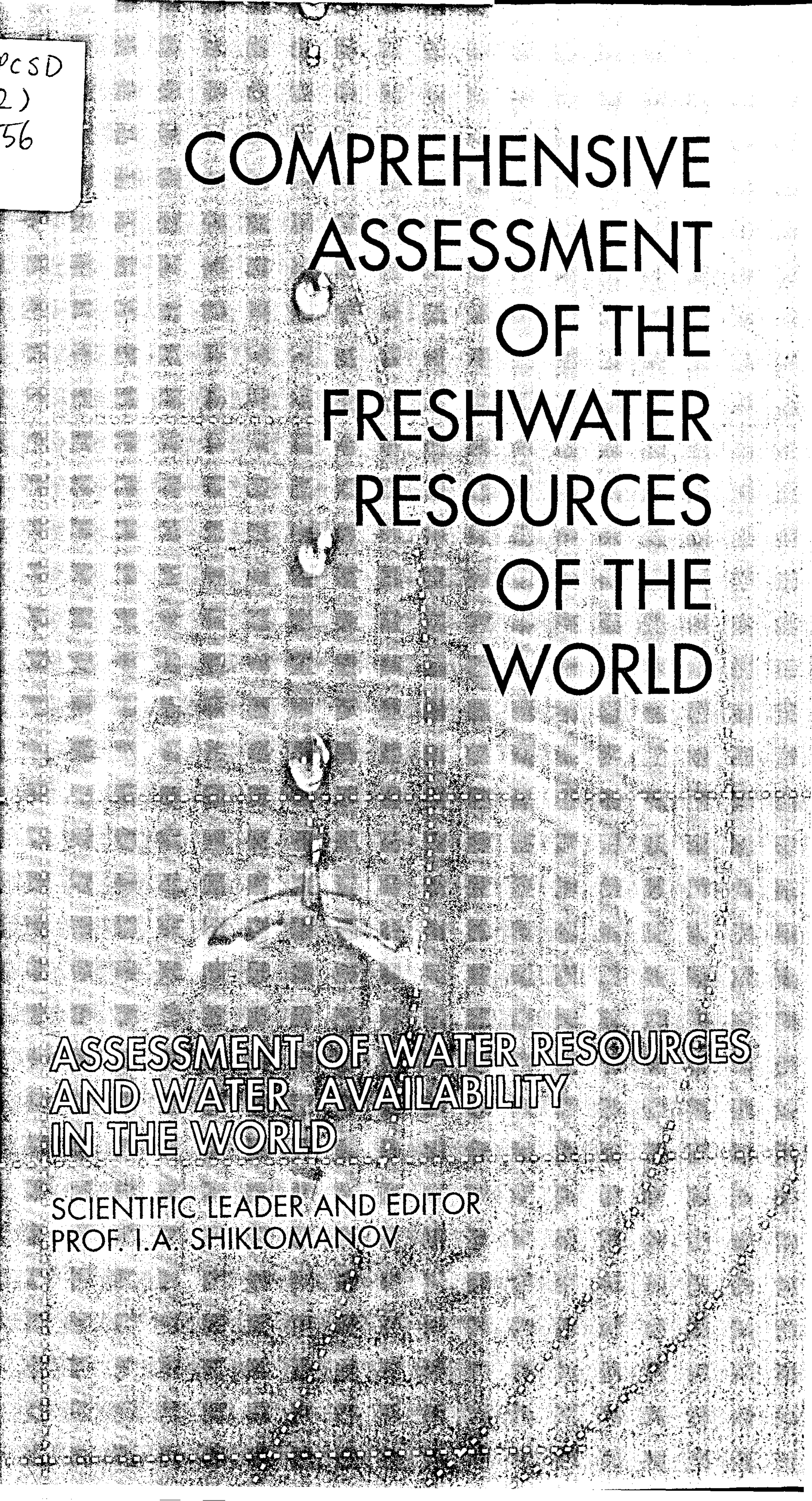

# COMPREHENSIVE ASSESSMENT OF THE FRESHWATER RESOURCES OF THE WORLD

## ASSESSMENT OF WATER RESOURCES AND WATER AVAILABILITY IN THE WORLD

SCIENTIFIC LEADER AND EDITOR
PROF. I.A. SHIKLOMANOV

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# FOREWORD

A rapidly growing demand on freshwater resources, resulting in increased water stress in several parts of the world, increasing pollution of freshwater resources and degraded ecosystems, made the UN Commission for Sustainable Development (CSD) in 1994 call for a Comprehensive Assessment of the Freshwater Resources of the World. The final report (E/CN.17/1997/9), prepared by a Steering Committee consisting of representatives for UN/DPCSD, Food and Agricultural Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), World Meteorological Organization (WMO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Health Organization (WHO), the United Nations Development Programme (UNDP), the United Nations Industrial Development Organization (UNIDO), the World Bank, and Stockholm Environment Institute, is presented to the CSD in 1997 and to the UN General Assembly Special Session in June 1997.

Within the process of the Assessment a number of background documents and commissioned papers were prepared by experts with various professional backgrounds. The document *Assessment of Water Resources and Water Availability in the World* is one of these. As a scientifically based document, any opinion expressed is that of the author(s) and does not necessarily reflect the opinion of the Steering Committee.

Gunilla Björklund
Executive Secretary
Comprehensive Freshwater Assessment
Stockholm, June 1997

# ABSTRACT

This report serves as the primary technical document source for Section 1 of the Comprehensive Freshwater Assessment. It contains an estimate of the water storage on the Earth, including fresh and salt water, the amount and distribution of the freshwater renewable resource, and estimates of past, present and future water withdrawals and consumption by sectors. The report also contains specific information on water quality and its implications for human health and the use — and overuse — made of groundwater to meet the ever growing needs of the world's population.

An evaluation is made of water availability per capita and regions of the world are identified where the present and future disparity between uses and renewable water supply will be the greatest. Future demand will be greatest in the developing countries because of population growth, and increasing agricultural and industrial sector utilization.

The report details the extreme difficulty in preparing a global assessment because of the lack of sufficient and reliable information on water availability, quality and use in many areas of the world. Efforts to balance supply and demand and plans for a sustainable future are severely hampered by this lack of information. International action is required to overcome these limitations, and assist those countries most in need to reach self-sufficiency in terms of reliable information and the capability to carry out water resource assessments and manage their water and related resources in a sustainable fashion.

# EXECUTIVE SUMMARY

This report was prepared by the State Hydrological Institute, St. Petersburg, Russian Federation, under the scientific leadership of Professor Igor A. Shiklomanov, who also acted as overall editor. Financial assistance was provided by UNESCO, WMO and the UN Department of Economic and Social Affairs. The report is the most recent and comprehensive global evaluation of the freshwater resources of the world and is based on previous work of the State Hydrological Institute, updated information obtained from UN and government agencies, and recent work carried out by international experts. The report serves as the primary technical document source for Chapter 2 of the Comprehensive Freshwater Assessment of the World.

The report contains an estimate of the water storage on the earth including fresh and salt water, the amount and distribution of the freshwater renewable resource, and estimates of past, present and future water withdrawals and consumption by sector. The report also contains specific information on water quality and its implications for human health, and the use and overuse made of groundwater to meet the ever-growing needs of the world's population.

Ninety seven and one-half per cent of all water on earth is salt water, primarily in the oceans. The total volume of freshwater storage is the remaining 2.5 per cent. The major portion of the freshwater (68.7) occurs as ice and perennial snow cover in Arctic and Antarctic regions and in the mountains. The most accessible water resource for human and ecosystem use is the freshwater contained in lakes, reservoirs and river channels. This amounts to only 0.26 per cent of the total amount of freshwater in storage, or 0.007 per cent of all water on earth.

The freshwater in rivers and streams, and that component of shallow groundwater recharged by rains, is a renewable resource and the primary source for all human and ecosystem uses. River runoff contributes more than 90 per cent of the global water supply and is the primary focus of the detailed evaluation of the renewable freshwater resources of the globe contained in the report. Representative streamflow data was used from 2,500 of the world's 40,000 hydrometric gauging stations and extended, where necessary, to the base time period of 1921-1985. Information gaps were filled by correlation techniques with streamflow in similar basins, and a "water budget" approach using meteorological data was utilized where no comparable streamflow data existed. In some cases, such as for Europe and North America, more recent streamflow data were incorporated. Based on this approach the total amount of renewable water resources in the world, computed for the period 1921 to 1985, is estimated to be 42,600 cubic kilometres per year. The per capita water availability in 1990 was 7,600 cubic metres per year, reduced from 12,900 cubic metres per year in 1970 because of population growth.

Renewable water resources are highly variable in time and space. To provide a better understanding of the actual availability of water resources, the seasonal distribution is provided by continents, and the annual variability by continents and regions. Annual mean values are also provided for 26 regions and 54 countries. Water availability per capita is also provided by the same region and country breakdown. A better measure of the actual availability is the base river flow, which averages 37 per cent of total river runoff or 18,800 cubic kilometres per year. The report notes that six countries, Brazil, Russia, Canada, the United States of America, China and India account for 49 per cent of the total river runoff in the world. The Amazon River, the largest river, represents 16 per cent of the runoff of the world total. The Amazon also has five times the flow of the next largest river, the Ganges.

The report contains detailed estimates of water withdrawal and water consumption by the sectors of municipal water supply, agriculture, industry and additional evaporation by reservoirs. Water withdrawal is the amount of water diverted, extracted or removed from surface water and groundwater. Some of the diverted water is not returned to rivers, lakes or other watercourses and this amount is called water consumption. Consumption includes water used by crops for transpiration or for building plant tissue, water evaporated from land and reservoirs and that part of the water diverted for industrial or community use that evaporates or is consumed. Water withdrawal and water consumption are estimated for the years 1900, 1940, 1950, 1960, 1970, 1980, 1990 and 1995. Projections are made to the years 2000, 2010 and 2025. The estimates were made at the country level and then generalized for river basins, regions and continents. Water withdrawal data are generally more reliable than water consumption, as water consumption had to be based on extrapolation from the limited number of countries with detailed reliable data. The irrigation sector is by far the biggest water user, accounting for 61 per cent of water withdrawal and 87 per cent of water consumption. Industry is the second largest water withdrawal sector, followed by municipal use and reservoirs respectively. Total global water withdrawal was 3 800 cubic kilometres in 1995 and water consumption was 2 280 cubic kilometres. Forecasts for the year 2025 are 5 200 cubic kilometres and 2 900 cubic kilometres for water withdrawal and water consumption, respectively.

The irrigation sector, the largest water user, has expanded tremendously over the past century. Between 1900 and 1995 irrigated area increased from 50 million hectares to 254 million hectares, an increase of 500 per cent. Fifty per cent of irrigated lands are concentrated in four countries: China, India, the United States of America and Pakistan. Irrigation area per capita peaked in the 1980s and has not kept up with population increases in recent years due to the costs of constructing new systems, problems of soil salinization, lack of water supply, and environmental consequences.

The report also evaluates water availability per capita and identifies the regions of the world where the present and future disparity between uses and renewable water supply will be the greatest. Future demand will be greatest in the developing countries because of population growth, and increasing agricultural and industrial sector utilization. A number of these countries are already overutilizing the renewable water supply. Major efforts will be required to bring supply and demand into balance, overcome overutilization of the non-renewable groundwater resource and address the serious problems associated with water quality deterioration and pollution.

The report details the extreme difficulty in preparing a global assessment because of the lack of sufficient and reliable information on water availability, its quality, and water use in many areas of the world. The lack of information is particularly severe in the developing countries, where the demand is often increasing most rapidly and scarcity is becoming a fact of life. Efforts to balance supply and demand, and plans for a sustainable future are severely hampered by this lack of information. International action is required to overcome these limitations and assist those countries most in need to reach self-sufficiency in terms of reliable information and the capability to carry out water resource assessments and sustainable management of the water and related resources.

# 1. INTRODUCTION

A reliable assessment of water resources, including the rate of their development, areal distribution and changes with time, are essential for carrying out regional hydrological investigations that serve as the basis for the design and development of multipurpose water management projects. The investigations also provide the basis for defining project economic cost and benefits, can lead to an improved standard of living and can ensure ecological sustainability.

At the very beginning of the present century, during the first stages of development of hydrological science, the basic investigations of hydrologists were aimed at the problems of estimating the water balance and water resources of individual regions. First, meteorological data were applied, and through the water balance approach compared to the limited streamflow data available and then used to extrapolate values to other basins and regions. As the availability of hydrological observation data increased, this information became the primary basis for the assessment of basin water resources on regional and global scales, and for the assessment of water resources variations in time and space. Reliability, and the methods used in these assessments, depended on the number of hydrological stations and on the duration of observations at those stations.

Freshwater in lakes and rivers has always sustained mankind, but the effect of man's activity on water resources in times past was generally insignificant and of a local nature. The natural water resources had a wonderful capacity to recover from the stresses placed on them and the ability to self-purify, and provided a sufficient quantity and quality of freshwater for most needs. Under these conditions the amount of water resources and their variability depended primarily on the natural variations of the climate. This situation has fundamentally changed during recent decades; in many regions and countries the effects of man's activity has become evident both in terms of water resources development and use, and in land use change to the basin surfaces where these water resources originate. This was to a great extent stimulated by a dramatic rise of water consumption in the world which began in the 1950s due to industrialization, construction of reservoirs and thermal power plants, intensive irrigation development to feed an expanding population, and changes in life-style as a result of scientific and technical development. The annual water consumption in the world during the 10-year period from 1951 to 1960 increased more than four times when compared with the previous decade.

During the past 25-30 years, intensive anthropogenic changes in the hydrological regimes of rivers and lakes has been observed, as well as changes to their water quality, water availability and water balance. The amount of water resources, and their distribution over time and space, depend not only on natural climate change but increasingly on the impacts of mankind. In many regions this impact is so significant that the water resources quantity and quality cannot satisfy the ever-growing needs for water, and hinders further economic progress and prosperity.

Particularly urgent freshwater problems are observed in arid regions where water resources are limited, the development of water resources is very intensive and the population growth is very high. The first UN World Conference on Water Resources held in Mar-del-Plata, Argentina in 1978 noted a scarcity in freshwater resources in one third of the countries of the world, mainly in those countries which were located in the more arid zones. It also noted that this situation might be expected to occur in the majority of countries before the end of the century. The Conference helped to stimulate wider international co-operation and efforts in the study and assessment of water resources, and led to the intensification of national and basin level investigations. The conference also attracted public attention, as well as the attention of governments, planning institutions and decision makers, to water problems and to the importance of water management and the need for further development of the hydrological sciences.

Anthropogenic changes to the global climate, caused by higher concentrations of carbon dioxide and of other "greenhouse" gases in the atmosphere, has the potential to impact significantly on the availability of water resources. Based on changes in climate characteristics predicted by climatologists, the amount of water resources, their time and space distribution, the extreme parameters of river runoff and the variability of these parameters will all be impacted upon. These potential changes must be taken into account in the assessment of future water availability, and in the development of long-term multipurpose plans for water resources development and protection. It is no longer satisfactory just to consider the natural variations experienced in the past.

The problems of assessment of water resources, water consumption and water availability in river basins on the sub-national level, to regional and to global scale, and for individual types of man's activity are receiving increased attention at the international level. Conferences such as the Conference on Water and the Environment, held in Dublin, Ireland in 1992, and the Ministerial Conference on Drinking Water and Environmental Sanitation, held in Norwjick, The Netherlands, in 1994 have helped to focus public and governmental attention on the nature of the creeping water crisis and the magnitude of the problem. The UN Conference on Environment and Development (UNCED) Conference (Rio de Janeiro, Brazil, 1992), and the resulting Agenda 21, have also assisted in providing additional definition to the problems and identifying the need for global action. In response, a number of governmental and non-governmental international organizations such as UNESCO, WMO, UNEP, FAO, International Association of Hydrological Science (IAHS), and International Water Resources Association (IAWR) have sponsored scientific conferences and symposia, and national efforts have resulted in the preparation of numerous publications in many countries. A number of integrated international activities have focused on the global and regional level as well.

Wide use of this information, focusing on a scientific generalization of world hydrological data, has made it possible for the State Hydrological Institute (SHI) of the Russian Federation to use a single methodological basis for a multipurpose assessment of water resource dynamics, water consumption and water availability, at both the regional and global scales. The assessment has been carried out for all continents, physiographic and economic regions, for selected countries and for individual river basins. A summary of results and basic conclusions of this work is presented in this report.

# 2. IMPLEMENTATION OF RESEARCH ON THE ASSESSMENT OF THE WORLD'S WATER RESOURCES

The renewable water resources of the world are generally defined as the freshwater resource contained in the rivers of the world and the shallow groundwater in the zone of intensive water exchange. Generally, the accounting is on an annual basis. Taking into account that most of the annually renewable shallow groundwater storage is drained by rivers, river runoff in fact makes up the greatest portion of the annually renewable freshwater resource. River systems, which are widely dispersed in all regions of the world and run over long distances, directly contribute more than 90 per cent of the global water supply used by mankind. As a consequence mean annual river runoff may serve as the basis for determining water availability in any large region of the world.

For individual specific regions and water users, an assessment of groundwater resources may be of great importance. In some arid regions (North Africa, Arabian Peninsula, Central Australia) water supply is provided primarily by direct groundwater withdrawal because of the lack of dependable surface water supplies, and includes deeper groundwater hydraulically not connected with river runoff. Groundwater is also widely used for drinking in many urban areas located in all climate regions. At the global scale, however, deeper groundwater hydraulically not connected with river runoff provides only an insignificant per centage of global water consumption.

Estimates of the total river runoff of the world, as the main component of the global water cycle, have been made since the end of the 19th century. The results of the different assessments differ greatly (up to 2.5-3 times). These results are now only of a historic interest and are summarized in the publications of Baumgartner and Reichel (1972, 1973). During the past 20-25 years various estimates have been published in Nace (1967), Lvovich, (1974), "World Water Balance and Water Resources of the Earth", 1974); Baumgartner and Reichel (1975); E. K. Berner and R. A. Berner (1987); as well as in the periodicals of the Institute of World Resources (World Resources, 1992). According to these estimates, mean total annual river runoff of the world is within the range of 37 400–44 500 $km^3$/year.

Of the above noted publications the most detailed and complete assessments of water balance and water resources on all the continents and physiographic zones of the Earth were contained in the Russian monograph "World Water Resources and Water Balance of the Earth" (1974) and the German monograph by Baumgartner and Reichel (1975). Although the two publications are now more than 20 years old they have been widely applied as the most reliable estimates available. More recent publications have generally not provided significant new information on the water resources of different continents, regions and countries. The results of various estimates are given in Table 2.1, and demonstrate the wide range of values, i.e. differences for individual continents of 30-40 per cent. These differences are mainly explained by the methods of total river runoff assessment. In the Russian publications the total river runoff has been directly determined from observed data obtained from hydrometric gauging stations. Baumgartner and Reichel computed river runoff by an indirect method as the difference between precipitation and evaporation. The latter approach generally gives larger errors in case of small values of river runoff and is not as applicable for the assessment of water resources in arid regions.

For example, data published in the works of I. A. Shiklomanov in "Nature and Resources" (Shiklomanov, 1990) and in the monograph "Water Crisis" edited by P. Gleick (Shiklomanov, 1993) are based on the monograph "World Water Balance and Water Resources of the Earth" (1974). Data periodically published by the Institute of Water Resources in Washington (World Resources, 1992) is based on a number of previous publications, covering the period from 1975 to 1987, primarily from the data of the Institute of Geography of the Russian Academy of Sciences (slightly corrected data of Prof. M. I. Lvovich, 1969-1972). Similarly, the recent publication of "Population Action International" ("Sustaining Water: Population and the Future of Renewable Water Supplies", 1993) is largely based on what can now be regarded as outdated information. This particular publication provided detail on total renewable water resources for 149 countries, specific indices of water availability per capita for 1955, 1990, and projected to 2025, taking into account future population growth. The publication was widely distributed within many countries, to international organizations, the public and politicians, and helped to highlight the nature of freshwater issues at the global level.

An analysis of the data contained in the Population Action International report by the State Hydrological

*Table 2.1 — Total river runoff from continents, according to different authors (in mm of depth)*

| *Author* | *Year* | *Europe* | *Asia* | *Africa* | *North America* | *South America* | *Australia and Oceania* |
|---|---|---|---|---|---|---|---|
| Lvovich | 1969 | 300 | 286 | 139 | 265 | 445 | 218 |
| Lvovich | 1972 | 319 | 293 | 139 | 275 | 583 | 226 |
| World Water Balance | 1974 | 283 | 324 | 153 | 339 | 661 | 280 |
| Baumgartner and Reichel | 1975 | 282 | 276 | 114 | 242 | 617 | 269 |
| Institute of Water Resources | 1992 | 312 | 324 | 126 | 326 | 588 | 263 |

Institute indicates a number of limitations, including lack of recent information for computation of water resources and water availability for many countries, double accounting of inflow for some countries located on international river basins, and the use of different methods, sources and time periods for determination of available water resources. There are also discrepancies when data is compared with more detailed information available at the country level.

During the last 20-25 years a number of attempts have been made to estimate the present and future water consumption at the global level. Analysis and comparison of the estimates are difficult because the available results are not homogeneous. Some authors give the computed total water consumption for the world as a whole, others classify water consumption over continents or by different water users. Some authors provide assessments of present and future water consumption, while others provide only the present or the future water consumption. Most of the authors do not estimate actual irretrievable water losses (true consumption as compared to water withdrawals) and they do not estimate water losses for additional evaporation from large man-made reservoirs. If we add that authors use different basic data and methodologies for the assessments for the past and future and that they refer the results to different years or design criteria, then it becomes evident how difficult it is to compare the conclusions drawn by different authors. Despite these limitations, it is interesting to compare major assessments of global water consumption published by different authors since 1967. The results of the comparison are shown in Figure 2.1, and contain the assessments of Doxiadis (1967), Kalinin (1968), Lvovich (1968, 1974), Holy (1971), SHI, made by the author of the present report together with G.P.Kalinin and published in the monograph "World Water Balance and Water Resources of the Earth" (1974), Falkenmark and Lindth (1974), Kalinin and Ermolina (1975), US Geological Survey, "Global 2000 report to the President of the U.S.: Entering the twenty-first century" (1980), Ambroggi (1980), and Riha (1982). A summary of the methodology and a critical analysis of these assessments are given in the monograph (Shiklomanov and Markova, 1987). This monograph also provides a detailed and complete assessment of the changes (1900–2000) in water withdrawal and water consumption for various economic sectors in different continents and physiographic and economic regions. These data, generalized for the whole world, are also shown in Figure 2.1.

The estimates made by Margat and Andreassian (Margat J., Andreassian, 1994), included in Figure 2.1, are lower than the estimates made by other authors. These publications estimated water withdrawal and water consumption for 30 regions of the world for 2010 and 2025, in comparison with data obtained for the end of 1980s. A simplified approach was used for the assessment of water consumed for municipal needs, for irrigation and for industry through the use of complex indices (population number and irrigated areas) with the coefficients constant for all countries and conditions. Future water withdrawal and consumption forecasts are also based on assumptions of significant reductions in industrial use in developed countries that appear to be at variance with the latest UNIDO data (Stztrepec, 1995) on the assessment of future industrial water consumption in different countries of the world. The Margat and Andressian estimates of water withdrawal are believed to be much lower than the other estimates, primarily due to under-estimation of industrial water consumption, not accounting for water diversions for thermal power generation and additional evaporation from man-made lakes. Nevertheless, the results of the critical analysis of the present and prediction of future water consumption in the world made by Prof. J.Margat, as well as information on different countries and regions given in his publication (Margat, 1994), are useful for assessing future global water consumption.

When analysing the general state of the art for the assessment of the global water resources and their use, the following conclusions can be drawn:

- Most of the detailed data on the world's water resources, their changes in time and space were published in the 1970s, and were based on the observation data prior to1965;
- Most detailed assessments of the changes of water consumption and water availability in the world, including their prediction up to 2000, were made in 1980s;
- During the last 20 years longer observation series became available on river runoff, precipitation and air temperatures and additional information was obtained on river runoff for poorly gauged areas in Africa, Asia and South America;
- National and regional assessments of the dynamics of water resources, water consumption and water availability were carried out and published for many countries and regions;
- Many publications were issued recently in which the present situation, trends and prospects of the global

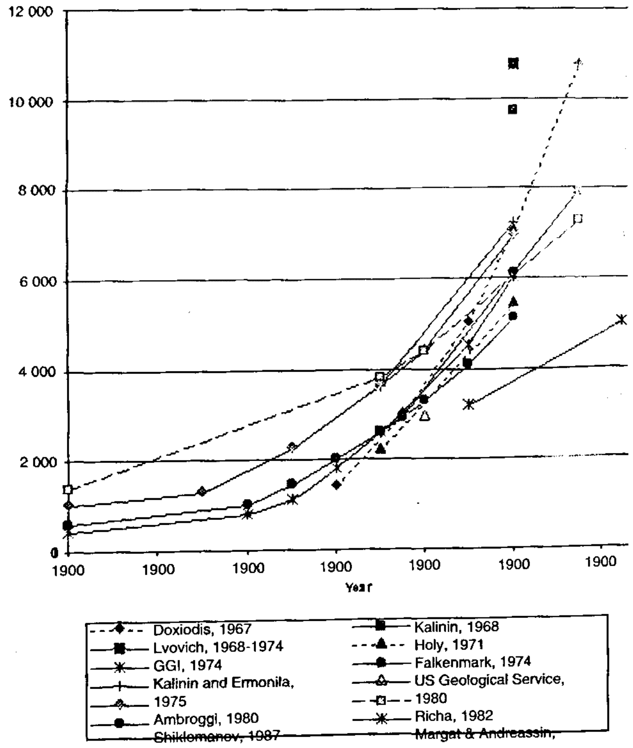


*Figure 2.1 World water withdrawal by the data of different authors*

development of industry and agriculture are described, including the development of irrigated farming and consumption for various needs; and
- New, more reliable forecasts are available on urban and rural population numbers, including forecasts well into the next century.

All these factors contribute to the implementation of multipurpose research and the development of new, more detailed and reliable data on the assessment of water resources, water consumption and water availability at the global level. It is now possible for the first time to make reasonable estimates of the quantity of freshwater resources available and the uses to which that water is put at the global and continental levels, over physiographic and economic regions, and to describe the changes for a long-term period and forecast into the future up to 2010-2025.

# 3. WORLD WATER STORAGE AND WORLD WATER CYCLE

A reliable assessment of freshwater storage in its different physical states on our planet is of great importance for a proper understanding of natural variations in the hydrological cycle and for estimation of man's possible impact on some components of this cycle, with particular reference to surface and subsurface runoff. Normally, values are expressed as long-term means to eliminate the impact of short-term changes.

Several estimates of water storage on the Earth have been published during the past 25 years: Nace (1967), Lvovich (1975), World Water Balance and Water Resources of the Earth, (1974), Baumgartner and Reichel (1975) and Berner and Berner (1967). A comparison of these data, given for example in the monograph edited by P. Gleick (Water in Crisis, 1994), shows that great differences are observed in some components. Differences are most evident in the assessment of groundwater storage, water storage in permafrost zones, and water storage in fresh and salt water lakes. An inter-comparison of the main components of the global hydrological cycle based on assessments by different authors is shown in Table 3.1. The largest differences are observed in the assessments of global freshwater resources. It is very difficult to evaluate the reliability of the data published by the different authors. The results are presented in greater detail and completeness in "World Water Balance and Water Resources of the Earth" (1974), where the data sources are described and the methodology of estimation is given.

Water storage on the Earth is given in Table 3.2, below, based on the results from several sources contained in that monograph.

It should be emphasized that the data on water storage on the Earth cannot be considered precise because of the lack of information on certain parameters. The least certainty can be attached to estimates of groundwater storage in the permafrost zone, and soil moisture and water storage in swamps. More reliability can be attached to the estimates of water storage in World Ocean, in lakes and

*Table 3.1 — Main components of global hydrological cycle, $km^3$*

| *Kinds of water* | *National Council on Scientific Research of the USA (1986)* | *World Water Balance and Water Resources of the Earth (1974)* | *A. Baumgartner /E. Reichel The World Water Balance (1975)* |
|---|---|---|---|
| Water content in atmosphere | 15 500 | 12 900 | 13 000 |
| over land | 4 500 | 3 100 | |
| over sea | 11 000 | 9 800 | |
| Transfer of moisture in the atmosphere from sea to the land | 36 000 | — | 39 700 |
| Precipitation (annual) over land | 107 000 | 119 000 | 111 000 |
| over sea | 398 000 | 458 000 | 385 000 |
| total | 505 000 | 577 000 | 496 000 |
| Evaporation and transpiration | 508 000 | 577 000 | — |
| (yearly) from land | 71 000 | 72 000 | 71 400 |
| from sea | 434 000 | 505 000 | 424 700 |
| Water storage on the land | 59 000 000 | 47 565 210 | 36 020 000 |
| ice and snow | 43 400 000 | 24 064 100 | 27 820 000 |
| surface water | 360 000 | 189 990 | 225 000 |
| groundwater | 15 300 000 | 23 400 000 | 8 062 200 |
| biological water | 2 000 | 1 120 | — |
| River runoff to ocean, annual | 36 000 | 47 000 = 44700surf + 2200underg | 39 700 |
| Water storage in ocean | 1 400 000 000 | 1 338 000 000 | 1 348 000 000 |
| Changeover of moisture in the atmosphere (per annum) | 33 times | 45 times | — |

*Table 3.2 — Water storage on the Earth*

| *Kind of water* | *Area of distribution km$^2$ ¥ 103* | *Volume, km$^3$ ¥ 103* | *Depth, m* | *Portion of water storage, in %* | |
|---|---|---|---|---|---|
| | | | | *of total water storage* | *of the amount of freshwater storage* |
| World Ocean | 361 300 | 1 338 000 | 3 400 | 96.5 | - |
| Groundwater | 134 800 | 234 001 | 174 | 1.7 | - |
| Freshwater included | 134 800 | 10 530 | 78 | 0.76 | 30.1 |
| Soil moisture | 82 000 | 16.5 | 0.5 | 0.001 | 0.05 |
| Glaciers and permanent snow cover, including: | 16 227 | 24 064 | 1 643 | 1.74 | 68.7 |
| Antarctica | 13 980 | 21 600 | 1 546 | 1.56 | 61.7 |
| Greenland | 1 802 | 2340 | 1 298 | 0.17 | 6.68 |
| Arctic islands | 226 | 83.5 | 369 | 0.006 | 0.24 |
| Mountain regions | 224 | 40.6 | 181 | 0.003 | 0.12 |
| Underground ice in the permafrost zone | 21 000 | 300 | 14.0 | 0.022 | 0.86 |
| Water stored in lakes including: | 2 059 | 1 76.4 | 85.7 | 0.013 | - |
| Freshwater storage | 1 236 | 91.0 | 73.6 | 0.007 | 0.26 |
| Saltwater storage | 822 | 85.4 | 104 | 0.006 | - |
| Water stored in swamps | 2 683 | 11.5 | 4.28 | 0/0008 | 0/03 |
| Water in river channels | 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 storage | 510 000 | 1 385 984 | 2718 | 100 | - |
| Freshwater storage | 148 800 | 35 029 | 235 | 2.53 | 100 |

Note: Does not include groundwater storage in Antarctica, approximately estimated at 2 000 000 km$^3$ including mainly freshwater storage of about 1 000 000 km$^3$.

reservoirs, in glaciers of polar and mountain regions, and in salt and fresh groundwater.

According to the data in Table 3.2, the total volume of freshwater storage equates to only 2.5 per cent of the total water storage of the Earth. Moreover, the major portion of the freshwater (68.7 per cent) occurs as ice and perennial snow cover in the Arctic and Antarctic regions and in the mountains. The most accessible water which is contained in river channels, freshwater lakes and reservoirs makes up only 0.27 per cent of the total freshwater storage on the Earth. It is this limited amount of accessible water that plays the main role in the global hydrological cycle and in the freshwater supply for human and ecosystem needs. The contribution of a particular water cycle component to global water circulation depends not only on the amount of water storage but, to a great extent, on the period of its renewal cycle or recovery. Based on the data contained in Table 3.3, the period for the complete renewal of some kinds of water varies within great limits, i.e. from several hours (biological water) up to several millennia (glaciers) and even dozens of millennia (groundwater). Atmospheric water is renewed every 8 days on average; water in rivers, every 16 days, in lakes, 17 years; and a complete renewal of water in oceans occurs once every 2 500 years.

River runoff, which is widely distributed geographically over the globe and has a high rate of complete renewal, is one of the most important water cycle components. Rivers have largely determined settlement patterns, heavily influenced economic development and are the lifeblood of

*Table 3.3 — Periods of complete renewal of water resources on the Earth ("World Water Balance and Water Resources of the Earth", 1974)*

| *Kinds of water* | *Period of renewal* |
|---|---|
| World Ocean | 2 500 years |
| Groundwater | 1 400 years |
| Soil moisture | 1 year |
| Polar ice floes and permanent snow park | 9 700 years |
| Mountain glaciers | 1 600 years |
| Underground ice in the perma frost zone | 10 000 years |
| Water storage in lakes | 17 years |
| Water in swamps | 5 years |
| Water in river channels | 16 days |
| Biological water | several hours |
| Atmospheric water | 8 days |

human and ecosystem activity. River runoff provides the major portion of the world's water withdrawals and water consumption.

Important differences in renewal of hydrospheric reservoirs is related to the diversity of their function and their participation in the global hydrological cycle, with some having mainly a transfer function and others a storage function.

The inter-connection between these different reservoirs is the basis of the hydrologic cycle; the storage reservoirs (aquifers, glaciers and lakes) ensuring a regulation role vis-à-vis the transfer mediums (atmosphere, rivers and transmissive aquifers).

*Table 3.4 — Functions of natural reservoirs*

| ***Type of reservoir*** | ***Transfer function*** | ***Storage function*** |
|---|---|---|
| rivers | major | secondary |
| soil moisture | minimal | limited |
| aquifers | variable | major |
| lakes | limited/weak | important (but restricted by low variability) |
| glaciers | very low | significant (but very slow response due to high inertia) |

# 4. WATER RESOURCES OF THE EARTH

## 4.1 Renewable Water Resources: Space-Time Variability

### *4.1.1 Base Data and Methodological Approaches*

In general, the renewable freshwater resources and their space-time variability may be determined on the basis of two methodological approaches: from meteorological data and from direct observations of river runoff. The meteorological data approach is usually applied in cases of inadequate hydrological observation data and the availability of detailed meteorological data. This approach is utilized for the assessment of water resources by developing regional correlations or coefficients between runoff and precipitation and other meteorological factors, or directly by using an equation of the long-term water balance of a river basin, i.e annual precipitation minus annual evaporation (Shiklomanov, 1988). Evaporation from basin surfaces is usually determined from methods developed in the 1940s and 1950s around the world, which made it possible to compute not only long-term values, but evaporation for particular years and months.

It should be noted that during recent decades the methods for the computation of evaporation have been applied mainly to studying the dynamics of the water balance of river basins and particular land areas with different physiographic features, not for water resources assessment. This is explained by the fact that computations of river runoff by the water balance equation are not particularly applicable to arid and semi-arid regions where river runoff is very low and of a similar magnitude to the error of determining precipitation and evaporation. Conversely, in humid regions with sparse hydrometric networks, meteorological data may be applied quite effectively for estimating the average characteristics of river runoff and total water availability.

As noted earlier in the report, the method to determine runoff from the difference between precipitation and evaporation was successfully applied in Germany (Baumgartner and Reichel, 1975) and it has been used at the continental scale for global estimates. Using this approach, it has been possible for the authors to develop ratios between water balance components (averaged for a long-term period) for particular continents, oceans, the northern and southern hemispheres, and various large regions. Estimates of river runoff, a very important water balance component which determines the renewable water resources available, are crude by this method in regions with a water deficit. From a water resources assessment perspective these arid regions are of great importance and there is also a strong interest in the extremes of variability as well as the mean values for longer time periods.

This report for the global assessment of water resources is based primarily on the use of observed data from the world hydrological networks, but utilizes meteorological data on a supplementary basis where hydrological information is deficient. This approach has been effectively applied by Russian scientists for the assessment of the global water balance and water resources as early as the 1970s ("World Water Balance and Water Resources of the Earth", 1974). Therefore, it is quite reasonable to apply this approach now, when longer observation series have been collected in most countries and previously non-accessible data for many poorly gauged areas in Africa, Asia and Latin America has become available. At present there are more than 64 000 hydrometric stations in the world (Rodda, 1995). When this report was prepared, runoff data on about 40 000 observation stations was available with the distribution of stations listed in Table 4.1 by continent.

Not all observation stations could be used directly because of missing periods of record, non-representative sites or short length of record. To the degree possible, data was used in the preparation of national and regional maps of isolines of mean annual river runoff. Data from about 2 500 observation stations were used for the assessment of renewable water resources, with the distribution of these stations over continents shown in Table 4.1 and in Figure 4.1. In general, these are the stations on the larger rivers, with systematic and reliable observation data more or less uniformly distributed over continents. Monthly and annual data for the whole observation period were utilized from each station. Unfortunately, a great number of the observation stations, especially those located in the developing countries in Africa and Latin America, have very short observation series. Moreover, the data from most of

*Table 4.1 – Distribution of observation stations by continents*

| *Continents* | *Total number of hydrometric stations* | *Used for assessment of water resources* | *Observation period* |
|---|---|---|---|
| Europe | 6 000 | 610 | 10-178 |
| Asia | 12 000 | 800 | 10-120 |
| Africa | 2 000 | 250 | 5-80 |
| North America | 12 000 | 300 | 10-130 |
| South America | 3 600 | 240 | 5-70 |
| Australia & Oceania | 3 000 | 200 | 5-80 |

the observation stations were available for 1983-1988 only. The standard observation period utilized for the computation of mean values and analysis of the dynamics of the renewable water resources, was 1921-1985. It should be noted that data was available up to 1990-1992 for some regions of Europe and North America, but similar recent information was not available from some other parts of the globe. The selection of a single, sufficiently long (65 years) design period makes it possible to get mean values of water resources for the whole world and to assess quite reliably the extreme values and characteristics of long-term water resources variability. To make the observation series longer, and to fill the gaps in observations at individual sites, the following well-known methodological approaches have been used: double and multiple correlations between different runoff parameters in adjacent rivers as well as methods of hydrological analogy. When it was impossible to get reliable correlations of runoff parameters meteorological data was used, i.e. observed data of precipitation and air temperature. The monthly precipitation and air temperatures for the whole observation period (up to 1990) from more than 7 000 meteorological stations were utilized in the analysis.

For river basins with long-term hydrometric observation series (including estimated data, if necessary), the water resources parameters (monthly, seasonal and annual values mean values and variability) were determined using standard statistical approaches. Adjustments were also made to observed values of runoff to account for runoff occurring between the observation station and the river mouth or basin outlet. These adjustments were usually based on isoline maps of specific discharge or runoff depth, or the hydrological analogy method was applied. In regions where river runoff occurs primarily in the mountains, and is used mainly for irrigation in downstream lowlands in the zone of water deficit, the total river runoff from the source areas is assumed to be the basin water resources.

For physiographic and economic regions and for some countries, the borders of which do not coincide with watershed boundaries or the location of hydrological stations, the quantity of water resources was determined by specially developed methods. The methods used included isolines, linear runoff equations, multiple regression, integral averaging of equations, and direct observations of surface runoff (Babkin et al., 1977, 1986; Shiklomanov, 1988).

The water resources available in any study region at the sub-basin level are based on a combination of the following: local runoff, inflow and outflow of river water. The local runoff is the runoff of all rivers and temporary streams formed on the territory of this region; inflow of river water is the total volume of water imported from adjacent areas; outflow of river water is the total amount of water discharged by all rivers and temporary streams beyond the boundaries of the region. The sum of the local runoff and river inflow is the total available renewable water resources of the region. In general, the larger the area of the study region the less is the difference between total and local water resources. For continents they coincide, for the majority of large countries and physiographic regions these differences are insignificant. However, for small countries the total available water resources may exceed local runoff by a factor of many times. In the latter case, the use of total water resources for the assessment of water availability in an

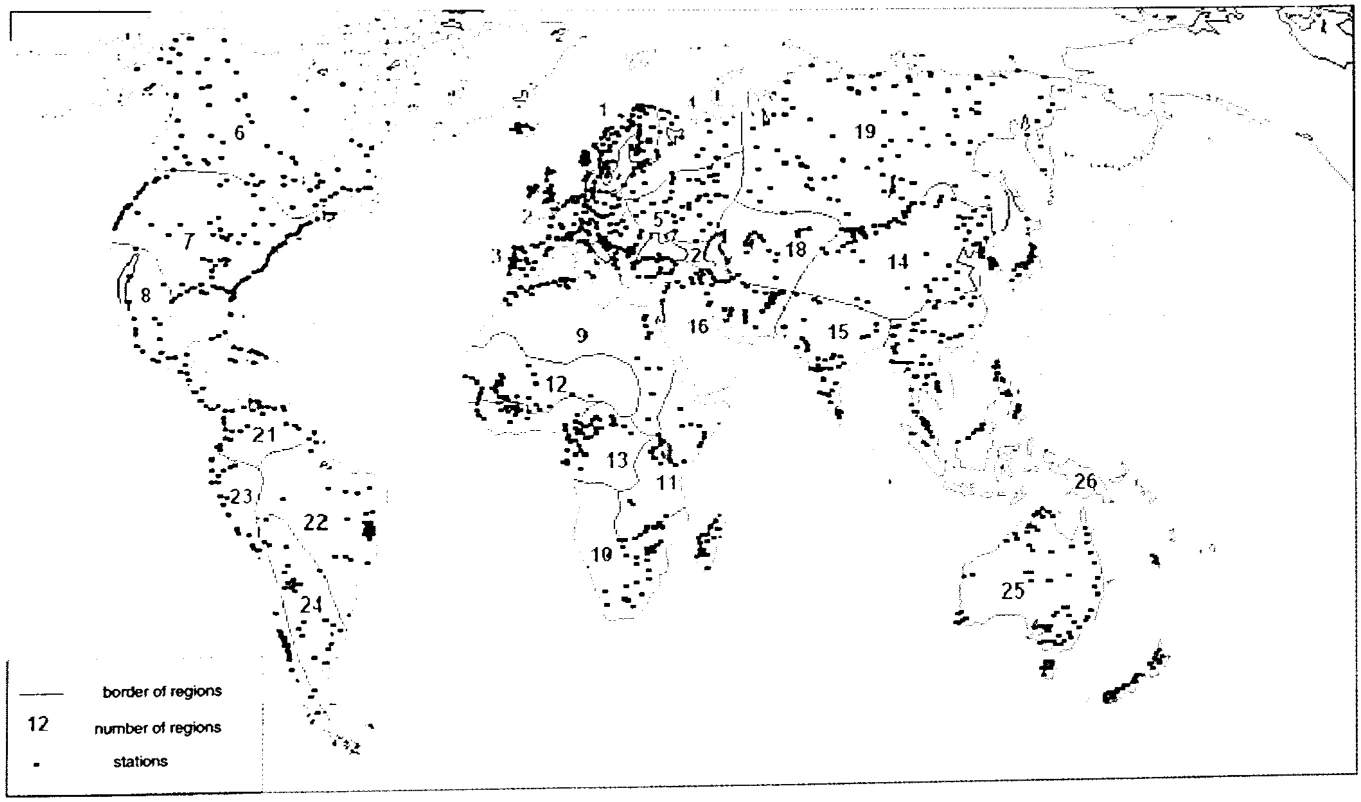


*Figure 4.1 — Main hydrological gauging stations, local water resources and percentage of their use in physiographic and economic regions of the world (in 1990)*

additive manner for several small regions is not correct and always gives overestimated results.

Yearly water resource characteristics for each region were determined from hydrometric data using either the so-called method of linear runoff equations or the method of integral averaging of surface runoff equations. The method of linear runoff equations divides the region into homogeneous sub-areas related to specific hydrometric stations. The quantity of water resources is determined from a linear equation which uses the yearly runoff values at hydrometric stations and the regional area. Weight coefficients, which are the ratio of runoff from the selected sub-area to the runoff at the hydrometric station, were applied. The value of weight coefficients was assumed to be constant for all years within the design period, and was determined from runoff values obtained from either the maps of isolines of specific discharges, or long-term runoff depths, or from the ratio of appropriate basin areas. In cases in which the method of integral averaging was used, the assessment of the water resources parameters for each region is based on a determination of the double integral of the surface runoff function taking into account basin coordinates and elevation (Babkin et al., 1974). The surface runoff equation normally takes the form of a polynomial equation with a variable exponent. This methodology takes into account not only the basin coordinates and average elevation, but also other factors which determine the amount of river runoff, such as soils and land use. An advantage of this method is the ability to use the same design equations and coefficients for various hydrometric sites, the number of which vary from year to year. The main difficulty of widespread application of this method is the necessity to establish reliable runoff relationships with elevation and other factors for all the regions, which generally requires detailed hydrological knowledge of the region. Therefore, this method was applied only to individual regions of the former Soviet Union territory (FSU). The two methods generally give similar results when applied to large areas. Using the two methods, the streamflow distribution during the year (by month) was determined as a percentage of the annual value, generally based on the average observed monthly runoff for the largest river basins located within the study region.

### 4.1.2 *Continents*

The renewable water resources of the rivers of the world, estimated by the use of methodological approaches described earlier in the report for physiographic and economic regions, and averaged for the continents, are given in Table 4.2. The total amount of renewable water resources in the world, based on a computational period of 1921-1985, has been estimated to be 42 600 km$^3$/year (without Antarctica). Compared to earlier estimates this is approximately 4 900 km$^3$ more than the value estimated by Paumgartner and Reichel (1975) and 1 900 km$^3$ less than the detailed estimates made by the SHI ("World Water Balance and Water Resources of the Earth", 1974) .

If we compare the assessments of water resources by individual continents (see Tables 2.1 and 4.2), the differences between the estimates of the SHI in 1974 and in 1995 are more significant and fall within the range of 5-12.4 per cent. The maximum differences are for Africa and Asia, which can be explained by the more reliable and complete data available for use in this report for poorly gauged regions of West and Central Africa, South-east Asia and Northern Canada. The second reason is the reduced river runoff observed during the last 20 years, most notable in Africa, Asia and Europe. This is evident from chronological graphs of total annual runoff by continents, as shown in Figures 4.2 and 4.3.

Table 4.2 provides data on the renewable water resources and potential water availability of the world by area and per capita. On average it was equal to 7 600 m$^3$/year per capita in 1994, ranging from 4 000 m$^3$/year per capita in Asia, to 38 000 m$^3$/year per capita in South America, and up to 84 000 m$^3$/year per capita for Australia and Oceania. It should be noted that the potential water availability per capita has been reduced by 1.7 times between 1970 and 1995 (from 12 900 to 7 600 m$^3$/year ). This reduction is primarily related to the population growth of 2 000 000 000 people over this time period. The maximum decrease in water availability per capita is observed in Africa (by 2.8 times), in Asia (double) and in the South America (by 1.7 times). By comparison, the water availability per capita in Europe has only decreased by 16 per cent ("World Water Balance and Water Resources of the Earth", 1974). The actual water availability, taking into account increased water uses, has

*Table 4.2 — Renewable water resources and water availability by continents*

| *Continent* | *Area (in mln. km$^2$)* | *Population in mln.* | *Water resources (in km$^3$/year)* | | | | *Potential water availability (in 1 000m$^3$/year)* | |
|---|---|---|---|---|---|---|---|---|
| | | | *Average* | *Max* | *Min* | *Cv* | *per 1 sq.km* | *per capita* |
| Europe | 10.46 | 685 | 2 900 | 3 210 | 2 442 | 0.10 | 278 | 4.2 |
| North America | 24.25 | 448 | 7 770 | 8 820 | 6 660 | 0.10 | 320 | 17 |
| Africa | 30.10 | 708 | 4 040 | 5 080 | 3 070 | 0.10 | 134 | 5.7 |
| Asia | 43.48 | 3 403 | 13 508 | 15 010 | 11 800 | 0.06 | 309 | 4.0 |
| South America | 17.86 | 315 | 12 030 | 14 350 | 10 330 | 0.07 | 674 | 38 |
| Australia and Oceania | 8.95 | 28.7 | 2 400 | 2 880 | 1 890 | 0.10 | 268 | 84 |
| The World | 135 | 5588 | 42 650 | 44 460 | 39 660 | 0.02 | 316 | 7.6 |

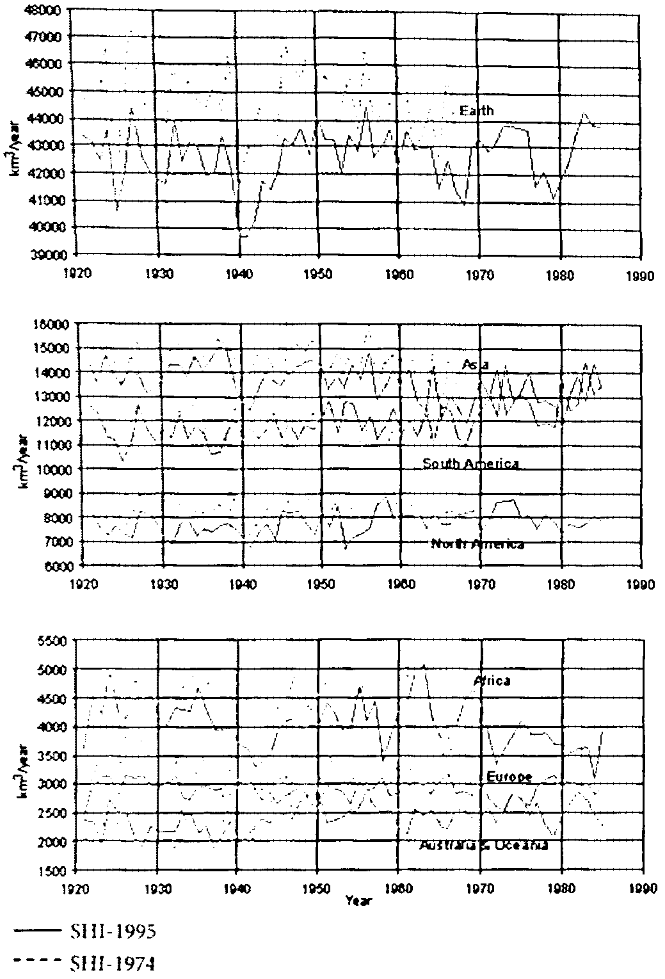


*Figure 4.2 — Renewable water resources of the Earth and continents*

been reduced even more significantly in the countries of Africa, Asia and South America (see Section 6 below).

