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Appraisal and Assessment of World Water Resources

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Abstract: *A critical analysis of the present situation on the global water resources assessment is made. Basic data and methodological approaches used by the author for the assessment and prediction of water resources, water use and water availability on the global scale are briefly described. On the basis of data generalization of the world hydrological network new data are given on the dynamics of renewable water resources of the continents, physiographic and economic regions, selected countries as well as on the river water inflow to the world ocean. The results of the assessments for the 20th century and for the future before 2010–2025 on the water supply for municipal, industrial and agricultural needs as well as an additional evaporation from reservoirs are presented. Loads on water resources and water availability depending on socio-economic and phisiographic factors are analyzed; regions of water scarcity and water resources deficit are discovered. Possible ways of water supply improvement and elimination of water resources deficit in different regions and countries are discussed.*

Keywords: *Assessment, natural-economic regions, global renewable water resources, water availability, water consumption, water use, water withdrawal.*

Background and Present Situation

Water resources occupy a special place among other natural resources. Water is the basis of life on earth; it is the main component of the environment and an essential element for human life. Water is also fundamental for sustaining a high quality of life and for economic and social development. Water greatly affects human health. Polluted water or water surplus or deficit may cause diseases, calamities, and damage to the environment. During the last 20 years it became evident that natural resources, water resources in particular, are limited and that they should be used rationally for sustainable development of human society, to meet the demands of the present and future and to maintain a favorable environment.

Reliable assessment of water storage on the earth is a complicated problem because water is very dynamic. It is in permanent motion, converting among liquid, solid, and gaseous phases. In addition to the quantitative estimation of water storage, it is necessary to determine the form (free or bounded) and the volume (sphere) of water on our planet.

The total amount of water in the hydrosphere consists of the free water in liquid, solid, or gaseous states in the atmosphere, on the earth's surface, and in the crust down to the depth of 2000 meters. By approximate estimates (Korzoun, 1974, 1978), the earth's hydrosphere contains a huge amount of water, about 1,386 million cubic kilometers (km^3). However, 97.5 percent of this amount is saline water, and only 2.5 percent is fresh water. The greater portion of the fresh water (68.7 percent) is in the form of ice and permanent snow cover in the Antarctic, the Arctic, and mountainous regions. Fresh groundwater comprises 29.9 percent of fresh water resources. Only 0.26 percent of the total amount of fresh water on the earth is concentrated in lakes, reservoirs, and river systems. The latter water sources are most accessible for economic needs and are very important for water ecosystems.

The above values characterize the so-called natural static water storage in the hydrosphere. It is the long-term, average amount of water simultaneously contained in water bodies, aquifers, and the atmosphere. For shorter time intervals (years, seasons, months), the values of water storage in the hydrosphere permanently vary during water exchange among the ocean, land, and the atmosphere. This exchange is usually called the turnover of water on the earth, or the global hydrological cycle.

River water is of great importance in the global hydrological cycle and in supplying humankind with freshwater. This is due to the fact that the role of individual components in earth's water turnover depends both on the value of water storage and its dynamics. Usually the latter is estimated by the period of full replenishment. Hydrospheric water of different kinds is fully replenished during this period in the process of hydrological cycle. The period of full recharge is about 2,500 years for oceanic waters, 10,000 years for permafrost and polar ice, and 1,500 years for deep groundwater and mountainous glaciers (Korzoun, 1974, 1978). Water storage in lakes is fully replenished in 17 years and in rivers in 16 days. In hydrology and water management, two concepts are often used to assess water resources in a region: static, or secular, freshwater storage and renewable water resources. The static storage conventionally includes freshwater with a period of full renewal of many years or decades (large lakes, groundwater, glaciers, etc.). Its intensive use unavoidably results in storage depletion and unfavorable ecological consequences. It also disturbs the natural equilibrium, established for centuries, whose restoration would require tens or hundreds of years.

Renewable water resources include the water yearly replenished in the process of water turnover on the earth. The annually renewed volume, usually measured as volume per unit of time (m^3/s, $km^3/year$), consists mainly of the regional runoff and the inflow of groundwater into the river network. Renewable resources also include the yearly renewable upper aquifer groundwater that is not drained by the river systems. However, on a global scale, the volumes involved are not large as compared to the volume of river runoff and are of considerable importance only for specific regions.

In the process of turnover, both the quantity of river runoff is replenished and its quality is restored. If we could stop the contamination of rivers, then, with time, water could return to its natural purity. Thus, the annually renewable river runoff is the most important component of the hydrological cycle, which exerts a pronounced effect on earth's surface ecology and the economic development of humankind. It is the river runoff that is most widely distributed over the land and provides a major part of water use in the world. In practice, the quantity of river runoff serves as a basis for determining the availability and deficits of water resources in a region.

The appraisal and assessment of renewable water resources consists of a discovery of water sources, inventory of spatial and temporal (both during the year and over multi-year periods) distribution of river runoff, and assessment of water quality, which is the basis for determining the possibilities for water use and protection. A discovery of the anthropogenic factors that effect change of the quantitative and qualitative parameters of river water, and generalization of data on water use for different needs, are very important aspects of the water resources appraisal and assessment. This information is required for decision making on the optimal water resources use in the present and for the future. Reliable assessment and appraisal of water resources is very important for each country or region and serves as an important prerequisite for all other aspects of the utilization and operation of water resources, and development of measures to protect against depletion and pollution. A great emphasis was focused on necessity of reliable appraisal and assessment of the national water resources during the UN Conference on water resources in Mar-del-Plata (United Nations, 1977) and at the International Conference on water resources and the environment in Dublin (United Nations, 1992). A number of recommendations were adopted at those conferences to support national efforts on the appraisal and assessment of water resources. To assist countries in multi-purpose appraisal and assessment of national water resources, special guides have been prepared by United Nations Educational, Scientific, and Cultural Organization (UNESCO) and World Meteorological Organization (WMO), which were published in 1997 and in 1998 and which are widely used by the specialists from many countries on each continent (UNESCO/WMO, 1988, 1997). During the last decades appraisal and assessment of the global water resources and their use were made by several different organizations and individuals.

Data on earth's total river runoff, as a major component of the global hydrological cycle and basic characteristic of renewable fresh water resources, are cited in many studies published since the turn of the past century in different countries of the world. For the past 30 years, the results of global estimations have been published with varying degrees of comprehensiveness (Nace, 1967; Lvovitch, 1974; Korzoun, 1974; Baumgartner and Reichel, 1975; Berner and Berner, 1987). Estimates have also been regularly published in the proceedings of the World Resources Institute (1992, 1994, 1996). Detailed data on water resources and water use taken from different sources are given in the monographs by Gleick (1993, 1998).

The most detailed and comprehensive estimations of the earth's water balance and water resources are presented in the two monographs published more than 20 years ago by Russian (Korzoun, 1974, 1978) and German (Baumgartner and Reichel, 1975) scientists. These data are widely considered by specialists of many countries as the most reliable. At the same time, the data cited in these monographs can differ for individual continents by up to 30 to 40 percent. This difference is mainly attributed to the methods used for estimating the total river runoff. In Russian studies, the estimates of runoff are determined directly from data observations at hydrological stations; in the German studies they are determined by an indirect approach of comparing the difference between evaporation and precipitation. The latter approach is likely to result in large errors for small values of river runoff. It is unreliable for the assessment of water resources, especially their dynamics in countries and regions located in areas with low rainfall.

It should be mentioned that later publications that cite data on the water resources of continents, regions, and countries of the world provide no information other than what appears in the above mentioned studies. For instance, the values of water resources cited in the author's studies (Shiklomanov, 1990, 1993) are fully based on the materials of the two earlier monographs (Korzoun, 1974, 1978). The data, periodically published by the World Resources Institute in Washington, DC (World Resources Institute, 1992, 1994, 1996), represent a compilation from different sources, which refer to different years of assessment (from 1970 to 1987). They are mainly obtained from the Institute of Geography, the Russian Academy of Sciences (in particular, the data by Prof. Lvovitch M.I., 1969–1972), and other national estimates. This is also largely true for the Population Action International study (1993), where estimates are made of the average quantities of renewable water resources for most countries. There are also specific indicators for per capita water availability in 1955, 1990, and 2025 based on demographic forecasts. Publications of the World Resources Institute are also widely used by many authors to analyze global water resources and water availability (Berner and Berner, 1987; Falkenmark and Widstrand, 1992; Kulshreshtha, 1992; Postel, 1992).

Global water use assessments have been made with different degrees of comprehensiveness and reliability in many countries of the world. They have been regularly published, beginning with the study by Doxiadis (1967). Of the most significant studies of this type, those of Lvovitch (1969, 1974), Holy (1971), Falkenmark and Lindth (1974), De Mare (1977), the US Geological (1980), and Ambroggi (1980) are worthy of notice. The most detailed assessments of world water use for the current century, with forecasts to 2000 for all continents, were first made and published jointly by the author and G.P. Kalinin in 1974 (Kalinin and Shiklomanov, 1974). More detailed data by continents and natural-economic regions were presented by the author in a 1987 monograph (Shiklomanov and Markova, 1987). Later publications on water use by countries of the world (World Resources Institute, 1992, 1994, 1996) give data taken from different sources for different years. However, there is no analysis or forecast of future changes.

Due to the existing situation with the assessment of world water resources and their use, a special project to analyze new data on world water resources was included into the IHP-IV UNESCO. Implementation of the project resulted in the publication of the monograph “World Water Resources at the Beginning of the 21st Century”. The Scientific Committee of the Russian Federation for IHP was responsible for fulfilling this project, and scientists of the State Hydrological Institute were charged with conducting the research and preparing the monograph. This monograph is now in print. The main research results obtained during the preparation of the monograph with a worldwide coverage are summarized below.

Initial Data and Methodological Approaches

Materials from the world hydrological network have been used to assess the water resources of continents, regions, and countries. Auxiliary meteorological information was also used. Observation data (monthly and annual values) from about 2500 hydrological sites (Figure 1) were selected to directly assess renewable water resources at the global scale. These hydrological sites were selected based on the following conditions:

- the availability of the long-term observation series;
- location of sites on large and medium rivers, uniformly spread across the region, if possible;
- observations should reflect the river runoff regime, natural, or close to natural.

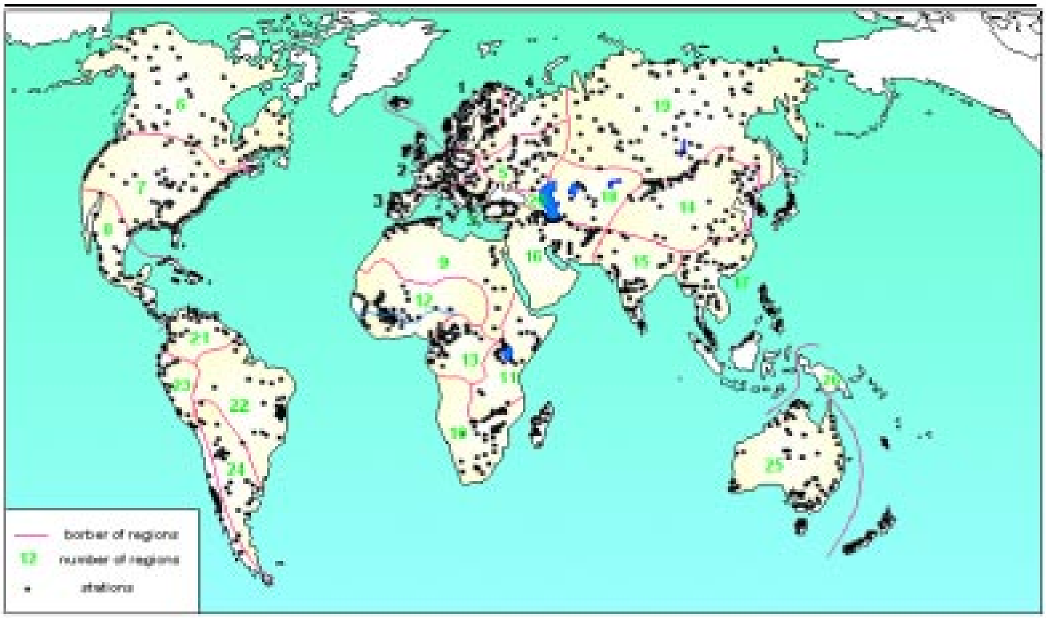


Figure 1. The natural-economical regions of the world and gauge stations.

