ORIGIN, RESOURCES AND DISTRIBUTION OF RIVERS AND STREAMS

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Contents

Summary

River systems are of the utmost importance for Nature and people, being the main source of fresh water supply. The origin and evolution of river systems took place during the geological history of the Earth under the effects of tectonic and volcanic processes and changes in the global climate. The present configuration of the hydrographic network on the Earth was formed about 10,000 years ago after the last glacial epoch.

Areal distribution of contemporary river systems, their quantitative characteristics and time changes are determined by a number of physiographic factors and human impact.

The hydrological network contains many hydrological stations where water levels and discharges are regularly measured in rivers, lakes and reservoirs. The data from this network is very important for studying the regimes of water bodies, and for estimation of water resources and their change due to human impact.

The world hydrological network data, as well as data on water use and socio-economic development of different countries of the world, have been used by scientists of the State Hydrological Institute (SHI, St. Petersburg, Russia) for assessment of river runoff dynamics and characteristics of past, present and future fresh water use on a global scale. Analysis and quantitative assessments have been made for the largest river systems, selected countries, all continents and natural-economic regions of the world.

The present paper contains information on the global scale; data on river systems on particular continents are given in other chapters of EOLSS.

1. Introduction

The system of permanent and temporary watercourse (rivers, streams and brooks) forms a hydrographic network on the land surface. According to the slope of the Earth's surface, this network is distributed among the largest waterways discharging to oceans, seas or endorheic lakes. The combination of all rivers and streams discharging to a main watercourse forms a river system. This can cover a vast area of hundreds of thousands and even millions of square kilometers. In fact, most of the land surface of our planet comprises a combination of river systems with permanent or temporary hydrographic network penetrating into the whole surface of the Earth, rather like the human blood circulatory system, and discharging fresh water from rains and snow or ice melt to the World Ocean.

River systems and the hydrographic network in general are of a great importance for nature and human life, providing people with fresh water for their activities. The spatial distribution of river systems, their quantitative characteristics and temporal changes in any region of the world depend on a range of physiographic factors (including climatic factors) and the effect of human activity.

The present article describes characteristics of river systems, their variations in time and over area under the effect of physiographic and anthropogenic factors on a global scale. More detailed information on each continent of the Earth is given in other chapters within this Topic of EOLSS.

2. Origin and Evolution of River Systems

The history of origin of rivers on the Earth is very long. Water on the planet appeared during the Archaen era about 4 to 5 billion years ago. According to the most commonly held viewpoint, the Earth's hydrosphere is the result of gaseous emission out of the solid envelope (mantle) of the Earth. About 500 million years ago the hydrosphere volume equaled more than 90% of its present volume. Great volumes of water were concentrated not only in oceans but in glacier shields, in large sea basins, lakes and swamps, in aquifers and in river systems during past geological epochs.

Formation of terrestrial hydrography, and origination and evolution of rivers systems in particular, was mainly determined by changes caused by the effect of tectonic and volcanic processes on relief formation, including appearance and evolution of continents, as well as seas and lakes on the continents. Formation of the hydrographic network was affected by changes in climate, water exchange and soil erosion under the influence of solar radiation on the Earth's surface.

During their evolution in different geological epochs, the river systems had various configurations and different hydrological characteristics. We do not have much reliable information about evolution of the river network on the continents during the geological past. Appropriate approximate assessments for individual past epochs are usually made by analyzing the remains of ancient river valleys and different types of deposits, such as continental pebbles and sands of marine, lake and river origin.

An intensive period of erosion caused by surface waters was initiated about 4 billion years ago when individual land masses (the primary continents) were formed. Most traces of the primary watercourses and lakes, however, on the primary continents disappeared as a result of erosion, tectonic and volcanic activities, and repeated oceanic transgressions. Little evidence has been found for surface water activity on land before the period of one thousand million years ago. Some information about evolution of river systems since that time in different regions of the world is given in *Origin and Evolution of River Systems.*

Data on paleoclimate reconstructions have been widely applied for description of the hydrographic network distribution and even for quantitative assessment of hydrological regimes of particular water bodies during the Quaternary geological period, the beginning of which is usually related to the time of 1.5 to 2.5 million years ago (Pleistocene). Most assessments were obtained for the territory of Eurasia (see *Origin and Evolution of River Systems*). It should be noted that the Pleistocene period was characterized by total climate cooling on Earth and by periodic glaciations at temperate latitudes of the northern hemisphere. Evolution of the river network, and formation of lakes and water resources in these regions, are closely connected with glaciation processes.

