Part I
The Challenges

1 World Population and Pressures on Land, Water and Food Resources

1.1 POPULATION

The world population was about 200 million in the year 500 AD, 275 million in the year 1000, 450 million in 1500 and one billion around 1800 (Cohen, 1995, Appendix 2). While the world population took most of human history to reach one billion, subsequent additions came much faster: 130 years to reach 2 billion, 30 years to reach 3 billion, then 14, 13, and 12 years to reach 4, 5, and 6 billion respectively (Gilbert, 2001, p. 1). The high rate of population growth in recent decades has been the result of improvements in public health and sanitation that have reduced the mortality rate, particularly in the developing countries. The population growth rate peaked at 2.1 percent per year during the period 1965–70 (World Bank, 1992, pp. 25–26) and then started to decline to 1.7 percent over the period 1975–80 and 1.3 percent (or approximately 80 million a year) over the period 1995–2000. The fertility rate declined from 3.9 in 1975–80 to 2.7 for the period 1995–2000 (Table 1.1).

The world population increased from about 2.5 billion in 1950 to 6 billion in 2000, representing an increase of 2.4 times, and is expected to reach 7.8 billion by 2025 (Table 1.1). Most of this increase will take place in the developing world. It is expected that Asia will reach a population of 4.3 billion and Sub-Saharan Africa 1.1 billion by the year 2025. In the year 2000, 78 percent of the world's 6 billion people lived in the developing countries. By 2025 this is predicted to rise to 83 percent of a total population of 7.8 billion. Population growth increases the demand for food, fibre, goods and services, and many of the Earth's new citizens will not be offered the health and educational resources necessary to reach their potential (World Resources Institute, 1992, Chapter 6). Cities are drawing people into ever-increasing concentrations. Urban regions

Table 1.1. *Estimated and projected world population from 1950 to 2025*

	Population (million)			Average annual population change (%)		Fertility rate (%)	
Region	1950	2000	2025 (projected)	1975 to 1980	1995 to 2000	1975 to 1980	1995 to 2000
Asia (excluding Middle East)	1338	3420	4308	–	–	–	–
Europe	504	728	702	0.5	0.0	2.0	1.4
Middle East and North Africa	112	404	614	–	–	–	–
Sub-Saharan Africa	177	641	1095	–	–	–	–
North America[(a)]	172	310	364	0.9	0.8	1.8	1.9
Central America and Caribbean	54	173	236	–	–	–	–
South America	113	346	461	2.3	1.5	4.3	2.6
Oceania	13	30	40	1.1	1.3	2.8	2.4
World	2521	6055	7823	1.7	1.3	3.9	2.7
Developed countries	853	1306	1358	0.6	0.3	1.9	1.6
Developing countries	1668	4746	6459	2.1	1.6	4.7	3.0

Note: [(a)] Updated population data for the United States and Canada are provided in Chapters 11 and 12.
Source: World Resources Institute (2000, Data Table HD.1).

tend to offer more opportunities economically as well as better education and health resources. Although these regions occupy only 4 percent of the Earth's land area, they are home to nearly half the world's population. Densely populated cities, the so-called mega cities, are a major source of pollution, particularly of surface and groundwater.

One of the main characteristics of the world population is its ageing profile, which is unprecedented in the history of humanity (United Nations, 2002). During the twentieth century the proportion of older persons (60 years or more) continued to rise. It was 8 percent in 1950, 10 percent in 2000, and is projected to reach 21 percent in 2050. This is being accompanied by a decline in the proportion of the young under the age of 15. By 2050, it is expected that the number of older persons in the world will exceed the number of young for the first time in history. Population ageing has major repercussions for many aspects of human life. It has an impact on economic growth, savings, investment, consumption, labour markets, pensions and taxation. Population ageing affects health care, family composition, housing and migration, and can influence voting patterns and representation. The number of support persons aged 15–64 years per one older person aged 65 years or older, fell from 12 to 9 between 1950 and 2000. It is expected to fall to 4 by 2050.

