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Water in Crisis

A Guide to the World's Fresh Water Resources

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Chapter 2
World fresh water resources

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Introduction

The rational use and protection of water resources and supplying humankind with adequate clean fresh water, or, to be concise, "water problems," are among today's most acute and complex scientific and technical problems. They increasingly reach beyond national and regional borders and are becoming global in nature. Shortages of fresh water and the increasing pollution of water bodies are becoming limiting factors in the economic and social development of many countries throughout the world, even countries not located in arid zones. Under these conditions the reliable assessment of water resources is extremely important, particularly the quantitative estimation and calculation of annual stream flows and their fluctuations in time and space. This is due to the fact that the mean annual river runoff and annually renewable ground water resources almost everywhere support the bulk of water consumption and determine the available water supply for a given region.

Scientists from around the world have prepared assessments of global water resources and their use. Information on water resources and the water balance, water use, and the impact of economic activity on water resources is available from several publications prepared over the last 20–25 years.[1] Additional information can be found in the tables in Part II, and in the references described there. More recently, three major monographs on global problems of water resources and the water balance have been published.[2] The conclusions presented in this chapter are based primarily on the results of the assessments given in the cited works, which remain pertinent today.

World water stocks

Reliable estimates of water resources stored in various water bodies and in different physical states are critical to a clear understanding of the natural water cycle and the effect that human activities might have. Data on global water resources collected by Soviet scientists are presented in Table 2.1.

It should be noted that the data on the amount of water on earth (as the authors of the cited monograph themselves note) should not be considered very accurate; they are only approximations of the actual values. The data on water stored in underground ice in permafrost regions, on the amount of soil moisture, and on water stored in bogs and marshes, which were obtained computationally under fairly crude assumptions, are especially rough. At the same time, much more reliable estimates are now available of water stored in the oceans, in lakes and reservoirs, in polar ice, and in mountain glaciers, and of stocks of fresh and saline ground water.

According to the data in Table 2.1, the total volume of (long-term) fresh water stocks is 35 million km^3, or just 2.5% of the total stock of water in the hydrosphere. A large fraction of the fresh water (24 million km^3, or 68.7%) is in the form of ice and permanent snow cover in the Antarctic and Arctic regions. Fresh water lakes and rivers, which are the main sources for human water consumption, contain on average about 90,000 km^3 of water, or just 0.26% of total global fresh water reserves.

The total area of all fresh water lakes in the world is about 1.5 million km^2; basic morphometric data on the 28 largest fresh water lakes in the

TABLE 2.1 Water reserves on the earth

	Distribution area (10^3 km^2)	Volume (10^3 km^3)	Layer (m)	Percentage of global reserves: Of total water	Percentage of global reserves: Of fresh water
World ocean 96.5%	361,300	1,338,000	3,700	96.5	–
Ground water	134,800	23,400	174	1.7	–
Fresh water 2.5%		10,530	78	0.76 [illegible]	30.1
Soil moisture		16.5	0.2	0.001 2.46	0.05
Glaciers and permanent snow cover	16,227	24,064	1,463	1.74	68.7
Antarctic	13,980	21,600	1,546	1.56	61.7
Greenland	1,802	2,340	1,298	0.17	6.68
Arctic islands	226	83.5	369	0.006	0.24
Mountainous regions	224	40.6	181	0.003	0.12
Ground ice/permafrost	21,000	300	14	0.022	0.86
Water reserves in lakes	2,058.7	176.4	85.7	0.013	–
Fresh	1,236.4	91	73.6	0.007	0.26
Saline	822.3	85.4	103.8	0.006	–
Swamp water	2,682.6	11.47	4.28	0.0008	0.03
River flows	148,800	2.12	0.014	0.0002	0.006
Biological water	510,000	1.12	0.002	0.0001	0.003
Atmospheric water	510,000	12.9	0.025	0.001	0.04
Total water reserves	510,000	1,385,984	2,718	100	–
Total fresh water reserves	148,800	35,029	235	2.53	100

world, each with an area of more than 5,000 km^2, are presented in Table 2.2. Additional data on lakes can be found in Table B.10. These lakes together account for approximately 85% of the volume and 40% of the water surface area of all fresh water lakes on earth.

The largest accumulations of fresh water lakes are concentrated in regions of ancient and recent glaciations and in regions of large tectonic fractures in the earth's crust. The Great Lakes in North America form the largest lake complex. Lake Baikal, in the former Soviet Union, which contains approximately 25% of global lacustrine fresh water, is the largest in volume.

The creation of artificial lakes and reservoirs is of great importance to the use of water resources and the control of river flow. The earliest water reservoirs were built on rivers thousands of years ago, in the heyday of ancient civilizations, but they have become global-scale objects only within the last few decades. The total volume of reservoirs in the world increased nearly tenfold from 1951 to 1980; at present it exceeds 5,000 km^3. The total surface area of these reservoirs is more than 400,000 km^2.[3] The largest volume of water in artificial reservoirs is found in three countries: the United States, the former Soviet Union, and Canada, where approximately half the total volume of reservoirs in the world is concentrated.

The largest reservoirs in the world by volume are Owen Falls off Lake Victoria in Uganda (205 km^3), the Kariba reservoir on the Zambesi river (182 km^3), and the Bratsk reservoir on the Angara river (169 km^3). Among the largest reservoirs by surface area are the Volta in Ghana (8,500 km^2) and the Kuybyshev reservoir in the former Soviet Union (6,500 km^2). According to long-range plans that exist in many countries, the total volume of the world's reservoirs may reach 7,000–7,500 km^3 by the end of this century.

TABLE 2.2 Large fresh lakes of the world (with surface area greater than 5,000 km^2)

Lake	Area (km^2)	Volume (km^3)	Maximum depth (m)	Continent
Superior	82,680	11,600	406	North America
Victoria	69,000	2,700	92	Africa
Huron	59,800	3,580	299	North America
Michigan	58,100	4,680	281	North America
Tanganyika	32,900	18,900	1,435	Africa
Baikal	31,500	23,000	1,741	Asia
Nyasa	30,900	7,725	706	Africa
Great Bear	30,200	1,010	137	North America
Great Slave	27,200	1,070	156	North America
Erie	25,700	545	64	North America
Winnipeg	24,600	127	19	North America
Ontario	19,000	1,710	236	North America
Ladoga	17,700	908	230	Europe
Chad	16,600	44.4	12	Africa
Maracaibo	13,300	–	35	South America
Tonlé Sap	10,000	40	12	Asia
Onega	9,630	295	127	Europe
Rudolf	8,660	–	73	Africa
Nicaragua	8,430	108	70	North America
Titicaca	8,110	710	230	South America
Athabasca	7,900	110	60	North America
Reindeer	6,300	–	–	North America
Tung Ting	6,000	–	10	Asia
Vänern	5,550	180	100	Europe
Zaisan	5,510	53	8.5	Asia
Winnipegosis	5,470	16	12	North America
Albert	5,300	64	57	Africa
Mweru	5,100	32	15	Africa

