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Resources and Needs: Assessment of the World Water Situation *

INTRODUCTION

THE POTENTIAL WORLD WATER CRISIS: A CALL FOR ACTION

Leonardo da Vinci described water as "the driver of nature". An overstatement? Perhaps. Still the fact remains: water makes human life possible. And it is difficult to imagine any programme for human development or improvement that does not presuppose or require a readily available supply of water.

Readily available for much of the world's population, water has traditionally been regarded as an inexhaustible gift of nature by many societies. Such complacency about this life-giving resource threatens human welfare, livelihood, development, and indeed life itself in the years to come.

One only has to consider that right now population growth accompanied by agricultural development is straining water resources even in humid lands — not only in highly industrialized regions but also in less developed areas of the world.

The projected doubling and trebling of the world population, coupled with increasing world industrialization and agricultural development, accelerates this trend. At the same time, population growth together with industrial and agricultural development all contribute to a serious deterioration in the quality of water.

It is consequently a statement of fact rather than mere conjecture to say that there will be a critical shortage of water of suitable quality to sustain future growth unless water management is radically improved.

In any discussion about water, it is important to stress that we are speaking of a *fixed* total stock. Unlike other natural resources, the total global supply of water can be neither increased (as timber or fish) nor diminished (as petroleum or coal). Since water is continuously being renewed through nature's hydrological cycle, it is potentially inexhaustible. While this is so, locally available supplies can at the same time be quickly depleted or made unusable by inadequate conservation, pollution or over-all careless management.

In theory, the global stock of water could meet greatly expanded human needs. In reality, the traditional sources of water supply, surface run-off and groundwater stores, are inequitably distributed among peoples and countries. Some communities live where regular precipitation gives them an ample surplus at present. Others have far more water than they want or need, but not necessarily in the right place or at the right time. Still others have barely enough water for current needs, and drought is perennial through the wide belt of arid lands.

* This document has been prepared by the Conference secretariat in co-operation with the interested organizations and programmes of the United Nations system. The secretariat gratefully acknowledges the assistance of Professor Gilbert F. White, who acted as consultant in the preparation of the document.

In short, globally there may be potentially enough water to meet forthcoming needs. But, frustratingly, it tends to be available in the wrong place, at the wrong time, or with the wrong quality. And in one way or another, all societies are affected, however rich, however poor.

This general assessment of a world-wide condition becomes a specific reality when one considers:

(a) Reasonably safe supplies of drinking water are unavailable for at least one fifth of the world's city dwellers and three quarters of its rural people; in many countries, less than one half of the urban population and less than one tenth of the rural population are served with an adequate and safe water supply;

(b) Increasing and unplanned concentration of population and industry in large urban areas strains water supply: this leads to problems of waste disposal which, in turn, degrade the quality of life and environmental health;

(c) Proliferation of industrial processes, greater use of energy and increased agricultural activity are causing progressive and chronic degradation of the quality of available water by the increase of toxic compounds and other pollutants: the mutagenic and carcinogenic effect of these substances poses a potential threat to human life;

(d) Backwardness and relative isolation of rural areas where the great majority of the world population now lives aggravate the difficulty of providing adequate and safe supplies of drinking water, improved sanitation and waste disposal;

(e) Expansion of food production in water-short areas and in marginal lands has necessitated rapid development of irrigation and land reclamation, to the degree that water and land resources have been exploited to their limit in many areas;

(f) Ever-growing land degradation from such causes as water-logging, salinization and erosion is leading to losses in production potential, investment and employment;

(g) Ground-water supplies are being exhausted, while both surface- and ground-water sources are deteriorating in many areas;

(h) Water use is often needlessly inefficient and wasteful, considering the possible application of scientific knowledge and the setting of appropriate service levels;

(i) Expensive technology for water development to compensate for shortage is straining inadequate resources in many regions;

(j) Conflicts about rights and priorities among users intensifies as the demand for available water accelerates.

These problems affect different societies in different ways. The immediate concern may be unpotable water and human waste in the shanty town of a tropical city, multiplying wastes in an industrialized high-income country, shortage of water impeding agricultural development in an arid land, watershed destruction and ground-water depletion in an entire nation.

One may perceive these as local, regional and national problems. And indeed they are. But while it may be said that arid lands, for instance, have their exclusive set of problems — as have industrialized nations — still, many problems are common to many regions and communities. In many instances, the resolution of these problems would benefit greatly from the sharing of national experience and the rational management of whole river basins that know no national boundary. For this reason, it is useful and practical to view current local and regional problems about this global resource as a global concern requiring co-operation among nations. Without such collaboration, it will not only be difficult to alleviate current short-comings, but more important, to curb their proliferation and avert a world water crisis.

Obstacles to such salutary co-operation are deeply rooted. Water has traditionally been regarded as a local concern, and much past management has been exclusively limited to local programmes. The major constraint, however, to broader co-operation is complacency about a natural resource that may currently be perceived as inexhaustible in some areas. This constraint is compounded by varying policies, or even lack of policies, that stem from widely varying national priorities, opportunities and limitations. Today circumstances of population and industrial growth, as well as technological complexities, force us to take a more comprehensive international view.

Nations may attempt to solve water problems unilaterally. But this may result in unnecessary and wasteful duplication of effort. What is more, many nations are limited not only in their ability to estimate the long-term effects of any new local water system they may initiate but also in their capability to appraise the full implications of such a system on the future well-being of the entire nation and its neighbouring countries.

This preamble serves as a brief statement of a grave condition and as an introduction to matters that will be developed and expanded in subsequent papers prepared by the secretariats, interested organizations and programmes of the United Nations system.