Investigations of long-term runoff variations in different regions of the world always demonstrate the cyclic nature of these variations. The same can be said for total runoff variations by continents, as demonstrated in Figure 4.2, where it is possible to discover cycles of wet and dry years which follow one after another and differ in duration and magnitude of deviation from the mean value. When considering variations of the total river runoff of the world, it is possible to identify periods of lower water availability (1940-1944, 1965-1968, 1977-1979), when runoff values were lower than the average values by 1 600-2 900 km$^3$. Similarly the periods of 1926-1927, 1949-1952, and 1973-1975 were characterized by higher runoff values. Besides the cyclic nature of the total runoff variations, there is no definite trend in the renewable water resources during the 65-year study period. For example the apparent runoff increase in South America during last 20 years was compensated for by decreased runoff from the rivers in Africa for the same period (Figure 4.2).

A lack of any evident runoff increase or decrease for the rivers of the world for the period 1921-1985 would indicate that the impact of climate change on water resources at the global level is not yet detectable. Changes consistent with the conclusions of the IPCC ("Climate Change", 1990) cannot be supported by the river runoff information available at this time. The observed water level rise in the world ocean since the beginning of the present century can probably be attributed to intensive melt of mountain glaciers on the continents.

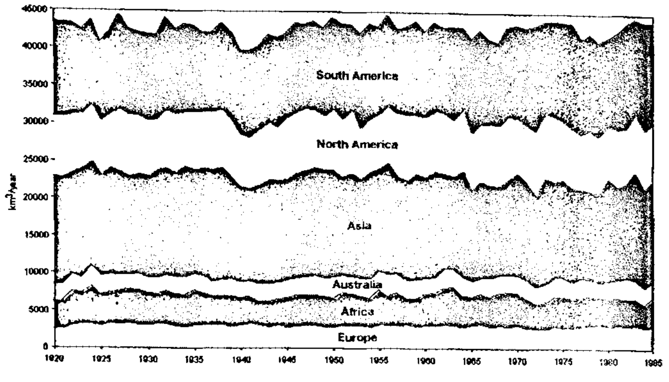


*Figure 4.3 — Renewable water resources of the Earth and continents*

The amount of average annual river runoff per capita per km$^2$ given in Table 4.2 is not a good measure of water availability for any continent or region. In the majority of regions the river runoff distribution is very uneven during the year. Most of it (60-70 per cent) occurs during the flood period which may not match the use patterns to which the water is put. There are also significant variations from year to year, particularly in arid zones .

Variations in the total river runoff over continents by months (in percentage of the total annual value) are shown in Figure 4.4. A comparison of these values with the estimates made by the SHI in 1974 (World Water Balance and Water Resources of the Earth, 1974) indicates quite similar results, except in Africa, where the use of new data on large rivers resulted in significant change to stream flow distribution during the year.

Based on the present assessment, the major portion of runoff in Europe occurs during April-July (46 per cent), in Asia during June-October (72 per cent), in Africa during August November (46 per cent), in North America during May-August (52 per cent), in South America during April-July (44 per cent), in Australia and Oceania during January-April (47 per cent). In general, for the land area, the wet season lasts from May to October. During this season, the total river runoff of the World equals about 63 per cent of the annual value.

Base flow, the amount of water available in the river most of the time, is very important for water supply. Its average value equals 37 per cent of the total river runoff ("World Water Balance and Water Resources of the Earth", 1974). Thus, the total base flow for the world equals 18 800 km$^3$/year. Where streamflow distribution is highly variable throughout the year it may become necessary to develop storage reservoirs to meet the needs during periods of low flow.

### 4.1.3 Physiographic and Economic Regions, Selected Countries and River Basins

Large physiographic and economic regions have been selected within the limits of each continent with more or less

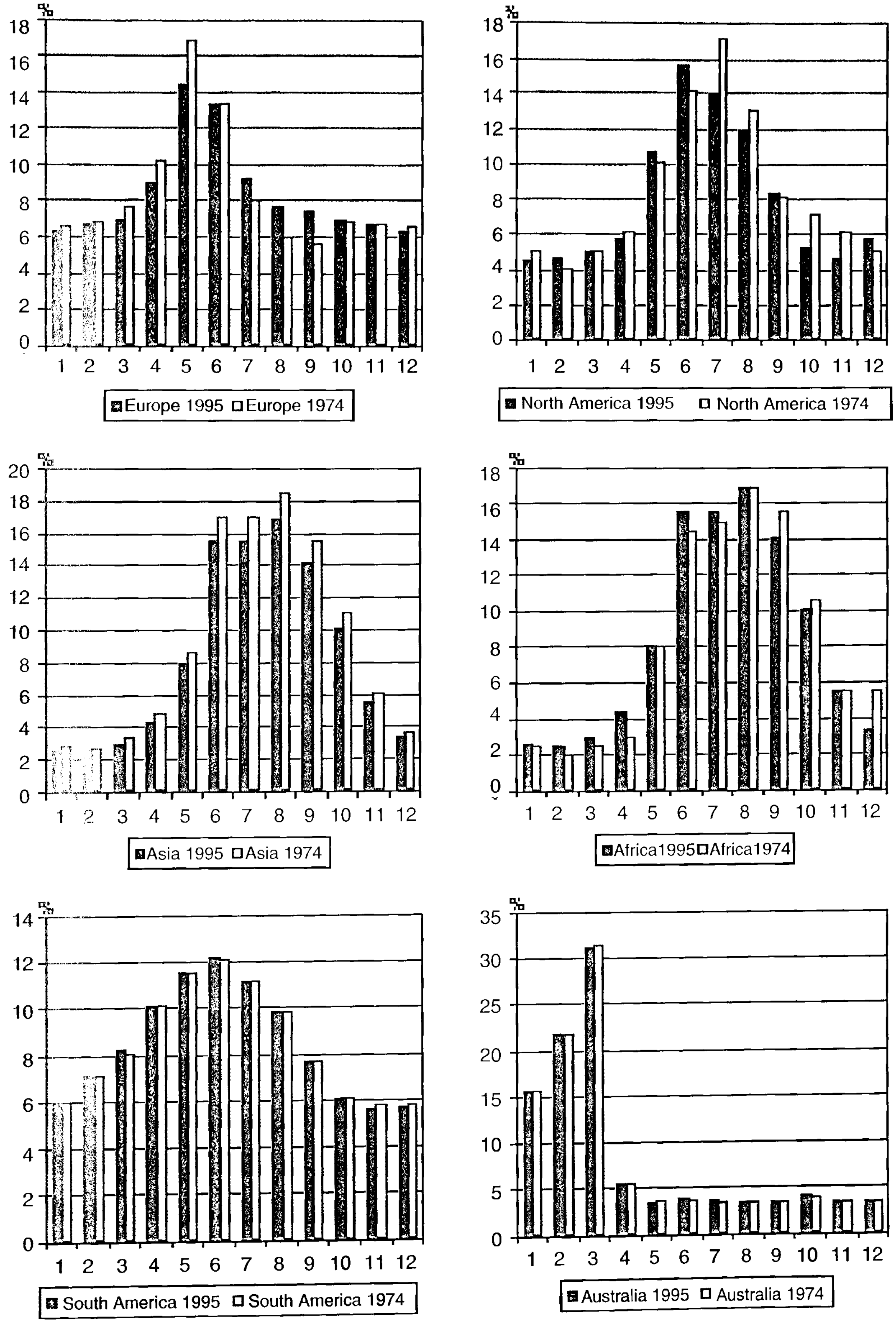


*Fig. 4.4 — Streamflow distribution during a year by continent*

homogeneous physiographic features and level of development to analyze space-time variations of the renewable water resources and water consumption in the world. Twenty-six regions have been selected, giving three to eight regions within each of the continents. In the majority of cases the boundaries selected for these regions were coincident with country boundaries, so that from one to 17 countries formed a region. The reason for this choice of regional boundaries was the necessity to analyze water resources together with population numbers and water consumption information, for which the data are published for countries only. Exceptions were made for very large countries (Russia, China and the United States of America) with individual parts of these countries included in various physiographic and economic regions. Distribution of countries according to physiographic and economic regions is shown in Table 4.3. Figure 4.1 shows the boundaries of these regions on a schematic map of the world.

For each region, using the base data and methodological approaches presented in Section 4.1.1, characteristics of the renewable water resources, for each year for the standard period (1921-1985) were obtained. The renewable water resources were broken down into local water resources, which are formed on the territory of the region and as water inflow imported from adjacent areas. For each region some extreme characteristics, and those averaged for a long-term period for each region, are given in Table 4.4. The areas of the selected regions vary within great limits, from 12-13 million km$^2$ (Siberia and the Far East of Russia, Canada and Alaska) down to 0.19 million km$^2$ (Trans-Caucasus), though most of the regions are from 1 to 8 million km$^2$ in area. Data in Table 4.4 demonstrate the extremely uneven distribution of renewable water resources over our planet, which generally does not coincide with the distribution of population. The unevenness is demonstrated by the potential water availability per unit area and per capita, which vary within wide limits; from 2 190 to 1 620 000 m$^3$/year per 1 km$^2$ and from 179 to 190 000 m$^3$/year per capita. It should be noted that the values of potential water availability in the table are calculated on the basis of the local water resources only. In some regions the inflow contributes a great portion of potential water availability and exceeds the local available water resources (e.g., South Europe and south of the European territory of the FSU, Central Asia and Kazakstan, eastern part of South America). For regions such as the central part of South America and North Africa, the amount of water inflow is comparable to the local water resources or greatly exceeds local water resources. In such cases the data in Table 4.4 underestimates the potential water availability, as inflow is not included. On the other hand, data in Table 4.4 was obtained from average values of renewable water resources, and the water resources variability from year to year may be quite significant, especially for the regions of water deficit. For such regions the coefficient of variation (Cv) of water resources is equal to Cv = 0.22 - 0.34, and the minimum value of water resources is 1.5-2 times less than mean annual values (Table 4.4). Concurrently, in regions with water surplus the water resources variability from year to year is insignificant and equals Cv = 0.08-0.10.

Long-term variations of the renewable water resources in the physiographic and economic regions of Africa and Europe are given in figures 4.5 and 4.6. The figures demonstrate the cyclic nature of these variations. The periods of lower water availability may last for up to three to six years, with such variations evident in practically all physiographic and economic regions.

Economic water resources development depends not only on the water resources variability from year to year, but also over seasons and months of the year. Total streamflow distribution during the year in various physiographic and economic regions (over months in per cent or annual runoff) is shown in Table 4.5. Many regions are characterized by extremely uneven distribution of streamflow during the year, as 60-80 per cent of annual runoff can occur during the three to four months of flood period. For example, during the three flood months in the North and South of the European territory of the FSU, 54 per cent of annual runoff occurs; in the Central part of South America and South Asia, 57 per cent; in Siberia and Far East, 59 per cent; in Australia, 68 per cent; and in West Africa, 80 per cent.

By contrast the river runoff in some regions during the low water period equals only 2-10 per cent of annual runoff. For example, during the three low-water months in the north of the European territory of the FSU, in Canada and Alaska and in North China and Mongolia the portion of annual runoff is 8-9 per cent; in Central America this portion equals 6.7 per cent; in Siberia, the Far East and in South Asia, 4 -5 per cent; in West Africa, only 0.8 per cent.

Renewable water resources and water availability have been determined not only for physiographic and economic regions but also for many countries from all the continents. More detailed estimates for each year of the standard design period of 1921-1985 have been developed for 53 countries, with the results of these estimates given in Table 4.6. The list of countries in this table covers developed and developing countries from all continents, countries with economies in transition, dense and sparsely populated countries, small and large countries, northern and southern countries, and countries with water surplus and water deficit. The countries listed in Table 4.6 contribute 69 per cent of the total world water resources produced by river runoff and contain 68 per cent of the global population.

Countries with the greatest renewable water resources are as follows: Brazil, Russia, Canada, the United States of America, China and India, with these six countries contributing about half (49 per cent) of the total river runoff of the world. These countries, with the exception of Canada, do not possess the maximum specific water availability. The maximum water availability per km$^2$ is observed in Panama (1 870 000 m$^3$/year) and in Surinam (1 411 000 m$^3$/year). The minimum water availability per km$^2$ is observed in Mauritania (390 m$^3$/year) and in Libya (3 010 m$^3$/year). The maximum water availability per capita is observed in Surinam (550 000 m$^3$/year), New Zealand (89 000 m$^3$/year) and in Canada (113 000 m$^3$/year). The minimum local water availability per capita among the countries for which data is present is in Mauritania (180 m$^3$/year) and in Jordan (180 m$^3$/year). However, if the water inflow imported from adjacent area is considered, the water availability per capita

*Table 4.3 — Distribution of countries according to physiographic and economic region*

| *Number of region* | *Continent, region* | *Countries (parts of countries) included in region* |
|---|---|---|
| | **Europe** | |
| 1 | Northern | Denmark, Finland, Iceland, Norway, Sweden |
| 2 | Western and Central | Austria, Belgium, Czech Republic, France, Germany, Ireland, Liechtenstein, Luxembourg, Monaco, The Netherlands, Poland, Slovakia, Switzerland, United Kingdom |
| 3 | Southern | Albania, Andorra, Azores (Spain), Bosnia and Herzegovina, Bulgaria, Croatia, Gibraltar, Greece, Hungary, Italy, Malta, Portugal, Romania, San Marino, Slovenia, Spain, TFYR of Macedonia, Vatican City, Yugoslavia |
| 4 | North of European part of FSU | part of Belarus, Estonia, Latvia, Lithuania, North of European Russia, |
| 5 | South of European part of FSU | part of Belarus, Moldova, South of European Russia, Ukraine |
| | **North America** | |
| 6 | Canada and Alaska | Canada, Alaska state of USA |
| 7 | USA | USA without Alaska and Hawaii |
| 8 | Central America and the Caribbean | Anguilla, Antigua, Aruba (Netherlands), Bahamas, Barbados, Barbuda, Belize, Bermuda, British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, France (Guadeloupe), France (Martinique), Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico, Saint Lucia, St. Kitts-Nevis, St. Martin, St. Vincent, Trinidad and Tobago, Turks and Caicos Islands, U.S. Virgin Islands |
| | **Africa** | |
| 9 | Northern | Algeria, Egypt, Libya, Morocco, Spain (Canary Islands), Sudan, Tunisia, Western Sahara |
| 10 | Southern | Angola, Botswana, Cabinda (Angola), Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe |
| 11 | East | Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Europa Islands, France (Réunion), Kenya, Madagascar, Mauritius, Mayotte, Rwanda, Seychelles, Somalia, Tanzania, Uganda |
| 12 | West | Benin, Burkina Faso, Cape Verde, Chad, Côte d'Ivoire, Gambia, Ghana, Guinea,Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo |
| 13 | Central | Cameroon, Central Africa, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Zaire |
| | **Asia** | |
| 14 | North China and Mongolia | China without the Yangtze river basin, DPR of Korea, Mongolia, Republic of Korea |
| 15 | Southern | Bangladesh, Butan, India, Maldives, Nepal, Pakistan, Sri Lanka |
| 16 | Western | Afghanistan, Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Republic of Yemen, Saudi Arabia, Syria, Turkey, United Arab Emirates |
| 17 | South East | Burúnei Darussalam, Cambodia, China (Yangtze River basin), Hong Kong, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, Singapore, Taiwan, Thailand, Vietnam |
| 18 | Central Asia and Kazakstan | Kazakstan, Kyrghyzstan, Tajikistan, Turkmenistan, Uzbekistan |
| 19 | Siberia and Far East of Russia | Asian part of Russia |
| 20 | Caucasus | Armenia, Azerbaijan, Georgia |
| | **South America** | |
| 21 | Northern | Colombia, France (Guyane), Guyana, Surinam, Venezuela |
| 22 | Eastern | Brazil |
| 23 | Western | Chile, Ecuador, Peru |
| 24 | Central | Argentina, Bolivia, Falkland Islands, Paraguay, Uruguay |
| | **Australia and Oceania** | |
| 25 | Australia | Australia |
| 26 | Oceania | Cook Islands, Fiji, French Polynesia, Hawaii (USA), Nauru, New Caledonia, New Zealand,Niue, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu, Western Samoa |

*Table 4.4 — Renewable water resources and water availability of physiographic and economic regions of the world*

| *Number of region* | *Continent, region* | *Area mln.km²* | *Population in mln. 1994* | *Water resources* | | | | | *Water availability (in thou. m³/year)* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Inflow km³/year* | *average* | *min* | *Local max* | *Cv* | *per 1 km²* | *per capita* |
| | **Europe** | 10.45 | 684.7 | | 2 900 | 2 440 | 3 210 | 0.10 | 278 | 4.24 |
| 1 | Northern | 1.32 | 23.5 | | 705 | 585 | 828 | 0.10 | 534 | 30.0 |
| 2 | Western and Central | 1.86 | 295.2 | 6.0 | 617 | 353 | 836 | 0.21 | 332 | 2.09 |
| 3 | Southern | 1.79 | 186.0 | 109 | 546 | 377 | 838 | 0.18 | 305 | 2.94 |
| 4 | North of the European part of FSU | 1.96 | 28.4 | 26.7 | 589 | 434 | 775 | 0.12 | 301 | 20.7 |
| 5 | South of the European part of FSU | 3.52 | 151.6 | 123 | 443 | 266 | 756 | 0.17 | 126 | 2.92 |
| | North America | 24.3 | 447.8 | | 7 770 | 6 660 | 8 820 | 0.1 | 320 | 17.0 |
| 6 | Canada and Alaska | 13.67 | 29.7 | 13.0 | 4 980 | 4 360 | 5 830 | 0.10 | 364 | 167.7 |
| 7 | USA | 7.84 | 260.0 | 67.0 | 1 700 | 950 | 2 480 | 0.17 | 217 | 6.54 |
| 8 | Central America and Caribbean | 2.74 | 158.1 | 3.0 | 1 090 | 530 | 2 000 | 0.20 | 399 | 6.89 |
| | **Africa** | 30.1 | 708.3 | | 4 047 | 3 073 | 5 082 | 0.1 | 134 | 5.7 |
| 9 | Northern | 8.78 | 157.0 | 140 | 41 | 19.0 | 96.0 | 0.34 | 4.67 | 0.26 |
| 9a | of which, Sahel | 5.30 | 46.94 | 77.4 | 104 | 52.3 | 175 | 0.29 | 19.6 | 2.21 |
| 10 | Southern | 5.11 | 83.53 | 86.0 | 399 | 270 | 549 | 0.14 | 78.1 | 4.78 |
| 11 | East | 5.17 | 193.5 | 26.0 | 749 | 504 | 940 | 0.11 | 144.9 | 3.87 |
| 12 | West | 6.96 | 211.3 | 30.0 | 1 088 | 581 | 1 948 | 0.28 | 156.3 | 5.15 |
| 13 | Central | 4.08 | 62.85 | 80.0 | 1 770 | 1 453 | 2 263 | 0.09 | 433.8 | 28.2 |
| | **Asia** | 43.5 | 3403 | | 13 508 | 11 800 | 15 000 | 0.06 | 310 | 3.96 |
| 14 | North China and Mongolia | 8.29 | 409 | | 1 029 | 590 | 1 630 | 0.23 | 124 | 2.52 |
| 15 | Southern | 4.49 | 1207 | 300 | 1 988 | 1 535 | 2 458 | | 443 | 1.65 |
| 16 | Western | 6.82 | 232.4 | | 490 | 297 | 622 | 0.18 | 71.8 | 2.11 |
| 16a | of which, Arab Peninsula | 3.11 | 37.98 | — | 6.80 | 1.77 | 12.8 | 0.31 | 2.19 | 0.179 |
| 17 | South East | 6.95 | 1442 | 120 | 6 646 | 5 342 | 7 607 | 0.1 | 956 | 4.61 |
| 18 | Central Asia and Kazakstan | 3.99 | 54.0 | 46.0 | 181 | 121 | 265 | 0.23 | 45.4 | 3.35 |
| 19 | Siberia and Far East of Russia | 12.76 | 42.5 | 218 | 3 107 | 2 725 | 3 412 | 0.05 | 244 | 72.7 |
| 20 | Caucasus | 0.19 | 16.5 | 12.1 | 67.8 | 51.5 | 85.4 | 0.12 | 364 | 4.11 |
| | **South America** | 17.9 | 314.5 | | 12 030 | 10 330 | 14 350 | 0.07 | 674 | 38 |
| 21 | Northern | 2.55 | 48.6 | | 3 340 | 2 390 | 4 670 | 0.15 | 1310 | 68.7 |
| 22 | Eastern | 8.51 | 159.1 | 1900 | 6 220 | 5 200 | 7 640 | 0.08 | 731 | 39.1 |
| 23 | Western | 2.33 | 57.3 | | 1 720 | 992 | 2 380 | 0.18 | 738 | 30.0 |
| 24 | Central | 4.46 | 49.4 | 720 | 750 | 531 | 1 310 | 0.17 | 168 | 15.2 |
| | **Australia and Oceania** | 8.95 | 28.7 | | 2 400 | 1 890 | 2 880 | 0.1 | 268 | 84 |
| 25 | Australia | 7.68 | 17.9 | | 352 | 228 | 701 | 0.24 | 45.8 | 19.7 |
| 26 | Oceania | 1.27 | 10.8 | | 2 050 | [illegible] | [illegible] | [illegible] | 1620 | 190 |
| | **The World** | **135** | **5580** | | **42 655** | | | | **316** | **7.6** |

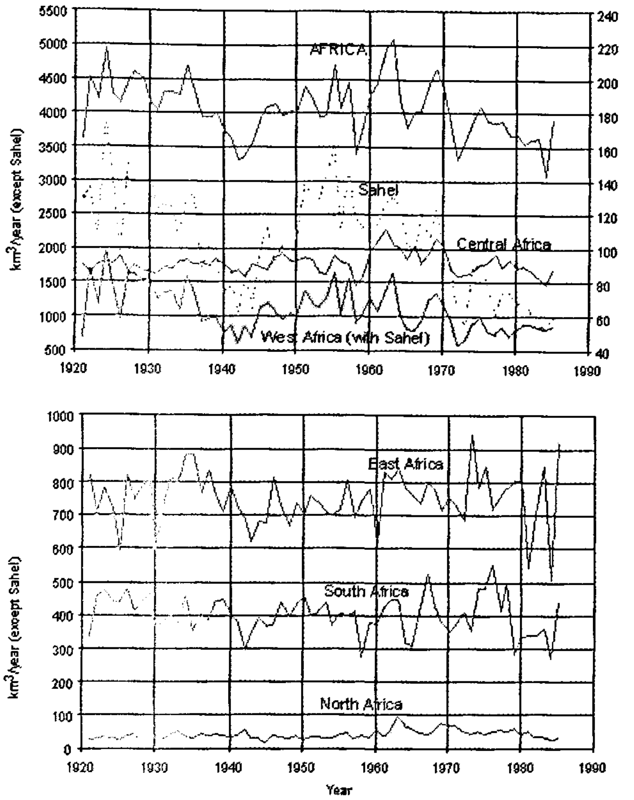


*Figure 4.5 — Renewable water resources of Africa and its regions*

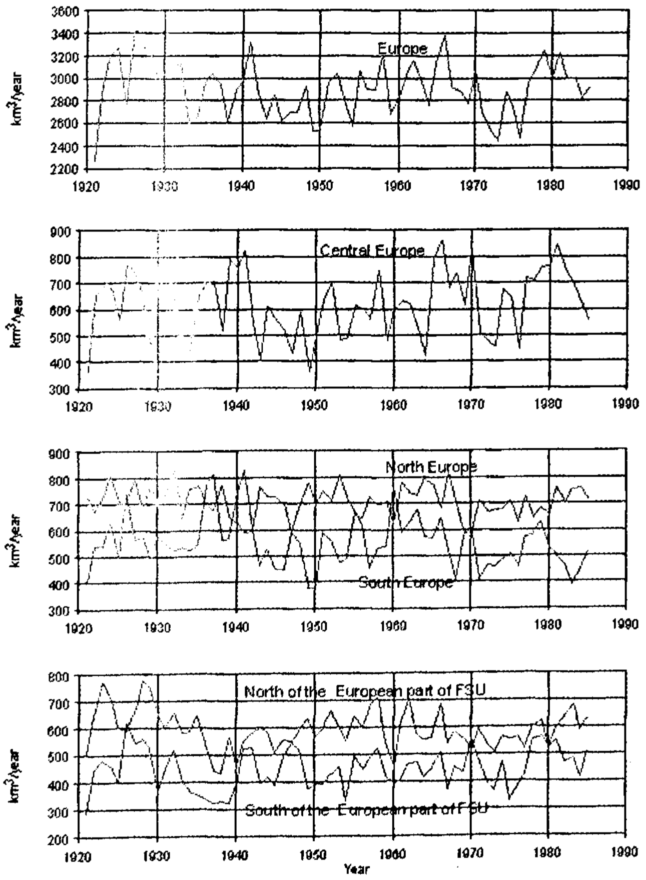


*Figure 4.6 — Renewable water resources of Europe and its regions*

would increase considerably for some countries. Countries of the world, classified by renewable water resources per capita, are shown in Figure 4.7 based on the work of Margat (1994).

The assessment of water resources in the selected countries presented in Table 4.6 improves greatly on the previous assessments published in different publications ("World Water Balance and Water Resources of the Earth", 1994; "Water in Crisis: A Guide to the World's Fresh Water Resources", 1993). The differences may be as much as tens of per cent, and may differ by several orders of magnitude for some water resources characteristics.

Table 4.7 shows characteristics of the renewable water resources for 24 selected rivers of the world from different continents. The data are quite reliable for annual and monthly runoff, as information was available for all of the standard period for each of these rivers. Total water resources of these selected rivers make up 40 per cent of the volume of the world river runoff, and one third of the world population inhabits these river basins. In addition to the mean and extreme river runoff characteristics and variations of these characteristics, the approximate data on basin population in 1994 are given in this table. Population data make it possible to compute specific water availability. The maximum potential is observed in the rivers of South America and South-eastern Asia , with water availability of 500 000-1 000 000 m$^3$/year per 1 km$^2$ of the basin area. The least potential is observed in the rivers of the basins which are located in the zones of water deficit. The water availability of these rivers varies within 20 000-100 000 m$^3$/year per 1 km$^2$.

The potential water availability per capita in these river basins is highly variable. The water availability of densely populated river basins is only 1 000-5 000 m$^3$/year per capita. In comparison, some large river basins with sparse population (Amazon, Mackenzie, Lena river basins ) have very high water availability which ranges between 200 000-1 000 0000 m$^3$/year per capita. Even greater differences in water availability are observed when streamflow distribution during the year, and year to year variability, are considered.

### 4.1.4 Groundwater and Surface Runoff

Surface and underground flows can be linked if there is a hydraulic connection between aquifers and rivers. A major part of the total continental river runoff has at the same time both underground and surfical sources, dependent on the climatic and hydrogeological conditions. In humid zones the major part of base river flow corresponds to groundwater flow provided by the inter-connected drained aquifers. Analysis of river hydrographs is the best approach for assessing groundwater inflow. In arid and semi-arid zones, an important part of aquifer recharge is provided, in a reverse way, by river losses during floods.

However, a part of the groundwater flux is not hydraulically linked with rivers (direct discharge to the seas or evaporation) and cannot be assessed by a surface flow analysis. Consequently, any renewable water resources assessment must take into account the following points:

*Table 4.5 Streamflow distribution during a year for the continents and physiographic and economic regions (in % of the mean annual value)*

| *Number of Region* | *Continent, Region* | *Mean Annual Water Resources (local) km³/year* | *Month* 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | *Year* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Europe | 2 900 | 6.2 | 6.6 | 6.9 | 8.9 | 14.3 | 13.3 | 9.2 | 7.6 | 7.3 | 6.9 | 6.6 | 6.2 | 100 |
| 1 | Northern | 705 | 4.9 | 4.9 | 4.6 | 4.4 | 8.8 | 15 | 15.4 | 12.6 | 10.2 | 7.8 | 6 | 5.4 | 100 |
| 2 | Western and Central | 617 | 9.7 | 10.8 | 9.7 | 9.4 | 8.3 | 8.5 | 8.2 | 7.1 | 6.3 | 6.2 | 6.9 | 9 | 100 |
| 3 | Southern | 546 | 7.6 | 8.0 | 9.5 | 11 | 11.5 | 10.7 | 9 | 7.1 | 6 | 5.7 | 6.4 | 7.5 | 100 |
| 4 | North of the European part of FSU | 589 | 3 | 2.5 | 3 | 6.5 | 25.8 | 19.7 | 8.9 | 6.2 | 6.5 | 7.8 | 6 | 4.1 | 100 |
| 5 | South of the European part of FSU | 443 | 3.6 | 3.5 | 5.2 | 12.4 | 23.1 | 17.7 | 9.5 | 6.1 | 4.8 | 5 | 5 | 4.1 | 100 |
| | North America | 7 770 | 4.4 | 4.5 | 4.9 | 5.6 | 10.6 | 15.5 | 13.9 | 11.8 | 8.3 | 5.2 | 4.5 | 5.6 | 100 |
| 6 | Canada and Alaska | 4 980 | 3.3 | 3 | 2.8 | 3.4 | 11.8 | 19.7 | 15.7 | 12.8 | 10.3 | 8.2 | 5.2 | 3.8 | 100 |
| 7 | USA | 1 700 | 8.8 | 10.5 | 12.7 | 14.2 | 12.3 | 9.3 | 7.3 | 4.9 | 4 | 4.1 | 4.9 | 7 | 100 |
| 8 | Central America and the Caribbean | 1 090 | 2.7 | 2.3 | 2.3 | 2.1 | 2.4 | 6.2 | 15.6 | 17.7 | 24 | 15.1 | 5.8 | 3.8 | 100 |
| | Africa | 4 047 | 6.7 | 6.2 | 5.5 | 7.1 | 8.4 | 6.5 | 6.7 | 9.3 | 14.8 | 13.6 | 8.5 | 7.4 | 100 |
| 9 | Northern | 41 | 5.96 | 6.11 | 6.4 | 6.16 | 6.13 | 6.11 | 7.24 | 9.84 | 7.85 | 11.8 | 13.9 | 12.5 | 100 |
| 10 | Southern | 399 | 17.8 | 13.4 | 10.8 | 7.35 | 4.91 | 3 | 6 | 6.93 | 7.31 | 6.08 | 7.02 | 9.4 | 100 |
| 11 | East | 749 | 4.55 | 8 | 7.72 | 15.8 | 21.7 | 11.3 | 6.84 | 5.26 | 4.49 | 6.35 | 4.9 | 3.09 | 100 |
| 12 | West | 1 088 | 1.04 | 0.56 | 0.36 | 0.17 | 0.27 | 1.17 | 5.53 | 17.3 | 33.6 | 28.7 | 8 | 3.3 | 100 |
| 13 | Central | 1 770 | 8.56 | 7.22 | 6.64 | 7.57 | 8.63 | 8.65 | 7.54 | 6.57 | 7.9 | 9.02 | 10.5 | 11.2 | 100 |
| | Asia | 13 508 | 2.5 | 2.4 | 2.9 | 4.3 | 7.8 | 15.4 | 15.4 | 16.7 | 14 | 10 | 5.4 | 3.2 | 100 |
| 14 | North China and Mongolia | 1 029 | 2.5 | 2.3 | 3.4 | 6.1 | 6.8 | 6.6 | 11.5 | 17.7 | 17.2 | 13.6 | 8.4 | 3.9 | 100 |
| 15 | Southern | 1 988 | 1.4 | 1.9 | 2.1 | 3.7 | 5.2 | 11.2 | 14.1 | 25.3 | 18 | 11 | 4 | 2.1 | 100 |
| 16 | Western | 490 | 7.9 | 9.4 | 14 | 16.8 | 15 | 8.4 | 4.8 | 3.5 | 2.9 | 4 | 5.9 | 7.4 | 100 |
| 17 | South-East | 6 646 | 2.6 | 2.5 | 3 | 4.4 | 7.3 | 10.9 | 17.1 | 17.4 | 14.4 | 10.3 | 6.5 | 3.6 | 100 |
| 18 | Central Asia and Kazakstan | 181 | 3.5 | 3.5 | 4.1 | 7.9 | 14.6 | 17 | 16 | 12.4 | 7.9 | 5.3 | 4.2 | 3.6 | 100 |
| 19 | Siberia and Far East of Russia | 3 107 | 1.8 | 1.4 | 1.2 | 1.5 | 9.3 | 31.6 | 15.7 | 12 | 11.9 | 8.7 | 3 | 1.9 | 100 |
| 20 | Caucasus | 68 | 6.1 | 6.7 | 7.3 | 15.9 | 19.5 | 12.3 | 6.9 | 4.6 | 4.3 | 5 | 5.9 | 5.5 | 100 |
| | South America | 12 030 | 5.9 | 7 | 8.1 | 10 | 11.4 | 12.1 | 11.1 | 9.7 | 7.6 | 6 | 5.5 | 5.6 | 100 |
| 21 | Northern | 3 340 | 4.2 | 3 | 2.5 | 3.1 | 6.2 | 10.2 | 13.5 | 15.3 | 14.7 | 11.8 | 9 | 6.5 | 100 |
| 22 | Eastern | 6 220 | 6.8 | 8.2 | 9.4 | 10.4 | 11 | 11 | 10.2 | 9.1 | 7.3 | 5.6 | 5.2 | 5.8 | 100 |
| 23 | Western | 1 720 | 8.3 | 9.6 | 10.8 | 9.2 | 9.2 | 9.3 | 7.9 | 7.1 | 6.5 | 6.7 | 7.8 | 7.6 | 100 |
| 24 | Central | 750 | 9.2 | 11.8 | 12.8 | 12.2 | 9.5 | 9.3 | 6.6 | 5.2 | 5.4 | 5.3 | 5.9 | 6.8 | 100 |
| | Australia and Oceania | 2 400 | 10.5 | 13.5 | 12.6 | 10.3 | [illegible] | 7.1 | [illegible] | 6.9 | [illegible] | 6.6 | 7.2 | 7.2 | 100 |
| 25 | Australia | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 5.74 | 3.21 | 3.15 | 100 |
| 26 | Oceania | 2 050 | 9.52 | 12 | 9.35 | 11.1 | 8.15 | 7.72 | 6.7 | 6.4 | 5.75 | 7.02 | 7.87 | 7.9 | 100 |

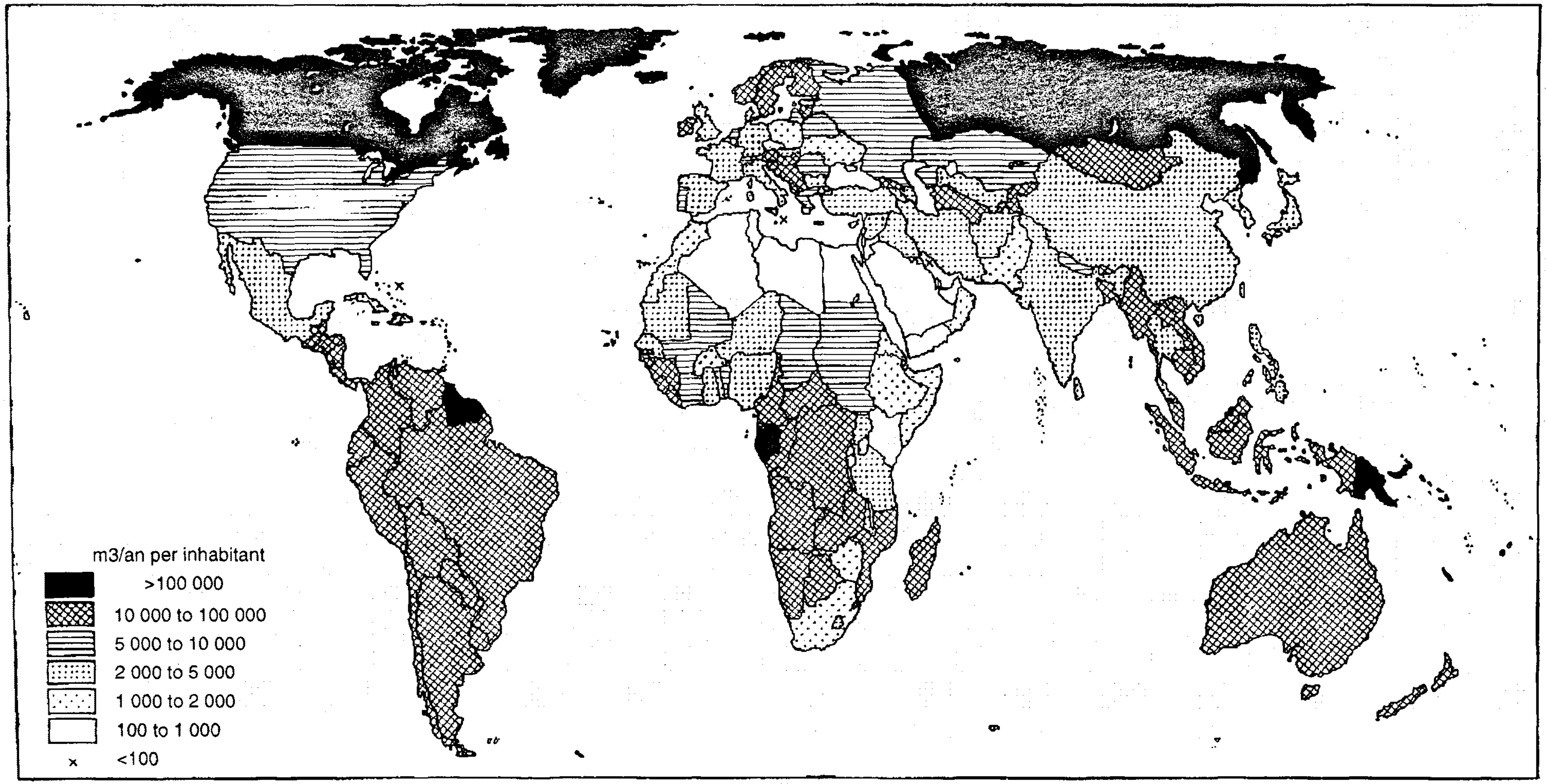


*Figure 4.7 — Countries classified by natural renewable water resources (local and inflow, mean annual) per capita, related to population in 1995*

*Table 4.6 — Renewable water resources and water availability of selected countries of the world*

| Countries | Area in mln.km² | Population in mln. | Inflow | Water resources km³/year Average | Local Max | Min | Cv | Potential water availability (in 1000m³/year) per km² | per capita |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 7.68 | 17.9 | 0 | 352 | 701 | 228 | 0.24 | 45.8 | 19.7 |
| Albania | 0.03 | 3.41 | 5.20 | 18.6 | 42.9 | 13.1 | 0.21 | 641 | 5.45 |
| Algeria | 2.38 | 27.3 | 0.4 | 13.9* | | | | 5.84 | 0.51 |
| Argentina | 2.78 | 34.2 | 623 | 270 | 610 | 150 | 0.27 | 97 | 7.89 |
| Belarus | 0.21 | 10.3 | 21.7 | 34.4 | 59 | 20.4 | 0.22 | 166 | [illegible] |
| Bolivia | 1.10 | 7.24 | 155 | 361 | 487 | 279 | 0.13 | 328 | [illegible] |
| Brazil | 8.51 | 159 | 1 900 | 6 220 | 7 640 | 5 200 | 0.08 | 731 | [illegible] |
| Burkina Faso | 0.27 | 10.0 | 2.0 | 14.7 | | | | 53.6 | [illegible] |
| Canada | 9.98 | 29.1 | 170 | 3 290 | 3760 | 2 910 | 0.10 | 330 | [illegible] |
| Chad | 1.28 | 6.18 | 28.3 | 15.8 | | | | 12.3 | [illegible] |
| Chile | 0.76 | 14.0 | 0 | 354 | | | | 468 | [illegible] |
| China | 9.60 | 1 209 | 0 | 2 700 | 3 930 | 1 970 | 0.15 | 281 | [illegible] |
| Colombia | 1.14 | 34.3 | 0 | 1 200 | | | | 1 054 | [illegible] |
| Congo D.R.of o | 2.34 | 42.6 | 313 | 987 | 1 328 | 786 | 0.10 | 422 | [illegible] |
| Cuba | 0.11 | 11.0 | 0 | 84.5 | | | | 761 | [illegible] |
| Ecuador | 0.28 | 11.2 | 0 | 265 | | | | 933 | [illegible] |
| France | 0.55 | 57.8 | 15.0 | 168 | 263 | 90.3 | 0.22 | 307 | [illegible] |
| Gambia | 0.01 | 1.08 | 4.70 | 3.20 | | | | 291 | [illegible] |
| Guyana | 0.22 | 0.83 | 0 | 270 | | | | 1 256 | [illegible] |
| Guatemala | 0.11 | 10.3 | 0 | 116 | | | | 1 064 | [illegible] |
| Honduras | 0.11 | 5.49 | 0 | 102 | | | | 911 | [illegible] |
| India | 3.27 | 919 | 581 | 1 456 | 1794 | 1 065 | 0.10 | 445 | [illegible] |
| Italy | 0.30 | 57.2 | 0 | 185 | | | | 615 | [illegible] |
| Jordan | 0.1 | 5.20 | 0 | 0.96* | | | | 9.84 | [illegible] |
| Jamaica | 0.01 | 2.43 | 0 | 8.3 | | | | 754 | [illegible] |
| Kazakstan | 2.72 | 17.0 | 56 | 70.2 | 111 | 39.3 | 0.24 | 25.8 | [illegible] |
| Lebanon | 0.01 | 3.06 | 0 | 2.8* | | | | 280 | [illegible] |
| Libya | 1.76 | 5.22 | 0 | 5.29* | | | | 3.01 | [illegible] |
| Madagascar | 0.59 | 14.3 | 0 | 395 | | | | 673 | [illegible] |
| Mali | 1.24 | 10.5 | 44.4 | 50.0 | | | | 40.3 | [illegible] |
| Mauritania | 1.03 | 2.22 | 11.0 | 0.4 | | | | 0.39 | [illegible] |
| Mexico | 1.97 | 91.9 | 2.60 | 347 | 645 | 229 | 0.18 | 176 | [illegible] |
| Morocco | 0.447 | 26.5 | 0 | 30.0* | | | | 67.1 | [illegible] |
| Nicaragua | 0.13 | 4.27 | 0 | 175 | | | | 1 346 | [illegible] |
| Niger | 1.27 | 8.85 | 30.4 | 3.0 | | | | 2.37 | [illegible] |
| Nigeria | 0.92 | 109 | 43.6 | 274 | 437 | 148 | 0.26 | 298 | [illegible] |
| New Zealand | 0.27 | 3.50 | 0 | 313 | 405 | 246 | 0.11 | 1 181 | [illegible] |
| Pakistan | 0.81 | 137 | 170 | 85 | 140 | 48 | 0.16 | 105 | [illegible] |
| Panama | 0.08 | 2.58 | 0 | 144 | | | | 1 870 | [illegible] |
| Peru | 1.28 | 23.3 | 144 | 1 100 | | | | 856 | [illegible] |
| Poland | 0.31 | 38.3 | 6.7 | 49.5 | | | | 158 | 1.29 |
| Portugal | 0.09 | 9.83 | 34.5 | 18.5 | 157 | 15.2 | 0.55 | 201 | 1.88 |
| Russia | 17.08 | 148 | 227 | 4 059 | 4 541 | 3 533 | 0.05 | 238 | 27 |
| SAR | 1.22 | 40.6 | 5.2 | 44.8 | | | | 36.7 | 1.10 |
| Senegal | 0.20 | 8.1 | 17.4 | 17.4 | | | | 88.8 | 2.15 |
| Spain | 0.51 | 39.6 | 0 | 108 | 253 | 27.2 | 0.47 | 214 | 2.73 |
| Sudan | 2.51 | 27.4 | 140 | 22.0 | | | | 8.78 | 0.80 |
| Surinam | 0.16 | 0.42 | 0 | 230 | | | | 1 411 | 550 |
| Sweden | 0.45 | 8.74 | 12.2 | 164 | | | | 364 | 18.8 |
| Thailand | 0.51 | 58.2 | 0 | 199 | | | | 387 | 3.42 |
| Tunisia | 0.16 | 8.73 | 0.42 | 3.52* | | | | 21.5 | 0.40 |
| Uruguay | 0.18 | 3.17 | 74.0 | 68.0 | | | | 382 | 21.5 |
| USA | 9.36 | 261 | 146 | 2810 | 3680 | 1960 | 0.11 | 300 | 10.8 |
| Uzbekistan | 0.45 | 2.03 | 98.1 | 9.52 | 19.7 | 4.98 | 0.27 | 21 | 0.43 |

Note: Water resources includes renewable groundwater resources.

*Table 4.7 — Renewable water resources of selected rivers of the world*

| *River* | *Area in mln.km$^2$* | *Population in mln* | *Water resources (in km$^3$/year)* | | | | *Potential water availability (in 1000m$^3$/year)* | |
|---|---|---|---|---|---|---|---|---|
| | | | *Average* | *Max* | *Min* | *Cv* | *per sq.km* | *per capita* |
| Amazon | 6.92 | 14.3 | 6 920 | 8 510 | 5 790 | 0.08 | 1000 | 484 |
| Ganges* | 1.75 | 439 | 1 389 | 1 690 | 1 220 | 0.10 | 797 | 3.2 |
| Congo | 3.50 | 48.3 | 1 300 | 1 775 | 1 050 | 0.10 | 371 | 27 |
| Orinoco | 1.00 | 22.4 | 1 010 | 1 380 | 706 | 0.15 | 1010 | 45 |
| Yangtze | 1.81 | 346 | 1 003 | 1 410 | 700 | 0.15 | 544 | 2.9 |
| La Plata | 3.10 | 98.4 | 811 | 1 860 | 453 | 0.26 | 262. | 8.2 |
| Yenisei | 2.58 | 4.77 | 618 | 729 | 531 | 0.07 | 240 | 130 |
| Mississippi | 3.21 | 72.5 | 573 | 880 | 280 | 0.24 | 160 | 7.1 |
| Lena | 2.49 | 1.87 | 539 | 670 | 424 | 0.11 | 216 | 289 |
| Ob | 2.99 | 22.5 | 404 | 567 | 270 | 0.16 | 135 | 18.0 |
| Mekong | 0.79 | 75.0 | 505 | 610 | 376 | 0.16 | 641 | 6.7 |
| Mackenzie | 1.75 | 0.35 | 333 | 420 | 281 | 0.12 | 191 | 951 |
| Amur | 1.86 | 4.46 | 328 | 483 | 187 | 0.21 | 177 | 73.5 |
| Niger | 2.09 | 131 | 303 | 482 | 163 | 0.26 | 145 | 2.3 |
| Volga | 1.38 | 43.3 | 255 | 390 | 161 | 0.19 | 185 | 5.9 |
| Danube | 0.82 | 85.1 | 225 | 321 | 137 | 0.18 | 275 | 2.3 |
| Indus | 0.96 | 150 | 220 | 359 | 126 | 0.19 | 229 | 1.5 |
| Nile | 2.87 | 89.0 | 161 | 248 | 94.8 | 0.16 | 80 | 1.8 |
| Amu Darya | 0.31 | 15.5 | 77.1 | 118 | 56.7 | 0.14 | 250 | 5.0 |
| Hwang Ho | 0.75 | 82.0 | 66.1 | 97 | 22.1 | 0.38 | 88 | 0.8 |
| Dnieper | 0.50 | 36.6 | 53.3 | 95 | 21.7 | 0.25 | 106 | 1.5 |
| Syr Darya | 0.22 | 13.4 | 38.3 | 75 | 26.2 | 0.21 | 175 | 2.9 |
| Don | 0.42 | 17.5 | 26.9 | 53 | 11.9 | 0.36 | 64 | 1.5 |
| Murray | 1.07 | 2.1 | 24 | 129 | 1.16 | 0.75 | 22 | 11.2 |

Note: Ganges includes Brahmaputra and Meghna rivers.

- Groundwater and surface water resources do not constitute two independent resources; double accounting should be avoided.
- Total country renewable water resources are not equivalent to the sum of the river runoff, which normally does not include 100 per cent of the groundwater outflow. However, as groundwater resources should not be accounted for as only independent groundwater flow, neither should surface water resources be accounted for as only runoff.
- Statistics of total natural water resources and their underground and surficial components should highlight shared components and present them in a manner similar to the example entitled "Statistics of water resources of African countries" — established by FAO in 1995 and contained in Table 4.8.

