A Review of Current Knowledge

WORLD WATER: RESOURCES, USAGE AND THE ROLE OF MAN-MADE RESERVOIRS

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Foundation for Water Research
Allen House, The Listons,
Liston Road, Marlow,
Bucks SL7 1FD, U.K.
Tel: +44(0)1628 891589
Fax: +44(0)1628 472711
E-mail: office@fwr.org.uk
Home page: www.fwr.org

TECHNICAL ENQUIRIES

Any enquiries relating to this review should be addressed to:-

Dr W R White
Foundation for Water Research

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WORLD WATER: RESOURCES, USAGE AND THE ROLE OF MAN-MADE RESERVOIRS

Kielder dam and reservoir, UK
Source: *W R White*

Author: Dr W R White

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Executive Summary

<u>Introduction</u> (Chapter 1)
This updated ROCK is concerned with the global availability and usage of fresh water and the role of man-made reservoirs in providing storage of this essential human resource. Man-made reservoirs play a particularly important role where natural precipitation is erratic or seasonal because they store water during wet periods to make it available during dry periods.

This ROCK was first produced in 2005 with the title *World Water Storage in Man-Made Reservoirs.* It was based on various sources of data relating to conditions between 1998 and 2003. This 2019 version of the ROCK utilises a) more recent data on population, water resources and reservoir storage where available and b) current evidence on global warming and climate change which may affect our perception of future water resources and storage needs.

In this ROCK five regions of the world are identified and the countries considered to be in each region are listed in the Appendix.

<u>Fresh water resources</u> (Chapter 2)
The Food and Agriculture Organisation (FAO) lists countries with limited availability of fresh water as water stressed or water scarce depending on the amount of renewable water resources available. It is suggested that water stressed and water scarce countries are those which have less than 1 700 m^3 and 1 000 m^3 of water available per person per year respectively.

On a worldwide basis the amount of fresh water available is currently approx. 6 000 m^3 per person per year. However, neither the population nor the availability of fresh water is uniformly spread across the globe. Some regions are clearly better off than others.

The regions of Asia and Africa are the ones with the least available fresh water at approx. 2 700 m^3 and 3 300 m^3 per person per year.

<u>Water usage</u> (Chapter 3)
The Food and Agriculture Organisation (FAO) lists water usage by country, sector and source. These data are used in this chapter using the newly defined Regional boundaries (see Appendix). Sectors include agriculture, domestic and industrial usage. Sources include surface water, groundwater, desalinated water and treated waste water.

Water is used for agricultural, industrial, domestic and other purposes. The actual usage in any particular country or region thus depends on the nature of the economy. Additionally there are climatological factors which vary across the globe.

On a worldwide basis the usage for all purposes is estimated at approx. 550 m^3 per person per year. There are major regional variations. Developed countries tend to use much more water per person per year, particularly in hot climates. The figures often exceed 1 500 m^3 per person per year. In developing countries the usage can be well below 100 m^3 per person per year.

<u>Population</u> (Chapter 4)
In 2018 the world population will be approx. 7.6 billion. It is projected to rise to approx. 9.5

billion by 2050. Projections beyond 2050 are more difficult to make and depend upon the assumptions made regarding the development of the nature of the world economies.

Fresh water storage in reservoirs (Chapter 5)
Data is held by the International Commission on Large dams (ICOLD) in its World Register of Dams (https://www.icold-cigb.org).

The records are compiled from data collected from Member and Non-Member countries. ICOLD requests, in its circulated instruction for reporting dam data, that respondents should include all dams with a height greater than 15 m.

The returns obtained by ICOLD have some limitations:

- In spite of the transparency affirmed by ICOLD, some countries hesitate to provide comprehensive information for political or economic reasons.
- Some countries fail to respond on a regular basis and, for these countries, data is often not up to date.

The construction of large dams peaked in the period 1965 to 1975. Current records show a total worldwide volume of storage as 6 300 km^3 with a significant slowing in construction in recent years.

The current register provides a breakdown, on a worldwide basis, of the number and purpose of registered dams. The purpose is divided into seven categories: hydropower, water supply, flood control, irrigation, navigation, recreation, fish breeding and others (unspecified).

Loss of storage due to sedimentation (Chapter 6)
With a current world storage in reservoirs of around 6 300 km^3 and an average annual sedimentation rate of 0.5% the current annual loss of storage due to sedimentation is 31.5 km^3. This loss of storage due to sedimentation is one of the factors which needs to be taken into account in any discussion of future storage needs.

Conservation of reservoir storage (Chapter 7)
In the twenty first century conservation of reservoir storage will be essential because of a) the increasing land take of reservoirs and b) the diminishing availability of suitable, environmentally acceptable and economically viable sites. Sediment management will become crucial.

Data from the World Bank (WB) and the International Commission on Large Dams (ICOLD) are quoted extensively in this ROCK.

Global warming and climate change (Chapter 8)
An enormous amount of scientific effort has been invested in the subjects of global warming and climate change in recent years. Extensive field measurements over many years and the development of soundly based numerical models have placed the subject on a much firmer footing. No longer are claims of global warming simply based on anecdotal evidence of "rare" or "unusual" climatic events or sequences of such events. Despite this, there remains a small group of sceptics who, in particular, query whether current climate change trends are natural or man-made.

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The Intergovernmental Panel for Climate Change (IPCC) was established by the United Nations Environmental Programme (UNEP) and the World Meteorological Organisation (WMO) in 1988 to provide a clear scientific view on the current state of climate change. It reviews and assesses the most recent scientific, technical and socio-economic information relevant to the understanding of climate change and collates scientific evidence from all over the world. Scientists contribute to the work of the IPCC on a voluntary basis and differing viewpoints existing within the scientific community are reflected in the IPCC reports.

Observed changes which show that the climate system has warmed significantly in the last 150 years include:

- Average air temperatures up from 13.5 to 14.5 deg C.
- Average sea levels up by 200 mm.
- Significant reductions in snow and ice cover.

The causes of climate change are identified as:

- Changes in the atmospheric concentrations of greenhouse gasses.
- Changes in vegetative land cover.
- Changes in solar radiation.

Estimates of historic greenhouse gases concentrations in the atmosphere have been made by various methods including ice cores going back many centuries and direct measurements in recent times. Carbon dioxide concentrations in the atmosphere for 10 000 years prior to 1800 were consistently in the range 260 to 280 ppm. However, since the start of the industrial era concentrations have risen continuously. They reached 310 ppm by 1950 and are currently approaching 380 ppm; a major escalation in the last 70 years

Many scientists around the world have developed numerical models to simulate the world's atmosphere. These models are capable of simulating changes in the atmosphere due to natural and also anthropogenic-induced causes. The models have been validated against observed data going back to around 1900 and have been used to make predictions about future changes to the year 2100.

Broadly speaking the observed changes in the climate system over the past 150 years can only be simulated with reasonable accuracy if anthropogenic causes are included.

The IPCC uses several models to make predictions of future changes to the climate system. Its approach is to use various scenarios which consider alternative development pathways covering a range of demographic, economic and technological driving forces and resulting greenhouse gas emissions.

Details are presented by the IPCC of the scenario in which the world population stabilizes at the 2050 level, there is a rapid introduction of new and more efficient technologies and a balance between energy from fossil and non-fossil fuel sources. Effects are categorized under the headings:

- Ecosystem
- Food
- Coasts
- Industry, settlement and society
- Water

Water is identified as of particular concern by the IPCC. Changes in runoff will affect the availability of water for domestic, industrial and agricultural purposes. Runoff is predicted with *high confidence* to increase significantly at higher latitudes and in some wet tropical areas, including populous areas in East and South East Asia. Significant reductions in runoff are predicted with *high confidence* for some dry regions at mid-latitudes due to reduced precipitation and increased evapo-transpiration. There is also *high confidence* that many semi-arid areas, such as the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil, will suffer a decrease in water resources. Drought areas are predicted to increase in area.

Overall, the consequences of the anticipated changes to the hydrological cycle on humanity, brought about by climate change are:

- An increased demand for irrigation water for food production, which is likely to translate into a demand for more storage reservoirs for fresh water.
- An increased demand for hydropower to enhance energy supplies from non-fossil related sources.
- A need to protect communities from flooding, whether caused by more severe storms in inland areas or the effects of sea level rise in coastal zones.

Future needs for reservoir storage (Chapter 9)

The continued development of fresh water storage on a worldwide basis is clearly important, not only because of the agricultural, domestic and industrial demands for fresh water but also because of the potential to provide non-fossil fuel related power.

In North America and Europe the stored water availability is likely, in general terms, to satisfy the needs of the population, certainly for the next 30 years or so. However, there are likely to be shortfalls in water storage in South America, Asia, the Middle East and North Africa.

Crucial factors which will affect the magnitude of the problem will include:

- Population growth rates.
- Balancing technological, economic and environmental needs.
- Identification and availability of suitable reservoir sites.
- The effectiveness of measures to prolong reservoir life.

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1 Introduction

This ROCK is concerned with the global availability and usage of fresh water and the role of man-made reservoirs in providing storage of this essential human resource. Man-made reservoirs play a particularly important role where natural precipitation is erratic or seasonal because they store water during wet periods to make it available during dry periods.

The ROCK was first produced in 2005 with the title *World Water Storage in Man-Made Reservoirs.* It was updated in 2010. This 2019 version of the ROCK utilises a) more recent data on population, water resources and reservoir storage where available and b) current evidence on global warming and climate change which may affect our perception of future water resources and storage needs.

The ROCK provides a worldwide review using data available from numerous sources which are in the public domain:

- Information on water resources and usage is collated on a worldwide basis by the Food and Agriculture Organisation (FAO). This updated ROCK uses the latest information from this source.
- Comprehensive information on population statistics is held by the United States Census Bureau and current information is available on-line.
- Much of the data on man-made reservoirs in the original ROCK was obtained from a publication by the International Commission on Large Dams (ICOLD) dated 1998. This 2019 version of the ROCK uses ICOLD data which is currently available on line at https://www.icold-cigb.org.
- Global warming and climate change have now become headline issues and credible data on these subjects is now available, particularly through the ***Intergovernmental Panel for Climate Change*** (IPCC). Future water issues, including storage requirements and the location of such storage are discussed generally, in this edition of the ROCK, in the light of climate change projections.

Data is not always consistent, nor is it presented in a uniform format. In particular, countries change their names and/or boundaries and the definition of which countries to group within particular regions has not been entirely consistent over the years. For example, it is difficult to compare the FAO information for 2010 with the latest data because FAO has re-defined regions of the world.

The current FAO format is used in this ROCK and five regions are identified as follows:-

- Africa
- Americas
- Asia
- Europe
- Oceania

The countries considered to be within these five regions are listed in the Appendix.

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Man-made reservoirs are important because of their role in providing fresh water for irrigation (food supply) and also for domestic and industrial consumption. The dams associated with these reservoirs also make a significant contribution to energy supplies.

There are many large reservoirs worldwide and they are used for water supply, power generation, flood control, etc. Increasing populations and increasing consumption per capita mean that the demand for storage is rising inexorably, despite the increasing use of alternative sources and the more efficient use of water.

The benefits attributable to dams and reservoirs, most of which have been built since 1950, are considerable and stored water in reservoirs has improved the quality of life worldwide, see ***White and Rofe***, 1996 [1]and ***International Commission on Large Dams ICOLD***, 2007 [2] .The three most obvious are:

- ***Irrigation:*** About 20% of cultivated land worldwide is irrigated, some 300 million hectares. This irrigated land produces about 33% of the worldwide food supply. Irrigation accounts for about 75% of the world water consumption, far outweighing the domestic and industrial consumption of water.
- ***Hydropower:*** About 20% of the worldwide generation of electricity is attributable to hydroelectric schemes. This equates to about 7% of worldwide energy usage.
- ***Flood control and storage:*** Many dams have been built with flood control and storage as the main motivator eg the Hoover dam, the Tennessee Valley dams and some of the more recent dams in China including the Three Gorges dam.

In many areas of the world the life span of reservoirs is determined by the rate of sedimentation which gradually reduces storage capacity and eventually destroys the ability to provide water and power. Many major reservoirs are approaching this stage in their life.

This ROCK reviews the world stock of reservoirs, considers the problem of sedimentation and possible measures to minimise the impact of sedimentation. But first, the contribution of reservoirs is put into context by considering overall water resources and water usage. Future demand for storage is considered in the light of the increasing world population and the need to provide extra water for domestic, industrial and agricultural purposes. Finally, the possible effects of global warming and climate change are considered with a view to establishing, in very general terms, regions where the provision of storage may become less or more important.

2 Fresh water resources

In discussing water resources and reservoir storage the quantities involved are very large indeed. It is convenient to quote volumes in cubic kilometres (km^3). One km^3 is equivalent to 10^9 cubic metres (m^3).

Fresh water resources represent but a small part of the total amount of water in the world. The ***International Commission on Large Dams***, ***ICOLD*** 2007 [2] suggests that the total amount of water is approximately 1 400 000 000 km^3. 97.5% of this is saltwater, 2.5% is fresh water. However, not all of the fresh water is readily available to mankind. Most of it, nearly 70%, is tied up in the form of glaciers and snow cover in the Arctic and Antarctic regions. The residual fresh water resources are almost entirely to be found in groundwater. Lakes and river storage amount to only 0.3% of the total fresh water resources.

In this ROCK, fresh water means water which is not saline or brackish. It is derived from precipitation and occurs in glaciers, natural lakes, man-made reservoirs, rivers and groundwater. ***The Food and Agriculture Organisation*** of the United Nations [3], provides information on fresh water resources. These are determined for each country by considering river flows, groundwater recharge and an estimated “overlap” between the two. In addition, the fresh water resources are considered in terms of those generated within the country being considered and those which enter or leave that country as a result of rivers which cross international boundaries.

The Food and Agriculture Organisation uses the following definitions:-

Groundwater Recharge is the total volume of water entering sub-surface aquifers from precipitation and surface water flow. Groundwater resources are estimated by measuring rainfall in arid areas where rainfall is assumed to infiltrate into aquifers. Where data is available, groundwater resources in humid areas are considered as equivalent to the residual dry weather flow of rivers.

Surface Water Resources include the average annual flow of rivers generated from precipitation and base flow generated by aquifers. Surface water resources are usually computed by measuring or assessing total river flow occurring in a country on a yearly basis.

Overlap is the volume of water resources common to both surface and groundwater. It is subtracted when calculating IRWR (see below) to avoid double counting. Two types of exchanges create overlap: contribution of aquifers to surface flow, and recharge of aquifers by surface runoff. In humid, temperate or tropical regions, the entire volume of groundwater recharge typically contributes to surface water flow. In regions with porous limestone rock formations, a proportion of groundwater resources is assumed to contribute to surface water flow. In arid and semi-arid countries, surface water flows recharge groundwater by infiltrating through the soil during floods. This recharge is either directly measured or inferred by characteristics of the aquifers and groundwater levels.

Internal Renewable Water Resources, IRWR, is the sum of surface and groundwater resources minus overlap:- IRWR = Surface Water Resources + Groundwater Recharge - Overlap.

Natural Renewable Water Resources, NRWR, is the sum of Internal Renewable Water Resources and natural flow originating outside of the country. Natural Renewable Water Resources are computed by adding together both Internal Renewable Water Resources and natural flows (flow to and from other countries). Natural incoming flow is the average amount of water which would flow into the country without human influence.

Actual Renewable Water Resources, ARWR. In some arid and semi-arid countries, actual water resources are presented instead of Natural Renewable Water Resources. These actual totals include the quantity of flows reserved to upstream and downstream countries through formal and informal agreements or treaties. The actual flows are often much lower than natural flow due to water scarcity in arid and semi-arid regions.

External Renewable Water Resources, ERWR. The data quoted by FAO, updated to 2016, has separated IRWR and ARWR and no-longer quotes the ARWR directly. However, details of EWRW are listed. In this edition of the ROCK it is assumed that ARWR is the sum of IRWR and EWRW. Comparison can be made with the earlier data using the derived values of ARWR.