Cohen (1995) provides an analysis of the upper limit of population that the Earth can sustain. Because of numerous ecological, social and technological constraints on the Earth's population, and different views on what is an acceptable standard of living for human beings, the carrying capacity of the Earth can be defined in many different ways. Cohen (1995, Appendix 3) gathered 66 estimates of how many people the Earth can support. These estimates range from less than one billion to more than 1000 billion. He demonstrated that one-quarter of them fall below 6.1 billion, half fall below 12 billion, and three-quarters fall below 30 billion. Others have estimated that the world population will stabilise at about 9.3 billion in the middle of the twenty-first century (UNESCO, 2003, p. 12), about 50 percent higher than the 2000 population of 6.1 billion (see Table 1.1).

1.2 DRYLAND AREAS

The extent of the world's dryland areas has been estimated by using an aridity index (Dregne *et al*., 1991). The index is expressed as the ratio of precipitation over potential evapotranspiration. The various categories of dryland have the following aridity index ranges: hyper-arid (<0.05); arid (0.05–0.20); semi-arid (0.21–0.50); dry sub-humid (0.51–0.65); moist sub-humid and humid (>0.65). With this method, the driest inhabited continent of the world is Australia where 75 percent of its area is dry (Table 1.2). It is followed by Africa and Asia. Drylands comprise about one-third of the areas of Europe, North America and South America. In total area, however, the largest drylands occur in Africa (1959 Mha), and Asia (1949 Mha) totalling about 64 percent of the world's drylands, whose area is about 6150 Mha, or 41 percent of the land area of the world. Of this nearly 978 Mha are hyper-arid deserts and 5172 Mha are arid, semi-arid and dry sub-humid. Figure 1.1 shows the distribution of the world's dryland areas.

1.3 EXTENT OF HUMAN-INDUCED LAND DEGRADATION

The International Soil Reference and Information Centre (ISRIC) published the results of a Global Assessment of Soil Degradation (GLASOD) in 1991. The assessment is based on the World Map of the Status of Human Induced Soil

Table 1.2. *World drylands (in million hectares)*

Dryland class	Africa	Asia	Australia	Europe	North America	South America	World total
Hyper-arid	672	227	0	0	3	26	978
Arid	504	626	303	11	82	45	1571
Semi-arid	514	693	309	105	419	265	2305
Dry sub-humid	269	353	51	184	232	207	1296
Total	1959	1949	663	300	736	543	6150
Percent of world total	32	32	11	5	12	8	100
Percent of continent	66	46	75	32	34	31	41

Source: Dregne *et al*. (1991, Table 1).