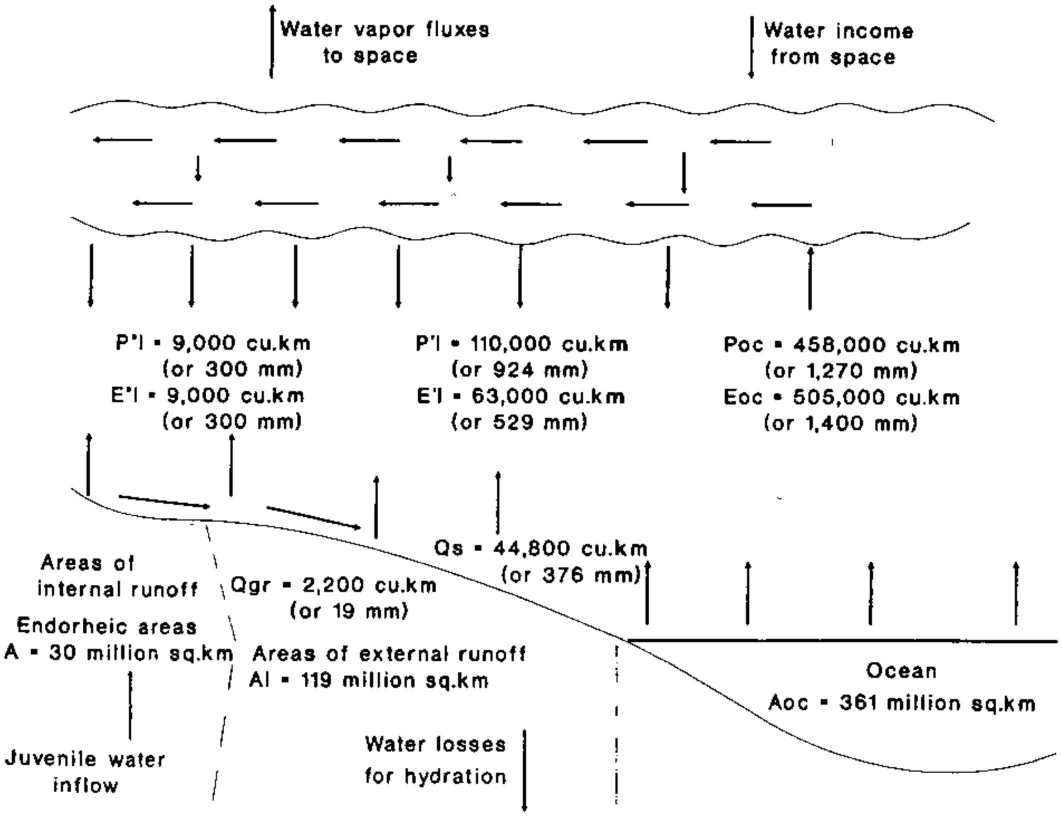

Fig. 2–1. The global water circulation. A generalized description of the global hydrologic cycle is shown here, including precipitation (*P*), evaporation (*E*), runoff (*Q*), and areas (*A*). Subscripts: oc, oceans; gr, ground water; s, surface; l, land.

TABLE 2.3 Water balance of the land

Continent	Precipitation (mm)	Precipitation (km^3)	Evaporation (mm)	Evaporation (km^3)	Runoff (mm)	Runoff (km^3)
Europe	790	8,290	507	5,320	283	2,970
Asia	740	32,200	416	18,100	324	14,100
Africa	740	22,300	587	17,700	153	4,600
North America	756	18,300	418	10,100	339	8,180
South America	1,600	28,400	910	16,200	685	12,200
Australia and Oceania	791	7,080	511	4,570	280	2,510
Antarctica	165	2,310	0	0	165	2,310
Land as a whole	800	119,000	485	72,000	315	47,000
Areas of external runoff	924	110,000	529	63,000	395	47,000[a]
Areas of internal runoff	300	9,000	300	9,000	34	1,000[b]

[a] Including underground water not drained by rivers.
[b] Lost in the region through evaporation.

The hydrologic cycle and the water balance

All types of water on earth interact closely as water passes from one form to another and moves from the ocean to land and back under the influence of solar energy and gravity.

All types of natural waters are renewed annually, but the rates of renewal differ sharply. Water present in rivers is completely renewed every 16 days on average and water in the atmosphere is renewed every 8 days, but the renewal periods of glaciers, ground water, ocean water, and the largest lakes run to hundreds or thousands of years. When slowly renewed resources are used by humans at a rapid rate, they effectively become non-renewable resources with subsequent disruptions of the natural cycle.

The main link in the water cycle in nature is exchange between the oceans and land, which includes not only quantitative renewal but – what is especially important – qualitative restoration as well. An overall diagram of the global hydrologic cycle with its main quantitative indices is presented in Figure 2.1.[4]

An enormous amount of water, equal to about 505,000 km^3, or a layer 1,400 mm thick according to current estimates, evaporates annually from the ocean surface. Of this amount, nearly 90% (458,000 km^3 per year) returns to the ocean in the form of atmospheric precipitation that falls on the ocean surface, and 10% (50,500 km^3 per year) falls on to dry land. Together with atmospheric precipitation of local origin (68,500 km^3 per year), the total precipitation falling on dry land and supplying all types of land water is 119,000 km^3 per year, or on average about 1,000 mm per year. Of this amount, 47,000 km^3 per year (about 35%) is returned to the oceans in the form of river, ground, and glacial runoff. On the whole, an average of 577,000 km^3 of precipitation, or 1,130 mm, falls annually on the earth's surface (this is 177,000 km^3 per year more than the value used in the hydrometeorological literature prior to 1965). Approximately the same amount of water evaporates annually from the ocean surface and dry land, i.e., the world water balance may be considered closed. At present, there are no data whatever to indicate a significant one-way outflow of water vapor from the earth's atmosphere into outer space. Similarly, an inflow of juvenile water from the earth's interior as a result of outgassing of the mantle probably does not play a significant part in the present world water balance as a whole. Although these processes do take place in some geologically active zones, there is every reason to believe that the influx of juvenile water is compensated by corresponding water consumption for hydration. Rounded data on the water balance of continents and for dry land as a whole are presented in Table 2.3.[5]

It should be noted that in addition to the quantitative characteristics of the components of the world water balance mentioned above, which are based on research conducted by Soviet scientists, other data that differ substantially can also be found in the hydrometeorological literature. Other estimates are presented in the Tables of Part II, Section A.[6]

Natural river flow and water supply

The main source of fresh water is surface runoff, which is used extensively to satisfy widely varying human needs. The most important feature of runoff compared with other natural resources is its annual renewal in the course of the hydrologic cycle in nature. Runoff is a dynamic part of long-term water reserves, and serves as a characteristic of potential renewable water resources, not only of rivers proper but also of lakes, reservoirs, and glaciers. The stable portion of runoff (about 25% of the total) is at the same time an index of potential renewable ground water resources (excluding deep subsurface waters that are located below the active zone and that directly enter the ocean and interior closed water bodies).

The total global runoff averages (excluding the ice flow of Antarctica) 44,500 km^3 per year (Table 2.4). Of this volume, 43,500 km^3 per year enters the oceans directly. Runoff to interior hydrologically-closed regions (such as the basins of the Caspian Sea and the Aral Sea, the lakes of Chad, the Great Salt Lake, and so on), where the stream flow goes entirely to evaporation, account for about 1,000 km^3 per year, or approximately 2.4%. It is important to emphasize that from the standpoint of practical use, the stream flows of exterior and interior (closed) regions differ significantly. The use of the flow from exterior regions has little effect on the oceans, entails essentially no pronounced changes in their water–salt balance, and can affect to one degree or another only the regime of marginal and interior seas (the Baltic Sea, Black Sea, etc.). The (unrecoverable) use of the runoff of interior regions can lead to a fundamental change in the water–salt balance of water bodies into which the streams flow (the Caspian Sea, Aral Sea, etc.).

It is well known that global runoff is distributed extremely unevenly – a fact apparent from a simple comparison of runoff by continent (Table 2.4). More than half the global runoff occurs in Asia and South America (31% and 25%, respectively), while Europe accounts for just 7% and Australia for only 1%. Most of the runoff (over 80%) is concentrated in the northern and equatorial zones, which have fairly small populations.

TABLE 2.4 River runoff resources in the world

Territory	Annual river runoff (mm)	Annual river runoff (km^3)	Portion of total runoff (%)	Area (10^3 km^2)	Specific discharge (l/s/km^2)
Europe	306	3,210	7	10,500	9.7
Asia[a]	332	14,410	31	43,475	10.5
Africa[b]	151	4,570	10	30,120	4.8
North America[c]	339	8,200	17	24,200	10.7
South America	661	11,760	25	17,800	21.0
Australia[d]	45	348	1	7,683	1.44
Oceania	1,610	2,040	4	1,267	51.1
Antarctica	160	2,230	5	13,977	5.1
Total land area	314	46,770	100	149,000	10.0

[a] Asia includes Japan, the Philippines, and Indonesia.
[b] Africa includes Madagascar.
[c] North and Central America.
[d] Australia includes Tasmania.