## 4.2 Non-renewable Groundwater Resources

Non-renewable groundwater resources may be defined as aquifer reserves which are not naturally or artificially recharged. Exploitation of such reserves leads to a one-time removal of the water available and is not sustainable on a long-term basis. Normally such resources occur in huge sedimentary basin aquifers with very limited renewal (average flux to storage ratio less than 0.01 which indicates a renewal period equal to or higher than one century). This occurs mainly in confined aquifers, but may also occur in free aquifers in arid and semi-arid zones.

An evaluation of the groundwater reservoir may be made on a theoretical basis by using the geometry of the reservoirs and storage coefficients. Any assessment should also take into consideration the feasibility of the reservoir exploitation (access, depth, productivity, initial and final withdrawal cost in relation to maximum pumping depth) and hence the economic aspect. The different types of groundwater mining, and intensity and duration of withdrawal, should also be taken into account. The non-renewable groundwater resource is expressed either in terms of volume (km$^3$), or in terms of average potential withdrawal by year (km$^3$/year) over the useful life of the reservoir.

Almost all the great sedimentary basins of the continents include aquifer reservoirs with a non-renewable water resource. Several of them (North America, Australia and Arab countries) have been exploited over a period of a few decades up to a century; their location is shown in Figure 4.8. It is in the arid and semi-arid zones, where renewable water resources are scarce, that non-renewable groundwater resources are of the greatest interest and where they have been exploited the most. Examples of non-renewable groundwater resources in Arab states are given in Table 4.9.

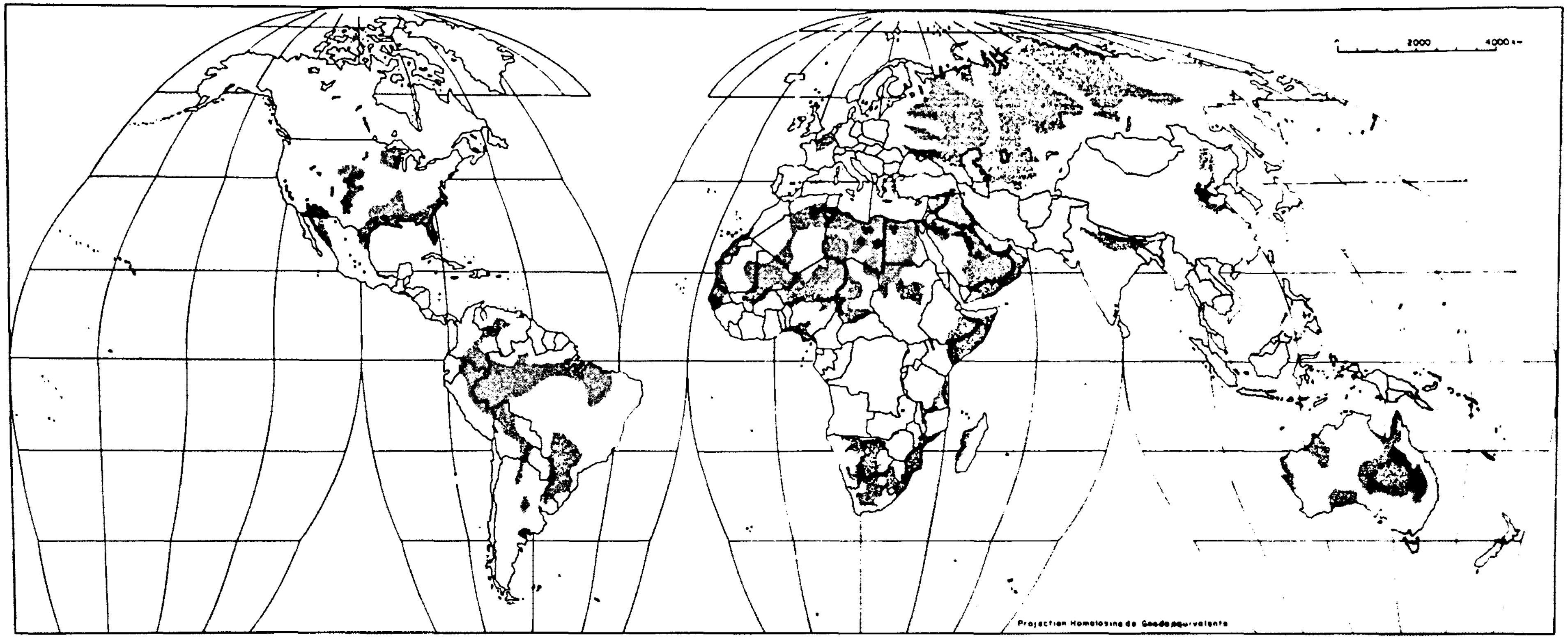
Table 4.8 — Water resources of African countries (all figures in $km^3$/year)

| | Country | Internal renewable water resource | | | | Incoming water | | | Global ren. water res. | | | Other resources desalination | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ground-water | Overlap | Total | Surface water | | Ground-water | Surface water | GW depletion | Total | | |
| | | | C | | 1+2-3 | T | B | | 1+5+6 | 2+7 | 8+9-3 | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | Algeria | 13.2 | 1.7a | 1 | 13.9 | 0.4 | 0 | 0.03 | 13.6 | 1.73 | 14.33 | 0.03 | 5 |
| 2 | Angola | 182 | 72b | 70 | 184 | 0 | 0 | 0 | 182 | 72 | 184 | x | 0 |
| 3 | Benin | 10 | 1.8a | 1.5 | 10.3 | 0.5 | 15 | 0 | 25.5 | 1.8 | 25.8 | 0 | 0 |
| 4 | Botswana | 1.7 | 1.7a | 0.5 | 2.9 | 11.5 | 0.3 | 0 | 13.5 | 1.7 | 14.7 | 0 | 0 |
| 5 | Burkina Faso | 13 | 9.5a | 5 | 17.5 | ... | x | 0 | x+13 | 9.5 | x+17.5 | 0 | 0 |
| 6 | Burundi | 3.5 | 2.1b | 2 | 3.6 | x | 0 | 0 | x+3.5 | 2.1 | x+3.6 | 0 | 0 |
| 7 | Cameroon | 268 | 100b | 100 | 268 | ... | 0 | 0 | 268 | 100 | 268 | 0 | 0 |
| 8 | Cape Verde | 0.18 | 0.12a | 0 | 0.3 | 0 | 0 | 0 | 0.18 | 0.12 | 0.3 | x | 0 |
| 9 | Central African Rep. | 141 | 56b | 56 | 141 | 0 | x | 0 | x+141 | 56 | x+141 | 0 | 0 |
| 10 | Chad | 13.5 | 11.5b | 10 | 15 | 28 | 0 | 0 | 41.5 | 11.5 | 43 | 0 | 0 |
| 11 | Comoros | x | x | x | 1.02 | 0 | 0 | 0 | x | x | 1.02 | 0 | 0 |
| 12 | Conco Dem. Rep. of | 934 | 421b | 420 | 935 | 84 | x | 0 | +1 018 | 421 | +1 019 | 0 | 0 |
| 13 | Congo | 222 | 198b | 198 | 222 | ... | 610 | 0 | 832 | 198 | 832 | ... | 0 |
| 14 | Cote D'ivoire | 74 | 37.7a | 35 | 76.7 | 1 | x | 0 | x+75 | 37.7 | x+77.7 | 0 | 0 |
| 15 | Dabouti | x | x | x | 0.3 | 0 | 2 | x | x+2 | x | x+2.3 | 0 | 0 |
| 16 | Egypt | 0.5 | 1.3a | 0 | 1.8 | 65.5 | 0 | 1.2 | 66 | 2.5 | 68.5 | 0.01 | ... |
| 17 | Equatorial Guinea | 25 | 10b | 5 | 30 | ... | 0 | 0 | 25 | 10 | 30 | 0 | 0 |
| 18 | Eritrea | x | x | x | 2.8 | 0 | 6 | 0 | x | x | 8.8 | 0 | 0 |
| 19 | Ethiopia | x | x | x | 110 | 0 | 0 | 0 | x | x | 110 | 0 | 0 |
| 20 | Gabon | 162 | 62b | 60 | 164 | 0 | 0 | 0 | 162 | 62 | 164 | 0 | 0 |
| 21 | Gambia | 3 | 0.5b | 0.5 | 3 | 5 | 0 | 0 | 8 | 0.5 | 8 | 0 | 0 |
| 22 | Ghana | 29 | 26.3a | 25 | 30.3 | 22.9 | 0 | 0 | 51.9 | 26.3 | 53.2 | 0 | 0 |
| 23 | Guinea | 226 | 38b | 38 | 226 | 0 | 0 | 0 | 226 | 38 | 226 | 0 | 0 |
| 24 | Guinea-Bissau | 12 | 14b | 10 | 16 | 11 | 0 | 0 | 23 | 14 | 27 | 0 | 0 |
| 25 | Kenya | 17.2 | 3a | 0 | 20.2 | ... | 10 | 0 | 27.2 | 3 | 30.2 | 0 | 0 |
| 26 | Lesotho | 4.73 | 0.5b | 0 | 5.23 | 0 | 0 | 0 | 4.73 | 0.5 | 5.23 | 0 | 0 |
| 27 | Liberia | 200 | 60b | 60 | 200 | 32 | 0 | 0 | 232 | 60 | 232 | 0 | 0 |
| 28 | Libya | 0.1 | 0.5a | 0 | 0.6 | 0 | 0 | 0 | 0.1 | 0.5 | 0.6 | 0.003 | 2 to 4 |
| 29 | Madagascar | 332 | 55b | 50 | 337 | 0 | 0 | 0 | 332 | 55 | 337 | 0 | 0 |
| 30 | Malawi | 16.1 | 1.4b | 0 | 17.54 | 1.18 | 0 | 0 | 17.28 | 1.4 | 18.68 | 0 | 0 |
| 31 | Mali | 50 | 20a | 10 | 60 | 40 | 0 | 0 | 90 | 20 | 100 | 0 | 0 |

*Table 4.8 — Continued*

| Country | | Internal renewable water resource | | | | Incoming water | | | Global ren. water res. | | | Other resources | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ground water | Overlap | Total | Surface water | | Ground-water | Surface water | GW depletion | Total | desali-nation | |
| | | | C | | 1+2-3 | T | B | | 1+5+6 | 2+7 | 8+9-3 | | |
| 32 | Mauritania | 0.1 | 0.3a | 0 | 0.4 | 0 | 11 | 0 | 11.1 | 0.3 | 11.4 | x | 0 |
| 33 | Mauritius | 2.03 | 0.68a | 0.5 | 2.21 | 0 | 0 | 0 | 2.03 | 0.68 | 2.21 | 0 | 0 |
| 34 | Morocco | 22.5 | 7.5a | 0 | 30 | 0 | 0 | 0 | 22.5 | 7.5 | 30 | 0.004 | 0 |
| 35 | Mozambique | 97 | 17b | 17 | 97 | 106 | 5 | 0 | 208 | 17 | 208 | 0 | 0 |
| 36 | Namibia | 4.1 | 2.1b | 0 | 6.2 | 11.3 | 28 | 0 | 43.4 | 2.1 | 45.5 | 0.003 | 0 |
| 37 | Niger | 1 | 2.5a | 0 | 3.5 | 29 | 0 | 0 | 30 | 2.5 | 32.5 | 0 | 0 |
| 38 | Nigeria | 214 | 87b | 80 | 221 | 59 | x | 0 | x+273 | 87 | x+280 | 0 | 0 |
| 39 | Rwanda | 5.2 | 36b | 2.5 | 6.3 | 0 | x | 0 | x+5.2 | 3.6 | x+6.3 | 0 | 0 |
| 40 | Sao Tome & Principe | x | x | x | 2.18 | 0 | 0 | 0 | x | x | 2.18 | 0 | 0 |
| 41 | Senegal | 23.8 | 7.6b | 5. | 26.4 | 2 | 11 | 0 | 36.8 | 7.6 | 39.4 | 0 | 0 |
| 42 | Seychelies | x | x | x | x | 0 | 0 | 0 | x | x | x | 0 | 0 |
| 43 | Sierra Leone | 150 | 50b | 40 | 160 | 0 | 0 | 0 | 150 | 50 | 160 | 0 | 0 |
| 44 | Somalia | 5.7 | 33b | 3 | 6 | 7.5 | 0 | x | 13.2 | x+3.3 | x+13.5 | 0 | 0 |
| 45 | South Africa | 40 | 4.8 | 0 | 44.8 | 5.2 | 0 | 0 | 45.2 | 4.8 | 50 | x | 0 |
| 46 | Sudan | 28 | 7 | 0 | 35 | 119 | 0 | 0 | 147 | 7 | 154 | 0 | 0 |
| 47 | Swaziland | x | x | x | 2.64 | 1.87 | 0 | 0 | x+1.87 | x | x+4.51 | 0 | 0 |
| 48 | Tanzania | 80 | 30b | 30 | 80 | 0 | 9 | 0 | 89 | 30 | 89 | 0 | 0 |
| 49 | Togo | 10.8 | 5.7a | 5 | 11.5 | 0.5 | 0 | 0 | 11.3 | 5.7 | 12 | 0 | 0 |
| 50 | Tunizia | 2.31 | 1.21a | 0 | 3.52 | 0.32 | 0 | 0.1 | 2.63 | 1.31 | 3.94 | 0.009 | 1 |
| 51 | Uganda | 35 | 29.b | 25 | 39 | 27 | 0 | 0 | 62 | 29 | 66 | 0 | 0 |
| 52 | Zambia | 33.1 | 47.1 | 0 | 80.2 | 35.8 | x | 0 | x+68.9 | 47.1 | x+116 | 0 | 0 |
| 53 | Zimbabwe | 13.1 | 5b | 4 | 14.1 | 0 | x.+5.9 | 0 | x+19 | 5 | x+20 | 0 | 0 |
| | Total | | | | | 3988 | | | | | | | |

C: Method of computing groundwater ; a= recharge of the aquifer, b= base flow of river system;
T: Transboundary flow; B: bordering river; x: unknown;.....: negligible.



▨ Main aquifers with potential non renewable groundwater resources

∴ Main groundwater mining operations

*Figure 4.8 — Principle non-renewable aquifers in the world*

The two main problems resulting from the use of non-renewable groundwater resources are:

- the choice of length of operating time (whether to be planned on a long-term or middle-term basis);
- the necessity to cope with the economic and social shock resulting at the end of exploitation, similar to the end of each mining exploitation or the exhaustion of the deposits — this makes it necessary to import or generate water from a generally more costly source of supply (transport, non-conventional source), or the activities using water must be dramatically reduced.

## 4.3 Status and Trends of World Water Quality

The activities of mankind, such as industrial development, discharge of sewage from urban centres and the use of pesticides and herbicides in the agricultural sector, have modified and changed the natural water quality of surface and groundwaters. Generally, water quality is measured in terms of physical, chemical and biological water characteristics corresponding to the use to which the water is put and then compared to a set of standards or guidelines developed for specific uses. The aquatic environment itself should be considered as a legitimate user and often is the most sensitive use to which the water can be put. Since the uses are very site specific, and natural water quality is highly variable, there is no singular set of water quality critera at the global level. In the following sections a few generalizations will be made but it must be pointed out that information on water quality at the global level is sadly lacking, particularly for persistent organic compounds.

### *4.3.1 Surface Waters*

### *4.3.1.1 Introduction*

The rapid increase of all kinds of anthropogenic activities in the last few decades has affected the terrestrial and aquatic ecosystems, and the atmosphere on a global scale. As a result, complex interrelationships between socio-economic factors and natural hydrological and ecological conditions have been identified. One consequence of these developments is the necessity of carrying out comprehensive and accurate assessments of status and trends in water quality on a river basin as well as on a worldwide scale. This is one way to raise awareness of the urgency of contamination

*Table 4.9 — Examples of non-renewable groundwater resources in some Arab states*

| *Country* | *Volume* (1) | *Long- term exploitation potential (capacity of average annual production)* | | *References* |
|---|---|---|---|---|
| | | *Reference time* | *$Km^3/year$* | |
| Saudi Arabia | 354 | | | J.Khouri 1990 |
| | 553 | | | H.Neuland 1988 |
| | 550 | | | Saud.Arab.Monitor 1992 |
| United Arab Emirates | 5 | | | J.Khouri 1990 |
| Qatar | 2.5 | | | J.Khouri 1990 |
| Jordan | 12 | | | |
| | | 100 years | 0.1 | J.Khouri 1990 |
| | | 50 years | 0.143 | M.A.Bromhead 1987 |
| | | | 0.17 (2) | A.Gärber ed. 1992 |
| | | | | Wat.intem.18.1. 1993 |
| Egypt | 6 000 | | | J.Khouri 1990 |
| Sudan | 40 | | | J.Khouri 1990 |
| Algeria | 1 500 | | | J.Khouri 1990 |
| | | ? | 5 | A.Salem |
| Libya | 4 000 | | | J.Khouri 1990 |
| | | ? | 2.8 (3) | O.Salem 1992 |
| | | ? | 3.9 | M.Shahin |
| Mauritania | 400 | | | J.Khouri 1990 |
| Tunisia | 1 700 | | | J.Khouri 1990 |
| | | | ~1 | ANPE 1992 |

(1) Estimation using non-homogeneous exploitation methodologies and criterion

(2) "Planned use of possible aquifers" (Wolf/ IWRA 1973)

(3) 1.6 to 2.2 km3/year from the Great Man Made River Project until 2025

threats, and to provide a rational basis for international action. (Helmer,1990, p.1-2).

Recognizing the importance of the task, the first global freshwater quality report was prepared under the Global Environment Monitoring System (GEMS)/Water programme in 1989 (Meybeck, Chapman and Helmer,1989), later on in 1991 (WHO/UNEP Report on Water Quality, 1991) and in 1995 (UNEP/GEMS, 1995). This report is based mainly on data and information which was compiled and analyzed under the framework of the GEMS/WATER, which was launched in December 1977 as a joint programme of four UN agencies: UNEP, WHO,WMO and UNESCO, and the other reports mentioned above. The GEMS/WATER Collaborating Centre for Water Quality of the National Water Research Institute (NWRI) in Canada regularly prepares data summaries and specific publications on the basis of the compiled data. Information on large river basins (case studies) were undertaken by the Environmentally Sound Management of Inland Water Programme (EMINWA) and also used to some extent in the report.

Data covered by GEMS/WATER relies on contributions by national water quality agencies, which are then reviewed both manually and against automated data quality standards. The database generally covers the time period 1979-80 to 1992-93 and covers major international rivers and lakes. The GEMS/WATER programme supports capacity building in selected national agencies. This includes analytical quality assurance, the provision of guidelines and other literature for different water-related areas, training courses for computers and laboratory equipment with special emphasis on national water quality agencies in developing countries.

This report is structured by water quality parameters. The last chapter presents a global strategy for the next few years, with the goals of controlling water pollution problems and protecting aquatic ecosystems. It also takes into consideration not only the progressive degradation of freshwater resources, but also the impacts on human health and the economy. Millions of people suffer from intolerable levels of disease, squalor and indignity because they lack access to a safe supply of drinking water and adequate means of sanitation (Ministerial Conference on Drinking Water and Environmental Sanitation, Noordwijk, Netherlands, March 1994).

### *4.3.1.2 Past and current state of water quality*

Water quality is closely linked to water availability and use and to the state of economic development. In industrialized countries, faecal contamination of surface water caused serious health problems (typhoid and cholera) in large cities in the past. The development of sewage networks and waste treatment facilities in urban areas has now expanded enormously. However, the rapid growth of urban population, especially in Latin America and Asia, has outpaced the ability of governments to expand sewage and water infrastructure. While water-born diseases have been virtually eliminated in the developed world, outbreaks of cholera and other gastroenteric diseases still occur with alarming frequency in developing countries.

Today the natural water quality has been greatly affected worldwide by industrial and agricultural chemicals. Eutrophication of surface waters from human and agricultural waste, and nitrification of groundwater from agricultural practices, have affected large parts of the world. Acidification of surface waters by air pollution is a recent phenomenon and threatens aquatic life in many areas. In developing countries, these general types of pollution have occurred sequentially with the result that most developed countries have successfully dealt with major surface water pollution. In contrast, newly industrialized countries such as China, India, Thailand, Brazil and Mexico, are now facing all these issues simultaneously. (UNEP/GEMS, 1995).

The need for clean water makes heavy demands on the total water resources. For example, it is estimated that some 450 km$^3$ of wastewater currently enters the world rivers each year. Some 6 000 km$^3$ of water is needed to transport and dilute this waste away. Cleansing the world's waste thus requires a volume of water equivalent to two-thirds of total reliable runoff.

Inadequate supplies and heavy pollution mean that at least one fifth of urban dwellers and three quarters of the rural population in developing countries still lack safe drinking water. The situation is particularly serious in countries with large arid and semi-arid zones and increasing populations, as well as in regions with abundant water resources but large populations.

Agriculture, particularly irrigation, accounts for more than two thirds of all human water use. At present, an estimated 50-80 per cent of irrigation water never serves the purpose for which it was intended, either because it percolates down through the soil too quickly or because it runs straight off the field before moistening the soil around the plant roots. With predictions that by the year 2000 irrigation demands alone will equal total worldwide needs in 1980, it is essential to improve irrigation efficiency.

Industrial needs are forecast to grow more slowly. Industry is becoming more water conscious and is beginning to recycle more of the water it uses. In the northern hemisphere, increased recycling in some industrialized countries has reduced industrial water demand, despite increased output.

While not the main concern here, questions of water supply and demand often cannot easily be disentangled from issues of water quality. Because human populations are pressing against the limits of available water supply in many parts of the world, water quality is frequently put at risk.

### *4.3.1.3 The acceleration of water pollution*

The major factors associated with the accelerating pace of freshwater pollution are described below (UNEP/GEMS, 1991).

- *Urbanization* and the consequent increase in population, intensification of agriculture, and growth in industries may result in increased freshwater pollution particularly when coupled with inadequate sewage collection and treatment. Water supplies can be overloaded by organic material, bacteria and nutrients from municipal sewage outlets and stormwater runoff into open drains. Oxygen levels are reduced as these contaminants are broken down, contributing to eutrophication.

- *Deforestation* to clear land for agriculture and urban growth often leads to water contamination. When soil is stripped of its protective covering, it becomes prone to soil erosion. This in turn leads to higher water turbidity as a result of increased amounts of suspended matter, nutrient leaching and the decreased water retention capacity of the soil.
- *Damming Rivers* to form reservoirs can alter water quality by increasing residence time and evaporation, and by decreasing levels of suspended matter. Fewer nutrients are carried downstream and fisheries often suffer.
- *Destruction of Wetlands*, besides destroying the habitat of many animals, removes natural filters capable of storing and degrading many pollutants, such as phosphorous and heavy metals.
- *Mining and Industrial Development* doubled between 1965 and 1984, generating much potentially toxic waste, including harmful synthetic organic pollutants. Some of this waste, through leaching of mine tailings, direct effluent discharge, atmospheric transport or other means, made its way into water supplies. It is difficult to monitor industrial pollutants because they are varied and often highly diluted.
- *Agricultural Production* increased globally by 19 per cent between 1975 and 1984, and doubled in many developing countries over the same period. The developed world has the highest levels of fertilizer use at present, but developing countries are catching up. Pesticide use has increased much more rapidly than fertilizer use. Over-irrigation can aggravate the situation by pushing water, with its chemical pollutants, below root level and closer to the groundwater.
- *Primary Energy Consumption* almost doubled between 1965 and 1984, resulting in greatly increased atmospheric emissions of sulphur and nitrogen oxides, the main cause of acid rain. Acidification of freshwater, particularly lakes, is of major concern. Many Scandinavian lakes have become acidified and the natural aquatic environment of thousands of lakes has been destroyed. More importantly for human health, this process has led to higher levels of metal in water supplies and food chains as trace elements are leached from soil and pipes by acid water.
- *Accidental Water Pollution* can arise from many sources (burst pipes and tanks, major leaks, fires, oil spills) and can cause various degrees of damage, depending on the quantity, toxicity and persistence of the pollutant, and the size and resilience of the water body.

### *4.3.1.4 Main water pollutants*

#### *Organic pollutants*

Organic material, from domestic sewage, municipal waste and agro-industrial effluent (based on GEMS/WATER assessments), is the most common water pollutant. This organic waste includes faecal material, some of which may be infected by pathogens such as viruses, bacteria and other biological organisms causing water-born diseases. These pathogens come primarily from sewage that is discharged directly into water courses, from stormwater runoff, from soil percolation from landfills or from agricultural areas where minimally treated wastewater is used on crops. These pathogens (bacteria, viruses and protozoans) are responsible for waterborne diseases with 5 million deaths annually, worldwide.

In Africa, anthropogenic caused water quality problems are mostly faecal contamination, both in rural areas (less than 25 per cent of the population has appropriate sanitation) and urban areas, where the few installed sewage systems (serving less than 12 per cent of the urban population) are not connected to any sewage treatment facilities. Concentrations of faecal bacteria in drinking water from various sources in Africa are contained in Table 4.10 (WHO/UNEP, 1991). Also see Figure 4.9 for statistics on water supply and sanitation development in Africa (WHO/UNEP, 1991). Associated with faecal pollution is widespread nitrate pollution of groundwaters in rural areas, originating from domestic waste.

Sewage treatment is still a topic of concern for North America as a whole. Approximately 57 per cent of Canadians (1980-1981 data) are served by wastewater treatment plants, compared with 74 per cent of Americans. Secondary treatment is not yet incorporated in all sewage treatment plants and tertiary phosphorus removal treatment is found with even lower frequency. That leads to an increased concentration of hazardous substances into the surface water (Water 2020, 1988). Other pollution sources are stormwater runoff, deteriorating sewage collection infrastructure and long-range transport of airborne pollutants (acid rain in eastern Canada and the north-east of the United States of America).

The major causes of water pollution in Latin America are the discharge of untreated or inadequately treated domestic and industrial wastewater. The statistics for Latin American countries is contained in Figure 4.10, Death from water-borne diseases (WHO/UNEP, 1991). For example, in Rio de Janeiro, Brazil, 70 per cent of the pollutants in the recipient waters around the city are of human origin, while only 30 per cent are industrial and organic waste (UNECLAC, 1989). For the region as a whole approximately 80 per cent of the urban and 30 per cent of the rural population have sewage services. But this relatively high percentage of coverage still results in water quality problems because only about 10 per cent of sewage collected receives any treatment before discharge. (See Figure 4.11, Water supply and sanitation development in Latin America) (WHO/UNEP, 1991).

Stormwater runoff is a further source of pollution in major urban areas of Latin America. There is a general absence of wastewater treatment plants. Virtually all municipal sewage and industrial effluent is discharged into the nearest river or stream without any treatment. Industrial effluents receive little or no treatment before discharge. Some of the important industries, such as slaughterhouses (Brazil,

*Table 4.10 — Concentrations of faecal bacteria in drinking water from various sources in Africa*

| *Type of source* | *Country* | *Faecal organisms per 100 ml (1)*<br>*Coliforms* | <br>*Streptococci* |
|---|---|---|---|
| Rainwater | Tanzania | 3 | 13 |
| Boreholes | Tanzania | 1 | 11 |
| | Nigeria (piped) | Up to 35 | Up to 6 |
| | Uganda | 0-60 | NR |
| Springs | Kenya | 0 | 0 |
| | Tanzania (protected) | 15 | 40 |
| | Lesotho (protected) | 200 | 250 |
| | Tanzania (unprotected) | 20 | 58 |
| | Lesotho (unprotected) | 900 | 1 700 |
| Ponds and dams | Kenya (dams) | 0-2 | 0-14 |
| | Lesotho (small dams) | 260 | 360 |
| | Nigeria (ponds) | 1 300-1 900 | 1 300-3 900 |
| Waterholes | Tanzania | 61 | 974 |
| | Kenya | 11-350 | 50-90 |
| | Lesotho | 860 | 1,600 |
| Hand dug wells | Tanzania (protected) | 7 | 33 |
| | Nigeria | 200-580 | 180-360 |
| | Tanzania (open) | 343 | 1,761 |
| | Gambia | Up to 100 000 | NR |
| Streams and rivers | Tanzania (streams) | 128 | 293 |
| | Uganda (rivers) | 500-8 000 | NR |
| | Lesotho (streams) | 5 000 | 4,100 |
| | Kenya (large river) | 0-100 000 | 10-10 000 |

(a) Where only a single value is given it is a geometric mean.
NR Not reported.
Source: World Health Organization

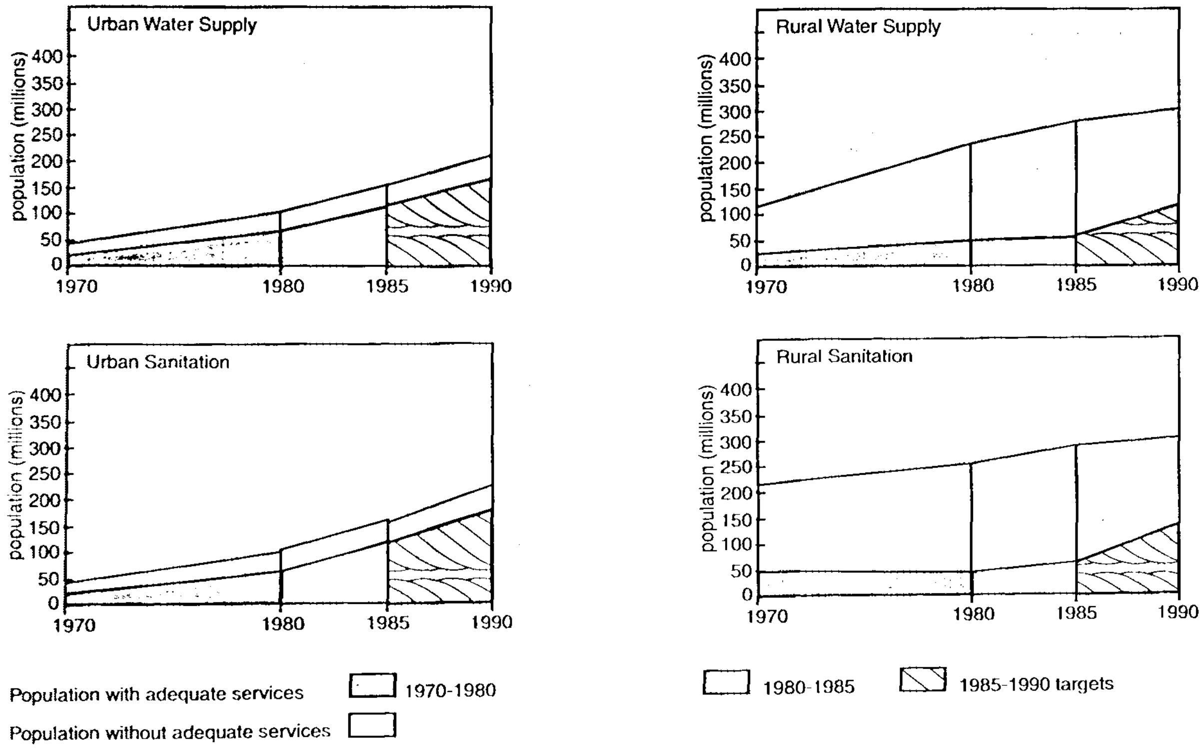


*Figure 4.9 — Water supply and sanitation development in Africa*

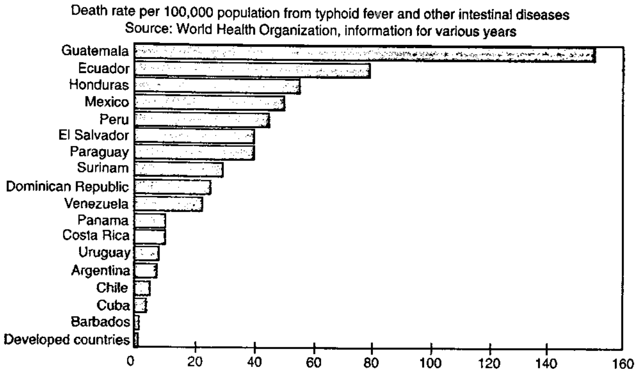


*Figure 4.10 — Deaths from water-borne disease*

Argentina, Uruguay), sugar processing (Cuba, Brazil), coffee processing (Colombia, Brazil) and fish processing (Brazil, Peru) also discharge high organic loads to water bodies.

The Caribbean islands lack the big urban centres that characterize the other parts of the continent. As in Latin America, a high proportion of the population is connected to sewage systems, which are mostly untreated or insufficiently treated. This organic and bacterial pollution, together with wastewater discharges from the food processing industry, creates the major pollution problems in this region and also influences the major industry of tourism. This is especially true for St. Lucia, Bahamas, Barbados, Netherlands Antilles, St. Vincent, Trinidad and Tobago (WMO, 1993).

In some countries of the Caribbean, groundwater is the predominant or unique source of water supply (Bahamas, Barbados, Guyana and Suriname). It is of considerable importance as a source of domestic, industrial and irrigation water supply in many of the other countries in the region. Microbiological contaminants in drinking water as well as chemical contaminants can cause a variety of diseases. The aesthetic quality of water (taste, odour, appearance) may influence the consumers to turn to other, possibly unsafe sources of water (WMO, 1993).

Within the countries of the Arabian Peninsula the percentage of population with access to safe drinking water in 1985 ranged from 53-94 per cent. The percentage of the urban population served ranged from 90-100 per cent and the rural population served ranged from 25-100 per cent. The percentage of total population which had access to sanitation services in 1985 ranged from 31-100 per cent (urban population from 83-100 per cent and the rural population from 25-100 per cent). Water quality and sanitation services have almost doubled during the Sanitation and Drinking Water Decade. In addition, management of water resources has improved. A major constraint in these countries is the lack of local, skilled experienced manpower at all levels and the lack of environmental data.

In the Eastern Mediterranean the proportion of the total population with access to safe drinking water is high (74-100 per cent), with 95-100 per cent of the urban population being serviced and 54-100 per cent of the rural population. The proportion of the total population which has access to sanitation services ranges from 50-70 per cent (56-92 per cent of the urban population and 0-28 per cent of the rural population). Complete sets of data are not available, but what data is available is contained in Figure 4.12 (Water supply and sanitation development in West Asia) (WHO/UNEP, 1991). Faecal pollution is one of the most serious problems for Pakistan, India, Sri Lanka, Bangladesh and Nepal. Contamination of surface water by domestic waste water has led to extremely high faecal coliform count numbers (more than 600 000/100 ml as mean values for 1979-1981, GEMS data). Groundwater contamination by faecal coliforms is severe especially in Sri Lanka (A mean of around

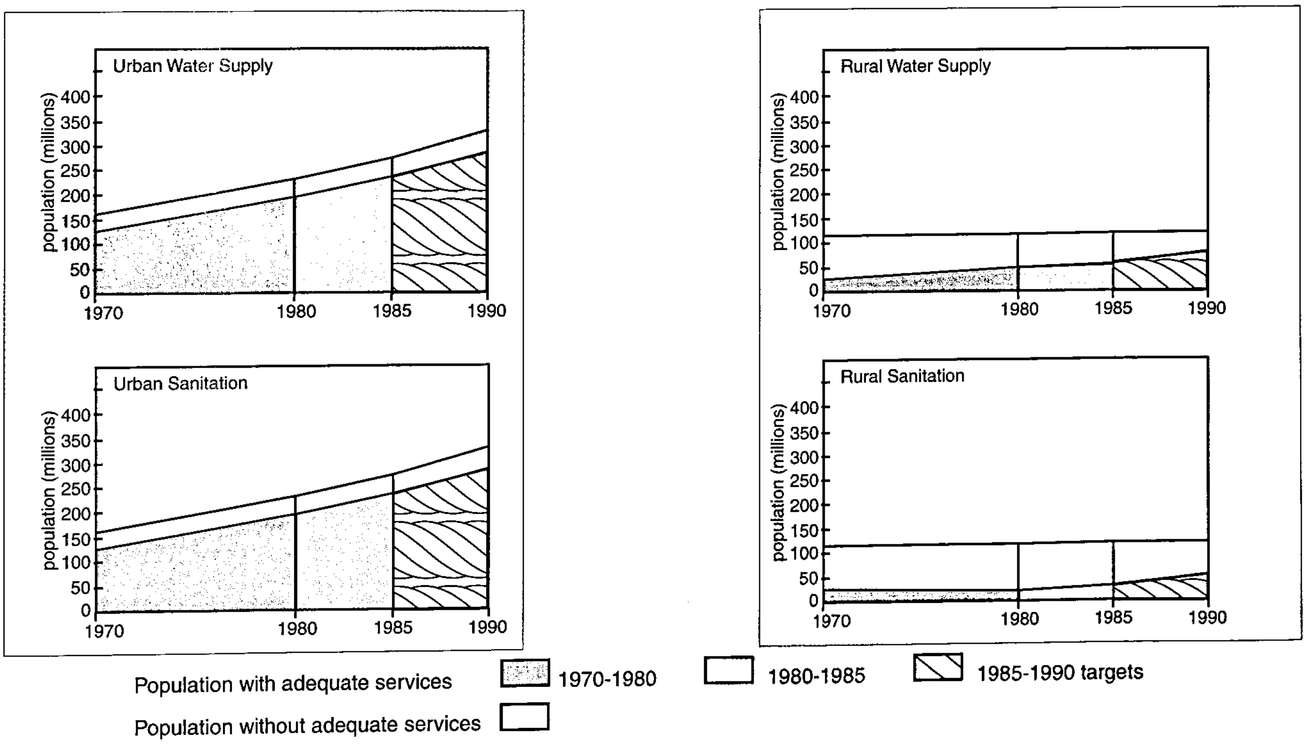


*Figure 4.11 — Water supply and sanitation development in Latin America*

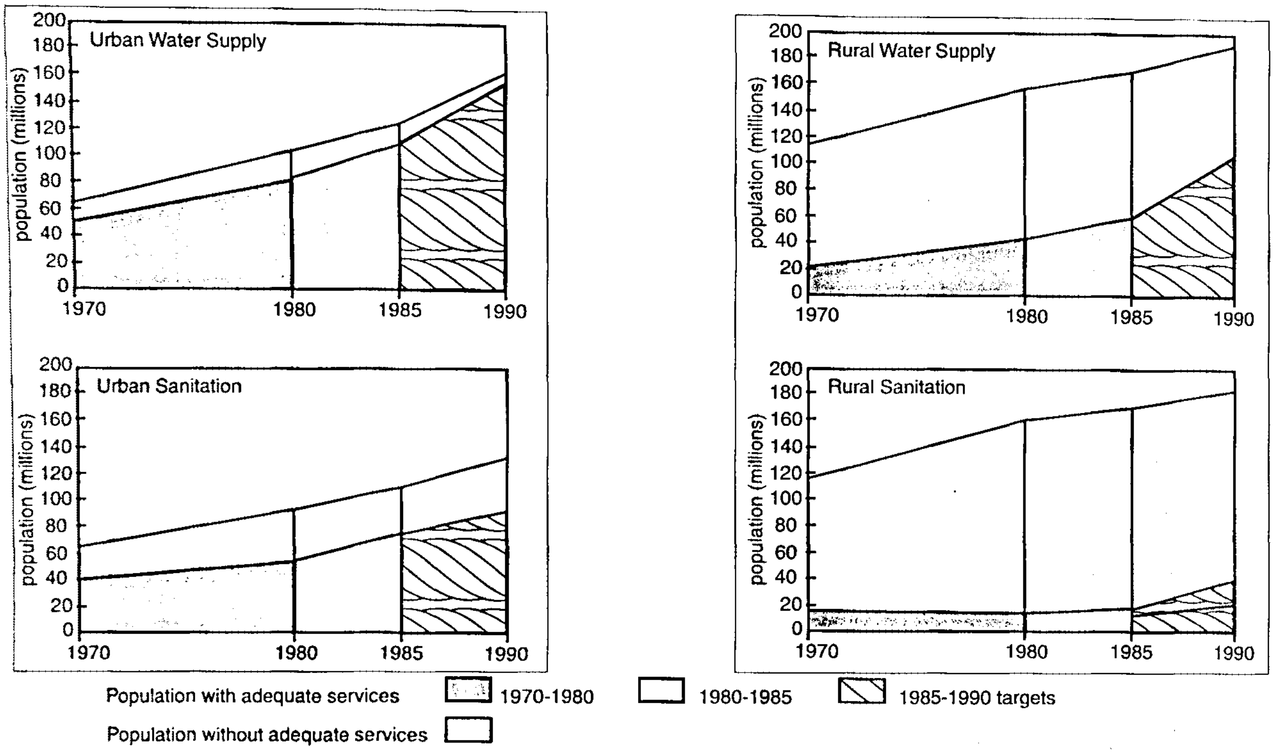


*Figure 4.12 — Water supply and sanitation development in West Asia*

20 000/100 ml was obtained from 1979-1981 by GEMS data). Organic pollution is directly related to faecal pollution, mainly due to domestic wastewater discharges. For example, in India only a very small percentage of cities with more than 100 000 inhabitants have sewerage systems. During the Water Decade, a large number of villages have been provided with sanitation facilities and the target, to serve 90 per cent of the population, is still being pursued. Organic pollution is severe in Sri Lanka and India, but is of less importance in Bangladesh and Pakistan.

Faecal pollution is significant in Indonesia, Malaysia, the Philippines, South Korea and Papua New Guinea, and to a lesser degree in Thailand, Viet Nam and Laos. Because of that, water-borne diseases, including cholera, typhoid and hepatitis, are still widespread. (See Figure 4.13, Water supply and sanitation development in south-east Asia) (WHO/UNEP, 1991). Low faecal pollution (about 3/100 ml) of groundwater has been reported for Indonesia and Thailand through the GEMS/WATER programme. High faecal pollution in groundwater has been reported in Sri Lanka and parts of India (GEMS data from 1979-87 in Khan, 1991). Significant organic pollution through discharge of domestic and industrial wastewaters occurs in South Korea, the Philippines, Papua New Guinea and Malaysia. For example, several rivers on the west coast of peninsular Malaysia are badly polluted by ammonial-N due to heavy loadings of sewage and animal waste. Some 69 per cent of the total biological oxygen demand (BOD) in certain Malaysian rivers comes from sewage and 23 per cent from livestock; the remainder comes from agro-industries (2 per cent) and other industries (5 per cent).

The region of the Pacific Islands contains a large number of islands ranging from large (Fiji and Samoa) to tiny atolls. Rivers are either few or non-existent. The only water available is limited groundwater and rainwater collected from roofs or other catchment points. Water quality in high islands, such as the Solomon Islands, is usually acceptable. On low atolls, however, the low elevation and shallow water table mean that pollution can rapidly reach the groundwater. That has led to health problems such as diarrhoea, hepatitis and other diseases. People living in limestone areas may also suffer from health problems due to a tendency to iodine deficiency leading to goitre. In most of the islands, only basic drinking water analyses are performed and information on toxic pollutants is generally lacking. Faecal pollution is the major cause of surface water pollution in the Marshall Islands, Fiji, Kiribati and the Federated States of Micronesia (FSM). For the same countries, faecal groundwater pollution is also reported.

In China, an examination of the different water sources shows that groundwater supplies 72 per cent of the requirements. Shallow wells account for the majority, 55 per cent of the total. The sanitary protection of this water is poor. The development of deep aquifers has been recommended for improving water quality in rural areas. Surface water provides over 20 per cent of the water supply, but only 10 per cent of the population has access to completely treated tap water. Partially treated or untreated tap water is supplied to 11 per cent of the population. Water supply for 62 per cent of the population is still drawn by hand from relatively shallow wells. The total amount of faecal coliform bacteria in groundwater is high, and creates the most serious health-related problems for drinking water in the country. Less contaminated sites occur in the north-east and Xingiang province, where population is sparse and the climate is cold. During 1985-87, under the GEMS/WATER programme the faecal coliform count was measured at 1 930/100 ml which indicates the severity of this groundwater pollution (Khan, 1991).

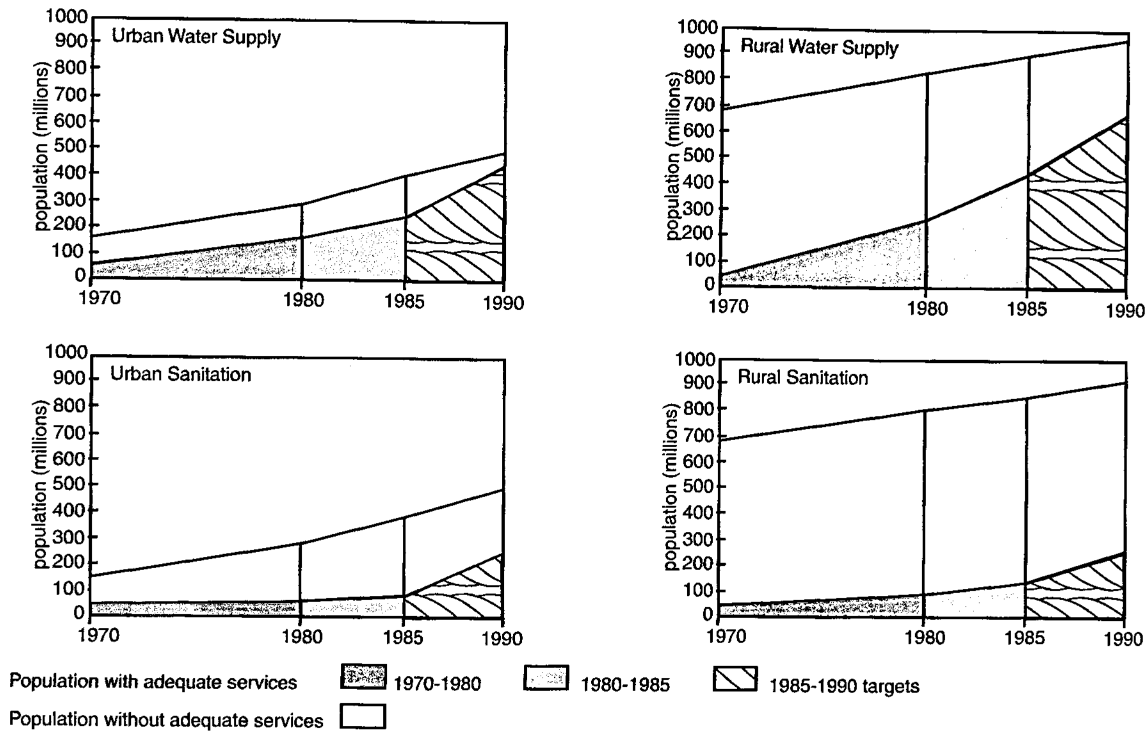


*Figure 4.13 — Water supply and sanitation development in South-east Asia*

In Australia, microbial contamination of surface water is a national problem of high severity and increasing importance. Central sewage systems serve almost 100 per cent of the population. In New Zealand the freshwater resources are adequate for the demands placed on it by the present population. The public water supply system provides 87 per cent of the water requirements, and more than two thirds of the population is served by wastewater treatment plants. Central sewage systems are in place in all cities and towns. In Japan, the high organic loads are a serious water quality problem in urban areas, arising from discharge of domestic and industrial waste. Sewage networks and sewage treatment are not always adequate to meet the needs of an increasing population.

In Europe, the contamination from raw sewage also creates problems. Big cities, such as Brussels or Venice do not have adequate wastewater treatment facilities. Bathing water surveys have led to closures of beaches in Great Britain and Italy, mainly because of sewage contamination.

### *Global Summary—Organic Pollutants*

The faecal pollution of freshwater bodies by untreated sewage is one of the most serious problems affecting human health at the global level and the impacts are felt primarily in developing countries. This kind of pollution is usually associated with the most densely populated regions of the world where domestic wastes and wastewaters are untreated, or insufficiently treated (Indian subcontinent, China, South-east Asia). In less densely populated regions of Africa or South America the water is often contaminated by human waste. Faecal contamination has led, and will increasingly lead, to severe outbreaks of infectious diseases in mega-cities or rural areas (for example, the outbreak of hepatitis in Shanghai, or the plague outbreak in rural areas of India). Table 4.11 (Estimates of morbidity and mortality of water - related diseases, WHO, 1995) shows the health consequences of the most serious of diseases associated with water pollution. The exceptions contained in the table are malaria, bancroftian filariasis and onchocerciasis, which can occur through water development projects like dam building or expansion of irrigated areas (water-related diseases).

The installation of domestic waste treatment facilities over the last 30 years in most Organization for Economic Cooperation and Development (OECD) countries has led to a marked decrease of BOD levels in rivers. In most developing countries, particularly those developing most rapidly, organic pollution cannot be tackled properly until organized programmes are in place at the national or regional level. A positive example is the Ganges Action Plan in India. In Central and South America only 5 per cent of municipal wastewaters are presently collected and treated adequately.