It has been established that the last glacial epoch began about 115 000 years ago and lasted for more than 100 000 years. Initially, the glaciation was not too intensive, with frequent intervals. The most intensive cooling and thickest ice cover in polar regions and at temperate latitudes of the northern hemisphere, as well as glacier formation in mountain areas, began about 50 000 years ago; the glacier coverage was most extensive before the 18th millenium B.C. At that time glacier coverage in the northern hemisphere extended to 50-60^{o}N and its maximum thickness was 2500 m. During that period glaciers in the mountains in southern areas of the Earth, including in subtropical zones, occupied very large areas; the lower boundaries of glaciers were 1 to 2.5 km lower than their present position. During the subsequent millennia, when climate warming began on Earth, the ice cover on the continents and glaciers in mountains began to melt. Most intensive melting occurred during the period of 16 to 13 thousand years ago and it was completed about 7000 years ago. Ice coverage extension and melting caused a fundamental change in the hydrographic network over a vast land area. During the postglacial period (Holocene), i.e. during the last 7 to 10 thousand years, the hydrographic network on our planet did not suffer great changes and its configuration has been similar to the contemporary one.

3. Factors Determining Evolution of the Contemporary Hydrographic Network and River Runoff Regime

The contemporary evolution of the hydrographic network and river runoff regime is explained by a complicated interaction between physiographic factors and human activity.

Physiographic factors may be combined into two basic groups:

- meteorological or climate factors, i.e. mainly precipitation, solar radiation, air temperature and humidity;
- factors of the underlying surface of the watershed, i.e. relief, geological structure, soils and vegetation, lakes and swamps, watershed area and configuration, river length and slope.

Factors of human activity are also variable and comprise different impacts on the hydrographic network, on watershed surface and river runoff characteristics.

In considering the dependence of the condition of the hydrographic network and river runoff regime on various factors, it should be taken into account that the rate and opportunity of these factors on different phases and characteristics of river regime (annual runoff, streamflow distribution during a year, maximum and minimum water discharges, etc.) may differ greatly.

3.1. Climate Factors

Solar radiation (and in particular the radiation balance at the Earth’s surface) is the main factor which determines water circulation on the planet and the climate situation in any region. The solar radiation onto the Earth’s surface is characterized by a clear latitudinal distribution: maximum values of radiation balance are observed at the equator and tropical latitudes; northward and southward these values decrease rapidly. For example, at 60-70^{o}N the radiation balance values are 5-6 times lower than those on the equator.

Non-uniform warming of the Earth’s surface because of variation in inflow of solar radiation with latitude, and different conditions of solar radiation absorption by different types of surface, explains the origin of large-scale air fluxes and atmospheric circulation. The greatest contrasts arise between land and ocean subject to seasonal and latitudinal changes, and between surfaces covered with ice/snow and bare surfaces. Latitudinal differences in solar energy inflow and contrasts between ocean and land and polar ice at the Earth’s rotation ultimately explain the fields of atmospheric pressure, large-scale transportation of air fluxes, energy and water vapor.

Air fluxes resulting from atmospheric circulation transport water vapor over long distances; when moving around high mountain massifs, these fluxes cause large-scale vertical movements causing water vapor to rise to the upper part of the troposphere and produce precipitation. They also explain the uneven fall of precipitation in time and space.

The processes of atmospheric circulation are not stable, both at the global scale and for particular regions. Air mass transportation along latitudes is overlapped by meridional movements, thus producing circulation zones that change by seasons; they are also affected by changes in the conditions of the Earth's surface. The atmospheric circulation is greatly affected by processes in the World Ocean, by factors of solar activity and by different cosmic factors. Therefore, atmospheric circulation and precipitation are subject to great time-space changes. On a small scale (small areas and short time intervals) this produces extreme meteorological situations, i.e. maximum or minimum precipitation, severe storms and floods, or very low streamflow. On a large time scale the processes of atmospheric circulation explain climate variation over a large areas, e.g. wet years (or periods) alternating with dry years (or periods).

According to the studies made in recent decades, atmospheric circulation processes, and consequently climate conditions, greatly depend on human impact that has changed the gas content of the atmosphere by increasing concentrations of CO_2 and other gases emitted during combustion of organic fuels and development of certain industries.

Total annual precipitation onto land (without Antarctica) is about 116 700 km^3, which equates to a water layer 864 mm deep evenly distributed all over the land surface. Maximum precipitation (on average about 1600 mm) is observed on the territory of South America; minimum precipitation (only 456 mm) falls on Australia. Mean average precipitation onto the territories of the other continents varies from 740 to 790 mm. Considering precipitation distribution over latitudinal zones, it should be noted that maximum precipitation (about 1900 mm) occurs in the equatorial zone within 10^{o}N and 10^{o}S. Northward of the equator, where most land area is located, the precipitation layer tends towards a regular decrease; mean precipitation in the zone between 40^{o}N and 60^{o}N is about 675 mm.