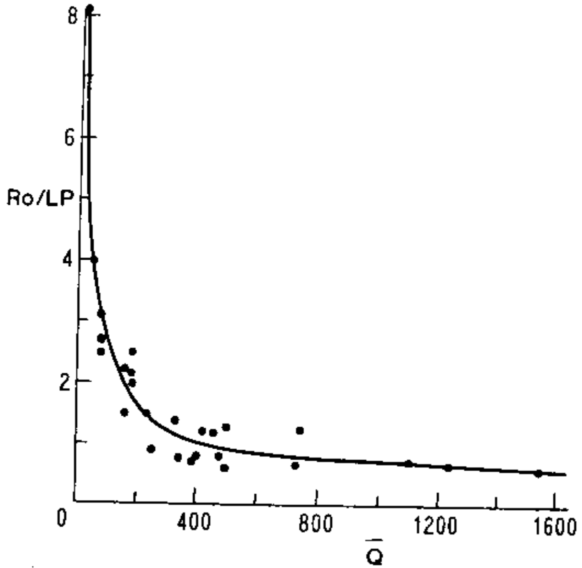

Fig. 2–2. Long-term runoff by region. The dependence of mean long-term river runoff (Q) is plotted for physiographic and economic regions of the world as a function of the aridity index ($R_0/(LP)$).

TABLE 2.5 Large rivers of the world (with mean annual runoff greater than 200 km^3)

River	Average runoff (km^3/ yr)	Area of basin (10^3 km^2)	Length (km)	Continent
Amazon	6,930	6,915	6,280	South America
Congo	1,460	3,820	4,370	Africa
Ganges (with Brahmaputra	1,400	1,730	3,000	Asia
Yangzijiang	995	1,800	5,520	Asia
Orinoco	914	1,000	2,740	South America
Paraná	725	2,970	4,700	South America
Yenisei	610	2,580	3,490	Asia
Mississippi	580	3,220	5,985	North America
Lena	532	2,490	4,400	Asia
Mekong	510	810	4,500	Asia
Irrawaddy	486	410	2,300	Asia
St. Lawrence	439	1,290	3,060	North America
Ob	395	2,990	3,650	Asia
Chutsyan	363	437	2,130	Asia
Amur	355	1,855	2,820	Asia
Mackenzie	350	1,800	4,240	North America
Niger	320	2,090	4,160	Africa
Columbia	267	669	1,950	North America
Magdalena	260	260	1,530	South America
Volga	254	1,360	3,350	Europe
Indus	220	960	3,180	Asia
Danube	214	817	2,860	Europe
Salween	211	325	2,820	Asia
Yukon	207	852	3,000	North America
Nile	202	2,870	6,670	Africa

In the temperate zones (the southern forest zone, the forest–steppe zone, the steppe zone) that are most suitable for human life and activities (especially for agricultural production), where most of the earth's population lives, flowing water resources are extremely limited.

On the continents and in large regions of the earth, the distribution of water resources is still more uneven. An analysis of the shortfall and excess of water resources in the world shows that within the confines of each continent there are vast regions with arid climate and regions with limited water resources; these regions occupy 33% of Europe, 60% of Asia, a large fraction of Africa, the south-western regions of North America, about 30% of South America, and the overwhelming majority of Australia. On the other hand, on all the continents listed there are wet regions with abundant water resources.[7]

With respect to the major natural and economic regions of the earth, it is not hard to identify quantitative relationships between total runoff and climatic factors. For instance, such a relationship is presented in Figure 2.2. This relationship shows the close dependence between the total perennial stream flow layer Q_{mm} determined for major natural and economic regions of the earth, on a complex climatic parameter expressed in the form of the "dryness index":

$$R_0/(LP)$$

where R_0 is the radiation balance of the wet surface, L is the specific heat of evaporation, and P is precipitation. This index has been determined on an approximate basis for each region by using very detailed global charts of the radiation balance and precipitation.[8] The names of the regions and the values of the runoff layer and dryness index for each are presented in Table 2.9.

According to Figure 2.2, the smallest value of a region's natural water resources corresponds to the largest dryness index; conversely, the largest flow layer is associated with regions with minimum values of the dryness index.

The development of the stream network and the water capacity of rivers depend on climatic factors, ruggedness of terrain, and geologic structure. The main characteristics of the world's largest rivers with an average flow of more than 200 km^3 per year are presented in Table 2.5. The Amazon, the largest river in the world, carries more than 15% of the annual global runoff, and the total annual flow of all rivers presented in Table 2.5 is approximately 40% of global runoff.

In most regions on earth the values of natural annual flow are not a realistic index of water supply, since runoff is distributed quite unevenly throughout the year. Most of it (60%–70%) occurs in the flood (high water) period. Naturally, for the continents as a whole total stream flow varies significantly throughout the year; these variations are shown by month in Figure 2.3. Most of the runoff (48%) in Europe occurs in April through July, in Asia in May through October (80%), in Africa in January through June (74%), in North America in May through August (54%), in South America in March through September (70%), and in Australia in January through March (68%). For all dry land as a whole, the highest water period extends from May to October, when the rivers transport 63% of the annual flow.

Naturally, for regions that are small in area, the non-uniformity of the stream flow increases sharply in both time (from year to year and within the year) and space. The values of the variability generally are largely dependent on total moisture and water resources. The higher the dryness index of a region, the greater the variability of water resources from year to year and by season and the more unevenly they are distributed in space.

To estimate the quantitative characteristics of the water resources of a given country or region, relative or specific indices of potential water supply are usually used in addition to absolute indices (such as km^3 per year or in a season). Relative or specific indices represent the volume of annual (or seasonal) runoff per unit area (for example km^3 per year per km^2) or per population (m^3 per year per capita).

Among the countries of the world, first place in absolute volume of runoff belongs to Brazil, whose water resources exceed 20% of all global renewable water resources (Table 2.6). This is nearly twice as much as the water resources of the former Soviet Union, which is second among the other countries (10.6%). China (5.7%) and Canada (5.6%) hold third and fourth place.

In terms of specific water supply, Norway is first both per unit area (1,250,000 m^3 per year [per km^2]) and per capita (98,800 m^3 per year per capita). For comparison, the potential specific water supply per unit area is 213,000 m^3 per year per km^2 in the former Soviet Union, and 207,000 m^3 per year per km^2 in the United States, or approximately one-sixth as much as in Norway. Some smaller countries, such as Iceland, exceed even