During the International Drinking Water Supply and Sanitation Decade (1981-90), some 1 600 million additional people were served with safe water and about 750 million with adequate environmental sanitation facilities. However, because of the population growth in the developing countries (800 million people) during the decade, by 1990 there remained a total of 1 015 million people without safe water and 1 764 million without adequate sanitation. The overall progress in reaching the unserved has been poor since 1990. Table 4.12 ("Water supply and sanitation coverage", 1994, Warner, 1995) shows that 34 per cent of the population of the developing countries still lack safe water, and 46 per cent do not have adequate environmental sanitation facilities. Not shown by these data is the fact that rapid population growth and lagging rates of coverage expansion has left

*Table 4.11 — Estimates of morbidity and mortality of water-related diseases*

| *Disease* | *Morbidity (episodes/year, or as stated)* | *Mortality (deaths/year)* | *Relationship of Disease to Water Supply and Sanitation* |
|---|---|---|---|
| Diarrhoeal diseases | 1 000 000 000 | 3 300 000 | Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water |
| Infection with intestinal helminths | (1) 1 500 000 000 | 100 000 | Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene |
| Schistosomiasis | (1) 200 000 000 | 200 000 | Strongly related to unsanitary excreta disposal and absence of nearby sources of safe water |
| Dracunculiasis | (1,2) 100 000 | - | Strongly related to unsafe drinking water |
| Trachoma | (3) 150 000 000 | - | Strongly related to lack of face washing, often due to absence of nearby sources of safe water |
| Malaria | 400 000 000 | 1 500 000 | Related to poor water management, water storage, operation of water points of drainage |
| Dengue Fever | 1 750 000 | 20 000 | Related to poor solid wastes management, water storage, operation of water points and drainage |
| Poliomyelitis | 114 000 | - | Related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water |
| Trypanosomiasis | 275 000 | 130 000 | Related to the absence of nearby sources of safe water |
| Bancroftian filariasis | (1) 72 800 000 | - | Related to poor water management, water storage, operation of water points and drainage |
| Onchocerciasis | (1,4) 17 700 000 | (5) 40 000 | Related to poor water management in large-scale projects |

1 People currently infected.
2 Excluding Sudan.
3 Case of the active disease. Approximately 5 900 000 cases of blindness or severe complications of Trachoma occur annually.
4 Includes an estimated 270 000 blind.
5 Mortality caused by blindness.
Source: 48th World Health Assembly, A48/INF.DOC./2, 28 April 1995

*Table 4.12 — Water supply and sanitation coverage, 1994 (in millions)*

| *Region(1)* | *Water supply* | | *Sanitation* | |
|---|---|---|---|---|
| | *Served* | *Unserved* | *Served* | *Unserved* |
| Africa | 259 | 304 | 208 | 352 |
| The Americas | 373 | 99 | 311 | 161 |
| Eastern Mediterranean | 287 | 155 | 150 | 292 |
| South-East Asia | 769 | 432 | 396 | 805 |
| Western Pacific | 1 024 | 418 | 1 168 | 274 |
| Global | 2 712 | 1 408 | 2 233 | 1 887 |

1 Europe, North America, Japan, Australia and New Zealand not shown, as statistics are for developing countries
Source: 48th World Health Assembly, A48/INF.DOC./2, 28 April 1995

more people without access to safe water and proper sanitation today than in 1990. Unless the current rate of coverage is increased, the expansion of water and sanitation services will continue to be matched or exceeded by population growth into the foreseeable future (Warner, 1995).

### *Nutrients*

The primary nutrients, phosphorous and nitrogen, are major constituents of agricultural fertilizer, animal wastes and municipal sewage. Runoff from agricultural lands and the discharge of municipal waste to rivers and lakes causes nutrient enrichment and leads to eutrophication of surface waters. Experience in phosphorous control strategies in North America and Europe has shown that, in some cases, lakes adversely affected by excessive levels of nutrients can be successfully remediated. Nitrate pollution in groundwater is becoming a major problem in many parts of the world.

In the United States of America, agriculture is the single most important non-point source of pollution. In 1985, non-point pollution affected water quality in 64 per cent of river-miles and 57 per cent of lake-acres in the country. In Canada, the full extent of the agricultural impact is not yet known. Nitrates may be the most common groundwater contaminant in the United States of America. Some 20 per cent of wells have nitrate-nitrogen concentrations greater than 3 mg/l, a level that may indicate pollution by human and animal wastes.

Several countries in Latin America have developed intensive agriculture with extensive use of fertilizers and pesticides. Brazil, for example, is the worlds third largest consumer of herbicides. As with industrial chemicals, data on the environmental concentrations and fate and effects, particularly in aquatic systems, are non-existent in most cases (see Table 4.13, "Latin America and the Caribbean: Pesticides used in or sold to agriculture whose consumption and /or sale have been banned, withdrawn, severely restricted or not approved by governments", PAHO, 1992).

Nitrate pollution in groundwater caused by the use of fertilizer and domestic wastewaters was found in some areas of Pakistan, India and the Maldives. In a survey of 100 wells around Nagpur, India, 70 per cent had nitrate levels far in excess of guidelines (more then 400 mg/l). The common use of low-cost sanitation in both urban and rural areas has contributed to high nitrate levels, especially in groundwater. High nutrient levels in runoff has contributed to eutrophication of several water bodies in Pakistan, India and Bangladesh. Nitrate pollution exists in the groundwater of Laos, Malaysia and South Korea, and to a lesser degree in Indonesia and Papua New Guinea, due to agricultural activities, some industrial waste discharge and low-cost sanitation practices. Eutrophication problems were reported in the surface waters of the Philippines, Laos, Indonesia and Thailand.

In China, nitrate levels are higher in the north, northwest and north-eastern regions than in other areas. Values over 23 mg/l NO3-N have been reported which has led to health impacts (cyanosis). In most southern areas values are less than 10 mg/l NO3-N. The nitrate content of surface water is generally lower than 2 mg/l NO3-N nationwide. Eutrophication of lakes and reservoirs is widespread and still increasing. In Japan, eutrophication problems arise in various inland waters and in enclosed sea areas and is caused by inadequate wastewater treatment. However, controls on nitrate and phosphate discharge are being enforced and programmes to protect and restore water bodies are underway.

Nitrates in ground and surface water are considered to be a major problem in Europe because of possible health risks. The main sources of the elevated nitrate levels are fertilizers and effluent discharges of treated and untreated sewage. The lowest nitrogen concentrations are found in Scandinavia; the highest concentrations occur in West and East European rivers (Figure 4.14 , "Phosphate concentration for major river basins in Europe", UNEP/GEMS, 1995). Organic enrichment and eutrophication are widespread problems in the whole of Europe, primarily due to discharge of animal manure directly to water or leaching of manure nutrients from land where it has been spread as a fertilizer. Several control programmes have already led to improve-

*Table 4.13 — Latin America and the Caribbean: Pesticides used in or sold to agriculture whose consumption and/or sale have been banned, withdrawn, severely restricted or not approved by governments* (1)

| *Product* | *Country* | *Year* (2) | *100 kg* |
|---|---|---|---|
| Aldrin (3) | Argentina | 1984 | 5 832 |
| | Ecuador | 1984 | 689 |
| | El Salvador | 1979/81 | 432 |
| | Guatemala | 1979/81 | 1 470 |
| | Guyana | 1979/81 | 22 |
| | Mexico | 1985 | 1 000 |
| | Suriname | 1979/81 | 630 |
| | Uruguay | 1985 | 126 |
| Arsenicals | Uruguay | 1979/81 | 26 |
| BHC | Argentina | 1984 | 60 |
| | El Salvador | 1979/81 | 12 |
| | Mexico | 1985 | 2 500 |
| | Suriname | 1979/81 | 961 |
| DDT | Argentina | 1979/81 | 6 |
| | Ecuador | 1984 | 4 000 |
| | El Salvador | 1979/81 | 1 269 |
| | Guatemala | 1979/81 | 12 570 |
| | Mexico | 1985 | 3 000 |
| | Suriname | 1979/81 | 33 |
| Lindane | Argentina | 1984 | 1 725 |
| | Guatemala | 1979/81 | 11 |
| | Honduras | 1986 | 1 371 |
| | Mexico | 1985 | 150 |
| | Uruguay | 1985 | 5 |
| Parathion | Argentina | 1984 | 9 234 |
| | Ecuador | 1984 | 584 |
| | El Salvador | 1979/81 | 12 144 |
| | Guatemala | 1979/81 | 905 |
| | Honduras | 1986 | 1 360 |
| | Mexico | 1985 | 46 000 |
| | Uruguay | 1985 | 140 |
| Toxaphen | El Salvador | 1979/81 | 5 252 |
| | Mexico | 1985 | 6 000 |
| 2, 4-D | Argentina | 1984 | 12 024 |
| | Ecuador | 1984 | 8 684 |
| | Honduras | 1985 | 28 |
| | Mexico | 1985 | 14 000 |
| | Suriname | 1979/81 | 525 |
| | Uruguay | 1985 | 1 424 |
| 2, 4, 5-T | Argentina | 1979/81 | 117 |
| | El Salvador | 1979/81 | 168 |
| | Guatemala | 1979/81 | 124 |
| | Mexico | 1984 | 500 |
| | Suriname | 1979/81 | 200 |

1 Data refer generally to quantities of pesticides used in, or sold to agriculture. They are shown in terms of active ingredients, except for Ecuador and Guatemala, where data refer to formulation weight. Formulation weight usually includes active ingredients plus diluents and adjuvants.

2 The latest year for which consumption data have been available.

3 Consumption figures are for aldrin and similar insecticides.

Source: FAO, 1987 FAO Production Yearbook, Vol.41, Rome, 1988, pp. 9-10 and 119-127; and United Nations, Consolidated list of products whose consumption and/or sale have been banned, withdrawn, severely restricted or not approved by governments, ST/ESA/192, 1987, Second issue.

ments in certain areas (Sweden, Denmark, Germany, Austria and Switzerland).

### *Global Summary-Nutrients*

Nitrate pollution of aquifers occurs through human and animal waste and through the use of fertilizers. Nitrate levels exceeding guidelines are widespread in European and North American aquifers. High nitrate concentrations in drinking water reduce the oxygen-carrying capacity of blood, with adverse health effects in infants. The reduction of fertilizer application or changes to agricultural practices will only be effective in reduction of nitrate levels after long periods of time (decades). Nitrate pollution from fertilizers will be one of the most pressing water quality problems in Europe and in several areas in North America in the next decade, and will start to be a serious problem for the next decades in several parts of the world (for example India, China and Brazil). Severe nitrate pollution through direct infiltration of human and animal excreta into shallow aquifers is found in certain African and Asian drinking water wells. Even if dramatic improvements in excreta disposal take place, this problem will remain very severe in these regions because of its health effects.

Eutrophication occurs in many European and North American lakes, reservoirs and slow-flowing rivers, where it leads to the deterioration of the aquatic environment and to serious problems for drinking-water treatment. Despite drastic efforts made to reduce inputs of phosphates (i.e. phosphate stripping in wastewater treatment plants or banning of phosphate detergents), eutrophication is widespread in all continents. Restoration of eutrophic water bodies is possible (for example lake Erie), but the response time of the ecosystem generally exceeds the water residence time.

### *Heavy metals*

Heavy metal pollution of water has a number of man-made causes, including the processing of ores and metals, the industrial use of metal compounds and particularly the leaching from domestic and industrial waste dumps, mine tailings, contaminated bottom sediments and lead pipes. Heavy metals have so far affected water quality only on a local or regional rather than at the global level. Only pollution from lead now occurs globally in coastal and marine environments. Arsenic, though not a heavy metal, is frequently monitored along with the heavy metals due to its high toxicity (UNEP/GEMS, 1991).

In Africa, industrial development (including breweries, sugar cane factories, pulp and paper mills, textile mills) and mines (gold, aluminium, phosphates), which are generally not connected to appropriate wastewater treatment systems, can cause serious problems especially in times of water shortage. These pollution problems already exist in the Nile Delta and are likely to occur in the Maghreb, southern Nigeria and mining districts in Zaire and Zambia.

Data from the United States of America indicates that aside from lead levels, which show improvement, the trend for many of the other heavy metals in surface waters continued to increase. Arsenic concentrations generally increased from 1974 to 1982, primarily in the Great Lakes and Ohio basins and the Pacific North-west. Cadmium measurements also showed an increasing trend, particularly in the Great

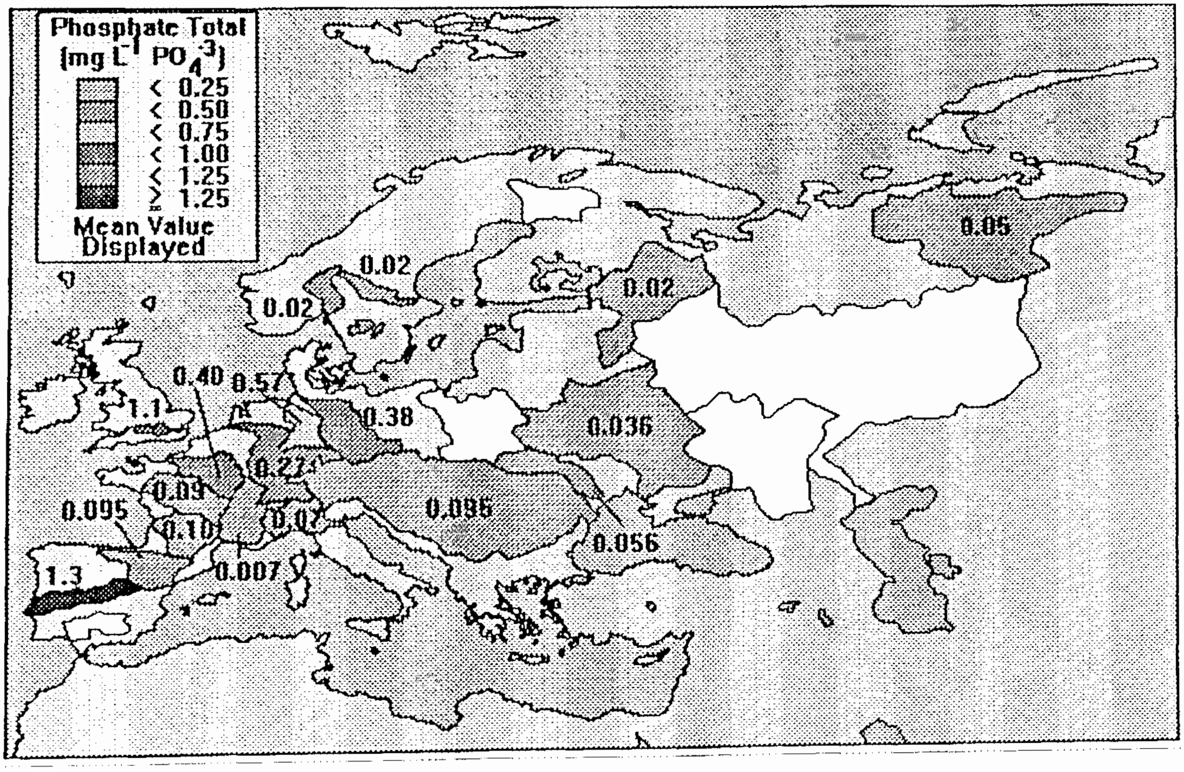


*Figure 4.14 — Phosphate concentration for major river basins in Europe*

Lakes, upper Mississippi and Texas Gulf regions. For other metals such as chromium (Cr), magnesium (Mg), selenium (Se), mercury (Hg), and Zinc (Zn), no significant trends were detected.

Peru, Chile, Mexico, Bolivia and Brazil have large mining industries for metals and minerals. The mostly untreated mining effluent discharges are particularly toxic to exposed aquatic life and humans. For example, the mercury pollution in the Orinoco and Amazon river basins is associated with gold extraction from river sediments. In Venezuela, gold exploration in the Orinoco River basin has had similar impacts and affects the treatment techniques used for drinking water and impacts directly on aquatic life. Guyana and Suriname suffer from mercury pollution in surface waters as a result of the mining industries there (WMO,1993).

Heavy metal pollution is a severe but localized problem in Asia, especially in India. In the Ganges River, for example, cadmium levels exceed the standards due to the discharges of tanneries. More investigation and monitoring is needed in all the countries of the region. Chemical analyses of chromium and arsenic and remedial measures are of special importance in Bangladesh. The major source of chromium is the numerous tanneries in and near Dhaka, while the high arsenic content is associated with the parent materials of the major aquifers in Bangladesh. Borehole-produced groundwater has an unacceptably high arsenic level (Grabs, 1995).

Heavy metal pollution in Malaysia, the Philippines and Papua New Guinea occurs mainly from mining activities (gold, silver, copper, tin) and industrial wastewater discharge. Metal pollution has been recorded in China, for example mercury in the Songhua Jiang and Ji Yun rivers, and is caused by effluents from chloralkali industries. Mines and smelters, especially those producing copper, zinc and lead, affect the communities and the environment, either directly or from erosion of mine tailings. Arsenic, mostly from air emissions from the smelting industry, has been reported at 0.75 mg/l in the most seriously affected areas of China. About 50 000 people were affected with mild arsenic poisoning by exposure over a 10-year period to arsenic concentrations as high as 0.12 mg/l in some villages.

In New Zealand, sulphates and especially arsenates occur locally at concentrations high enough to pose potential health risks. Likewise, mercury and other heavy metals from geothermal springs can be bioaccumulated by aquatic organisms. Such areas have been identified and remedial actions undertaken. In Japan, priority has been given to the control of metals, industrial organic chemicals and pesticides in waters. Great efforts are being made to control such substances as mercury, cadmium and PCBs in water and in food fish through the establishment and enforcement of environmental quality standards.

Heavy metals are a matter of concern in western Europe but stringent controls have led to declines in concentrations in water bodies such as the Rhine River (see Figure 4.15, Trends in undissolved heavy metal and arsenic concentrations found in The Netherlands section of the Rhine, UNEP/GEMS, 1995). In general, the concentrations reported are well below drinking water standards; only cadmium and mercury exceed the standard in some rivers. Within Poland and the Czech Republic, as well as in the Danube River and the Ukraine, the level of heavy metals is still excessive in industrial or mining areas (Europe's Environment, 1995).

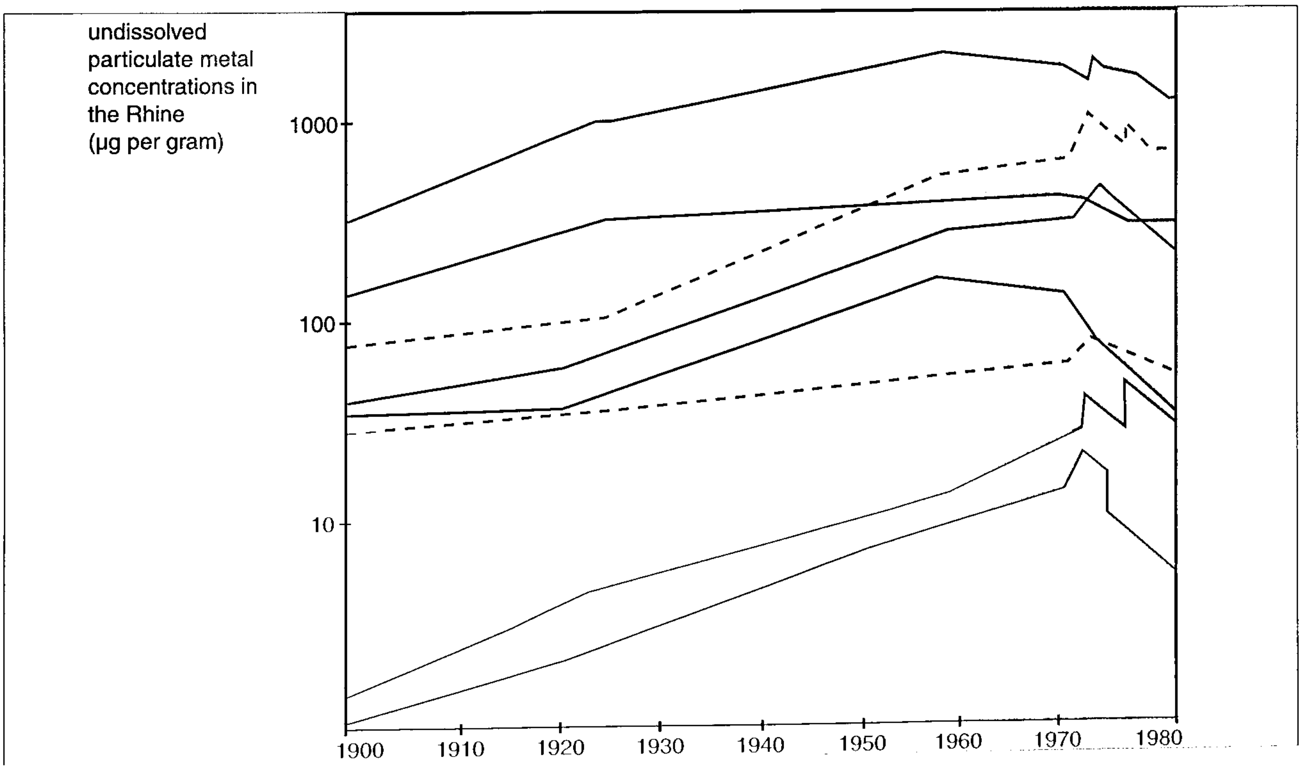


*Figure 4.15 — Trends in undissolved heavy metal and arsenic concentrations found in The Netherlands section of the Rhine*

*Global Summary-Heavy Metals*

Heavy metal contamination occurs mostly in industrialized regions and in mining areas, sometimes located in scarcely populated regions (e.g. northern Canada, Siberia, Zaire, South America). This pollution is best assessed by sediment analysis and suspended solids analyses. Heavy metal pollution will persist over long time periods even if appropriate measures to cut direct (sewage outfalls) or indirect (atmospheric releases of industrial and vehicle origin) inputs are implemented. Decreasing trends in metal pollution resulting from appropriate control measures have been observed in the Rhine and Mississippi rivers (for lead). In other areas, such as around the town of Samara in Russia, people still suffer from diseases caused by high metal concentrations in the environment (WHO meeting paper (unpublished), 1995).

*Salinization*

Salinization is caused primarily by a combination of poor drainage and high evaporation rates that concentrate salts in the surface layers of irrigated lands. It occurs mainly in arid or semi-arid regions that rely primarily on irrigation for crop production (Figure 4.16, Arid and semi-arid zones, "WHO/UNEP Report on Water Quality", 1991). Another cause of salinity is over-pumping of coastal aquifers, which leads to intrusion of saline water. Natural water quality problems related to saline waters limit the use of some African water resources for drinking water and other uses. Examples include the high salt content in surface and groundwater in parts of the Maghreb, Ethiopia and the Rift Valley. Saltwater intrusion into coastal aquifers can also be a major problem, usually made worse by over-pumping of the shallow fresh groundwater resource (e.g. Senegal, Gulf of Guinea and Egypt). According to water quality surveys, Cuba, Trinidad and Tobago (WHO/UNEP, 1991,p.28) the Bahamas, Barbados, Guyana, Netherlands Antilles and Suriname (WMO,1993, p.3) have identified salt water intrusion of coastal aquifers as a major problem. The Marshall Islands and Kiribata are also known to have the same problem. This is of particular significance for Small Island States because of the lack of alternative water supplies.

Within the Western Asia region water quality problems occur through heavy use of water for irrigation, which contaminates water bodies with chemicals and salts. Over-pumping from aquifers leads to intrusion of saltwater and the contamination of the remaining supplies as is now occurring in the Gaza Strip (Environment, 1994). Within the Arab Peninsula, the highly variable and low precipitation amounts, and the scarce groundwater, are the only natural water resources available. Further development of aquifers is generally not possible because of heavy existing uses. Over-pumping of groundwater has caused brackish and sea-water intrusion into aquifers along the coasts (salinization of 5,000- 20,000 mg/l). Saline intrusion into coastal aquifers is a major problem in Spain, were reliance on groundwater is combined with a high density of coastal population.

Salinization of fresh groundwater through over-pumping has also created severe problems in the Maldives and in the coastal areas in India (Khan, 1991). Natural salinization occurs in Thailand on the Khorat plateau (salty halite soils). In Viet Nam, river salinization occurs through salt wedge intrusion in the Mekong and the Hong Deltas. In Australia, the surface water quality varies greatly and salinization is a major problem affecting significant areas of the country. Salinization in groundwater is still of moderate severity but believed to be on the increase.

Irrigation has a significant impact on surface and groundwater quality, but data at the regional or global level

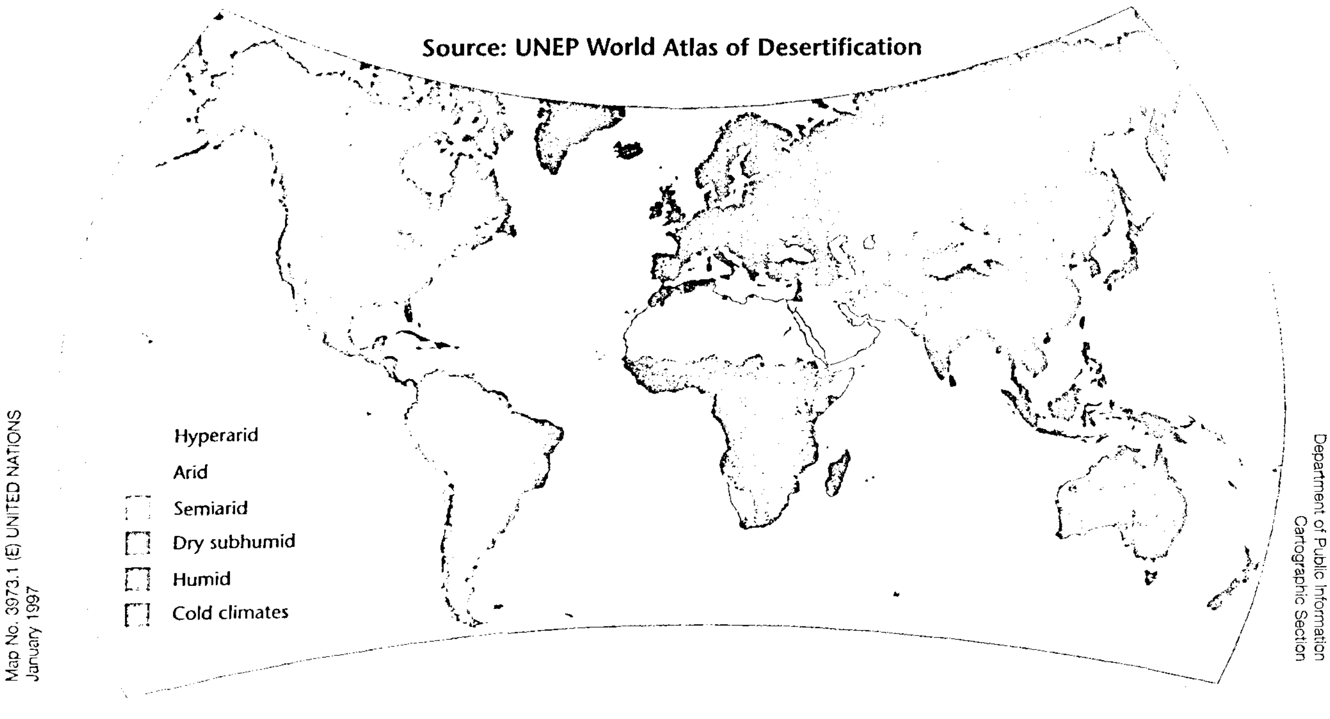


*Figure 4.16 — Arid and semi-arid zones*

is generally not available. An extreme example is the deterioration of the natural environment in and around the Aral Sea in Russia and Kazakstan through diversion of upstream runoff for irrigation purposes.

### *Global Summary—Salinization*

High salinity of surface and groundwater may result from natural evaporation, as for example in many countries in the belts of acid rocks which extend from Morocco to Rajasthan and from Chile to Australia. The increasing use of water for irrigation results in increased surface evaporation and concentration of salts carried by the irrigation waters. Trends of increasing salt levels have been noted in some of the world's major rivers (such as the Colorado, Rio Grande, Murray, Amu-Darya, and Syr-Darya) where the total salt content has reached levels at which most uses are impaired, including use for agricultural purposes.

Naturally high salinity due to the peculiar local geochemistry is observed in Thailand, north-west Canada, Chile and Turkey. Specific problems from high fluoride content in groundwaters (>5 mg/l) are also found over wide areas of Africa, such as in Senegal and Tanzania, and in Asia (Rajasthan). Severe dental and skeletal fluorosis is observed in China, where more than 30 million people are suffering from dental fluorosis and 2 million from skeletal fluorosis. High natural arsenic levels are also reported in China. Deficiencies of iodine in water in China are reported to cause widespread cretinism and goitre.

In coastal aquifers, which are now exploited all over the world, excessive extraction of freshwater has commonly led to intrusion of saltwater into the freshwater zone.

### *Organic micro-pollutants and pesticides*

Organic micropollutants, including chemical substances such as DDT, PCBs and industrial solvents, originate primarily in industries such as coal mining, petroleum refining, textile production, wood pulp and paper production, and pesticide factories. Production of domestic goods, particularly plastics, can also result in the production of organic pollutants. Such pollutants are released into the environment through urban and agricultural runoff, atmospheric fall-out, and urban and industrial wastewater. An assessment of global organic micropollution is difficult, and monitoring of micropollutants in freshwater is not often included in routine national monitoring programmes (UNEP/GEMS, 1991).

In North America, in spite of the high level of environmental control and legislation, both Canada and the United States are faced with water pollution problems requiring mediation. For example, in the Great Lakes more than 360 organic compounds have been identified, many of them persistent and toxic to humans, aquatic organisms and wildlife. One result of the discharge of persistent organic pollutants is the impact on commercial and sport fisheries. While the commercial catch in Canada's Great Lakes fishery doubled between 1891 and 1980, the proportion of preferred, high value species fell from 50 per cent to approximately 3 per cent of the total catch. The drinking water supplies of millions of people are being impacted by toxins in the Great Lakes basin, although most of the measured concentrations are below the recommended drinking water guidelines (Water 2020, 1988).

On the Indian Subcontinent organic micro-pollution is associated primarily with the use of pesticides and fungicides in agriculture. The most affected countries are Pakistan, India, Sri Lanka and Bangladesh. Because of limited organic pollutant monitoring programs, data are available mostly through site or purpose-specific surveys and the true magnitude of the problem is hard to judge. Present water treatment practices generally do not remove pesticides unless activated carbon is used, which is rarely done because of the cost. Pesticides occur in many surface waters in Indonesia, Malaysia, South Korea, the Philippines and Thailand. According to surveys in Thailand, 15-20 per cent of samples in certain rivers had pesticide concentrations in excess of 150 ng/l. Within the Pacific islands pesticide and herbicide use has caused only localized problems due to poor disposal practices close to, or directly into, water bodies (PIDC, 1992). In China, pesticide use and animal wastes create problems in some provinces, and monitoring of pesticides is carried out in a number of river and lake systems.

In Europe, industrial organic chemicals are also of great concern because of their possible toxicity and carcinogenicity. The extent of the contamination is poorly known as many of the countries do not carry out routine analyses for organic pollutants. Pesticides are a significant and widespread contaminant in Europe. Control is difficult because of the diffuse sources, but most western countries take precautionary approaches to control of pesticides similar to the approaches taken for industrial effluent sources of organic compounds. The level of pesticides is particularly high in rivers and lakes located in intensive agriculture areas.

### *Global Summary—Organic Pollutants and Pesticides*

The aquatic environment is exposed to ever-increasing quantities of pesticides, especially in fast-developing countries such as India and Brazil, but monitoring and analyses are difficult, costly and complex. As a result, pesticide contamination of the aquatic environment is poorly documented in most parts of the developing world. DDT contamination, for example, is present globally from the Amazon River to the Arctic icecaps as a result of the long-range transport of airborne pollutants. Although banned in most European and North American countries, DDT is still manufactured and used in many parts of the world. In tropical countries where intensive aquatic disease vector control is taking place (i.e. west Africa), enormous quantities of insecticides and molluscicides are used to control schistosomiasis, onchocerciasis and malaria.

The production of synthetic organic chemicals used in industrial activities has led to global pollution from substances such as chlorinated hydrocarbons and polycyclic aromatic hydrocarbons. Monitoring of these substances in the aquatic environment is very difficult and expensive and the understanding of impacts insufficient on a worldwide scale. In the coming decade, three major problems concerning organic pollutants are forecast to arise, namely;

- increase of global pollution through atmospheric contamination;
- severe contamination in aquifers, arising from waste disposal landfill sites; and
- accidents in manufacture, storage, transport or use of chemicals, resulting in pollution of the aquatic environment.

### *Acidification*

Atmospheric emissions, particularly those containing sulphur and nitrogen oxides from fossil-fuel combustion, are the major cause of acid rain and consequently acidified freshwater. Acidified freshwater was first noted in Sweden and Norway, but is now found in eastern North America, much of northern and central Europe, and in some of the rapidly industrializing developing countries. The industrialized countries are overwhelmingly responsible for acid deposition, contributing about 90 per cent of global man-made emissions. Sulphur emissions have declined by 15-40 per cent since 1970 in developed western nations, mostly because of control policies.

Precipitation containing sulphur dioxide ($SO_2$) exceeding 1.5-2 mg/l can be found in the rapidly developing areas of Asia and South America, as well as in Japan and South Africa (Figure 4.17, Global acidification, WHO/UNEP Water Quality Report, 1991, p.66). Acidification is a problem of increasing concern, particularly in the south-west of China, due predominantly to acid rain from coal combustion and metal smelting activities. Although emissions of sulphur dioxide are high in the north, effects of alkaline air-borne dust from the Loess plateau have reduced acidification problems there. Acid drainage from mine tailings occurs in some areas of China, but no comprehensive studies are available. In Australia, acidic mine effluents are reported, particularly in Tasmania.

In Europe, acidification of surface waters has occurred locally in many countries, especially in Scandinavia and the western part of Germany. Depletion of fish stocks has been observed in Norway and Sweden. The pH of many lakes in southern Scandinavia has fallen by 0.5-1.5 pH units since the mid-1900s, with serious consequences for aquatic life and also potential implications for human health. The most important human health effect of acidified water comes from its ability to leach trace metals from soil and distribution pipes. That was the case, for example in some private wells in western Sweden, where aluminium levels of up to 1.7 mg/l were measured, whereas the WHO guideline for drinking water is only 0.2 mg/l. (UNEP;1991,p. 25).

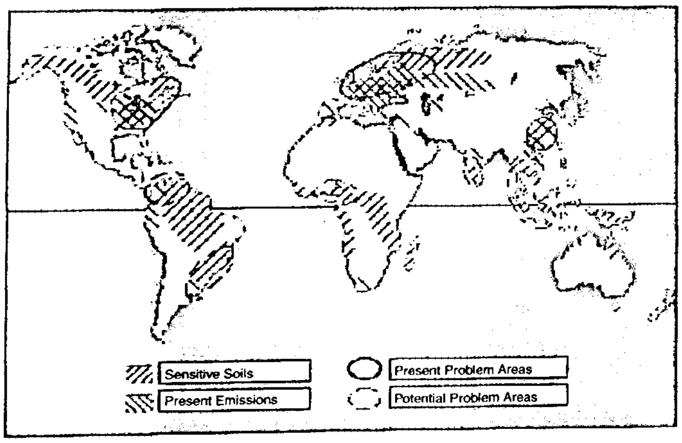


*Figure 4.17 — Acidification*

### *Global Summary—Acidification*

Acidification began to be recognized as a major issue in the early 1970s in Scandinavia and north-east United States of America. It is now a widespread problem, distributed around the Baltic and North seas in northern Europe and in most of the eastern parts of North America. Acidification of surface waters is likely to grow in many other regions of the world as industrialization takes place.

### *Suspended particulates and natural pollutants*

Suspended particulate matter (SPM) consists of materials that float in suspension in water. There are three main sources:

- natural soil erosion;
- matter formed organically within a water body; and
- material produced as a by-product of human activity.

In slow-moving waters, SPM settles on the stream or lake bed and forms deposits. Human activities that cause or increase the rate of erosion, such as deforestation, damming, agriculture and mining, add to the level of SPM in rivers and lakes. Numerous natural water quality problems limit the use of some African water resources for drinking water and other uses. A few examples at the global level are noted below:

- High fluoride content in surface (the Rift Valley) and groundwater (Morocco, Senegal and the Rift Valley) leading to widespread dental and skeletal fluorosis. The high natural concentration of fluoride in well water in northern China (2-4 mg/l, with values of over 30 mg/l) is causing morbidity rates of 43 per cent from dental fluorosis and 2 per cent from skeletal fluorosis.
- Very high suspended solids in some rivers at the beginning of the rainy season (Maghreb and East Africa).

Within the Indian Subcontinent, suspended solids are associated with heavy rainfall during the monsoon, which causes natural soil erosion and erosion from open and agricultural lands. This problem is seasonal and results in rapid siltation of reservoirs and creates problems in treating the drinking water supply. Especially affected are Nepal, Pakistan and India, with occasional problems in Sri Lanka and Bangladesh. In Malaysia, suspended solids are of special concern during seasonal monsoon floods as the turbidity, resulting from erosion, can rise to 20 000 units compared with less than 100 units at other times.

Groundwater accounts for 14 per cent of water used in Australia. The groundwater of shallow aquifers is rich in sodium, calcium and magnesium ions and the groundwater of the deep aquifers in Australia is of poor water quality. In New Zealand, high sediment loads in major rivers of the western Southern Alps of the South Islands are caused by erosion. Volcanic and hydrothermal activities affect water quality locally, specifically in the Central Plateau of the North Island of New Zealand. Sulphates and especially arsenates occur locally at concentrations with potential health risks. Likewise, mercury and other heavy metals from geothermal and some hot and cold springs can be bioaccumulated in aquatic organisms. Such areas have been identified and remedial measures undertaken.

#### *Global Summary-Suspended Particulates and Natural Pollutants*

The natural sediment loads of rivers has been greatly increased through a variety of human activities such as deforestation, agricultural practices and land disturbance. Due to construction of reservoirs the total quantity of river sediment reaching the sea may already have been reduced by 10 per cent compared to natural conditions. This led to a natural nutrient depletion downstream and the follow-up is an increased use of fertilizer that may decrease the coastal fishery yields (i.e. the Nile).

### *4.3.1.5 Global synopsis of water quality issues*

Over the past decades, natural water quality has been degraded by the impact of various human activities and water uses (see Table 4.14, Limitations of water use owing to water quality degradation, WHO/UNEP Water Quality Report, 1991). The GEMS/WATER assessment found that sewage, nutrients, toxic metals, and industrial and agricultural chemicals are the main water pollutants at the global level. Of these, the most widespread pollutant is the organic matter present in domestic sewage. In developing countries, untreated water represents the most commonly encountered health threat, and causes an estimated 25 000 deaths per day. By the year 2025, 56.4 per cent of the population in developing countries will live in urban areas. Total developing country population in 1995 was 4 580 million, and is forecast to rise to 7 071 million people in 2025 (UN Demographic Indicators, 1994). This extensive urbanization has generally not been accompanied by an adequate rate of development of a clean water supply, environmental sanitation and health care. Industrial development, the advent of intensive agriculture and the production and use of synthetic chemicals are the other main causes of water quality deterioration at the local to global levels.

Depending on the level of socio-economic development, public awareness, political will, and technological progress, the traditional water quality problems (pathogens oxygen balance, eutrophication, heavy metals) have been recognized, researched, regulations introduced and remedial actions undertaken. Conversely, in some European countries in transition, outbreaks of infectious diseases still occur today, for example the cholera outbreak in 1995 in the Ukraine. New pollution problems are of a different nature and include point and non-point sources of nitrates and other nutrients, environmental contamination with synthetic organics (such as pesticides) and long-range transboundery air pollution which causes acidification. Developing countries must often cope with traditional and

*Table 4.14 — Limitations of water use owing to water quality degradation*

| *Pollutant type* | *Water use* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Drinking water* | *Aquatic wildlife & fisheries* | *Recreation* | *Agriculture (including irrigation)* | *Industrial uses* | *Power and cooling* | *Transport* |
| Pathogens | + | 0 | + | + | ++(a) | 00 | 00 |
| Suspended solids | + | + | + | + | + | +(b) | ++(c) |
| Organic matter | + | + | + | 0(d) | ++(e) | +(f) | 00 |
| Algae | +(f) | +(g) | + | 0(d) | ++(e) | +(f) | +(h) |
| Nitrates | + | + | 00 | 0(d) | ++(a) | 00 | 00 |
| Salts | + | + | 00 | + | ++(i) | 00 | 00 |
| Metals | + | + | + | + | + | 00 | 00 |
| Industrial Organics | + | + | + | + | 0 | 00 | 00 |
| Acidification | + | + | + | 0 | + | + | 00 |

++ Marked impairment requiring major treatment or precluding this use.
\+ Minor impairment.
0 No known impairment.
00 Irrelevant.
(a) Food industries.
(b) Abrasion.
(c) Sediment settling in channels.
(d) Water quality changed in this way may be beneficial for this specific use.
(e) Electronic industries.
(f) Filter clogging.
(g) In fish ponds higher algal blooms can be accepted.
(h) Development of water hyacinth (Eichhornia crassipes).
(i) Iron and manganese in textile industries, etc.

Source: WHO/UNEP Water Quality Report, 1991, p. 59

new pollution problems at the same time due to the modern international trade in chemicals, the dispersion of persistent contaminants and other changes which are taking place within the country as development proceeds. These rapid changes complicate an already difficult situation and make mitigation difficult. Monitoring and studies information about water quality is scarce for many countries, either because of a lack of proper monitoring activities or because of difficulties in obtaining existing information.

Irrigation may lead to salinization through evaporation of irrigation water in two ways:

- higher concentrations of existing ions, which are then returned to rivers or seep into groundwater aquifers; and
- salt deposition on the soil surface and high salinity in surface soil layers if the water table rises to near the surface as a result of irrigation.

Because of the increasing area of irrigated land, the salinization of freshwater will be one of the primary water quality problems of the decades to come. It is estimated that approximately 8 per cent of the total irrigated area of the globe is already seriously affected by soil and water salinization.

Human enhancement of erosion may cause enormous turbidity problems, resulting in water quality impairments and coastal siltation (i.e. all over South-East Asia from China to India). Human activities can also modify the general hydrologic characteristics of water bodies including enhanced evaporation through the construction of reservoirs, increases in irrigation area, water diversion from one basin to another and over-abstraction of groundwater aquifers.

All of this leads to salinization of rivers, lakes and soils; salt water intrusion into coastal aquifers; reduction of the dilution and self-purification capacities of rivers; reduced river flows; erosion and losses of soil; and diminishing water quality. All of these problems can be evidenced in the Colorado and Rio Grande basins, the Nile and the Indus river systems, and the Aral Sea. Major rivers in the world impacted by dam construction and operation include the Columbia, Colorado, Rio Grande, Tocantin, Caroni, Parana, Nile, Senegal, Volta, Zambesi, Niger, Indus, Yangtze, Yenisei , Ob and Volga.

Water quality degradation is linked to many other key environmental quality issues such as air quality, soil fertility, food production, drinking water supply and the fisheries of coastal marine waters. The interactions between environmental compartments, and the implications for water quality, will change based on the water quality parameter, the characteristics of the natural ecosystem and the type of associated human activity.

### 4.3.2 *Groundwater*

*Groundwater quality*

Groundwater has three major attributes related to water quality:

- It is primarily used as a drinking water supply and for other domestic uses. Often it is used untreated so that the standards of protection must remain high and prior rights to its use must be protected.
- Its biological characteristics are generally good, and better than those of surface water. Accordingly, groundwater is generally cleaner, safer and more appropriate for human water supply than surface water.
- Its physio-chemical characteristics are more variable from place to place due to changing mineralization (generally higher than those of surface water) and increases of temperature with depth. Generally, salinity increases with depth and is higher in arid and semi-arid zones.

Global statements on the quality of groundwater are difficult to make because of the extreme variability and lack of comparable information from place to place. Qualitative characteristics are well defined at the local level in several countries, but the information is often scattered and non-homogeneous. Information is usually defined by hydro-chemistry maps of an elemental nature, established for specific aquifers or regions, or expressed in terms of "quality maps" based on classifications corresponding to various water uses. It is, therefore, difficult to collate the information in a form useful for developing tables or maps of the quality of groundwater at the regional and global level. An example of available information is given below in Table 4.15 for Tunisia, where a classification of salinity classes of the groundwater volumes abstracted was established.

The above example highlights:

- the scarcity of fresh groundwater, and the relative importance of brackish water for a country in the arid or semi-arid zones; and
- the better quality of the deep aquifers which are less affected by evaporation.

The quality of groundwater, particularly in the case of shallow aquifers, is vulnerable to pollution coming from anthropological factors. The monitoring and analysis of agricultural activities (excess fertilizers and pesticides), industrial activities (manufacturing or transport accidents, effluent discharges), or urban activities (lack of sanitation) is usually undertaken in developed countries. However, the study and regional evaluation of the degree of water quality

*Table 4.15 — Classification of salinity classes of the groundwater volumes abstracted*

| | | *Salinity in g/l* | | | | | |
|---|---|---|---|---|---|---|---|
| | | *<1.5* | | *1.5 to 5* | | *>5* | |
| Groundwater system | Total present abstraction hm≥/year | hm≥/year | % | hm≥/year | % | hm≥/year | % |
| Shallow aquifers | 700 | 59 | 8.4 | 495 | 70.7 | 146 | 20.9 |
| Deep aquifers | 830 | 165 | 19.9 | 653 | 78.7 | 12 | 1.4 |
| Total | 1 530 | 224 | 14.6 | 1 148 | 75 | 158 | 10.4 |

Statistics provided by D.G.R.E./Tunis

degradation resulting from pollution is less often carried out. The parameters most often used in regional synthesis, in particular for mapping, are generally those which correspond to diffuse pollution sources (salinity and nitrates in particular). An example of assessments that have been completed include one carried out in 12 countries of the European Commission. The results indicate that the nitrate concentration of water infiltrating into the soil exceeds 50 mg/l on 25 per cent of area, and is between 25 and 50 mg/l on 45 per cent of the area (RIVM-RIZA/CCE 1991). Mapping of the present nitrate content in groundwater has also been carried out in different countries based on highly variable sampling densities. The maps are often used to delineate the areas where the nitrate contents are considered in excess when compared with potability standards. The results can also be compared to the total area of the aquifers of one region or one country to give an approximation of the seriousness of the pollution problem.

### *Groundwater Quality Monitoring*

Monitoring of groundwater quality parameters is generally not implemented on a routine basis, nor carried out in all countries. The knowledge of quality changes with time is available in limited regions only, and is based on a limited number of variables. Trends for nitrates, which have been increasing for several decades in many shallow aquifers due to intensive agricultural activities or untreated sewage from urban development, have been observed in a number of countries. An example is France where nitrate contents higher than 50 mg/l were monitored in different aquifers from the 1970s (see Figure 4.18).

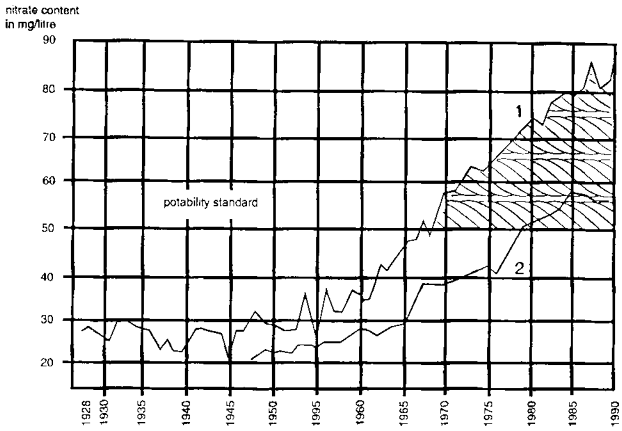


*Figure 4.18 — Example of increase of nitrate contents in groundwater in intensive-agriculture areas: Springs in the Brie plain (France) capted for the City of Paris*

# 5. WATER RESOURCES USE

## 5.1 GENERAL

Characteristics of the renewable freshwater resources and their space-time variation given in Section 4 of the report reflect the natural hydrologic interrelationships between heat and moisture in any given region and river basin. This scale of data, however, is inadequate for a reliable assessment of water resources and water availability for the present and for the future. A more detailed quantitative assessment of water resources, which includes the variability due to man's impact, is required instead.

Since time immemorial, people have used the runoff of rivers to sustain their domestic, industrial, agricultural and other activities. Rivers flow over long distances cover practically all regions of the world and are easily accessible for use and transport. Rivers supply people with an easily accessible source of freshwater, and runoff to some extent clear the land of various pollutants. Though river runoff can be renewed and self-purified, intensive development of industry and agriculture, population growth, urbanization, cultivation of new lands and the resultant growth of water withdrawal have greatly affected natural variations of streamflow, as well as quantitative and qualitative characteristics of the freshwater resource. At present, there is no large river system in the populated areas of the world where the river regime has not been disturbed by man's impact.

Within large river basins, countries and vast physiographic and economic regions, the river runoff has been affected simultaneously by numerous anthropogenic factors which influence the characteristics of the water regime, total annual runoff and water quality. The influence of man's activity on hydrologic processes may be combined into the following four groupings:

- Factors affecting river runoff due to direct water diversions from rivers, lakes, reservoirs and underground sources, and the use and return of these waters as waste discharges to the channel network. Examples include water diversion for irrigation and water withdrawal for industry and municipal needs;
- Factors affecting the hydrological regime and water resources due to different transformations of the channel network. Examples include construction of reservoirs and ponds, dyking and river training, and excavation of sand and gravel out of the river channel;
- Factors producing changes in the conditions of runoff formation and other components of the water balance by affecting the basin surfaces. Examples include agricultural development, drainage of swamps and marshes, cutting of forests, afforestation and urbanization; and
- Factors of man's activity affecting water resources and water balance by changes in climate characteristics on global and regional scales. Examples include changes in the composition of the atmosphere and changes in water cycle characteristics caused by large-scale water projects.

Evaluation of anthropogenic changes in the characteristics of river runoff at the global scale, or within continents and large physiographic and economic regions, is not possible because of the inability to estimate all of the above factors of man's activity quantitatively. Nor is it necessary to do so. In our opinion, it is possible to neglect the influence of factors producing changes at the basin level when developing a global overview. The most significant effect of these factors is at the small and mid-size basin scale. Moreover, the change usually applies to streamflow distribution during a year, extreme runoff characteristics and water quality, not the annual runoff. In addition, depending on physiographic and other features, these anthropogenic factors usually affect river runoff in different ways. For example, under particular conditions they may even increase annual runoff in small and mid-size rivers due to decreased evapotranspiration from the basin. Of the anthropogenic factors affecting the channel network (the second group above) it is possible to make an assessment of the effect of large reservoirs relative to the runoff from large basins and regions. The other factors in the group are either local in nature or their impact on the quantitative characteristics of water resources is negligibly small.