Man-made **Reservoir Storage** is achieved by constructing dams which impound fresh water. The amount of reservoir storage in the previous version of the ROCK was estimated using information from the International Commission on Large Dams (ICOLD). The quality and quantity of the data depends on the response from member countries. Details are available in ***ICOLD***, 2003 [4]. In the current ROCK, data are all from the FAO AQUASTAT listings as updated in 2016. The reservoir storage data records the percentage change since 2003. A regional summary is given in Table 1 whereas details are discussed in Chapter 5.

Figure 1, from the FAO Aquastat database, gives a broad picture of water resources available per inhabitant.

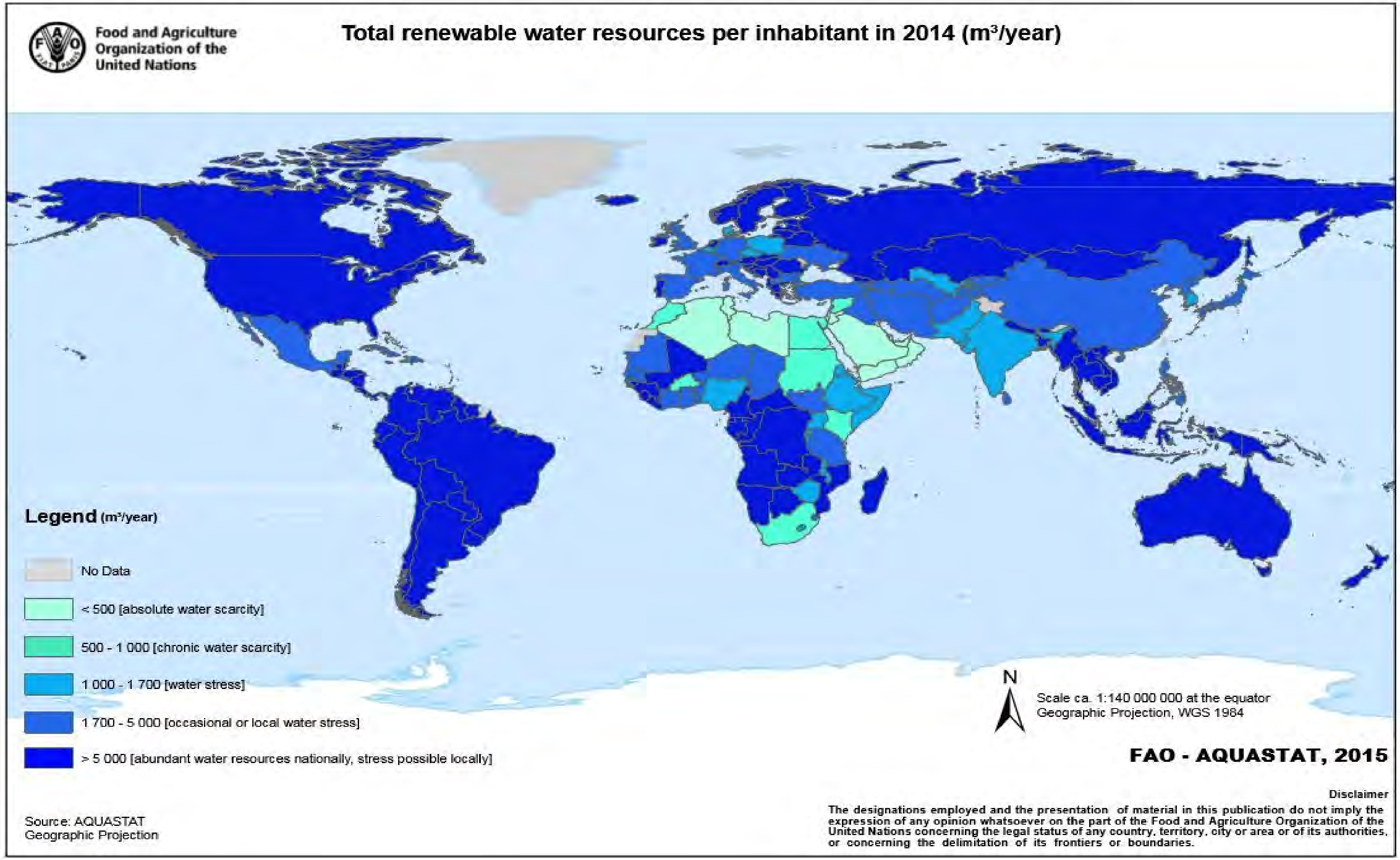

Figure 1 **Total renewable water resources per inhabitant**
Source: ***FAO*, Aquastat database**

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Table 1 gives a summary, region by region, of population, water resources and reservoir storage. The population data and the water resources data are all from the FAO AQUASTAT listings as updated in 2016. The percentage change in the world population since 2006 is given in column 2 of the table. The percentage change in the world water resources data are given in columns 3, 4 and 5. The percentage change in world reservoir storage since 2003 is given in column 6 of the table. The final column in Table 1 is a measure of how much storage is available in each region compared with the actual Annual Renewable Water Resources.

It should be noted that FAO has re-defined regions of the world since the previous version of this ROCK, moving some countries from one region to another. The new categories and the countries within each region are given in the Appendix. With this change since the 2010 version of this ROCK it has not been possible to compare changes within each region but worldwide variations remain valid.

Region	Population (millions)	IRWR (km^3/year)	IRWR per capita (m^3)	ARWR (km^3/year)	Reservoir storage [TRS] (km^3)	TRS/ARWR (%)
Africa	1 185	3 931	3 319	5 631	1 056	18.7
Americas	990	19 536	19 725	25 174	2 734	10.9
Asia	4 400	11 865	2 697	15 243	1 373	9.0
Europe	739	6 576	8 895	7 635	1 042	13.6
Oceania	31	902	29 225	902	95	10.5
WORLD	**7345 (+11.9%)**	**42 810 (-0.0%)**	**5 829**	**54 585 (-0.0%)**	**6 301 (-4.8%)**	**11.5 (-4.2%)**

Table 1 Water resources and reservoir storage (FAO 2016)

Year	World Population	Yearly Change	Net Change	Density (P/Km²)	Urban Pop	Urban Pop %
2018	**7,632,819,325**	1.09 %	82,557,224	51	4,186,975,665	55 %
2017	**7,550,262,101**	1.12 %	83,297,821	51	4,110,778,369	54 %
2016	**7,466,964,280**	1.14 %	83,955,460	50	4,034,193,153	54 %
2015	**7,383,008,820**	1.16 %	84,555,787	50	3,957,285,013	54 %
2014	**7,298,453,033**	1.18 %	85,026,581	49	3,880,128,255	53 %
2013	**7,213,426,452**	1.20 %	85,249,517	48	3,802,824,481	53 %
2012	**7,128,176,935**	1.21 %	85,168,349	48	3,725,502,442	52 %
2011	**7,043,008,586**	1.22 %	84,839,427	47	3,648,252,270	52 %
2010	**6,958,169,159**	1.23 %	84,428,105	47	3,571,272,167	51 %

Table 2 Growth in world population from 2010 (Worldometers)

The data from FAO for the world population relates to 2016 and is close to the 2016 estimate given by Worldometers, see Table 2 taken from (www.worldometers.info). There is no error band given in either sets of data.

The world population has risen by around 10 % since 2010 ie an increase of around 1.2 % per year. Reservoir storage has fallen 4.8 % in the 13 years from 2003 to 2016 ie a decrease of around 0.4 %per year.

The reasons for the reduction in world reservoir storage are complex and there is a degree of uncertainty in all the estimates from a multitude of sources. Broadly speaking dams are not being built in North America, Oceania and Europe where the dam building programme was mainly in the latter half of the 20th century. However, this is not the case in South America, Africa and Asia where major developments are planned in the Amazon, Congo and Mekong basins. Further details can be found in ***E F Moran et al***, 2018 [5].

Dams provide water for irrigation in those countries where there is a defined seasonal variation in flows and also hydropower from the head of water they create. However, they have a limited life span for both aspects due to siltation. Typically, dams may be designed with a life span of 40 years in mind.

So why is world reservoir storage relatively static? It is probably a balance between:

- Siltation in existing reservoirs
- The construction of new dams, mainly in Africa and Asia
- The demolition of some dams, often following failure events, mainly in North America and Europe.

Potential difficulties arise where individual countries are heavily dependent upon water resources which are generated externally and there are many international agreements in place aimed at defining water usage. Tables 3, 4 and 5 identify those countries which are particularly dependent on externally generated water resources.

Region	Country
Africa	Botswana, Egypt, Mauritania, Namibia, Niger, Sudan.
Americas	---
Asia	Azerbaijan, Bangladesh, Kuwait, Pakistan, Syria, Turkmenistan, Uzbekistan.
Europe	Hungary, Moldova, Netherlands, Romania, Serbia.
Oceania	---

Table 3 Countries where over 75% of water resources are generated externally

Region	Country
Africa	Benin, Chad, Congo, Eritrea, Gambia, Mozambique, Somalia
Americas	---
Asia	Cambodia, Iraq, Israel, Jordan, Vietnam
Europe	Croatia, Latvia, Portugal, Slovakia, Ukraine
Oceania	---

Table 4 Countries where 50% to 75% of water resources are generated externally

Those countries which have reservoir storage of greater than half their actual renewable water resources per year are given in Table 5.

Region	Country	Reservoir Storage as % of annual ARWR
Africa	Algeria	71
	Egypt	288
	Ghana	264
	Kenya	80
	Lesotho	93
	Libya	56
	Morocco	62
	South Africa	60
	Sudan	56
	Tanzania	108
	Uganda	133
	Zimbabwe	500
Americas	---	
Asia	Iraq	169
	Kazakhstan	74
	Turkey	74
Europe	---	
Oceania	---	

Table 5 Countries with reservoir storage in excess of half their actual renewable water resources per year

Those countries which have reservoir storage of less than 1 % of their actual renewable water resources are given in Table 6.

Region	Countries with reservoir storage less than 1% of ARWR
Africa	Benin, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Djibouti, Eritrea, Guinea, Gabon, Gambia, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Niger, Rwanda, Sao Tome and Principe.
Americas	Bahamas, Barbados, Bolivia, Colombia, Cuba, Dominica, Grenada, Guatemala, Guyana, Jamaica, Mexico, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines.
Asia	Armenia, Bahrain, Bhutan, Brunei, Cambodia, Democratic People's Republic of Korea, India, Isreal, Japan, Kuwait, Kyrgystan, Lao People's Democratic Republic, Maldives, Myanmar, Nepal, Palestine, Papua New Guinea, Philippines, Qatar, Sri Lanka, Syria, Tajikistan, Thailand, Timor, Turkmenistan, Uzbekistan, Vietnam, Yemen.
Europe	Andorra, Belarus, Belgium, Croatia, Cyprus, Denmark, Germany, Hungary, Italy, Malta, Republic of Moldova, Slovenia, Ukraine.
Oceania	Cook Islands, Fiji, Kiribati, Marshal Islands, Micronesia, Nauru, Niue, Palau, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu.

Table 6 Countries with reservoir storage less than 1% of their actual renewable water resources per year

3 Water usage

The Food and Agriculture Organisation lists water usage by country, sector and source. These data are used in this chapter using the newly defined Regional boundaries (see Appendix). Sectors include agriculture, domestic and industrial usage. Sources include surface water, groundwater, desalinated water and treated waste water.

Figure 2, from the FAO Aquastat database, gives a broad picture of water withdrawal per inhabitant.

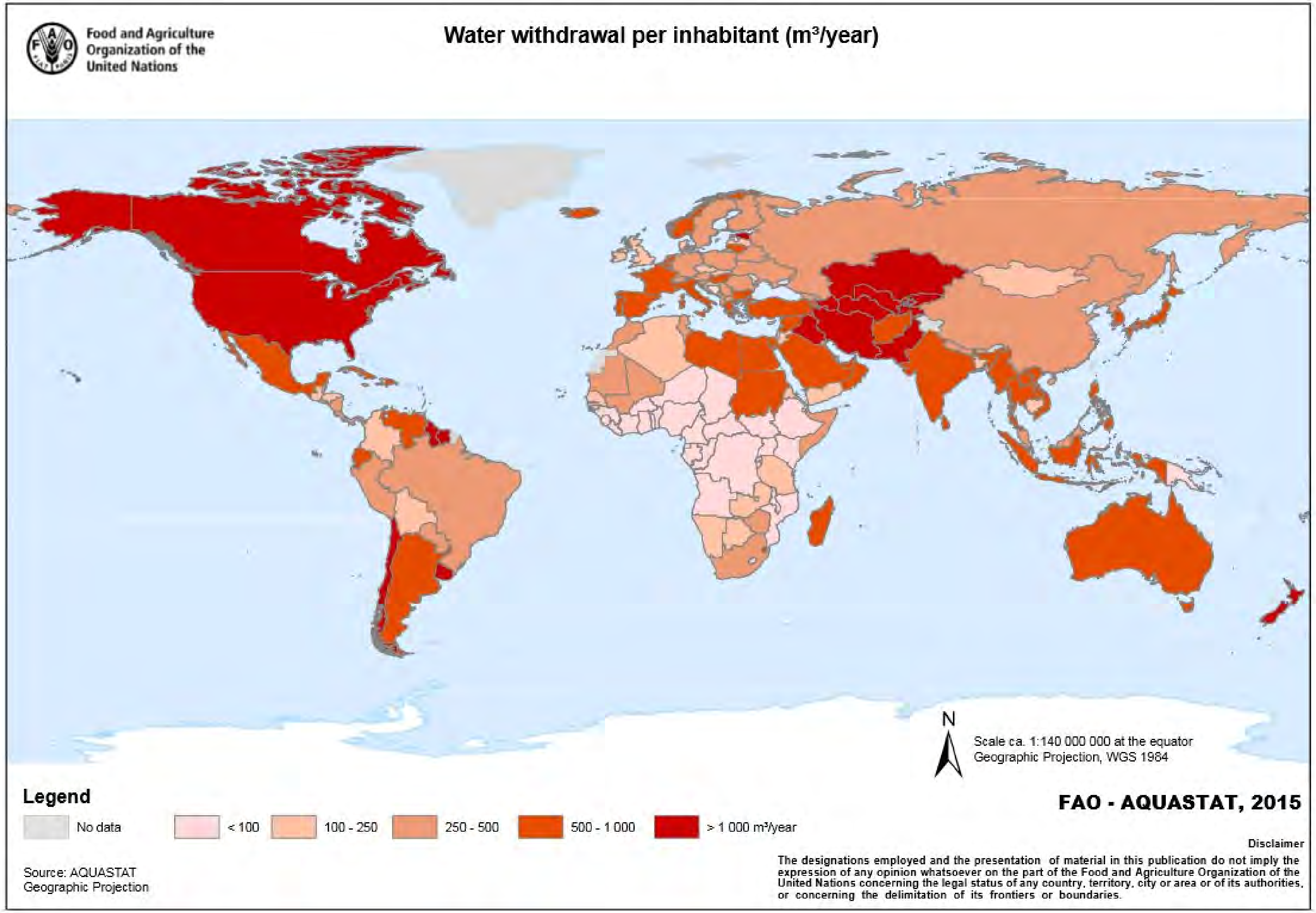

Figure 2 **Water withdrawal per inhabitant**
Source: *FAO*, Aquastat database

Water usage by region

Water usage by region is illustrated in Table 7.

Region	Total water usage (km^3/year)	Total water usage per capita (m^3/person)	Total water usage to Actual Renewable Water Resources (%)
Africa	222	188	3.9
Americas	789	877	3.1
Asia	2393	543	15.7
Europe	333	450	4.4
Oceania	22	710	2.4
WORLD	**3 759**	**512**	**6.9**

Table 7 Water usage by region

The region where water usage compared with the water availability is highest is Asia where water resources are limited and the usage per person is relatively high.