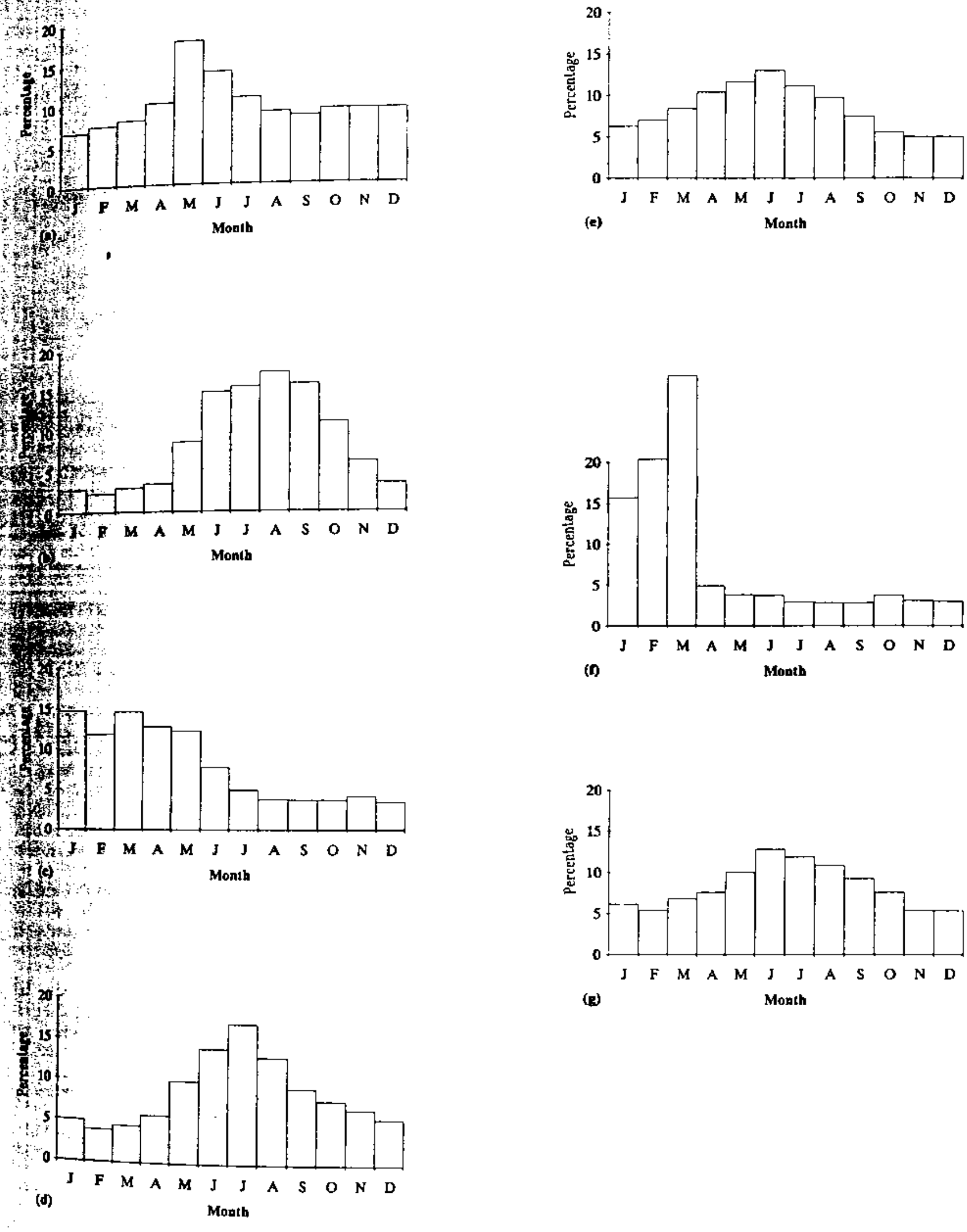

Fig. 2-3. Average monthly runoff as a fraction of annual runoff, by continent. Variations of total river runoff of the continents during a year: (a) Europe, (b) Asia, (c) Africa, (d) North America, (e) South America, (f) Australia, (g) total land area.

TABLE 2.6 Water availability in some countries, late 1980s

Country	Area (10^3 km^2)	Population (10^6)	Long-term mean annual river runoff: Runoff total (km^3)	Runoff per unit area (10^3 m^3 per km^2)	Runoff per capita (10^3 m^3 per person)	Percentage of global runoff
Brazil	8,512	129.9	9,230	1,084	71.1	20.7
USSR	22,274	275	4,740	213	17.2	10.6
China	9,561	1,024	2,550	267	2.49	5.7
Canada	9,976	24.9	2,470	248	99.2	5.6
India	3,288	718	1,680	511	2.34	3.8
United States	9,363	234.2	1,940	207	8.28	4.4
Norway	324	4.1	405	1,250	98.8	0.9
Yugoslavia	256	22.8	256	1,000	11.2	0.6
France	544	54.6	183	336	3.35	0.4
Finland	337	4.9	110	326	22.4	0.2
World total[a]	134,800	4,665	44,500	330	9.54	100

[a] World total does not include Antarctica.

the values of Norway, while many countries have far fewer water resources per capita or per unit area.

And these numbers are not fixed. As we know, the earth's population is growing rapidly. Whereas it was 1,170 million in 1850, today it already exceeds 5,400 million, and according to demographic forecasts it will exceed 6,000 million by the turn of the century. Population has been growing especially quickly since the 1950s. Population growth is accompanied by a progressive reduction in specific per capita water supply in the world, which has decreased from 33,300 m^3 per year per capita in 1850 to 8,500 m^3 per year per capita today. A change in specific water supply due to human impact on water resources and on the quality of natural water is occurring to no less a degree in many parts of the world.

Impact of economic activities on water resources

The problem of studying water resources includes not only an assessment of their natural state, territorial distribution, and fluctuations in time, but also of changes due to human economic activities. Despite the ability of stream flow to renew and self-purify, in recent decades the intensive development of industry and agriculture throughout the world, population growth, the opening of new territories, the associated sharp increase in water withdrawals on all continents (except most recently in the United States and parts of Europe), and the transformation of the earth's natural cover have begun to exert a significant impact on the natural fluctuations of the stream flow and the state of fresh water resources.

In the regions that have been most developed to date, no major river systems remain with a regime that has not been disturbed by human activities to one degree or another.

Within major river drainage basins and vast territories located in regions that have been most developed economically, runoff is usually affected by a host of anthropogenic factors that have various effects on the characteristics of the water regime, total annual flow, and water quality. According to the nature of the effect on hydrologic processes (quantitative characteristics of the regime and the quality of natural waters), factors of economic activities may be combined into the following groups:[9]

1. Factors that principally affect flow due to direct diversions of water from water sources (the stream network, lakes, reservoirs, aquifers), the use of these stocks and flows, and the discharge of water back into the river system (water intakes for irrigation, industrial and municipal water use, agricultural water supply, and runoff diversions).
2. Factors that affect the hydrologic cycle and water resources as a result of direct transformations of the stream network (construction of reservoirs and ponds, damming and straightening of channels, excavation of earth from river channels, etc.).
3. Factors that alter the conditions of formation of flow and other components of the water balance by affecting the surface of drainage basins (agrotechnical measures, drainage of swamps and marshlands, cutting and planting of trees, urbanization, etc.).
4. Factors of economic activities that affect the flow, water bala[illegible] and hydrologic cycle through alterations of overall climatic cha[illegible]teristics on global and regional scales as a result of anthropoge[illegible] modifications of atmospheric gas composition and air pollution, as well as changes in characteristics of the hydrologic cycle due to incremental evaporation resulting from the development of large-scale water management measures.

In examining anthropogenic changes in the characteristics of runoff on the global scale and within continents and major natural and economic regions, it is practically impossible to give a quantitative assessment of the importance of all the factors of economic activity listed above, and indeed there is scarcely any need to do so. We believe that one may full well ignore the effect of factors that act on drainage basins (the third group). These factors have their primary impact on the flow of small and medium-sized drainage basins, and usually not on annual flow but on the distribution within the year, the extreme characteristics of the flow, and water quality. Here, depending on specific geophysical conditions, the anthropogenic factors indicated above usually affect the flow in different directions, i.e., under certain conditions they may even promote some increase in the perennial flow of small and medium-sized rivers by reducing total evaporation.

Of the anthropogenic factors acting in the stream network (the second group) as applicable to the discharge of large basins and regions, we may well confine ourselves to an assessment of the role of large reservoirs; other factors are of local importance, and their impact on the quantitative characteristics of water resources is limited.

Thus, to assess the impact of economic activities on the state of global water resources, we must first take account of anthropogenic factors related to direct water consumption, as well as flow regulation by large reservoirs. These factors, which cause a one-way decrease in surface and subsurface flows, are ubiquitous, develop most intensively, and are capable of exerting an especially large impact on the state of water resources in large regions.

In the past 20 years many attempts have been made in various countries to estimate the size of current and future water withdrawals and consumption throughout the world for various economic needs.

Reliable and detailed data were obtained in 1974 at the State Hydrological Institute of the former Soviet Union and in 1980 by the US Geological Survey.[10] These estimates were made independently, and for this reason comparing them with each other is of particular interest (Table 2.7).