The availability of long-term observation series was one of the important conditions for selecting hydrological sites, as this corresponded to a basic, accepted methodological principle: assessment of the water resources of all continents and regions of the world is to be carried out concurrently for the single, sufficiently long period.

The 1921–1985 period served as this single period. The data for later years were impossible to obtain for many regions of Africa, Asia, and South America. To obtain continuous data for the selected long-term period, the series were updated and the gaps in observations restored. For this purpose, two well-known methodological approaches from hydrology were used: correlation models and hydrological analogy methods. In many cases, observations of precipitation and air temperature were used to obtain more reliable results. The use of a single sufficiently long period of observation allowed for the estimation of comparable average values of water resources for all the regions of the world and rather reliable estimation of their extreme values and characteristics of long-term variability. Since a considerable portion of the land mass (up to 15-20 percent) has no observation data, hydrological models and methods for mapping runoff were applied to calculate runoff from these territories.

To assess the water resources of individual countries and natural-economic regions whose borders do not coincide with river divides, observations of local river runoff and river water inflow from adjacent territories were used to determine the major characteristics of national and regional renewable water resources. The natural-economic regions of the world are shown in the map on Figure 1.

In the present study, the values of renewable water resources are equated with annual river runoff. For global assessments this is quite admissible, since renewable groundwater resources not drained by rivers comprise only a small proportion of the total river runoff, for example, five percent for Africa (FAO, 1995). At the same time, for individual countries located in arid regions, renewable groundwater can represent a significant part of the total volume of renewable water resources.

To analyze the water resources of regions or basins, it is necessary to know the monthly distribution of flows. For watersheds, estimates can be made directly from the observation data. For the natural-economic regions, monthly values of water resources are estimated as fractions of the annual values of monthly runoff data of the main river basins located in the territory of the region.

Past and future water withdrawals of water resources were assessed, taking into account water use for public services, industrial production (including power generation), agriculture (irrigation), and water lost by evaporation from reservoirs. These factors cause decreases in surface and groundwater runoff, are widely distributed, and are able to exert an especially pronounced effect on water resources in large regions.

There are several basic factors that determine the quantitative characteristics of water use in large regions and countries of the world: the socio-economic development level, population, physiographic (including climatic) features, and the area of the territory. Their combination determines the volume and structure of water use, its dynamics, and future tendencies.

An analysis was made of spatial and temporal dynamics of water use for all world regions and for selected countries and river basins with reliably determined water resources characteristics. For every region, country, or basin, the total water withdrawal and consumption for urban population needs (domestic or municipal water use), industry (including thermal power), and irrigated farming and agriculture were estimated. An assessment also was made of evaporation losses from reservoirs. All estimations have been made for a number of benchmark years: for the previous years, including 1900, 1940, 1950, 1960, 1970, 1980, and 1990; for the present time (1995), and for the future for 2000, 2010, and 2025. This approach made it possible to follow the distribution of water use in the world by the territory and over time.

Water use was primarily estimated for the countries of the world. Then the values obtained were generalized for large natural-economic regions and continents. The analysis of water use data and the determining factors was made for about 100 countries. Preference was given to national data on actual or calculated water use in individual countries or groups of countries. At the present time, these data, more or less detailed and reliable, are available for many countries on all the continents. When actual data were not available, estimations were made by using specially developed methodological approaches. These approaches took into account the principal factors determining the value and dynamics of water use (total water withdrawal and consumption). An analogue method was employed, based upon the countries with reliable water use data. These countries were located in similar physiographic conditions and had the same level and features of economic development.

Municipal Water Uses

Municipal (domestic) water uses are the water withdrawals made by the populations of cities, towns, and housing estates, and domestic and public services and enterprises. The municipal use also includes water used to directly provide for the needs of urban populations, which consumes high-quality water from the city water supply system. In many cities, a considerable volume of water is used to water vegetable gardens and residential landscapes.

The volume of public water use depends on population, the level of services and utilities, and the availability of water pipelines, drainage and, centralized hot-water supply. The volume of water used very much depends on climatic conditions. In many well-equipped cities of the world, water withdrawals equal 300–600 liters per day per person (lcd). By the end of the 20th century, in industrially developed countries of Europe and North America, the per capita urban water withdrawal was expected to increase up to 500–800 l/day. On the other hand, in developing agricultural countries of Asia, Africa, and Latin America, public water withdrawal is 50 to 100 lcd; in individual regions with insufficient water resources, it is not more than 10 to 40 lcd of fresh water per person (Shiklomanov and Markova, 1987; Gleick, 1993, 1998).

A greater part of the water that has been withdrawn from the urban water supply systems is returned (purified or not) as wastewater to the hydrographic network. This occurs if the urban drainage operates effectively. The principal part of consumption consists of water losses from evaporation, leakage from water supply and drainage systems, and water used for plants, streets, recreation zones, and personal plots. Thus, to a large extent, consumption depends on climatic conditions. In dry, hot regions, losses are certainly larger than in cold, humid regions. The water consumption for personal needs is insignificant as compared with water losses due to evaporation.

Relative values of consumption are usually expressed as the percentage of water intake. So, in modern cities equipped with centralized water supply and efficient drainage systems, the specific water withdrawal is 400 to 600 lcd, and consumption does not usually exceed 5 to 10 percent of total water intake. Small cities with a large stock of individual buildings not fully provided with centralized systems have a specific water withdrawal of 100 to 150 lcd. Consumption rates can reach 40 to 60 percent of water intake. The smallest values occur in the northernmost regions, the largest in dry, southernmost regions (Korzoun, 1974; Shiklomanov and Markova, 1987).

The modern tendency of public water supply development in all cities of the world is the construction of effective, centralized water supply and drainage systems and the connection of these systems to a large number of buildings and populated areas. Future per capita water withdrawal is expected to increase, and the values of water consumption expressed in percentage of water intake will be considerably decreased. Water use by populations in cities and rural areas was estimated using population dynamics data (urban and rural) and per capita water withdrawal. Population dynamics for past years were taken from statistical handbooks, and future population numbers were taken from the 1994 UN forecasts (United Nations, 1994). Per capita water withdrawal and the fraction of total water consumption for every country were taken from published national data or the materials of international organizations. In case of data unavailability, the above values were based on water withdrawal in analogous countries.

Industrial Water Uses

Water in industry is used for cooling, transportation, as a solvent, and as an ingredient of finished products. The principal water user in industry is thermal and atomic power generation, which requires a great amount of cooling water. The volumes of industrial water withdrawal are quite different not only for individual branches of industry, but also within each kind of production, depending on the technology of manufacturing process. Climatic conditions are also a factor. As a rule, in the northern regions, industrial water withdrawals seem to be considerably less than in southern regions with higher air temperatures.

In addition to thermal power, the principal industrial water users are chemistry and petroleum chemistry, ferrous and non-ferrous metallurgy, wood pulp and paper industry, and machine building. Major characteristics of industrial water use (the volume of freshwater withdrawal, water consumption, water diversion) depend to a very large extent on the water supply system. There are two basic schemes: an inflow and circulating. With the inflow water (or once-through) supply system, the water extracted from the source is discharged into water streams after use (purified or not). With the circulating system, the used water is cooled, treated, and returned back to the water supply system. Thus, the system of circulating water supply excludes the discharge of used waters back into water bodies or water streams and depends on the multiple use of water in production. The necessary freshwater intake for a circulating water supply is insignificant. It is determined by the discharge necessary to restore water consumption spent in production and regeneration processes as well as for periodic water replenishment in circulating cycles.

The value of industrial water consumption is usually an insignificant fraction of water intake. However, it varies greatly depending on the type of industry, the nature of the water supply, technological process, and climatic conditions. In thermal power generation, consumption is about 0.5–3.0 percent of water intake. In most industries it is 5 to 20 percent, reaching 30 to 40 percent in some industries (Shiklomanov, 1986, 1989; Shiklomanov and Markova, 1987; Margat, 1994; Shiklomanov, 1997). With the inflow water supply system, water consumption expressed in percentage of water intake is considerably less than with the circulating system. The reverse is true for freshwater intake.

When estimating the future volume of industrial water use for individual regions, countries or river basins, it should be recognized that industrial use varies under the influence of different tendencies. On the one hand, this volume should increase due to industrial growth and thermal power production. On the other hand, this increase will not necessarily be proportional to industrial growth. In the future, most countries will need to continuously increase the transition to circulating water supply systems. Many industries will convert to water-free, or dry, technologies. In some countries and regions of the world, there is a tendency to increase the use of marine waters for industrial purposes.

All other things being equal, the volume of industrial and thermal power water consumption will be much greater in southern regions with dry, hot climates than in the northern regions with abundant rainfall. In addition, industrial and thermal power water consumption depends on the type of water supply system. The inflow system has the least consumption, and with the circulating system, fresh water intake and wastewater volume drastically decrease. However, consumption frequently increases by 1.5 to 3 times. Therefore, in the future, circulating water supply systems should be developed by all possible means. This would make it possible to recycle water in industry. Thus, water consumption may be expected to slightly increase (in percentage of water intake) as a whole for individual countries, regions, and large river basins.

Industrial water withdrawals were calculated based on the dynamics of industrial production in different regions of the world. Available data on industrial water withdrawal are applied by analogy to many countries of the world, including those with different level of economic development, located in different physiographic conditions. Calculations for the current and future periods were carried out separately for thermal power and other industries with considerably differing tendencies and rates of development and water losses. Then they were summed up for every region.

Total water consumption by thermal power generation was assumed to be 1 to 4 percent. In other industries, it was taken as 10 to 40 percent of water intake, depending on the level of industrial development, the availability of water circulating supply systems, and climatic conditions. An assessment for the future period to 2025 was made for every country, taking into account special UNIDO developments (Strzepec and Bowling, 1995) with significant adjustment for developing and developed countries (Shiklomanov, 1997).

Agricultural Water Uses

Water use by agriculture is primarily determined by the development of irrigated land use. In many countries and regions of the world, irrigation is the principal water user. Irrigation has been practiced for millennia. However, most irrigated lands were introduced in the 20th century. By the late 1970s, almost all developed and developing countries on all the continents initiated intensive irrigation development. This intensive irrigation could provide for the growth of irrigated areas and guarantee increased crop production. In the 1980s, the global rate of increase in irrigated areas slowed considerably. (Postel, 1992; Shiklomanov, 1997). This occurred in both the developed and developing countries. The primary cause was the very high cost of irrigation system construction, soil salinization, the depletion of irrigation water-supplying sources, and the problems of environmental protection. In a number of developed countries, the amount of irrigated lands has stabilized or even decreased.

Considering the problem on the global scale, it is important to mention that the development of irrigation of dry lands follows from the need to increase food supply. At the present time, about 15 percent of all cultivated lands are being irrigated. However, the food produced in irrigated areas amounts to almost half the total crop production in terms of value. In the modern world, the population is growing at a rapid rate. At the same time, there is a critical food deficit experienced now by almost two-thirds of the world population. Therefore, irrigation is being given an important role in increasing land use and cattle-breeding efficiency. Thus, irrigated farming is expected to expand rapidly in the future. Irrigated areas would expand mainly in countries with an extremely rapid population growth and sufficient water and land resources. The total global irrigated areas are expected to increase, although with not the same rate as in the 1970s. Subsequently, water use for irrigation is expected to grow.

Water required for irrigation is determined by irrigated area, the values of specific water intake in cubic meters per hectare per year (m^3/ha/year), and returnable waters in percentage of water intake. They depend on general physiographic conditions, serviceable condition of irrigation systems, watering techniques, and crop composition.