The first of these papers, "Resources and needs: an assessment of the world water situation", is a preliminary step in the understanding of the problem and its possible solution. The second paper will treat technology and how it may best be used under different socio-economic conditions.* A third paper will explore policy options and consider how institutions and water policies may best be adapted to the physical, economic and cultural conditions of individual countries.**

Finally, it is expected that concern about this vulnerable resource will be translated into a series of concrete proposals for action at national and international levels. Water resources might then be efficiently and rationally developed and used for the betterment of all concerned nations and mankind. To quote from the conclusion of this first paper: "It should ... not be taken for granted that any sector of the world's population need drink contaminated water, that industry need continue its present pattern of largely unregulated water use and discharge, that agriculture cannot alter its current pattern of irrigation loss and misuse of water, or that productive soils need be destroyed and aquifers exhausted beyond our ability to replenish them in our own lifetime."

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*See *Water Development and Management*, edited by Asit K. Biswas, Pergamon Press, Oxford, 1978.

**Included in this volume, see pp. 70-110.

I. AN OVERVIEW OF THE WORLD SITUATION

The total amount of world water is constant and can be neither increased nor diminished. Most is ocean water. Only a small proportion is fresh, and of this fresh supply, less than 1 per cent is available for human use in streams, lakes, swamps and in the ground; the rest is locked away in ice-caps and glaciers.

Estimates of the volume of fresh-water supply can be derived from observation and measurement of precipitation, evaporation and ground water. Short-comings in appraisal methods, however, and lack of basic hydrological data in some areas limit the accuracy of these estimates. Still, rough estimates can be made for continents and for the world as a whole. These reveal tremendous variations in local supply, ranging in scale from rocky deserts with virtually no water to tropical forests with a water surplus throughout the year. At any one place, the available supply may vary from day to day and from year to year. Water supply also varies in mineral, chemical and bacteriological quality.

Water is mostly used for domestic, industrial and irrigation purposes, and of these, irrigation often accounts for more withdrawal than all the other uses combined. Some water is used for on-site agriculture and mining. Livestock, fish and wildlife all require water. Lakes and streams are used for transportation, recreation, and the generation of hydroelectric power. Other water is stored, diverted or confined to reduce losses from floods. A rapidly growing use is for the conveyance and disposal of wastes from cities, factories and farms.

What will be the future demand for these uses? What effect will this demand have upon supply and its quality? How will this, in turn, affect human health and welfare?

These questions are crucial. Faced with fixed supply and growing demand, their solution in any area will depend upon prevailing economic and social conditions, administrative and judicial processes, the availability of funds to effect change, and the availability and suitability of technology in so far as it affects the environment and the health of the population.

Since these are dynamic considerations, any measure taken for the improvement of water supply and use in a country may become inappropriate in that country at a later time and may be entirely inapplicable to the aims and policies of other countries at any time.

In a world context, the long-term effects of man-inspired development are conjectural. Just as shifts in the relative properties of the land surface may influence climate, so may the construction of new water reservoirs and the diversion of streams and ocean currents. Further, alterations in the chemical content of streams flowing into the ocean may affect ocean life.

In the short run, the welfare of humanity is likely to be measurably affected by the success with which nations adapt their activities to the realities of available water supply and human needs in specific river basins or regions. With few exceptions, supply is highly variable in each region; information

about water resources is inadequate, potential uses are multiple and involve trade-offs in allocating supply; standards of quality tend to be determined by local or national preference; the application of scientific knowledge about water and its use lags far behind the findings of basic research.
These generalities only take on their full meaning when expressed in terms of concrete situations. However important global statistics may be, they have more significance when expressed in terms of a specific water basin or country. Only then do they reveal the problems affecting the capability of peoples and nations to develop and even survive.

II. ASSESSMENT OF FRESH-WATER SUPPLIES: PHYSICAL RESOURCES

A. *Water and Fresh Water in the Global Cycle*

Recent estimates show that the total volume of water on earth is about 1.4×10^9 cubic kilometres. More than 97 per cent is ocean water. At any given moment, an estimated 77.2 per cent of fresh water is stored in ice-caps and glaciers, 22.4 per cent is ground water and soil moisture, 0.35 per cent is in lakes and swamps, 0.04 per cent is in the atmosphere and less than 0.01 per cent is in streams (see table 1).

Table 1. *Total volume of water on earth*

	Percentage
Ocean water	97.3
Fresh water	2.7
Location of fresh water:	
Ice-caps and glaciers	77.2
Ground water* and soil moisture	22.4
Lakes and swamps	0.35
Atmosphere	0.04
Streams	0.01

Source: A. Baumgartner and E. Reichel, *The World Water Balance* (Munich, 1975).

* About two thirds lies deeper than 750 metres below the surface.

While ice-caps, glaciers and ground water account for most fresh water resources, for all practical purposes, it is surface water that constitutes the basic available supply for most people.

Through the hydrological cycle, water circulates from earth to atmosphere to earth: driven by the suns's energy, water moves endlessly from the oceans to the atmosphere to the continents, and back again to the oceans; much precipitated water that falls on land is evaporated into the atmosphere; some is absorbed by plant roots and re-enters the atmosphere via leaf-pore transpiration; some travels over or under the earth's surface and eventually reaches the sea. Because oceans cover seven tenths of the earth's surface, it is evident that a major part of precipitation falls directly into the sea; it has passed through the hydrological cycle without having been a natural resource at all.

With a few minor exceptions, the only water that can thus be considered as a potential resource for man is that portion of total precipitation that happens to fall on land. It is a usable resource only from the moment it strikes the land surface until the moment it re-enters the oceans or one of the land-locked seas or salt lakes, and only so long as it remains comparatively pure.