In analyzing the data in Table 2.7, let us note first that the data on total global water withdrawals match very well (to within 5%), and in general, water diversions throughout the world are in quite good agreement for

TABLE 2.7 Water withdrawals by continents and individual countries, 1975–1977

Continent and country	Source	Industrial and energy water withdrawals (km^3 per year)	Irrigation: Area (10^6 hectares)	Irrigation: Water withdrawals (km^3 per year)	Commercial-residential water withdrawals (km^3 per year)	Total water withdrawals (km^3 per year)
Africa	SHI[a]	6	10	120	6	170
	USGS[b]	15.4	6.4	60.8	12	88
Asia	SHI	80	187	1,500	50	1,700
	USGS	98.7	147.4	1,400	98	1,597
Australia and Oceania	SHI	10	1.8	14	1.5	30
	USGS	13.6	1.4	13	2	29
Europe	SHI	195	24	150	36	380
	USGS	350.6	12.2	116	40	516
USSR	SHI	83	14	181	14	290
	USGS	182.8	9.9	94	18	295
North America	SHI	340	27	230	46	640
	USGS	308.6	21.6	205	38	551
United States	SHI	305	21	181	42	540
	USGS	285.4	16.9	160	32	477
South America	SHI	12	8	60	7	90
	USGS	10.8	3.7	35	11	57
World total	SHI	630	260	2,100	150	3,020
	USGS	887	192.7	1,830	201	2,838

[a] State Hydrological Institute, forecasts published in 1974.
[b] United States Geological Survey, estimates published in 1980.

individual water consumers (the differences are 13%–25%). The values of total water withdrawals by continent are in fair agreement, with the greatest uncertainties in the data for Africa and South America. There are significant differences (up to a factor of 2) in the assessment of the importance of individual consumers for countries and continents. Unfortunately comparison of the data presented in these two works is possible only for a few indices – the work of most US hydrologists does not contain any data on consumptive water use or on water losses to incremental evaporation from reservoirs, nor does it give an analysis of the dynamics and trends of global water withdrawals in past periods or for the long term.

The situation is considerably worse for the continents, although some data (including long-term forecasts) are available.[11] Nevertheless, having been calculated 15 years ago, those data undoubtedly need to be refined and updated by using more complete data gathered in recent years. Data on the dynamics of water withdrawals and consumption for individual natural and economic regions of the world were, until recently, almost entirely unavailable. In 1985 new data on these variables were published in a monograph.[12]

The values of water use in various large regions of the earth are determined by three main factors: the level of economic development, population, and the geophysical (especially climatic) peculiarities of the territory in question.

To analyze the temporal and spatial variability of global water withdrawals within each continent, we identified major natural and economic regions characterized by more or less uniform geophysical conditions and a more or less uniform level of development of economic activity; in all, 26 such regions were identified, each continent having between 3 and 8.

For each region estimates were obtained of total water withdrawals and consumptive water use for needs of the urban and rural population, industry (including the heat and power industry), and irrigation, as well as water losses to incremental evaporation from reservoirs. All estimates were made for different years from 1900 to 2000. This made it possible to investigate the dynamics of global water use in space and time throughout the present century, with some extrapolation beyond the year 2000.

In the absence of data on water withdrawals for each large country or for a region as a whole, the calculations made use of indirect methods of estimation, using data on countries with similar geophysical conditions that are close in their level and features of economic development.

Water use by the public was determined separately for cities and inhabited rural points by using actual data available for each country on the dynamics and predicted total size of the urban and rural population, as well as specific water withdrawals per capita, as obtained from similar countries. For extrapolation into the future, allowance was made for trends in the change in per capita water use by the urban and rural populace and for consumptive use of water as a percentage of total water withdrawals.

The estimate of water used for irrigation was based on data on irrigation areas and specific water withdrawals for irrigation that had been obtained for many countries and averaged for certain regions. Irrigation is the primary consumer of water on earth. Therefore, the accuracy of the determination of global water use overall, and especially for continents such as Asia, Africa, and South America, where irrigation determines 70%–90% of total water withdrawals, largely hinges on the accuracy with which irrigated areas are taken into account.

In calculations of irrigated areas for continents and natural and economic regions throughout the world for the period 1990–2000, the author used long-term forecasts and data on irrigation-development programs, which are available for many countries. To estimate the required volumes of water for irrigation needs, we took into account decreases in per capita water consumption because of measures that are being taken to improve the efficiency of production processes, equipment, and methods of irrigation. According to available detailed analyses, recoverable water from irrigation was assumed to be 20%–50% of water diversion (see Chapter 5, this volume).

Industrial water use was calculated on the basis of the dynamics of industrial production in various regions of the earth. Here, available data on the dynamics of this type of water use in the countries listed above, including countries with different levels of economic development that have the most disparate geophysical conditions, were adopted as counterparts. The calculations were done separately for the heat and power industry and for all other branches of industry, which have significantly different trends and rates of development and consumptive use, and then were summed for each region.

Consumptive use of water in the electric utility industry was assumed to be 1%–4%, and in other branches of industry from 10% to 40%, depending on the level of industrial development, the presence of circulating water supply systems, and climatic conditions. In the long term, industrial production (and accordingly water consumption) will develop at a much faster pace in developing countries than in developed ones.

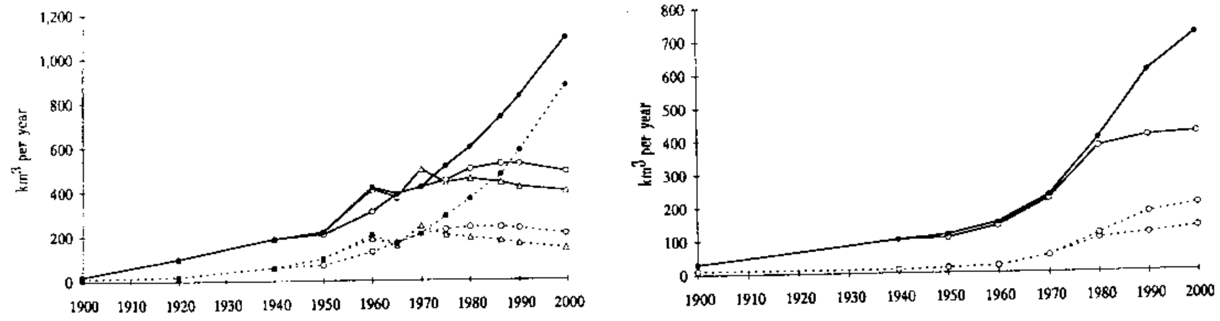

Fig. 2–4. Estimates of consumptive water use in the United States and the former Soviet Union. The dynamics of water consumption in (a) the United States, and (b) the area of the former Soviet Union, computed and predicted in different years in km^3 per year. Computations and forecasts: (•), 1965–1970; (Δ), 1977–1981; (○), 1983–1985. Total water consumption is indicated by solid lines; industrial water consumption (including power generation) by broken lines.

Incremental losses to evaporation from reservoirs were calculated for all of the world's largest reservoirs with a volume of more than 5 km^3 from the difference in mean evaporation from the water surface and from dry land; here allowance was made for a factor that gives the ratio of the incremental surface area of a reservoir to its total area. The total volume of evaporative loss was computed for each region by adding the data for each large reservoir (larger than 5 km^3) and increasing the result by 20%, since reservoirs larger than 5 km^3 in volume account for approximately 80% of the total reservoir volume and surface area. For the long term, losses to evaporation from reservoirs in each region were computed, with consideration for the rates of and plans for construction of large reservoirs in different countries and regions and for their geophysical peculiarities.

Before turning to an analysis of water use by region and continent, it would be of interest to consider the dynamics of water use in different countries throughout the world, especially the United States and the former Soviet Union, for which detailed analyses are available (Figure 2.4).

In the United States a detailed estimate and long-range forecasts (for the period 2000–2020) of water required for various economic needs were first carried out in the 1960s.[13] According to predictions from that period, between 1970 and 2000 there would be an increase of 100%–150% in annual fresh water use in the United States (Figure 2.4a) to a total of 850–1,100 km^3 per year. Most of the increase was expected to be for water supply for industry and power plant cooling. In the United States, the period since 1975 has, in fact, been characterized by fundamental changes in the approach to the use of water resources, with a great deal of attention being given to problems of conservation and reuse of water resources, and a transition from extensive to intensive and comprehensive use taking place. All these factors have led to the stabilization of the volume of water withdrawals and have been the basis for a fundamental review of predictions of water needs for the future. Data from actual accounting of water withdrawals attest to this stabilization, beginning in the 1980s, of the amount of fresh water withdrawals in the United States and even to a slight decrease in withdrawals, mainly through a reduction of water use in agriculture, industry, and the electric utility sector (Figure 2.4a).[14]

Analogous trends also hold in the former Soviet Union: whereas in the 1960s and 1970s an increase in water withdrawals to 600–700 km^3 per year by the turn of the century was planned for the Soviet Union, present forecasts now postulate a very slight increase to 400–450 km^3 per year (Figure 2.4b). It should be noted that in addition to the United States, beginning in the 1970s and 1980s, the volume of total water withdrawals has stabilized in a number of countries in northern and western Europe (Sweden, Great Britain, and the Netherlands, for example), and will even decrease somewhat by the turn of the century.