For most of the world the water usage represents a small proportion of the available water resources. However, much of the available water cannot be used because it returns directly to the oceans during flood events. This is particularly true in monsoon areas where there is a prolonged wet season. The arguments for storing a proportion of this fresh water are strong.

Water Stress

Water stress within individual countries is indicated by the ***Food and Agricultural Organisation***, 2009 [3].

One simple measure of water stress is the amount of water available per person. The Food and Agriculture Organisation suggests that any country with less than 1 700 m^3per person per year suffers water stress. This is a simplified measure of water stress because it takes no account of the needs of the economy of particular countries for the industrial or agricultural water usage. They suggest a second threshold of less than 1 000 m^3per person per year which is defined as water scarce. Table 8 lists those countries with less than 1 700 m^3per person per year and suggests that more than 30 countries, with a total population of around 1.7 billion, are already water stressed. Of these countries, about half already fit into the water scarce category.

By 2025 the ***Food and Agriculture Organisation*** predicts that the number of water stressed countries will approach 50 with a combined population of around 3 billion.

Regiopm	Country
Asia	India, South Korea , Pakistan , Singapore.
Europe	Czech Republic, Denmark, Moldova, Poland
Middle East and North Africa	Algeria, Egypt, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Saudi Arabia, Syria, Tunisia, United Arab Republic, Yemen
Sub-Saharan Africa	Burkino Faso, Burundi, Eritrea, Ethiopia , Kenya, Lesotho, Malawi, Rwanda, South Africa, Zimbabwe
Central America and Caribbean	Haiti

Table 8 Countries with less than 1 700 m^3/person/year of fresh water

A second measure of water stress might be to look at the actual water usage and compare it with the actual available water resources country by country. A summary is given in Tables 9, 10 and 11.

Region	Country
Asia	Tajikistan
Middle East and North Africa	Algeria, Iran, Iraq, Tunisia
Sub-Saharan Africa	Sudan

Table 9 Countries where water usage is between 50% and 75% of actual renewable water resources

Region	Country
Asia	Pakistan, Turkmenistan
Middle East and North Africa	Oman, Syria

Table 10 Countries where water usage is between 75% and 100% of actual renewable water resources

Region	Country
Asia	Uzbekistan
Middle East and North Africa	Egypt, Israel, Jordan, Kuwait, Libya, Saudi Arabia, United Arab Emirates, Yemen

Table 11 Countries where water usage is greater than 100% of Actual Renewable Water Resources

<u>Water usage by sector</u>

In 2009 ***FAO*** provided data on the use of water in agriculture, municipalities and industry. At that time, on a worldwide basis, the use of fresh water for agricultural purposes far outweighs other sectors. The data suggests 72.3% usage in agriculture, 9.4% by municipalities and 14.9% in industry. The remaining 3.4% is for other purposes, unspecified.

More recent data, ***FAO***, 2015 [3], on the agricultural use of water is shown in Figure 3

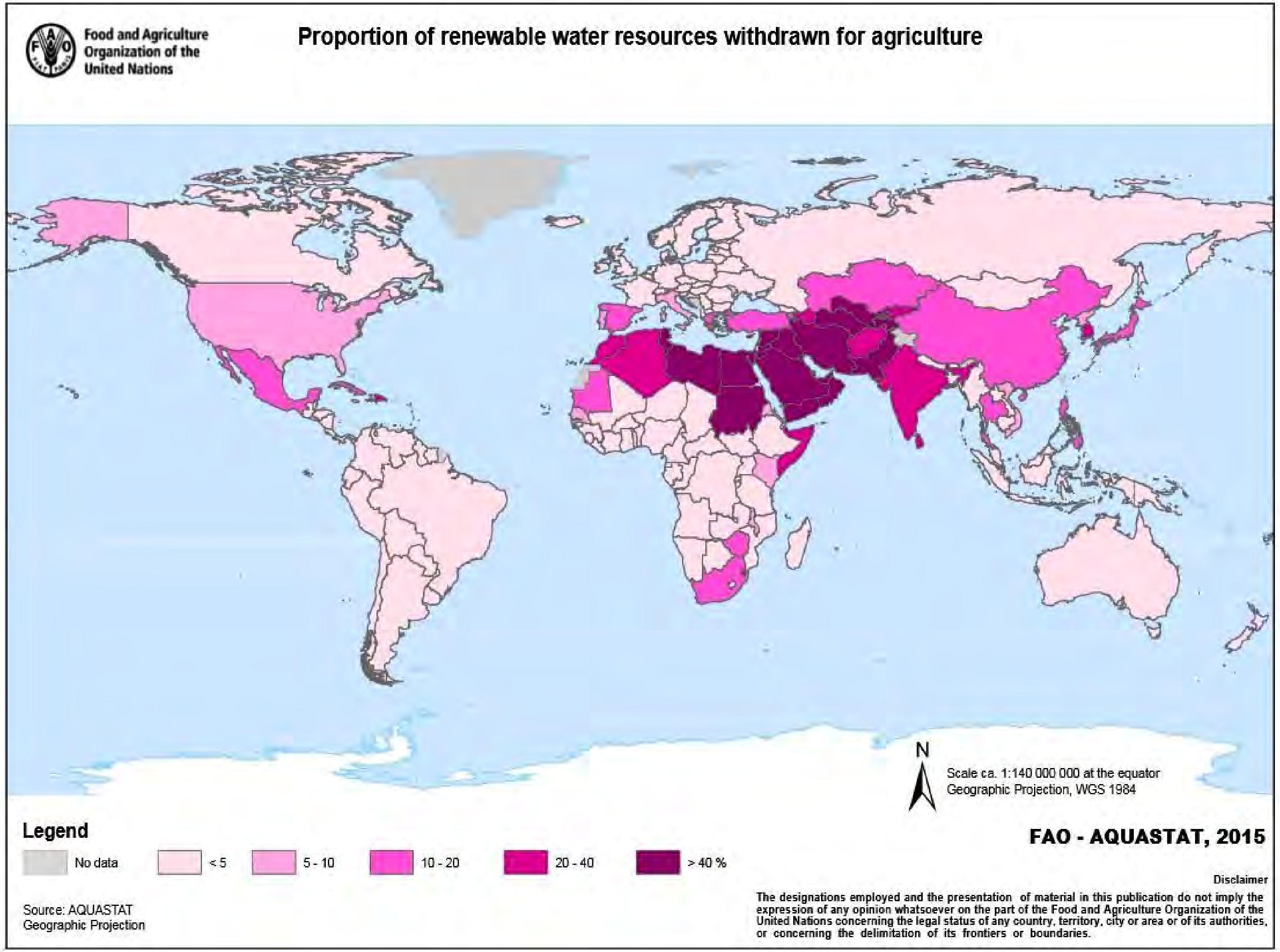

Figure 3 **Agricultural use of water in each region of the world**
Source: *FAO,* Aquastat databas

4 Population

The current (2018) world population is around 7.6 billion. The current growth rate globally is around 1.2% per annum. Projections for mid 2025 and mid 2050 given by the ***United States Census Bureau***, 2009 [6] are 8.1 billion and 9.4 billion respectively, see Figure 4.

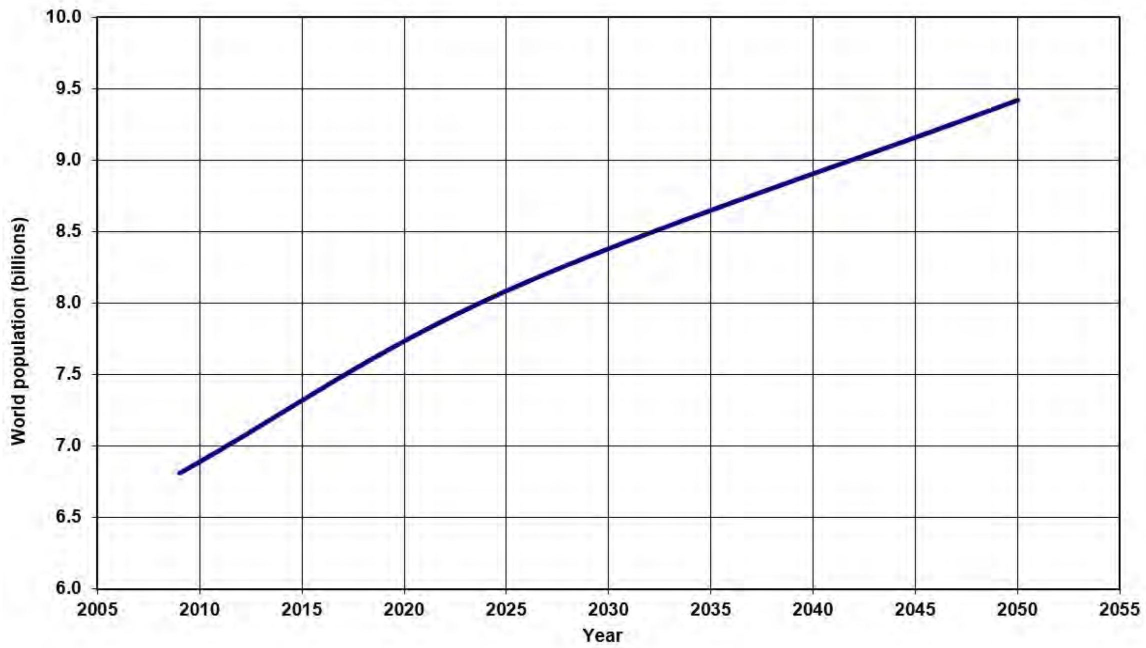

Figure 4 **World population growth projection**
Source: www.prb.org

Projections suggest changes in the demographic distribution of the world population due to differing birth and mortality rates and migration from one region to another. This is illustrated in Table 12 by considering the most populous countries in 2015 and the projected listing for 2050. The percentage of the total world population is given in brackets. The data is derived from that presented by the ***United Nations Population Fund*** (UNFPA).

Date	Country	Population (millions)	Date	Country	Population (millions)
2015	China	1 410 (18.6%)	**2050**	India	1 572 (16.5%)
	India	1 230 (16.2%)		China	1 462 (15.4%)
	United States	321 (4.2%)		United States	397 (4.2%)
	Indonesia	250 (3.3%)		Pakistan	344 (3.6%)
	Pakistan	204 (2.7%)		Indonesia	311 (3.3%)
	Brazil	201 (2.6%)		Nigeria	279 (2.9%)
	Bangladesh	183 (2.4%)		Bangladesh	265 (2.8%)
	Nigeria	165 (2.2%)		Brazil	247 (2.6%)
	Russia	133 (1.8%)		Japan	109 (1.1%)
	Japan	127 (1.7%)		Russia	104 (1.1%)

Table 12 The ten most populous countries in 2015 and 2050 (projected)

World population growth is predicted to be almost entirely concentrated in the world's less developed countries. Figure 5 shows the long term trends from 1950 to 2050.

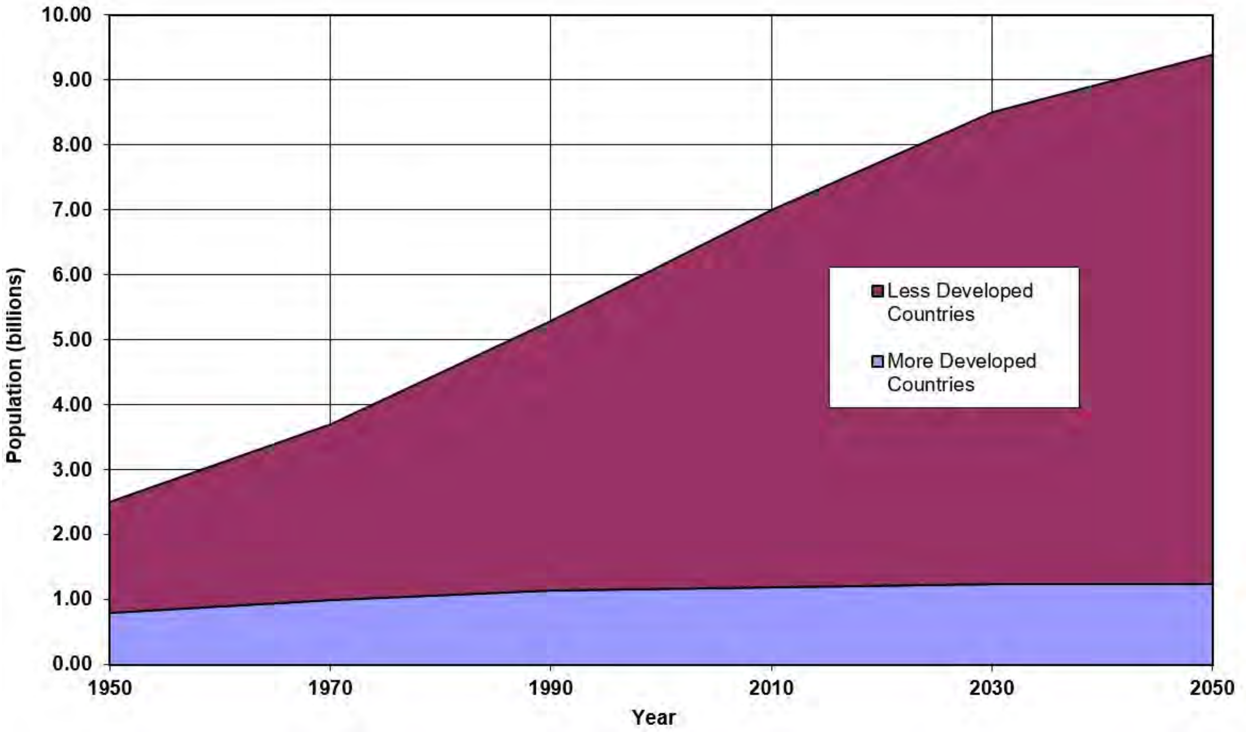

Figure 5 **Regional distribution of population growth 1950 to 2050**
Source: www.prb.org

5 Fresh water storage in reservoirs

World storage
Data is held by International Commission on Large Dams (ICOLD) in its World Register of Dams (https://www.icold-cigb.org).

The records are compiled from data collected from Member and Non-Member countries.

ICOLD requests, in its circulated instruction for reporting dam data, that respondents should include all dams with a height greater than 15 m.

The returns obtained by ICOLD have some limitations:
- In spite of the transparency affirmed by ICOLD, some countries hesitate to provide comprehensive information for political or economic reasons.
- Some countries fail to respond on a regular basis and, for these countries, data is often not up to date.

The current register includes information relating to:-
- The volumes of water stored
- The installed hydroelectric capacity
- The usage of stored water for irrigation
- The usage of stored water for domestic and industrial purposes
- The way in which reservoirs aid inland navigation
- The benefits of reservoirs in the control of floods
- The environmental impact of dams including the number of people affected by resettlement.

The construction of large dams peaked in the period 1965 to 1975. Current records show a total worldwide volume of storage as 6 300 km^3 with a significant slowing in construction in recent years.

The current register provides a breakdown, on a worldwide basis, of the number and purpose of registered dams. The purpose is divided into seven categories: hydropower, water supply, flood control, irrigation, navigation, recreation, fish breeding and others (unspecified).

Dams are divided into two categories, single purpose and multi purpose. Figure 6 shows the distribution of the number of dams which serve each purpose. This plot is in terms of the number of dams, not their capacity. It does not necessarily reflect the volumes of water used for each purpose.