Although surface water provides most of man's available supply, ground-water use has been heavily developed in some parts of the world and this has resulted in the excessive exploitation of some water-bearing formations. With improved knowledge, reliance on ground water will undoubtedly increase. But there is much to learn about ground water and its rational use, and it will require particularly intelligent management. In contrast, surface water has been far more thoroughly and systematically studied.
Given favourable circumstances, water supplies can be increased by such techniques as watershed management and the direct harvesting of precipitation.

Less conventional sources of increased availability include cloud-seeding, desalination and waste water re-use. While these non-conventional sources may be important in a particular local context and may become more important in the future, surface and ground water will probably remain the most important supplies for some time to come.

The usefulness of water and its socio-economic value depend upon its quality. For this reason, any assessment of fresh water must take into account both quality and quantity.

B. *Methods of Appraising Surface Water*

All the water reaching the streams within a river basin is potentially available as surface-water supply. The degree of availability will vary at different places along the flow of a stream; the quantity of water available at any specific location can be determined by estimates of discharge flow, measurement of stage, velocity and channel section of the stream flow.

Since the design, planning and management of water resources require knowledge of the time characteristics of flow, it is important to have a continuous record of stream-flow data for many years at points of withdrawal or use. Of course, it is rarely possible to forecast the locations for which stream-flow data will be needed in the future. Moreover, lack of funds and trained manpower often preclude the possibility of maintaining extensive data-gathering networks. Great skill and care are required in the design and operation of basic data networks to maximize the benefits from limited expenditure. For these and other reasons, it is necessary to rely heavily on estimates. These may be derived either from measurements made at other locations or from analysis of the relationship between stream-flow and other hydrometeorological data and physiographic characteristics. Observations from similar locations may be judiciously pooled to provide better data than could be derived exclusively from any one location.

Whether estimated or directly measured, the mean annual flow of a stream over a period of many years will thus represent available surface-water supply. Full use of this supply would require that demand coincide with flow at any given time. The extent to which supply is in fact used will depend upon the interrelation of rate of flow at a particular time, areal distribution and the technology that can be applied by the people concerned.

Consequently, any appraisal of water supply must take economic and environmental as well as hydrological data into account if we are to develop plans that harmonize demand and supply within acceptable economic limits. The physical studies require frequency and sequential analyses of flow data, and should also pay heed to the availability of ground water supplies.

Annual analysis of discharge data will yield adequate information for the planning and management of very large reservoirs such as Lake Volta. In such large reservoirs, a series of *annual* discharge data may permit evaluation of the possibility of critically low inflow for periods of several years. In contrast, in the case of smaller water supply reservoirs, it is necessary to know the variability of discharge *within* the year. And for many projects it is even necessary to consider *daily* discharges and possible extreme flood conditions.

Although sufficiently reliable estimates of the volume and variability of stream flow can sometimes be made by direct comparison with flow at nearby locations, it is more often necessary to use relationships between flow itself and other factors.

Hydrologists and engineers have many scientific tools and methods for assessing water supply in the absence of direct measurements. The improvement of these methods and their dissemination was the main objective of the International Hydrological Decade (1965-1974) and of the International Hydrological and Operational Hydrology Programmes of UNESCO and WMO, respectively, particularly concerning the water balance.

Fundamental to the water balance concept is the equation of continuity. That is, for any hydrological unit and specified time period:

$$\text{Outflow} = \text{inflow} \pm \text{change in storage.}$$

This principle is applicable to a small catchment, a major river basin, a reservoir, a continent, or the world as a whole. Since changes in storage become negligible when projected over a long period of time, the mean annual water balance for a river basin can be stated:

$$\text{Run-off} = \text{precipitation} - \text{evapotranspiration.}$$

(Evapotranspiration may be defined as transpiration and evaporation from soil, water and other surfaces.)

Maps of average annual precipitation, evaporation and run-off, are best derived from systematic water balance analysis. The isolines can be constructed so that a balance of the three terms of the equation is achieved at all locations, thereby providing a quick, approximate estimate of the three terms on a geographical basis.

The water balance concept is basic to water resource analysis because it provides a means for estimating the value of hydrological and meteorological data in assessing the effects of proposed developments. The water balance is applicable for any period of time. For short periods of time, changes in storage become a predominant consideration and cannot be neglected. In such circumstances, it is helpful to apply conceptual modelling techniques in which factors and natural laws governing the movement of waters in a basin are represented by mathematical formulae. Modelling involves repetitive solution of complex functions requiring the aid of an electronic computer. Such techniques can provide estimated daily values of several components in the cycle and may serve many purposes. They are particularly helpful in evaluating the consequences of man's activities on water resources.

C. Methods of Appraising Precipitation and Evapotranspiration

Precipitation is the primary source of water supply for world food production: though irrigation places many demands upon stream flow and ground water, it only supplements precipitation in meeting the basic consumption requirement of crops. Precipitation data therefore play a vital role in water resource development and management. Records are generally more extensive and more numerous than those for stream flow, largely because the measurements can be made by lay observers and the equipment used is less costly. Consequently, measurement networks are often densely concentrated in some regions. Average annual precipitation values can be correlated with physiographic characteristics. The resulting relationships can then be used for interpolation of data in areas of sparse measurement networks. On the whole, however, precipitation is generally undermeasured and reliable averages are difficult to obtain.

The common methods of projecting water supply assume a continuation of prevailing climatic conditions. Since planning for the development and use of water supplies is, by necessity, based on the recently recorded past, the possibilities of significant changes in climate are of critical concern. For example, it is important to know whether widespread and prolonged drought — such as that experienced recently in the Sudano-Sahelian zone of West Africa — can be expected to occur within the natural year-to-year cycle or should rather be considered the result of climatic change.