Despite the progressive trends toward stabilization of water needs that have clearly taken shape in a number of countries, for the world as a whole water requirements are growing and will continue to grow through the turn of the century in all types of economic activity (Table 2.8). Present (as of 1990) gross water withdrawals in the world are 4,100 km^3 per year,

TABLE 2.8 Dynamics of water use in the world by human activity

Water users[a]	1900 (km^3 per year)	1940 (km^3 per year)	1950 (km^3 per year)	1960 (km^3 per year)	1970 (km^3 per year)	1975 (km^3 per year)	1980		1990[b]		2000[b]	
							(km^3 per year)	(%)	(km^3 per year)	(%)	(km^3 per year)	(%)
Agriculture												
Withdrawal	525	893	1,130	1,550	1,850	2,050	2,290	69.0	2,680	64.9	3,250	62.6
Consumption	409	679	859	1,180	1,400	1,570	1,730	88.7	2,050	86.9	2,500	86.2
Industry												
Withdrawal	37.2	124	178	330	540	612	710	21.4	973	23.6	1,280	24.7
Consumption	3.5	9.7	14.5	24.9	38.0	47.2	61.9	3.2	88.5	3.8	117	4.0
Municipal supply												
Withdrawal	16.1	36.3	52.0	82.0	130	161	200	6.0	300	7.3	441	8.5
Consumption	4.0	9.0	14	20.3	29.2	34.3	41.1	2.1	52.4	2.2	64.5	2.2
Reservoirs												
Withdrawal	0.3	3.7	6.5	23.0	66.0	103	120	3.6	170	4.1	220	4.2
Consumption	0.3	3.7	6.5	23.0	66.0	103	120	6.2	170	7.2	220	7.6
Total (rounded off)												
Withdrawal	579	1,060	1,360	1,990	2,590	2,930	3,320	100	4,130	100	5,190	100
Consumption	417	701	894	1,250	1,540	1,760	1,950	100	2,360	100	2,900	100

[a] Total water withdrawal is shown in the first line of each category; consumptive use (irretrievable water loss) is shown in the second line.

[b] Estimated.

of which 2,300 km^3 per year (56% of total water withdrawals) are unrecoverable (consumed). By the turn of the century we should expect an increase in total water withdrawals to 5,200 km^3 per year, and an increase in consumptive use of about 30%, to 2,900 km^3 per year.

Agriculture currently accounts for approximately 69% of total water use and 89% of consumptive water use in the world. In the long term, the fraction accounted for by agriculture will decrease somewhat, principally as a result of an increase in the fraction used by industry. Incremental evaporation from reservoirs plays a prominent part in total unrecoverable water losses throughout the world: it exceeds consumptive use by industry and municipal services combined.

Absolute amounts of water use by region vary quite significantly. For example, in 1980, withdrawals ranged from 530–670 km^3 in the United States and South Asia to 2.4–2.8 km^3 in Central Africa and Oceania (Table 2.9).

In considering the dynamics of water use throughout the world, we should note that a continual increase in water withdrawals during this century has been characteristic of all regions, the largest growth occurring in the 1950s and 1960s.[15] A significant increase in water requirements over 1980 levels is also expected through the turn of the century, with the largest increases expected to occur in South America and Africa (95% and 70%). Decreases are possible in many major industrialized countries.

The volume of water needed in each region depends on population, climatic factors, and the level of economic and social development; here climatic characteristics are especially important. The graphs presented in Figure 2.5 confirm this relationship. In these graphs we see the direct relationships between the volumes of consumptive water use per capita and the dryness index – the higher the dryness index, the greater the consumptive use in a region.

Analysis of the relationships presented in Figures 2.2 and 2.5 shows convincingly that under the conditions of a dry, hot climate, where water resources are minimal, all other conditions being the same, water consumption for economic needs increases sharply, creating a shortage of water resources and an exceptionally low actual level of water supply. The reverse picture is observed in moist regions, where there is a surfeit of water resources under natural conditions. Here the dryness index has its minimum value and consumptive water use is small.

Thus, under the conditions of intensive economic activity the impact of climatic factors on water resources is not diminished but rather is significantly enhanced. In arid regions, climatic factors determine not only the natural stream flow but also, to a significant extent, the degree of reduction of natural runoff as a result of human activities.

It is of interest to compare the amounts of water withdrawals and consumption throughout the world with stream flow resources; this is not hard to do by using the data in Table 2.9.

For the entire earth, total water withdrawn for use in 1990 was 9.3% [redacted] total surface runoff and unrecoverable consumptive use was 5.2%; by t year 2000 these values will be 11.6% and 6.5%, respectively. At the same

TABLE 2.9 Annual runoff and water consumption by continents and by physiographic and economic regions of the world

Continent and region	Mean annual runoff (mm)	Mean annual runoff (km^3 per year)	Aridity index (R/LP)	Water consumption (km^3 per year) 1980 Total	1980 Irretrievable	1990 Total	1990 Irretrievable	2000 Total	2000 Irretrievable
Europe	310	3,210		435	127	555	178	673	222
North	480	737	0.6	9.9	1.6	12	2.0	13	2.3
Central	380	705	0.7	141	22	176	28	205	33
South	320	564	1.4	132	51	184	64	226	73
European USSR (North)	330	601	0.7	18	2.1	24	3.4	29	5.2
European USSR (South)	150	525	1.5	134	50	159	81	200	108
North America	340	8,200		663	224	724	255	796	302
Canada and Alaska	390	5,300	0.8	41	8	57	11	97	15
United States	220	1,700	1.5	527	155	546	171	531	194
Central America	450	1,200	1.2	95	61	120	73	168	93
Africa	150	4,570		168	129	232	165	317	211
North	17	154	8.1	100	79	125	97	150	112
South	68	349	2.5	23	16	36	20	63	34
East	160	809	2.2	23	18	32	23	45	28
West	190	1,350	2.5	19	14	33	23	51	34
Central	470	1,909	0.8	2.8	1.3	4.8	2.1	8.4	3.4
Asia	330	14,410		1,910	1,380	2,440	1,660	3,140	2,020
North China and Mongolia	160	1,470	2.2	395	270	527	314	677	360
South	490	2,200	1.3	668	518	857	638	1,200	865
West	72	490	2.7	192	147	220	165	262	190
South-east	1,090	6,650	0.7	461	337	609	399	741	435
Central Asia and Kazakhstan	70	170	3.1	135	87	157	109	174	128
Siberia and Far East	230	3,350	0.9	34	11	40	17	49	25
Trans-Caucasus	410	77	1.2	24	14	26	18	33	21
South America	660	11,760		111	71	150	86	216	116
Northern area	1,230	3,126	0.6	15	11	23	16	33	20
Brazil	720	6,148	0.7	23	10	33	14	48	21
West	740	1,714	1.3	40	30	45	32	64	44
Central	170	812	2.0	33	20	48	24	70	31
Australia and Oceania	270	2,390		29	15	38	17	47	22
Australia	39	301	4.0	27	13	34	16	42	20
Oceania	1,560	2,090	0.6	2.4	1.5	3.3	1.8	4.5	2.3
Land area (rounded off)		44,500		3,320	1,450	4,130	2,360	5,190	2,900

time, in many major regions of the world total water withdrawals are already 20%–65% of annual runoff (North Africa, Central Asia and Kazakhstan, West and South Asia, the Trans-Caucasus, the United States, southern and central Europe, the southern part of the European part of the former Soviet Union), and in the long term will reach 40%–100% by the turn of the century, i.e., in some regions total demand will equal the entire stream flow (Table 2.9).

Thus, in the long term the change in the evaporation regime as a result of economic activities may lead to some transformation of the ratios between elements of the water balance in different parts of continents and large regions. Quantitative estimates of these changes are of great scientific and practical importance to long-term planning of large-scale measures to ensure the rational use of water resources. These problems should become a subject of research based on international collaboration between hydrologists and climatologists.