These values of precipitation have been averaged for large areas. Annual precipitation on the territory of each continent and within each latitudinal zone is distributed extremely unevenly. As a whole for the territory of our planet, the mean annual precipitation varies within very wide limits, i.e. from 5 to 25 mm (deserts on different continents) to 11 000 mm (southern slopes of the Himalayas). A very uneven distribution of precipitation occurs on each continent.

This uneven distribution of precipitation over the land area on our planet mainly explains the extremely uneven spatial distribution of streamflow. The most moistened regions of the Earth have the most developed hydrographic networks and highest values of annual river runoff (renewable water resources). In deserts where precipitation fall may not occur for several years, the permanent hydrographic network is practically missing and river runoff is about zero.

Precipitation is the main climate factor affecting streamflow formation; nevertheless, there are some other climate factors affecting to a certain extent the amount and regime of river runoff, streamflow distribution during a year and extreme runoff characteristics. These are air temperature, air humidity and wind velocity, which determine evaporation values, thus affecting different characteristics of river runoff and water resources. This effect is particularly great in regions of water deficit and during hot and dry seasons in the regions of temperate climate when precipitation may be completely lost to evaporation.

Thus, streamflow characteristics, annual or seasonal runoff in particular, depend on the ratio between precipitation and evaporation, which is expressed by the so-called aridity index. The regions of excessive and sufficient water amount where the aridity index is small are characterized by the greatest river runoff volumes. In such regions precipitation is the main factor determining runoff space-time variation. Regions with dry and hot climates and a high aridity index are characterized by very small runoff values and, as a rule, by great runoff variability in time and space.

It should be noted that in some physiographic conditions the air temperature affects the amount and distribution of streamflow not only indirectly via evaporation but directly, too, e.g. during melting of ice and snow cover. This is typical of regions where a high proportion of annual precipitation is snow and it is accumulated during the cold season; it is also typical of high mountain areas where rivers are recharged by melting glaciers. In these regions air temperature variations directly affect snow and ice melting, and as a result, affect streamflow variations during a year and its extreme characteristics. Nevertheless, the total values of annual runoff in these regions mainly depend on the annual precipitation.

As noted above, precipitation and air temperature are subject to great time-space changes. If they are estimated on average for a large area and for a long-term period, however, these values are rather stable and characterize the natural climate condition of particular regions. A rather stable value of the natural streamflow corresponds to this climate condition. All present and future assessments of climate, runoff, water resources and water use characteristics are based on the assumption of stability or sustainability of climate and river runoff.

Studies by climatologists, however, made since the early 1990s have proved quite convincingly that the hypothesis about climate stability under present conditions is not correct. This is explained by human activity and by ever-growing combustion of fossil fuels resulting in higher carbon dioxide (CO_2) concentration in the atmosphere, global air temperature rise, and change in atmospheric circulation, precipitation regime and runoff characteristics [see: *Anthropogenic Effects on the Hydrological Cycle*].

According to the available prognostic assessments, the air temperature by the end of the twenty-first century may be by 2.0 to 3.0 ^{o}C higher; moreover, in high and middle latitudes a warming of 6-8 ^{o}C may be expected. It is also possible to expect precipitation change during the cold and warm seasons. As for particular regions, long-range forecasts of anthropogenic climate change (precipitation in particular) have many uncertainties both concerning the scale of change and timing of occurrence. Nevertheless, it is evident that these changes will be significant and may greatly affect the river systems, river runoff regime, and characteristics of fresh water use. In many regions, and the arid and semi-arid ones in particular, which are especially vulnerable even to a slight climate change, the results of global warming may be extremely adverse.

Taking this into account, development of reliable forecasts of anthropogenic climate change, assessment of these results in relation to river runoff regime, water resources and water use, development of a number of projects for future mitigation of possible negative effects, and adaptation to these effects, are vitally important and urgent problems for contemporary hydrometeorological science.

It should also be noted that the above possible great anthropogenic climate change refers to the semi-distant future, i.e. to the end of the twenty-first century. According to the available assessments, climate change during the next two or three decades is not so great (a global air temperature rise of 0.5 to 0.6 ^{o}C is predicted). Taking this into account, and noting the great uncertainty of the present prognostic assessments of the change in regional climate characteristics, when computing water resources and water availability in the world for the next 10 to 20 years, it is quite possible to use the present climate data based on long-term observations.

3.2. Factors of the Underlying Surface

The factors of the underlying surface affect river systems in different ways. As noted above, the amount of renewable water resources or river runoff on large territories mainly depends on the climate conditions determining the amount of precipitation and evaporation. Specific features of the underlying surface of river basins in this case are displayed by the effect of these features on precipitation and evaporation.