There is abundant evidence that major changes in climate have occurred during the history of the earth (the ice-ages, for example), and there is no reason to presume that the present climatic régimes will not change within the next 1000-5000 years. More important, but less evident, is the magnitude and probability of natural changes which can occur within periods of, say, 50 to 100 years. Such information, if it were available, could be advantageously used for planning purposes. There is, therefore, an obvious need for improved understanding of the nature and causes of trends in climatic change.

Evapotranspiration is the most difficult term to evaluate in the water-balance equation. Observations are usually restricted to measurements of loss from tanks containing water, plants and soil, or soil alone. There are many techniques for computing free-water evaporation and *potential* evapotranspiration (the maximum water loss under prevailing meteorological conditions uninfluenced by soil-moisture deficiency). These techniques involved the observation of the influence of radiation, wind movement, temperature and humidity, for example. While it is hoped that ways will be found to improve methods of estimating evapotranspiration in the future, reasonably reliable analyses can be made, even at present, where an adequate data-gathering network exists. The techniques for estimating free-water evaporation are more reliable than for evapotranspiration. This is a matter of some importance in project planning and design. For example, the evaporation from Lake Nasser represents about one quarter of the normal flow of the Nile at Aswan.

D. *Methods of Appraising Ground Water*

Ground water and surface water commonly form a linked system. Flow can be in either direction, and the rate of flow varies geographically and chronologically.

The interchange is not significant for some aquifers (rock or soil containing and transmitting water). But it has been estimated that about 30 per cent of the total flow in surface streams is supplied from ground water, and seepage from streams is known to be a principal source of inflow to some aquifers. Water withdrawn from riparian wells along an alluvial stream can effect an appreciable reduction in surface flow, and the diversion of surface flow can reduce ground-water recharge. But in other instances, withdrawal from either source has no effect on supply from the other. Although the methods of appraisal are different for ground and surface water, supply from either source cannot be evaluated independently unless it is established that the interchange is minimal.

It is important to note that there are two distinct types of circumstances concerning the development and management of ground-water supplies. Normally, ground water is considered a renewable resource with optimal use restricted to the average rate of recharge. "Mining" of ground water, however, is sometimes carried out with fixed-term objectives: the aquifer which supports 1.5 million hectares of irrigated land in the Texas Panhandle will be exhausted within a few decades at current pumping rates.

Average annual recharge can in extreme cases be relatively insignificant, as in the large artesian basin of the intercalary of the northern Sahara. This basin contains immense quantities of fresh water, some of it with ages up to 40,000 years.

To reflect the possible mining of water in appraisals of total regional or global supply, it is necessary to assume withdrawal rates and take into account the total storage and planned development. The appraisal of aquifer storage in particular requires extensive on-site exploration.

The estimated rate of withdrawal of ground water on a continuing basis is a key factor in the appraisal of regional or global water supply. The maximum rate at which water can be withdrawn without adversely affecting the source may be termed "safe yield". Since supply recharge in many cases tends to increase with draw-down, the safe-yield concept must incorporate economic considerations if it is to serve any practical purpose. Safe yield may also depend upon the location, spacing and depth of the bore-holes in relation to the speed of movement of water underground.

Flow rates in aquifers are normally extremely slow, and time lags in underground phenomena can therefore be very long. It may take more than a century for an increase in water level in the recharge area of an extensive artesian aquifer to be transmitted to remote locations in the aquifer. It is important, therefore, that variations in pressure or water level be correctly related to causal factors, with due consideration given to lags in time.

The quantity of water available under specified conditions may be estimated from the water-balance equation. The equation can be written for surface and subsurface components of the basin as a whole, or for the ground-water reservoir only. The latter approach is essential for adequate understanding of the ground-water régime and for management purposes, while the former is more suitable for evaluation of total surface and ground-water supplies.

Either way, a sound estimate requires accurate hydrological data and extensive information about aquifer characteristics. Because of the interrelationships involved, the solution may become extremely complex and the results somewhat less accurate than for surface-water evaluation alone. Various types of models have been devised to cope with ground-water assessment — physical, analogue and mathematical — and these are acquiring widespread use.

E. *Methods of Appraising Water Quality*

The physical, chemical and biological properties of water determine the suitability of its quality for various uses.

Water is considered to be polluted when it is altered in composition, directly or indirectly, to the degree that it is less suitable or even unsuitable — for a particular use or function. Pollution increasingly results from man's activities, but water in its natural state is not always of sufficiently good quality to serve all uses. For example, saline waters are sometimes found in arid and semi-arid regions, some streams in their natural state carry heavy loads of silt in suspension or as bed load.

Pollutants reach water bodies from "point sources" such as power stations, factories, mines and city sewer outlets, and from "non-point sources" such as eroding banks and cultivated fields.

Measurement of the concentration of pollutants can be made at points of waste discharge and in downstream reaches or aquifers. The monitoring of quality is made difficult by two conditions. First the concentration of pollutants in aquatic ecosystems is affected by many external conditions, including stream flow, turbidity and temperature, and these episodic effects are rarely proportionate to the average volume of the pollutant. Secondly, it is uncertain how a given dose of a particular polluting substance will adversely affect humans, fish, benthic and other organisms in the environment.

It is impractical and incorrect to consider data from one measurement station as representative of the characterisitics of a long water stream. Accordingly, observations of water quality are made by collecting and analysing samples periodically at a network of stations along streams, lakes and at bore-holes. On a stream such as the Rhine or the Ohio, the analyses take into account: temperature, sediment load, dissolved solids, major nutrients such as phosphorous and nitrogen, organic material as measured by biochemical oxygen demand and dissolved oxygen, salts, acidity, bacteriological contamination as measured by coliform organisms, and heavy metals.