Information about water intakes and available irrigated areas in different countries permits the calculation of water withdrawals for irrigation under different physiographic conditions. After the adequate analysis and generalization, it can be included into the calculations of total water intakes by large natural-economic regions and continents. It is natural that the smallest values of water withdrawal are observed in northern countries and regions. For example, in northern Europe, withdrawals are 300–5,000 m^3/ha, while in southern and eastern European countries they amount to 7,000–11,000 m^3/ha. The returnable waters equal approximately 20–30 percent of water intake. In the USA, evaporation of water withdrawals is estimated by different authors at 8,000–10,000 m^3/ha, and returnable waters at 40–50 percent of water intake. In the countries of Asia, Africa, Central and South America, there is a great variety of climatic conditions, crop compositions, and watering techniques. Therefore, the values of annual water withdrawal vary greatly, from 5,000–6,000 m^3/ha to 15,000–17,000 m^3/ha, and in individual regions of Africa to 20,000 or 25,000 m^3/ha. (Shiklomanov and Markova, 1987; Shiklomanov, 1989, 1997; FAO, 1995, 1999).

In the future, the quantity of water withdrawals will change considerably because of advanced irrigation systems, improved watering requirements, regime, and techniques. All these need to be taken into account in preparing forecasts of irrigation water withdrawals in large regions of the earth. A considerable water economy can be attained through use of the most efficient modern engineering methods and means of watering (sprinkling, drip irrigation, etc.) that increase crop productivity and decrease irrigation water volume.

In terms of water economy, the most efficient systems of drip irrigation are still very expensive and not widely used in the world (Postel, 1992, 1999). However, these techniques reduce water expenses by approximately half and increase productivity. Therefore, they are expected to be more widely used in the future, which should result in decreasing the quantity of water withdrawn. The same result is achieved by improving the available irrigation systems, raising their efficiency and general effectiveness.

In agriculture, in addition to irrigation, water is spent on domestic needs of the population, in cattle breeding, and on modernizing rural populated areas. The problem of supplying the rural population and livestock with high-quality fresh water is of great importance in many developing countries of the world, especially arid regions. However, quantitatively, the total water contribution to other agricultural uses are insignificant when compared to those for irrigation (approximately, 5 to 8 percent). The largest water use in agriculture is irrigation.

An assessment of water use for irrigation was carried out by analyzing the dynamics of some characteristics for the previous 30–40 years. These include population, area of irrigated lands (such as in ha per capita) (by FAO data), and Gross National Product (GNP), expressed in US dollars per capita. In this case, the values of specific water withdrawal and water consumption were taken from the data of national estimations or by country analogues.

Calculations of water withdrawal for 2000, 2010, and 2025 were mainly based on forecasts of the areas of irrigated lands. For this purpose, the analysis was primarily based on trends from previous years, in combination with the above determining factors. The analysis was carried out separately for every country. Clear similarities were found in the changes in irrigation areas by population and GNP. These trends served as the basis for forecasts of future irrigation area based on forecasts of population and GNP for each country. Limiting factors are the area of land suitable for irrigation and the quantities of water resources accessible for use. In estimating future water withdrawals for irrigation, the trend of irrigation to decrease due to improving technological procedures and engineering efficiency was considered.

Water Reservoirs

The construction of large water storage reservoirs can lead to fundamental transformations in the temporal-spatial distribution of river runoff and can increase water resources in regions during low-flow periods and dry years. As a result of the flooding of vast territories, reservoirs make a considerable contribution to surface water evaporation in arid regions. This leads to a decrease in the total water resources of the regions. Thus, reservoirs are one of the largest fresh water users. This role of reservoirs must be taken into account in estimations of total water consumption by countries and continents, although many authors do not do this.

As long as a millennia ago, reservoirs were being constructed. However, as the objects of global scale, they appeared only in the second half of the 20th century. All the largest reservoirs, with a total volume of more than 50 km^3, have been built in the past 40 years. At the present time, the total volume of world reservoirs is about 6,000 km^3, and the total area of their water surface reaches 500,000 km^2 (Shiklomanov, 1989, 1997).

In developed countries of the world, reservoir construction was most intensive during 1950–1970. At that time, river runoff was almost fully regulated in many well-developed regions. Subsequently, the rates of reservoir construction decreased considerably. However, in the countries with rich natural resources of river runoff construction rates are still high. In developing countries, the highest rates of river runoff regulation were recorded during the 1970–80s. In accordance with modern tendencies and available plans for the future, during the next few decades reservoir construction will proceed in different regions of the world. This is due to the increasing role of hydropower engineering during shortages of liquid and solid fuel. In addition, reservoirs are used by industry, thermal and atomic power stations, and agriculture. They are the basis for large-scale water management systems regulating the extent and duration of river runoff as well as protecting populated areas from floods and inundations. However, in the future, the types of reservoirs constructed will need to be modified as will their objectives and territorial location. Reservoirs will be constructed in mountainous, piedmont, and sparsely developed regions with no flooding and vast areas of fertile lands suitable for agricultural use. In developed countries, predominantly small and middle-sized reservoirs will be built.

Reservoir construction in different regions will result in decreasing quantities of fresh water resources. This will occur because of the additional losses from evaporation. The loss of this water will be significant in the total water consumption of individual regions. Additional water losses from reservoir evaporation were calculated for all of the principal reservoirs of the world with a volume of more than 5 km^3 using the difference between the average evaporation from water and land surfaces. In this calculation, the ratio of the additional area of reservoir water surface to its total area was taken into account. The initial data on reservoirs (area, volume, location, years of construction, and other characteristics) were taken from generalizing international monographs and other publications describing individual countries and regions. The evaporation norms for water and land surfaces were determined by the charts of the *Atlas of World Water Balance* (Korzoun, 1974). Future losses due to evaporation from reservoirs were estimated for every region. These

Table 1. Renewable Water Resources and Water Availability by Continents

Continent	*Area $10^6 km^2$*	*Population (millions) (1994)*	*Water Resources, km^3/year*				*Potential water availability 1,000m^3/year*	
			Average	*Max.*	*Min.*	*c.v.*	*per 1 km^2*	*per capita*
Europe	10.46	685	2,900	3,410	2,254	0.08	277	4.23
North America	24.3	453	7,890	8,917	6,895	0.06	324	17.4
Africa	30.1	708	4,050	5,082	3,073	0.10	134	5.72
Asia	43.5	3,445	13,510	15,008	11,800	0.06	311	3.92
South America	17.9	315	12,030	14,350	10,320	0.07	672	38.2
Australia and Oceania	8.95	28.7	2,400	2,880	1,891	0.10	269	83.7
The World (rounded)	135	5,633	42,780	44,750	39,780	0.03	316	7.60

c.v. = coefficient of variation.

estimations took into account the trends in recent decades, available long-term plans to build large reservoirs in different countries and regions, and physiographic features of these areas.

Renewable Water Resources

Time and Space Variability

The mean value of renewable global water resources is estimated at 42,750 km^3 per year, and it varies greatly in space and time. Table 1 presents the distribution of water resources and water availability on the earth's continents. In terms of absolute value, the largest water resources are located in Asia and South America (respectively, 13,500 and 12,000 km^3 per year). The smallest volumes are typically found in Europe and Australia with Oceania (respectively, 2,900 and 2,400 km^3 per year). For individual years, the quantities of water resources can vary in the range of ±15-25 percent of their average values. Absolute values do not completely reflect the water availability of the continents, as they differ very much in area and especially in population. Water availability of the continents in cubic meters of water per km^2 and per person is presented in Table 2. Because of the rapid global population growth between 1970 and 1994, the potential water availability for the earth's population decreased from 12,900 to 7,600 m^3 per year per person. The greatest reduction in annual per capita water supply took place in Africa (by 2.8 times), Asia (by 2.0 times), and South America (by 1.7 times). Water supply in Europe decreased for that same period by only 16 percent.

Studies have shown that variations in the total river runoff on the continents and on earth as a whole are cyclical. As seen in Figure 2, the cycles of wet and dry years alternate, and deviations from average values differ considerably in duration and magnitude. For instance, the low-water periods (1940–1944, 1965–1968, 1977–1979) are clearly seen in the variations of the total runoff of the world rivers. During those periods, runoff values were 1,600 to 2,900 km^3 below their average values. However, the periods of 1926–1927, 1949–1952, and 1973–1975 had an appreciably increased river runoff. Along with clearly defined cyclic variations in the total runoff of world rivers, the unavailability of any detectable trends for the entire 65-year period is quite typical. This pertains to all of the continents, especially if the two most recent decades for Africa and South America are disregarded. During this period there is a clear trend of increasing river runoff in South America and decreasing runoff in Africa (Figure 2).

World river runoff is very unevenly distributed during a year in almost all regions of the world. About 45–55 percent of this runoff occurs during periods of flooding. Therefore, the values of renewable water resources on the continents vary noticeably during a year. According to recent estimates, the major part of river runoff in Europe occurs during April-July (46 percent), in Asia during June-October (54 percent), in Africa during September-December (44 percent), in South America during April-July (45 percent), and in Australia-Oceania during January-April (46 percent). On average, about 46 percent of the annual total global river runoff occurs between May and August.

The unevenness of river runoff distribution during a year leads to the necessity for human regulation through the creation of different types of reservoirs. Most important for water supply is the stable, basic runoff, which varies little during a year or year-to-year, and whose use is possible with no artificial regulation. It is approximately 37 percent of the total volume of global river runoff, or about 16,000 km^3 per year.

The temporal-spatial variations in renewable water resources need to be analyzed in more detail on the global scale. For this purpose, large natural-economic regions with homogeneous physiographic conditions and a similar economic development level were selected within every continent. A total of 26 regions were selected, between three to eight for each continent.

In the majority of cases, the regional boundaries coincided with administrative borders, and thus the regions included the entire territories of individual countries (from one to 15–17 countries). This was done because of the necessity of analyzing the quantities of water resources as well as the dynamics of population and water use. The data on these variables are published only by individual countries. One exception was the principal countries of the world: Russia, China, and the USA, whose individual parts were included into different natural-economic regions. Figure 1 shows a schematic map of the world with the boundaries and the numbers of the regions. The areas of selected regions vary widely, from 12–13 million km^2 (Siberia and the Russian Far East, Canada, and Alaska) to 0.19 million km^2 (Transcaucasia). However, most regions have areas of 1 to 8 million km^2.