Population dynamics as well as climatic factors and economic activities contribute to the extremely uneven distribution of water supply in various regions throughout the earth. The unevenness of the distribution of water resources and the fact that they are ill matched to the disposition of the population and economy can be vividly illustrated by comparing the actual or residual water supply per capita of individual regions for the same periods of time. For each period the specific (per capita) actual water supply of regions was determined by dividing the total runoff of a region, less the volume of unrecoverable water consumption, by the number of inhabitants.[16]

The values obtained for the actual water supply (in 10^3 m^3 per year per capita) are presented in Table 2.10 for all regions and continents at the levels for the years 1950, 1960, 1970, 1980, and 2000. To analyze them, it is convenient to group them on the following scale (10^3 m^3 per year per

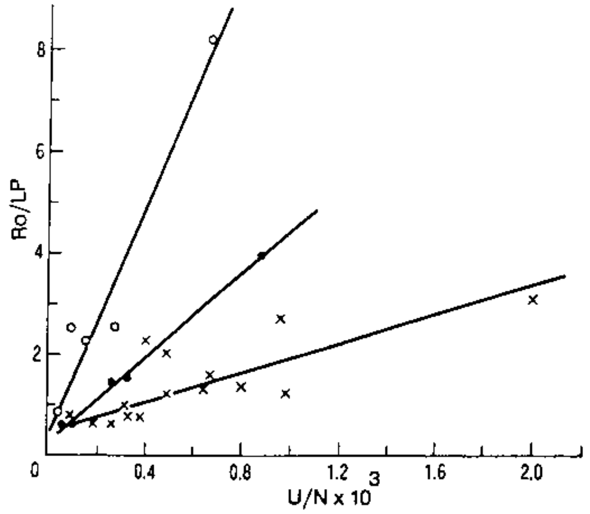

Fig. 2–5. Consumptive water use by region as a function of climatic conditions. Estimates of the consumptive use of water ("specific irretrievable water losses") are shown for different physiographic and economic regions of the world (1980) as a function of the aridity index (*Ro/LP*). (O), Africa; (•) Europe and Australia; (×) North and South America, and Asia.

TABLE 2.10 Dynamics of actual water availability in different regions of the world

Continent and region	Area (10^6 km^2)	Actual water availability (10^3 m^3 per year per capita)				
		1950	1960	1970	1980	2000
Europe	10.28	5.9	5.4	4.9	4.6	4.1
North	1.32	39.2	36.5	33.9	32.7	30.9
Central	1.86	3.0	2.8	2.6	2.4	2.3
South	1.76	3.8	3.5	3.1	2.8	2.5
European USSR (North)	1.82	33.8	29.2	26.3	24.1	20.9
European USSR (South)	3.52	4.4	4	3.6	3.2	2.4
North America	24.16	37.2	30.2	25.2	21.3	17.5
Canada and Alaska	13.67	384	294	246	219	189
United States	7.83	10.6	8.8	7.6	6.8	5.6
Central America	2.67	22.7	17.2	12.5	9.4	7.1
Africa	30.10	20.6	16.5	12.7	9.4	5.1
North	8.78	2.3	1.6	1.1	0.69	0.21
South	5.11	12.2	10.3	7.6	5.7	3.0
East	5.17	15.0	12	9.2	6.9	3.7
West	6.96	20.5	16.2	12.4	9.2	4.9
Central	4.08	92.7	79.5	59.1	46.0	25.4
Asia	44.56	9.6	7.9	6.1	5.1	3.3
North China and Mongolia	9.14	3.8	3.0	2.3	1.9	1.2
South	4.49	4.1	3.4	2.5	2.1	1.1
West	6.82	6.3	4.2	3.3	2.3	1.3
South-east	7.17	13.2	11.1	8.6	7.1	4.9
Central Asia and Kazakhstan	2.43	7.5	5.5	3.3	2.0	0.7
Siberia and Far East	14.32	124	112	102	96.2	95.3
Trans-Caucasus	0.19	8.8	6.9	5.4	4.5	3.0
South America	17.85	105	80.2	61.7	48.8	28.3
North	2.55	179	128	94.8	72.9	37.4
Brazil	8.51	115	86	64.5	50.3	32.2
West	2.33	97.9	77.1	58.6	45.8	25.7
Central	4.46	34	27	23.9	20.5	10.4
Australia and Oceania	8.59	112	91.3	74.6	64.0	50.0
Australia	7.62	35.7	28.4	23	19.8	15.0
Oceania	1.34	161	132	108	92.4	73.5

capita): ≤1 extremely low; 1.1–2.0 very low; 2.1–5.0 low; 5.1–10.0 average; 10.1–20.0 above average; 20.1–50 high; >50 very high.

In 1950 (Table 2.10) the level of per capita water supply throughout most of the earth was average or higher, and the level was low (from 2.1 to 5.0×10^3 m^3 per year per capita) only in North Africa, central and southern Europe, China, and South Asia. In no region on earth was the level of water supply very low or extremely low.

Thirty years later, in 1980, the actual level of per capita water supply had decreased sharply in many regions throughout the world due to population increases. It had become extremely low in North Africa, very low in North China and Mongolia, Central Asia, Asia, and Kazakhstan, and low in six other regions (Table 2.10). By the turn of the century, a low actual level of per capita availability is anticipated in three regions (North Africa, Central Asia, and Kazakhstan), very low in three (North China and Mongolia, South Asia, and West Asia), and low in seven (central and southern Europe, the southern European part of the former Soviet Union, South-east Asia, and West, East, and South Africa). At the same time, in all periods in question there is a high or very high level of water supply in North Europe, the northern European part of the former Soviet Union, Canada, and Alaska, nearly all of South America, Central Africa, Siberia, the Far East, and Oceania. It is important to note here that the dynamics of the actual level of water supply is such that the rate of decrease in it is especially significant in regions with a low absolute level of water supply, i.e., where there is a shortage of water resources. For example, in regions with the lowest water supply (Central Asia, Kazakhstan, and North Africa) per capita availability decreases by a factor of 11 in the period 1950–2000, but in regions with a larger supply (Siberia, the Far East, North Europe, Canada, Alaska, Central Africa) it decreases by a factor of just 1.5–5 over the same period. Thus, the very high natural non-uniformity in the distribution of water supply throughout the earth is increasing still more with time as a result of human economic activities and population change, and at an extremely rapid rate. Because of this, the urgency of the problem of the territorial redistribution of water resources on the global scale will increase significantly with time.

In conclusion, it should be noted that the values presented above for water resources and for volumes of water withdrawals were calculated for the long term on the basis of the assumption of steady climatic fluctuations, and are characteristic of the mean climatic conditions of each region, i.e., it was assumed that the possible anthropogenic global-scale climatic changes through the year 2000 are not included (see Chapter 9). Allowing for the impact of possible anthropogenic changes in global climate on world water resources and water consumption is a problem for the next decade, and, the author believes, the role of effective international cooperation in resolving it would be hard to overestimate.

Conclusions and tasks for further research

Considerable advances have been made in the study of the global water balance and water resources, but as more complete observational data are collected and the requirements for water use and environmental protection grow, the imperfection and inadequacy of our knowledge of water resources become increasingly apparent.

In the development of research on water resources and regional and world water balances, a transition is needed to a qualitatively new stage: expansion of theoretical and experimental research on the mechanism of hydrologic phenomena and processes, all components of the water, heat, and salt balances, and the changes therein as a result of anthropogenic factors. A transition is needed from the study of water resources and the water balance under static conditions based on perennial data to the pursuit of an immeasurably more complex undertaking: the consideration of hydrologic processes under dynamic conditions, over shorter time intervals – the year, season, or month, on a global scale, and for the most important natural and economic regions of the world. To date no patterns have been identified in perennial fluctuations in water resources, and no trends in or causes of the appearance of protracted periods of abundant precipitation and drought that often have catastrophic consequences to the public and the economy have been elucidated. The role of the oceanic and atmospheric component of the hydrologic cycle in the formation of water resources of large regions is not entirely clear; no summarization of the dynamics of the world water balance has been performed with consideration for changes in water reserves in glaciers, ground waters and soils, or in the lake and stream network; and no reliable assessments or predictions are available for anthropogenic changes in the water resources of many regions and river basins as a result of the use of fresh water, the conversion of the surface of drainage basins, and pollution of water bodies.