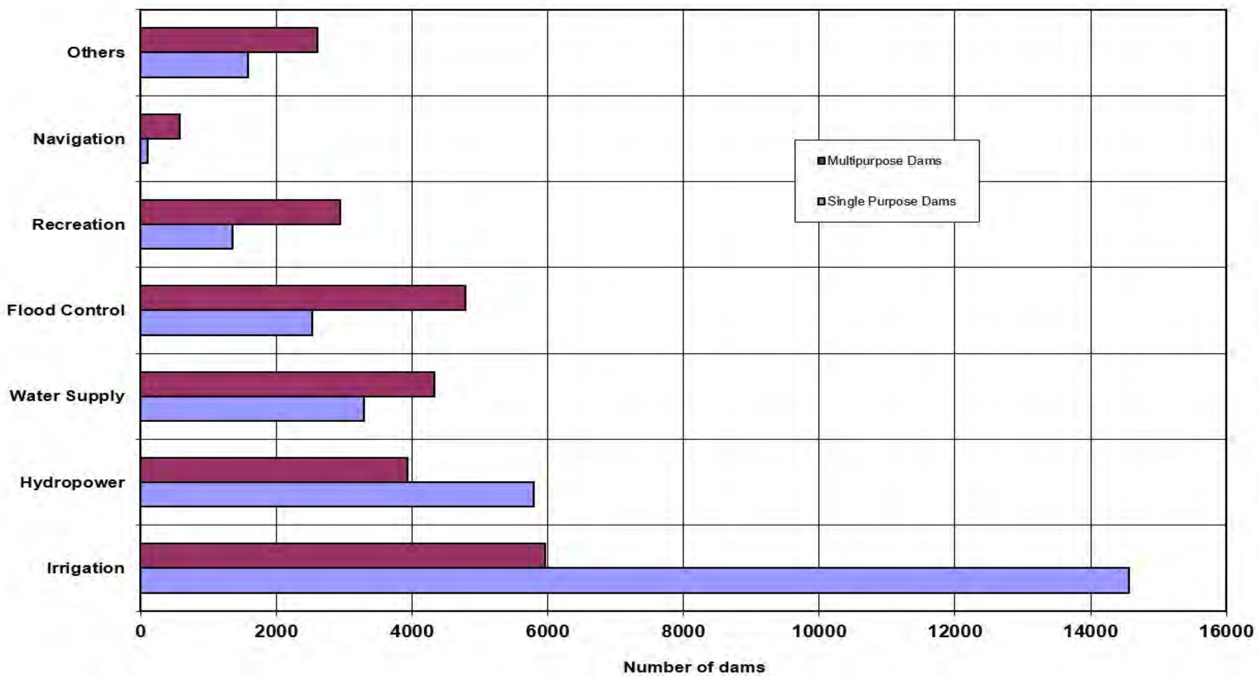

Figure 6 **Dam distribution by purpose**
Source: https://www.icold-cigb.org

Figure 7 shows the categories of usage for single purpose dams. Irrigation and hydropower represent the major uses.

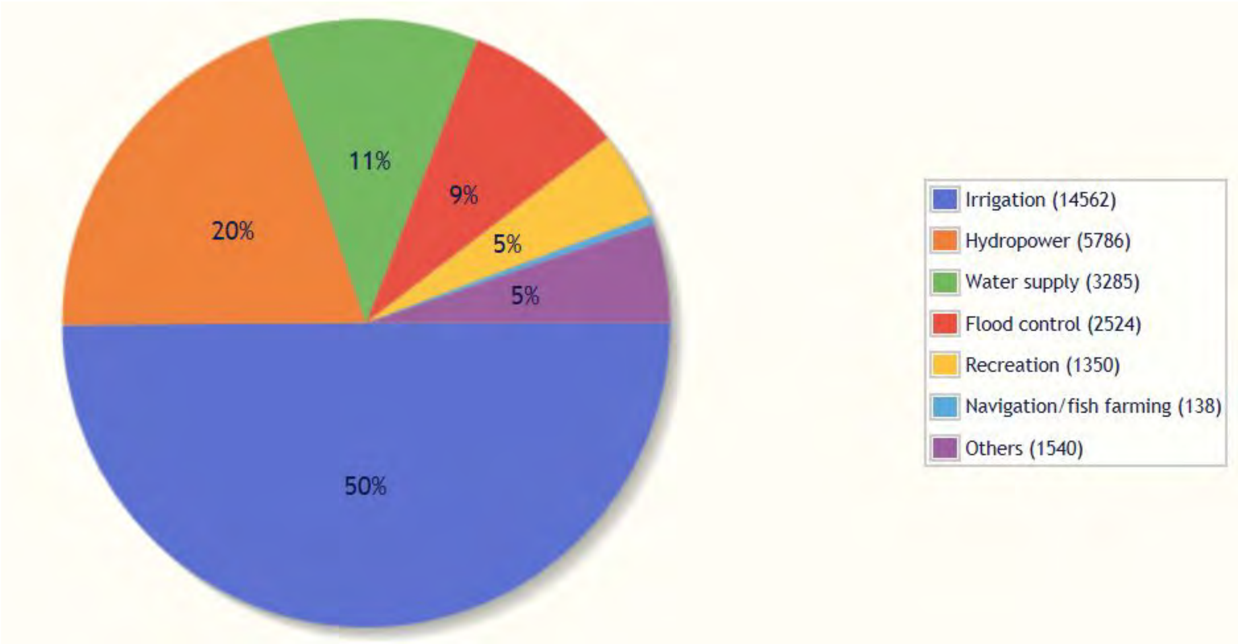

Figure 7 **Single purpose dams**
Source: https://www.icold-cigb.org

Figure 8 shows the corresponding data for multipurpose dams. Here they are more evenly spread between the categories

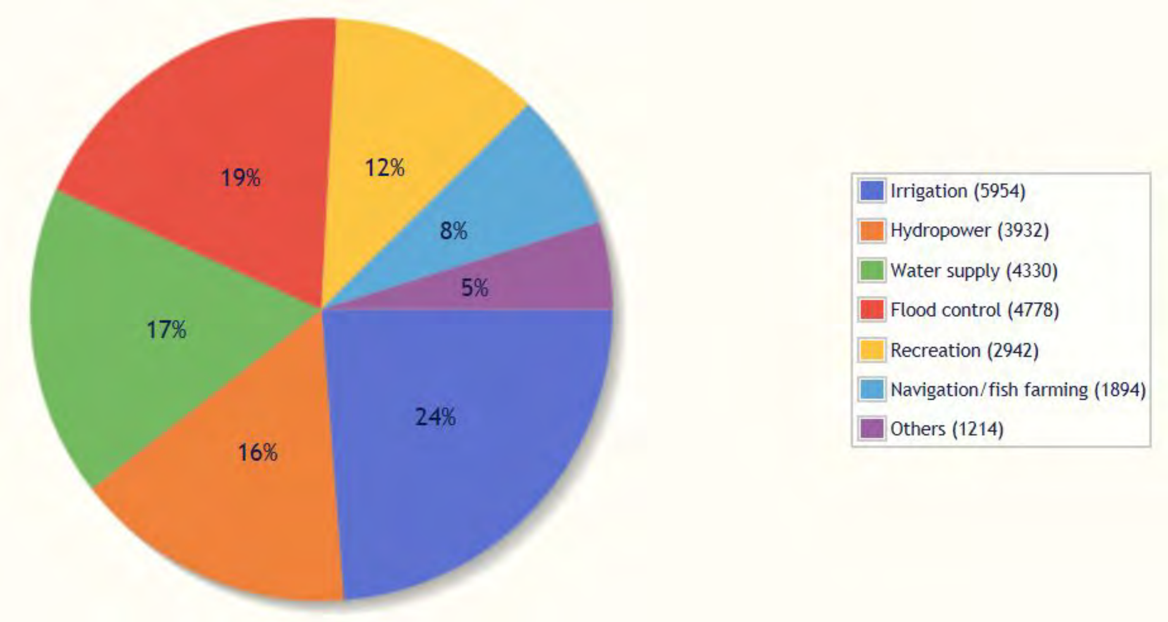

Figure 8 **Multipurpose dams**
Source: https://www.icold-cigb.org

<u>Distribution of storage</u>

The distribution of this storage, by reservoir volume, in each region (as defined in the Appendix) is shown in Figure 9.

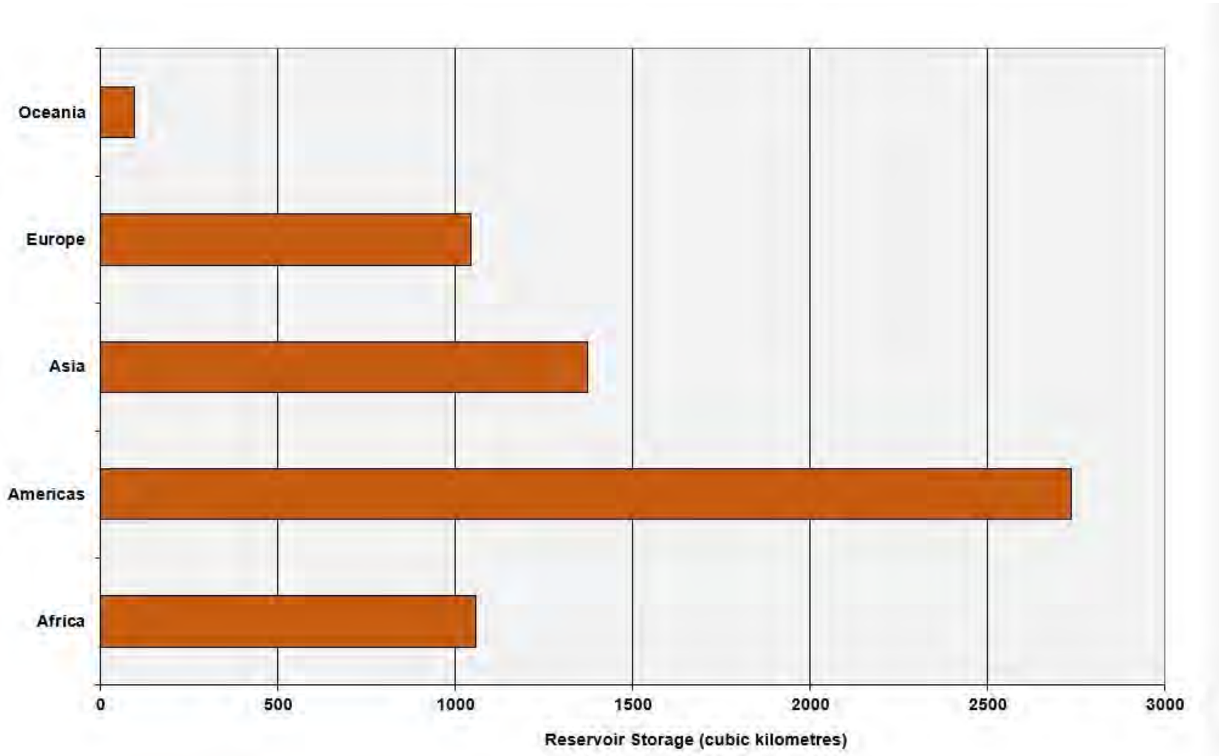

Figure 9 **Reservoir storage by region**
Source: https://www.icold-cigb.org

Reservoirs vary in size and capacity. There are six reservoirs with capacities greater than 100 km^3. These are listed in Table 13.

Dam / Reservoir	Capacity (km^3)	Purpose	Country
Kariba	181	Hydroelectricity	Zambia/Zimbabwe
Bratsk	169	Hydroelectricity Navigation Water Supply	Russia
High Aswan	169	Irrigation Hydroelectricity Flood Control	Egypt
Akosombo	150	Hydroelectricity	Ghana
Daniel Johnson (Manic 5)	142	Hydroelectricity	Canada
Guri	135	Hydroelectricity	Venezuela

Table 13 Highest capacity reservoirs

The development of storage in man-made reservoirs in the 20th century is shown in Figure 10. Progress was slow until the mid 1950s when large projects began to come on stream. Dam building continued apace until the 1980s when the rate began to slow. That pattern continues today.

The reduced rate of increase of storage since the 1980s is likely to be due (i) to the economics of construction (the best and most economical sites have been exploited first) and (ii) the increased awareness of the need to consider the environmental impact of large dams.

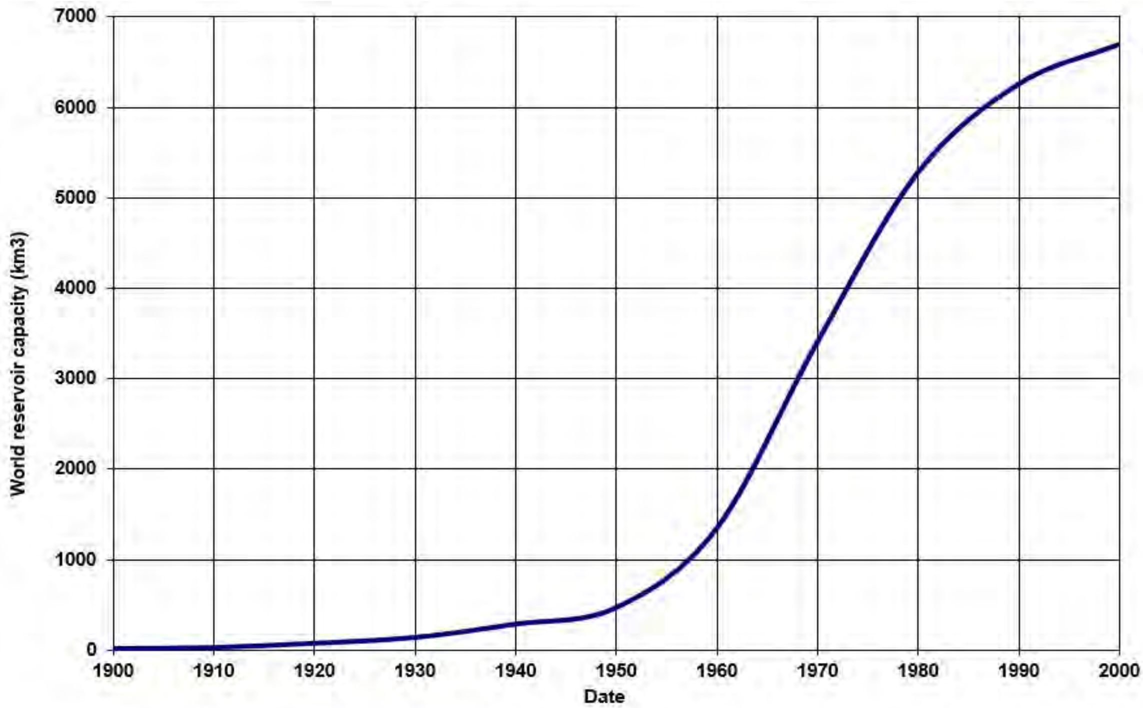

Figure 10 **Development of worldwide reservoir storage since 1900**
Source: https://www.icold-cigb.org

The development of reservoir storage within the UK during the 20th century is shown in Figure 11.