The difficulties of monitoring quality are intensified by the proliferation of man-made chemical compounds that find their way into water bodies. As a result, it is debatable whether existing networks and current monitoring methods are truly effective in identifying the existence and point of entry of potentially harmful substances. It should also be noted that some chemical pollutants are removed in conventional water-treatment processes, while others remain.

Table 2. Networks of hydrological stations

Region	Non-recording rain-gauges		Self-recording rain-gauges		Evaporation stations		Discharge stations		Sediment stations		Water-quality stations	
	Number existing	Existing density 1000 square kms/station	Number existing	Existing density 1000 square kms/station	Number existing	Existing density 1000 square kms/station	Number existing	Existing density 1000 square kms/station	Number existing	Existing density 1000 square kms/station	Number existing	Existing density 1000 square kms/station
Africa[a]	18 520	1.48	1 214	22.61	1 043	26.32	4 390	6.19	740	36.73	801	33.94
Asia[b]	17 815	1.69	2 489[c]	11.92	1 590	18.00	6 386	4.58	1 601	17.30	3 290	7.94
South America	12 200	1.05	2 106	5.92	1 091	11.72	3 709	3.45	701	18.24	374	34.20
North and Central America[d]	19 499	1.11	4 547	4.78	2 538	8.56	14 521	1.49	1 851	11.70	3 291	5.94
South West Pacific	16 419	0.69	1 795	6.13	569	19.32	4 801	2.19	749	14.06	2 399	4.39
Europe[e]	44 704	0.13	5 356	1.09	1 004	5.53	12 926	0.82	2 057	4.63	8 284	0.53

Source: Survey made by the World Meteorological Organization in 1975.

a Excluding Botswana, Congo, Ivory Coast, Sierra Leone, Somalia.

b Excluding Afghanistan, China, Democratic Yemen, Kuwait, Nepal, Yemen.

c Excluding Japan, which alone has 4,167 stations.

d Excluding British Caribbean Territories, Cuba, Haiti, Honduras, Panama, St. Pierre and Miquelon.

e Excluding USSR except for discharge and sediment stations.

F. Reliability of Water Supply and Quality Appraisals

The reliability of appraisal varies according to the method used and the amount and accuracy of the data available for study.

1. Surface water

At gauged stations, surface-water supply may be reliably estimated depending upon how long records have been kept and the accuracy of the measurements themselves.

At ungauged stations, reliability will be contingent upon the historical length of records and the accuracy of measurement for other components in the water-balance equation as well as the relative density of observation stations in the area.

2. Precipitation

As a rule, reasonably accurate measurements of rainfall can be made with less than 10 per cent error, but wide margins of error are to be expected in measuring snowfall under windy conditions. Here again, an adequate network density is crucial. Precipitation is extremely variable in a mountainous terrain where network density is usually low, while snowfall may be high.

3. Evapotranspiration

Although evapotranspiration is less variable, measurements from pans and tanks serve only as an indication of potential evapotranspiration. Actual evapotranspiration is also a function of the evaporation of soil moisture and is difficult to estimate. When estimated from one of many equations, then reliability also depends upon the adequacy of whatever other types of data are used: radiation, temperature, rainfall, humidity and wind, for example.

4. Ground water

While appraisals of ground-water supply reply in part on the same observation networks as surface water, they are largely dependent upon measurements of aquifer characteristics, artificial withdrawals and water levels, as well as geological studies of the formation. The accuracy of these measurements varies widely according to the nature of the aquifer and the thoroughness with which the study is conducted. Even well executed surveys sometimes result in estimates of recharge which later prove to be from 50 to 100 per cent wide of the mark.

5. Water quality

The accuracy of quality measurement varies considerably among the many parameters observed and with the methods of sample analysis. The long-term goal in the United States of America and the United Kingdom is for a system accuracy within 1 per cent. Automatic water quality monitors will certainly gain widespread use in the future, at least for the more common parameters. The achievable accuracy of such instruments at a reasonable cost is within 1 to 5 per cent variant. But most observation networks currently have a much wider range of error. The reliability of appraisals once again depends to a great extent on the network density, the parameters observed and the degree of standardization achieved.

In short the reliability of all water appraisals depends heavily on the adequacy of national observation networks. The present status of stream-flow, water-quality and sediment networks is presented in table 2. Ground-water networks (water levels) exist in a few countries but for the most part the only data on ground-water resources are those collected in connexion with water development projects or with oil prospecting.

Table 2 compares the existing density of stations with the densities recommended in the World Meteorological Organization (WMO) *Guide to Hydro-meteorological Practices*. Because these "required" densities are for average conditions, and because more than 20 countries, including China and the USSR are omitted, the resulting measurements are, at best, very rough. They suggest that networks are conspicuously in excess of the minimum in Europe, less so in Central and North America and the south-west Pacific, least dense in Africa, and generally less than minimum both in Africa and Asia. The more obvious deficiencies are in rain gauges and discharge stations for the latter two regions. But it should be stressed that network density in excess of the recommended minimum does not imply that this is unwarranted. The optimum density is always greater than the minimum, and the statistics in table 2 include many stations required for operating purposes.

The inadequacy of networks is not restricted to deficiencies in the number of stations and their period of record. In both developing and industrialized countries, it is often the areal distribution of stations and the over-all network design that limit the accuracy of assessment.

It is also important that the various types of network (water-quality, water-quantity, precipitation etc.) and related services be closely co-ordinated to take advantage of the physical relationships involved. Although much has been written about network design, practical application has lagged behind knowledge gained through research and experience.