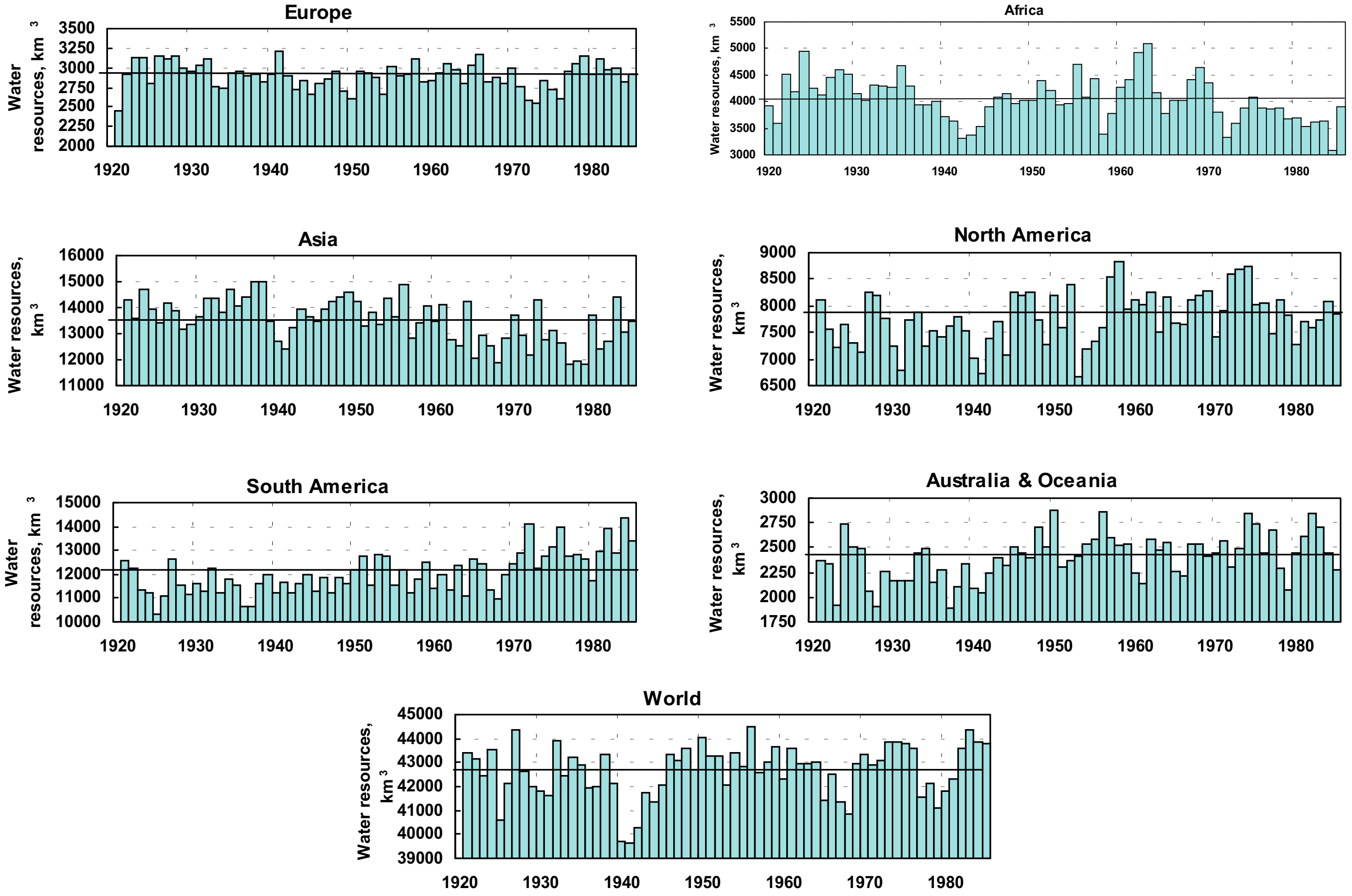
Figure 3 and Table 2 present the mean values of renewable water resources. They were obtained for every region from 1921–1985 as local water resources, originating in the territory of the region, and as the freshwater inflow from the neighboring territories. As seen in Figure 3, in most regions, basic water resources originate in the territory of the region, and the inflow from outside is insignificant. The exceptions are regions 3, 5, 10, 18, and 22, where the value of the inflow reaches 20–25 percent of the local water resources. In regions 9 and 24 (northern Africa and central South America), the inflow is comparable to the quantities of local water resources, or even exceeds them by several times.

Year-to-year variability of water resources of the natural-economic regions can be quite significant and considerably exceed average data for all the continents. This pertains especially to arid and semiarid regions, where the values of water resources themselves are small. There, in individual years their volumes can be 1.5 to 2.0 times less than the averages over a long period, whereas for wet

Table 2. Renewable Water Resources and Potential Water Availability by Natural - Economic Regions of the World

			Popula-tion per	*Water Resources, km^3/year*					*Potential water avail.(10^3m^3/yr)**	
No. of Region	*Continent, Region*	*Area 10^6 km^2*	*10^6 km^2 1994*	*Inflow*	*Avg.*	*Local Min.*	*Max.*	*c.v.*	*Per 1 km^3*	*Per Capita*
	Europe	**10.46**	**684.7**		**2,900**	**2,454**	**3,410**	**0.08**	**277**	**4.24**
1	Northern	1.32	23.2		705	567	829	0.08	534	30.4
2	Central	1.86	293	6	617	356	857	0.21	333	2.12
3	Southern	1.79	188	109	546	372	828	0.18	335	3.19
4	North of the European part of FSU	2.71	28.5	27	589	450	714	0.1	222	21.1
5	South of the European part of FSU	2.78	152	123	443	275	629	0.18	181	3.32
	North America	**24.3**	**453**		**7,890**	**6,895**	**8,917**	**0.06**	**325**	**17.4**
6	Canada and Alaska	13.67	29	130	4,980	4,360	5,830	0.06	369	174
7	USA	7.84	261	70	1,800	1,004	2,621	0.17	234	7.03
8	Central America and Caribbean	2.74	163	2.5	1,110	920	1,340	0.1	406	6.82
	Africa	**30.1**	**708**		**4,050**	**3,073**	**5,082**	**0.1**	**135**	**5.72**
9	Northern	8.78	157	140	41	19	96	.34	12.6	0.71
10	Southern	5.11	83.5	86	399	270	549	0.14	86.5	5.29
11	East	5.17	193.5	26	749	504	940	0.11	147	3.94
12	West	6.96	211.3	30	1,088	581	1,948	0.28	158	5.22
13	Central	4.08	62.8	80	1,770	1,453	2,263	0.09	444	28.8
	Asia	**43.5**	**3,445**		**13,510**	**11,800**	**15,000**	**0.06**	**311**	**3.92**
14	North China and Mongolia	8.29	482		1,029	587	1,735	0.23	124	2.13
15	Southern	4.49	1,214	300	1,988	1,535	2,458	0.1	476	1.76
16	Western	6.82	232		490	227	931	0.35	71.8	2.11
17	South East	6.95	1,404	120	6,646	5,342	7,607	0.09	965	4.78
18	Central Asia and Kazakhstan	3.99	54	46	181	121	265	0.17	51.1	3.78
19	Siberia and Far East of Russia	12.76	42	218	3,107	2,628	3,500	0.06	252	76.6
20	Transcaucasia	0.19	16	12.1	68	51.5	88.8	0.12	390	4.63
	South America	**17.9**	**314.5**		**12,030**	**10,320**	**14,350**	**0.07**	**672**	**38.3**
21	Northern	2.55	57.3		3,340	2,390	4,670	0.15	1,310	58.3
22	Eastern	8.51	159.1	1,900	6,220	5,200	7,640	0.08	843	45.1
23	Western	2.33	48.6		1,720	840	2,380	0.18	738	35.4
24	Central	4.46	49.4	720	750	531	1,310	0.17	249	22.5
	Australia and Oceania	**8.95**	**28.7**		**2,404**	**1,891**	**2,880**	**0.1**	**269**	**83.8**
25	Australia	7.68	17.9		352	228	701	0.24	45.8	19.7
26	Oceania	1.27	10.8		2,050	1,510	2,570	0.1	1,614	190
	The World (rounded)	**135**	**5,633**		**42,780**	**39,780**	**44,750**	**0.03**	**316**	**7.60**

*Potential water availability per km^2 is estimated by average local water resources, and per capita - by average local water resources plus a half inflow.



Europe

Africa

Asia

North America

South America

Australia & Oceania

World

Figure 2. Renewable water resources (km^3/year) of the world and the continents.

regions, this difference is within 15 to 25 percent.

The possibilities of using water resources for economic needs are determined not only by their year-to-year variability, but also by seasonal and monthly variability. Many regions are characterized by an extremely uneven river runoff distribution, when during the three to four month flooding season, 60 to 80 percent of annual runoff occurs. For example, 64 percent of annual runoff occurs during the three months of flooding in the north and south of the European part of the former Soviet Union. Similarly, in the central part of North America and in southern Asia, flood runoff equals 57 percent, in Siberia and the Far East 59 percent, in Australia 68 percent, and in Western Africa 80 percent.

At the same time, during low-flow periods, lasting three to four months in some regions, the river runoff amounts to only 2 to 10 percent of annual runoff. For example, for the three low-flow months, river runoff is 8 to 9 percent of annual runoff in the north of the European territory of the Former Soviet Union, Canada and Alaska, and North China and Mongolia. It is 6 to 7 percent in Central America, 4 to 5 percent in Siberia, the Far East, and Southern Asia, and as much as 0.8 percent in Western Africa.

In addition to the natural-economic regions, an estimation of renewable water resources was made for 60 countries. The selected countries include developed and developing countries on all of the continents, as well as countries with transitional economies, and the largest and smallest in area and population. Also included are southern countries with water resources deficits and surpluses. The countries included in the analysis contain the sources of 71 percent of global water resources and about 70 percent of the earth's population. Table 3 shows the values of renewable water resources of these selected countries.

The greatest renewable water resources are concentrated in six principal countries of the world: Brazil, Russia, Canada, the USA, China, and India. The origins of more than 40 percent of total annual river runoff are in these countries. An assessment of renewable water resources for countries, regions, and the continents is based on the runoff of river basins calculated by observation data from the hydrological network.

Information is available on water resources of all the world's principal rivers. The greatest river of the world, the Amazon, contributes 16 percent of annual global river runoff. Twenty-seven percent of world water resources are formed by the five largest river systems: Amazon,

Table 3. Renewable Water Resources and Potential Water Availability by Selected Countries of the World

Countries	*Area in 10^6 km²*	*Population in millions*	*Water Resources km³/year*								*Potential Water Availability (in 10^3m³/year)*	
			Inflow				*Local*					
		1995	*Average*	*Max.*	*Min.*	*c.v.*	*Average*	*Max.*	*Min.*	*C.V.*	*Per km²*	*Per capita*
Albania	0.03	3.60	5.30	10.0	3.30	0.20	19.1	34.3	11.9	0.20	637	6.04
Argentina	2.78	34.2	623	1,410	343	0.27	270	610	149	0.27	97.1	17.0
Armenia	0.03	3.55	2.06	3.50	0.68	0.29	6.58	9.21	4.60	0.13	219	2.14
Australia	7.68	17.9	0	0	0	0	352	701	228	0.24	45.8	19.7
Azerbaijan	0.09	7.47	20.4	32.4	12.4	0.19	7.56	12.6	5.13	0.17	84.0	2.38
Belarus	0.21	10.3	22.4	34.2	13.2	0.22	34.8	58.8	20.4	0.23	166	436
Bolivia	1.10	7.20	155	209	120	0.13	361	487	279	0.13	328	60.9
Brazil	8.51	159	1,900	2,350	1,600	0.08	6,220	7,640	5,200	0.08	730	45.2
Canada	9.98	28.0	130	166	99.4	0.12	3,287	3,760	2,910	0.06	329	120
Chad	1.28	6.18	36.6	59.2	3.70	0.31	10.4	13.2	7.1	0.13	8.12	4.64
Chile	0.76	14.0	0	0	0	0	354	515	266	0.13	466	25.3
China	9.60	1,209	0	0	0	0	2,701	3,455	2,015	0.12	281	2.23
Colombia	1.14	34.3	0	0	0	0	1,200	1,436	1,049	0.06	1,053	35.0
Costa Rica	0.05	3.42	0	0	0	0	110	158	75.0	0.16	2,200	32.1
Cuba	0.11	11.1	0	0	0	0	34.7	48.5	24.2	0.16	315	3.11
Ecuador	0.28	11.2	0	0	0	0	265	324	197	0.07	946	23.7
El Salvador	0.02	5.2	0	0	0	0	18.9	27.4	10.2	0.16	945	3.65
Estonia	0.05	1.54	5.01	13.9	2.20	0.33	11.7	22.2	6.2	0.28	234	9.22
France	0.55	56.8	26.8	38.6	11.9	0.23	168	232	78.1	0.23	305	3.19
Gabon	0.27	1.28	15.6	21.0	10.3	0.15	205	272	133	0.15	759	166
Gambia	0.01	1.08	6.70	9.62	2.10	0.28	3.97	5.69	1.24	0.28	397	6.78
Georgia	0.07	5.45	9.56	14.4	5.85	0.17	51.1	66.3	38.5	0.13	730	10.2
Honduras	0.11	5.49	0	0	0	0	93	128	66.2	0.14	845	17.3
India	3.27	919	581	697	508	0.03	1,456	1,794	1,065	0.11	445	1.90
Jamaica	0.01	2.43	0	0	0	0	8.20	16.0	3.88	0.29	820	3.42
Kazakhstan	2.72	16.7	55.9	97.0	29.7	0.29	68.4	111	38.0	0.28	25.1	5.77
Kyrgizstan	0.20	4.67	0	0	0	0	48.9	71.6	37.3	0.15	245	10.5
Latvia	0.06	2.58	17.4	27.8	10.3	0.24	15.9	27.0	8.90	0.27	265	9.53
Lithuania	0.07	3.72	10.4	16.1	7.10	0.17	13.5	21.9	7.90	0.24	193	5.03
Mali	1.24	10.5	54.8	81.5	21.8	0.27	39.6	62.2	18.4	0.32	31.9	6.38
Mexico	1.97	94.8	2.51	5.20	0.30	0.38	345	476	236	0.12	175	3.67
Moldova	0.03	4.43	11.9	21.4	5.46	0.30	1.20	3.59	0.19	0.65	40.0	1.61
Nicaragua	0.13	4.50	0	0	0	0	176	226	134	0.13	1,354	39.1
Niger	1.27	8.85	32.1	47.2	13.7	0.24	2.33	5.40	0.28	0.43	1.83	2.08
Nigeria	0.92	108	43.7	69.4	23.4	0.26	275	437	148	0.26	299	2.75
New Zealand	0.27	3.50	0	0	0	0	313	405	246	0.11	1,159	89.4
Panama	0.08	2.60	0	0	0	0	144	196	98.0	0.17	1,800	55.4
Peru	1.28	23.3	144	204	119	0.09	1,100	1,526	911	0.09	859	50.3
Portugal	0.09	9.93	34.1	101	10	0.55	18.9	56.0	5.00	0.55	210	3.62
Russia	17.08	148	222	330	144	0.17	4,053	4,513	3,533	0.05	237	28.1
Senegal	0.20	8.1	14.9	21.9	5.27	0.30	21.4	31.1	6.31	0.28	107	3.56
Spain	0.51	39.6	0	0	0	0	109	256	27.7	0.48	214	2.75
Sudan	2.51	27.4	132	194	88.7	0.14	34.6	65.3	9.74	0.31	13.8	3.67
Tadjikistan	0.15	5.93	46.9	70.4	30.7	0.16	47.2	69.7	30.4	0.15	315	11.9
Turkmenistan	0.49	4.01	69.6	112	43.1	0.17	1.07	1.66	0.20	0.26	2.18	8.94
Ukraine	0.60	51.4	159	233	91.8	0.17	51.2	91.9	25.6	0.30	85.3	2.54
Uruguay	0.18	3.20	74.1	150	25.0	0.38	68.1	201	10.3	0.50	378	32.9
USA	9.36	262	148	178	107	0.13	2,930	3,864	2,058	0.11	313	11.5
Uzbekistan	0.45	20.3	94.8	142	66.1	0.15	9.52	19.7	4.98	0.25	21.2	2.80
Zaire	2.34	42.6	313	420	248	0.10	989	1,328	786	0.10	423	26.9