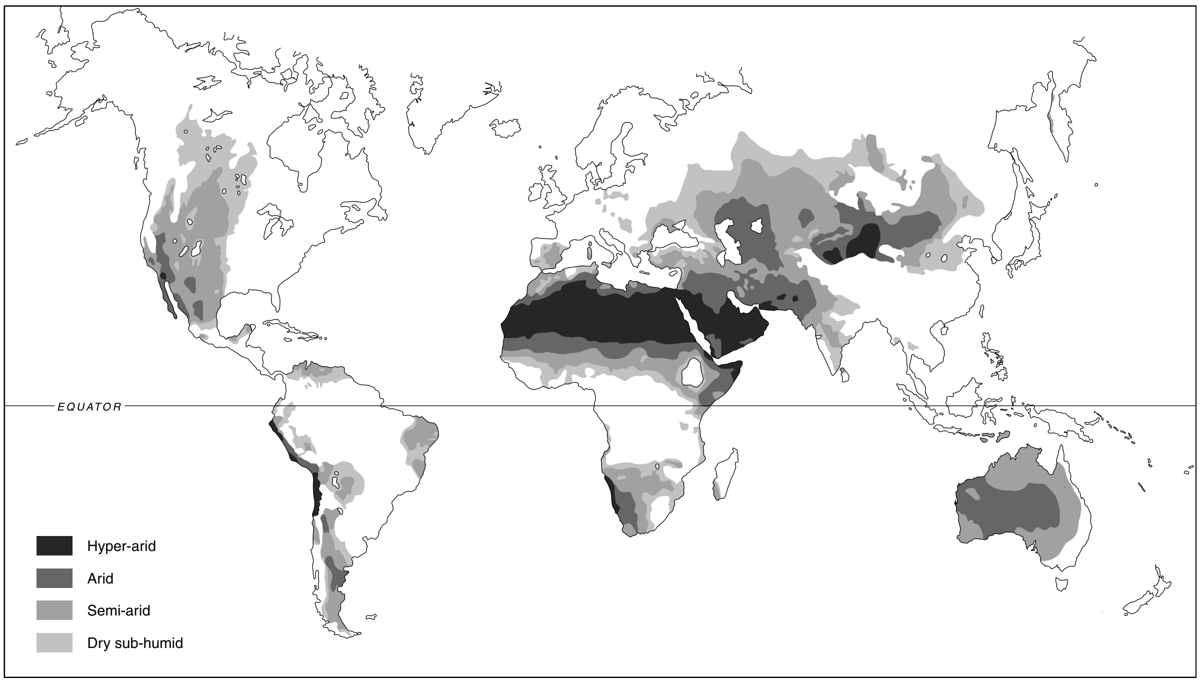

Figure 1.1 Drylands of the world (UNEP, 1992).

Degradation (Oldeman *et al.*, 1991a). The map, at a scale of 1:10 million, was prepared with financial support from the United Nations Environment Programme (UNEP) through a cooperative effort of about 250 soil scientists from international institutions throughout the world. Soil scientists were asked to only categorise soils degraded since the Second World War as a result of human intervention (World Resources Institute, 1992, pp. 111–118).

A primary objective for the creation of the soil degradation map was to generate awareness of the status of soil degradation in the mind of policy makers, and the general public (Oldeman *et al.*, 1991a). The GLASOD map covers 13 billion hectares of the land surface between 72° N and 57° S. Its results are alarming because, unlike other attempts to estimate land degradation, they do not include land degraded by ancient civilisations or even by colonial expansions, nor do they include land that is naturally barren.

GLASOD considered two categories of human-induced soil degradation processes. The first deals with soil degradation by displacement of soil material and the second with physical and chemical soil degradation. The two major types of soil degradation in the first category are erosion by water and wind. Water erosion includes loss of topsoil and terrain deformation. The most common forms are rill and gully erosion. Wind erosion includes loss of topsoil, terrain deformation and over blowing. Chemical deterioration is caused by a loss of nutrients and/or organic matter, salinisation, acidification and contamination by pollutants. Physical deterioration includes compaction, waterlogging and subsidence of organic soils caused by drainage and/or oxidation (Oldeman *et al.*, 1991a).

Globally, water erosion is by far the most important type of soil degradation, occurring in 1094 Mha or 56 percent of the total area affected by human-induced soil degradation (Table 1.3). The area affected by wind erosion is 548 Mha (28 percent); by chemical soil degradation, 239 Mha (12 percent); and by physical soil degradation, 83 Mha (4 percent).

Four degrees of soil degradation are recognised (Table 1.3). Light soil degradation, implying somewhat reduced productivity, which is manageable, by local farming systems, is identified for 38 percent of all degraded soils. A large percentage (46 percent) has a moderate soil degradation and greatly reduced productivity. Major improvements, often beyond the means of local farmers in developing countries, are required to restore productivity. Strongly degraded soils cover 296 Mha worldwide. These soils are no longer reclaimable at farm level and are virtually lost. Major engineering work or international assistance is required to restore these soils. Extremely degraded soils are considered to be beyond restoration. Their worldwide coverage is estimated to be around 9 Mha.

Table 1.3. *Global human-induced soil degradation*

Type	Light (Mha)	Moderate (Mha)	Strong (Mha)	Extreme (Mha)	Total (Mha)	Total (%)
Loss of topsoil	301.2	454.5	161.2	3.8	920.3	
Terrain deformation	42.0	72.2	56.0	2.8	173.3	
Water	343.2	526.7	217.2	6.6	1093.7	55.7
Loss of topsoil	230.5	213.5	9.4	0.9	454.2	
Terrain deformation	38.1	30.0	14.4	–	82.5	
Overblowing	–	10.1	0.5	1.0	11.6	
Wind	268.6	253.6	24.3	1.9	548.3	27.9
Loss of nutrients	52.4	63.1	19.8	–	135.3	
Salinisation	34.8	20.4	20.3	0.8	76.3	
Pollution	4.1	17.1	0.5	–	21.8	
Acidification	1.7	2.7	1.3	–	5.7	
Chemical	93.0	103.3	41.9	0.8	239.1	12.2
Compaction	34.8	22.1	11.3	–	68.2	
Waterlogging	6.0	3.7	0.8	–	10.5	
Subsidence of organic soils	3.4	1.0	0.2	–	4.6	
Physical	44.2	26.8	12.3	–	83.3	4.2
Total (Mha)	749.0	910.5	295.7	9.3	1964.4	
Total (percent)	38.1	46.1	15.1	0.5		100

Source: Oldeman *et al.* (1991b, Table 9).