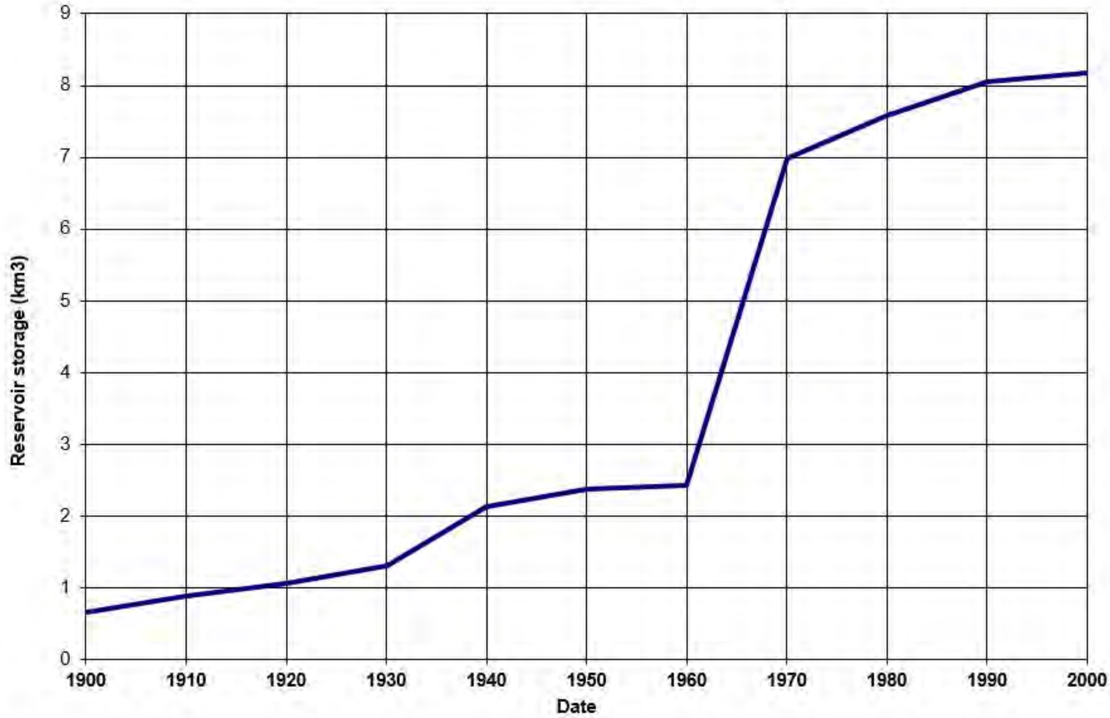

Figure 11 **Development of reservoir storage in the UK since 1900**
Source: https://www.icold-cigb.org

6 Loss of storage due to sedimentation

Loss of reservoir storage occurs when sediments are eroded from the land surface and are transported to reservoirs by the rivers which feed them. Sediment transport in rivers and in reservoirs is affected by a) the nature of the sediments, b) the geometric characteristics of river channels and reservoirs and c) water flows within the system. The loss of storage due to sedimentation exacerbates the problem of providing enough storage of fresh water for the rising world population with its increasing aspirations and standards.

Erosion of the land surface yields sediments which are transported downstream by rivers. Globally the erosion rate has been estimated by many authors. ***White***, 2001 [7] gives the results of 14 studies which show estimates of between 0.06 mm/year and 0.16 mm/year. The most comprehensive study was reportedly that given by ***Lal***, 1994 [8] with a computed global erosion rate of 0.09 mm/year. This equates to 132 t/km^2/year assuming a specific weight of eroded sediment of 1.5. Further information is given by ***Walling***, 1984 [9].

The rate of erosion is very variable and depends on a complex interaction of the following factors:
- Climate: precipitation and runoff, temperature, wind speed and direction.
- Geotechnics: geology, volcanic and tectonic activity, soils.
- Topography: slope, catchment orientation, drainage basin area, drainage density.
- Vegetation cover.
- Land use and human impact.

Most of the sediment which is eroded from the land surface is in the form of fine particles which are transported in water courses as a suspended load. These fine sediments account for the turbidity often observed in rivers and their fall velocity in water is so low that the turbulence maintains them in suspension. A small proportion of the sediment, perhaps around 10%, is coarser material which is transported as bed load. These sediments roll along the bed of the river or saltate (hop) close to the bed. Reservoirs act as settling basins for both types of sediment. Coarser sediments tend to be deposited towards the upstream end of reservoirs whereas the finer sediments accumulate further downstream. During the early stages in the life of a reservoir, much of the incoming sediment is trapped and forms areas of sedimentation which progress downstream from the upstream end of the reservoir. However, as the volume of the reservoir diminishes more and more of the incoming sediment passes through the reservoir due to increasing water velocities and reducing times of residence.

Estimates for the rate of loss of global storage are given by ***White***, 2001 [7], ***Morris and Fan***, 19971 [11] and ***Mahmood***, 1987 [12]. The global estimates varied from 0.5% per annum to 1.0% per annum. The regional distribution of the rate of loss of storage is also considered in these references. Sedimentation causes a reduction in reservoir capacity but the rate of sedimentation diminishes with time, due to the increased throughput of sediment associated with higher flow velocities. Using an analogy with the decay of radiation activity, reservoirs can be assigned a "half-life" dependent upon the sedimentation rate. This is the number of years over which reservoir capacity will be halved.

White, 2001 [7] gives the results of the analysis of sedimentation data for 2 300 of the reservoirs in 31 countries given by ***ICOLD***, 2003 [4]. The results published by ***White***, 2001 [7] are given in Table 14 using the regions defined by ***Walling and Webb***, 1996 [14]. The annual loss of world storage quoted is 0.5% per annum.

Region	Estimated annual loss of storage due to sedimentation (%)	Estimated reservoir half -life (years)
Southern Asia	0.52	96
Central Asia	1.00	50
South-East Asia	0.30	167
China	2.30	22
Northern Europe	0.20	250
Southern Europe	0.17	294
Middle East	1.50	33
Northern Africa	0.08	625
Sub-Saharan Africa	0.23	217
North America	0.20	250
South America	0.10	500
Pacific Rim	0.27	185

Table 14 Regional distribution of reservoir sedimentation

With a current world storage in reservoirs of around 6 300 km^3 and an average annual sedimentation rate of 0.5%, the current annual loss of storage due to sedimentation is 31.5 km^3. ***Mahmood***, 1987 [11], based on far less data, gives a much higher annual sedimentation rate of 1% which would double this figure. The loss of storage due to sedimentation is one of the factors which needs to be taken into account in any discussion of future storage needs.

7 Conservation of reservoir storage

Whereas the twentieth century was concerned with the development of reservoir storage, more emphasis will be required in the twenty first century on the conservation of storage because of a) the increasing land take of reservoirs and b) the diminishing availability of suitable, environmentally acceptable and economically viable sites. Sediment management will become crucial. The goal will be to convert the present inventory of non-sustainable reservoirs into sustainable assets for future generations. There have been two recent studies which are very significant in identifying the issues which will be important in this transition from non-sustainable to sustainable storage.

World Bank

The World Bank, see ***Palmieri, Shah, and Dinar***, 1998 [13] and ***Palmieri, Shah, Annandale and Dinar***, 2003 [14], has made a contribution to promote conservation of water storage assets worldwide. This work concentrated on the specific issue of reservoir sedimentation and how it might be reduced, or in some very favourable conditions, eliminated. The work developed the concept of "reservoir life cycle management" and looked at the physical processes by which sediment could be removed, on a regular basis, from reservoirs. A simple mathematical model (RESCON) was developed which enabled decisions to be made on the financial and engineering viability of preserving storage.

Several ways of removing sediments from reservoirs were considered by the World Bank and the following text in italics is a direct quotation from World Bank references:

Flushing: *Flushing is a technique whereby the flow velocities in a reservoir are increased to such an extent that deposited sediments are re-mobilized and transported through low-level outlets in the dam.*

Two approaches to flushing exist: complete drawdown flushing and partial drawdown flushing. Complete drawdown flushing occurs when the reservoir is emptied during the flood season, resulting in the creation of river-like flow conditions in the reservoir. Partial drawdown flushing occurs when the reservoir level is drawn down only partially. In this case the sediment transport capacity in the reservoir increases, but usually only enough to allow sediment within the reservoir to be relocated, ie sediment is moved from upstream locations in the reservoir basin to locations further downstream and closer to the dam.

Low-level outlets for flushing operations should be close to the original river bed level and of sufficient hydraulic capacity to achieve full drawdown. The intent with flushing operations is to recreate river-like flow conditions in the reservoir. By doing so, the sediment that has deposited is re-mobilized and transported through the low-level gates to the river reach downstream from the dam. This operation is usually performed during the flood season. The low-level gates are closed towards the end of the flood season to capture clearer water for use during the dry season.

Flushing with partial drawdown may be used to move sediments from the upper reaches of a reservoir to zones closer to the dam. If this is done, studies should be completed beforehand to ensure that intake structures and other ancillary facilities are not impacted. Flushing with partial drawdown may be used to clear more live storage space and locate the sediment in a *more favorable position for future complete drawdown flushing.*

Sluicing: *Sluicing is an operational technique by which a substantial portion of the incoming sediment load is passed through the reservoir and dam before the sediment particles can settle. This is accomplished in most cases by operating the reservoir at a lower level during the flood season in order to maintain sufficient sediment transport capacity through the reservoir. Higher flow velocities and higher sediment transport capacities in the water flowing through the reservoir result from operating the reservoir at these lower levels. The increased sediment transport capacity of the water flowing through the reservoir reduces the volume of sediment that is deposited. After the flood season, the pool level in the reservoir is raised to store relatively clear water.*

Effectiveness of sluicing operations depends mainly on the availability of excess runoff, on the grain size of the sediments and on reservoir morphology. In many cases sluicing and flushing are used in combination.

Density current venting: *Density currents may develop under exceptional conditions, causing more sediment to be transported towards the dam than the relationships for turbulent suspension indicate. Such currents occur because the density of the sediment carrying water flowing into the reservoir is greater than the density of clear water impounded in a reservoir. The increased density, increased viscosity and concomitant reduction in turbulence intensity result in a coherent current with a high sediment concentration that dives underneath the clear water and moves towards the dam.*

If it is known that density currents occur in a particular reservoir, installation and operation of low-level gates in the dam will make it possible to pass the sediment current through the dam for discharge downstream. By passing the density current through the low-level gates, sediment that would have deposited in the reservoir is released downstream, thus reducing storage loss. Density current venting is an attractive way of releasing sediment laden flows because, unlike flushing operations, it does not require the lowering of the reservoir level.

Mechanical removal*: Mechanical removal of deposited sediment from reservoirs takes place using conventional dredging techniques, dry excavation or hydrosuction.*

Dredging: *The process of excavating deposited sediments from under water is termed dredging. Dredging is a highly specialized activity which is mostly used for clearing navigation channels in ports, rivers and estuaries. However, the technology is often used in reservoirs also.*

Sediment dredging is commonly used to reclaim storage lost to sediment deposits. However, conventional hydraulic dredging is often much more expensive than the cost of storage replacement and it is generally not economically viable to remove all sediment from reservoirs by means of dredging alone. With large contracts the cost of dredging can approach the cost of building a new dam.

Disposal of dredged material can constitute an environmental problem and suitable mitigating measures, which can be quite expensive, have to be found on a case-by-case basis. If discharged directly downstream from the dam, the high sediment concentrations generally associated with dredging can be unacceptable from an environmental point of view. However, it may be possible *to reduce the sediment concentration of the water flowing in the river by releasing clean water from the reservoir concurrently with the release of dredged material. If the material is not deposited downstream of the dam, then large expanses of landfill may be required.*

***Dry excavation**: Dry excavation (also known as trucking) requires the lowering of the reservoir during the dry season when the reduced river flows can be adequately controlled without interference with the excavation works. The sediment is excavated and transported for disposal using traditional earth moving equipment. Excavation and disposal costs are high, and as such this technique is generally used for relatively small impoundments. Reservoirs used for flood control may be more amenable to sediment management by trucking, such as has been performed at Cogswell Dam and Reservoir in California. The sediment from this reservoir has been excavated with conventional earth moving equipment and has been used as engineered landfill in the hills adjacent to the reservoir.*

***Hydrosuction:** This is a variation of traditional dredging. The difference is that the hydraulic head available at the dam is used as the energy for dredging instead of pumps powered by electricity or diesel. As such, where there is sufficient head available, the operating costs are substantially lower than those of traditional dredging. The system consists of a barge that controls the flow in the suction and discharge pipe and can be used to move the suction end of the pipe around. The upstream end of the pipe is located at the sediment level in the reservoir and its downstream end is usually draped over the dam to discharge sediment and water to the downstream river. The arrangement of the pipe layout essentially creates a siphon and the suction at the upstream end of the siphon is used to evacuate sediment. The system can be used in relatively short reservoirs, not longer than approximately 3 km and also depends on the elevation of the dam and reservoir.*

Of these methods, the viability of flushing has been researched in detail, including a worldwide review of the application of this method, see ***White***, 2001 [7]. The study showed that, for effective flushing, the following factors need to be considered and satisfied:

Hydraulic conditions required for efficient flushing: Riverine conditions must be created in the reservoir for a significant length of time. The reservoir level must be held low throughout the flushing period, possibly with minor fluctuations in level to activate sediment movement. To achieve this:

- The hydraulic capacity of the bypass must be sufficient to maintain the reservoir at a constant level during the flushing period.
- Flushing discharges of at least twice the mean annual flow are required.
- Flushing volumes of at least 10% of the mean annual runoff should be anticipated.

Quantity of water available for flushing: There must be enough water available to transport the required volume of sediment. This has the following implications:-

- Reservoirs where the annual runoff is large compared with the volume of the reservoir are best suited for sediment flushing.
- A regular annual cycle of flows and a defined flood season provide optimum conditions for sediment flushing. This favours sites in monsoon areas and sites where flood flows are generated by annual snowmelt in the spring and summer months.

- A balance must be achievable between the significant quantities of water required for sediment flushing and water required to satisfy demands at other times of the year - for irrigation and hydropower, for example.
-

Mobility of reservoir sediments: Sediment sizes are an important factor in determining whether the quantity of water available for flushing will be adequate to remove the desired quantity of sediment from the reservoir.

- Deposited coarse sediments are more difficult to remove than fine sediments. These sediments progress from the upstream end of the reservoir and the toe of the fore-set slope reaches the dam well into the life of the reservoir. The sustainable volume achievable by sediment flushing depends on the nature of the deposited sediments and other factors.
- The sediment sizes in transport in rivers entering a reservoir can be of paramount importance in determining the success of flushing. From the point of view of achieving a sediment balance, a large factor is desirable between the sediment sizes being transported as suspended bed material load in the rivers entering the reservoir and the sizes found in the river bed material. Such conditions are typical for gravel rivers with a widely varying bed material composition. In large rivers this situation is found where the longitudinal bed gradient is between, say, 0.002 and 0.001. In smaller rivers the equivalent range may be 0.005 to 0.002.
- From the point of view of sediment size alone, delta deposits of fine sand and coarse silt are the most likely to produce success in flushing a reservoir. Coarser material may inhibit a sediment balance and finer material will deposit in the body of the reservoir outside any incised channel and so will not be available for reworking during flushing.

Site specific factors: The most suitable conditions for flushing are to be found in reservoirs which approximate in shape to the incised channel which develops during flushing. Long, relatively narrow reservoirs are better suited to flushing than short, wide, shallow reservoirs.

Sluicing, density current venting, mechanical removal, dredging, dry excavation and hydrosuction are less well documented in terms of the practical constraints on their usage. Further research is required including surveys of worldwide experience using these techniques.

World Commission on Dams

The World Commission on Dams carried out an extensive series of studies, see ***WCD***, 2000 [15]. Whilst acknowledging the contribution made by storage reservoirs in terms of power generation, irrigation and water supply, the overwhelming emphasis was on the social and environmental impacts of large reservoirs and how decision-making could be improved in future developments. The following quotation from the Commission's report summarises its recommendations for change:

From Global Review to Future Practice

Along with all development choices, decisions on dams must respond to a wide range of needs, expectations, objectives and constraints. As matters of public choice and policy they will always reflect competing interests and require negotiation. Reconciling competing needs and entitlements is the single most important factor in addressing the conflicts associated with development projects and programmes - particularly large-scale interventions such as dams.

Access to water provides a graphic illustration of such competing needs and development objectives and the reason why equity and justice considerations emerge as key issues. Riparian communities with longstanding use rights and economies that depend on local resources have an immediate interest in maintaining current use patterns and assuring fulfilment of their future needs. However, in the context of national policies, meeting development needs may require sharing water resources. To balance these needs societies will have to negotiate a framework for equitably sharing the resource. History shows that this can be done successfully provided a transparent and legitimate process is followed.

Dams have often been seen as an effective way of meeting water and energy needs. However, the Global Review has emphasised the wide range of problems associated with them. The Commission acknowledges that today's perspective on development reflects the benefit of knowledge that may not have been available to past decision-makers. Nonetheless, it is clear that the positive contribution of large dams to development has, in many cases, been marred by significant social and environmental impacts which are unacceptable when viewed from today's values.