Allowance for the impact of economic activities on the hydrologic cycle is of very great importance in the problem of studying water resources and their fluctuations in time and space, and of evaluating the dynamics of the level of water supply in various regions.

Human economic activities and population growth already have led, in the most oversettled regions of the world, to a sharp decrease in per capita water availability, some actual decreases in surface runoff, a decrease in the levels of interior closed water bodies, and contamination of both surface and ground waters. The impact of anthropogenic factors on surface runoff depends not only on their scale and rates of development, but also largely on natural fluctuations of climatic characteristics. These circumstances largely govern the attitude toward large water management projects.

In arid and semi-arid regions and during hot, dry periods the impact of economic activities has an especially pernicious effect on water resources and the level of water supply, greatly aggravating the water management situation and providing an incentive for the planning and development of measures intended to provide a fundamental solution to water supply problems.

In cooler regions and during cold, moist periods lasting many years, the impact of economic activities manifests itself to a much lesser degree in a decrease in the water content of rivers, the water management situation improves sharply, the development of water management measures often grinds to a halt, and projects that have been drawn up are subjected to bitter criticism, with attention focused on their negative aspects.

As economic activity increases, the dependence of water resources and the level of water supply on climatic characteristics increases significantly, especially in zones of variable moisture and arid regions. Here climatic conditions determine not only natural runoff, but also largely the degree of the reduction of flow as a result of all anthropogenic factors. The great natural non-uniformity in the distribution of water supply on earth is increasing still further as a result of population growth and the intensification of human economic activities, and at an extremely rapid pace. Plans for new large-scale flow diversions are now extremely unpopular in many developed countries because of their substantial ecological and economic costs. However, there may be objective grounds for further development, particularly in poorer countries. They offer one way of reducing both the shortage of water resources in particular countries and regions and the impacts of severe floods. For this reason, comprehensive research should be continued and developed in this area, including research within the framework of international cooperation, especially to provide a reliable assessment of the impact of flow diversions on the environment under the conditions of anthropogenic changes in global climate.

The ever-growing dependence of water resources and water supply on climatic factors accounts for the very close linkage between modern problems of supplying fresh water to humankind and problems of natural and anthropogenic changes in climate.

From the standpoint of future water resources, changes in global climate due to an increase in the carbon dioxide concentration in the atmosphere as a result of human activities are of primary importance. The anthropogenic changes in climate predicted by climatologists in the next 20–30 years are so significant in scale, especially for the temperate and high latitudes, that scientists already are confronted with major scientific problems: above all, to estimate water resources and the water balance in the future and changes in them as a result of economic activities; water supply for the public, industry, and agriculture in the long term; and the territorial redistribution of water resources and regulation of runoff.

The resolution of all these problems requires effective international cooperation in conducting comprehensive research, with participation by hydrologists, climatologists, and specialists in water management and environmental protection.

Notes

1. See, for example, C.A. Doxiadis, 1967, Water for human environment, in *Proceedings of the Conference "Water for Peace," vol. I, Washington, DC, pp. 33–60; G.P. Kalinin, 1968, Global Hydrology Problems*, Gidrometeoizdat, Leningrad (in Russian); M.I. L'vovich, 1969, *Water Resources in the Future*, Prosveshcheniye, USSR (in Russian); M.I. L'vovich, 1974, *World Water Resources and their Future*, Mysl' Publishing, Moscow (in Russian), 1979 US translation available from the American Geophysical Union, Washington, DC; R. Nace, 1968, *Water of the World*, US Department of the Interior, US Geological Survey, Washington, DC (July); IAHS/UNESCO/WMO, 1972, *World Water Balance, Proceedings of the International Symposium on World Water Balance*, Reading, July 1970, vols. 1–3; and M. Holy, 1974, *Water and the Environment*, Food and Agricultural Organization, United Nations, Rome.
2. These include a book by a team of Soviet scientists dealing with Earth's water balance and water resources: *World Water Balance and the Water Resources of the Earth*, 1974, Gidrometeoizdat, Leningrad (in Russian), later translated into English by UNESCO, 1978, *World Water Balance and Water Resources of the Earth*, R. Nace (ed.), Paris; a review of the world water balance, published by West German scientists: A. Baumgartner and E. Reichel, 1975, *The World Water Balance*, R. Oldenburg Verlag, Munich, and Elsevier Scientific Publishing Co., New York; and a monograph on the use of the earth's water resources, prepared under the supervision of the author of the present chapter: I.A. Shiklomanov and O.A. Markova, 1987, *Specific Water Availability and River Runoff Transfers in the World*, Gidrometeoizdat, Leningrad (in Russian).
3. I.A. Shiklomanov, 1989, *Man's Impact on River Runoff*, Gidrometeoizdat, Leningrad (in Russian).
4. These were drawn from *World Water Balance and Water Resources of the Earth*, 1974, Gidrometeoizdat, Leningrad (in Russian), and I.A. Shiklomanov, 1989, *Man's Impact on River Runoff*, Gidrometeoizdat, Leningrad (in Russian).
5. I.A. Shiklomanov and A.A. Sokolov, 1983, Methodological basis of world water balance investigation and computation, in *Proceedings of the Hamburg Workshop*, August 1981, IAHS Publication no. 148, pp. 77–91.
6. For example, a monograph by Baumgartner and Riechel presents data on the water balance of the continents, which for some components differ from the data presented above by up to 20%–30% (A. Baumgartner and E. Reichel, 1975, *The World Water Balance*, R. Oldenburg Verlag, Munich, and Elsevier Scientific Publishing Co., New York). These differences are explained by different raw data and methodological approaches. With respect to the evaluation of water resources of regions, the author believes that the data presented in *World Water Balance and Water Resources of the Earth*, 1974, Gidrometeoizdat, Leningrad, (in Russian), which were obtained directly by summarizing observational data from the world hydrological network, are more reliable. These issues are also discussed in I.A. Shiklomanov and A.A. Sokolov, 1983, Methodological basis of world water balance investigation and computation, In *Proceedings of the Hamburg Workshop*, August 1981, IAHS Publication no. 148, pp. 77–91.
7. I.A. Shiklomanov, 1985, Large-scale water transfer, in J. Rodda (ed.) *Facets of Hydrology*, vol. II, pp. 345–387, John Wiley & Sons, London.
8. According to data of the *World Water Balance and Water Resources of the Earth*, 1974, Gidrometeoizdat, Leningrad (in Russian) and M.I. Budyko, 1956, *The Heat Balance of the Earth's Surface*, Gidrometeoizdat, Leningrad (in Russian).
9. I.A. Shiklomanov, 1988, *Studying Land and Water Resources: Results, Problems, and Outlook*, Gidrometeoizdat, Leningrad (in Russian).
10. Data on total withdrawals and consumptive use for all continents and water consumers from 1900 to 2000 are available from *World Water Balance and Water Resources of the Earth*, Gidrometeoizdat, Leningrad (in Russian). Data on total water withdrawals for all water consumers and continents and selected countries as of 1977 are available from *The Global 2000: Entering the 21st Century, 1980*, Report to the President of the USA, vols. 2–9, US Government Printing Office, Washington, DC, pp. 137–159.
11. *World Water Balance and Water Resources of the Earth*, 1974, Gidrometeoizdat, Leningrad (in Russian).
12. I.A. Shiklomanov and O.A. Markova, 1987, *Specific Water Availability and River Runoff Transfers in the World*, Gidrometeoizdat, Leningrad (in Russian).
13. H.H. Landsberg, L.L. Fishman and J.L. Fisber, 1963 *Resources in America's Future: Patterns of Requirements and Availabilities 1960–2000*, Johns Hopkins, Baltimore.
14. US Geological Survey, 1984, *National Water Summary 1983: Hydrologic Events and Issues*, US Geological Survey Water Supply Paper 2250, Washington, DC.
15. I.A. Shiklomanov and O.A. Markova, 1987, *Specific Water Availability and River Runoff Transfers in the World*, Gidrometeoizdat, Leningrad (in Russian).
16. This last quantity was determined from data of the United Nations Food and Agricultural Organization (FAO) and from forecasts in I.A. Shiklomanov and O.A. Markova, 1987, *Specific Water Availability and River Runoff Transfers in the World*, Gidrometeoizdat, Leningrad (in Russian).