Table 1.4. *Global extent of human-induced salinisation*

Continent	Light (Mha)	Moderate (Mha)	Strong (Mha)	Extreme (Mha)	Total (Mha)
Africa	4.7	7.7	2.4	–	14.8
Asia	26.8	8.5	17.0	0.4	52.7
South America	1.8	0.3	–	–	2.1
North and Central America	0.3	1.5	0.5	–	2.3
Europe	1.0	2.3	0.5	–	3.8
Australia	–	0.5	–	0.4	0.9
Total	34.6	20.8	20.4	0.8	76.6

Source: Oldeman *et al.* (1991b, Tables 2–8).

Five types of human intervention resulting in soil degradation were identified:

(1) degradation and removal of natural vegetation, 579 Mha;
(2) overgrazing of vegetation by livestock, 679 Mha;
(3) improper management of agricultural land, 552 Mha;
(4) overexploitation of vegetation cover for domestic use, 133 Mha; and
(5) industrial activities leading to chemical pollution, 23 Mha.

Table 1.4 shows that more than 76 Mha of the world's land is salt affected, out of which 52.7 Mha (69 percent) are in Asia, 14.8 Mha (19 percent) in Africa and 3.8 Mha (5 percent) in Europe. The four degrees of light, moderate, strong and extreme salt-affected land cover 34.6 Mha, 20.8 Mha, 20.4 Mha and 0.8 Mha respectively.

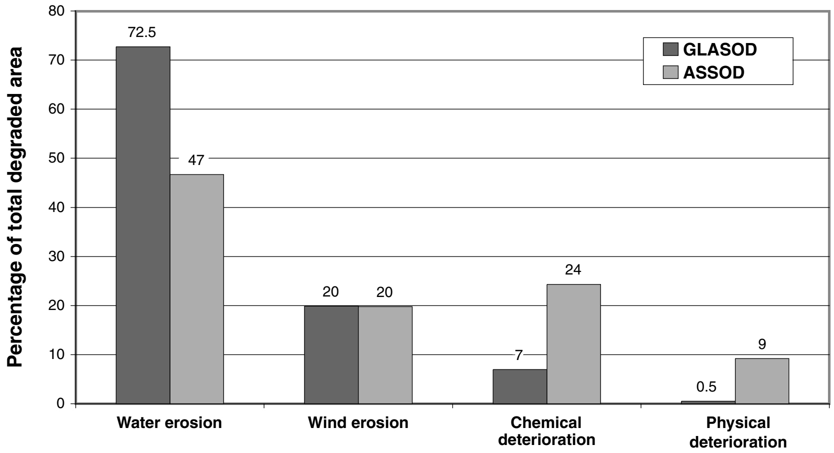

Figure 1.2 Distribution of main land degradation types in South and Southeast Asia as percentage of total degraded area assessed by GLASOD and ASSOD projects (van Lynden and Oldeman, 1997, Figure 1).

Because of funding problems, GLASOD has unfortunately not been refined or updated. Luckily, however, a number of other documents have been published regarding assessment of land degradation at the regional or national scale. These include the following publications:

- Acton and Gregorich (1995) describe the status of soil degradation in Canada, where almost all land suitable for crop production has been developed. Thus agricultural productivity must now be maintained through wise use of the existing resources, preserving both the area and quality of this land. The publication indicates that: (1) some Canadian agricultural soils are improving in health and becoming less susceptible to erosion and damage, mainly because of increased use of conservation farming methods; (2) this trend does not apply to all soils; (3) further maintenance and improvement of agricultural soil health depends on selecting appropriate land use and management practices; (4) a new government policy for soil conservation is needed, aimed at achieving sustainable agriculture and built on the understanding that agro-ecosystems are part of the broader environment; and (5) soil management programmes are best designed at the farm level, integrating management practices to suit specific, local soil needs.
- van Lynden and Oldeman (1997) describe the Assessment of the Status of Human-induced Soil Degradation in South and Southeast Asia (ASSOD). This study was commissioned by the UNEP and used a slightly modified GLASOD methodology. It covers the following 17 countries: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, North Korea, South Korea, Laos, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam. Figure 1.2 compares results of GLASOD and ASSOD assessments. It indicates that GLASOD showed a high predominance of water erosion (72.5 percent of degraded lands), while the picture that emerged from ASSOD is more varied. Although water erosion remained a dominant feature in the ASSOD inventory (47 percent of degraded land), chemical and physical deteriorations were also prominent.
- Stolbovoi and Fischer (1998) describe the compilation of a new digital georeferenced database on human-induced soil degradation for Russia. The Russian territory covers 1710 Mha, which includes 131 Mha of cultivated land and 91 Mha of other agricultural lands. The extent of land degradation is estimated at 234 Mha, which includes: 58.3 Mha by compaction, 35.7 Mha by desertification, 25.8 Mha by water and wind erosion, 25.4 Mha by disturbance of soil organic horizons due to cutting and fire and 3.5 Mha by secondary salinisation.
- Hamblin (2001) describes the state of Australian lands as part of the Australia State of the Environment 2001 report for the period of 1995–2000. The publication covers various issues including: accelerated erosion and loss of surface soil, salinity and acidity, nutrient and carbon cycle issues, and land pollution. Soil acidification looms as a major soil degradation issue in Australia. Estimates indicate that 50 Mha and 23 Mha of Australia's agricultural zone are already experiencing impacts from soil acidity in surface and subsoil layers respectively (National Land & Water Resources Audit, 2001). It is estimated that in the absence of remedial lime application, which neutralises acidity, between 29 Mha

Table 1.5. *Global distribution of water*

Location	Volume (10^3 km^3)	Percentage of total volume in hydrosphere	Percentage of freshwater	Renewal period (years)
Ocean	1 338 000	96.5	–	2500
Groundwater (gravity and capillary)	23 400[(a)]	1.7	–	1400
Predominantly fresh groundwater	10 530	0.76	30.1	–
Soil moisture	16.5	0.001	0.05	1
Glaciers and permanent snow cover:	24 064	1.74	68.7	–
Antarctica	21 600	1.56	61.7	–
Greenland	2340	0.17	6.68	9700
Arctic islands	83.5	0.006	0.24	–
Mountainous regions	40.6	0.003	0.12	1600
Ground ice (permafrost)	300	0.022	0.86	10 000
Water in lakes:	176.4	0.013	–	17
Fresh	91.0	0.007	0.26	–
Salt	85.4	0.006	–	–
Marshes and swamps	11.5	0.0008	0.03	5
River water	2.12	0.0002	0.006	16 days
Biological water	1.12	0.0001	0.003	–
Water in the atmosphere	12.9	0.001	0.04	8 days
Total volume in the hydrosphere	1 386 000	100	–	–
Total freshwater	35 029.2	2.52	100	–

With the exception of the last column, data provided in this table have been previously published by Korzun *et al.* (1978).
Note: [(a)] Excluding groundwater in the Antarctica estimated at 2 million km^3, including predominantly freshwater of about 1 million km^3.
Source: Shiklomanov and Rodda (2003, Tables 1.8 and 1.14).

and 60 Mha will reach the limiting soil pH value of 4.8 within 10 years, and a further 14 Mha to 39 Mha will reach the pH value of 5.5, where growth of sensitive plant species is impaired.

1.4 WATER RESOURCES

Humans, and almost all other terrestrial life, depend on the availability of freshwater resources. However, the global distribution of water is highly uneven. Water is also limited by its accessibility and suitability. Of the Earth's total volume of about 1386 million km^3, some 96.5 percent is saline ocean water, unsuitable for human use (Table 1.5). Of the remaining 3.5 percent, 35 million km^3 is fresh, but 24 million km^3 is stored in ice sheets and glaciers,[1] and 10.5 million km^3 is groundwater resources. Freshwater in lakes totals 91 000 km^3 and rivers 2120 km^3.

The average annual precipitation on the Earth's surface is about 800 mm (Chow *et al.*, 1988, p. 71). However, the hydrological cycle distributes water unevenly around the globe, and the world can be divided into water surplus and water deficit regions. Water is in surplus when precipitation is high enough to satisfy the potential evapotranspiration demand of the vegetation cover. When precipitation is lower than potential demand, there is a water deficit. In general, most of Africa, much of the Middle East, the western United States, north-western Mexico, part of Chile and Argentina, and major parts of Australia are water deficit regions (World Resources Institute, 1986).