*Potential water availability per km² is estimated by average local water resources, and per capita - by average local water resources plus a half inflow.

Ganges with Brahmaputra, Congo, Yangtze, and Orinoko. Rivers with an average long-term runoff volume above 100 km³ comprise 46 percent of the world's renewable water resources.

Inflow to the World's Oceans

Using river runoff data from the global hydrological network, it was possible to assess the freshwater inflow to the world's oceans. This inflow is very important to

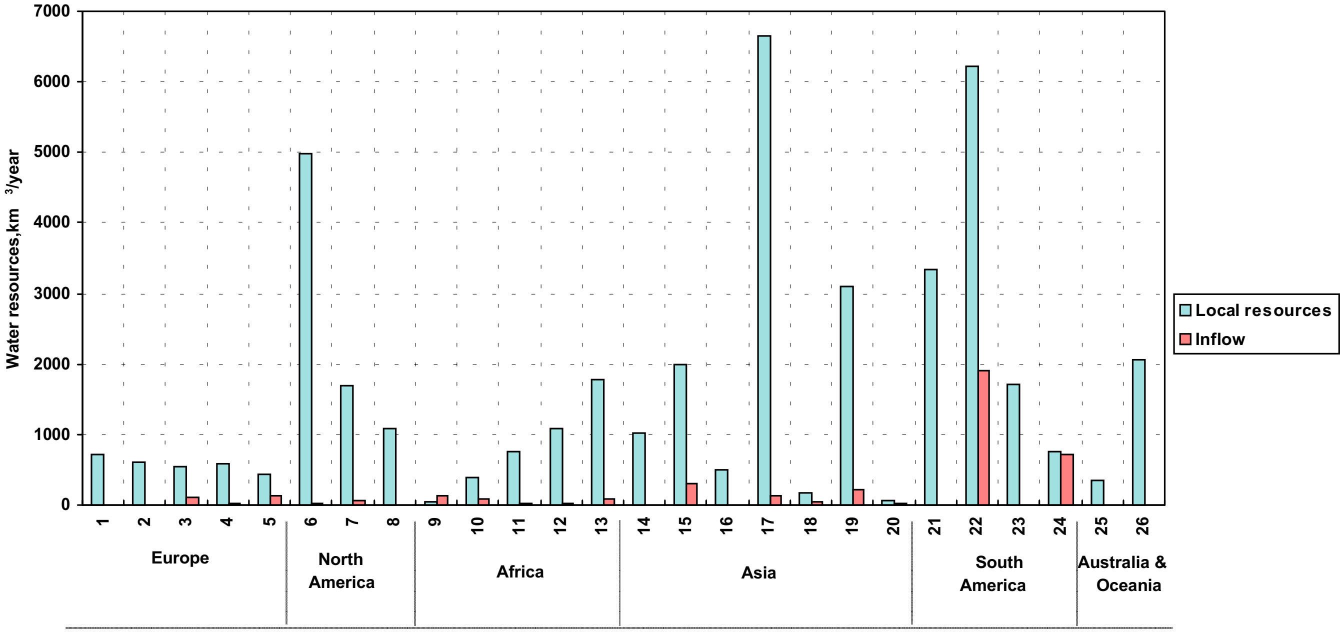


Figure 3. Renewable water resources by natural-economic region of the world: 1 - North; 2 - Central; 3 - South; 4 - North part of ETS SU; 5 - South part of ETS SU; 6 - North; 7 - Central; 8 - South; 9 - North; 10 - South; 11 - East; 12 - West; 13 - Central; 14 - North China; 15 - Mongolia; 15 - South Asia; 16 - West Asia; 17 - Southeast Asia; 18 - Middle Asia; 19 - Siberia, Far East of Russia; 20 - Caucasus; 21 - North; 22 - East; 23 - West; 24 - Central; 25 - Australia; 26 - Oceania.

Table 4. Dynamics of Water Use in the World by Continents (km³/year)

	Assessment								*Forecast*		
Continent	*1900*	*1940*	*1950*	*1960*	*1970*	*1980*	*1990*	*1995*	*2000*	*2010*	*2025*
Europe	37.5	96.1	136	226	325	449	482	455	463	535	559
	13.8	38.1	50.5	88.9	122	177	198	189	197	234	256
North America	69.6	221	287	410	555	676	653	686	705	744	786
	29.2	83.8	104	138	181	221	221	237	243	255	269
Africa	40.7	49.2	55.8	89.2	123	166	203	219	235	275	337
	27.5	32.9	37.8	61.3	87.0	124	150	160	170	191	220
Asia	414	682	843	1,163	1,417	1,742	2,114	2,231	2,357	2,628	3,254
	249	437	540	751	890	1,084	1,315	1,381	1,458	1,593	1,876
South America	15.1	32.6	49.3	65.6	87.0	117	152	167	182	213	260
	10.8	22.3	31.7	39.6	51.1	66.7	81.9	89.4	96.0	106	120
Australia and Oceania	1.60	6.83	10.4	14.5	19.9	23.5	28.5	30.4	32.5	35.7	39.5
	0.58	3.30	5.04	7.16	10.3	12.7	16.4	17.5	18.7	20.4	22.3
Total (rounded)	579	1,088	1,382	1,968	2,526	3,175	3,633	3,788	3,973	4,431	5,235
	331	617	768	1,086	1,341	1,686	1,982	2,074	2,182	2,399	2,764

Remarks: First line - water withdrawal, second - water consumption.

the study of freshwater balance and dynamic processes. It is worth mentioning that the freshwater inflow to the world's oceans cannot simply be equated to global river runoff for two reasons.

First, river watersheds of the endorheic (drainless) runoff regions are not connected to the world's oceans. The total area of endorheic runoff regions is about 30 million km² (20 percent of the total land area). However, only 2.3 percent (about 1,000 km³/year) of annual global river runoff orginate in these regions. This is because most of the territory of drainless regions is deserts and semideserts with very low precipitation. The largest drainless regions include the Caspian Sea basin in the territory of Europe and Asia, the greater part of Central Asia, Northeastern China, and Australia, as well as the Arabian Peninsula, and North Africa. Small drainless regions also occur in other regions, including North and South America.

Second, in the regions of exorheic drainage directly connected to the world's oceans, estimates of water resources of the river basins do not always coincide with runoff estimates at the river mouth. This especially pertains to the regions in hot climates. There, basin water resources originate in mountainous areas with large amounts of precipitation. As it moves towards the mouth, runoff is lost through evaporation in the plains and lowland parts of the basin. The Ganges and Indus in Asia, Niger and Zambezi in Africa, and Mississippi and Colorado in North America are examples of this type of river basin. In exorheic regions, about 1,100 km^3 of runoff per year are lost to evaporation and do not reach river mouths. Of this amount, 380 km^3 is lost in Asia, 300 km^3 in Africa, and 340 km^3 in North America.

Thus, the total river water inflow to the world's oceans will be somewhat less than the value of renewable water resources of the earth's continents. The values of an average long-term river water inflow to the oceans for 1921–1985 are shown in Figure 4.

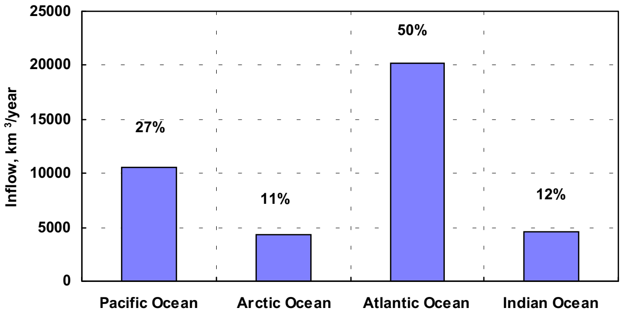


Figure 4. River water inflow to the world's oceans.

Approximately half the total river water inflow to the world's oceans falls on the Atlantic Ocean, which received the waters of four of the six largest rivers of the world (Amazon, Congo, Orinoko, and Parana). The smallest amount of river water inflows are to the Arctic Ocean (5,000 km^3 per year). However, river waters are of the greatest importance to the regime of this ocean because the Arctic Ocean contains as much as 1.2 percent of the total water storage in the world's oceans, while it receives 11 percent of global river runoff.

To simulate the dynamic processes in the oceans, it is very important to take into account not only the volume of river water inflow, but also its distribution over the world's oceans. River runoff enters the world's oceans very unevenly. The data presented in Figure 5 demonstrates this very clearly; it presents the distribution of inflow to the world's oceans by latitudinal zones. On the average, about 42 percent of total river runoff enters the ocean in the equatorial region between 10°N and 10°S. This observation data for individual years or seasons obtained from the global hydrological network is of great interest to oceanologists, who develop water circulation models for the ocean.

The Dynamics of Water Use in the World

Table 4 and Figure 6 show the dynamics of water use by continent for the current century and for the future until 2025, obtained on the basis of the above initial data and methodological approaches. Current (1995) global total water withdrawal comprises about 3,790 km^3/year, consumption 2,070 km^3/year (61 percent of withdrawal). In the future the total water withdrawal will grow by about 10-12 percent for every 10 years, and by 2025, it will reach approximately 5,240 km^3/year (a 1.38-fold increase). Water consumption will increase somewhat slower, by 1.33 times. At the present time, about 57 percent of total water withdrawal and 70 percent of global water consumption occurs in Asia, where the major irrigated lands of the world are located. During the next decades, the most intensive growth in water withdrawal is expected to occur in Africa and South America (by 1.5-1.6 times), the smallest in Europe and North America (1.2 times).