The organization of comprehensive national networks and data-processing services remains one of the most urgent tasks in water development and management. At the international level, this is the core of the WMO Operational Hydrology Programme. Such services may sometimes be advantageously organized on a regional basis. The operation of unified networks is critical wherever basins or aquifers are shared by two or more countries that require commonly accepted data for management. Several UNDP/WMO projects have taken this approach.

G. Global Supplies of Fresh Water

The study of the global water balance was the principal topic of the International Hydrological Decade (IHD) and three important monographs on the subject were published towards the end of the Decade (Baumgartner, 1975; Lvovich, 1974; the USSR National Committee for IHD, 1974). Although the methodology used in the three studies differs to some extent, the results are relatively consistent (see table 3).

Table 3. Average annual water balances of the world according to authors published since 1970.

P = Precipitation
E = Evaporation
R = Run-off

Region	Baumgartner 1975			USSR Monograph 1974			Lvovich, 1974		
	P	E	R	P	E	R	P	E	R
Volume of water (thousands of cubic kilometres)									
Europe	6.6	3.8	2.8	8.3	5.3	3.0	7.2	4.1	3.1
Asia	30.7	18.5	12.2	32.2	18.1	14.1	32.7	19.5	13.2
Africa	20.7	17.3	3.4	22.3	17.7	4.6	20.8	16.6	4.2
Australia	7.1	4.7	2.4	7.1	4.6	2.5	6.4	4.4	2.0
North America	15.6	9.7	5.9	18.3	10.1	8.2	13.9	7.9	6.0
South America	28.0	16.9	11.1	28.4	16.2	12.2	29.4	19.0	10.4
Antarctica	2.4	0.4	2.0	2.3	0	2.3	...	...	...
Land areas*	111	71	40	119	72	47	113	72	41
Oceans	385	425	-40	458	505	-47	412	453	-41
World	496	496	0	577	577	0	525	525	0
Depth of water (Millimetres)									
Europe	657	375	282	790	507	283	734	415	319
Asia	696	420	276	740	416	324	726	433	293
Africa	696	582	114	740	587	153	686	547	139
Australia	803	534	269	791	511	280	736	510	226
North America	645	403	242	756	418	338	670	383	287
South America	1564	946	618	1595	910	685	1648	1065	583
Antarctica	169	28	141	165	0	165	...	...	...
World	973	973	0	1130	1130	0	1030	1030	0

Sources: USSR, National Committee for IHD, *World Water Balance and Water Resources of the Earth* (Leningrad, 1974); Lvovich, *Global Water Resources and the Future* (Moscow, 1974); A. Baumgartner and E. Reichel, *The World Water Balance* (Munich, 1975).

*Values are adjusted upwards to include Antarctica for comparison with corresponding volumes derived by the other two authors.

The major differences among the estimates stem from the difficulty of calculating precipitation and evaporation in the ocean basins. In contrast, estimates for land areas, where more stations record both precipitation and evaporation, are very close.

1. Surface run-off and run-off to the sea

The run-off of roughly 40,000 to 47,000 cubic kilometres, annually occurs chiefly in Asia and South America. The heaviest concentration in terms of average depth by region is found in South America. The volume in Africa, Australia, Europe and North America combined is less than 40 per cent of the total (see table 3).

Frequently "run-off to the sea" is treated as a limiting measure of water available for the support of human needs. Run-off to the sea may, however, be the best available measure of the real water resources of human society, provided one considers and understands the underlying possible deficiencies. For instance, it must be assumed that:

(a) Land areas which do not contribute run-off to the sea are without water supply;

(b) Losses from streams and ground-water storage, such as non-beneficial evapotranspiration by vegetation in the valley bottom, are either inconsequential or would not be reduced by upstream withdrawals;

(c) Possible mining of ground water is inconsequential;

(d) Average consumptive use during the period analysed is inconsequential unless observed discharges are not used in the analysis or adjustment is made for measured withdrawal.

It must also be considered that there are many closed basins, some as large as the Caspian drainages, which contribute no run-off to the sea but do, however, experience surface run-off and ground-water recharge. Non-beneficial evapotranspiration from ground storage is a serious problem in some areas, and lowering the water table tends to reduce such losses. Much water is lost in transit to the sea, particularly in swampy areas such as the Sudd of the Sudan, and constitutes available supply at upstream locations. Moreover, while the quantities of water involved may not be significant on a regional or global scale when considered individually, yet they all constitute incremental increases to the supply as measured by run-off to the sea. They cannot be presumed to be inconsequential when one considers available supply for an individual basin or any other relatively small area. In these cases, as with other sources of supply, the definition of available water is shaped by demand in relation to technology and cost. The estimated volume of water that can be abstracted from a stream or aquifer is influenced by judgement concerning feasible storage facilities, pumping lifts and the like. The demand component, as will be shown in the following section, should not be obscured by physical calculations.

2. Lakes and reservoirs

The total volume of fresh water stored in lakes (about 2×10^5 cubic kilometres) represents about four times the average yearly run-off from all land areas. The volume of water accumulated in man-made reservoirs (about 5×10^3 cubic kilometres) represents about 11 per cent of the yearly run-off.

Lakes and reservoirs play an important role in regulating stream flow and thus facilitate its use, although they do not themselves constitute a major source of supply. The "mining" of water in lakes would lower their levels and adversely affect the water balance. Lowering of lake levels can result from changes in upstream areas. The Caspian Sea is a classic example of this.

3. *Ground water*

Except for Europe, part of Africa, part of North America and small parts of Asia, the availability of ground-water resources is not well established.

Recent estimates of the global store of fresh ground water above 4000 metres in depth range from 8.1×10^6 to 10.5×10^6 cubic kilometres. Ground-water reserves, however, only have significance where conditions are favourable for their exploitation.

