, South America has many small reservoirs with a volume of one to ten million cubic meters used for irrigation of land.

Reservoirs were also built for flood control. In Argentina, for example in Buenos Aires, Cordoba and Santa-Fe provinces, up to 25 million hectares are periodically flooded. In Columbia, this figure comprises about 7.5 million hectares, in Chile 3.0 and in Venezuela 12 million hectares.

For water supply, about 100 water reservoirs are used. In spite of large supplies of groundwater, its use for drinking purpose, in industry and agriculture has not been widely developed.

#### 2.4.2 Irrigation

Irrigated farming is the main water consumer in the countries of the continent. In 1990 water withdrawal comprised 64% of the total use for all needs. Land irrigation is inseparable from the construction of different channels, check plots and plantations, export of excessive waters to depressions also leading to creation of artificial hydrographic network components.

The South American countries are characterized by quite high growth rates of irrigated land. Currently around 1.26 million hectares are irrigated in Chile, around 1.3 million hectares in Peru and around 0.6 million hectares in Ecuador. Irrigation is also developed in Venezuela, Columbia, Surinam, Uruguay, Bolivia, Argentina, Brazil, Paraguay, Guiana and other countries of the continent. A range of agricultural crops is grown on irrigated land: sugar cane, rice, vegetables, fruits, forage crops as well as vines, cotton and tobacco. Water consumption in irrigated territories changes across a wide range: from 90 to 95% with sprinkling or other irrigation methods to 25 to 30% for rice plantations with flowing check plots.

In the 1980s, the growth of irrigated land in the countries of the continent comprised almost 2 million hectares. Water use in agriculture increased by almost  $19.0 \text{ km}^3$ , to  $97 \text{ km}^3$  a year. Water use in industry during this period increased only by  $2.5 \text{ km}^3$ .

### **3. Hydrography, hydrological knowledge, river runoff, water use and water availability**

#### **3.1. Rivers. Largest river systems**

The densest river network is typical of the excessive moistening areas of South America. The largest river basins in the world—the Amazon and La Plata—are located in the near-equatorial and southeastern coastal parts of the continent. North and southwest of the Amazon in the areas of variable moistening, the river network density decreases. Around 10% of the mainland area belongs to the inner runoff areas. Here, the rivers do not convey their waters to the ocean. The area of all internal drainage zones comprises about  $1\,410\,000 \text{ km}^2$ , including the Altiplano Plateau whose area is  $220\,000 \text{ km}^2$ . The Plateau is located at 3500 to 4100 m. Within the Plateau, there are high mountainous Lakes—Titikaka, Poopo and Coipasa—collecting water runoff from much of Puna. South of Lake Coipasa, there is the depression of the Uyni salt-marsh (solonchak) with an area of about  $10\,000 \text{ km}^2$ .

An extensive internal drainage area includes Pampa (steppes of the Parana right-hand bank) as well as the areas of Pre-Cordilleras and Pampina Sierres. The total area of these regions is greater than one million  $\text{km}^2$ . A small internal drainage area of more than  $130\,000 \text{ km}^2$  is located in the desert northeast of Patagonia between the Rio Negro and Chubut Rivers. The rest of the continent belongs to the basins of two oceans—the Atlantic and the Pacific.

The peculiarities of configuration, horizontal dissection of the territory, relief and climate of South America are exclusively favorable for the formation of large river systems. The largest river systems of the continent include the basins of the Amazon, La Plata and Orinoco Rivers.

The greatest river system in the world, the Amazon, is situated to the east of the Andes. The main source of the Amazon is the Marañon River, which originates on the eastern slopes of Cordillera Occidental in Peru at a height of 4840 m above the ocean level. The river flows in the mountains parallel to the shore of the Pacific Ocean in a deep depression that turns to the east and then breaks through the Andes. Here, the Marañon

water mingles with water of the other Amazon source, the Ucayali River, which serves as the beginning of the Amazon River proper. Over the rest of its length, this river flows across the plain, which is frequently swampy and covered with humid equatorial forests. Downstream of the confluence of the Rio Negro, the width of the Amazon floodplain is 80 to 100 km. However, near Obidus and Santaren, it slightly narrows. The length of the Amazon is 6300 kilometers and its basin area is 6 915 000 km<sup>2</sup>. Around 350 km from the ocean, the Amazon forms a delta with an area of about 100 000 km<sup>2</sup>. The main portion of the runoff volume flows to the Atlantic Ocean by the northeastern arms and the eastern arm, the Para.

The Amazon is fed by numerous tributaries. About 20 of them are large rivers with a length of 1500 to 3500 km. The most significant tributaries flowing to the Amazon on the right are: Ucayali, Jurua, Purus, Madeira, Tapajos, Shingu, Tokantins, and on the left, the Napo, Isa, Japura and Rio Negro. The tributaries of the Amazon differ not only in their parameters and water volume, but also in their color. Waters of the Rio Negro are dark and those of the Rio Branco are milk-colored. There are rivers with yellow, grey, greenish and even reddish colors.