Table 5 and Figure 7 show the role of individual water uses in the dynamics of global total water withdrawal and consumption. At the present time, agriculture receives 66 percent of total water withdrawal and 85 percent of consumption in the world. In the future, the role of agriculture will slightly decrease relative to other uses, due to the expected intensive growth of other water uses, primarily industrial and public water withdrawal. By 2025, agriculture is expected to increase its requirements for water withdrawal by 1.3 times, industry by 1.5 times, and the

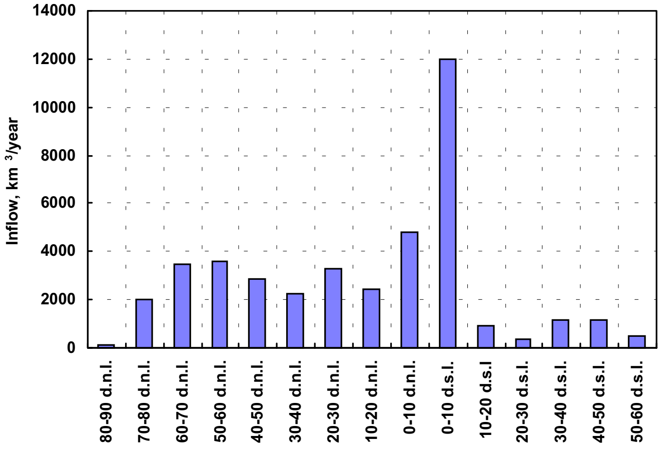


Figure 5. River water inflow to the world's ocean by latitudinal zones.

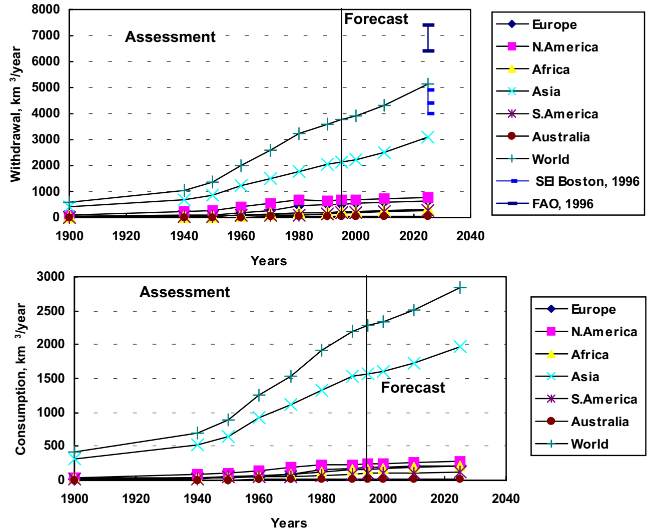


Figure 6. The dynamics of water withdrawal and water consumption in the world by the continents.

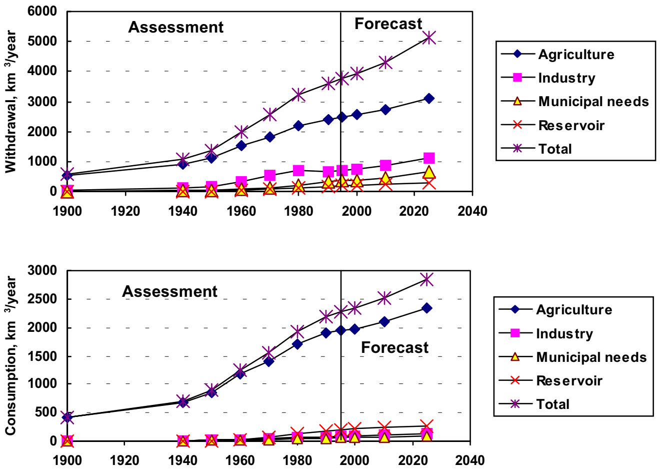


Figure 7. Dynamics of total water withdrawal and water consumption in the world over the kinds of economic activities.

public supply by 1.8 times. In addition, evaporation from reservoirs greatly contributes to water losses. These are greater than the total water consumption of industry and public water supply combined.

The global irrigation area in 1995 was 253 million ha. By 2010 it is expected to grow up to about 290 million ha, and by 2025 to 330 million ha.

The above prediction estimates refer to moderate climatic conditions (without taking into account possible anthropogenic changes in global climate) and to the most realistic scenarios of a developing world economy. Taking account of uncertainties in the developing economy, population growth, and climatic situation, by 2025 the total water withdrawal is expected to be within the range of 10–12 percent of the above average value, i.e., 4,600–5,800 km^3/yr.

The dynamics of water withdrawal by natural-economic regions of the world is shown in Table 6. The quantities of water withdrawals are very unevenly distributed by the regions of the continents and do not coincide with the availability of water resources. For instance, in Europe 95 percent of water withdrawal occurs in the southern and central parts of the continent; in North America, the USA uses 73 percent of total water withdrawals; in Australia and Oceania, 89 percent of total water withdrawals occur in Australia. On the Asian continent, the greatest volume of water is withdrawn from Southern Asian regions, including India, Pakistan, Bangladesh, and Southeastern Asia, with the greatest part attributed to irrigated areas in China. In Africa, the greatest water withdrawal takes place in the northern part (North Africa); 50 percent of water withdrawal on the continent occurs in this

Table 5. Dynamics of Water Use in the World by Sector of Economic Activity (km^3/year)

	Assessment								*Forecast*		
Sector	*1990*	*1940*	*1950*	*1960*	*1970*	*1980*	*1990*	*1995*	*2000*	*2010*	*2025*
Population (million)			2,542	3,029	3,603	4,410	5,285	5,735	6,181	7,113	7,877
Irrigated Land Use 10^6 ha)	47.3	75.9	101	142	169	198	243	253	264	288	329
Agricultural Use	513 321	895 586	1,080 722	1,481 1,005	1,743 1,186	2,112 1,445	2,425 1,691	2,504 1,753	2,605 1,834	2,817 1,987	3,189 2,252
Municipal Use	21.5 4.61	58.9 12.5	86.7 16.7	118 20.6	160 28.5	219 38.3	305 45.0	344 49.8	384 52.8	472 60.8	607 74.1
Industrial Use	43.7 4.81	127 11.9	204 19.1	339 30.6	547 51.0	713 70.9	735 78.8	752 82.6	776 87.9	908 117	1,170 169
Reservoirs	0.30	7.00	11.1	30.2	76.1	131	167	188	208	235	269
Total (rounded)	579 331	1,088 617	1,382 768	1,968 1,086	2,526 1,341	3,175 1,686	3,633 1,982	3,788 2,074	3,973 2,182	4,431 2,399	5,235 2,764

Remarks: First line - water withdrawal, second - water consumption.

Table 6. Dynamics of Water Withdrawal by Continents and Natural-economic Regions of the World (km^3/year)

Number of Region	*Continent, Region*	*Assessment*								*Forecast*		
		1900	*1940*	*1950*	*1960*	*1970*	*1980*	*1990*	*1995*	*2000*	*2010*	*2025*
	Europe	**37.5**	**96.1**	**136**	**226**	**325**	**449**	**482**	**455**	**463**	**535**	**559**
1	Northern	1.40	2.80	3.80	7.30	9.80	10.3	10.3	11.0	11.7	12.7	13.4
2	Western and Central	12.8	33.7	51.5	87.2	120	142	146	154	161	172	176
3	Southern	16.1	40.2	60.0	95.3	120	157	177	186	194	204	204
4	North of the European part of FSU	0.30	0.75	0.89	1.76	3.13	9.80	13.4	10.8	10.5	14.1	16.8
5	South of the European part of FSU	6.90	18.6	20.2	34.4	71.5	130	135	94.5	85.4	133	149
	North America	**69.6**	**221**	**287**	**410**	**555**	**676**	**653**	**686**	**705**	**744**	**786**
6	Northern	2.60	8.80	13.2	19.2	26.1	41.4	52.2	55.8	58.4	64.9	73.7
7	Central	54.2	191	248	347	470	538	492	503	512	530	549
8	Southern	12.8	20.9	25.5	44.1	59.4	97.5	109	127	135	149	163
	Africa	**40.7**	**49.2**	**55.8**	**89.2**	**123**	**166**	**203**	**219**	**235**	**275**	**337**
9	Northern	36.6	41.0	43.0	68.3	84.8	98.7	106	110	114	127	145
10	Southern	1.90	4.41	6.50	9.38	14.7	21.8	25.5	27.3	29.2	34.4	44.8
11	East	1.04	2.10	3.70	7.20	13.6	25.3	46.6	52.6	58.5	71.2	85.7
12	West	1.00	1.50	2.30	3.93	8.74	18.4	23.2	26.5	29.8	37.5	52.4
13	Central	0.10	0.20	0.30	0.40	0.82	1.64	2.07	2.60	3.14	4.90	9.21
	Asia	**414**	**682**	**843**	**1,163**	**1,417**	**1,742**	**2,114**	**2,231**	**2,357**	**2,628**	**3,254**
14	North China and Mongolia	37.0	66.0	93.0	153	186	215	241	268	295	319	372
15	Southern	201	312	366	426	523	667	850	887	925	1,025	1,339
16	Western	42.8	68.0	90.0	133	157	183	232	249	267	299	356
17	South East	99.0	165	220	357	419	478	572	631	683	760	949
18	Central Asia and Kazakhstan	28.7	55.0	57.2	67.4	94.4	151	170	154	147	174	182
19	Siberia and Far East of Russia	0.61	4.90	5.62	10.4	16.3	25.4	26.5	21.0	20.6	27.2	30.4
20	Transcaucasia	5.20	11.3	11.4	15.8	20.7	22.9	23.7	20.4	19.4	24.5	26.4
	South America	**15.1**	**32.6**	**49.3**	**65.6**	**87.0**	**117**	**152**	**167**	**182**	**213**	**260**
21	Northern	1.70	4.20	6.40	9.12	13.0	17.4	22.0	24.1	26.3	30.9	38.3
22	Eastern	0.99	2.04	2.88	7.34	13.6	25.2	43.0	49.0	54.6	68.8	87.6
23	Western	8.80	19.9	26.7	29.4	33.1	38.8	45.1	48.0	50.8	55.9	65.0
24	Central	3.60	6.41	13.32	19.79	27.4	36.1	42.2	46.1	49.9	57.6	69.2
	Australia and Oceania	**1.60**	**6.83**	**10.4**	**14.5**	**19.9**	**23.5**	**28.5**	**30.4**	**32.5**	**35.7**	**39.5**
25	Australia	1.59	6.60	10.0	13.8	18.9	21.6	25.5	27.1	28.9	31.7	35.0
26	Oceania	0.01	0.23	0.37	0.69	1.04	1.93	2.98	3.29	3.60	4.02	4.49

region. In South America, water withdrawal is more or less evenly distributed. The dynamics of water use growth until 2025 considerably differs by regions. In developed countries and in countries with limited water resources, water withdrawal is expected to rise by 15-35 percent. In regions with developing countries with sufficient water resources, water withdrawal growth may reach 50 to 200 percent.

Water Resources and Water Withdrawals

Of particular interest is a comparison of water withdrawals with renewable surface water resources. The relevant data for 26 regions of the world for 1950, 1995, and 2025 are presented in Figure 8. The percentages shown are based on a comparison between the total water withdrawal and the annual volumes of local water resources, plus half of the inflow from outside of each region. Thus, it is assumed that every region can have at its disposal half of the fresh water inflow from neighboring regions. According to the data presented in Figure 8, the current total water withdrawals in the world is not great, amounting to 8.4 percent of global water resources. By 2025, the withdrawals are expected to increase up to 12.2 percent. However, water resources in the world are distributed very unevenly, which can be seen by comparing the global average to the water withdrawal and river runoff within individual continents. In Europe and Asia, the current water withdrawal comprises 15–17 percent of water resources, and in the future it will reach 21–23 percent. At the same time, in South America and Oceania, only 1.2–1.3 percent of river runoff is used, and even in the future it is unlikely that this value will be above 1.6–2.1 percent.