A relatively small quantity of ground water (about 13×10^3 cubic kilometres or roughly 0.1 per cent of total reserves) participates in the hydrological cycle in the average year. Most of this takes place through contribution to stream flow and is therefore included in the appraisal of surface supply.

There are no available estimates for global or continental recharge, or the difference between recharge and contribution to stream flow. Detailed studies have been made, however, for selected areas such as the Lake Chad basin.

H. *Climate and Human Activity*

Just as there is no substantial agreement among the world scientific community whether or not climate is changing at a rapid rate, there is similarly no general agreement that human activities *per se* have a significant effect upon climatic change.

Some scientists believe, however, that some activities are likely to effect significant climatic changes: burning of fossil fuels, burning of grasslands and forests, cultivation of semi-arid lands, cutting of forests, ploughing of grasslands, and transfer of pollutants destructive to the ozone into the stratosphere, for example.

These potential material changes seem to warrant a major and continuing endeavour to improve our ability to assess the present and predict the possible future consequences of human activities upon changes in climate. Unfortunately, the extensive lag in time between cause and effect, the difficulties in limiting or even isolating possible causes, and the complex relationships involved virtually preclude our arriving at positive conclusions through correlation analysis of climatic and other relevant data.

Models have been developed which depict the principal features of global climate with limited application. Once it is possible to develop models which simulate climate accurately, it may be possible to determine how specific activities of man influence the input parameters and thus stimulate how these activities correspondingly effect changes in climate. This approach could also be used to test hypotheses for modifying climate, such as the damming of the Bering Strait.

Water-resource development might conceivably induce changes in climate. Irrigation of large tracts of land, for example, affects the climate down-wind of the area, but appreciable effects appear to be relatively local. Proposals to divert immense quantities of water from rivers feeding into the Arctic Ocean have caused some concern, since these rivers constitute a heat source for the ocean. There are divergent views on whether the resulting increase in ice-cover would materially affect the climate of inhabited regions.

World-wide concern about climatic change led the WMO Seventh Congress to undertake, with the co-operation of other concerned bodies, an integrated international effort to study the question.

I. Global Assessment of Water Quality

Of the numerous water quality parameters relevant to water use, our knowledge and available data are both so limited that, with few exceptions, even approximate continental or global assessment is not possible. Figure 1 presents estimates of the erosion products from continents. The total of dissolved solids carried to the oceans is estimated at more than 2480 million metric tons annually; a total of 3905 million metric tons of soluble material has been calculated (D.A. Livingstone, 1964).

The total products of erosion carried by streams have been estimated between 12 and 51 thousand million metric tons annually (Lvovich 1974, pp. 246-257). The sediment comes largely from Asia, where removal may average as much as .16 millimetres per year from the land surface.

Organic waste from cities and factories constitutes a rapidly growing hazard to health for urban populations, especially for those in squatter settlements on the peripheries of tropical cities which are not supplied with purified water. Even in an industrialized nation such as the United States, 92 per cent of the total suspended solids, 37 per cent of the biochemical oxygen demand, and 98 per cent of the coliform bacteria will remain uncontrolled in natural surface water once all discharge has been eliminated from point sources; this is largely the consequence of agricultural activity (United States National Commission on Water Quality 1976). There are no general measurements of volumes of synthetic organic compounds and heavy metals reaching the oceans.

Ground water usually contains far more dissolved salts than surface water. The chemical composition of precipitation is gradually modified as it infiltrates and moves through soil and rock, the water taking up soluble compounds of the medium. The main compounds are calcium, magnesium, fluorides, sodium, potassium, iron, bicarbonate, sulphate, chloride and nitrate ions. Their combined concentration in water is measured as salinity. And in arid regions, salinity is increased as a result of high evaporation.

Irrigation tends to increase the load of salts in streams by leaching salts from the soil and returning them to the stream by drainage. At the same time, irrigation concentrates salts by removing part of the water that would otherwise dilute the load.

Salt-water intrusion from the sea to coastal aquifers can cause a drastic increase in the salinity of ground-water supply. Intrusion can result from the lowering of the water table through the exploitation of fresh water. Since