The Amazon has a peculiar complicated runoff regime. It has high water throughout the year. The right-hand tributaries whose basins are located in the southern hemisphere and the left-hand tributaries with watersheds in the northern hemisphere have floods in different seasons of the year, due to the different period of rainfall. In the right-hand tributaries, floods occur from October to March (summer of the southern hemisphere) and in the left-hand tributaries from April to October (summer of the northern hemisphere). This is why the seasonal runoff oscillations are smoothed. The southern tributaries have a high water content. In May-July, they cause the highest water rises in the Amazon and the largest floods. In August-September, comparatively low water levels are observed.

The Amazon River runoff is exceptionally large comprising 15 to 17% of the total volume of river water on Earth. The maximum water discharges in the river are greater than 300 000 m<sup>3</sup>/s. The yellowish waters of this river are noticeable at this time in the Atlantic Ocean at a distance of up to 300 km from the shore.

The Amazon runoff in the lower reaches is significantly influenced by tides propagating upstream over a distance of up to 1400 km. The second largest river system of South America (with a length of 4700 km and a basin area of 3 100 000 km<sup>2</sup>) is the La Plata system (Parana River with the Paraguay and Uruguay tributaries). In the Misiones Province, the main river of this system, the Parana River, flows in a cliffy ravine with abundant rapids and waterfalls.

On exiting from the ravine, it merges with the Paraguay River and is then divided into several arms reaching a width of 1.5 km near Corrientes. From here, it flows in flooded lowland. The Parana, Uruguay and Paraguay Rivers have an irregular runoff regime. Their alimentation is mainly due to rain.

Their water level strongly varies, especially in the Parana. The significant floods in these rivers inflict great damage on the population of countries located in this basin. The

Parana is very significant for the development of the economies of Brazil, Argentina and other countries. It is an important shipping artery and its waters are widely used for water supply purpose. Its economic significance is especially high for the lower reaches of the river where the most important industrial centers are located, consuming a large quantity of water. In addition to Paraguay and Uruguay, the large tributaries of Parana are the Pilcomayo, Rio Bermejo and Rio Salado. They are all rain-fed.

The third largest river system in South America is the Orinoco (with a river length of 2740 km and a basin area of 1 000 000 km<sup>2</sup>). The Orinoco originates on the western slopes of the Serre-Parima Mountains on the borders of Venezuela and Brazil and flows to the Atlantic Ocean.

The main tributaries flowing to the Orinoco on the left-hand side are the Guaviare, Vichada, Meta, Arauca and Apure and on the right, the Ventuari, Caura and Caroni. In the upper reaches, the Casiquiare River separates from the Orinoco, with one third of the runoff volume flowing along its channel to the Amazon Basin.

Many other large rivers flow along with the aforementioned largest river systems of South America. Table 2 presents summary data on a number of river basins of South America.

No.	River	Basin area, thousand km <sup>2</sup>	Length, km
1	Amazon	6915	6280
2	La Plata	3100	4700
3	Orinoco	1000	2740
4	Sao-Francisco	600	2800
5	Paranaiba	325	1450
6	Magdalena	260	1530
7	Essequibo	155	970
8	Chubut	138	850
9	Rio Negro	130	(1000)
10	Mearin	89.7	(800)
11	Riu-Dosi	81.3	(600)
12	Rio Colorado	65.0	(1000)
13	Paraiba	59.0	800
14	Atrato	32.2	644
15	Bio-Bio	24.3	380

Table 2. Main information about the rivers of South America

The rivers of South America are predominantly rain-fed, but in the extreme south of the continent there is also snow-glacial alimentation.

The fraction of underground alimentation varies from 20 to 25% in the rivers of the South Andes, to 50% on the well moistened margins of the Brazilian and Guiana highlands, as well as in the desert tropical west.

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### **Biographical Sketch**

**Vladimir Ivanovitch Babkin** was born in 1941. In 1965, he graduated from the Voronzh State University. Since 1969 he has worked at the State Hydrological Institute. In 1970, Babkin defended theses for the degree of candidate of geographical– sciences, and in 1984 – doctor theses of geography. Since 1982, he has been the head of the laboratory “Water Resources and Water Balance” at the State Hydrological Institute, St. Petersburg.

V.I. Babkin is the author of 130 scientific papers including seven monographs on hydrology, hydrophysics, and water balance and water resources. Most of his studies deal with hydrological cycle processes (evaporation, runoff, precipitation, and infiltration), developing methods for their estimation, as well as discovering global mechanisms of land moisturizing on the continents.