For example, elevated areas (highlands) in basins lead to higher precipitation, and, consequently, to greater river runoff if compared with flat river basins in similar climate condition. On the other hand, large lakes, and temporary overflows of rivers over vast areas in arid climate conditions, cause intensive evaporation, and, consequently, lead to decreased river runoff if compared to river basins in a similar climate without large water areas. The factors of the underlying surface greatly affect the hydrographic network structure, extreme characteristics of river runoff and, to a lesser extent, streamflow distribution during a year.

Geological structure and relief are the most stable characteristics of any river basin. They determine to a great extent the general structure and density of the hydrographic network, river slopes and surface-subsurface water interaction. The hydrographic network density in a mountain river basin is higher, river slopes are steeper and, consequently, water flow velocities are higher; this explains intensive and short-term floods caused by rainfall. On flat watersheds the river slopes are gentle; closed depressions filled with water during floods are often observed in such terrain. Water outflow from such watersheds is difficult; maximum water discharges are small; most precipitation is accumulated on the watershed and it is later lost to evaporation.

Specific conditions of the hydrographic network and runoff regime formation are observed in so-called “karst” regions where large areas are occupied by soluble rocks (limestone, gypsum, rock-salt, etc.) and a range of different cavities, caves, subsurface lakes and streams occur. Karst regions are characterized by specific conditions of surface and subsurface water interaction. The river network is not permanent because precipitation disappears to subsurface cavities and discharges to large rivers as subsurface flow. Spring snowmelt and rainfall floods are not well expressed in rivers in karst regions; higher runoff, however, is observed during periods of low surface water discharge in ordinary rivers in the same climate zone. Soils and plants affect river runoff primarily by precipitation loss to evaporation, and, secondarily, by precipitation overflow and infiltration losses. In general, different plant species are characterized by different evaporation rates and create different conditions for runoff formation. For example, in forests a high proportion of surface runoff percolates into the ground and becomes subsurface runoff due to the high infiltration capacity of forest soils and leaf litter. As a result, runoff from forested areas, as compared with open ground, is more uniform, and usually forested watersheds are characterized by lower maximum and higher minimum water discharges.

The effect of forests on river runoff is most significant in regions where a major portion of the precipitation is snow; it melts in spring to produce a spring snowmelt flood. This effect on river runoff is produced not because of greater melt water infiltration but as a result of different accumulation rates of snow on forested and bare localities, as well as by delay of snow melt in forests. The effect of lakes on river runoff is different. Annual river runoff in lacustrine areas tends to be lower because of higher evaporation losses from water surfaces than from land. This is extremely important for arid and semi-arid regions where evaporation from water surfaces greatly exceeds evaporation from land. As for humid regions, evaporation from the water surface and from land is about the same and the effect of lakes on annual river runoff is insignificant.

The effect of lakes on uniform streamflow distribution during a year is great; it occurs because water in lakes is accumulated during wet periods and is released during dry periods, as it is in man-made reservoirs.If a watershed is low-lying and swamps occupy large areas, maximum discharge during rainfall and snowmelt is greatly reduced and flood duration increases. This mainly occurs due to slower runoff and overflows of the swampy rivers in wide river valleys. The effect of various physiographic factors (e.g. river length and watershed shape) on river runoff is not great but can slightly affect maximum water discharge in cases of extreme floods.

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Biographical Sketch

Igor Alexeevich SHIKLOMANOV was born on 28 February 1939. In 1961 he graduated from the Leningrad Hydrometeorological Institute (Hydrological Faculty). Since 1961 up to the present time has been working at the State Hydrological Institute in St. Petersburg (Russia) in different appointments. Since 1981 he is the Director of the State Hydrological Institute.

In 1967 he defended his theses for a candidate’s degree and in 1975 – a theses for a doctor’s degree on the speciality «Hydrology and Water Resources»; since 1985 – a professor on «Water Resources» speciality; since 1991 – a Corresponding Member and since 2000 – Academician of the Russian Academy of Natural Sciences on «Hydrology» speciality.

His scientific interests include water resources, water balance, water use, the global hydrological cycle, effects of man’s activity and anthropogenic climate change on water resources and hydrological regime. He has published about 200 scientific papers, 9 monographs included.

He has made a notable contribution to the international cooperation within the framework of UNESCO, WMO, IAHS, IPCC: during 1992-1994 he was the Chairman of the Inter-Governmental Council for the IHP (UNESCO), since 1992 up to the present time he is a member of the Advisory Working Group, Commission of Hydrology WMO; since 2000 he is the Chairman of the Working Group on Water Resources of the Commission of Hydrology (WMO).