Globally, river run-off is one of the main sources of freshwater for human use. Through its continuous renewal by the hydrological cycle, river run-off represents the dynamic component of the Earth's total water resources, compared to the less mobile volume of water contained in lakes, groundwater reservoirs and glaciers (Shiklomanov, 1990). Table 1.6 shows the distribution of river run-off by continents. The average annual river run-off of the

[1] For details of freshwater reserves in glaciers and ice sheets see Shiklomanov and Rodda (2003, Table 1.9, p. 14). Wadhams (2000) provides an introduction to our modern knowledge of sea ice and icebergs, while Lewis *et al.* (2000) describe freshwater balance of the Arctic Ocean.

world is about 43 000 km^3. Asia has the highest run-off (13 510 km^3), followed by South America (12 030 km^3), and North America (7870 km^3).

La Rivière (1989) argues that about 9000 km^3 of water are available for human exploitation worldwide, which is enough to sustain 20 billion people. Yet, because both the world's population and usable water are unevenly distributed, the local availability of water varies widely. Currently, much of the Middle East and North Africa, parts of Central America and many other countries are experiencing extreme scarcity of water due to increasing demands to satisfy their agricultural, industrial and domestic requirements.

Water resources of the world have been developed rapidly to satisfy demand. These developments included construction of large dams, and numerous inter-basin water transfer projects in all continents. During the twentieth century about 23 700 large dams higher than 15 m were constructed for town water supply, irrigation, flood control and hydro-power generation. However, this does not include a substantial number of large dams in China (Gleick, 2002, p. 301). Current estimates suggest that dams and diversion structures have affected some 60 percent of the world's rivers. The total investment in large dams is estimated at more than US$2000 billion, supplying some 30–40 percent of irrigated lands and generating 19 percent of the world electricity (World Commission on Dams, 2000, p. XXIX). Figure 1.3 shows that the peak in large dam construction occurred in the 1970s with construction of 5418 dams. Since then, dam construction has declined significantly and only 2069 dams were built in the 1990s. This has been due to opposition against dam construction for ecological, economical and social reasons (see section 2.1). The number of high dams worldwide is estimated at about 47 000, which includes 22 000 in China, 6575 in the United States of America, 4291 in India, 2675 in Japan, and 1196 in Spain (Gleick, 2002, pp. 291–295).

Table 1.6. *River run-off in various continents*

Continent	Annual run-off in: (mm)	(km^3)
Europe	274	2900
Asia	311	13 510
Africa	134	4047
North America	324	7870
South America	672	12 030
Australia and Oceania	268	2400
Total	–	42 757

Source: Shiklomanov and Rodda (2003, Table 10.1).

Table 1.7 shows the number of reservoirs (listed by continent) with storage capacities greater than 0.1 km^3. The largest number is located in North America (915) followed by Asia (815) and Europe (576). In terms of total reservoir capacity, Asia has the greatest volume (1980.4 km^3), followed by North America (1692.1 km^3) and Africa (1000.7 km^3). Further information on the distribution of dams, their dimensions and functions, is provided by the World Commission on Dams (2000, pp. 368–382).

1.4.1 Water Use

Global water withdrawal and consumption have been rapidly increasing due to the increasing world population

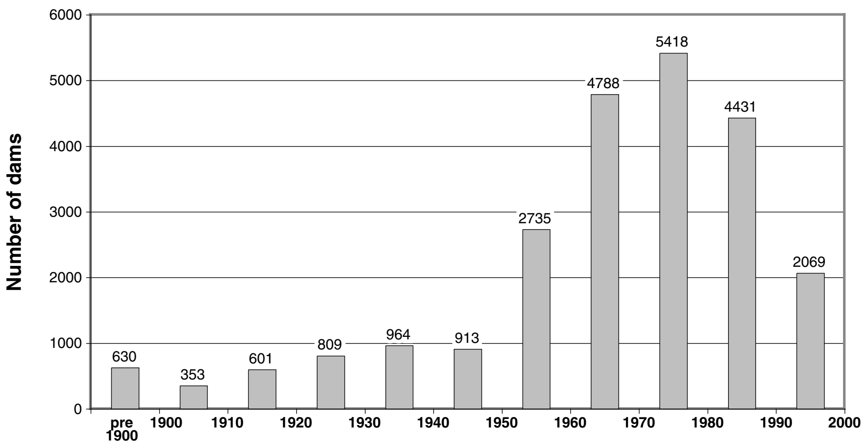

Figure 1.3 Number of large dams higher than 15 m commissioned in the twentieth century, listed by decades (World Commission on Dams, 2000, Figure V.3, and Gleick, 2002, Table 15).