The assessment of the effect of man's impact on water resources at the global scale requires an accounting for direct water withdrawal from water bodies and for the runoff storage and release by reservoirs. These factors, when combined, generally explain the observed decrease of surface and subsurface runoff throughout the world, and can greatly affect the state of water resources in large regions. Section 5 describes, to the extent possible, the global freshwater withdrawal for municipal needs, for industry and agriculture, as well as water losses caused by the construction of reservoirs.

For this report it was not feasible to explore the possible effect of climate change on water resources. All the forecasts for the future are made under the assumption of a stationary climate situation.

## 5.2 Main Water Users and Trends in Their Development

### 5.2.1 *Municipal Water Withdrawal*

Municipal water withdrawal consists of the water diverted by the population of towns and small settlements, as well as water supplied to different enterprises providing various services to the population. Municipal water withdrawal also includes water supplied to industries taking water of high quality directly from the municipal water pipelines. In many towns and settlements, in hot areas in particular, much water is used for watering of vegetable and private gardens.

The amount of municipal water withdrawal is dependent on the number of urban dwellers and the level of development, i.e. availability or absence of water pipelines, sewage systems, central heating, etc., and on the climatic conditions as well. In general it can be assumed that 150-250 litres of water per day per capita (including 2.5-3.0 litres of water for drinking and cooking) are required to satisfy all personal requirements. The operation of municipal enterprises, including different services and the cleaning of the urban centre, would require additional 150-200 litres per capita. Utilization in excess of the values given can generally be explained in terms of the use of water by industrial enterprises or leakage from the system. For small towns without modern sewage systems, the water consumption would decrease to 75-100 l/day per capita. Design standards for municipal water supply for urban centres have been developed in many countries of the world. These standards are usually dependent on the level of development, rate of growth and on the climate. Water supply standards in northern countries are lower, if compared with those in southern countries where the climate is hot and dry. In some countries, the standard for municipal water withdrawal rate in urban centres is differentiated, depending on the population number and basic type of economic activity. For example, in Japan the water supply standard for small communities with a population less than 10 000 is 150-300 l/day per capita, with this amount increasing up to 400-560 l/day in big cities where the population exceeds one million. In addition, the standards generally take into account the type of economic activities in which the population of the urban centre is engaged. Using this type of methodology, the volumes of water withdrawal can usually be forecast within 5-10 per cent (Zarubaev, 1976; Shiklomanov and Markova, 1987; "On the methods of water requirements forecasting in Japan", 1985). The actual water withdrawal in many large cities of the world corresponds to the standards noted above and falls into the range of 300-600 l/day per capita.

Improved standards of living, industrialization and levels of development in urban centres has led to higher water demands per capita for municipal needs in most countries. For example, in Russia early in the 20th century, the water withdrawal for Russian towns with water pipelines was equal to 15-30 l/day per capita; at present the urban population in Russia consume 300 l/day per capita on average. In the United States of America the water consumption of the urban population increased from 100-150 l/day per capita in 1900 to 400-500 l/day in 1970 (Murray and Reeves, 1972; The Nation's Water..., 1968), an increase of three to four times. Western European countries have experienced an increased use per capita of more than double during the same time period. In the industrially developed countries of Europe and North America, the water withdrawal per capita can be as much as 400-1000 l/day. Based on information available, it can be assumed that 1 000 l/day per capita is the maximum amount of water required for urban water supply in developed countries in a hot climate; 600 l/day per capita would generally be sufficient in a moderate or warm climate. By contrast, the actual water withdrawal equals 50-100 l/day per capita in the developing agricultural countries of Asia, Africa and Latin America, while in some countries in water deficit areas withdrawal is as low as 10-40 l/day of freshwater per capita.

The total volume of water used for municipal needs in any country or region depends primarily on the specific uses to which the water is put and the amount of population. Annual municipal water withdrawal during different years or periods is given in numerous publications, e.g., in generalized publications (Shiklomanov and Markova, 1987; "World Water Resources", 1990; "Water in Crisis", 1993; Kulshreshtha, 1992). It should be noted that the data on individual countries are not always compatible because some publications give the total water withdrawal for urban and rural populations (e.g., in the United States of America, Australia, Brazil) while other publications give the amount of water consumed by the urban population (e.g., Russia, East European countries and African countries).

During water balance computations, if the volume of wastewater discharge and quantitative characteristics of water resources development are to be determined, it is very important to know the amount of water withdrawal and the amount of water losses for municipal purposes. Most of the water withdrawn by a municipal water supply system is discharged to the sewage system and returns to the drainage network (with or without treatment) as sewage wastes. Most of the consumption consists of water losses to evaporation, leakage from water pipelines and the sewage system, to water plants, to clean streets, and water parks, private gardens and garden plots. Use is therefore greatly dependant on the climate conditions and losses are greater in dry and hot regions compared with cold and humid areas. Water losses associated with direct personal human needs such as drinking, cooking and hygiene are small compared with the other water losses such as evaporation.

Relative values of water losses, usually expressed as a percentage of water withdrawal, depend to a certain extent on the specifics of water consumption for each urban centre. For example, in modern cities with a centralized water pipeline system and a relatively new sewage system, the water withdrawal generally falls in the range of 400-600 l/day per capita and water consumption does not usually exceed 5-10 per cent of the total water withdrawal. In contrast, in small communities with numerous private houses and without a completely centralized sewage system, specific water withdrawal can be equal to 100-150 l/day per capita and the water losses may reach 40-60 per cent. As a general rule, the lower values occur in northern regions, with greater percentage losses in dry southern areas.

Water losses therefore depend on many factors and vary within wide limits in different towns, regions and countries. For example, in Russia the average water losses for urban municipal water supply are generally in the range of 15-20 per cent of the water withdrawal, and vary from 10 to 30 per cent within individual large river basins. In the United States of America the average values quoted in the literature fall in the range of 20-35 per cent. The discrepancies can be explained by the inclusion of both urban and rural water withdrawal in the United States of America figures. In the industrial countries of Western Europe, the water losses for municipal water supply equal 5-10 per cent of the water withdrawal. For the globe as a whole the water losses for municipal water supply equal 52 km$^3$, or 17 per cent of the water withdrawal, according to the forecasts of Shiklomanov (1987) made for 1990.

The trends in development of municipal water supply in both large and small urban centres in all countries of the world are focused on the construction of centralized water pipelines and sewage systems to serve as many houses as possible. The impact is to increase the specific water withdrawal per capita. Therefore, water losses should decrease in the future, if expressed in per cent of the water withdrawal. For example, losses in the FSU in 1980 were equal to 15-20 per cent of the water withdrawal, with a forecast that losses will be reduced to 10-15 per cent before 2000. This change in loss rate should be taken into account when forecasts are made of future water withdrawal in different regions of the world.

### 5.2.2 *Water Withdrawal for Industrial Needs and for Thermal Power Generation*

Within industry, water is used to cool machinery and equipment, to produce energy, for cleaning and washing the goods produced, as an ingredient in manufactured items, as a solvent and for the transportation of goods. Significant water is used in industry to maintain the mandated sanitary and hygienic conditions and to satisfy the needs of the workers.

Thermal power generation is the main water user in industry; it requires much water for cooling the generators and other equipment. The volumes of industrial water used differ not only on the kind of industry, but also on the technology of the production process. These volumes are also dependent on the climatic conditions. In general, the amount of industrial water used in northern regions is much less than that used in southern dry regions with high air temperatures. The main water use sectors in industry are thermal power generation, chemistry and petroleum products, ferrous and non-ferrous metallurgy, wood-pulp and paper industry, and the construction of engineering works. For example, in the FSU in 1980, out of 107 km$^3$ of water consumed by industries, the portion of water consumed by thermal power generation was about 66 per cent, and the total for the other five industry sectors was equal to 89 per cent of the remainder of the total industrial water use. According to the publication "Global 2000 report to the President of the U.S.: Entering the twenty-first century", (1980), in 1977 in the United States of America, 76 per cent of the total water use was for thermal power generation; in Japan, 72 per cent; in Australia, 60 per cent; in Brazil, 14 per cent and in Italy, 11 per cent in the year 1977.

To characterize the water-consuming capacity of products manufactured by different industries, the factor of freshwater supply per ton of manufactured goods is often used. For example, on average for ferrous metallurgy, mining and separation, one ton of iron would require two to four m$^3$ of freshwater; the production of one ton of cast iron would require 40-50 m$^3$ of freshwater; the production of rolled stock, 10-15 m$^3$; copper, 500 m$^3$; and nickel, up to 4 000 m$^3$. A particularly large amount of freshwater; is required in the wood-pulp and paper industry, and for the production of petroleum based products. For example the production of one ton of cellulose pulp usually requires 400-500 m$^3$ of water; viscose silk, 1 000-1 100 m$^3$; synthetic rubber, up to 2800 m$^3$; synthetic fibres and plastics, 2 500-5 000 m$^3$; and capacitor paper, up to 6 000 m$^3$. A thermal power plant of one million kw capacity (using a once-through system of water supply) would require 1.0-1.6 km$^3$ of water per year. Still greater amounts of water (1.5-2 times and even 3-4 times) are required for atomic power stations of this capacity. It should be noted that there are thermal and atomic power stations of 3-5 million kw capacity in operation and even more powerful stations are planned. An integrated pulp-and-paper mill with a production capacity of 500 000 tons/year would require 435 million m$^3$ of freshwater, and a metallurgical works of mid-range capacity would require about 250 million m$^3$/year of freshwater (Levin, 1973). Industrial development, particularly during the last 20-30 years, has resulted in significant increases in industrial water withdrawal due to the construction of a new generation of thermal and atomic power stations, and the rapid rise in production of synthetic fibres, synthetic rubber, plastic materials and cellulose pulp, all of which are water-use intensive industries.

The characteristics of industrial water withdrawal (volumes of freshwater diversion, water consumption and wastewater discharge) are greatly dependent on the water supply system used. In general, there are two basic systems, once-through and recirculated. In the case of the once-through system, the water withdrawal from the water body is returned to this water body after use with or without treatment. In the case of the recirculated water system, the water is reused and recycled, and is usually cooled and treated before being discharged to the water-supply system. A recirculated water system results in multiple water use, significant reductions in water withdrawal, and a generally better quality of effluent because of the treatment. Some intake water is generally required to make up for losses internal to the system, but there are some closed loop systems in place. Technical progress in industrial production has resulted in not only more efficient recirculated water systems but also the use of dry technologies or those reducing the amount of freshwater used greatly. For those industries where the major portion of water is used for cooling, it is very important to replace the water cooling by air cooling, from the viewpoint of rational water resources management. This change may reduce freshwater use by 50-70 per cent in some industries (Levin, 1973).

The amount of industrial water consumption is usually a small portion of the water withdrawal, but it varies greatly depending on the type of industry, nature of water supply, technologies and climate. Consumption makes up only 0.5-3 per cent of the water withdrawal in thermal power generation, and 5-20 per cent in most industries, but can attain 30-40 per cent in some cases. For the once-through system, the water consumption (in per cent of the water withdrawal) is much lower when compared to the recirculated water system, but the freshwater withdrawal is higher.

The development of water resources to meet industrial needs is one of the main contributing factors to natural water contamination. This can be attributed, firstly, to intensive development of industries requiring excessive amounts of much water (production of synthetic fibres, petroleum products, wood-pulp and paper industry, etc.), secondly to rapid industrial development in general, and thirdly by industrial effluents that are highly concentrated or discharged as partly treated or untreated wastes. Thermal and atomic energy stations discharge significant amounts of water heated by 8-12°C over the intake temperatures, which disrupts the natural thermal regime in water bodies, causing changes in many natural processes and producing so-called "thermal pollution".

Industry is the second main water user in the world, with irrigation being the largest. According to the data contained in the "Global 2000 report to the President of the U.S.: Entering the twenty-first century", (1980), total industrial water withdrawal in the world in 1977 was equal to 805 km$^3$, including 502 km$^3$ for thermal power generation. Based on the estimates of the authors (Shiklomanov and Markova, 1987) the world water withdrawal for industry, including thermal power generation, was equal to 710 km$^3$/year in 1980. Moreover, the water consumption was equal to 62 km$^3$, or 8.7 per cent of the water withdrawal. Seventy-five per cent of the water withdrawal for industrial purposes took place in Europe and North America. Analysis of the trends of industrial water withdrawal for the last 30 to 40 years shows a major increase for all parts of the world. In many developed countries, however, a consistent trend to a stabilization of the water withdrawal for industrial needs has been observed since the 1980s. This observed trend for developed countries has been used in preparation of short-term forecasts of water withdrawal in this report.

When estimating the future volume of industrial water withdrawal for particular regions, countries or river basins, it should be borne in mind that these volumes depend on the combination of different trends. Water withdrawal should increase because of the growth of industry and thermal power generation, but on the other hand this increase may not be proportional to the growth rate of industry, as new technologies such as recirculation systems and dry technologies are introduced. In some countries and regions there is a trend toward more intensive use of sea water for industrial needs and for thermal power generation cooling (e.g., in the United States of America, Japan and Germany). In 1970 in the United States of America the portion of sea water of industrial water withdrawal was about 20 per cent. Forecasts assume that by the year 2000 about one third of the total water withdrawal for industrial needs would be satisfied by sea water. Despite all these trends, including stabilization of the industrial water withdrawal in industrially developed countries, the total water withdrawal for industrial needs in the world will probably continue to increase for the next 15-20 years. The future rates of increase of water withdrawal are forecast to be in the range of 1.5-3 times lower than the rates of increase in industrial production.

Water consumption by industry and thermal power generation can be divided into three parts for analysis purposes:

1) water losses to additional evaporation due to solar radiation when the water is diverted from the water body to the factory site, when water is used for cooling in the technological cycle, and as a result of warm water discharge back to the river system;
2) water losses to evaporation within the factory due to the energy absorbed during the technological process; and
3) water losses due to its inclusion into manufactured goods.

The second and the third groups of water losses, above, do not depend on the climatic conditions but instead are completely dependent on the production process. Based on an analysis of water consumption patterns, the major portion of water losses for industry and thermal power generation fall within the first group. Consequently, the amount of water consumed should be greater in southern areas with a dry climate when compared with northern areas with water surplus, assuming other conditions are similar.

Water consumption in industry and thermal-electric power plants greatly depends on the system of water supply. In the case of the once-through system, the water losses are minimal. In the case of the recirculated water system, the freshwater withdrawal and wastewater discharge tend to be significantly decreased, but the amount of the water consumed is often increased by 1.5-3 times. Based on present trends toward recirculated water supply systems and multiple water use in industry, an increase of water consumption (as a percentage of the water withdrawal) should be expected for certain countries, regions and large river basins. This fact must be taken into account for prognostic estimates of the effect of industrial water consumption on the quantitative characteristics of water resources.

The effect of industry on water resources includes not only the increased water use for industrial needs and great quantities of waste discharges to the hydrographic network, but also changes to the basin runoff characteristics resulting from mining, construction of industrial enterprises, intensive groundwater withdrawals and urbanization. Mining and groundwater withdrawals can cause the level of the groundwater table to decline and produce depression cones up to many thousands of square kilometres in area, which may greatly affect the water balances of river basins. In the case of a shallow water table, its decline may decrease evapotranspiration from river basins, thus actually increasing river runoff. On the other hand, the decline of the water table may reduce the natural groundwater outflow to the river network, which would reduce total river runoff (Dobroumov and Ustiuzhanin, 1980). In the case of mining, groundwater withdrawal may be accompanied by water discharge from the mines to rivers, which increases the runoff from small river systems. Thus, mining and use of groundwater withdrawals for water supply may give rise to a number of factors which can lead to both increases or decreases of natural river runoff. Similarly, hydraulic structures such as dams and diversions constructed in river basins for different industrial and transport purposes and urbanization can all effect the basin runoff characteristics. Runoff characteristics from small and even mid-size rivers can change as development takes place. The impacts of development on the water resources of large regions, large countries and continents is generally not significant, and the effect of those factors may be neglected there.

### 5.2.3 *Water Use by Agriculture*

The amount of water used for agriculture is primarily dependent on the level of irrigation development. In many countries and regions of the world, irrigation is the main water user and explains water deficit, particularly during dry years. Irrigation has been practiced for thousands of years, but the major irrigated lands in the world were developed during the 20th century, especially during the second half of the century. Based on the data of the FAO (Houston, 1977), development of irrigated lands in the world is presented below in millions of hectares:

| 1800 | 1900 | 1945 | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|---|---|
| 8 | 50 | 90 | 95 | 120 | 150 | 180 | 195 | 220 |

Thus, during the first 75 years of the present century, the irrigated lands in the world increased by a factor of 4.5 times. More than 50 per cent of the irrigated lands are concentrated in China, India, the United States of America and Pakistan. Prior to 1980, a trend to intensive irrigation development was observed in all developed and developing countries, i.e. increase of irrigated lands associated with an increase of agricultural products output.

A peculiar feature of irrigation farming was its introduction to northern areas, even to regions of water surplus. Irrigation was regarded there as an integral part of measures to provide high and permanent yields of all crops, irrespective of meteorological conditions. At present there is no country in Europe without irrigation, with large tracts of irrigated lands in Poland, Great Britain, Germany, France and the Netherlands. The so-called bilateral control of water regime, which comprises a combination of irrigation and drainage of the reclaimed lands, extends well into northern Europe.

During the 1980s the intensity of irrigated land development in the world was slower; a trend that was evident in both developed and developing countries. According to S. Postel (1992), during 1960-1979 the increase in irrigated lands followed or anticipated the population growth. After that period the irrigated area per capita began to drop, i.e. the rate of irrigated land development was lower. This may be explained by various reasons, including the costs of construction of new irrigation systems, problems of soil salinization experienced in existing irrigation lands, lack of water sources which could be developed for irrigation and environmental problems. At present the irrigated area is stable in a number of countries and may even trend toward reduction. These countries can satisfy their needs for agricultural products by increases in efficiency or find it is more efficient to import these products from other countries.

Considering this problem on a global scale, it should be noted that irrigation development in arid regions results from a necessity, or desire, to meet food self-sufficiency. At present about 15 per cent of the global cultivated areas are irrigated, with the products from the irrigated lands contributing more than half the value of agricultural products produced. Under conditions of high rates of population growth and under-nourishment, which is valid for about two thirds of the global population, the development of irrigation is important for achieving more efficient land use and increasing livestock carrying capacity. Therefore, it is possible to expect increased irrigation development in the countries with a rapid population growth and with sufficient water and land resources available. The amount of irrigated lands in the world can be expected to continue to increase (but the rate of this increase will probably not be as high as was experienced in the 1970s); consequently, it is possible to expect greater water volumes to be used for irrigation in the future.

Irrigation is the main water user on the Earth, with about 65 per cent of the world water withdrawal being attributed to use on irrigated lands. Therefore, an accurate inventory of irrigated lands is required to estimate water demands for irrigation for such continents as Asia, Africa and South America, where the water withdrawal for irrigation is 70-90 per cent of the total water withdrawal. A reliable assessment of the amount of irrigated lands in the world over time is not a simple problem. Reliable data is not available for many countries. In some cases the data available are approximate and even contradictory, with big differences dependent on the reference cited. And often these data give the results of inventory for different years and for variable factors. FAO has published data since 1961-1964, and this information is probably one of the more reliable sources of information at the global level. However, it must be recognised that the data published is submitted by individual countries every year, and is far from being uniform. According to recent FAO data, (FAO. Prod. 1968-1993) the total irrigated area in the world was 2 million hectares in 1990. This is less than forecasts made by different authors (Shiklomanov and Markova, 1987) in the past.

Forecasts of future irrigation development in the world looking 20 to 30 years into the future have been made by different authors. For example, the following areas of irrigated lands in the world (in millions of hectares) have been predicted over the last 20 years for the year 2000: Lvovich (1974), 500; Kalinin and Shiklomanov (1974), 420; Batisse (1976), 420; Ambroggi (1980), 302; Zonn and Nosenko (1981), 538; Franji (1982), 400; and Shiklomanov and Markova (1987), 317. All of these forecasts were based on the high rates of irrigation development that occurred during the 1970s. Optimistic national forecasts were also made at that time, but all of these forecasts probably overestimate the situation which has or will prevail. More reliable prognostic assessments can be made taking into account updated trends in irrigation development in combination with a number of socio-economic and physiographic factors in each country.

Water losses for irrigation depend not only on the irrigated area, but also on the amount of specific water diversion (in cubic metres per hectare per year) and on the amount of return flow (in percentage of the water diversion). These losses depend on general physiographic features, technical condition of the irrigation systems, irrigation methods and kinds of agricultural crops. Data on actual water consumption and water diversion for irrigation are not available for many countries and the accuracy of these data is not high, especially when the volumes of return flow are considered. Return flow is seldom measured directly and is often determined by generalizing the data from individual irrigated areas, computed by analogy, taken from project data or based on the assessments of the experts.

Data on water diversions and on irrigated areas, which are available for different countries, make it possible to compute irrigation requirements under certain physiographic conditions and this may be used as the basis for a computation of total water diversions over large physiographic regions and continents. It is quite natural that the least values of water withdrawal for irrigation are observed in northern countries and regions, e.g., in North Europe (Sweden, Germany, England, Finland, Belgium), as well as in Switzerland. These values generally fall in the range of 300-9 000 $m^3$/ha. In southern regions of France, Italy and Spain these values are equal to 5 000-6 000 $m^3$/ha and values of 8 000-10 000 $m^3$/ha are reported for the Eastern European countries on average (without the FSU). Return flow is estimated as 20-30 per cent of water diversion. In the United States of America irrigation requirements have been estimated by different authors to be as high as 8 000-10 000 $m^3$/ha, and the return flow as much as 40-50 per cent of water diversion. Rather high values of water withdrawal are observed in the FSU; i.e. 10 000 $m^3$/ha on average, which is explained by water transfer in large canals over long distances (hundreds of kilometres from the water source). Return flow in the FSU ranges from 20-40 per cent of water diversion.

In Asian countries, because of a great variety of climate conditions and kinds of crops, the irrigation requirements are quite variable; e.g., in Iran and Iraq they equal 11 000-12 000 $m^3$/ha on average; in Indonesia, 10 000 $m^3$/ha; in Israel and Jordan, 5 000-6 000 $m^3$/ha. Still greater differences in irrigation requirements are observed in the countries of Central and South America (from 8 000-9 000 to 15 000-17 000 $m^3$/ha) and particularly in Africa (from seven to 20-25 $m^3$/ha).

Forecasts of water consumption for future irrigation needs should keep in mind that irrigation requirements are not constant and may change in the future, depending on the physical conditions of the irrigation systems, reduced crop water requirements and changes in irrigation practices. In this respect, it is very important to replace small and midsize open canals by pipelines and to line trunk canals with concrete, which would make the efficiency of irrigation systems higher (from 0.4-0.6 up to 0.8-0.9). Water may be saved in great amounts if improved technologies such as sprinklers, subsurface irrigation, and drop irrigation, which also stimulate higher crop yields, are introduced.

During the last few decades, the use of sprinklers for irrigation has been introduced in many areas of the world. Sprinkler irrigation provides water only when it is required and reduces non-productive water losses. This latter fact is important from the viewpoint of water resources development as a more uniform distribution of water is provided and deep water outflow and soil salinization is reduced. Besides, water losses are reduced in the supply network which usually consists of pipes.

According to present estimates, the total area under sprinkler irrigation is about 20 million hectares. The largest sprinkler irrigated areas are located in the United States of America, Italy, France, Bulgaria and in some of the other developed countries of Europe. Experience in the United States of America indicates that the area irrigated by sprinklers tends to increase at a constant rate, and presently makes up about one third of the total irrigated area. A similar trend is observed in Russia. In Italy about 25 per cent of irrigated lands are irrigated by sprinklers. Sprinkler irrigation is becoming more and more popular in other countries as well.

During recent years a new kind of sprinkling irrigation called mist irrigation has been developed and applied. Water is dispersed in very fine drops, thus regulating the microclimate of the surface layer whereby air humidity rises and temperatures of the air and of the plants fall. This produces favourable conditions for plant development, reduces evapotranspiration, reduces the specific water requirements for irrigation to half or less and generally results in an increase in crop yields.

Drip irrigation is another new method which has been introduced into practice and it promises a great reduction in crop water requirements. Under drip irrigation, water is applied directly to the soil through small diameter pipes and nozzles located at the roots of individual plants. Under drip irrigation, the water supplied to the plant is used almost completely for transpiration. Water losses to infiltration and non-productive evaporation are minimal, water table rise cannot happen and salinization of the irrigated lands will not occur. A very important advantage of this method is a great water saving, which can range from 25 to 90 per cent. Crop yields can increase by 50-100 per cent compared to standard surface irrigation. Drip irrigation is now widely applied in many countries (Australia, the United States of America, Israel, Italy, Mexico, Tunisia, etc.) to irrigate orchards and vineyards, as well as vegetables and field cultures planted in wide-spaced rows. At the global level drip irrigation is applied to only 0.7 per cent of the irrigated areas (Postel, 1992). The systems of mist and drip irrigation are quite costly at present, approximately three to five times the cost of ordinary sprinkler irrigation, but reduce water consumption to half or less and increase the crop yield. Therefore, it is probable that these techniques will become more widely used throughout the world, particularly for high-value crops. Any forecast of future water requirements for irrigation must take into account these new technologies and the improved system efficiencies that can be achieved by modified facilities and instrumentation.

In the agricultural sector, water is used not only for irrigation but also for domestic purposes, for livestock production and for the improvement of rural settlements. Water withdrawals depend primarily on the climate conditions and the availability of centralized systems of water pipelines and sewage. Water withdrawals may range from 20-30 to 200-250 l/day per capita. The supply of high-quality drinking water for rural populations and for livestock production is a major challenge in many developing countries in arid regions. However, the quantity of water required for rural water supply and for livestock production is small compared to the water withdrawal for irrigation, and these uses are most often combined. For example, water supply in the FSU in 1980 to meet the needs of the rural population and livestock production was equal to about 7 per cent of the total water withdrawal and 5 per cent of the water consumed by irrigation. In the future this percentage is expected to decrease.

An approximate assessment of total water withdrawal for agricultural purposes in any region can be made from mean consumption (in litres per day per capita) and rural population number. Water losses (in percentage of water withdrawal) for the agricultural sector depend on the amount of water withdrawal and on the climate, as is the case also for municipal water withdrawal. At a water supply level of 100-200 l/day per capita, the water consumption does not usually exceed 15-30 per cent of the water withdrawal, while at a lower water supply level of 20-50 l/day per capita the water consumption may be 70-100 per cent of water withdrawal. Thus, when forecasts are made for the future, it is necessary to take into account that extensive construction of water pipelines and sewage systems in rural areas will result in an increase of mean regional specific water consumption for agricultural purposes, accompanied by a simultaneous decrease in the relative values of water consumption.

When future forecasts of water withdrawal for agricultural purposes are made, some scientists (e.g., M.I. Lvovich, 1979, 1982) recommend that water losses for dry land farming development be taken into account. Dry land farming generally increases the volume of water consumed by crops and results in higher crop yields when compared to natural cover conditions. On the basis of studies carried out (Vodogretsky, 1979; Rakhmanov, 1973; Shiklomanov, 1976) it is possible to conclude that changes to agricultural practices in the steppe and forest-steppe zones of Europe reduced overland flow and may affect total annual runoff in small water bodies. For large river basins the relative effect of the overland flow on total runoff tends to be smaller, and the effect of changes in agricultural practices is not large. The changes to normal runoff due to changes in agricultural practices do not normally exceed 4-8 per cent in large basins. This decrease is explained by some increase of evapotranspiration from ploughed fields where agricultural crops are planted. Concurrently, soil infiltration can increase, resulting in increased shallow seepage and groundwater recharge. These observations are in agreement with the analysis of actual long-term observation data on runoff of large river basins.

Improvement of land-use practices and higher crop yields, according to the results of numerous studies (Alpatiev, 1974; Kalinin, 1968; Vodogretsky, 1979), can be accompanied by lower specific water consumption, more economical water consumption by plants and by lower non-productive evaporation from the soil. As a result, the total water consumption by agricultural fields is either unchanged or only slightly increased. For example, investigations by V.V. Rakhmanov (1973) in the Don river basin where new agricultural techniques were introduced (agricultural crops occupy more than 60 per cent of the basin drainage area), show that the increase of crop yields was three-fold during the period 1880-1970, but the basin water resources were not significantly affected.

The effect of changed agricultural practices and higher crop yields on dry lands is generally of a local nature and it is quite insignificant. Therefore, this effect may be neglected, when considering changes to water withdrawal and the water balance of large regions and continents. The same may be said about drainage works in regions of excessive and sufficient water availability. Such works or projects do not greatly affect the water balance of large river basins even if these projects are extensive in scale.

### 5.2.4 *Reservoirs as Freshwater Users*

The construction of large reservoirs may lead to a fundamental transformation of streamflow distribution in time and increase water availability during low-water limiting periods and in dry years. Reservoirs, however, flood vast areas and the increased evaporation from the water surface in regions of water deficit can significantly reduce the water resources available and make reservoirs one of the most important of the freshwater users. Therefore, it is necessary to take this reservoir effect into account for estimating total water withdrawal at the country and continental level, although it is not a common practice to do so.

Reservoirs were constructed many thousands of years ago, but only during the second half of the 20th century did they become significant water bodies on the global scale. All the largest reservoirs, with volumes exceeding 50 km$^3$, have been constructed during the past 40-year period. At present the total capacity of reservoirs in the world equals about 6 000 km$^3$, and the total water area of these reservoirs at full supply level is approximately 500 000 km$^2$. More than 1 000 reservoirs have been constructed in the FSU. The total volume of these reservoirs exceeds 500 km$^3$, the total full supply level capacity of these reservoirs equals 1 000 km$^3$, and the total surface water area exceeds 70 000km$^2$ (not counting the surface area of lakes within the backwater effect). Channels of some large rivers are in fact transformed into systems of reservoirs which follow step-wise one after another. The Volga-Kama system of reservoirs, the Dnieper system of reservoirs and the Angara-Yenisei system of reservoirs are the largest and best examples. For example, 11 large reservoirs were constructed in the Volga basin with a total full supply level capacity of 180 km$^3$, effective capacity of 94 km$^3$ and total surface water area of about 25 000km$^2$. In the Dnieper basin six large reservoirs were constructed with a total full supply level capacity of 40 km$^3$, effective capacity of 18 km$^3$ and total surface area of 7 000 km$^2$. Systems of reservoirs of this magnitude can completely change the hydrological regime of river systems.

The total effective capacity of U.S. reservoirs equals about 800 km$^3$, compared to the reservoirs in the FSU, which equal about 500 km$^3$. Taking into account that the total river runoff in the United States of America is half that of the FSU, the rate of runoff control in the United States of America is rather high. In Canada, the total reservoir full supply level capacity is similar to the United States of America. These three countries (FSU, the United States of America and Canada) have developed about 40 per cent of the total reservoir full supply capacity of the world (Shiklomanov, 1989). Large reservoirs, with a capacity of more than 2 km$^3$ and surface water area exceeding 1 000 km$^2$, are found in many other countries, including China, Iran, Iraq, India, Pakistan, Norway, Brazil and Uruguay. Most of these reservoirs have been constructed since 1970. In Europe (except the FSU) the largest full supply-level capacity reservoirs are found in Spain, Bulgaria, Portugal and in the Czech and Slovak Republics. In some European countries, the total reservoir capacity is equivalent to 15-50 per cent of total annual river runoff. The largest reservoirs in the world in terms of capacity are Lake Victoria in the Nile river (205 km$^3$) and the Bratskoje reservoir in the Angara river (169 km$^3$). Lake Volta in Ghana (8 500 km$^2$) and the Kiubyshevskoje reservoir in Russia (6 500 km$^2$) have the largest surface areas.

The construction of reservoirs in developed countries was most intensive during the period from 1950 to 1970, when river runoff was almost completely controlled in many cultivated regions. Later, the rate of reservoir construction slowed, but it is still high in the countries with large quantities of natural water resources. In developing countries the highest rates of river runoff control occurred during the 1970s and 1980s. For example, in Africa four reservoirs out of the seven largest reservoirs in the world (Lakes Victoria and Nasser in the Nile, Lake Volta in the Volta river, Kariba Lake in the Zambesi River) were constructed with a full supply level reservoir capacity exceeding 130 km$^3$. Based on present trends, and specific country proposals for future development, it is possible to predict that the total full supply-level reservoir capacity in the world will be equal to 6 800-7 000 km$^3$ at the beginning of the 21st century. This high rate of reservoir construction may be explained by a greater reliance on hydroelectric power as liquid and solid fuels became less readily available and expensive. In general, hydroelectric power is very important to satisfy peak load demands for electricity, which cannot be as effectively met by thermal power plants or nuclear energy stations. In addition, reservoirs provide water for industrial needs, for thermal and nuclear atomic power station cooling, and for agricultural and municipal needs. Reservoirs also serve as the basis for large-scale water management systems, providing space-time runoff control and protection against floods. Reservoirs will continue to be constructed in the future but we may expect that the types of reservoirs, their purposes and locations will be different. Reservoirs will most likely be constructed in mountainous and in semi-mountainous regions, and in areas of poor agricultural potential so that fertile lands suitable for agriculture are protected. In developed countries, the construction of small and mid-size reservoirs will probably prevail.

Reservoir construction leads to a reduction of freshwater resources due to additional water losses for evaporation. In some regions of the world, the volume of water consumption by reservoirs is quite significant. The volume of the additional water losses caused by reservoir construction may be computed as the difference between evaporation from the reservoir surface and from that area before the flooding, including the land and the river under natural conditions. Reservoirs constructed in zones of intermittent and inadequate water availability, for example arid regions, result in decreased water resources downstream, due to the higher evaporation from the water surface compared with evaporation from the land submerged by the reservoir. If the reservoir is largely confined to the old river channel this decrease is not great, because the additional water area is not large and evaporation from the flood plain is close to that from the reservoir surface. In some cases, when vast flood plain areas occupied by water-loving plants with intensive transpiration capacity are flooded, the construction of a reservoir does not necessarily lead to water resources decrease even in regions with a hot climate. Additional water losses for evaporation from the world's reservoirs have been estimated (Shiklomanov and Markova, 1987). By 1980, this value was about 120 km3 per year and is forecast to be about 1.8 times higher by the end of the century.

It should be noted that the effect of large reservoirs on evaporation occurs not only within the flooded area, but also in the river reaches downstream, because the river regime is changed and the flood plain is no longer flooded on a regular basis as a result of the runoff control. According to the data in Shiklomanov (1976), the construction of a system of reservoirs on the Volga River (the largest river in Europe) resulted in a shorter duration and reduced flooded areas in the Volga-Akhtuba flood plain and in the delta, thus reducing evaporation losses in these river reaches by 1.4 km$^3$/year if compared with the undisturbed conditions. A similar effect may occur in other basins; moreover, this effect would be most significant in southern arid regions. The reduced evaporation downstream of reservoirs may be neglected in zones of water surplus and sufficient water availability. On the other hand, the rise of the water table in areas adjacent to reservoirs usually cause greater water losses from evaporation. Taking these two additional factors into account, it is possible to assume that if these factors are neglected, they would not greatly affect the averages values of water resources variation due to reservoir construction as they compensate each other to a certain extent. For that reason, the influence of reservoir construction on water withdrawal is based in this report on a computation of the additional evaporation from the reservoir surface only.

## 5.3 Methodological Principles for Assessment and Forecast of World Water Use

Quantitative characteristics of water use in any large region or country are generally based on the following factors: rate and level of economic and social development, population, physiographic characteristics including climate, and the size of the area. A combination of these factors explains the volume and structure of water withdrawal, its dynamics and trends for future development.

The analysis of renewable water resources and water availability for each physiographic and economic region was given in Figure 4.2 and Table 4.4, as well as for selected countries and river basins from all continents in Section 4.3. This section of the report describes the determination of both water withdrawal and water consumption for a similar geographical breakdown. For each region, country or basin separate assessments have been made for water withdrawal and for water consumption under the sectors of municipal water supply (including needs of the urban population), agricultural water use (including rural water supply and livestock), industry (including thermal power plants), irrigation, and reservoirs (additional evaporation from reservoir surfaces). All these assessments have been carried out for the following time periods: the past years (1900, 1940, 1950, 1960, 1970, 1980), the present (1990) and forecasts for the future (2000, 2010 and 2025). This approach makes it possible to follow the space-time dynamics of water withdrawal in the world during the 20th century and into the early 21st century. An assessment made by the authors of various physiographic and economic regions during the 1980s and published in Shiklomanov and Markova (1987), were used as the basis for the information presented covering 1900 to 1980. A comparison of results based on the use of more complete recent data for the period 1975-1980 shows a good coincidence with the earlier results for practically all physiographic and economic regions of the world.

The assessment of water withdrawal was made for different countries, then the values obtained were generalized for individual river basins, large physiographic and economic regions and continents. Data on the water withdrawal characteristics and on the factors which determine these characteristics were analyzed for different years for about 100 countries altogether. The starting point was national data on the observed or computed water withdrawal in a country or combination of several countries. Data are available for many countries from all the continents to different levels of completeness and reliability. The most detailed and reliable data on a systematic basis for a long-term period (several decades) have been published in various international publications and by individual authors. Assessments prior to the year 2000 are available for the United States of America, countries of the FSU, practically all the countries of Europe, Canada, China, India, Pakistan, Mexico, Cuba, Brazil, Argentina, Uruguay, Chile, South Africa, Japan, Turkey and Australia.

The analysis of water withdrawal and other water management characteristics, and forecasts for the future for different countries and regions of the world has been carried out by various authors. The major publications used are listed in the References to this Report. During recent years a number of publications with generalized data on water withdrawal for the 1980s and for 1990 for the majority of countries of the world have been produced. The key publications in this category are World Resources, 1991-1994; Kulshreshtha, 1992; Water in Crisis, 1993; and recently published statistical data on the economics of different countries of the world for 1990 (Statistical Yearbook, 1992). Detailed data on the analysis of updated and future water availability have been obtained for the countries of the Mediterranean basin and for Arabian countries (Alam, 1989, Margat 1990,1992).

It should be noted that in evaluating this information the authors faced great difficulties as the data given in different publications is often contradictory and poorly compatible. The information is often not complete, the time period this information relates to may not be clear, and it must be recognized that the volumes of water withdrawal differ greatly from year to year at the local or country level. Reliable data on water consumption is very difficult to obtain and is missing for the majority of countries. Information of generally poor quality is available in various publications on water withdrawal in different countries prior to the 1960s-1970s, and some contain forecasts of water withdrawal after 2000. There are no published data on a systematic basis on water losses from additional evaporation from reservoirs. Assessments were made of water withdrawal and consumption for the past, present and future by specially developed methodological approaches which took into account the main factors which determine the amount and dynamics of water withdrawal and consumption. The method of analogy was widely applied whereby the information for countries with reliable data on water withdrawal was applied to other countries with similar physiographic features and similar levels of economic development.

Water withdrawal for population needs in urban and rural areas was estimated from the data on the dynamics of population numbers (urban and rural) and from specific water withdrawal per capita. The population numbers for the previous years were extracted from statistical manuals ("Population numbers in different countries in the world", 1980). For 1994, and for the future, the UN forecasts were used ("World Population Prospects: The 1994 Revision", 1994). These forecasts predict the population numbers for all countries of the world up to 2050. A specific water withdrawal per capita and the amount of the water consumed in each country were taken from the published national data or from the international publications. If such data were missing, these values were estimated by analogue from the specific water withdrawals in countries with data. When assessments were made for the past and for the future, the trends in water withdrawal for urban and rural population and water losses in percent of the total water withdrawal (described in Section 5.2) were taken into account.

Assessment of water withdrawal for irrigation was carried out by analysing the following characteristics; the 1950-1990-1994 population numbers (UN data), the size of irrigated lands in the same years, including specific values in hectares per capita (FAO data), and gross national product (GNP) expressed in U.S. dollars per capita. The specific water withdrawal and water consumption were estimated from the national data or on the basis of country analogues. The amount of water consumption for irrigation purposes (in percentage of the water withdrawal) varies from 50 to 80 per cent in various countries and regions of the world.

Water withdrawal forecasts for 2000, 2010 and 2025 were mainly based on the prediction of the amount of irrigated lands. Trends in the changes (in combination with the above determining factors) for the previous 30 years were developed and analyzed first. The analysis was made for each country separately and as a result it was possible to establish analogues for the trends of irrigated area based on variations in population number and GNP for groups of countries with different GNP levels. These trends were used as the basis for prediction of future amounts of irrigated area using the population number in each country and GNP data. These values were extracted from publications (International, 1950-1994; Strzepek, 1995), which contain forecasts up to 2025. When the size of irrigated lands was predicted for the future, the limiting factors of size of areas suitable for irrigation (taken from the data, Zonn,1974; Irrigation, 1995) as well as data on water resources accessible for use were taken into account.

Forecasts of future water withdrawal for irrigation take into account that water withdrawal will tend to be lower than at present due to improved technologies and facilities used for irrigation designed to make more economical use of water resources. The decrease is different in each region and country, depending on the level of development and physiographic conditions. In the majority of cases, this decrease is within the range of 10-25 per cent. The maximum values were utilized for relatively rich and rapidly developing countries with restricted water resources.

Industrial water withdrawal is computed on the basis of trends and conditions related to the industrial production in different regions of the world. Estimates of water withdrawal for industrial use were based on actual data or an analogue with countries with similar levels of economic development and located in similar physiographic zones. Computations for the past and present have been made separately for thermal power generation, and for other branches of industry which have different trends and rates of development and water losses. The results have then been summed up for each region. Water losses in thermal power stations have been taken to be equal to 1-4 per cent of water withdrawal and other branches of industry from 10 to 40 per cent, depending on the level of industrial development, available recirculated water systems and climate conditions.

Predictions for the future up to 2025 are made separately for each country, taking into account the work undertaken by UNIDA (Strzepek and Bowling, 1995). This publication takes into account the present situation in the world, and based on forecasts of GNP data makes a prognostic assessment of the increase in water withdrawal for industrial needs up to 2025. This forecast is then compared with 1990 data for major countries of the world. Forecasts are made for high and low levels of electric power generation in the world, and for four different variants of global development (Global Shift, European Renaissance, Global Balance, Global Crisis). The optimistic variant (Global Balance) and middle rate of electric power generation has been selected as the basis for forecasting future water demand. In accordance with this variant of UNIDA, a water withdrawal increase of 1.4-2.9 times for the developed countries and three-10 times for the developing countries can be expected. Similar values are obtained if the European Renaissance variant is used. When analyzing the data on the industrial water withdrawal increase proposed by UNIDA (by all the variants), we have come to the conclusion that these values are overestimated and they do not fully reflect the present trends in the changes of water withdrawal by various branches of industry. Therefore, the UNIDA data for 2025 (according to the accepted "Global Balance" variant) are reduced by 20-30 per cent for developing countries and by 40-60 per cent for developed countries.

Additional water losses for evaporation from reservoirs have been computed for all the larger reservoirs of the world if the difference between mean evaporation from the water surface and the land surface exceeds 5 km$^3$ in volume. In this case the coefficient Kr ,which is the ratio of additional surface area of the reservoir to its total surface area, is taken into account. For lake-type reservoirs Kr=0.90-0.95, and for channel-type reservoirs Kr=0.60-0.80. Investigations made for the Volga and Dnieper basins (the largest European rivers), where reservoirs of different volume, surface area and reservoir type exist, show that on average the coefficient Kr=0.80 for large territories (Shiklomanov, 1979). This value of the coefficient has been an accepted constant for all regions of the world, with the exception of reservoirs which raise the level of existing large lakes due to the backwater effect. Base data on reservoirs (surface area, capacity, location, years of construction, etc.) are taken from summary publications ("World Water Balance and Water Resources of the Earth", 1974; Reservoirs of the World, 1979; Water in Crisis, 1993), as well as from other publications on individual countries and regions.

Normal evaporation from water surfaces and from land were taken from the maps of the Atlas attached to ("World Water Balance and Water Resources of the Earth", 1974). The total volume of additional water losses for evaporation has been computed for each region by summing up the data for each large reservoir (>5km$^3$) and by increasing the obtained result by 20 per cent. This increase accounts for small reservoirs, as large reservoirs make up 80 per cent of the total volume of all reservoirs in the world.

Future water losses for evaporation from reservoirs have been estimated for each region taking into account trends discovered during the last decades, available plans for construction of large reservoir in these regions or countries, and physiographic characteristics. Trends in reservoirs construction in developed and developing countries, as discussed in Section 5.1, has been taken into account.

## 5.4 Distribution of Sources of Supply by Sector of Use and by Country

Surface water and groundwater are the two conventional sources of water supply and the majority of withdrawals by the different sectors come from these two categories in most countries. In order to evaluate the distribution for each sector of worldwide and regionwide withdrawal of surface water and groundwater, it would be necessary to obtain comprehensive data at the country level. The ideal presentation for each country would include sector of ge (agriculture, industry, municipal use, energy) and source of supply (surface and groundwater).

Unfortunately, that level of information does not exist at the global level and only a selection of examples can therefore by provided in Table 5.1. A classification of nearly all the countries in the world, showing the proportion of supply sources to total water demand without any distinction between the sectors of utilization, has been developed and is expressed in map form in Figure 5.1.

The distribution of water withdrawals by type of source (surface water—regular or irregular, groundwater-renewable or non renewable) mainly follows the structure and relative importance of these resources at the level of each country. But it also partly depends on whether demand is concentrated or scattered, individual or collective.

Surface water dominates at the global level (80 per cent of world withdrawals) and prevails in humid countries with concentrated and abundant fluvial systems, whereas exogenous rivers constitute the main source of supply in arid countries (Egypt, Iraq, Kazakstan). Surface water is the

*Table 5.1 — Distribution of water use by sectors and by source for selected countries (in km³ /year)*

| *Selection of countries (incl. Mines)* | *Sectors use Source (incl. Thermal)* | *Municipal Use* | *Agricultural Use* | *Industrial Use* | *Energy* | *Total* |
|---|---|---|---|---|---|---|
| United States of America 1990 | Groundwater | 26.62 | 74.14 | 8.25 | 0.72 | 109.69 |
| | Surface water | 34.55 | 121.34 | 22.99 | 180.26 | 359.18 |
| | Total | 61.17 | 195.48 | 31.24 | 180.98 | 468.87 |
| Spain 1992 | Groundwater | 0.961 | 4.364 | 0.103 | 0 | 5.428 |
| | Surface water | 3.326 | 19.785 | 1.854 | 3.986 | 28.951 |
| | other | 0.019 | 0.096 | 0 | 0 | 0.115 |
| | Total | 4.305 | 24.245 | 1.944 | 3.986 | 34.494 |
| France 1990 | Groundwater | 3.487 | 1.009 | 1.7 | 0.014 | 6.210 |
| | Surface water | 2.603 | 3.919 | 2.745 | 22..253 | 31.520 |
| | Total | 6.090 | 4.928 | 4.445 | 22..267 | 37.730 |
| Egypt 1990 | Groundwater | 1.56 | 1.11 | e | 0 | 2.67 |
| | Surface water | 1.54 | 45.09 | 4.6 | 0 | 51.23 |
| | other | | 3.5 | | | 3.5 |
| | Total | 3.1 | 49.7 | 4.6 | 0 | 57.4 |
| India 1990 | Groundwater | 16 | 160 | 4 | 0 | 180 |
| | Surface water | 9 | 300 | 11 | 19 | +other 33 |
| | | | | | | 372 |
| | Total | 25 | 460 | 15 | 19 | 552 |

main source of water used for irrigation, for supplying major urban centres, for thermal electric power plant cooling and industrial water supply.

Groundwater exploitation is predominant in countries with limited surface water resources, in particular where major non-renewable aquifers are available for development (Saudi Arabia, Libya). However, groundwater use is significant in temperate or tropical countries with important groundwater resources and often meets a major part of dispersed water demands such as rural supply and individual irrigation. In India, for example, 160 km/year of groundwater is withdrawn for irrigation which corresponds to 35 per cent of the entire volume of water used for irrigation in that country. This constitutes a world record for use of groundwater.

At the global level, use of surface water and groundwater by sector is shown below in Table 5.2.

The term "Groundwater" includes shallow groundwater, hydraulically connected with the river system. Use of these shallow groundwaters leads to a direct decrease of the river runoff.

*Table 5.2 — Use of surface and groundwater by sector*

| *World use* | *Surface Water %* | *Groundwater %* |
|---|---|---|
| Municipal water supply | 50 | 50 |
| Irrigation | 80 | 20 |
| Industry | 90 | 10 |
| Power stations (with freshwater cooling) | ≅100 | 0 |

*Table 5.3 — Provisional estimate of distribution of water volumes used in the world — 1990, shown by supplies to user sectors (in km³ /year)*

| *World use* | *Surface water* | *Groundwater* | *Total* |
|---|---|---|---|
| Municipal water supply | 160 | 160 | 320 |
| Agriculture | 480 | 1 940 | 2 420 |
| Industry | 30 | 220 | 250 |
| Power stations cooling | 0 | 450 | 450 |
| Reservoirs | 0 | 160 | 160 |

## 5.5 Groundwater Use — Trends in Development and Overexploitation

The present total volume of water withdrawal for all uses from all the aquifers in the world is estimated to be 600 to 700 km³/ year, distributed approximately as follows:

- municipal water supply — 65 per cent;
- industry, including mines — 15 per cent; and
- agriculture and livestock — 20 per cent.