The debate about dams is a debate about the very meaning, purpose and pathway of development as well as the role that the State plays in both protecting the rights of its citizens and responding to their needs through development policies and projects. The WCD Global Review showed clearly that large-scale infrastructure projects such as dams can have devastating impacts on the lives and livelihoods of affected communities and ecosystems, particularly in the absence of adequate assessments and provisions being agreed to address these impacts.

Improving the development process and its outcomes must start with a clear understanding of the shared values, objectives and goals of development and their implications for institutional change. The Commission grouped the core values informing its understanding on these issues under five main headings:

- *Equity*
- *Efficiency*
- *Participatory decision-making*
- *Sustainability*
- *Accountability*

8 Global warming and climate change

This chapter discusses the water issues surrounding global warming and climate change. The evidence for global warming and climate change is now well established and documented and this ROCK relies heavily on the work of the ***Intergovernmental Panel for Climate Change*** (IPCC).

An enormous amount of scientific effort has been invested in the subjects of global warming and climate change in recent years. Extensive field measurements over many years and the development of soundly based numerical models have placed the subject on a much firmer footing. No longer are claims of global warming simply based on anecdotal evidence of "rare" or "unusual" climatic events or sequences of such events. Despite this, there remains a small group of sceptics who, in particular, query whether current climate change trends are natural or man-made and whether the trends are cyclic or progressive.

The Intergovernmental Panel for Climate Change (IPCC) was established by the United Nations Environmental Programme (UNEP) and the World Meteorological Organisation (WMO) in 1988 to provide a clear scientific view on the current state of climate change. It reviews and assesses the most recent scientific, technical and socio-economic information relevant to the understanding of climate change and collates scientific evidence from all over the world. Scientists contribute to the work of the IPCC on a voluntary basis and any differing viewpoints existing within the scientific community are reflected in the IPCC reports.

Because of its scientific and intergovernmental nature, the IPCC embodies an opportunity to provide rigorous and balanced scientific information to decision-makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. The work of the organization is therefore policy-relevant and yet policy-neutral, never policy-prescriptive.

Climate change, in IPCC usage, refers to a change in the state of climate that persists for an extended period, typically decades or longer. It refers to climate change over a long period induced by natural causes and human activity. Pre 1850 almost all variations in climate had natural causes and were not affected by man. However, human activities have had a noticeable effect in more recent times, particularly during the latter half of the 20th century.

The following summary is based on IPCC reports, see ***IPCC***, 2007 [16]. The main findings and projections for the future are given in this report together with an indication of the uncertainties associated with the data and the predictions. These are summarised in the following sections.

Uncertainties

The subject of climate change is not an easy one. The collection of data is challenging and the scale and complexity of the science should not be underestimated. Hence the data, the physics embodied in climate models and the prediction from the models all have a degree of uncertainty. The IPCC approach is to define sets of descriptors which enable the reader to assess the reliability (or otherwise) of the data, the theory, the model(s), future predictions etc.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of the evidence. Terms such as *high agreement*, *medium evidence* and *poor agreement* are used.

Where uncertainty is assessed more quantitatively using expert knowledge / judgement, a range of so-called confidence levels are used, such as *very high confidence, high confidence, medium confidence* and *low confidence.*

Where uncertainty in specific predictions is assessed using expert knowledge / judgement / statistical analysis of a body of evidence / numerical models, then the following ranges of likelihood are used to express the assessed probability of occurrence: *virtually certain, extremely likely, very likely, likely, more likely than not, about as likely as not, unlikely, very unlikely, extremely unlikely and exceptionally unlikely.*

This ROCK follows these descriptors where possible.

<u>Observed changes in climate</u>

Direct evidence to show that the climate system has warmed significantly during the last 150 years is now strong. Three main indicators are quoted by IPCC:

1. The average temperature of the world's near surface air and also the oceans has increased significantly since 1850 from approx. 13.5 deg C to approx. 14.5 deg C.
2. Since 1870 the average sea level has increased by approx. 200 mm, a average rate of 1.4 mm per year. The rate of increase over that period is not constant and in the period 1960 to 2003 it was 1.8 mm per year. From 1993 to 2003 the rate was 3.1 mm per year but it is not clear whether this was a short or a long term effect.
3. Observations of snow and ice cover are also consistent with warming. Satellite data from 1978 onwards shows major changes in global ice cover. The annual average extent of the Arctic sea ice has shrunk by 2.7% per decade, with larger decreases in summer of 7.4% per decade.

Indirect evidence from all continents and most oceans shows, with *high confidence,* that many natural systems are being affected by regional climate change, particularly temperature increases. Examples include:

1. Enlargement and increased number of glacial lakes.
2. Increased ground instability in permafrost regions and rock avalanches in mountainous regions.
3. Changes in some Arctic and Antarctic ecosystems.

<u>Causes of climate change</u>

The drivers of climate change are:

1. Changes in the atmospheric concentrations of greenhouse gases and aerosols.
2. Changes in vegetative land cover.
3. Changes in solar radiation.

Human activities influence items 1 and 2.

These drivers affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in the energy balance influence the global climate.

Human activities result in emissions of four long-lived greenhouse gases: carbon dioxide, methane, nitrous oxide and the halocarbons. The concentrations of these increase in the atmosphere when emissions exceed natural absorption levels.

Figure 12 shows the observed emissions of these four greenhouse gases between 1970 and 2004. Total emissions have increased by 70% over that period and emissions of the major contributor, carbon dioxide, have increased by 80%.

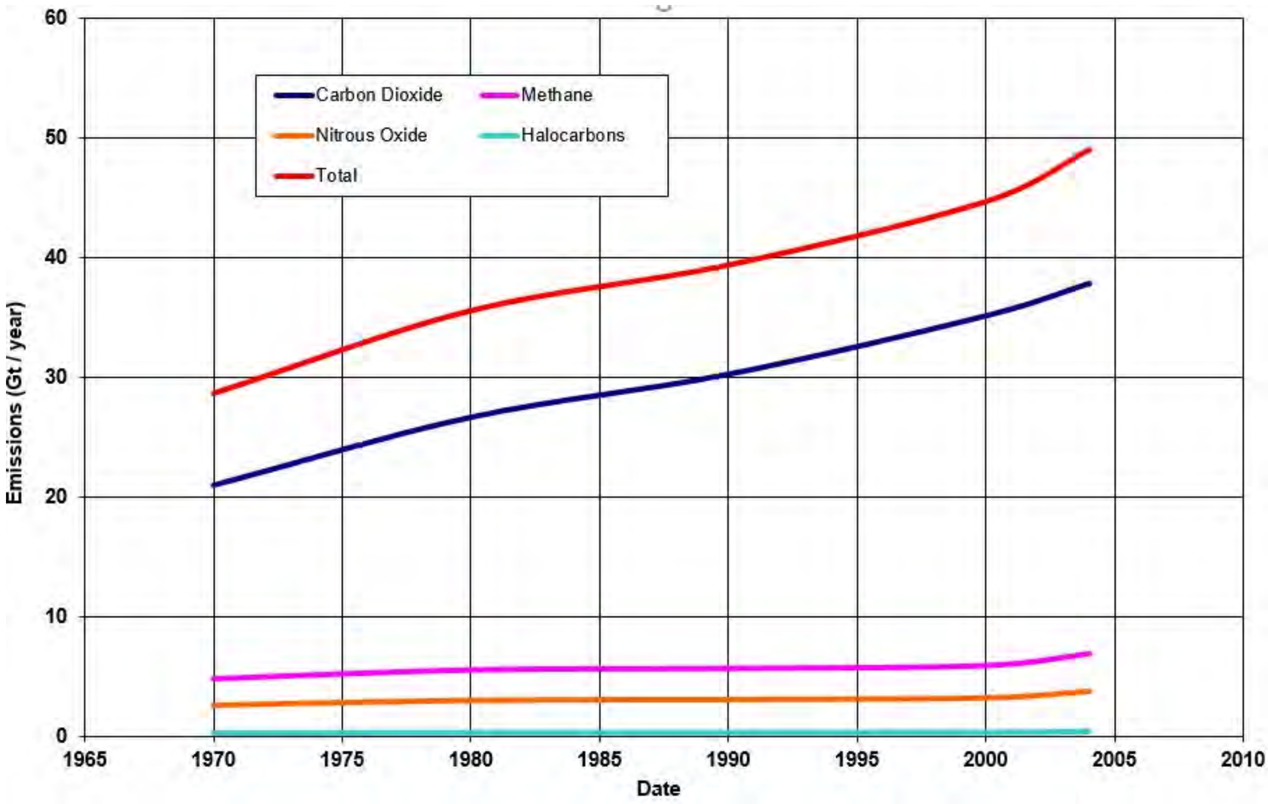

Figure 12 **Worldwide greenhouse gas emissions from 1970 to 2004**
Source: www.ipcc.ch/ipccreports

The **IPCC** report [16] identifies the source of these emissions sector by sector. The distribution is shown in Figure 13.

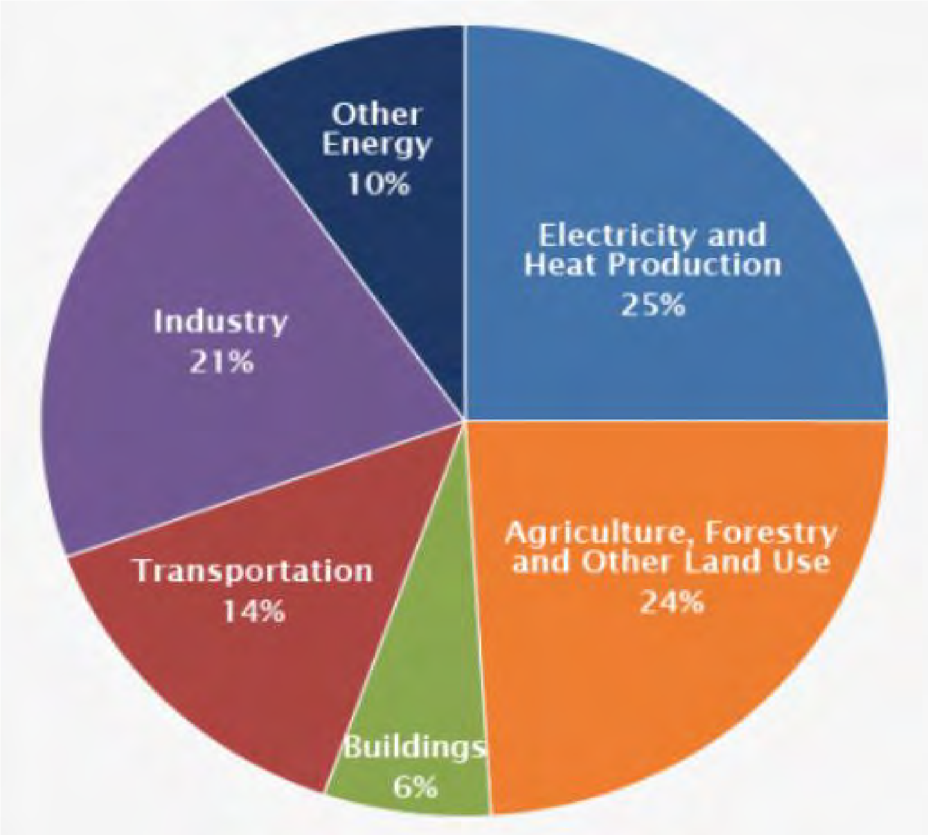

Figure 13 **Worldwide greenhouse gas emissions from 1970 to 2004 by sector**
Source: www.ipcc.ch/ipccreports

Table 15 is taken from ***USCB***, 2009 [6] and shows those countries with the ten highest carbon dioxide emissions in 2006. It also shows the carbon dioxide emissions per person. The populous countries of China and India currently have emissions per person much lower than other countries in this list.

Country	Carbon dioxide emissions per annum (million tonnes)	Carbon dioxide emissions per person per annum (tonnes)
United States	5 697	19
China	5 607	4
Russia	1 587	11
India	1 250	1
Japan	1 213	9
Germany	823	10
Canada	539	17
United Kingdom	536	9
South Korea	476	10
Italy	448	8

Table 15 **Carbon dioxide emissions by country**

In an attempt to put these increases in greenhouse gas emissions into perspective, the IPCC has looked at historic concentrations in the atmosphere based on samples from ice cores spanning many thousands of years. Carbon dioxide concentrations in the atmosphere for 10 000 years prior to 1800 were consistently in the range 260 to 280 parts per million (ppm). However, since the start of the industrial era concentrations have risen continuously. They reached 310 ppm by 1950 and are currently approaching 380 ppm, a major escalation in the last 70 years.

The IPCC concludes that most of the observed increase in global average temperature since the mid 20th century is *very likely* to be due to the observed increases in anthropogenic greenhouse gas concentrations.

Further information on both carbon dioxide concentrations and atmospheric temperatures are provided by the ***European Project for Ice Coring in Antarctica***, EPICA [17]. The data from ice cores goes back at least 80 000 years. Data on atmospheric temperatures covering the last 60 years, based on readings taken at Mauna Loa, are available through a US Federal Agency, the ***National Oceanic and Atmospheric Administration***, NOAA, [18]. ***The Meteorological Office, Hadley Centre*** [19] , also provides detailed information, including very recent trends.

Global warming since 1900

Further confirmation comes from the use of climate change models which can simulate changes in surface temperature as affected by (i) natural causes and (ii) natural causes plus anthropogenic causes associated with human activities. Many models have been used to simulate temperature changes over the last 100 years with and without anthropogenic influences and the results compared with observations. Whilst the models have difficulty in simulating local conditions, they can be applied to the oceans and land masses on a global scale and to continents on a regional scale.

The IPCC reports that none of the models using only natural influences has reproduced the continental mean warming trends in individual continents (except Antarctica) over the second half of the 20th century. Those models which include anthropogenic influences show much closer agreement with observations.

Climate change since 1900

The IPCC reports that most models under most circumstances suggest that discernable human influences extend beyond average global temperatures to other aspects of climate, including temperature extremes and wind patterns. Table 16 gives a summary of the changes since 1900 together with their likelihood.

Effect	Likelihood of anthropogenic cause
Sea levels rise	*Very likely*
Temperatures of the most extreme hot nights, hot days and cold days.	*Likely.*
Increased risk of heat waves.	*More likely than not.*
Changes in wind patterns affecting extra-tropical storm tracks and temperature patterns in both Hemispheres	*Likely.*
Changes in the wind circulation patterns in the Northern Hemisphere	*No strong evidence* *(Not well simulated by climate models)*
Changes in the hydrological cycle and an increased precipitation over land.	*Some evidence.*
Increase in areas affected by drought since 1970.	*More likely than not.*
Global scale changes in many physical and biological systems	*Likely*

Table 16 Climatic changes since 1900 as related to human activities

<u>Climate change in the near and long term future</u>

Climate models are being developed continuously and their ability to simulate the complicated processes which occur in the Earth's atmosphere is improving all the time. They are now capable of simulating the changes which have occurred up until the present time with reasonable accuracy as described in the previous sections of this chapter. It is therefore appropriate to use these models to look into the near and long term future; although the further one goes into the future the less reliable the predictions become. The task is not straightforward because of the number of variables which have to be considered. Future population growth and the associated domestic, industrial and agricultural activities will all influence greenhouse gas emissions and the natural ability of Earth's atmosphere to absorb these changes.

The IPCC approach is to use various scenarios which consider alternative development pathways covering a range of demographic, economic and technological driving forces and resulting greenhouse gas emissions. The scenarios assume the internationally agreed climate policies in place in 2007 and exclude any more recent agreements.

In general terms, there are four basic scenarios:

- A[1]. A world in which there is continued rapid economic growth, a global population which peaks in 2050 and a rapid introduction of new and more efficient technologies. This scenario is sub-divided depending upon whether the technological change is fossil fuel related (A1F) or non-fossil fuel related (A1T) or a balance between the two (A1B).
- A2. A heterogeneous world with high population growth, slow economic development and slow technological change.
- B1. A convergent world with the same population as in A1 but with more rapid changes in economic structures towards service and information economies.
- B2. A world with intermediate population and economic growth, emphasising local solutions to economic, social and environmental sustainability.