The distribution of river runoff and water use is especially uneven in the natural-economic regions of the world. Within every continent (except for South America), there

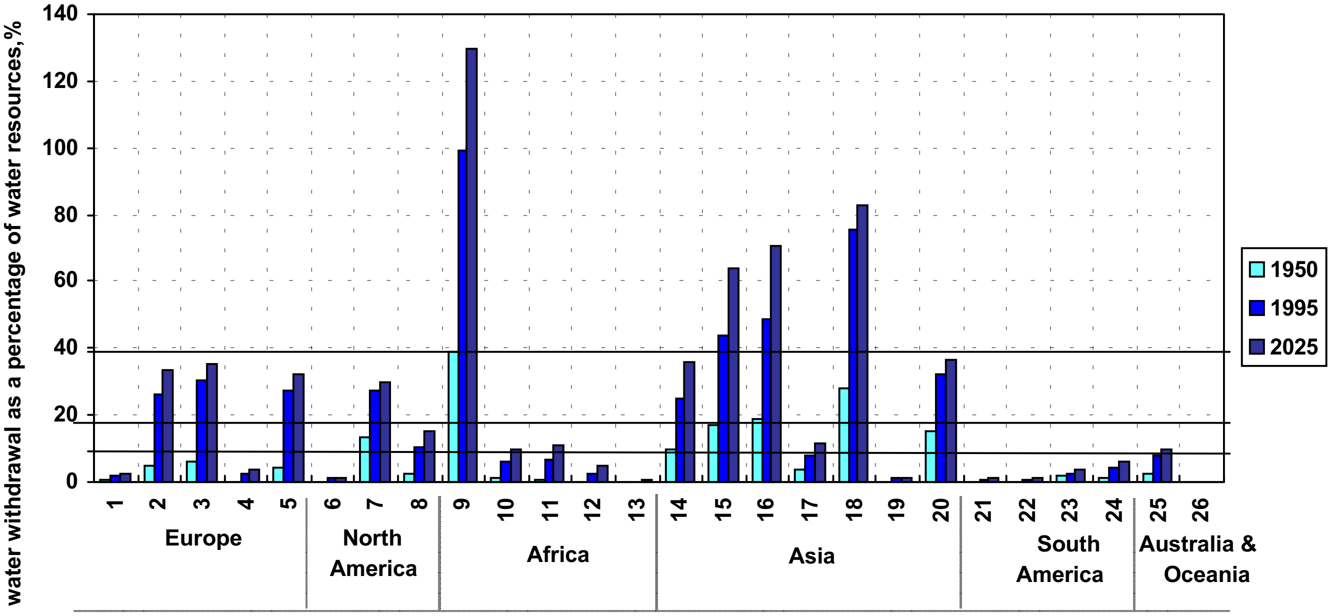


Figure 8. Water withdrawal by the natural-economic regions in percentage of water resources for 1950, 1995, and 2025 years: 1 - North; 2 - Central; 3 - South; 4 - North part of ETS SU; 5 - South part of ETS SU; 6 - North; 7 - Central; 8 - South; 9 - North; 10 - South; 11 - East; 12 - West; 13 - Central; 14 - North China; 15 - Mongolia; 15 - South Asia; 16 - West Asia; 17 - Southeast Asia; 18 - Middle Asia; 19 - Siberia, Far

are regions with large water use and regions with an insignificant water use (especially water consumption), as compared to water resources (see Figure 8). For instance, in Southern and Central parts of Europe, current water withdrawals already amount to as much as 24–30 percent of available water resources. At the same time, in the northern part of the continent these values do not exceed 1.5–3.0 percent. In the northern part of North America, water withdrawal is below 1.0 percent of water resources, and for the US as a whole, this value is 28 percent. Even greater contrast can be found in Africa and Asia. In the northern part of Africa, even the presently available renewable water resources are almost totally withdrawn (water withdrawal is 95 percent of water resources). In other regions (especially in Central Africa), water withdrawal is negligibly small as compared with the volume of water resources. In Asia, including the regions of Southern, Western, and Central Asia and Kazakhstan, the use of water resources is very great (42-84 percent). At the same time in the region of Siberia and the Far East, this use does not exceed one percent. Only in South America, of all regions, the use of water is insignificant and does not exceed two to four percent of available resources.

By 2025, the uneven distribution of water resources and water use will be preserved and may even increase. At the present time in many regions, the use of water resources is already significant. In the future, this use will grow further and will reach critical values. By contrast, in northern regions and in regions with excessive moisture on all continents, water use (especially water consumption) will continue to represent a very insignificant part of water resources.

The extent of use of water resources has also been assessed for individual countries in terms of the ratio of water withdrawal (for 1995) to water resources (local water resources plus half of the inflow). The results show in many countries, not only are all local water resources used, but also a greater part of freshwater inflow from neighboring territories. According to these estimates, about 75 percent of the earth's population lives in countries and regions with a present extent of water resources use of more than 20 percent. By 2025, the situation will deteriorate even more, especially in developing countries on all continents. By that time, 80 percent of the earth's population is expected to live under conditions of high and very high loads on water resources. One third of the earth's population will exert a load on water resources of more than 60 percent, which can be classified as catastrophically high.

Water Availability and Water Resources Deficit

The distribution of water over the earth is uneven. Also, available water resources do not coincide with population spread and economic development. These disparities are clearly revealed by analyzing and comparing the specific water availability for a single period of time for different regions and countries. The specific water availability represents the value of actual per capita renewable water resources.

For all three benchmark years, water availability is determined by dividing water resources without water consumption by the population. In this case, water resources are assumed to be the river runoff formed in the

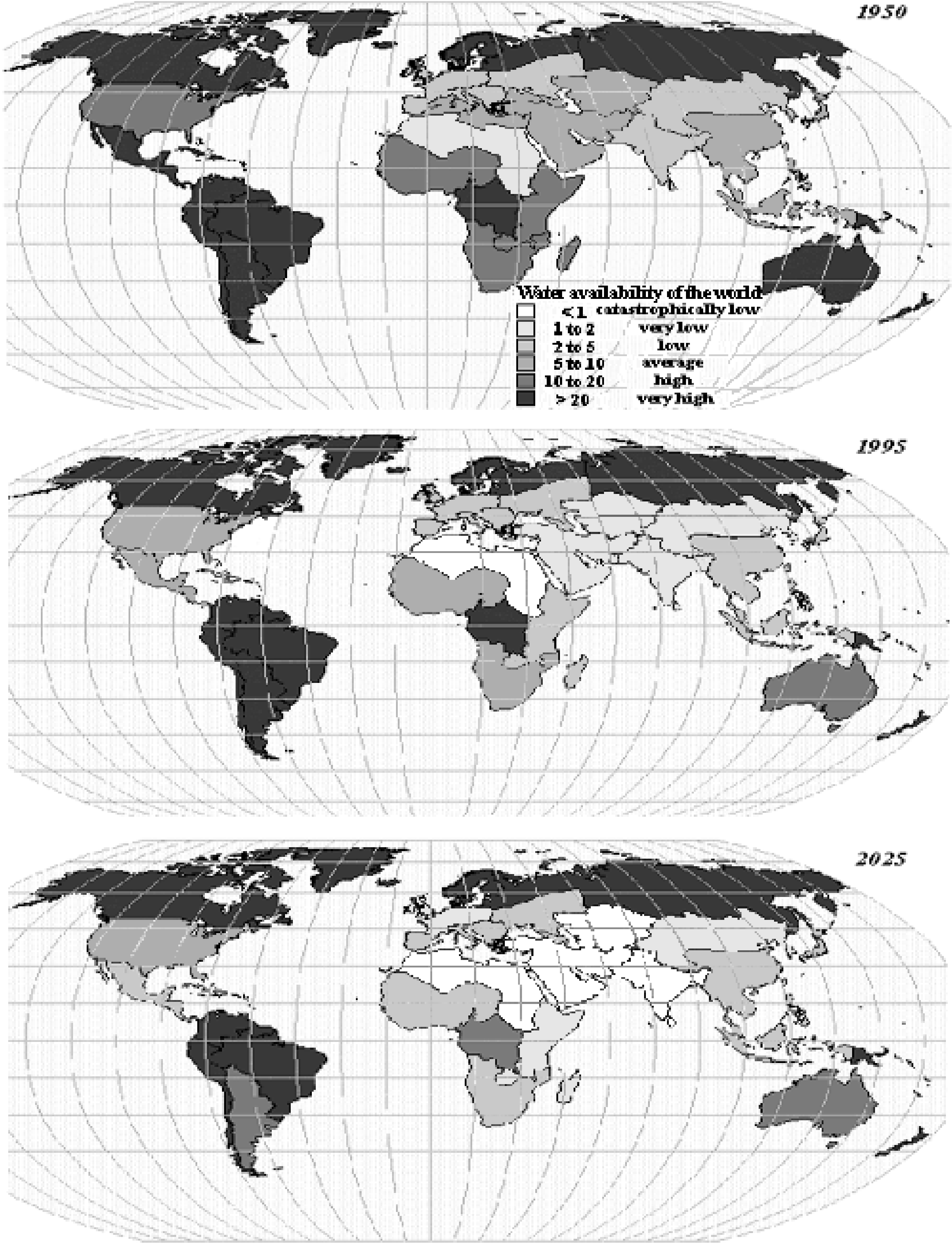


Figure 9. Water availability of the world by natural-economic regions.

territory of a given region plus half of the river water inflow from outside. Thus, the specific water availability includes the residual (after use) per capita quantity of fresh water. Obviously, as population and water consumption grow, the value of water availability decreases.

The values of water availability were obtained for all natural-economic regions and selected countries for the 1950–2025 period. As expected, the estimates reveal a strong unevenness in the distribution of water over the earth. For instance, the greatest water availability of 170,000–180,000 m^3 per capita per year can be found in the regions of Canada and Alaska and in Oceania. At the same time, in densely populated regions of Asia, Central and Southern Europe, and Africa, the current water availability is within 1,200–5,000 m^3 per year. In the north of Africa and on the Arabian Peninsula, it is as little as 200–300 m^3 per year. It is worth mentioning that water availability of less than 2,000 m^3 per year per capita is considered to be very low, and less than 1,000 m^3 per year, catastrophically low (Shiklomanov, 1997). With these values of water availability, very serious problems arise unavoidably with population life-support and industry and agriculture development.

Figure 9 shows the distribution of water availability values by natural-economic regions of the world, for 1950, 1995, and 2025. In 1950 (Figure 9), over major parts of the earth's surface, water availability was average or above average, and only in North Africa it was very low. In Central and Southern Europe, North China, and South Asia it was low (from 2,100 to 5,000 m^3 per year). No regions of the world showed catastrophically low water availability.

By 1995, the situation had drastically changed. In many regions of the world (Figure 9), water supply sharply decreased and became "catastrophically low" in North Africa and on the Arabian Peninsula and "very low" in North China and Southern and Western Asia. In seven other regions, a low water availability (2,100 to 5,000 m^3 per year) was recorded. At the present time, for 76 percent of the population, water availability is less than 5,000 m^3 per year per capita (by the accepted gradation low, very low, and catastrophic water availability) and 35 percent of the earth's population has very low or catastrophically low water availability.

The situation will likely deteriorate in the beginning of this century (Figure 9). By 2025, the greater part of earth's population will likely live under conditions of low and catastrophically low water supply. Approximately 30-35 percent of the world population will have catastrophically low fresh water supply (less than 1,000 m^3 per year per capita). At the same time, for all three benchmark years, high water availability can be found in Northern Europe, Canada and Alaska, almost all of South America, Central Africa, Siberia, the Far East, and Oceania.

The prediction of future water resources deficits throughout the world is dependent on analysis of the tendencies and rates of change in specific water availability as a result of socio-economic and physiographic conditions. Such analysis of the data obtained for natural-economic regions of the world showed that the rates of water availability depended on two factors: socio-economic development of the countries included into the region and climatic conditions of the region. The graphs presented in Figure 10 convincingly confirm this. They show the dynamics of specific water availability from 1950 to 2025 in relative units (as compared with 1950) averaged for the three groups of regions including industrially developed countries, developing countries under the conditions of sufficient and excessive moisture, and developing countries in arid and semiarid countries.