Withdrawal and use of groundwater is unequal throughout the world and is depicted in the map constituting Figure 5.2 and Tables 5.4 and 5.5. Only 10 countries extract more then 10 km³/year at present, of which two (India and the United States of America) extract more than 100 km³/year. These extractions represent variable proportions of the total sources of supply — from some 1/100 to as

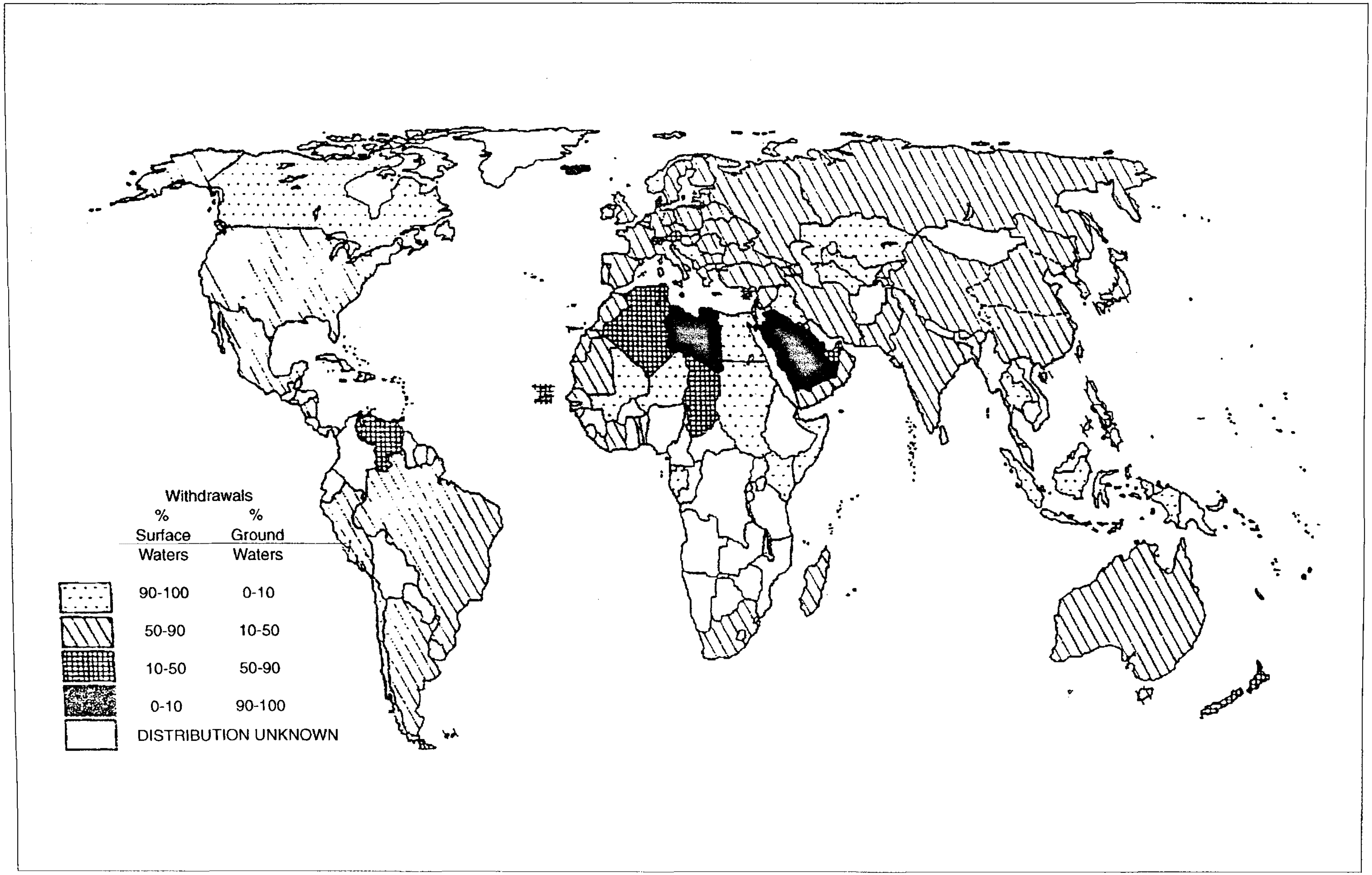


*Figure 5.1 — Distribution in each country of water withdrawals by type of resource*

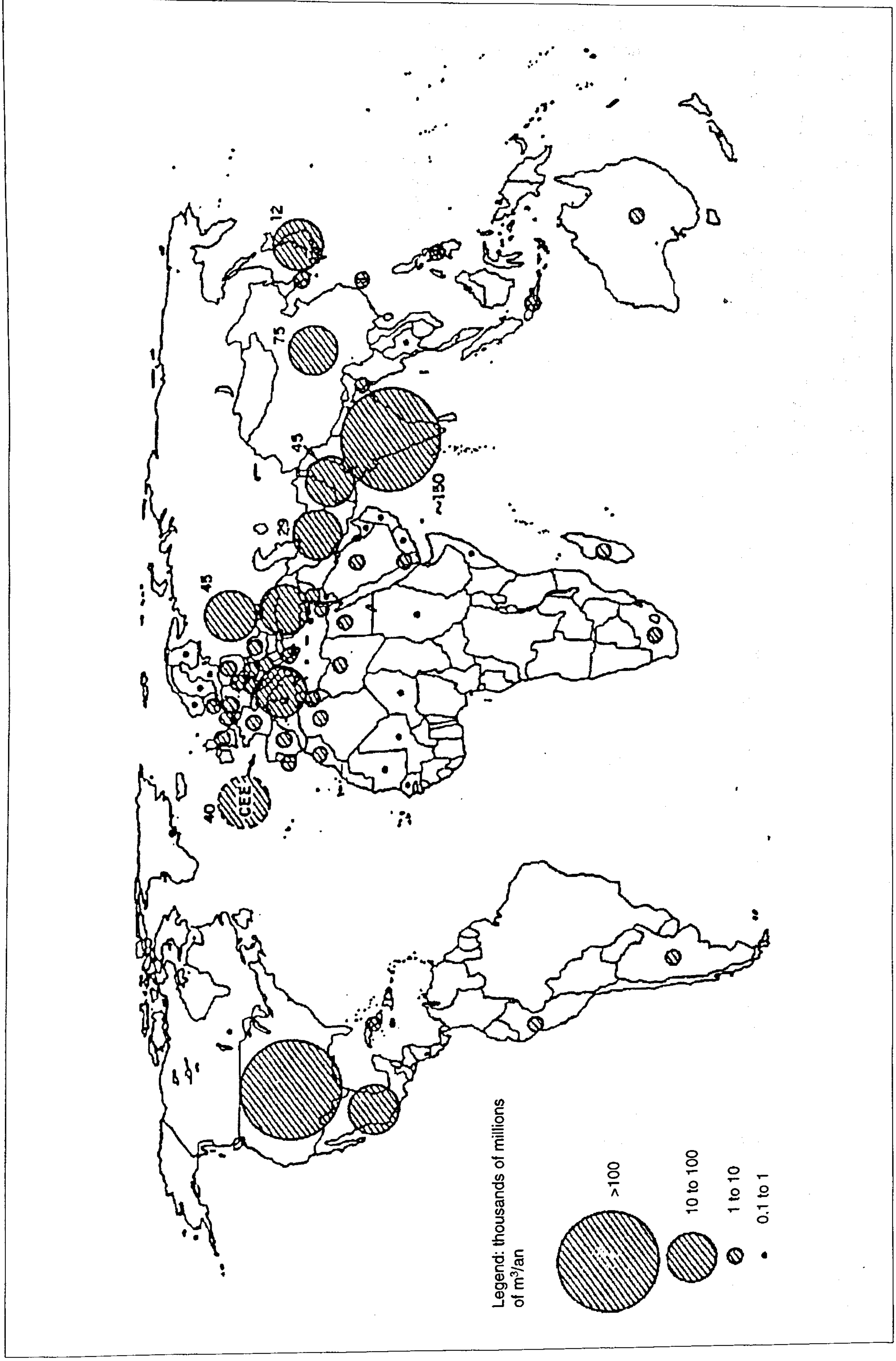


*Figure 5.2 Groundwater withdrawals in each country; estimates for years 1980-1990*

much as the total supply in some countries. Use of groundwater is variable; irrigation is predominant in many cases, but its use as a source of drinking water supply predominates in several countries and nearly always takes second place in other countries.

Analysis of Table 5.5 indicates that the total groundwater abstraction in all Mediterranean countries in 1990 (or nearest year) amounted to 55.2 km$^3$/year, which corresponds to 20.6 per cent of the total water abstraction.

The rate of development of groundwater exploitation and use is not documented to any great extent. What is known generally covers periods too short to make significant conclusions on trends. The small amount of data available indicates changeable trends. Some developed countries show significant growth (144 per cent in 30 years, 1950-1980, in the United States of America; 54 per cent in 25 years, 1950-1975, in the United Kingdom; 70 per cent in seven years, 1970-1977, in Denmark; 12 per cent in five years, 1971-1976, in The Netherlands; and 15 per cent in 10 years in Spain and Russia. Groundwater use in Germany, Belgium, France and Sweden has been relatively constant over the years, while a decrease in groundwater withdrawal in Canada and in the United States of America started in about 1980 (-12 per cent between 1980 and 1985). However, increases in groundwater withdrawal are expected in a number of developing countries such as China, India, Iran, Mexico, Pakistan. Not surprisingly, the highest increases are in developing countries with strong demographic growth in arid and semi-arid climates. For example, groundwater withdrawals have increased more than 300 per cent between 1975 and 1985 in Saudi Arabia, 44 per cent between 1977 and 1985 in Libya, and almost 100 per cent between 1977 and 1985 in Tunisia. Water withdrawal is estimated to have increased by three times in Egypt between 1976 and 1985. An example of the evolution of total fresh groundwater abstraction in the United States of America between 1950 and 1990 is shown in Figure 5.3.

Two examples of recent increases in groundwater abstraction in arid countries, driven by the expansion of irrigation, where the predominant part of the freshwater resource is non renewable (groundwater mining) is given in Table 5.6.

*Table 5.4 — Abstraction and use of groundwater in selected countries having a high rate of exploitation (statistics taken from national sources)*

| | | | | *Type of Use* | | |
|---|---|---|---|---|---|---|
| *Country* | *Date* | *Total abstraction of groundwater km$^3$/year* | *Ratio of total abstraction %* | *Municipal water supply %* | *Agriculture (irrigation, animal husbandry) %* | *Industrial (including mining) %* |
| Africa | | | | | | |
| Egypt | 1990 | 2.67 | 4.5 | 58.4 | 41.6 | E |
| Libya | 1990 | 4.50 | 95.0 | 9.0 | 90.0 | 1 |
| Madagascar | 1984 | 4.76 | 29.0 | — | — | — |
| Morocco | 1991 | 3.79 | 32 | 16 | 84 | E |
| North America | | | | | | |
| Mexico | 1985 | 23.5 | 4.1 | 13 | 64 | 13 |
| USA | 1990 | 109.69 | 23.5 | 24 | 67.5 | 8.5 |
| South America | | | | | | |
| Brazil | ~1987 | 8 | 23.5 | 37.5 | 37.5 | 25 |
| Asia | | | | | | |
| India | ~1990 | 180 | 32 | 9 | 89 | 2 |
| China | 1988 | 52.85 | 10.6 | — | 54 | — |
| Pakistan | ~1990 | ~60 | ~30 | — | ~90 | — |
| Japan | 1987 | 12.88 | 14.4 | 29 | 30 | 41 |
| Iran | ~1980 | 29 | ~40 | — | — | — |
| Saudi Arabia | 1990 | 14.43 | 94 | 10 | 90 | — |
| Bangladesh | ~1980 | 7.73 | ~35 | 22 | 77.5 | 0.5 |
| Turkey | 1990 | 6.3 | 20.5 | 31 | 60 | 9 |
| Europe | | | | | | |
| Russia | 1988 | 12.55 | 11.8 | — | — | — |
| Italy | 1990 | 13.9 | 31 | 39 | 57.5 | 3.5 |
| Germany | 1990 | 7.73 | 13.1 | — | — | — |
| France | 1990 | 6.21 | 16.5 | 56 | 16 | 28 |
| Spain | 1992 | 5.43 | 16 | 18 | 80 | 2 |
| Ukraine | 1988 | 4.22 | 13.8 | — | — | — |
| United Kingdom | 1990 | 2.71 | 19 | — | — | — |
| Romania | 1993 | 3.63 | 22.4 | — | — | — |
| Australia | 1983 | 2.46 | 14 | ~30 | 67 | ~3 |

*Table 5.5 — Groundwater Use in Mediterranean Countries*

| *Country* | *Date* | *Total groundwater abstraction km³/year* | *of which the following was overpumped or extracted from non-renewable sources km³/year* | *Proportion of the total water demand %* | *Drinking water supply %* | *Use by Sector* |  | *Proportion covered drinking water supply %* | *of Water by agriculture %* | *Demand groundwater 10 industries not connected to a water supply network %* | *References* |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | *Agri-culture %* | *Industries not connected to a water supply network %* |  |  |  |  |
| Spain | 1992 | 5.428(4) | 1.055 | 16 | 18 | 80 | 2 | 22 | 18 | 5 | MOPU/Plan Hidrol.Nac.93 |
| France | 1990 | 6.210 | E | 16.5 | 56 | 16 | 28 | 57 | 20.5 | 38 | Min.Envir. 92 |
| Italy | 1990 | 13.9(1) | — | 31 | 39 | 57.5 | 3.5 | 91 | 29 | 7 | Conf. Dublin 91 |
| Malta | 1990 | 0.021 | 0.005 | 53.5 | 85 | 13.5 | 1.5 | 50 | 100 | 100 | Water Serve. Corp., A.Guttierez 94 |
| Ex.Yugoslavia | 1990 | ~2.25(6) | 0 | 13 | ~50 | ~5 | ~45 | ~60 | ~10 | ~17 | Semin. Algeria 90 |
| Albania | — | ? |  | ? |  |  |  |  |  |  |  |
| Greece | ~1990 | 2.0 |  | 28 | ~37 | 58 | 5 | 64 | 20 | 71 | Rome conf. 92,<br>CNUED 92 |
| Turkey | 1990 | 6.3 |  | 20.5 | 31 | 60 | 9 | 38 | 17.5 | 15 | OECD 1993 |
| Cyprus | ~1990 | 0.31(6) | 0.04 | 81 | 13 | 87 | E | 90 | 80 | 100 | UNDTCD 82, Zomenis 85. Lytras &al. Semin. Alger 90 |
| Syria | 1990 | 2.3(6) |  | 22 | ~13 | ~83 | ~4 | ~36.5 | ~21.5 | ~10 | N. Beschorner 92 |
| Lebanon | 1991 | ~0.4(6) | 0 | 32 | ~13 | ~78 | ~9 | ~20.5 | ~44 | ~72 | ARMER 86, J.Kolars 92 |
| Israel | 1994 | ~1 | E(5) | 57 | ~18 | ~80 | ~2 | 45 | 63 | 23.5 | Centr.Bur.Statist. Israel 95 |
| Palestine |  |  |  |  |  |  |  |  |  |  |  |
| - West Bank | 1994 | 0.180 |  | 90 | 36 | 61 | 3 | 100 | 85 | 100 | ANTEA-BRL 95 |
| - Gaza | 1994 | 0.104 | 0.03 | 84 | 35 | 65 | E | 100 | 100 | — |  |
| Egypt | 1990 | 2.67 |  | 4.5 | 58.4 | 41.6 | E | 50.3 | 2.2 | — | RIGW 85,Hydrog. Map88 Abu Zeid 91,92 |
| Libya | ~1990 | 4.5 | ~4.0 | 95 | 9 | 90 | 1 | 90 | ~95 | 95 | O.Salem 92 |
| Tunisia | 1990 | 1.535 | 0.23 | 54.4(8) | ~13(9) | ~85(9) | ~2(9) | ~77(9) |  |  | H.E.Bech94, DGRE 91,<br>A.Hamdane, 94 |
| Algeria | 1989 | 2.85(6) | ~0.4 | 61 | 46 | 49 | 5 | 72 | 56 | 75 | Rome conf 92. S.Zaouche 94, A.Garadi 93,95 |
| Morocco | 1991 | 3.79 | E | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Adm.Hydraul.Conf.meditea Rome 92.M.Jellali 95 |

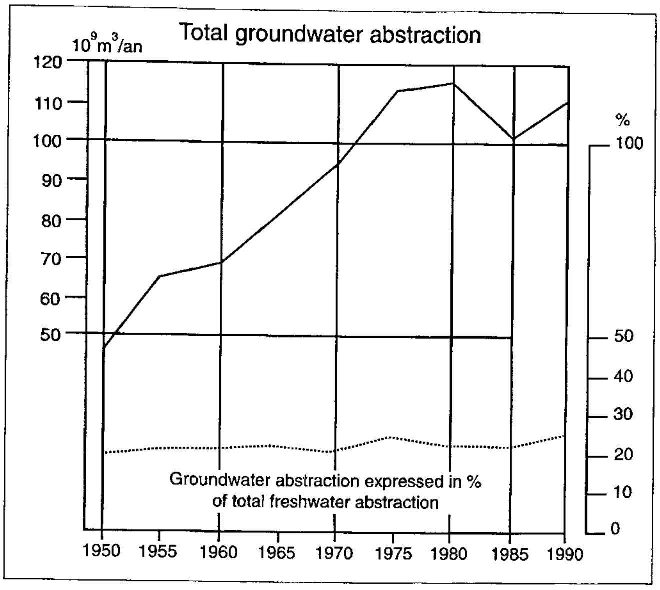


*Figure 5.3 — Evolution of total fresh groundwater abstraction in the United States of America between 1950 and 1990 (USGS, 1992)*

*Table 5.6 — Increases of groundwater abstractions in Saudi Arabia and Libya*

| Date | Annual abstractions in km³/year | |
|---|---|---|
| | *Saudi Arabia* | *Libya* |
| 1974 | ~1.70 | ~1.0 |
| 1977-1978 | — | 1.3 |
| 1980 | ~2.1 | — |
| 1985 | 7.43 | 2.65 |
| 1990 | 14.43 | 4.50 |

*Table 5.7 — Evolution of the abstractions and exploitation of groundwater in Algeria and Tunisia*

| Year | Total abstraction hm³/year in (Algeria + Tunisia) | | Exploitation index % (ratio abstraction/ renewable resource) | |
|---|---|---|---|---|
| | CI | CT | CI | CT |
| 1900 | 124 | 270 | 46 | 46 |
| 1925 | 137 | 340 | 51 | 58 |
| 1950 | 153 | 404 | 57 | 69 |
| 1960 | 175 | 445 | 65 | 76 |
| 1970 | 218 | 530 | 81 | 91 |
| 1980 | 314 | 470 | 116 | 81 |
| 1992 | 498 | 741 | 184 | 127 |

Note: The abstractions include the discharge of springs and the foggaras (C.I. in Algeria) which represented almost all the abstractions in 1900. The discharge of springs decreased significantly after 1950 due to increased abstraction from boreholes, and has stopped altogether at the present.

An example of exploitation of a large sedimentary aquifer system in an arid zone is the Northern Sahara Basin Aquifer (Continental Intercalaire layer (CI), and Complex Terminal layer (CT)), located in Algeria and Tunisia. The evolution of the abstractions and the exploitation index is contained in Table 5.7. The exploitation index compares abstraction to the present mean recharge index (CI: 270 hm³/year, of which 120 corresponds to the discharge of springs and foggaras; CT: 583 hm³/year, of which about 200 corresponds to the initial discharge of the springs).

As can be seen from the table, both countries are now overutilizing the groundwater resource and extracting more than is being recharged. In fact, over-extraction began before the exploitation index reached 100 per cent as withdrawal from boreholes exceeded the rates of depletion of the natural springs. Outflows from the aquifer in the form of evaporation in closed depressions and by discharge to the sea have also been significantly reduced.

There are highly exploited aquifer systems throughout the world, not only in arid and semi-arid zones, but also in some temperate zones of developed countries. It is important to make a close distinction between two cases:

- intensive exploitation of renewable resource aquifers, which may approach or exceed the average rate of recharge and produce undesirable impacts, as well as the risk of disrupting the water balance and leading to water withdrawal not being sustainable; and
- the mining exploitation of non-renewable aquifers, where the abstraction of groundwater leads to the exhaustion of the groundwater in a short time frame.

Over-exploitation of the groundwater resource is not sustainable and will ultimately have a negative impact on users. Table 5.8 on the following page groups a few examples of very heavily exploited aquifers in the world. The first consequence of intensive exploitation of groundwater systems is large regional drawdowns in the water table. During the 20th century, especially starting with the 1950s, drawdowns of several tens of metres, and sometimes more than 100 metres, of free or confined aquifers have been observed in different parts of the world. Examples include European countries such as Germany, Spain, France, the United Kingdom and Russia, China, the United States of America and Arab countries such as Saudi Arabia and Libya.

Some of these well known over-withdrawals resulted from a long period of cumulative effect (one century or more), for example in California (United States of America), in the regions of Lille and Paris (France), or in the Dniepr-Donetz and Azov-Kouban basins (Russia). Other more recent examples have resulted from rapid urban and agricultural growth which has induced high water demand in localized zones. In Spain and in several Mediterranean coastal plains, in Italy (down 40 metres in the alluvial aquifer of Milan), in the High Plains of Texas aquifer in the United States of America, in Saudi Arabia and Libya and in the Hebei plain of China overutilization has resulted in decreasing availability of the groundwater resource and land subsidence. In several coastal plains the freshwater table level has dropped below sea level (examples in Germany, Denmark, Spain, Italy, The Netherlands, United Kingdom) resulting in salt water intrusion.

These groundwater over-withdrawals have induced negative impacts on the base flows of rivers and in particu-

*Table 5.8 — A few examples of very heavily exploited aquifers in the world*

| Country | Aquifer | Average flux of recharge km³/year | Recent abstractions | | Exploitation index (renewable resources) | Accumulated water volume taken from storage | |
|---|---|---|---|---|---|---|---|
| | | | date | km³/year | % | Period of time | km³ |
| Australia | Great Artesian Basin | 1.1 | ~1985 | 0.6 | 55 | 1880-1973 | 25 |
| Algeria-Tunisia | Complexe terminal (Bassin du Sahara Septentrional) | 0.58 | 1992 | 0.74 | 127 | 1900-1981 | ~3 |
| Saudi Arabia | Saq Aquifer | ~0.3 | 1984 | 1.43 | 477 | 1970-1983 | ~2 |
| China | Aquifer of Hebei Plain | ~35 | 1978 | ~19 | 54 | 1960-1980 | 15 to 20 |
| Spain | Volcanic Aquifer of Tenerife Island (Canarias) | 0.22 | 1980 | 0.22 | 100 | 1900-1990 | 8 to 10 |
| Israel and Gaza | Coastal Plain Aquifer | 0.31 | 1990 | 0.50 | 160 | — | — |
| | Alluvial Aquifers | 0.37 | 1975 | 6.56 | 1 773 | 1920-1980 | 202 |
| | | | 1985 | 4.35 | 1 151 | | |
| | | | 1990 | 3.78 | 1 022 | | |
| USA | Central Valley California | ~7 | 1980 | 13.80 | ~200 | 1950-1980 | 20 |
| | | | 1990 | ~20 | ~280 | | |
| | Ogallala Aquifer (High Plains) | 6 to 8 | 1980 | 22.2 | ~300 | 1940-1980 | 196 |
| Tunisia | Coastal multilayered Aquifer of Djeffara | 0.19 | 1990 | 0.125 | 64 | — | — |

lar springs, and changed the balance of the freshwater/salt water interface in some aquifers. Salt water intrusion can result when coastal aquifers are depleted or continental sedimentary aquifers with deep brackish salt water are over-exploited. Examples of the latter exist in the United States of America and Hungary.

There are several cases of land-subsidence with severe consequences, particularly in urban areas, due to intensive exploitation of sedimentary aquifers, which are partly compressible. Land subsidence of several decimetres to several metres has occurred in Europe (Berlin, London, Milan, Venice, Ravenna), in the United States of America (Denver, Houston, Las Vegas, San Francisco, Tucson), in Mexico (Mexico City, where subsidence of 10 metres occurred), in China (Shanghai), in Vietnam (Hanoi). UNESCO had identified 42 cases in the world by 1984.

## 5.6 Assessment and Prediction of Water Withdrawal in the World

Water withdrawal for selected countries and each region of the world, based on the methods described in Section 5.3, and averaged over individual continents are shown in Table 5.9 and Figure 5.4. Present (1990) total water withdrawal in the world equals about 3 600 km³/year, and the water consumption equals 2 200 km³/year which is 61 per cent of the total water withdrawal. It is expected that the total water withdrawal will rise by about 10-12 per cent for every 10-year period and by 2025 it would be about 5 200 km³/year, an increase of 1.45 times. Water consumption is estimated to have a slower rate of increase of 1.3 times during the same time period.

At present, about 57 per cent of the total water withdrawal and 70 per cent of the water consumption in the world occurs within the countries of Asia where most of the irrigated lands are located. The most rapid rise in water withdrawal rates during the next few decades is expected in Africa and South America (1.6-1.7 times). The least rate of rise is expected in Europe and North America (1.2-1.3 times). Water withdrawal and water consumption in the world by sector, as well as world population and size of the irrigated lands are shown in Table 5.10 and Figure 5.5.

At present, 67 per cent of the total water withdrawal and 87 per cent of the water consumption in the world are in the agricultural sector, primarily for irrigation use. In the future,

*Table 5.9 — Dynamics of water use by continents (km³/year)*

| | Assesment | | | | | | | | | Forecast | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Continent* | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Europe | 37.5 | 71 | 93.8 | 185 | 294 | 445 | 491 | 512 | 534 | 578 | 619 |
| | 17.6 | 29.8 | 38.4 | 53.9 | 81.8 | 158 | 183 | 187 | 191 | 202 | 217 |
| North America | 69.4 | 222 | 286 | 411 | 556 | 663 | 642 | 679 | 718 | 780 | 836 |
| | 29.3 | 83.8 | 107 | 145 | 183 | 224 | 225 | 247 | 269 | 304 | 329 |
| Africa | 41 | 49 | 56 | 86 | 116 | 168 | 199 | 215 | 230 | 270 | 331 |
| | 34 | 39 | 45 | 66 | 88 | 129 | 151 | 160 | 169 | 190 | 216 |
| Asia | 414 | 689 | 859 | 1222 | 1499 | 1784 | 2067 | 2156 | 2245 | 2483 | 3104 |
| | 322 | 528 | 654 | 932 | 1116 | 1324 | 1529 | 1566 | 1603 | 1721 | 1971 |
| South America | 15.2 | 27.7 | 59.4 | 63.6 | 85.2 | 111 | 152 | 166 | 180 | 213 | 257 |
| | 11.3 | 20.6 | 44.7 | 44.4 | 57.8 | 70.9 | 91.4 | 96.9 | 103 | 112 | 123 |
| Australia and Oceania | 1.6 | 6.8 | 10.3 | 17.4 | 23.3 | 29.4 | 28.5 | 30.5 | 32.6 | 35.6 | 39.6 |
| | 0.6 | 3.4 | 5.1 | 9.0 | 11.9 | 14.6 | 16.4 | 17.7 | 18.9 | 21 | 23.1 |
| Total (rounded) | 579 | 1066 | 1365 | 1985 | 2574 | 3200 | 3580 | 3760 | 3940 | 4360 | 5 187 |
| | 415 | 705 | 894 | 1250 | 1539 | 1921 | 2196 | 2275 | 2354 | 2550 | 2879 |

*Table 5.10 — Dynamics of water use by sector (km³/year)*

| | Assesment | | | | | | | | | Forecast | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sector* | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Population (millions) | | | 2493 | 2963 | 3527 | 4313 | 5176 | 5520 | 5964 | 6842 | 8284 |
| Irrigated land area (mln.ha) | 47.3 | 75.9 | 101 | 142 | 173 | 200 | 243 | 254 | 264 | 288 | 329 |
| Agricultural Use | 525 | 891 | 1124 | 1541 | 1850 | 2191 | 2412 | 2503 | 2595 | 2792 | 3162 |
| | 407 | 678 | 856 | 1183 | 1405 | 1698 | 1907 | 1952 | 1996 | 2133 | 2377 |
| Industrial Use | 37.9 | 127 | 182 | 334 | 548 | 683 | 681 | 715 | 748 | 863 | 1106 |
| | 2.96 | 9.49 | 14.4 | 24.6 | 38.3 | 61.8 | 72.7 | 79.7 | 86.7 | 111 | 146 |
| Municipal Use | 16 | 36.8 | 52.6 | 82.7 | 130 | 208 | 321 | 354 | 386 | 464 | 645 |
| | 3.87 | 9.04 | 13.8 | 20.1 | 29.4 | 41.9 | 53.2 | 57.4 | 61.6 | 68.1 | 80.9 |
| Reservoirs | 0.3 | 3.7 | 6.47 | 22.7 | 65.9 | 119 | 164 | 188 | 211 | 239 | 275 |
| Total (rounded) | 579 | 1066 | 1365 | 1985 | 2574 | 3200 | 3580 | 3760 | 3940 | 4360 | 5187 |
| | 415 | 705 | 894 | 1250 | 1539 | 1921 | 2196 | 2275 | 2354 | 2550 | 2879 |

the impact of agriculture is expected to diminish as industrial and municipal water withdrawals in particular rise at a more rapid rate. For example, by 2025 the water withdrawal for agriculture is expected to increase by 1.3 times, industrial water use by 1.6 times and municipal water use would be twice as great. Water losses associated with additional evaporation from reservoirs are a significant factor at the global level, being higher than the amounts of water consumed by industry and by municipal needs combined. Based on recent and more accurate data, the irrigated lands in 1995 covered 253 million hectares. By 2010 the irrigated lands are forecast to rise to 290 million hectares, and by 2025 - up to 330 million hectares.

Comparing data on water withdrawal in Tables 5.9 and 5.10 with the data in Figure 2.1, it is possible to see that all previous forecasts of water withdrawal greatly overestimated what will probably occur. This also holds true for the forecasts made in (Shiklomanov and Markova, 1987) contained in Figure 5.6. This overestimation may be explained by two factors.

Firstly, all the authors who made forecasts during the 1960s through the 1980s predicted a large increase of irrigated lands in the world because they noted very high rates of irrigation development in the world, which were higher even than the rate of the population growth (Figures 5.7,

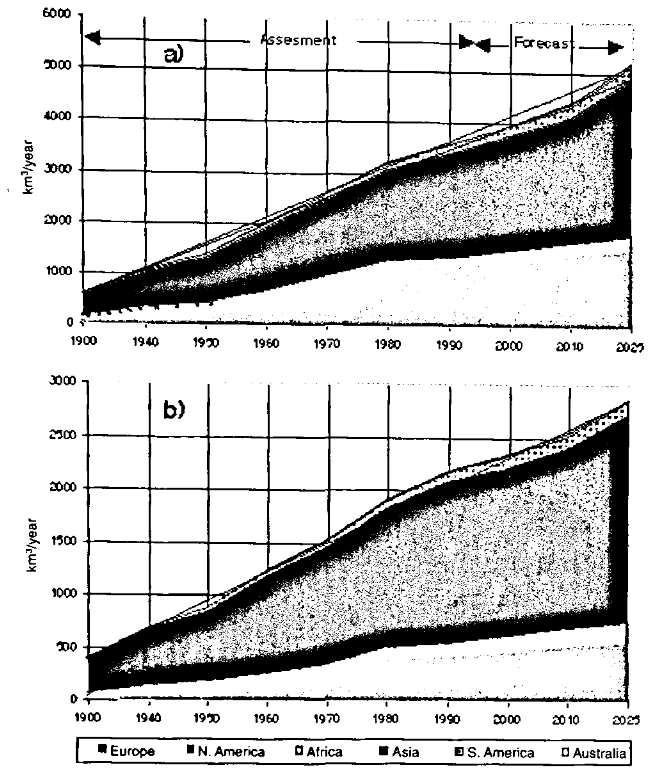


*Figure 5.4 — Dynamics of total withdrawal (a) and water consumption (b) in the world by continents*

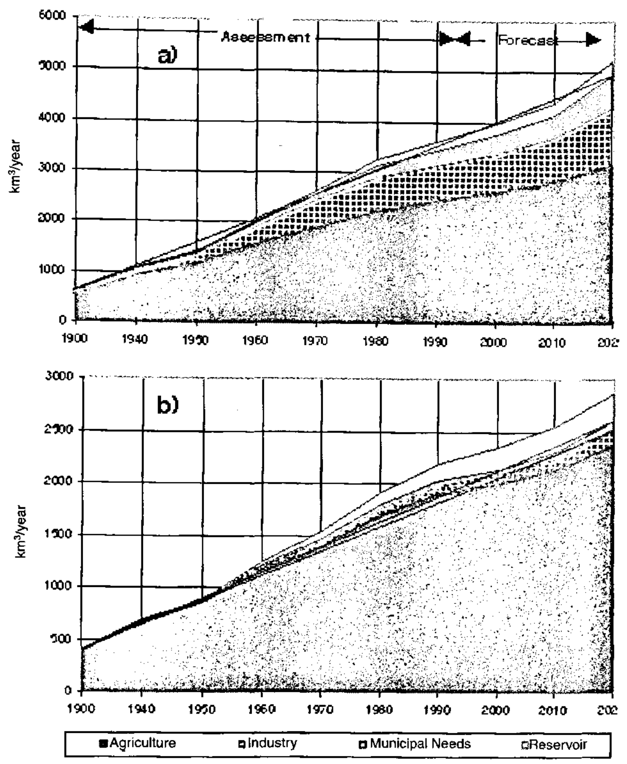


*Figure 5.5 — Dynamics of total withdrawal (a) and water consumption (b) in the world by different water users*

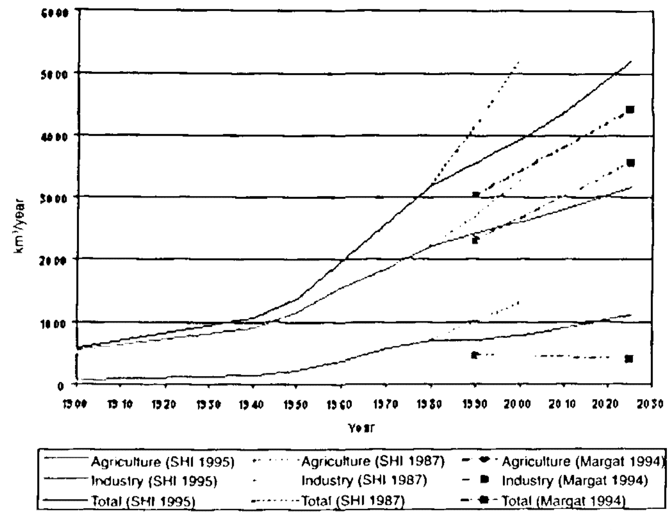


*Figure 5.6 — Comparison of different total water withdrawal assessments*

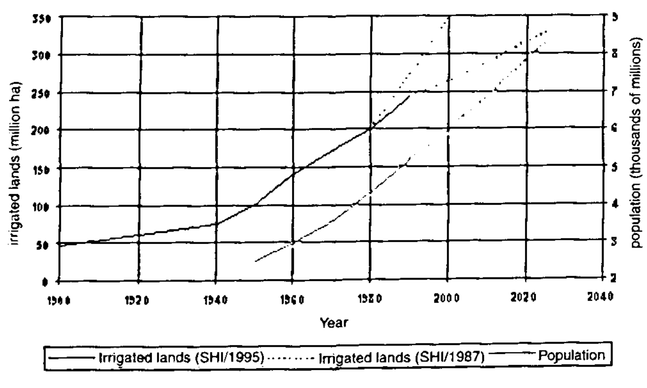


*Figure 5.7 — Dynamics of population and irrigated land areas in the world*

5.8). For example, FAO, Framji (1982) predicted an increase of irrigated lands up to 400 million hectares by 2000. The author of the present report predicted in 1985, that by 2000 the increased irrigated lands would cover up to 350 million hectares. Based on present information it is unlikely that this value would exceed 260-270 million hectares.

Secondly, the forecasts did not take into account the trends observed in the 1980s of stabilization and even reduction of industrial water withdrawal in many developed countries of the world. These trends are now quite evident, and consequently the French specialists (Margat, 1994; Andreassian, 1994) developed a hypothesis that industrial water withdrawal would decrease by 50 per cent in the developed countries by 2025 (relative to 1990). Based on this hypothesis, the industrial water withdrawal at the global level would be lower by about 16 per cent by 2025. This is most likely one of the reasons why the French specialists predicted lower values of total world water withdrawal, when compared with the updated forecasts made at the State Hydrological Institute (SHI) (Figure 5.6). Another reason is that freshwater withdrawal for cooling of thermal and atomic power stations is not taken into account in the industrial water withdrawal forecasts by Margat and Andreassian. In some developed countries the amounts of freshwater withdrawal for the cooling of thermal power plants surpass water use for all the other branches of industry combined.

The dynamics of water withdrawal for each of the sectors for all continents is listed in Tables 5.11-5.16 and presented graphically in Figures 5.9-5.14. Europe and North America have similar patterns of present and future water withdrawal (Tables 5.11 and 5.12, Figures 5.9 and 5.10). On these continents the impact of industry is significant in the

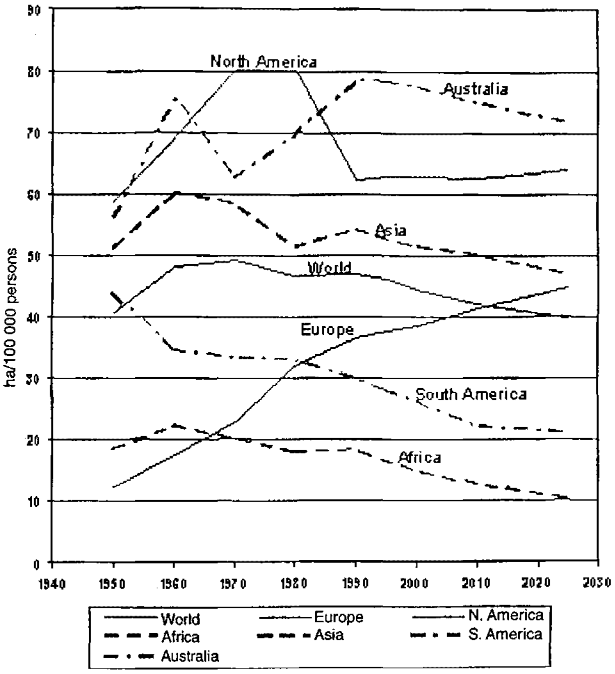


*Figure 5.8 — Dynamics of irrigated land areas per 1 000 persons*

total water withdrawal. In Europe the industrial water demand in 1990 was 44 per cent of the total water withdrawal, by 2025 it is expected to be about 50 per cent. In North America, industry accounts for about 40 per cent of the total water withdrawal, but by 2025 that is expected to decrease by 37 per cent. This reduction in percentage is primarily due to the major increase in water withdrawals for irrigation in Central America, which is included in the North American continent.

Agriculture accounts for more than 70 per cent of the total water consumption in Europe and in North America. In Asia, Africa and South America agriculture, irrigation in particular, is the major component of water withdrawal. In 1990, irrigation accounted for 64-82 per cent of total water withdrawal and 65-92 per cent of the water consumption on these continents. These percentages will not change significantly by 2025, although the industrial water withdrawal is expected to increase by two to three times. The portion of industry in the total water withdrawal is not expected to exceed 20 per cent in South America, 13 per cent in Asia, and 6 per cent in Africa. The great impact of evaporation from reservoirs is a peculiar feature of the water withdrawal pattern in Africa. For both the present and for the future it is about 33-35 per cent of the total water consumption on the continent.

A comparison of updated and predicted water withdrawals by continents between the estimates of the authors (Shiklomanov and Markova, 1987) and the forecasts of the French specialists (Margat, 1994; Andreassian, 1994) is given in Figure 5.15.

As mentioned earlier, the major differences between Russian and French forecasts of total global water withdrawal are in fundamental approaches to the assessment of industrial water withdrawal, in particular, neglecting the industrial water withdrawals for cooling of thermal power plants, as well as not accounting for water losses for the additional evaporation from reservoirs. For example, not accounting for freshwater losses for the cooling of thermal power plants in North America results in underestimation of water withdrawal by more than 150 km$^3$/year.

The prognostic assessments made by the author in 1987 for future (1990-2000) water withdrawals overestimated for all the continents (except North America), because it was assumed at the time that the growth of irrigated lands would be intensive and water withdrawal for industrial needs would increase. In fact, the rate of this growth has lagged considerably compared to long-range national forecasts of economic development in the majority of countries.

*Table 5.11 — Dynamics of water use by sector in Europe (km$^3$/year) — First line, water withdrawal; second, water consumption*

| | *Assesment* | | | | | | | | | *Forecast* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sector** | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Population (millions) | | | 519 | 570 | 622 | 657 | 681 | 686 | 690 | 694 | 685 |
| Irrigated lands (millions ha) | 2.9 | 5.1 | 6.5 | 9.9 | 14.2 | 21.1 | 24.9 | 25.8 | 26.6 | 28.7 | 30.6 |
| Agriculture | 19.6 | 34.5 | 40.9 | 53.9 | 82.2 | 169 | 195 | 199 | 203 | 209 | 212 |
| | 14.6 | 25 | 31.5 | 38.4 | 55.6 | 117 | 133 | 134 | 136 | 139 | 142 |
| Industry | 9.3 | 23.4 | 36.3 | 104 | 168 | 206 | 214 | 228 | 242 | 273 | 305 |
| | 1.1 | 2.2 | 3.2 | 7 | 11.6 | 22.3 | 26.9 | 28.5 | 30 | 37.5 | 47.4 |
| Municipal needs | 8.5 | 12.7 | 15.6 | 21 | 33.7 | 58.5 | 67.1 | 70.0 | 72.6 | 78.7 | 84.5 |
| | 1.8 | 2.3 | 2.7 | 3 | 4.2 | 7.2 | 8.4 | 8.6 | 8.8 | 9.2 | 9.5 |
| Reservoirs | 0.1 | 0.3 | 1 | 5.5 | 10.5 | 11.4 | 14.9 | 15.4 | 15.9 | 16.8 | 17.6 |
| Total | 37.5 | 71 | 93.8 | 185 | 294 | 445 | 491 | 513 | 534 | 578 | 619 |
| | 17.6 | 29.8 | 38.4 | 53.9 | 81.8 | 158 | 183 | 187 | 191 | 202 | 217 |

*Table 5.12 — Dynamics of water use by sector in North America (km³/year) — First line, water withdrawal; second, water consumption*

| | | | | | Assesment | | | | | Forecast | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sector* | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Population (millions) | | | 217 | 263 | 317 | 371 | 423 | 455 | 487 | 542 | 595 |
| Irrigated lands (millions ha) | 4.2 | 6.1 | 12.7 | 18.1 | 25.4 | 29.8 | 26.3 | 28.5 | 30.6 | 33.9 | 38 |
| Agriculture | 42.6 | 123 | 155 | 205 | 250 | 300 | 291 | 315 | 339 | 375 | 399 |
| | 27.8 | 74.8 | 94 | 125 | 151 | 179 | 178 | 192 | 206 | 228 | 243 |
| Industry | 21.8 | 79.5 | 104 | 165 | 250 | 290 | 259 | 266 | 273 | 286 | 306 |
| | 0.5 | 2.8 | 3.9 | 6.7 | 11.2 | 17.1 | 13.6 | 16.9 | 20.2 | 26.2 | 30 |
| Municipal needs | 4.8 | 16.3 | 22 | 33 | 44 | 57.1 | 67.1 | 70.6 | 74 | 81.5 | 88.5 |
| | 0.8 | 3 | 4.8 | 5.8 | 8.2 | 12 | 9.1 | 10.1 | 11.2 | 12.3 | 13.2 |
| Reservoirs | 0.2 | 3.2 | 4.7 | 7.8 | 12.4 | 16.2 | 24.6 | 28.3 | 32 | 38 | 43 |
| Total | 69.4 | 222 | 286 | 411 | 556 | 663 | 642 | 680 | 718 | 780 | 836 |
| | 29.3 | 83.8 | 107 | 145 | 183 | 224 | 225 | 249 | 269 | 304 | 329 |

*Table 5.13 — Dynamics of water use by sector in Africa (km³/year) — First line, water withdrawal; second, water consumption*

| | | | | | Assesment | | | | | Forecast | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sector* | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Population (millions) | | | 220 | 273 | 354 | 472 | 630 | 743 | 856 | 1136 | 1558 |
| Irrigated lands (millions ha) | 2.8 | 3.5 | 4 | 6 | 7.1 | 8.4 | 11.4 | 12.0 | 12.6 | 14.1 | 16.1 |
| Agriculture | 40.8 | 47.7 | 53.5 | 79.4 | 89 | 106 | 127 | 134 | 140 | 156 | 175 |
| | 33.1 | 38.4 | 43.6 | 63.3 | 71.3 | 85.4 | 98 | 102 | 106 | 118 | 131 |
| Industry | 0.4 | 0.8 | 1.4 | 2.7 | 5.8 | 9.7 | 9 | 9.6 | 10.2 | 12.3 | 18.8 |
| | 0.1 | 0.1 | 0.2 | 0.5 | 0.8 | 1.4 | 1.6 | 1.7 | 1.8 | 1.9 | 2.5 |
| Municipal needs | 0.3 | 0.7 | 1.3 | 3.1 | 5.8 | 11.7 | 12.8 | 17.2 | 21.6 | 34.7 | 59.9 |
| | 0.2 | 0.3 | 0.5 | 0.9 | 1.2 | 1.8 | 1.7 | 2.1 | 2.5 | 3.7 | 6 |
| Reservoirs | 0 | 0 | 0 | 1 | 15 | 40 | 50 | 54 | 59 | 66 | 77 |
| Total | 41 | 49 | 56 | 86 | 116 | 168 | 199 | 215 | 230 | 270 | 331 |
| | 34 | 39 | 45 | 66 | 88 | 129 | 151 | 160 | 169 | 190 | 216 |

*Table 5.14 — Dynamics of water use by sector in Asia (km³/year) — First line, water withdrawal, second, water consumption*

| | | | | | Assesment | | | | | Forecast | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sector* | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Population (millions) | | | 1415 | 1697 | 2021 | 2549 | 3120 | 3332 | 3543 | 3982 | 4913 |
| Irrigated lands (millions ha) | 36.1 | 58.6 | 72.5 | 102 | 118 | 131 | 169 | 175 | 182 | 199 | 231 |
| Agriculture | 408 | 658 | 815 | 1140 | 1350 | 1526 | 1688 | 1741 | 1794 | 1925 | 2245 |
| | 320 | 517 | 643 | 907 | 1066 | 1247 | 1412 | 1435 | 1457 | 1553 | 1762 |
| Industry | 4.1 | 18 | 33.1 | 51 | 107 | 153 | 176 | 184 | 193 | 248 | 409 |
| | 0.8 | 3.5 | 6 | 9 | 13 | 19.1 | 28.9 | 30.4 | 31.9 | 40.3 | 57.5 |
| Municipal needs | 2 | 6 | 11 | 20.1 | 38 | 65.1 | 143 | 160 | 177 | 218 | 343 |
| | 0.9 | 3 | 5 | 9 | 14 | 18.1 | 28.7 | 30.8 | 33 | 36 | 44 |
| Reservoirs | 0 | 0.1 | 0.23 | 7 | 23 | 40 | 59.8 | 70.3 | 80.8 | 92 | 107 |
| Total | 414 | 689 | 859 | 1222 | 1499 | 1784 | 2067 | 2156 | 2245 | 2483 | 3104 |
| | 322 | 528 | 654 | 932 | 1116 | 1324 | 1529 | 1566 | 1603 | 1721 | 1971 |

*Table 5.15 — Dynamics of water use by sector in South America (km³/year) — First line, water withdrawal; second, water consumption*

| | *Assesment Forecast* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sector*** | ***1900*** | ***1940*** | ***1950*** | ***1960*** | ***1970*** | ***1980*** | ***1990*** | ***1995*** | ***2000*** | ***2010*** | ***2025*** |
| Population (millions) | | | 110 | 144 | 188 | 240 | 294 | 326 | 357 | 453 | 494 |
| Irrigated lands (millions ha) | 1.2 | 2.2 | 4.81 | 4.97 | 6.24 | 7.9 | 8.76 | 9.06 | 9.35 | 10 | 10.4 |
| Agriculture | 13.6<br>10.9 | 24.6<br>19.7 | 54.3<br>40.2 | 53.6<br>41.7 | 65.9<br>51.3 | 77.3<br>59.3 | 96.7<br>74.2 | 99.9<br>76.0 | 103<br>77.8 | 110<br>81.6 | 112<br>84.7 |
| Industry | 1.3<br>0.26 | 2.2<br>0.44 | 3<br>0.6 | 4.9<br>0.8 | 8.4<br>0.96 | 13.3<br>1.1 | 15.9<br>1.23 | 19.0<br>1.60 | 22<br>1.98 | 34.5<br>3.4 | 56.5<br>6.21 |
| Municipal needs | 0.25<br>0.14 | 0.78<br>0.36 | 1.9<br>0.68 | 4.4<br>1.2 | 6.9<br>1.5 | 12.4<br>2.5 | 28.1<br>4.96 | 32.6<br>5.31 | 37<br>5.65 | 47.5<br>6.45 | 64.5<br>7.75 |
| Reservoirs | 0 | 0.1 | 0.2 | 0.7 | 4 | 8 | 11 | 14.5 | 18 | 21 | 24 |
| Total | 15.2<br>11.3 | 27.7<br>20.6 | 59.4<br>44.7 | 63.6<br>44.4 | 85.2<br>57.8 | 111<br>70.9 | 152<br>91.4 | 166<br>97.2 | 180<br>103 | 213<br>112 | 257<br>123 |

*Table 5.16 — Dynamics of water use by sector in Australia (km³/year) — First line, water withdrawal; second, water consumption*

| | *Assesment* | | | | | | | | | *Forecast* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sector*** | ***1900*** | ***1940*** | ***1950*** | ***1960*** | ***1970*** | ***1980*** | ***1990*** | ***1995*** | ***2000*** | ***2010*** | ***2025*** |
| Population (millions) | | | 11.8 | 16 | 25.3 | 24 | 27.8 | 29.6 | 31.4 | 34.8 | 38.7 |
| Irrigated lands (millions ha) | 0.05 | 0.43 | 0.66 | 1.2 | 1.58 | 1.67 | 2.18 | 2.31 | 2.43 | 2.6 | 2.77 |
| Agriculture | 0.46<br>0.35 | 3.5<br>2.8 | 5.2<br>4.1 | 9.4<br>7.5 | 12.5<br>9.9 | 13<br>10.2 | 14.7<br>11.6 | 15.5<br>12.2 | 16.3<br>12.7 | 17.4<br>13.5 | 18.5<br>14.3 |
| Industry | 1<br>0.2 | 3<br>0.45 | 4.1<br>0.5 | 6.2<br>0.64 | 8.3<br>0.69 | 10.5<br>0.78 | 6.7<br>0.46 | 7.2<br>0.62 | 7.8<br>0.77 | 8.7<br>1.44 | 10.3<br>2.18 |
| Municipal needs | 0.14<br>0.03 | 0.33<br>0.08 | 0.75<br>0.16 | 4.4<br>0.21 | 6.9<br>0.25 | 12.4<br>0.3 | 28.1<br>0.36 | 32.6<br>0.38 | 37<br>0.41 | 47.5<br>0.43 | 64.5<br>0.46 |
| Reservoirs | 0 | 0 | 0.34 | 0.7 | 1 | 3.1 | 4 | 4.5 | 5 | 5.6 | 6.2 |
| Total | 1.6<br>0.6 | 6.8<br>3.4 | 10.3<br>5.1 | 17.4<br>9 | 23.3<br>11.9 | 29.4<br>14.6 | 28.5<br>16.4 | 30.5<br>17.7 | 32.6<br>18.9 | 35.6<br>21 | 39.6<br>23.1 |

## 5.7 Dynamics of Water Use by Physiographic and Economic Regions of the World

The dynamics of water withdrawal and consumption by physiographic and economic regions of the world are given in Table 5.17 and in Table 5.18. Water withdrawal is distributed quite unevenly over regions and does not correspond with the amount of water resources available. For example, in Europe 94 per cent of the water withdrawal is within the southern and central areas of the continent. In North America, 76 per cent of the water withdrawal occurs within the continental territory of the United States of America, and in Australia and Oceania, 89 per cent of the water withdrawal occurs within the territory of Australia. In Asia, the maximum water withdrawal occurs within the region of South Asia covering the territories of India, Pakistan, Bangladesh and South-eastern Asia where the vast irrigated areas of China are located. In Africa, the maximum water withdrawal is observed in the northern part of the continent (North Africa), with this region accounting for 53 per cent of the total water withdrawal. In South America, the water withdrawal is more or less evenly distributed over the different regions of the continent.