and rising living standards. Table 1.8 lists the changes in world water withdrawal for the major sectors of the economy during the period of 1900–2000, and its projection to the year 2025. Global water withdrawal has increased by about seven-fold during the twentieth century compared to a four-fold increase in population from 1.5 billion to 6 billion.

Table 1.7. *Number of reservoirs with capacities of more than 0.1 km^3, by continent, for mid-1990s and their capacities*

Continent	Number of reservoirs	Volume of reservoirs (km^3)
Asia	815	1980.4
North America	915	1692.1
Africa	176	1000.7
Central and South America	265	971.5
Europe	576	645.0
Australia and New Zealand	89	94.8
Total	2836	6384.5

Source: Gleick (2000, Table 15).

By the year 2025 more than half of the 9000 km^3 of available water supply estimated by La Rivière (1989) will be in use. Agriculture is the largest consumer of water resources (Figure 1.4). Its share of total water use was about 91 percent in 1900, decreased to 66 percent by the year 2000 (although total volume increased) and is expected to decline to about 61 percent by 2025. Industry is the second largest water consumer and is followed by domestic water use. Excessive use of water for irrigation has led to waterlogging and salinisation (Ghassemi *et al.*, 1995), thereby accelerating land degradation and associated environmental problems.

Water use has not been efficient and there has been a significant difference between the annual volume of water withdrawn and consumed (Figure 1.5). In 1900, the ratio of water consumption to water withdrawal was about 71 percent. The gradual introduction of more efficient technologies, especially in the agricultural sector, resulted in this ratio declining to 66 percent in 1940 and 60 percent in year 2000. It is estimated that this trend will continue, and by 2025 the ratio will drop to 55 percent (Shiklomanov and Rodda, 2003, Chapter 11).

Table 1.8. *World water withdrawal by sectors of economic activity from 1900 to 2025 (in km^3)*

	Year							
Water use	1900	1950	1970	1980	1990	1995	2000	2025
Agriculture	525	1125	1834	2190	2412	2494	2571	3114
Industry	38	182	544	686	681	714	748	1105
Domestic	16	52	130	206	321	356	388	650
Reservoirs[a]	0.3	10	76	130	170	188	210	270
Total	579	1369	2584	3212	3584	3752	3917	5139

Note: [a] This is mainly because of evaporation.
Source: Shiklomanov and Rodda (2003, Table 11.3).

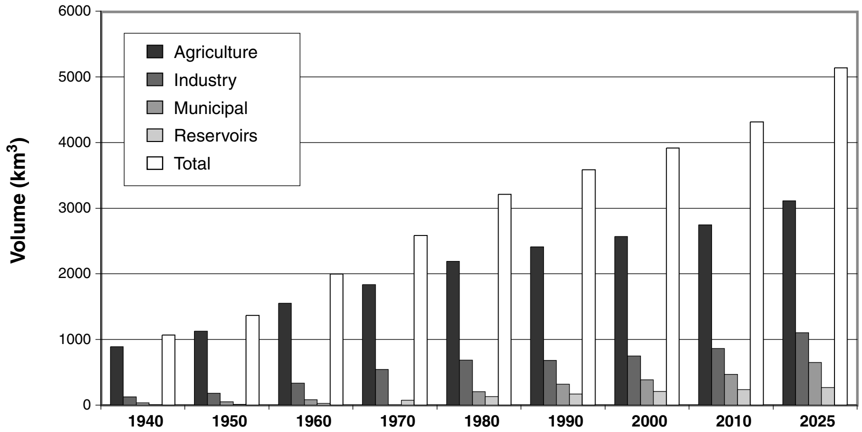

Figure 1.4 Water withdrawal for various sectors of the economy from 1940 to 2025 (Shiklomanov and Rodda, 2003, Table 11.3).