As can be seen in Figure 10, a reduction of specific water availability is relatively low for the regions that include industrially developed countries. It does not depend on climatic conditions and water resources storage amounting, on the average, to 1.7 times for the period under consideration. The relative water availability drastically decreases for the regions including mainly developing countries. They are, on the average, 4.5 times lower for the conditions with sufficient and excessive moisture and 7.5 times lower for arid conditions with insufficient moisture. Thus, a very large natural unevenness of the distribution of water over the earth will intensify with time due to humankind's activities and population growth.

An analogous situation is clearly seen when analyzing water availability of the selected countries of the world. The analysis of the country-level data confirms the tendencies of long-term variability in water availability. The industrially developed countries located in different moisture conditions have relatively small rates of decrease in water availability. At the same time, the developing countries have a very low water availability and very high rates of decrease due to rapid population growth and increasing water consumption. These conditions pertain primarily to developing countries with insufficient rainfall. Many of these countries will have a critically low fresh water supply in the decades to come.

It should be noted again that the above assessments for the future are based on a stable climatic situation. They do not take into account the possible anthropogenic global climate change caused by the increasing of greenhouse gases in the atmosphere. Consideration of global warming processes can be especially important for water availability assessment in regions of insufficient rainfall, where the hydrological characteristics are very sensitive to seemingly insignificant climate changes (Shiklomanov and Lins, 1991).

Methods of Eliminating Fresh Water Deficit in the World

As shown in Figures 9 and 10, even at the present time, significant fresh water deficits occur in many countries and regions of the world, especially during dry years,

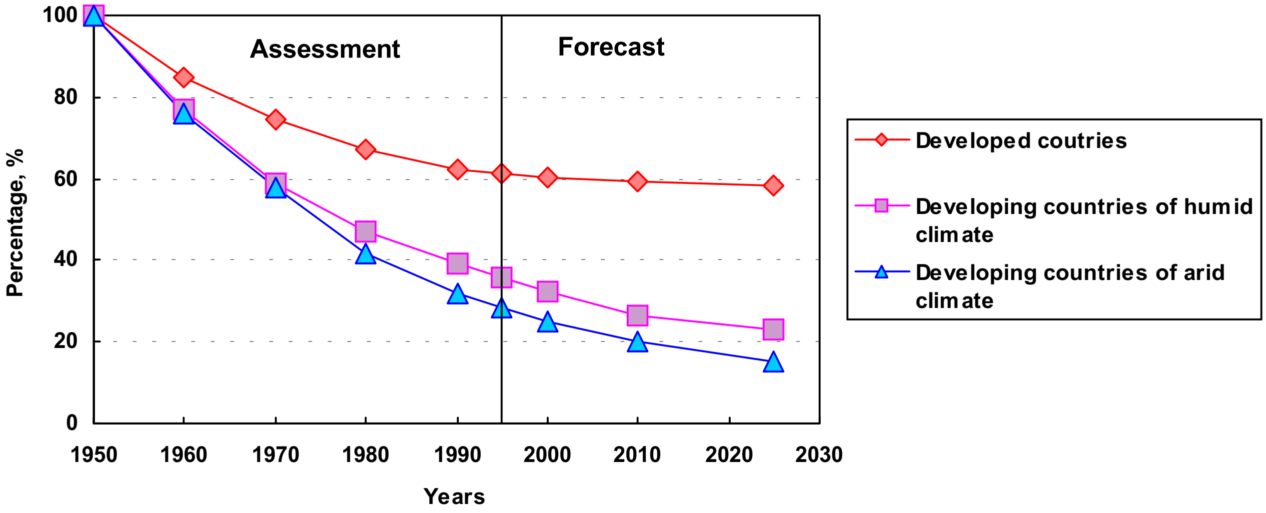


Figure 10. Dynamics of specific water availability by natural-economical region sof the world in percent, 1950–2025.

because of the extremely uneven natural distribution of water in space and time, intensification of humankind's activities, and rapid population growth. Future projections show that in the decades to come, the majority of the earth's population in dozens of countries will face a critical water supply situation. Water resources deficit becomes a factor that contributes to the deterioration of living standards and the delay in the economic and social development in most developing countries of the world. It is already clear that in the first half of the 21st century the water problem rank high, even among such global problems as food and power production. The critical situation with water supply will require enormous financial and material expenses for elaboration and realization of the measures to eliminate the deficit of pure fresh water in different physiographic conditions.

At the present time and in the foreseeable future, the most realistic and efficient measures would be: (1) an overall economy and protection of water resources by a drastic decrease in water consumption, especially in irrigated land use and industry, (2) reduction or full cessation of wastewater discharges into the hydrographic network, (3) better utilization of local waters through seasonal and long-term river runoff regulation, (4) the use of salt and brackish waters, (5) an active intervention in precipitation-forming processes; (6) the use of secular water storage in lakes, underground aquifers, and glaciers, and (7) the redistribution of water resources across territories.

All these measures require rather great material expenses and have different limitations. Almost all of them exert a pronounced effect on the natural environment and are far from being harmless in terms of ecological consequences. These consequences could be significant and difficult to predict. However, the measures for wastewater treatment and in specific water withdrawals are an exception. They are always necessary, desirable, and useful for preserving water resources and the natural environment (Shiklomanov and Markova, 1987).

Methods for obtaining additional water resources seem to continue to be widely used in solving the water supply problem. Primarily, this pertains to those regions of the world where they would appear to be most appropriate, ecologically admissible, and economically profitable when considering the local physiographic conditions and the character of water use. It is worth mentioning that among the promising measures for eliminating long-established water resources deficits is regulation of runoff and its territorial. The measures for a partial transfer of river runoff from one region to another are objectively grounded by the current reality of water resources formation, spatial distribution, and character of use. First, the total river runoff resources on the earth are sufficient to meet the demands for water requirements for many decades ahead. Second, freshwater resources on the earth are distributed extremely unevenly: on every continent, there are regions with excessive water resources and regions with a deficit. Third, human economic activities magnify the natural unevenness in the spatial distribution of water resources. This means that where water resources are in excess, they are less used, and river runoff practically is not reduced. In regions with water resources deficits, the anthropogenic influences affect the water deficits, which become more tangible in time. Therefore, an obvious human intention is to work out and implement measures for importing water from regions of water surplus to the regions with deficits. In the future, as water requirements and technological and economic possibilities increase, the volumes and scales of runoff transfer may also increase. As this takes place, the principal difficulties of developing large-scale measures for river runoff diversion in the world will not be financial and technological, but will stem from the necessity of detailed estimation of the effects of water transfers on the natural environment, reliable forecast of possible ecological consequences, and development and implementation of effective measures for their elimination.

In a more distant future, when the anthropogenic global climate change and heat-moisture redistribution over the earth's surface takes place, as some scientists believe, it will be necessary to return to the large-scale projects of the territorial redistribution of river runoff. Such projects were under intensive development during the 1960s and1970s. However, our knowledge about the possible anthropogenic climatic changes causes great difficulties in the use of large-scale projects of river runoff diversions to solve the water supply problems due to the two reasons. First, unfavorable climatic changes could cover vast areas including the basins planned for runoff withdrawals. Second, we have very great uncertainties concerning possible regional climatic changes in order to realistically plan different large-scale measures even in the far distant future.

Conclusion

Every time new data on earth's water resources and their use are presented, especially forecasts of future use, the question arises as to their reliability and accuracy. These depend on many factors and differ considerably between individual countries, regions, and even continents. Renewable water resources estimates are based on observation data from the hydrological network. Therefore, their reliability is primarily determined by the condition of this network: the number of hydrological sites, the character of their spatial distribution, the duration and continuity of observations, measurement quality, and processing. Regarding the UNESCO/WMO analysis, it should be noted that more than half the observational stations for water discharge on world rivers are located in Europe and North America. The countries of these continents have the longest observation series. Most hydrological monitoring sites (70 percent) equipped with self-recorders allowing detailed and objective information to be obtained, are located in these countries. Therefore, it is natural that the most reliable estimates are obtained for water resources dynamics and water availability for the regions and countries of these continents. They agree well with previous estimates. Discrepancies are almost fully attributed to different periods of averaging of observed data.

Water resources estimates are most erroneous for a number of regions of Africa (Northern, Eastern, and Western Africa), Asia (Southern and Southeastern Asia), and the islands in the northern part of the North American continent. To more reliably estimate water resources in these regions, it is necessary to develop a hydrological monitoring network and improve the quality of observations and the processing of information.

In many developing countries, hydrological monitoring networks are underdeveloped and declining. Meanwhile, the time spans between measurements, processing, and data publication and submission to regional and international centers are increasing. There are many countries with the capability but not the interest in the operational exchange of hydrological information and its timely publication. As a result, the worldwide situation with hydrometeorological information exchange cannot be considered normal. At end of the 1990s, it was only possible to analyze global river runoff data for the period to 1985, in contrast to meteorological information (air temperature and precipitation), which is generated for the entire globe with only a few months delay. This situation prevents not only reliable estimation of water resources but also studying the global hydrological cycle and improving Global Circulation Models (GCMs). Urgent measures should to be undertaken by authoritative international organizations to improve the state of the global hydrological network and the collection, processing, and exchange of hydrological information.

The situation is no better with regard to the monitoring of fresh water use. In most developing countries, reliable, systematized materials about water withdrawals and diversion are, as a rule, unavailable. Even the published national data are based on proxy estimates.

It should be noted that the water availability data presented above was calculated for all regions and countries using mean annual river runoff with no consideration of their variability from year-to-year and during a year, which is especially important for arid and semiarid regions. When calculations are based on minimum annual river runoff for the observation period, water availability decreases by about 1.2–2.0 times depending on the climatic conditions of individual regions and countries. Thus, the inferences made about water availability level and water resources deficit by regions or countries should probably be considered as one of the most optimistic variants of global water availability dynamics.

That the variant of above estimates is optimistic is confirmed by the fact that they were obtained with no account of the qualitative depletion of water resources caused by the ever-increasing pollution of natural water. This problem is very acute in industrially developed and densely populated regions of the earth where no efficient wastewater purification takes place. The major sources of intensive pollution of waterways and water bodies are contaminated industrial and municipal wastewater discharges as well as returnable water from irrigated massifs. In 1995, wastewater volume was approximately 270 km3/year in Europe, 450 km^3/year in North America, 850 km^3/year in Asia, and 60 km^3/year in Africa. Many countries discharge wastewater containing harmful substances directly into the aquatic environment. No preliminary purification is carried out. Thus, water resources are polluted and become unsuitable for subsequent use, especially for drinking water supply.

Every cubic meter of contaminated wastewater discharged into water bodies and streams makes 8 to 10 cubic meters of pure water unsuitable. This means that most regions and countries of the world are already facing the threat of catastrophic qualitative depletion of water resources. Therefore, it is necessary to consider the water supply problems of every region in detail. In this case, the dynamics of fresh water quantity and quality due to anthropogenic change needs to be taken into account.

The reliability of the forecasts for 2010–2025 require special attention. They certainly consider the trends observed during the past decades. However, to a considerable extent they are based on long-term demographic and global economic development forecasts by countries expressed in GNP. The reliability of these forecasts affect our future estimations of water withdrawal and water availability. To some extent, additional errors can arise, especially for arid and semiarid regions because of the difficulty in accounting for the expected anthropogenic global climate change due to increasing atmospheric carbon dioxide and other greenhouse gases.

Forecasts of future population, industry, and thermal power growth are usually given for different socio-economic development alternatives based on various factors and premises. This information is used to predict water withdrawal and water availability. Nevertheless, we give an average, we think realistic, variant of the process development in the future. An approximate estimation was made for potential departures from the mean water availability indicators in 2025 for different variants of initial data. The values obtained are more than 10–15 percent for the regions with a predominance of developed countries and more than 20–25 percent for the regions with a predominance of developing countries.

More reliable and detailed water availability records for the future can be obtained. They should consider river runoff variability annually and in the long term, groundwater data, the dynamics of water resources quantity and quality with a stationary climate, and anthropogenic global climate change. All these are to be considered as the goals for subsequent studies on the problem of complex estimation of global water resources.

To solve this problem, it is necessary to provide a close cooperation of scientists from different countries and international organizations dealing with the problems of hydrology, climatology, complex use, and protection of water resources.

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