The dynamics of water withdrawal increases by 2025 differ from region to region. In developed countries and in countries with limited water resources, a water withdrawal increase of 15-35 per cent is expected. In developing countries with sufficient water resources, the water withdrawal increase may be as much as 200-300 per cent.

A comparison of water withdrawal with the renewable surface water resources is of particular interest. The data for all regions of the world for 1995 and for 2025 are given in Table 5.19. The table shows the amounts of local water resources arising within the territory of the region, and the amount of water that flows into that territory from adjacent regions. The quantity of water withdrawal is compared to the amount of local water resources plus half of the imported

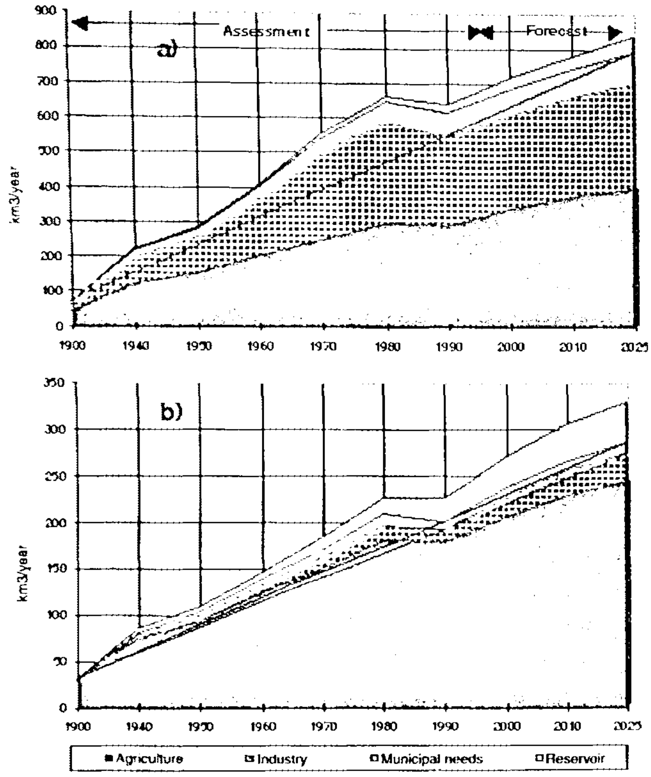


*Figure 5.9 — Dynamics of water use in Europe — a) total water withdrawal; b) consumption*

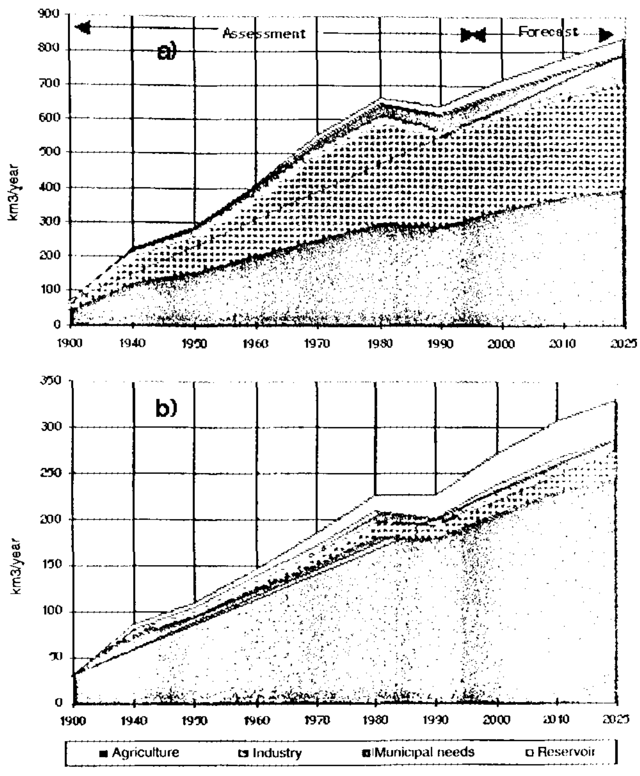


*Figure 5.10 — Dynamics of water use in North America — a) total water withdrawal; b) consumption*

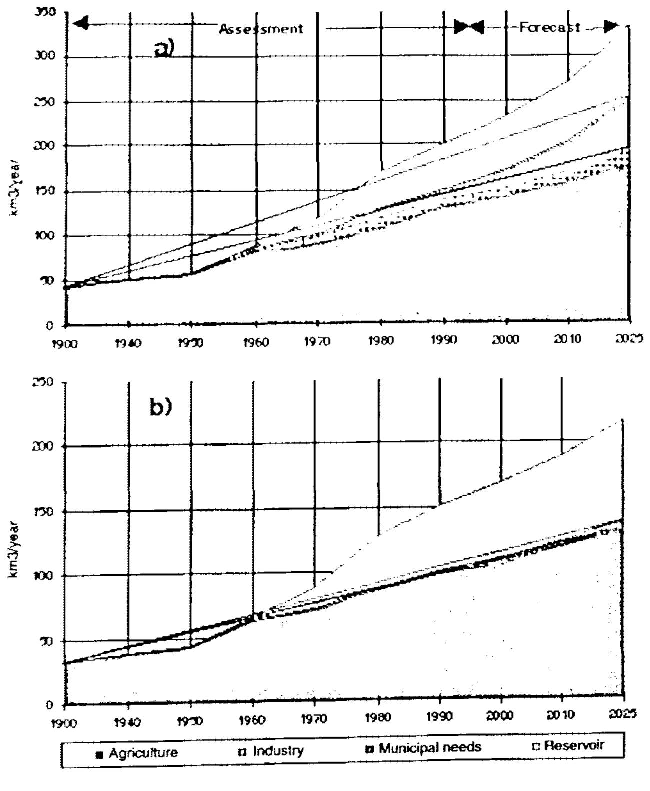


*Figure 5.11 — Dynamics of water use in Africa — a) total water withdrawal; b) consumption*

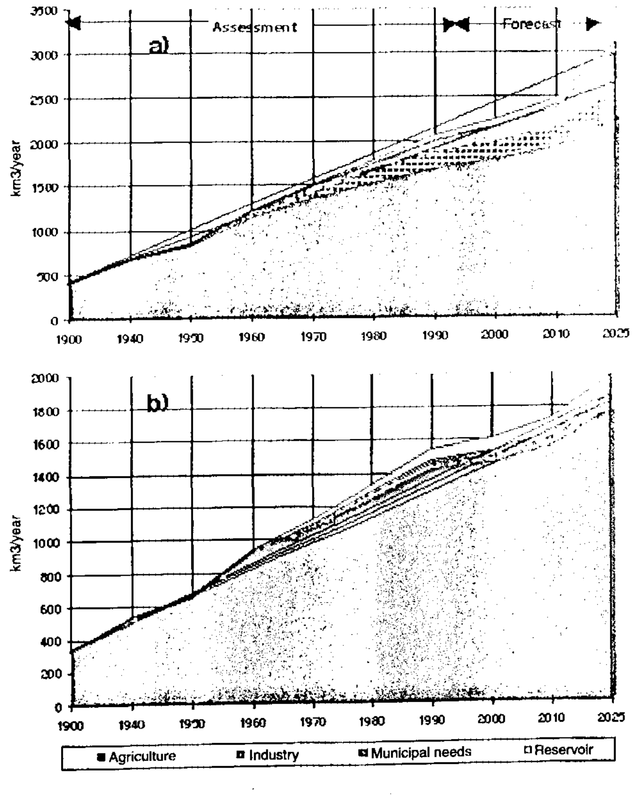


*Figure 5.12 — Dynamics of water use in Asia — a) total water withdrawal; b) consumption*

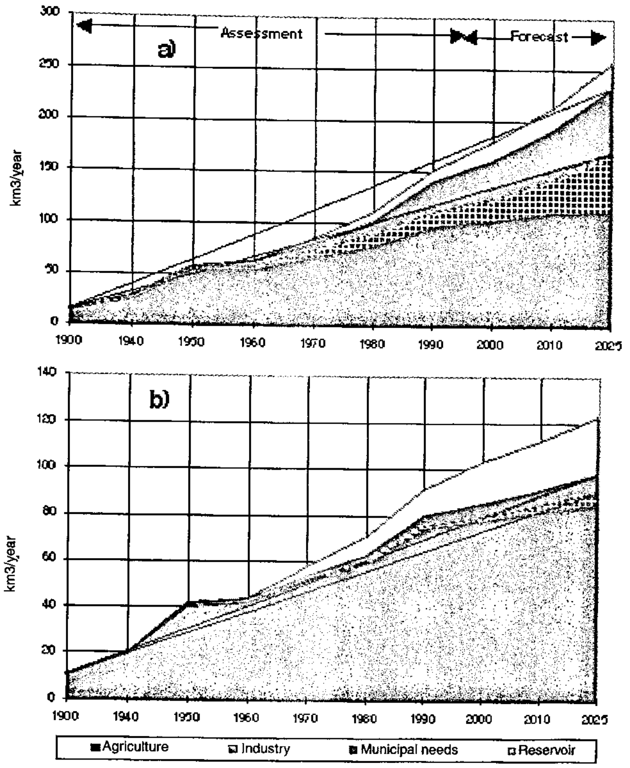


*Figure 5.13 — Dynamics of water use in South America — a) total water withdrawal; b) consumption*

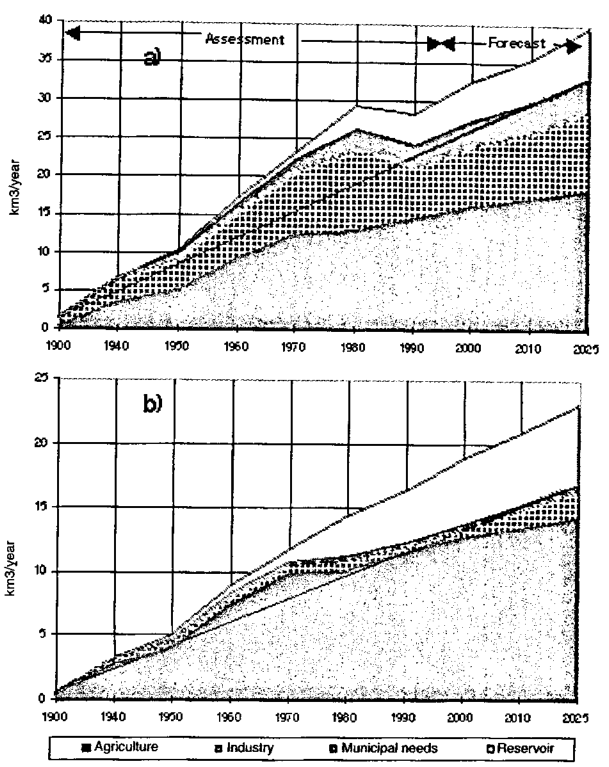


*Figure 5.14 — Dynamics of water use in Australia — a) total water withdrawal; b) consumption*

inflow. This approach is based on the general practice in International Apportionment Agreements that each region is entitled to half of the freshwater inflow imported from the upstream adjacent regions. It should be noted that for most of the regions of the world, the inflow from the adjacent regions is a small portion of the local water resources. North Africa is an exception, as the water inflow exceeds local water resources by a factor of several times. In the Central region of South America, the amount of water inflow is close to the amount of local water resources. In seven other regions, the water inflow ranges from 15-30 per cent of local water resources. In the remainder of the regions, the amount of water inflow is either zero or negligibly small when compared with the local water resources.

Based on the data given in Table 5.19, the present total global water withdrawal represents 8.4 per cent of the world's renewable water resources, with an increase to 12.2 per cent by 2025. This does not appear to be a large percentage, but it must be recognized that the world's water resources are distributed quite unevenly. A comparison of water withdrawal and river runoff on average for the continents makes this evident. The present water withdrawal in Europe and Asia represents 15-17 per cent of the renewable water resources, and will climb to 21-23 per cent by 2025. By comparison, South America, Australia and Oceania withdraw only 1.2-1.3 per cent of river runoff and this value is not expected to exceed 1.6-2.1 per cent in the future.

Even greater unevenness in water withdrawal and river runoff distribution is observed if individual physiographic and economic regions are considered. Within each continent (except South America) there are regions where the rate of water resources development is very high and also regions where the portion of water withdrawal (consumed water in particular) is very small compared to the renewable water resources (see Figure 4.1). For example, in Europe, in regions 2, 3 and 5 (southern and central Europe) the present water withdrawal represents 24-30 per cent of the renewable water resources. Meanwhile in the northern part of the continent, in regions 1 and 4, these values do not exceed 1.5-3.0 per cent. In North America, in the northern areas of the continent, the water withdrawal does not exceed 1 per cent of the water resources. In comparison, this value equals 28 per cent for the continental United States of America. Still greater contrast is observed in Africa and Asia. In the northern part of Africa, in region 9 the almost complete use of surface water resources is observed (water withdrawal equals 95 per cent of the water resources), whereas in other regions of Central Africa water withdrawal is very small compared with the renewable water resources. In Asia, the water resources are used quite intensively (42-76 per cent) in regions 15, 16, and 18, particularly in the Arab Peninsula. Meanwhile, in region 19 (Siberia and Far East), the portion of water resources use does not exceed 1 per cent. Only in South America is the water resource withdrawal not great in all the regions, and does not exceed 2-4 per cent of the renewable water resource.

By 2025, this unevenness in water resources distribution and water withdrawal is forecast to be the same or would even tend to increase. In many regions, where the present water resource withdrawals are quite significant, the percentage of renewable water resources used will increase and reach critical values. In contrast, the northern regions, and regions with water surplus all over the continents, will continue to have water withdrawal rates and consumption that is a very small portion of the renewable water resources available.

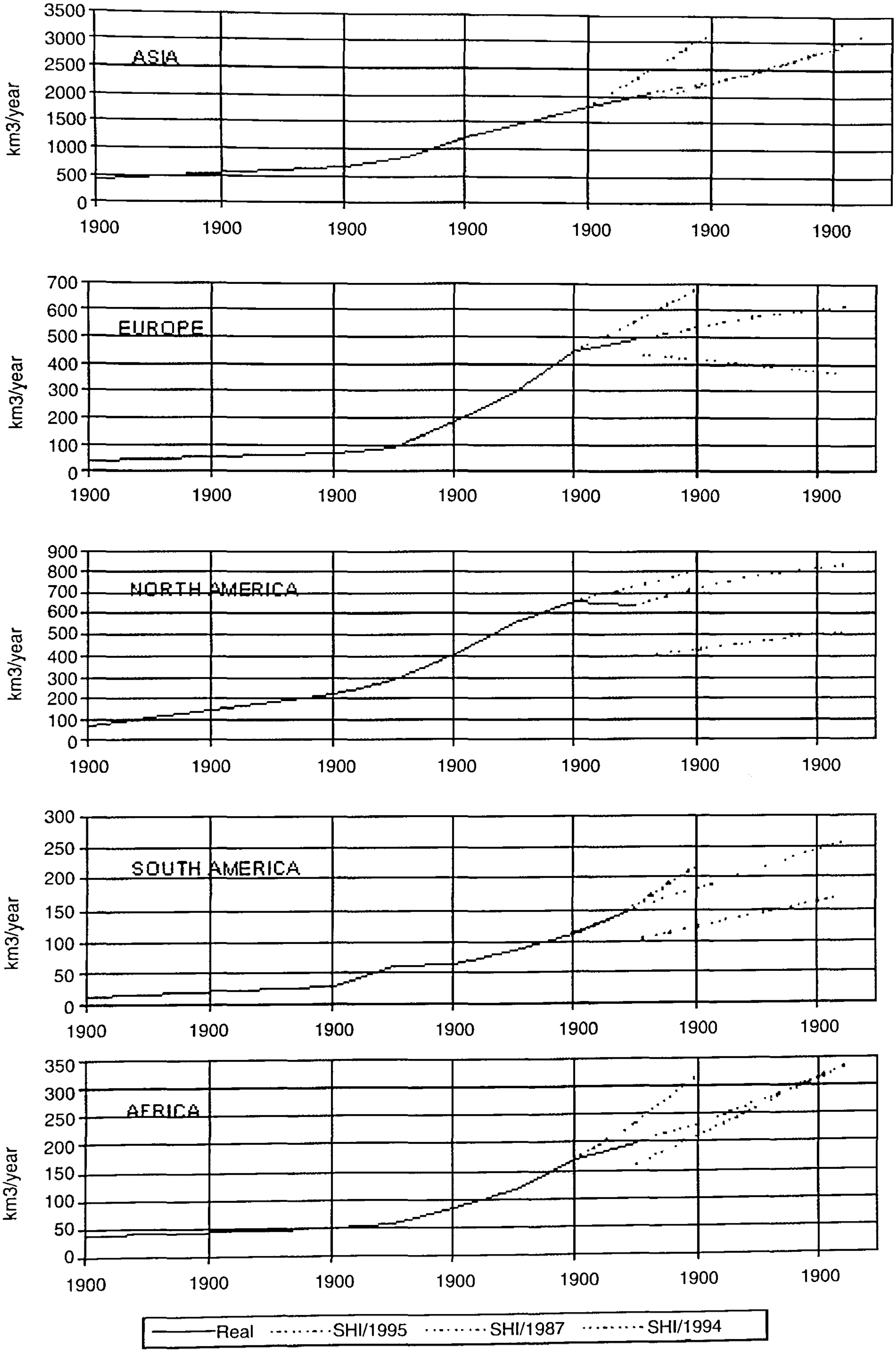


*Figure 5.15 — Forecasts of water withdrawal by countries according to estimates of SHI/1995, SHI/1987 and Margat/1994*

*Table 5.17 — Dynamics of water withdrawal by continents and physiographic and economic regions of the world in km³/year*

| *Number of region* | *Continent, Region* | *Assessment* | | | | | | | | | *Forecast* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| | **Europe** | 37.4 | 71.0 | 93.9 | 185 | 294 | 445 | 491 | 512 | 534 | 578 | 619 |
| 1 | Northern | 1.4 | 2.8 | 3.9 | 7.5 | 9.8 | 11 | 11.4 | 12.3 | 13.2 | 14.8 | 16.4 |
| 2 | Western and Central | 12.8 | 21.5 | 31.5 | 87.2 | 120 | 142 | 150 | 162 | 173 | 192 | 208 |
| 3 | Southern | 16 | 27.1 | 37.4 | 53.9 | 88.6 | 155 | 174 | 184 | 194 | 208 | 212 |
| 4 | North of the European part of FSU | 0.3 | 0.8 | 0.9 | 1.8 | 3.1 | 13.9 | 16.3 | 15.6 | 14.9 | 16.8 | 20.3 |
| 5 | South of the European part of FSU | 6.9 | 18.8 | 20.2 | 34.4 | 72 | 123 | 139 | 139 | 139 | 146 | 162 |
| | **North America** | 69.4 | 221 | 286 | 411 | 556 | 664 | 642 | 680 | 719 | 781 | 837 |
| 6 | Canada and Alaska | 2.6 | 8.8 | 13.2 | 19.2 | 25.9 | 41.1 | 52 | 55.8 | 59.5 | 66.6 | 75.9 |
| 7 | USA | 54 | 191 | 244 | 340 | 460 | 527 | 488 | 510 | 532 | 570 | 600 |
| 8 | Central America and Caribbean | 12.8 | 20.9 | 28.5 | 51.5 | 69.9 | 95.4 | 102 | 114 | 127 | 144 | 161 |
| | **Africa** | 41.0 | 49.3 | 56.0 | 85.9 | 116 | 168 | 199 | 214 | 230 | 270 | 331 |
| 9 | Northern | 37 | 41 | 43 | 65 | 78 | 100 | 105 | 110 | 114 | 127 | 144 |
| 9a | of which, Sahel | | | | | | | 5.71 | 6.49 | 7.27 | 9.63 | 13.8 |
| 10 | Southern | 1.9 | 4.4 | 6.5 | 10 | 16 | 23 | 24.5 | 26.4 | 28.2 | 32.6 | 43.1 |
| 11 | East | 1 | 2.1 | 3.7 | 6.1 | 12 | 23 | 44.7 | 50.4 | 56 | 67.9 | 83.4 |
| 12 | West | 1 | 1.5 | 2.3 | 3.8 | 8.4 | 19 | 22.7 | 26.0 | 29.2 | 37.4 | 51.7 |
| 13 | Central | 0.1 | 0.3 | 0.5 | 1 | 1.6 | 2.8 | 2 | 2.5 | 3 | 4.8 | 8.9 |
| | **Asia** | 414 | 689 | 860 | 1222 | 1499 | 1784 | 2067 | 2156 | 2245 | 2483 | 3104 |
| 14 | North China and Mongolia | 36.6 | 66.6 | 98.4 | 165 | 217 | 241 | 234 | 254 | 273 | 305 | 373 |
| 15 | Southern | 201 | 312 | 367 | 429 | 524 | 668 | 895 | 932 | 969 | 1060 | 1370 |
| 16 | Western | 42.8 | 68.8 | 90 | 135 | 158 | 192 | 227 | 238 | 248 | 283 | 346 |
| 16a | of which, Arab Peninsula | | | | | | | 21.9 | 26.1 | 30.4 | 36.2 | 44.9 |
| 17 | South-East | 98.6 | 170 | 230 | 399 | 469 | 484 | 499 | 525 | 551 | 617 | 781 |
| 18 | Central Asia and Kazakstan | 29.6 | 55 | 57.2 | 67.3 | 94.4 | 151 | 156 | 154 | 151 | 160 | 169 |
| 19 | Siberia and Far East of Russia | 0.7 | 4.9 | 5.6 | 10.4 | 16.3 | 25.4 | 31.3 | 30.6 | 30 | 32.5 | 37.9 |
| 20 | Caucasus | 4.2 | 11.3 | 11.4 | 15.8 | 20.7 | 23 | 24.4 | 23.7 | 23 | 25.5 | 27.4 |
| | **South America** | 15.1 | 27.7 | 59.4 | 63.5 | 85.2 | 111 | 152 | 166 | 180 | 213 | 257 |
| 21 | Northern | 1.6 | 4.2 | 6.4 | 7.7 | 11.3 | 15.4 | 22.1 | 24.5 | 27 | 32.6 | 41 |
| 22 | Eastern | 1.1 | 2.1 | 3 | 7.3 | 12.1 | 23.2 | 43 | 49.0 | 55.1 | 68.8 | 87.6 |
| 23 | Western | 8.8 | 14.9 | 36.7 | 32.5 | 35.8 | 40 | 45 | 47.1 | 49.2 | 54.8 | 63.9 |
| 24 | Central | 3.6 | 6.5 | 13.3 | 16 | 26 | 32.6 | 42 | 45.6 | 49.1 | 57.2 | 64.6 |
| | **Australia and Oceania** | 1.6 | 6.8 | 10.3 | 17.4 | 23.3 | 29.4 | 28.5 | 33.6 | 32.6 | 35.6 | 39.6 |
| 25 | Australia | 1.5 | 6.2 | 9.4 | 16 | 21.4 | 27 | 25.5 | 27.2 | 28.9 | 31.7 | 35.2 |
| 26 | Oceania | 0.1 | 0.6 | 0.9 | 1.4 | 1.9 | 2.4 | 3 | 3.4 | 3.7 | 3.9 | 4.4 |
| | World (rounded) | 578 | 1064 | 1365 | 1984 | 2573 | 3201 | 3579 | 3760 | 3941 | 4360 | 5188 |

*Table 5.18 — Dynamics of water consumption by continents and physiographic and economic regions of the world in km³/year*

| *Number of region* | *Continent, Region* | *Assessment* | | | | | | | | | *Forecast* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1900* | *1940* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| | Europe | 17.6 | 29.8 | 38.4 | 53.9 | 82 | 158 | 183 | 187 | 191 | 202 | 216 |
| 1 | Northern | 0.2 | 0.3 | 0.4 | 0.7 | 1.2 | 2 | 2.4 | 2.5 | 2.7 | 2.9 | 3 |
| 2 | Western and Central | 2.7 | 4.2 | 6 | 9.5 | 15.1 | 28.2 | 32.5 | 34.8 | 37.2 | 40.1 | 40.4 |
| 3 | Southern | 11 | 18.4 | 25.2 | 29.5 | 39.1 | 74.2 | 82.1 | 83.9 | 85.7 | 85.1 | 82 |
| 4 | North of the European part of FSU | 0.2 | 0.2 | 0.2 | 0.4 | 0.6 | 2.2 | 2.8 | 2.85 | 2.9 | 3.4 | 5 |
| 5 | South of the European part of FSU | 3.5 | 6.7 | 6.6 | 13.8 | 25.7 | 51.2 | 63.2 | 62.8 | 62.4 | 70.8 | 86.1 |
| | North America | 29.3 | 83.8 | 107 | 146 | 182 | 224 | 225 | 247 | 269 | 304 | 329 |
| 6 | Canada and Alaska | 0.5 | 1.6 | 2.3 | 3.3 | 4.8 | 7.8 | 10.1 | 11.4 | 12.6 | 14.8 | 17 |
| 7 | USA | 20 | 68 | 86 | 108 | 132 | 155 | 150 | 165 | 180 | 203 | 219 |
| 8 | Central America and Caribbean | 8.8 | 14.2 | 18.8 | 34.2 | 45.5 | 61.2 | 64.8 | 70.8 | 76.8 | 85.9 | 92.9 |
| | Africa | 33.5 | 38.8 | 44.3 | 65.7 | 88.2 | 128 | 151 | 160 | 169 | 190 | 216 |
| 9 | Northern | 30.4 | 32.5 | 34.6 | 51 | 61 | 79 | 75.7 | 78.0 | 80.3 | 88.6 | 94.5 |
| 9a | of which, Sahel | | | | | | | 4.30 | 4.75 | 5.20 | 6.49 | 8.70 |
| 10 | Southern | 1.5 | 3.5 | 5 | 7.2 | 11 | 16 | 18.2 | 19.1 | 20 | 21.8 | 27.8 |
| 11 | East | 0.8 | 1.6 | 2.8 | 4.6 | 9.3 | 18 | 37.3 | 41.0 | 44.6 | 52 | 58.8 |
| 12 | West | 0.7 | 1.1 | 1.7 | 2.6 | 6.3 | 14 | 18.2 | 20.1 | 22 | 25.6 | 32 |
| 13 | Central | 0.05 | 0.12 | 0.18 | 0.29 | 0.6 | 1.3 | 1.3 | 1.4 | 1.6 | 2 | 2.8 |
| | Asia | 322 | 528 | 654 | 932 | 1116 | 1324 | 1529 | 1566 | 1603 | 1721 | 1971 |
| 14 | North China and Mongolia | 30.4 | 52.7 | 74.5 | 129 | 163 | 172 | 179 | 182 | 185 | 194 | 210 |
| 15 | Southern | 160 | 249 | 293 | 341 | 412 | 518 | 664 | 687 | 710 | 767 | 944 |
| 16 | Western | 34 | 54.6 | 71.2 | 107 | 123 | 147 | 167 | 174 | 181 | 201 | 229 |
| 16a | of which, Arab Peninsula | | | | | | | 16.8 | 19.6 | 20.3 | 24.4 | 28.1 |
| 17 | South East | 76.6 | 129 | 170 | 299 | 337 | 365 | 383 | 388 | 393 | 413 | 425 |
| 18 | Central Asia and Kazakstan | 18.9 | 34.7 | 36.7 | 43.1 | 60.9 | 97.4 | 103 | 102 | 102 | 110 | 122 |
| 19 | Siberia and Far East of Russia | 0.4 | 1.1 | 1.3 | 2.8 | 7.9 | 10.9 | 15 | 14.8 | 14.6 | 16.7 | 20.7 |
| 20 | Caucasus | 2.1 | 7 | 7.1 | 10 | 11.9 | 14.1 | 18.1 | 17.5 | 17 | 19 | 20.4 |
| | South America | 11.3 | 20.6 | 44.8 | 44.4 | 57.8 | 70.9 | 91.4 | 97.7 | 104 | 113 | 123 |
| 21 | Northern | 1.3 | 3.4 | 5 | 5.8 | 8.3 | 11 | 14.4 | 15.6 | 16.8 | 18.3 | 21 |
| 22 | Eastern | 0.52 | 0.96 | 1.15 | 3 | 5.6 | 10.3 | 18 | 20.4 | 22.9 | 25.8 | 28 |
| 23 | Western | 6.9 | 11.7 | 29 | 25.1 | 27.3 | 29.9 | 32.7 | 33.6 | 34.5 | 36.5 | 40 |
| 24 | Central | 2.6 | 4.5 | 9.6 | 10.5 | 16.6 | 19.7 | 26.3 | 28.0 | 29.8 | 32.4 | 33.9 |
| | Australia and Oceania | 0.6 | 3.4 | 5.1 | 9.0 | 11.9 | 14.6 | 16.4 | 17.6 | 18.9 | 21 | 23.1 |
| 25 | Australia | 0.5 | 3 | 4.6 | 8.1 | 10.7 | 13.1 | 14.5 | 15.4 | 16.4 | 18.1 | 19.7 |
| 26 | Oceania | 0.1 | 0.3 | 0.5 | 0.9 | 1.2 | 1.5 | 1.9 | 2.2 | 2.5 | 2.9 | 3.4 |
| | World (rounded) | 415 | 704 | 893 | 1250 | 1538 | 1920 | 2196 | 2275 | 2354 | 2551 | 2878 |

*Table 5.19 — Water use by continents and physiographic and economic regions of the world (in % of water resources)*

| *Number of region* | *Continent, Region* | *Inflow* | *Local water resources* | *1995* | | *2025* | |
|---|---|---|---|---|---|---|---|
| | | | | *Withdrawal* | *Consumption* | *Withdrawal* | *Consumption* |
| | Europe | 2900 | 16.9 | 6.3 | 21.3 | 7.5 | |
| 1 | North | | 705 | 1.6 | 0.3 | 2.3 | 0.4 |
| 2 | Central | 6.0 | 617 | 24.2 | 5.2 | 33.4 | 6.5 |
| 3 | South | 109 | 546 | 29.0 | 13.7 | 35.3 | 13.7 |
| 4 | North of the European part of FSU | 27.0 | 589 | 2.7 | 0.5 | 3.4 | 0.8 |
| 5 | South of the European part of FSU | 123 | 443 | 27.6 | 12.5 | 32.1 | 17.1 |
| | North America | | 7 770 | 8.3 | 2.9 | 10.8 | 4.2 |
| 6 | Canada and Alaska | 233 | 4 980 | 1.00 | 0.2 | 1.5 | 0.3 |
| 7 | USA | 67.0 | 1 700 | 28.2 | 8.7 | 34.6 | 12.6 |
| 8 | Central America | 3.0 | 1 090 | 9.3 | 5.9 | 14.8 | 8.5 |
| | Africa | | 4 047 | 4.9 | 3.7 | 8.2 | 5.3 |
| 9 | North | 140 | 41.0 | 94.6 | 68.2 | 130 | 85.1 |
| 9a | of which, Sahel | 77.4 | 104 | 4.0 | 3.0 | 9.7 | 6.1 |
| 10 | South | 86.0 | 399 | 5.5 | 4.1 | 9.8 | 6.3 |
| 11 | East | 26.0 | 749 | 5.9 | 4.9 | 10.9 | 7.7 |
| 12 | West | 30.0 | 1 088 | 2.1 | 1.6 | 4.7 | 2.9 |
| 13 | Central | 80.0 | 1 770 | 0.11 | 0.07 | 0.5 | 0.2 |
| | Asia | | 13 508 | 15.3 | 11.3 | 23.0 | 14.6 |
| 14 | North China and Mongolia | | 1 029 | 22.7 | 17.4 | 36.2 | 20.4 |
| 15 | South | 300 | 1 988 | 41.9 | 31.1 | 64.1 | 44.2 |
| 16 | West | | 490 | 46.3 | 34.1 | 70.6 | 46.7 |
| 16a | of which, Arab Peninsula | 0 | 26* | 84.2 | 64.6 | 92.2 | 57.7 |
| 17 | South-east | 120 | 6 646 | 18.4 | 14.2 | 28.9 | 15.7 |
| 18 | Middle Asia and Kazakstan | 46.0 | 181 | 76.5 | 50.5 | 82.8 | 59.8 |
| 19 | Siberia and Far East of Russia | 202 | 3 107 | 1.0 | 0.5 | 1.2 | 0.6 |
| 20 | Caucasus | 12.1 | 67.8 | 33.0 | 24.5 | 37.1 | 27.6 |
| | South America | | 12 030 | 1.3 | 0.8 | 2.1 | 1.0 |
| 21 | North | | 3 340 | 0.66 | 0.4 | 1.2 | 0.6 |
| 22 | East (Brazil) | 1900 | 6 220 | 0.6 | 0.2 | 1.2 | 0.4 |
| 23 | West | | 1 720 | 2.6 | 1.9 | 3.7 | 2.3 |
| 24 | Central | 720 | 750 | 3.8 | 2.4 | 5.8 | 3.1 |
| | Australia and Oceania | | 2 400 | 1.2 | 0.7 | 1.6 | 1.0 |
| 25 | Australia | | 352 | 7.2 | 4.1 | 10.0 | 5.6 |
| 26 | Oceania | | 2 050 | 0.15 | 0.01 | 0.20 | 0.17 |
| | World (rounded) | | 42 655 | 8.4 | 5.1 | 12.2 | 6.7 |

# 6. WATER AVAILABILITY AND WATER RESOURCES DEFICIT IN THE WORLD

The uneven distribution of water resources over the Earth, particularly when compared to population distribution and the level of economic development, means that many areas of the globe experience water shortages. Forty per cent of the world's land mass produces only 2 per cent of the global runoff, and population is often centred in areas far away from major sources of supply. A comparison of specific water availability for several regions provides some insights into the differences. The specific water availability (per capita) for any region or country (V.B.) for each design level is determined from the following ratio:

V.B.=[(local water resources + 1/2 of inflow)-
water consumption]/population number

Thus, specific water availability defines the residual amount of fresh water per capita left after present uses are accounted for. If all water resources available are consumed by the different sectors, the specific water availability would be zero. The computed values of specific water availability (in thousand $m^3$/year per capita), for all continents and all physiographic and economic regions of the Earth, are given in Table 6.1. for 1950 to 2025. The specific water availability per capita at the global level has deceased from 16.8 thousand $m^3$/year in 1950 to 7.3 thousand $m^3$/year in 1995, a reduction to less than one half. A further decrease to 4.8 thousand $m^3$/year is expected by 2025. The rate of water availability decrease differs greatly by continents, and is most evident when comparing developed and developing countries. For example, the per capita availability in Europe, the United States of America and Canada would be decreased by 1.5-2 times over the period 1950-2025, but for the countries of Asia and Latin America, this decrease would be four to five times, and more than seven times for Africa. This rapid decrease is related to the intensive growth of population in the developing countries.

Still greater differences are observed in the dynamics of specific water availability by physiographic and economic regions of the world (Table 6.1). For greater clarity, the values of specific water availability of all the regions for the years 1950, 1990 and 2025 are presented in map form (Figures 6.1, 6.2, and 6.3) using the following categories of specific water availability (in thousand $m^3$/year per capita):

≤ 1 - catastrophically low;
1.1-2.0 - very low
2.1-5.0 - low
5.1-10.0 - middle
10.1-20.0 - high
> 20 - very high.

In 1950 (Figure 6.1) the specific water availability was in the middle or above middle categories for most of the regions of world. It was very low in North Africa only, and low in Central and South Europe, in Northern China and in South Asia (from 2.1 to 5.0 thousand $m^3$/year). There were no catastrophically low water categories in any region of the world. By 1995, the water availability per capita was reduced in many regions of the world (Figure 6.2). It was catastrophically low in North Africa and very low in Northern China, and in South and West Asia. A low water availability category (from 2.1 up to 5.0 thousand $m^3$/year) was now observed in seven regions of the world. At present, 76 per cent of the world's population lives under conditions of specific water availability below 5 000 $m^3$/year per capita. Moreover, 35 per cent of the world's population lives in regions suffering from very low or catastrophically low water availability.

By the beginning of the 21st century (Figure 6.3), this situation will be even worse. By the year 2025, the majority of the world's population will probably live under conditions of very low and catastrophically low water availability. About 30-35 per cent of the world's population will be living in countries having a catastrophically low fresh water supply (< 1 thousand $m^3$/year per capita). In comparison, a very high water availability will continue to be observed in North Europe, in Canada and Alaska, almost everywhere in South America, in Central Africa, in Siberia and Far East, and in Oceania.

Figure 6.4 shows the dynamics of specific water availability compiled over different regions of the world for 1950 at various values based on the data from Table 6.1. The data analysis demonstrates that the rate of water availability decrease depends on two main factors, namely the level of economic development of the countries included in the region and climate conditions in the region. For regions embracing industrially developed countries, the rates of specific water availability decrease for the study period (1950-2025) are not high (1.5-2.0 times), irrespective of climate conditions and amount of water resources available. Regions 1-7 and 19 are good examples. For regions embracing mainly developing countries, the decrease of specific water availability during 1950-2025 is much greater and falls into the range of three to six times for regions with sufficient and excessive water resources (e.g., Regions 8, 13, 17, 21-24 and 26), and is eight to 20 times under conditions of water deficit and in arid regions (Regions 9, 11, 12 and 16). It may be concluded that the greatest problems of specific water availability in the future will occur in developing countries in the generally water-short middle latitudes.

An even more critical situation is observed in the analysis of specific water availability for selected countries of the world, contained in Table 6.2. Big and small countries, developed and developing countries located in different physiographic zones on all the continents, with very high and very low specific water availability have been selected. Quantitative characteristics of the specific water availability have been developed for all these countries according to the same methodology used for the physiographic and economic regions listed in Table 6.1.

Sixty-eight per cent of the world's population lives in the countries selected for Table 6.2, and 69 per cent of the world river runoff occurs in these countries. Water withdrawal in these countries accounts for 72.6 per cent of the

Table 6.1 — *Dynamics of water availability by continents, physiographic and economic regions of the world (in 1 000m$^3$/year)*

| *Number of region* | *Continent, region* | *Population mln. 1994* | *Inflow km$^3$/yr* | *Local water resources* | *Water availability in 1 000 m$^3$/year per capita* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Assessment* | | | | | | | *Forecast* | |
| | | | | *km$^3$/yr* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| | Europe | 685 | | 2 900 | 5.51 | 4.99 | 4.53 | 4.17 | 3.99 | 3.96 | 3.93 | 3.89 | 3.92 |
| 1 | Northern | 23.5 | 0 | 705 | 37.7 | 34.9 | 32.4 | 31.2 | 30.3 | 30.5 | 30.8 | 31.5 | 30 |
| 2 | Western and Central | 295 | 6 | 617 | 2.69 | 2.47 | 2.24 | 2.11 | 2.02 | 2.01 | 2 | 1.98 | 1.94 |
| 3 | Southern | 186 | 109 | 546 | 4.08 | 3.73 | 3.38 | 2.92 | 2.79 | 2.70 | 2.61 | 2.54 | 2.69 |
| 4 | North of the European part of FSU | 28.4 | 26.7 | 569 | 31.4 | 27.3 | 24.6 | 22.9 | 21.1 | 21.4 | 21.7 | 22.3 | 23.3 |
| 5 | South of the European part of FSU | 152 | 123 | 443 | 4.49 | 3.87 | 3.46 | 3.12 | 2.92 | 2.94 | 2.96 | 2.94 | 2.91 |
| | North America | 448 | | 7 770 | 35.3 | 29 | 23.9 | 20.3 | 17.8 | 16.6 | 15.4 | 13.8 | 12.5 |
| 6 | Canada and Alaska | 29.7 | 233 | 4 980 | 366 | 282 | 234 | 206 | 188 | 180 | 172 | 162 | 154 |
| 7 | USA | 260 | 67 | 1 700 | 10.8 | 9.1 | 7.84 | 6.95 | 6.34 | 6.08 | 5.82 | 5.36 | 4.96 |
| 8 | Central America and Caribbean | 158 | 3 | 1 090 | 21 | 15.8 | 11.5 | 8.62 | 7.02 | 6.19 | 5.37 | 4.46 | 3.79 |
| | Africa | 630 | 0 | 4 047 | 18.2 | 14.6 | 11.2 | 8.3 | 6.18 | 5.35 | 4.53 | 3.4 | 2.46 |
| 9 | Northern | 140 | 140 | 41 | 1.49 | 0.91 | 0.6 | 0.29 | 0.25 | 0.22 | 0.18 | 0.11 | 0.06 |
| 9a | of which, Sahel | 46.9 | 77.4 | 104 | | | | | 3.32 | 2.94 | 2.55 | 1.90 | 1.25 |
| 10 | Southern | 76.5 | 86 | 399 | 15.4 | 13.1 | 9.69 | 7.14 | 5.54 | 4.80 | 4.06 | 3.11 | 2.54 |
| 11 | East | 169 | 26 | 749 | 14.2 | 11.4 | 8.69 | 6.1 | 4.28 | 3.67 | 3.06 | 2.2 | 1.46 |
| 12 | West | 200 | 30 | 1 088 | 16.8 | 13.3 | 10.2 | 7.29 | 5.43 | 4.61 | 3.79 | 2.74 | 2.05 |
| 13 | Central | 44.1 | 80 | 1 770 | 87.9 | 75.4 | 56 | 57.2 | 41 | 36.6 | 32.2 | 24.1 | 15.4 |
| | Asia | 3403 | | 13 508 | 9.18 | 7.41 | 6.13 | 4.78 | 3.84 | 3.60 | 3.36 | 2.96 | 2.35 |
| 14 | North China and Mongolia | 409 | 0 | 1 029 | 4.18 | 3.35 | 2.73 | 2.11 | 1.8 | 1.71 | 1.62 | 1.47 | 1.32 |
| 15 | Southern | 1207 | 300 | 1 988 | 3.78 | 3.02 | 2.49 | 1.87 | 1.32 | 1.21 | 1.1 | 0.93 | 0.59 |
| 16 | Western | 232 | 0 | 490 | 5.68 | 4.11 | 3 | 2.25 | 1.56 | 1.37 | 1.19 | 0.91 | 0.59 |
| 16a | of which, Arabian Peninsula | 19.3 | 0 | 26* | | | | 0.29 | 0.28 | 0.30 | 0.32 | 0.31 | 0.24 |
| 17 | South-East | 1442 | 120 | 6 646 | 10.5 | 8.65 | 7.16 | 5.64 | 4.78 | 4.54 | 4.31 | 3.9 | 3.41 |
| 18 | Central Asia and Kazakstan | 50.3 | 41 | 181 | 11.2 | 7.99 | 5.92 | 4.76 | 3.96 | 3.62 | 3.29 | 2.82 | 2.32 |
| 19 | Siberia and Far East of Russia | 42.5 | 202 | 3107 | 125 | 99.9 | 91.9 | 83.8 | 75.7 | 76.4 | 77 | 78.3 | 80.2 |
| 20 | Caucasus | 15.9 | 12.1 | 67.8 | 9.22 | 7.17 | 5.79 | 5.03 | 4.55 | 4.35 | 4.16 | 3.85 | 3.57 |
| | **South America** | 314 | | 12 030 | 109 | 83.1 | 63.6 | 49.8 | 40.6 | 37.0 | 33.4 | 26.3 | 24.1 |
| 21 | Northern | 48.6 | 0 | 3 340 | 196 | 138 | 102 | 78.9 | 62.8 | 57.3 | 51.8 | 29.3 | 35.2 |
| 22 | Eastern | 159 | 1900 | 6 220 | 138 | 103 | 77.5 | 59.2 | 48.2 | 44.2 | 40.1 | 34.7 | 29.3 |
| 23 | Western | 57.3 | 0 | 1 720 | 98.1 | 76.9 | 58.3 | 46.3 | 37.3 | 33.2 | 29.2 | 25 | 21.8 |
| 24 | Central | 49.4 | 720 | 750 | 46.3 | 38.5 | 32 | 27.1 | 22.8 | 21.0 | 19.1 | 16.3 | 13.9 |
| | Australia and Oceania | 28.7 | | 2 400 | 203 | 149 | 118 | 99.6 | 85.8 | 80.8 | 75.9 | 68.3 | 61.4 |
| 25 | Australia | 17.9 | 0 | 352 | 42.5 | 33.4 | 27.3 | 23.1 | 19.8 | 19.0 | 18.1 | 16.4 | 14.4 |
| 26 | Oceania | 10.8 | 0 | 2 050 | 566 | 362 | 262 | 221 | 191 | 176 | 160 | 141 | 130 |
| | World (rounded) | 5 629 | | 42 655 | 16.8 | 14 | 11.7 | 9.4 | 7.8 | 7.3 | 6.8 | 5.9 | 4.8 |