No likelihood is attached to these scenarios.

Simulations of these scenarios assume an emission rate of 40 Gt of greenhouse gases in 2000 and compute rates of emission through to 2100. A summary of the results is given in Table 17.

Scenario	Annual greenhouse gas emissions (Gt)	
	2050	**2100**
A1F	110	130
A1T	61	28
A1B	76	61
A2	85	137
B1	55	25
B2	57	67

Table 17 Projected greenhouse gas emissions as influenced by development paths

Projected global effects of these emissions from the year 2000 to the year 2100 are given in Table 18.

Scenario	Temperature increase (deg C)		Sea level rise (m)
	Best estimate	**Range of model results**	**Range of model results**
A1F	4.0	2.4 - 6.4	0.26 - 0.59
A1T	2.4	1.4 - 3.8	0.20 - 0.45
A1B	2.8	1.7 - 4.4	0.21 - 0.48
A2	3.4	2.0 - 5.4	0.23 - 0.51
B1	1.8	1.1 - 2.9	0.18 - 0.38
B2	2.4	1.4 - 3.8	0.20 - 0.43

Table 18 Projected global increases in temperatures and sea levels from 2000 to the year 2100

In 2007 the IPCC expressed a growing confidence in the ability of climate models to make reasonable projections of future changes on a regional basis, including changes in wind patterns and precipitation.

The projected warming to the year 2100 shows geographical patterns similar to those observed in recent decades. Warming is expected to be greatest over land, particularly at high northern latitudes. It is expected to be least in the Southern Ocean and the North Atlantic.

In December 2015, at an IPCC meeting in Paris, 192 countries committed to a climate change agreement that is dynamic, durable and applicable to all countries. The aim was to restrict mean global temperature rise to 1.5 deg C in the period up to 2100. Since then 181 countries have ratified the Agreement; although in 2017 the United States expressed its intention to withdraw from the agreement after a three-year notice period.

At the heart of the Paris agreement is a commitment by countries to submit nationally determined contributions (NDCs), setting out their national targets for reducing greenhouse gases and, in some cases, plans for adapting to the impacts of climate change and providing finance and other support to developing countries. These pledges are the foundation of the Agreement. They are to be resubmitted to the UN every five years, and each must be more ambitious than the last.

At the recent IPCC meeting in Katowice (December 2018), 163 countries were reported as having presented NDCs. However, even if countries fully implement their NDCs, and take comparable action afterwards, the global temperature is currently expected to increase by about 3.2 deg C by 2100 relative to pre-industrial levels. (https://www.unenvironment.org)
This is well above the "safe" level of 1.5 deg C considered appropriate in 2015 in Paris.

General impacts of future climate change

IPCC, 2007 [16] gives key findings in terms of the impacts of future climate change to 2100 and these are summarised in Table 19.

	Impact	Likelihood
Ecosystems	The resilience of many systems will be exceeded due to the effect of climate change on flooding, drought, wildfires, ocean acidification etc.	*Likely*
	Approx. 20 to 30% of plant and animal species will be at an increased risk of extinction.	*Likely*
	Increased greenhouse concentrations in the atmosphere will cause major changes in ecosystem structure and function.	*Not stated*
Food	On a global basis, crop production will generally increase slightly for temperature increases up to 3 deg C and then decrease beyond that in some areas.	*Medium confidence*
	At low altitudes, in some areas, crop production will reduce with increases of only 1 or 2 deg C.	*Medium confidence*
Coasts	Coasts will suffer increased risks from coastal erosion and sea level rise	*Very high confidence*
	Large populations will be exposed to increased flood risk especially in the low-lying mega-deltas of Asia and Africa	*Very high confidence*
Industry, settlement and Society	The most vulnerable will be those located in coastal and river floodplain areas, those where the economy is closely related to climate sensitive resources and those in areas prone to extreme weather events.	*Not stated*
Health	Health will generally be affected, for example, by malnutrition, the consequences of extreme weather etc. Factors such as education, health care and economic development will be crucial.	*Not stated*
	Some minor benefits may arise from increased temperatures in some areas.	*Not stated*
Water	Water impacts are key to all sectors and regions.	*See below*

Table 19 Projected impacts of climate change to the year 2100

Impacts of future climate change on water issues

Climate change is affecting the water environment and further changes to the year 2100 have been investigated using 12 independent climate models. The results using the A1B scenario (mixed use of fossil and other fuel sources) are reported by ***IPCC*** [16]

A visual global impression of the IPCC results is shown in Figure 14.

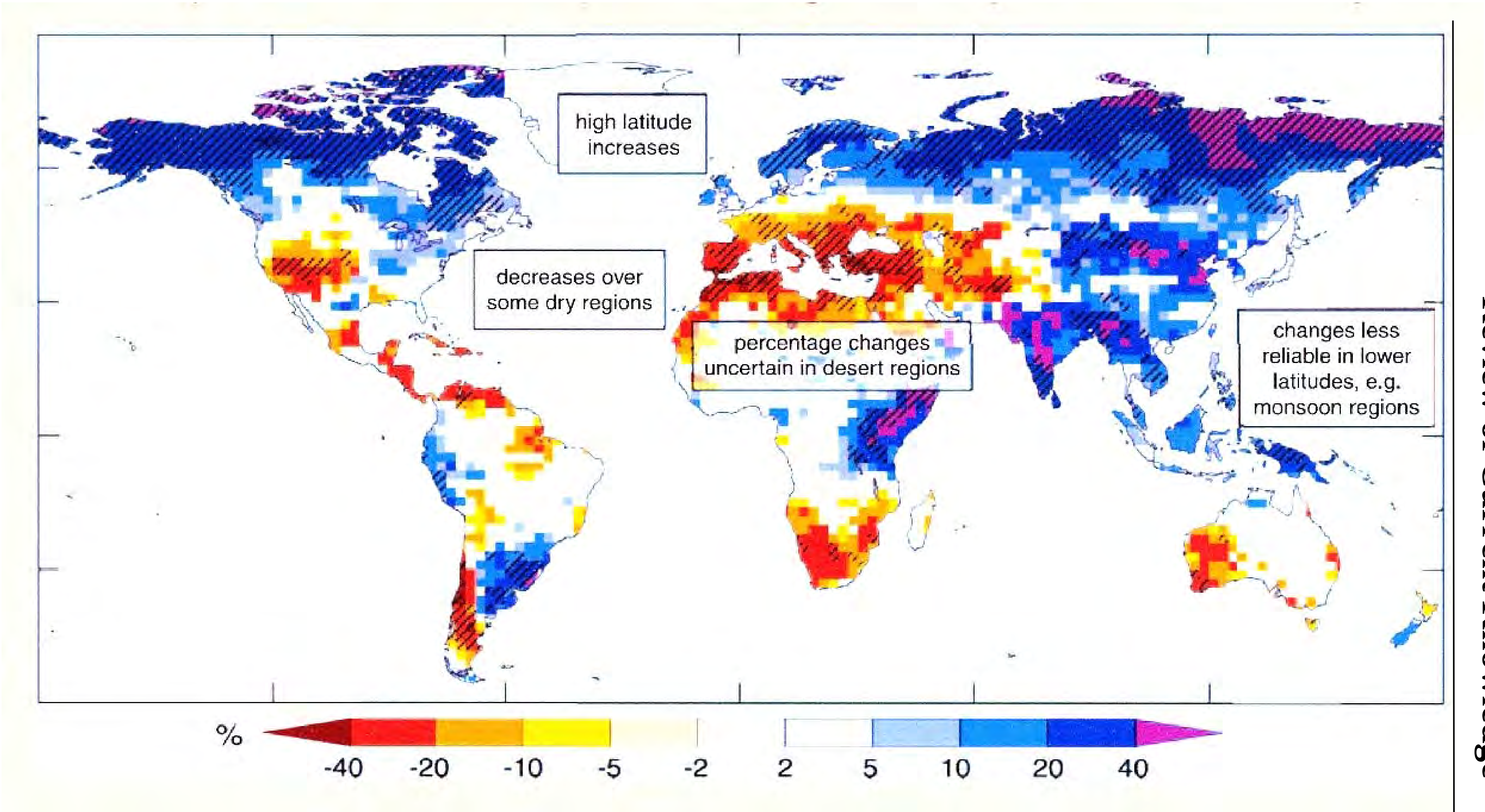

Figure 14 **Projections and model consistency of change in runoff by 2100**
Source: www.ipcc.ch/ipccreports

Results by region are summarised in Table 20.

Changes in runoff will affect the availability of water for domestic, industrial and agricultural purposes. Runoff is predicted with *high confidence* to increase significantly at higher latitudes and in some wet tropical areas, including populous areas in East and South East Asia. Significant reductions in runoff are predicted with *high confidence* for some dry regions at mid-latitudes due to reduced precipitation and increased evapo-transpiration. There is also *high confidence* that many semi-arid areas, such as the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil, will suffer a decrease in water resources. Drought areas are predicted to increase in area.

Region	Predicted change in annual runoff to 2100
Asia	Northern latitudes (+ 20% to + 40%) Mid latitudes (+ 2% to + 20%) Southern latitudes (+ 10% to + 40%)
Europe	Northern latitudes (0% to + 20%) Southern latitudes (0% to - 40%)
Middle East and North Africa	All region (- 5% to - 40%)
Sub Saharan Africa	Eastern seaboard, mid latitudes (+ 5% to + 40%) Southern region (- 5% to - 20%) Little change elsewhere
North America	Northern latitudes (+ 10% to + 40%) Western seaboard, mid latitudes (- 5% to - 20%) Little change elsewhere
Central America and Caribbean	All region (0% to - 20%)
South America	Eastern seaboard, southern latitudes (+ 5% to + 20%) Western seaboard, northern latitudes (+ 5% to + 10%) Eastern seaboard, southern latitudes (0% to - 40%) Little change elsewhere
Oceania	Northern latitudes (0% to + 20%) Western seaboard, mid latitudes (- 5% to - 20%) Southern latitudes (0% to +10%) Little change elsewhere

Table 20 Projected regional changes in the annual runoff to 2100

Overall, the consequences of the anticipated changes to the hydrological cycle on humanity, brought about by climate change are:

- An increased demand for irrigation water for food production, which is likely to translate into a demand for more storage reservoirs for fresh water.
- An increased demand for hydropower to enhance energy supplies from non-fossil related sources.
- A need to protect communities from flooding, whether caused by more severe storms in inland areas or the effects of sea level rise in coastal zones.

9 Future needs for reservoir storage

Man-made reservoirs are used for many purposes. They are particularly useful where precipitation patterns are seasonal, storing flood waters which would otherwise be lost to the system and releasing water during prolonged dry periods. The pressure for more storage comes from two main factors:

- Increasing world population
- Increasing needs and aspirations of the population

As a result of these two factors there are pressures on food production, power production, and water quantities for industrial and domestic purposes. Man-made reservoirs are particularly relevant to all of these.

The prediction of how much more storage will be required to meet future needs is a complex issue. It depends on many individual factors which are difficult to predict and which are often inter-dependent. Past experience can be used to look at short to medium term needs, say up to 25 years ahead, but uncertainties in longer term predictions remain high. This is particularly so in the light of climate change and the measures which are taken to combat climate change.

Short term requirements for reservoir storage

The approach adopted by ***White***, 2001 [7] was to look at historic growth rates for several relevant parameters for the period from 1975 to 1995 and then to use these trends to make predictions for the mid-term future.

The relevant parameters included:

- Population growth rate
- Water demand for both domestic and industrial purposes
- Demand for hydro-power
- Demand for irrigation water for food production

White, 2001 [7] assumed a population growth rate globally of 1.4% per annum in the year 2000 falling to 0.45% per annum by 2050 when the population would be around 10 billion. Subsequent estimates reduce this final figure marginally. Global growth rates in the demand for water were considered to be 2.5% per annum in 1975 and 2.3% per annum in 1995. Corresponding rates for hydropower were 3.2% per annum and 2.6% per annum and for irrigation 1.8% per annum and 1.5% per annum. These data, together with population data are shown in Figure 15.

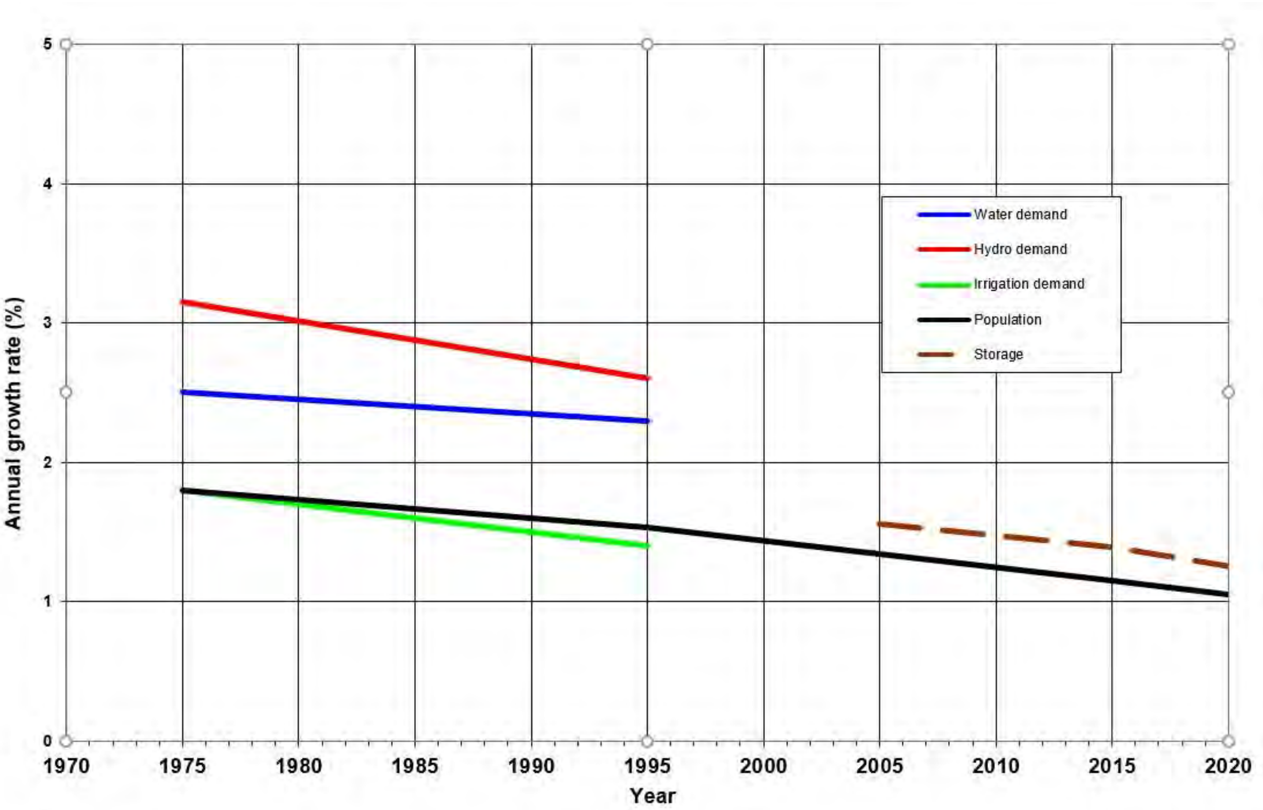

Figure 15 Global growth rate for new storage
Source: ***White W R***, 2001 [7]

White, 2001 [7] suggested that, to meet demand, a modest growth rate in reservoir storage of 1.5% in 2005 falling to 1.3% in 2020 would be required. Dams under construction at the date of this study would provide a reservoir capacity of 489 km^3, representing 7% of the world total. Russia and China accounted for 235 km^3 of this additional reservoir capacity.

In the analysis made by ***White***, 2001 [7], known rates of dam construction in the period 2000 to 2010 were applied to the following two decades. The current rate of loss of storage due to sedimentation of 0.5% was applied throughout the period. The demand for additional storage is assumed to be 1.6% in 2000 falling to 1.2% in 2030. The results of this analysis, on a global scale, are shown in Figure 16.