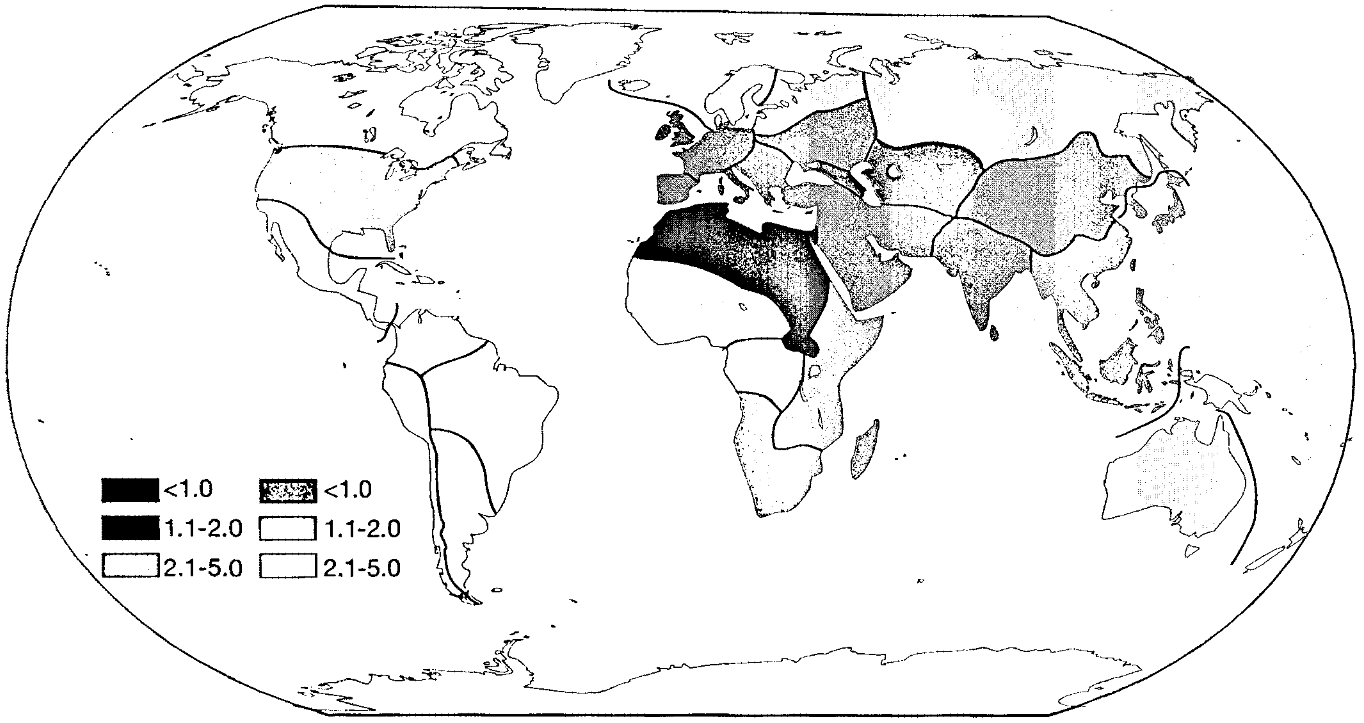


*Figure 6.1 — Water availability of the world regions in 1950 (1 000 m³/year per capita)*

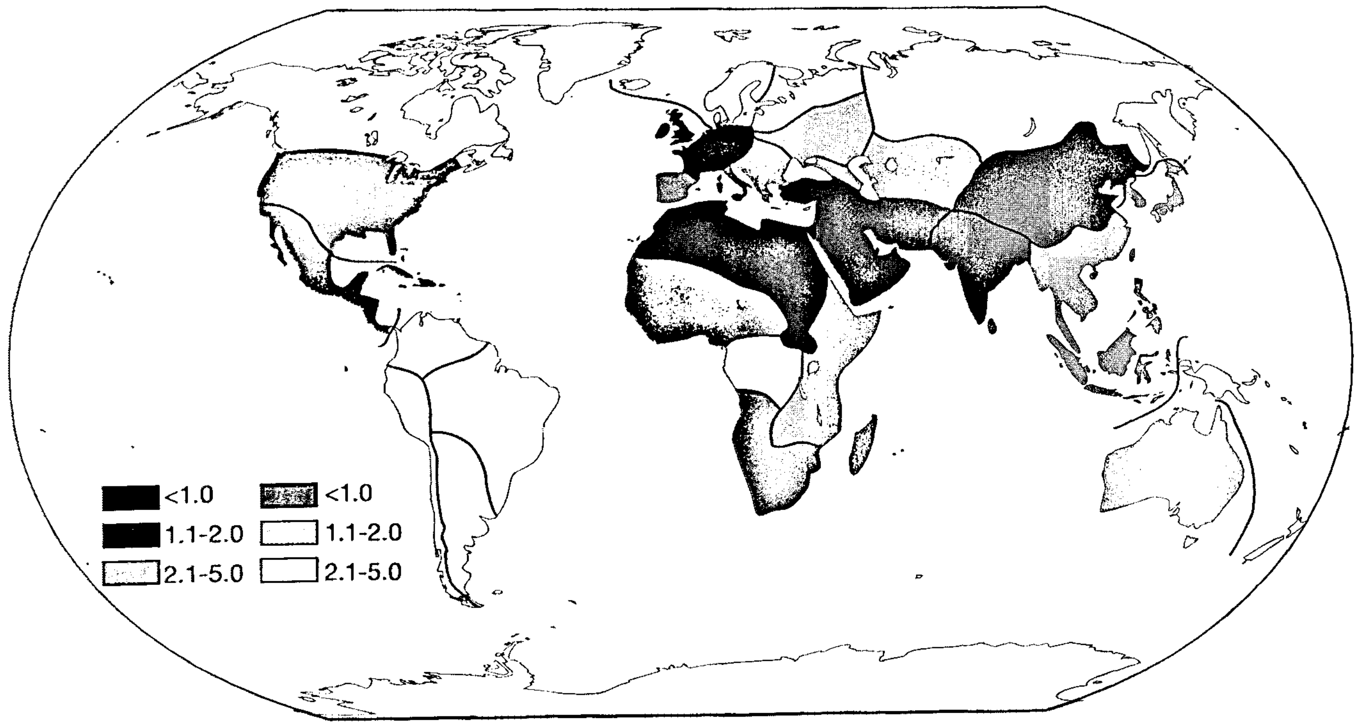


*Figure 6.2 — Water availability of the world regions in 1995 (1 000 m³/year per capita)*

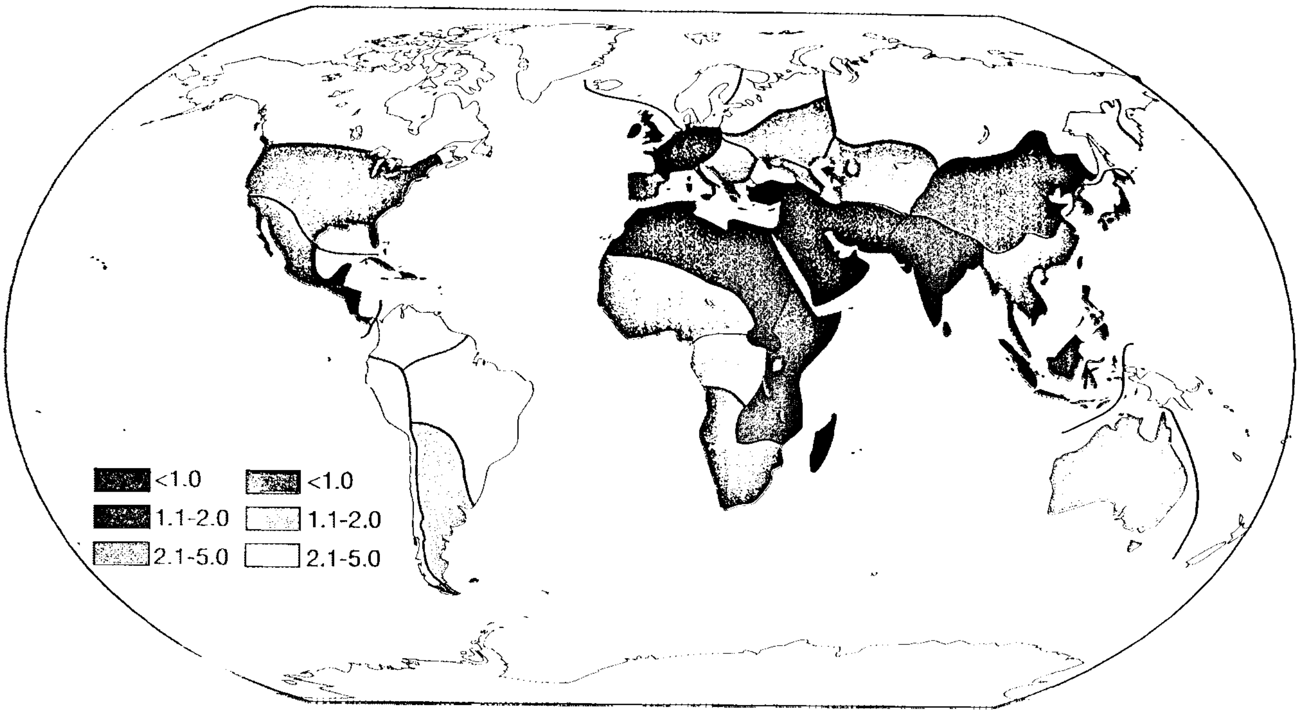


*Figure 6.3 — Water availability of the world regions in 2025(1 000 m³/year per capita)*

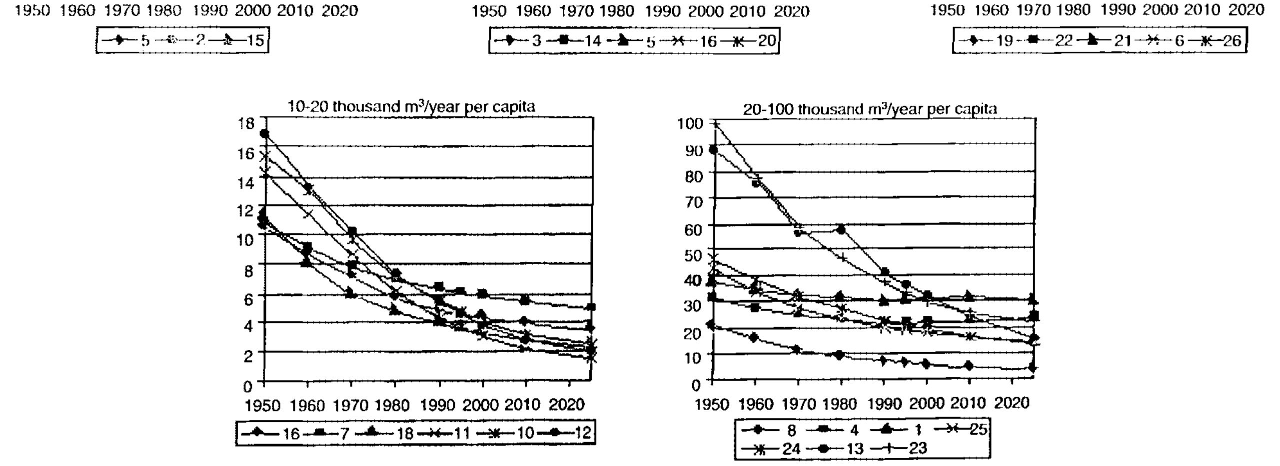


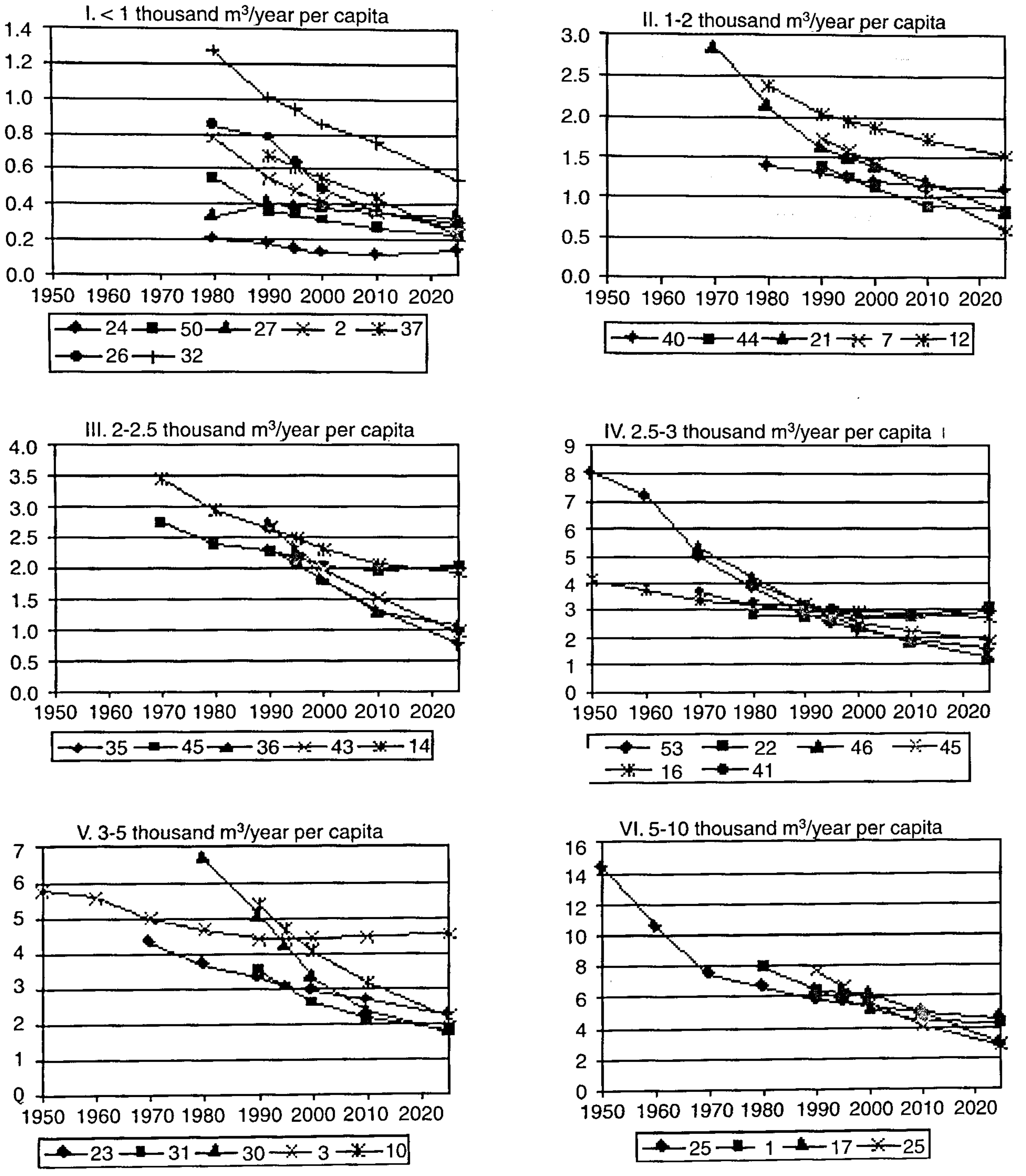
*Figure 6.4 — Dynamics of the specific water availability by world regions during 1950-2025*

*Table 6.2 — Dynamics of water availability in selected countries in the world*

| *No* | *Country* | *Population mln. 1994* | *Water resources Km³/year* |  | *Water use 1990 Km³/yr* |  | *Water availability in 1 000 m3/year per capita* |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  |  | *Assesment* |  | *Forecast* |  |  |
|  |  |  | *Local* | *Inflow* | *withdrawal* | *consumption* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| 1 | Albania | 3.41 | 18.6 | 5.2 | 0.34 | 0.2 |  |  |  | 7.9 | 6.46 | 5.79 | 5.11 | 4.38 | 4.17 |
| 2 | Algeria | 27.3 | 13.9* | 0.4* | 450 | 2.63 |  |  |  | 0.78 | 0.55 | 0.48 | 0.42 | 0.36 | 0.27 |
| 3 | Argentina | 34.2 | 270 | 623 | 33.7 | 20.1 |  |  | 25.3 | 21.2 | 17.4 | 16.2 | 15.1 | 13.5 | 12.3 |
| 4 | Australia | 17.9 | 352 | 0 | 25.5 | 14.5 | 42.5 | 33.4 | 27.3 | 23.1 | 19.8 | 18.9 | 18.1 | 16.4 | 14.4 |
| 5 | Bolivia | 7.24 | 361 | 155 | 1.38 | 0.92 |  |  |  |  | 61.2 | 53.1 | 45.1 | 34.3 | 24.1 |
| 6 | Brazil | 159 | 6220 | 1900 | 43.0 | 18.0 | 138 | 103 | 77.6 | 59.2 | 48.2 | 44.0 | 40.1 | 34.7 | 29.3 |
| 7 | Burkina Faso | 10.0 | 14.7 | 2.0 | 0.38 | 0.26 |  |  |  |  | 1.73 | 1.59 | 1.45 | 1.07 | 0.60 |
| 8 | Belarus | 10.3 | 34.4 | 21.7 | 3.0 | 0.9 | 5.78 | 5.59 | 5.0 | 4.71 | 4.39 | 4.41 | 4.43 | 4.48 | 4.54 |
| 9 | Canada | 29.1 | 3290 | 170 | 51.2 | 10.1 | 246 | 188 | 159 | 140 | 127 | 122 | 117 | 110 | 106 |
| 10 | Chad | 6.18 | 15.8 | 28.3 | 0.19 | 0.13 |  |  |  |  | 5.36 | 4.71 | 4.06 | 3.16 | 2.21 |
| 11 | Chile | 14.0 | 354 | 0 | 21.4 | 15.4 |  |  |  |  | 25.7 | 24.3 | 22.9 | 20.7 | 17.1 |
| 12 | China | 1209 | 2700 | 0 | 477 | 365 |  |  |  | 2.38 | 2.02 | 1.94 | 1.86 | 1.72 | 1.52 |
| 13 | Colombia | 34.3 | 1200 | 0 | 5.55 | 3.62 |  |  |  |  | 37.0 | 34.3 | 31.5 | 27.3 | 22.1 |
| 14 | Cuba | 11.0 | 84.5 | 0 | 9.2 | 6.3 |  |  | 3.45 | 2.94 | 2.66 | 2.48 | 2.30 | 2.06 | 1.92 |
| 15 | Ecuador | 11.2 | 265 | 0 | 5.98 | 4.35 |  |  |  |  | 24.7 | 21.0 | 17.4 | 15 | 13.1 |
| 16 | France | 57.8 | 168 | 15 | 35.6 | 7.53 | 4.13 | 3.77 | 3.37 | 3.14 | 2.96 | 2.94 | 2.91 | 2.86 | 2.75 |
| 17 | Gambia | 1.08 | 3.2 | 4.7 | 0.03 | 0.02 |  |  |  |  | 6.36 | 6.25 | 6.14 | 4.86 | 2.93 |
| 18 | Guyana | 0.83 | 270 | 0 | 6.02 | 3.92 |  |  |  |  | 334 | 313 | 291 | 257 | 230 |
| 19 | Guatemala | 10.3 | 116 | 0 | 1.3 | 0.9 |  |  | 22.6 | 16.7 | 12.5 | 11.0 | 9.40 | 7.24 | 5.26 |
| 20 | Honduras | 5.49 | 102 | 0 | 2.6 | 1.8 |  |  | 40.2 | 27.3 | 19.5 | 16.9 | 14.3 | 11.1 | 8.58 |
| 21 | India | 919 | 1456 | 581 | 518 | 384 |  |  | 2.83 | 2.12 | 1.61 | 1.50 | 1.38 | 1.19 | 0.81 |
| 22 | Italy | 57.2 | 185 | 0 | 54.6 | 25.3 |  |  |  | 2.84 | 2.77 | 2.76 | 2.75 | 2.79 | 3.10 |
| 23 | Jamaica | 2.43 | 8.3 | 0 | 0.4 | 0.3 |  |  | 4.33 | 3.69 | 3.33 | 3.05 | 2.96 | 2.63 | 2.23 |
| 24 | Jordan | 5.20 | 0.984* | 0 | 0.71 | 0.40 |  |  |  | 0.20 | 0.17 | 0.14 | 0.12 | 0.11 | 0.13 |
| 25 | Kazakstan | 17.0 | 70.2 | 56 | 43 | 24 | 14.3 | 10.5 | 7.49 | 6.63 | 5.84 | 5.61 | 5.38 | 4.99 | 4.57 |
| 26 | Lebanon | 3.06 | 2.80* | 0 | 1.00 | 0.66 |  |  |  | 0.85 | 0.78 | 0.64 | 0.49 | 0.36 | 0.28 |
| 27 | Libya | 5.22 | 5.29* | 0 | 4.69 | 3.46 |  |  |  | 0.33 | 0.40 | 0.39 | 0.38 | 0.35 | 0.33 |

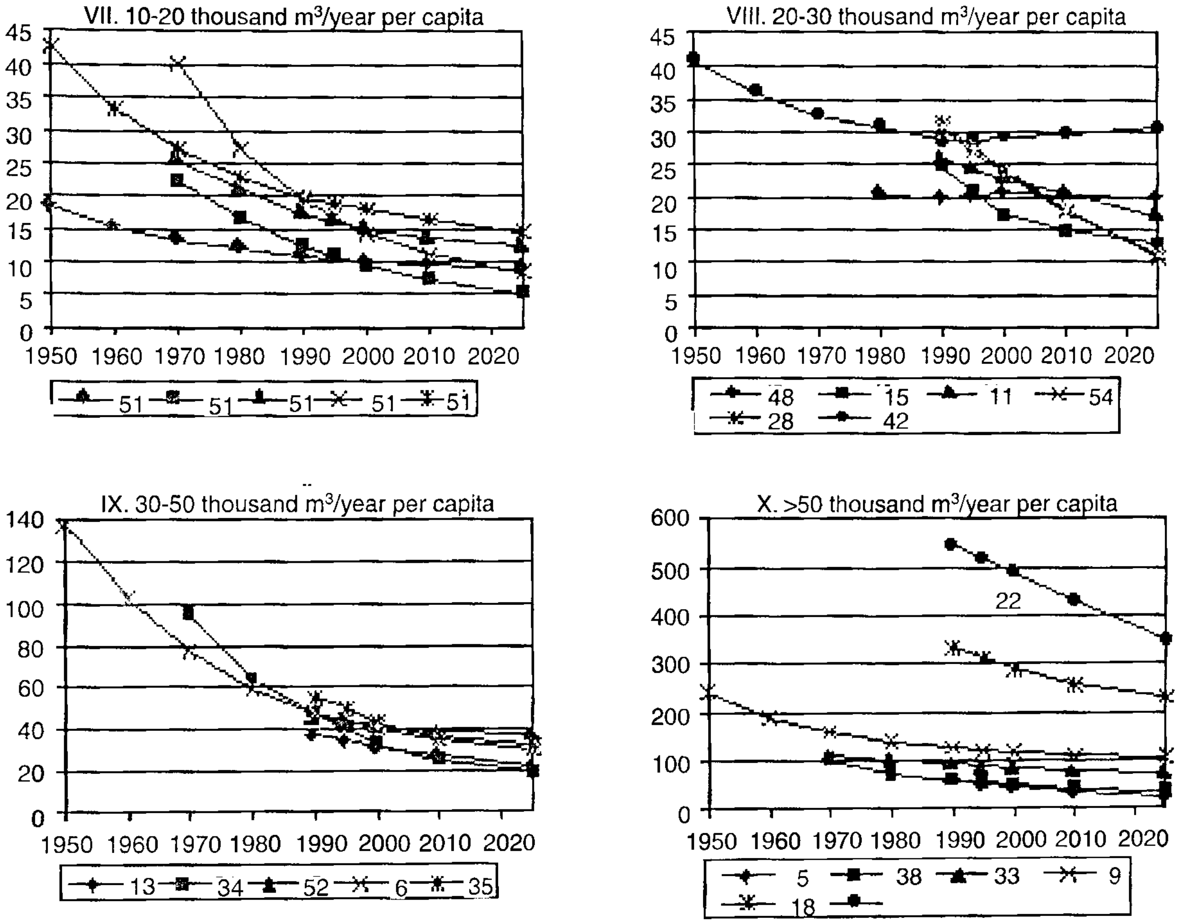
*Table 6.2 —Continued.*

| No | Country | *Population* | *Water resources* | | *Water use* | | *Water availability in 1 000 m3/year per capita* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *mln.* | *Km$^3$/year* | | *1990 Km$^3$/yr* | | | | | | *Assesment* | | *Forecast* | | |
| | | *1994* | *Local* | *Inflow* | *withdrawal* | *consumption* | *1950* | *1960* | *1970* | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| 28 | Madagascar | 14.3 | 395 | 0 | 19.7 | 15.4 | | | | | 31.6 | 27.9 | 24.2 | 18.2 | 10.9 |
| 29 | Mali | 10.5 | 50.0 | 44.4 | 1.49 | 1.19 | | | | | 7.71 | 6.65 | 5.60 | 4.16 | 2.84 |
| 30 | Mauritania | 2.22 | 0.4* | 11.0 | 1.63 | 1.22 | | | | 6.65 | 5.03 | 4.18 | 3.33 | 2.35 | 1.75 |
| 31 | Mexico | 91.9 | 347 | 2.60 | 73.9 | 51 | | | | | 3.51 | 3.06 | 2.6 | 2.16 | 1.81 |
| 32 | Morocco | 26.5 | 30.0* | 0 | 11.1 | 7.75 | | | | 1.28 | 1.01 | 0.94 | 0.86 | 0.75 | 0.54 |
| 33 | New Zealand | 3.50 | 313 | 0 | 2 | 1.03 | | | 111 | 100 | 93.7 | 88.7 | 83.2 | 78.6 | 75.6 |
| 34 | Nicaragua | 4.27 | 175 | 0 | 1.4 | 1.0 | | | 95.4 | 63.7 | 47.3 | 40.2 | 33.0 | 25.4 | 18.8 |
| 35 | Niger | 8.85 | 3.0 | 30.4 | 0.50 | 0.35 | | | | | 2.31 | 2.07 | 1.82 | 1.31 | 0.78 |
| 36 | Nigeria | 109 | 274 | 43.6 | 4 | 2 | | | | | 2.71 | 2.26 | 1.81 | 1.29 | 1.04 |
| 37 | Pakistan | 137 | 85 | 170 | 242 | 180 | | | | | 0.68 | 0.62 | 0.55 | 0.43 | 0.23 |
| 38 | Panama | 2.58 | 144 | 0 | 1.8 | 1.2 | | | 100 | 73.0 | 59.0 | 54.2 | 49.3 | 42.9 | 36.8 |
| 39 | Peru | 23.3 | 1100 | 144 | 17 | 12.3 | | | | | 55.0 | 49.5 | 42.4 | 35.4 | 31.8 |
| 40 | Poland | 38.3 | 49.5 | 6.7 | 15.5 | 3.82 | | | | 1.38 | 1.29 | 1.24 | 1.20 | 1.13 | 1.08 |
| 41 | Portugal | 9.83 | 18.5 | 34.5 | 9.6 | 3.76 | | | 3.67 | 3.22 | 3.15 | 2.99 | 2.83 | 2.71 | 2.91 |
| 42 | Russia | 148 | 4059 | 227 | 136 | 49.0 | 41.0 | 36.0 | 32.6 | 30.7 | 28.6 | 28.8 | 29.0 | 29.5 | 30.6 |
| 43 | Senegal | 8.10 | 17.4 | 17.4 | 1.50 | 0.97 | | | | | 2.68 | 2.34 | 2.00 | 1.52 | 0.97 |
| 44 | South Africa | 40.6 | 44.8 | 5.2 | 13.3 | 8.1 | | | | | 1.38 | 1.25 | 1.12 | 0.9 | 0.84 |
| 45 | Spain | 39.6 | 108 | 0 | 40.2 | 20 | | | 2.74 | 2.38 | 2.26 | 2.15 | 2.04 | 1.94 | 2.04 |
| 46 | Sudan | 27.4 | 22.0 | 140 | 17.4 | 12.4 | | | 5.29 | 4.21 | 3.16 | 2.78 | 2.4 | 1.88 | 1.3 |
| 47 | Surinam | 0.42 | 230 | 0 | 0.49 | 0.32 | | | | | 544 | 517 | 490 | 430 | 348 |
| 48 | Sweden | 8.74 | 164 | 12.2 | 4.0 | 0.48 | | | | 20.4 | 19.8 | 20.2 | 20.7 | 20.2 | 19.7 |
| 49 | Thailand | 58.2 | 199 | 0 | 33.1 | 21.5 | | | | 3.99 | 3.24 | 2.92 | 2.59 | 2.21 | 1.92 |
| 50 | Tunisia | 8.73 | 3.52* | 0.42* | 3.08 | 1.94 | | | | 0.55 | 0.36 | 0.34 | 0.31 | 0.27 | 0.22 |
| 51 | United States | 261 | 2810 | 146 | 489 | 150 | 18.3 | 15.3 | 13.4 | 12 | 10.9 | 10.4 | 10 | 9.32 | 8.85 |
| 52 | Uruguay | 3.17 | 68.0 | 74.0 | 4.2 | 3.1 | | | | | 44.9 | 43.0 | 41 | 38 | 37.2 |
| 53 | Uzbekistan | 22.3 | 9.52 | 98.1 | 82.1 | 51.7 | 8.03 | 7.22 | 4.97 | 3.81 | 2.88 | 2.59 | 2.3 | 1.91 | 1.6 |
| 54 | Congo D.R of | 42.6 | 987 | 313 | 0.36 | 0.08 | | | | | 30.6 | 27.3 | 24 | 17.9 | 11.5 |



| I | | II | | III | | IV | | V | | VI | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Jordan | 40 | Poland | 35 | Niger | 53 | Uzbekistan | 23 | Jamaica | 25 | Kazakstan |
| 50 | Tunisia | 44 | South Africa | 45 | Spain | 22 | Italy | 31 | Mexico | 1 | Albania |
| 27 | Libya | 21 | India | 36 | Nigeria | 46 | Sudan | 30 | Mauritania | 17 | Gambia |
| 2 | Algeria | 7 | Burkina Faso | 43 | Senegal | 49 | Thailand | 8 | Belarus | 29 | Mali |
| 37 | Pakistan | 12 | China | 14 | Cuba | 16 | France | 10 | Chad | | |
| 26 | Lebanon | | | | | 41 | Portugal | | | | |
| 32 | Morocco | | | | | | | | | | |

*Figure 6.5 (part 1) — Dynamics of water availability by selected countries of the world*



| | VII | | VIII | | IX | | IX |
|---|---|---|---|---|---|---|---|
| 51 | United States | 48 | Sweden | 13 | Colombia | 5 | Bolivia |
| 19 | Guatemala | 15 | Ecuador | 34 | Nicaragua | 38 | Panama |
| 3 | Argentina | 11 | Chile | 52 | Uruguay | 33 | New Zealand |
| 20 | Honduras | 54 | Zaire | 6 | Brazil | 9 | Canada |
| 4 | Australia | 28 | Madagascar | 39 | Peru | 18 | Guyana |
| | | 42 | Russia | | | 47 | Surinam |

*Figure 6.5 (part 2) — Dynamics of water availability by selected countries of the world*

world water withdrawal. The dynamics of specific water availability for the period 1950 to 2025 computed from the data of Table 6.2, are displayed graphically in Fig. 6.5. The analysis of the data at the country level demonstrates the trends in the long-term changes in specific water availability. Industrially developed countries located in areas of different water availability are characterized by relatively low rates of specific water availability decrease. Developing countries, especially those located in areas of water deficit, have a very low specific water availability and very high rates of decrease due to rapid population growth and increased water consumption per capita. A critically low water availability will be observed in many of these countries in the decades to come.

A special approach to the assessment of available water resources, water withdrawal and water availability is required for the economically developed and prosperous countries of the Arabian Peninsula, where most of the limited renewable water resources are already utilized. The rapid economic development, population growth and higher standards of living of this area constantly drive a higher water withdrawal, which is met not only from undeveloped surface runoff but by intensive use of groundwater and also by the so-called non-traditional water resources sources (desalination of salt and brackish water). The estimates of water withdrawal in the countries of the Arabian Peninsula cited in different publications are quite variable. The most recent data have been prepared under the auspices of the UN Department of Power and Natural Resources ("Implication of Agenda 21 for water management in the ESCWA region", 1995) and by regional offices of ACSAD and ROSTAS ("Rainfall Water Management in the Arab Region", 1995; "Groundwater Protection in the Arab Region", 1995). Additional data are also available submitted to regional symposia on water resources ("Procedural Symposium on Water Resources and Utilization in the Arab World", 1986; "Procedural First Meeting of the IHP Arab Permanent Committee", 1992).

Table 6.3 and Figure 6.6 display the compilation of results for total (traditional and non-traditional) water

*Table 6.3 — Total water tesources and eater eithdrawal (km$^3$/year ), and water availability (1 000 m$^3$/year per capita) for the countries of Arabian Peninsula*

| *Country* | *Characteristic* | | | *Design levels* | | | |
|---|---|---|---|---|---|---|---|
| | | *1980* | *1990* | *1995* | *2000* | *2010* | *2025* |
| Saudi Arabia | Water resources | 3.69 | 17.6 | 21.0 | 24.4 | 27.9 | 32.8 |
| | Total water withdrawal | 2.36 | 16.3 | 19.7 | 23.1 | 26.6 | 31.5 |
| | Water consumption | 1.65 | 12.8 | 15.2 | 17.7 | 19.1 | 21.0 |
| | Water availability | 0.218 | 0.328 | 0.335 | 0.342 | 0.331 | 0.624 |
| Yemen | Water resources | 3.75 | 4.94 | 5.30 | 5.67 | 6.40 | 7.88 |
| | Total water withdrawal | 1.70 | 2.89 | 3.18 | 3.47 | 4.35 | 5.83 |
| | Water consumption | 1.39 | 2.19 | 2.16 | 2.12 | 2.57 | 3.62 |
| | Water availability | 0.394 | 0.235 | 0.28 | 0.326 | 0.260 | 0.151 |
| United Arab Emirates | Water resources | 0.685 | 1.119 | 1.376 | 1.634 | 2.210 | 2.833 |
| | Total water withdrawal | 0.610 | 1.044 | 1.302 | 1.559 | 2.135 | 2.980 |
| | Water consumption | 0.486 | 0.826 | 1.072 | 1.317 | 1.452 | 1.894 |
| | Water availability | 0.714 | 0.443 | 0.439 | 0.435 | 0.424 | 0.403 |
| Oman | Water resources | 1.308 | 1.441 | 1.570 | 1.698 | 1.973 | 2.593 |
| | Total water withdrawal | 0.665 | 0.798 | 0.926 | 1.055 | 1.330 | 1.950 |
| | Water consumption | 0.561 | 0.621 | 0.666 | 0.712 | 0.840 | 1.031 |
| | Water availability | 0.759 | 0.538 | 0.518 | 0.499 | 0.439 | 0.329 |
| Kuwait | Water resources | 0.186 | 0.383 | 0.512 | 0.640 | 1.071 | 1.721 |
| | Total water withdrawal | 0.186 | 0.383 | 0.512 | 0.640 | 1.071 | 1.721 |
| | Water consumption | 0.049 | 0.099 | 0.124 | 0.148 | 0.199 | 0.264 |
| | Water availability | 0.100 | 0.132 | 0.148 | 0.164 | 0.231 | 0.385 |
| Bahrain | Water resources | 0.138 | 0.225 | 0.266 | 0.306 | 0.365 | 0.425 |
| | Total water withdrawal | 0.138 | 0.225 | 0.266 | 0.306 | 0.365 | 0.425 |
| | Water consumption | 0.084 | 0.118 | 0.122 | 0.126 | 0.132 | 0.138 |
| | Water availability | 0.156 | 0.213 | 0.236 | 0.260 | 0.273 | 0.287 |
| Qatar | Water resources | 0.128 | 0.250 | 0.270 | 0.290 | 0.349 | 0.475 |
| | Total water withdrawal | 0.128 | 0.250 | 0.270 | 0.290 | 0.349 | 0.475 |
| | Water consumption | 0.102 | 0.102 | 0.122 | 0.143 | 0.160 | 0.196 |
| | Water availability | 0.116 | 0.347 | 0.302 | 0.258 | 0.262 | 0.324 |
| Arabian Peninsula as a whole | Population | 19.3 | 32.7 | 35.8 | 38.9 | 51.3 | 86.0 |
| | Water resources | 9.88 | 26.0 | 30.3 | 34.6 | 40.3 | 48.7 |
| | Total water withdrawal | 5.79 | 21.9 | 26.2 | 30.4 | 36.2 | 44.9 |
| | Water consumption | 4.32 | 16.8 | 19.6 | 22.3 | 24.4 | 28.1 |
| | Water availability | 0.288 | 0.281 | 0.300 | 0.318 | 0.308 | 0.239 |

resources, total water withdrawal and water consumption as well as for water availability for the countries of the Arabian Peninsula for the period 1980 to 2025. The amount of water resources in Table 6.3 is comprised of the total surface runoff in perennial and intermittent streams, the water storage in the upper aquifers, water volumes withdrawn from deep aquifers and the non-traditional water resources received, or to be received, in each of these countries. Present levels of water withdrawals were obtained from the references mentioned. Future water withdrawal forecasts took into account national strategies for water policy, the availability of funds and labour resources in each country, and the level of institutional development. The priority is to supply the population with drinking water and to introduce technologies which will result in more efficient water use.

Table 6.3 and Figure 6.6 indicate a great increase in the available water resources due to groundwater extraction from deep aquifers and intensive desalination of sea water, both of which require major infrastructure investments. As a result, it is possible to expect a stabilization in specific water availability in the region and its significant rise in some countries such as Kuwait, Bahrain or Qatar as additional non-traditional resources are developed. Nevertheless, the specific water availability will remain extremely low in the near future at less than 1 000 cu m/year per capita.

As is evident from the country level data, many countries and regions of the world already experience a freshwater deficit, particularly during dry years. Forecasts demonstrate that during the next few decades the majority of the world population, and many individual countries, will

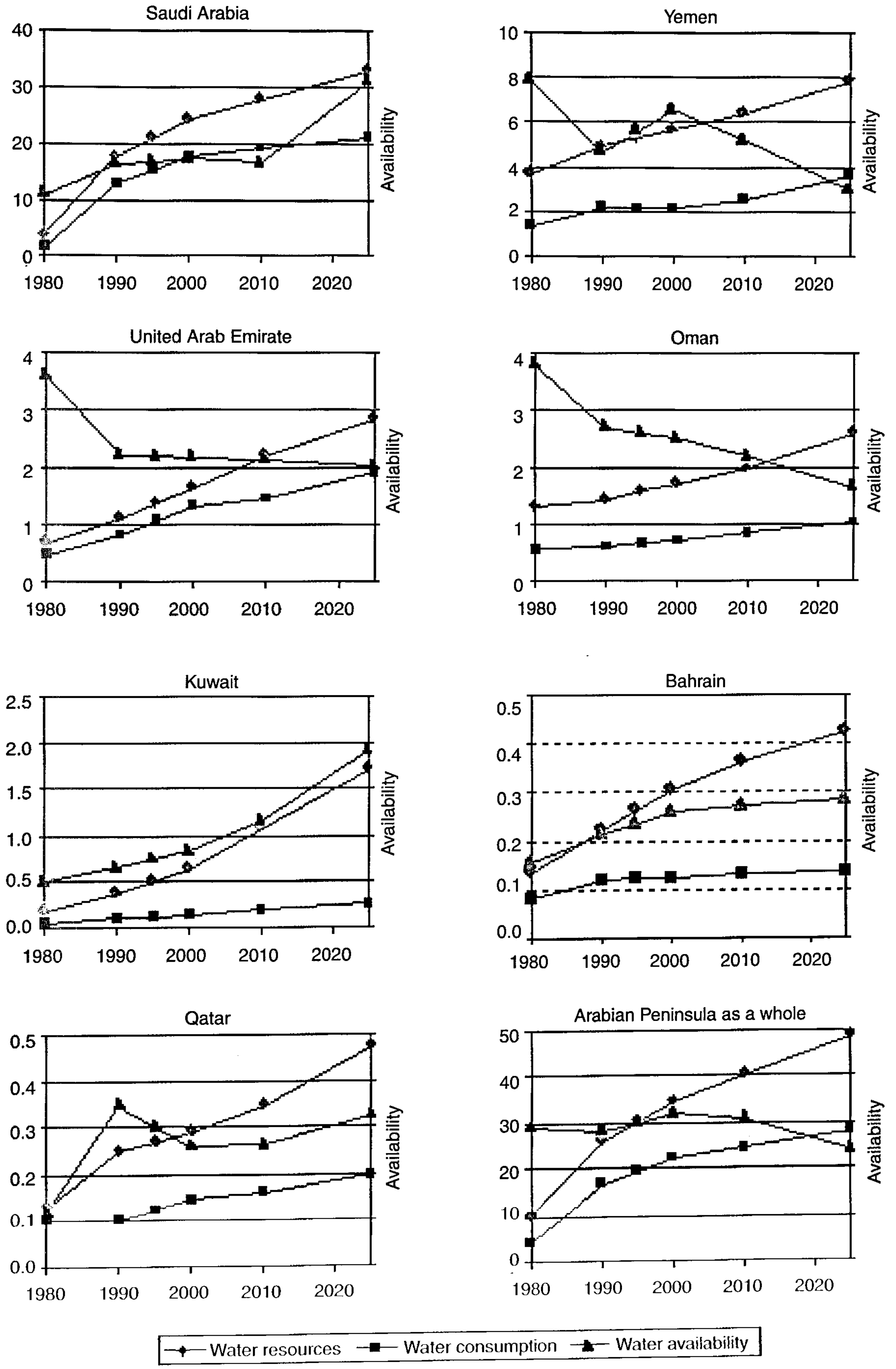


*Figure 6.6 — Total water resources (km³/year) and water availability (1 000 m³/year per capita) for population needs in the countries of Arabian Peninsula*

face a critical freshwater supply situation, attempting to meet the needs of a growing population. The growing freshwater shortage, and the increasing cost of meeting basic and developmental needs, will result in declining standards of living and hinder socio-economic development in the majority of developing countries in the world by 2025. There are grounds to assume that during the first half of the 21st century water shortages will be among the most important global problems, joining related issues such as food security and energy production. The balancing of supply and demand will require major financial and material investments for development and implementation of measures to eliminate the freshwater deficit in different physiographic zones. The following approaches would be the most realistic and effective for the present and near future:

- Water resource efficiency measures applied to all sectors;
- Water resource conservation by means of significant decreases in specific water withdrawal, in irrigation and industry in particular;
- Reduction or elimination of waste discharges to the hydrographic network;
- More complete use of local water resources by development of seasonal and long-term river runoff control;
- Use of brackish and saline water;
- Modification of weather (impact on rainfall formation);
- Integrated use of water storage in lakes, underground aquifers, glaciers;
- Water transfers; and
- Allocation of available water resources to higher value uses.

All of these projects require large infrastructure investments and have certain restrictions in that almost all of them affect the environment to a certain extent and compete with existing uses. Many of the impacts are difficult to predict accurately. Projects related to wastewater treatment or decrease of the specific water withdrawal are the exceptions, as these projects are desirable and useful to conserve water resources and the environment. All approaches to balancing supply and demand will probably be widely applied sooner or later in the regions of the world where they would be acceptable to users, ecologically admissible and economically profitable based on the physiographic features and the nature of water use.

It should be noted that runoff control and water transfer projects have been undertaken by many civilizations over the span of history and will continue to have application in the future. Firstly, river runoff resources at the global level are quite sufficient to satisfy the water demands for many dozens of years. Secondly, freshwater resources are distributed quite unevenly over the Earth; there are regions on each continent with water surplus, and water deficit. Thirdly, man's activity generally creates a more uneven water resources distribution. In the regions with water surplus the water resources withdrawal is not as great and river runoff is not reduced, whereas in regions with water deficit, the effect of the anthropogenic factors make this water deficit even more acute every year. Hence, the pressures to develop and implement projects to transfer water from regions of water surplus to regions with water deficit can be expected to increase. As technical facilities and financial capabilities are enhanced, the scale of water transfers will probably be extended. In general, the limitations on development of large-scale water transfer projects are determined not by financial and technical capabilities or engineering decisions, but rather by the necessity of a careful and extensive assessment of the projects effect on the environment and a reliable forecast of possible ecological effects.

# 7. RELIABILITY OF ASSESSMENTS OF WATER RESOURCES AND WATER AVAILABILITY

Reliability and accuracy of assessments of water resources and water availability presented in this Report, their areal distribution and dynamics in time depend on many factors and greatly differ for individual countries, regions and even continents. Since these assessments are based on observations from the hydrological network, the reliability of these data depend on the state of the network. Factors such as the number of gauging stations, station distribution within physiographic regions, duration and continuity of observations, quality of measurements and data processing are all important. There is no need to describe in detail here the shortcomings in hydrological data received from individual countries, and the difficulties of data analysis and generalization. These problems are discussed in detail in the publications of P. Gleick and J. Rodda ("Water in Crisis", 1993; Rodda, 1995). However, it is worth noting here that more than half of the observation stations for discharge measurement are installed in the rivers of Europe and North America, the observation series are the longest in the countries of these continents, and 70 per cent of all the gauging stations equipped with automatic recorders are located there (Rodda, 1995). As a consequence, the most detailed and objective information on water resources is available for these continents. Therefore, it is quite natural that the assessments of water resources and water availability are most reliable in the regions and countries of these continents, and that these assessments are in agreement with previous estimates. Differences can usually be explained by different periods over which the observed data is averaged.

Large errors in assessments of water resources and water availability are typical of some regions in Africa (North, East and West Africa) and in Asia (South and South-East Asia), as well as on the poorly gauged islands in the northern part of North America. It is necessary to develop the hydrological network, to improve the quality of measurements and data processing for a more reliable assessment of water resources in these regions.

In many regions, groundwater is used extensively for water supply. Based on the work of J. Margat, it is possible to estimate that approximately 600-700 km$^3$/year of water were withdrawn from underground aquifers in 1990. Moreover, the major portion out of this amount is used for irrigation, followed by municipal water supply. In some countries where river runoff is practically non-existent (e.g., Libya and Saudi Arabia), groundwater is the main source of supply to communities, agriculture and industry. It is quite natural that in these countries, computations of water availability should be based primarily on the groundwater resources. Any assessment of water availability for these countries based only from river runoff data would provide underestimated results.

However, at the global scale, for continents, and even for selected physiographic and economic regions, not accounting for groundwater use would not change the overall picture on water availability to a significant extent. Firstly, the water withdrawals from underground aquifers make up only 15 per cent of the world's water withdrawal, and is a consistent percentage across most continents and regions of the world. The exception is South Asia, where groundwater withdrawals represent 20-25 per cent of the total withdrawals. Secondly, a significant portion of groundwater used, especially in the regions of sufficient water quantity, is from aquifers hydraulically connected with river runoff. In this case the groundwater withdrawal results in an equivalent reduction to river runoff. For the majority of countries there are no reliable data on water withdrawals from the underground aquifers hydraulically connected or not connected with river runoff. It is possible to assume, however, that water withdrawals would be approximately distributed in equal proportions from the two groundwater sources. For example similar ratios are typical of the FSU territory. In 1986-1988 about 10 per cent of the total water withdrawal was provided from underground aquifers, including about 5 per cent from deep aquifers not hydraulically connected with river runoff. Because of the inter-relationship of river runoff and hydraulically connected groundwater aquifers the data presented in this report on water withdrawal from underground aquifers could be reduced by half. The end result of not adjusting the groundwater withdrawal numbers is a somewhat pessimistic assessment of water availability for some regions.

Another point of some significance is that the values of specific water availability for all regions and countries have been computed from values of mean annual river runoff. This approach does not account for streamflow variation during a year and from year to year, both of which are especially high in arid and semi-arid regions. If computations happen to be based on a series of dry years over the entire observation period, the values of specific water availability in Tables 6.1 and 6.2, and in Figs 6.4 and 6.5 could be reduced by about 1.2-2.0 times, depending on the climate conditions in different regions and countries. Thus, the conclusions on the amount of water available and the water resources deficit in some regions (Figs 6.1-6.3) may be regarded as optimistic.

The assessments of water availability in this report are also optimistic from another perspective in that water quality contamination could not be accounted for and is increasingly rendering water supplies unfit for sensitive uses such as drinking water. This problem is very acute in industrially developed countries and in densely populated regions where no effective wastewater treatment is undertaken. Untreated industrial and municipal wastes, as well as return flow from irrigated lands, serve as the main sources of pollution impairment of rivers and lakes. According to the data presented in Tables 5.11-5.14, the volume of wastewater was equal to 308 km$^3$/year in Europe, 417 km$^3$/year in North America, 538 km$^3$/year in Asia, and 48 km$^3$/year in Africa in 1990. In many countries the major portion of wastewater, which contains chemical and biological contaminants, is discharged to the hydrographic network without preliminary treatment, making them useless for a future water supply. If we take into account that each cubic meter of contaminated wastes discharged to water bodies can make eight to 10 cubic meters of pure water useless for human consumption, it would appear that many regions and countries in the world are threatened by a catastrophic qualitative exhaustion of the available water resources. Any detailed assessment of water resources at the basin or country level must consider both the quantitative and qualitative aspects.

In conclusion, it should be noted that the assessments of water resources, water withdrawal and water availability, given in the present Report, were obtained for past and present conditions which do not include the impact of possible future climate change. Thus, the anthropogenic changes in the global climate predicted by climatologists due to higher concentrations of CO2 and other "greenhouse" gases in the atmosphere are assumed to be insignificant for the forecast period. This assumption is probably valid for the assessments up to 2000-2010. It is probably desirable to take into account the possible anthropogenic changes in the global climate for the longer-range forecast up to 2025. The concern would be greatest for regions with insufficient water available, the hydrological characteristics of which (as evident from the studies carried out) are very sensitive even to a slight change in the climate. Ideally, the anthropogenic change in climate could be accounted for by a recompilation of forecasts considering not only the amount of water resources but also water withdrawal and water consumption, primarily for irrigation and for the additional evaporation from surfaces, which fully depend on the climate characteristics. To solve these problems on the global scale, for particular regions and countries, a reliable scenario of climate change by 2020-2025 is required. Unfortunately, scenarios for the anthropogenic change in the global climate based on different general circulation models are far from perfect, and give incompatible results at the small scales needed for water resources assessment. Under such limitations, the only option is to assume conditions of a stationary climate.

A more reliable assessment of water resources and water availability would be possible with additional data on groundwater. Other information limitations are the inability to account for long-term runoff changes and streamflow variations during the year, limitations imposed on water availability by water quality contamination and possible anthropogenic change in the global climate. These are first-priority problems for future investigations related to multi-purpose assessment of global water resources. The solution to these problems requires the joint efforts of scientists from different countries, and the cooperation of international organizations engaged in the problems of hydrology, climatology, multi-purpose use and conservation of water resources.

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