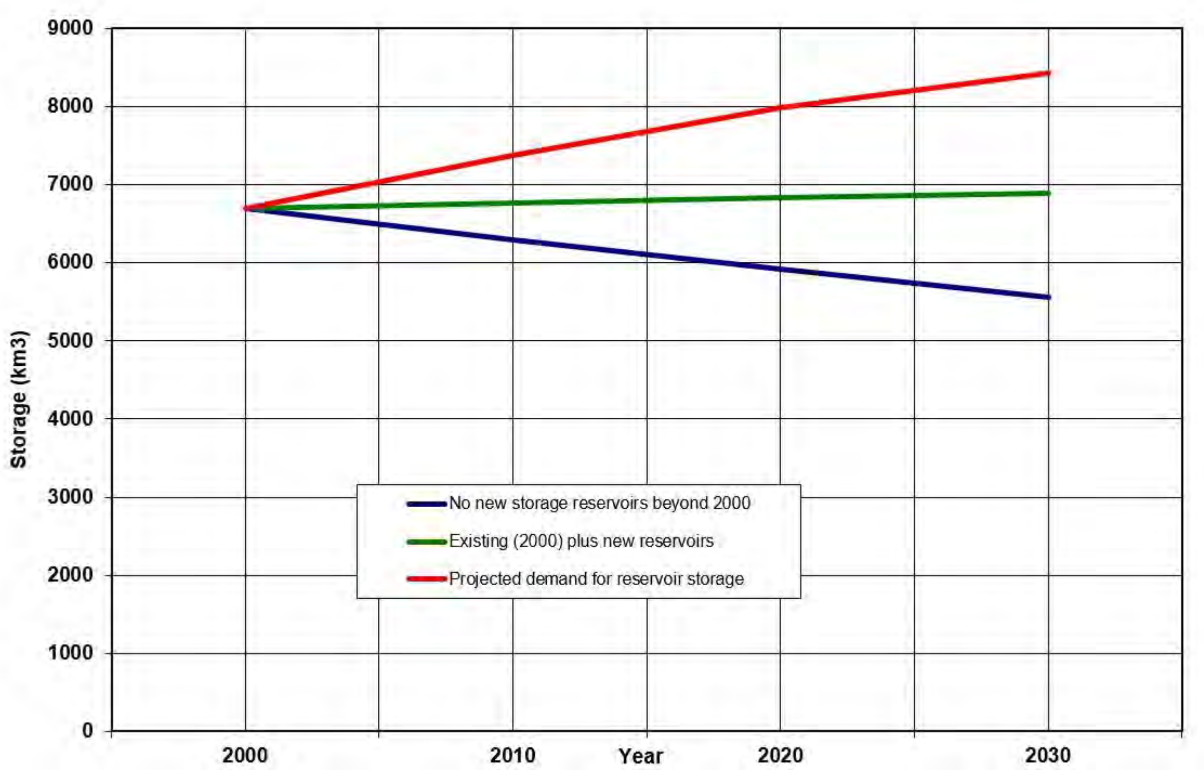

Figure 16 **Future trends in reservoir storage**
Source: ***White W R***, 2001 [7]

The lower curve in Figure 16 shows how reservoir storage would diminish due to sedimentation if no new reservoirs were to be constructed. The central curve shows how reservoir storage would develop if the rate of dam construction in 2000 to 2010 continues to 2030. The upper curve is the projected demand for storage. A shortfall of around 1 500 km^3 is anticipated in 2030 using this analysis.

The analysis presented by ***White***, 2001 [7] also provides an indication of regional mis-matches between projected supply and demand for storage. These are illustrated in Figure 17.

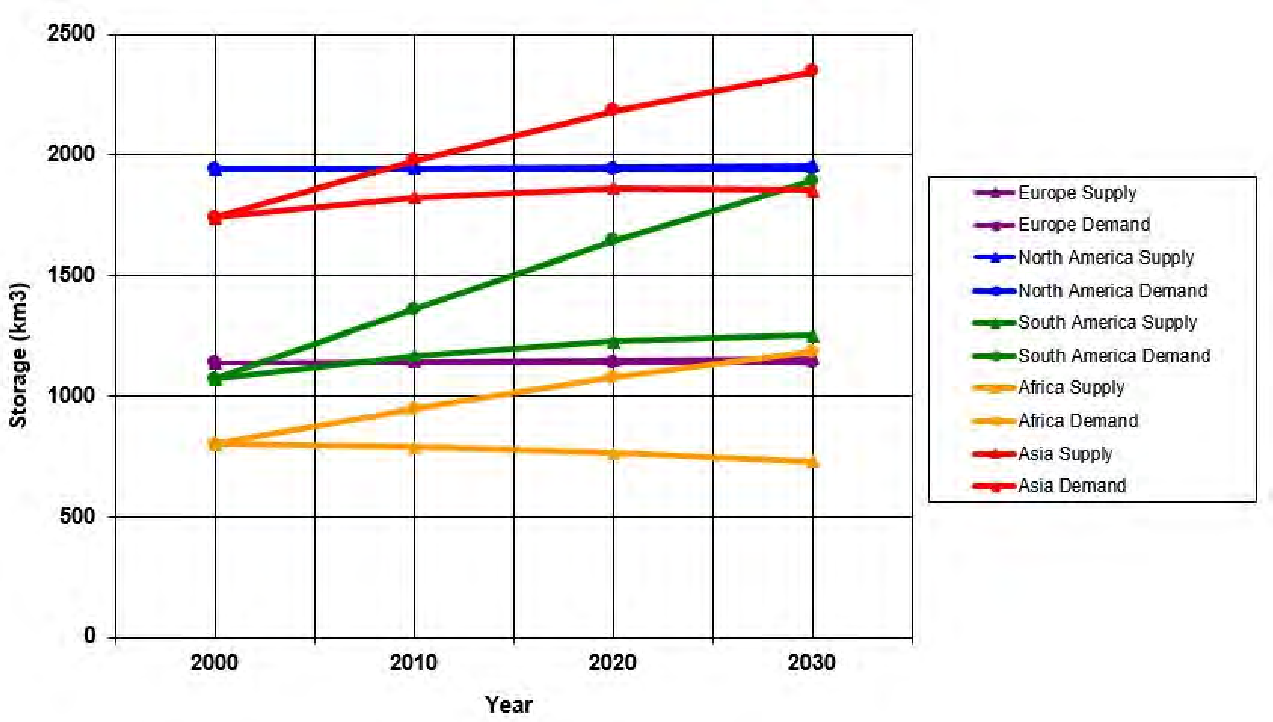

Figure 17 **Future regional trends in reservoir storage**
Source: ***White W R***, 2001 [7]

Figure 17 shows that in Europe and North America the demand for, and supply of, reservoir storage will generally remain in balance for the foreseeable future. This is due to relatively low population growth rates and public aspirations which are already largely met. The picture in South America, Africa and Asia is very different with demand outstripping supply in the foreseeable future.

Longer term requirements for reservoir storage

Table 21 lists the more important regional parameters which are of relevance in deciding where the most and the least pressures will lie for more reservoir storage in the longer term.

Column 2 lists the water resources available per person and column 3 lists their current usage of water. Column 4 is the ratio of columns 2 and 3 and shows the percentage usage of available water resources in the region. Column 5 is the current reservoir storage in the region and column 6 is the ratio of the reservoir storage to available water resources per annum. Column 7 is taken from ***USCB***, 2009 [6] and gives an indication of the rate of population growth in the regions. Column 8 is taken from Table 20 and gives an indication of the likely changes in precipitation / runoff in the regions.

Region	Actual renewable water resources [ARWR] per person (m^3/yr)	Water usage [WU] per person (m^3/yr)	Total WU / ARWR (%)	Total reservoir storage [TRS] (^{km3})	TRS as % of annual ARWR	Predicted growth of population from 2009 to 2050 (%)	Predicted change in annual runoff to 2100 (%)
1	2	3	4	5	6	7	8
Asia	3 938	581	15	1 299	9	+ 33	+ 2 to + 40
Europe	10 663	566	5	1 199	48	- 14	+ 20 to - 40
Middle East and North Africa	1 408	782	56	285	62	+ 59	- 5 to - 40
Sub-Saharan Africa	6 944	152	2	580	11	+ 110	- 20 to + 40
North America	17 770	991	6	1 922	32	+ 41	- 5 to + 40
Central America and Caribbean	6 956	561	8	150	12	+ 29	0 to - 20
South America	45 323	437	1	969	6	+ 23	+ 20 to - 40
Oceania	52 906	812	2	111	7	+ 61	- 20 to + 20
WORLD	**8 281**	**555**	**7**	**6 616**	**12**	**+ 38**	**0 to + 10**

Table 21 Some regional parameters relating to reservoir storage requirements

Table 22 is an attempt to summarise the needs of different regions for more storage in fresh water reservoirs based on the information given in Table 21 and elsewhere in this ROCK. The predictions of the effects of climate change and future world development scenarios are such that it would be invidious to deal with this subject country by country.

Region	Notes	Storage needs
Asia	• High population growth rate • Significant increase in runoff in most areas • Water usage a significant proportion of runoff • Many developing countries with power needs	*Very likely* to need a significant increase in reservoir storage for agricultural, domestic and industrial needs.
Europe	• Population almost static • Less runoff in southern areas • Countries mainly developed	*Unlikely* to need significant increase in reservoir storage except in drought prone southern areas.
Middle East and North Africa	• Very high population growth rate • Significant reduction in runoff • Water usage a high proportion of runoff • Mixture of developed and developing countries	*Likely* to need more reservoir storage for agricultural, domestic and industrial needs but this will be difficult to provide.
Sub-Saharan Africa	• Extremely high population growth rate • Less runoff in central areas, more elsewhere • Mainly developing countries	*Very likely* to need a significant increase in reservoir storage for agricultural, domestic and industrial needs.
North America	• Medium population growth rate • Significant increase in runoff in most areas • Developed countries	*Unlikely* to need significant increase in reservoir storage except in areas of reduced runoff.
Central America and Caribbean	• Medium population growth rate • Not much change in runoff • Mainly developing countries	*Likely* to need some increase in reservoir storage for agricultural, domestic and industrial needs.
South America	• Medium population growth rate • Significant reduction in runoff in many areas • Mixture of developed and developing countries	*Unlikely* to need significant increase in reservoir storage except in areas of reduced runoff and in some developing countries.
Oceania	• Very high population growth rate • Modest increases or decreases in runoff dependent upon location • Mainly developed countries	*Likely* to need some increase in reservoir storage for agricultural, domestic and industrial needs dependent upon location.

Table 22 Regional needs for freshwater storage

Despite the perceived need for more storage in many parts of the world the construction of large dams has slowed significantly in recent years. Figure 18 shows data on the construction of large dams for the period from 1900 to 2010. This data comes from the ***Global Reservoir and Dam*** (GRanD) Database which is hosted by the Center for Development Research at the University of Bonn.

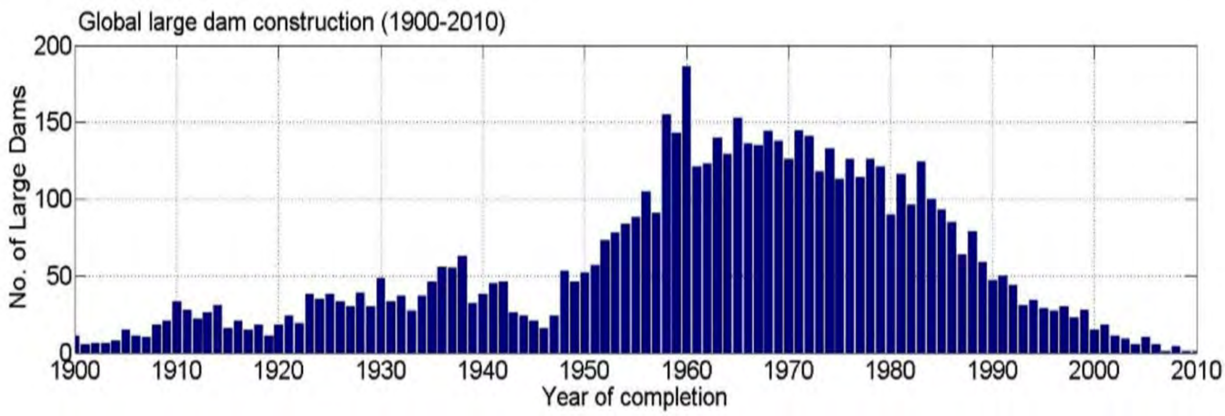

Figure 18 **Global large dam construction (1900 – 2010)**
Source: www.gwsp.org/products/grand-database.html

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Appendix Regional Distribution of Countries

Africa

Algeria	Congo	Guinea	Morocco	South Africa
Angola	Democratic Republic of the Congo	Guinea-Bissau	Mozambique	South Sudan
Benin	Djibouti	Kenya	Namibia	Sudan
Botswana	Egypt	Lesotho	Niger	Togo
Burkina Faso	Equatorial Guinea	Liberia	Nigeria	Tunisia
Burundi	Eritrea	Libya	Rwanda	Uganda
Cabo Verde	Eswatini	Madagascar	Sao Tome and Principe	United Republic of Tanzania
Cameroon	Ethiopia	Malawi	Senegal	Zambia
Central African Republic	Gabon	Mali	Seychelles	Zimbabwe
Chad	Gambia	Mauritania	Sierra Leone	
Comoros	Ghana	Mauritius	Somalia	

Americas

Antigua and Barbuda	Chile	Grenada	Panama	Trinidad and Tobago
Argentina	Colombia	Guatemala	Paraguay	United States of America
Bahamas	Costa Rica	Guyana	Peru	Uruguay
Barbados	Cuba	Haiti	Puerto Rico	Venezuela (Bolivarian Republic of)
Belize	Dominica	Honduras	Saint Kitts and Nevis	
Bolivia (Plurinational State of)	Dominican Republic	Jamaica	Saint Lucia	
Brazil	Ecuador	Mexico	Saint Vincent and the Grenadines	
Canada	El Salvador	Nicaragua	Suriname	

Asia

Afghanistan	Georgia	Kyrgyzstan	Pakistan	Thailand
Armenia	India	Lao People's Democratic Republic	Papua New Guinea	Timor-Leste
Azerbaijan	Indonesia	Lebanon	Philippines	Turkey
Bahrain	Iran (Islamic Republic of)	Malaysia	Qatar	Turkmenistan
Bangladesh	Iraq	Maldives	Republic of Korea	United Arab Emirates
Bhutan	Israel	Mongolia	Saudi Arabia	Uzbekistan
Brunei Darussalam	Japan	Myanmar	Singapore	Vietnam
Cambodia	Jordan	Nepal	Sri Lanka	Yemen
China	Kazakhstan	Occupied Palestinian Territory	Syrian Arab Republic	
Democratic People's Republic of Korea	Kuwait	Oman	Tajikistan	

Europe

Albania	Denmark	Ireland	Norway	Spain
Andorra	Estonia	Italy	Poland	Sweden
Austria	Faroe Islands	Latvia	Portugal	Switzerland
Belarus	Finland	Liechtenstein	Republic of Moldova	The former Yugoslav Republic of North Macedonia
Belgium	France	Lithuania	Romania	Ukraine
Bosnia and Herzegovina	Germany	Luxembourg	Russian Federation	United Kingdom
Bulgaria	Greece	Malta	San Marino	
Croatia	Holy See	Monaco	Serbia	
Cyprus	Hungary	Montenegro	Slovakia	
Czechia	Iceland	Netherlands	Slovenia	

Oceania

Australia	Marshall Islands	Niue	Tokelau	
Cook Islands	Micronesia (Federated States of)	Palau	Tonga	
Fiji	Nauru	Samoa	Tuvalu	
Kiribati	New Zealand	Solomon Islands	Vanuatu	