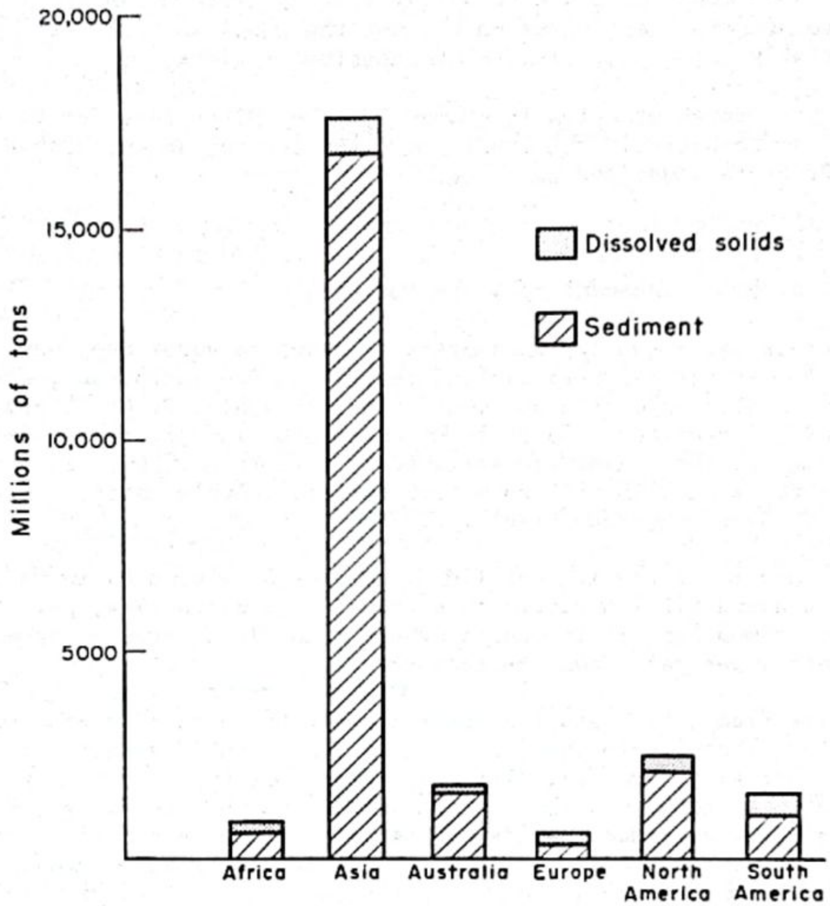

Fig. 1. Estimated erosion products and dissolved solids carried by streams.
Source: Lvovich, *Global Water Resources and Their Future* (Moscow, 1974).

coastal zones are generally heavily populated, with growing demands for water supply, salt-water intrusion can become a serious problem. While the encroachment process may be slow, it tends to become irreversible.

Ground-water pollution induced by man is also an increasing concern. Fecal pathogenic organisms die off relatively quickly and seldom constitute a hazard, except in limestone areas where underground water may travel long distances relatively rapidly. On the other hand, drainage waters from urban or agricultural lands may contain objectionable chemicals which percolate into the soil and irreversibly contaminate the adjacent aquifer. Since surface water is a source of ground-water recharge, this, too, is a source of contamination. Here again, the process may evolve slowly, but the effects are persistent.

J. Non-conventional Sources of Water Supply

Many technological devices are used either to change salt water into fresh water or to change the place of water in the hydrological cycle so as to increase its availability. These technologies include: desalination, weather modification, phreatophyte modification, evaporation suppression, waste water re-use, geothermal water exploitation, and the transport of icebergs.

Of these, only desalination has had a significant, yet moderate result. A few islands and countries, such as Kuwait, derive virtually all their fresh water from desalination plants. Between 1961 and 1971, the output of large desalting plants for brackish or ocean water expanded at an annual rate of 18 per cent. By 1972, the output from 812 land-based plants was 1.39×10^6 cubic metres daily. By 1975, the number of plants of 100 cubic-metre capacity or greater had increased to 1036 and world capacity had risen to 2.1×10^6 cubic metres.

Weather modification has been practised on such a limited scale so far that it is difficult to make a sound assessment of its potential effect on the water balance of large areas.

Waste water re-use is a growing source of supply. Already well established in Chinese agriculture, it is now more widely applied in industry as well as in irrigation.

III. ASSESSMENT OF USE AND DEMAND

The particular significance of estimates for water use and prospective demand is that they show the *relative* volumes of use for different purposes.

It is important to recognize that these uses, purposes, and their resulting effects are interwoven regionally and nationally. Any strategy that is devised to satisfy prospective demand must take this into account.

A. Multiple Uses, Purposes and Impacts

The uses that make most demand upon water supply and water-related services are shown in table 4.

TABLE 4. Components and impacts of water use

Components	Common Substitutes	Type: With-drawal	Type: In-stream	Type: On-site	Impacts: Potential quality effect	Impacts: Potential consumptive use (percentage consumed)
Drinking	None	x				1-15
Other domestic		x				1-15
Public, urban		x				1-15
Livestock	None	x	x		Organic	1-15
Soil moisture conservation	None			x	Sediment	0-100
Irrigation	None	x			Salt	10-80
Drainage					Salt	0
Wetland habitat	None			x		0-10
Aquatic habitat	None	x	x			0
Navigation	Land transport		x			0-10
Hydropower	Other energy sources		x			0
Mining		x	x			1-5
Manufacturing:						
Cooling (including steam power)	Air	x			Thermal	0-3
Processing	Mechanical	x			Organic, toxic	0-10
Waste disposal	Air and mechanical	x	x		Organic	0
Recreation			x			0
Aesthetic			x			0
Flood loss reduction	Land use		x	x		0

Source: Gilbert F. White, 1976.

All of these uses contribute to the vitality of human settlement, the quality of life, agriculture, industry and the social infrastructure. They vary in the degree to which they are essential to an economy and in the degree to which they affect the human environment.

At the simplest level, uses are single-purpose: providing drinking water, driving a hydroelectric turbine or carrying barges in a canal, to cite a few examples. But increasingly, water uses are combined and multiple. For example, a large proportion of the water distributed to a community is used for washing and for carrying away human and other wastes and may subsequently be used in agriculture; a storage reservoir for electric power also offers recreation and irrigation facilities; a canal provides wildlife benefits.

It is therefore misleading to think of a cubic metre of water diverted from a stream as serving only one purpose in only one sector of an economy. The technology for achieving multiple benefits has expanded rapidly and this has improved our capability to use, purify and reuse available water supplies.

If we classify water use by withdrawal, on-site and in-stream, as in table 4, and take into account the consumptive or non-consumptive character of each, we then have a better understanding of the effect of water use on the human environment.

Uses which actually withdraw from a water body — drinking water, irrigation, industry, for example — deplete the source unless it is refed by return drainage.

In-stream uses — navigation, hydropower, fisheries, for instance — leave the volume of flow unchanged.

On-site uses — for rain-fed crops or wildlife habitat, for example — may or may not affect the volume of flow.

All these uses, whether consumptive or non-consumptive, may cause a change in water quality. And all may potentially result in a loss of available supply through evaporation, transpiration or diversion, so that there may be a net depletion of a source stream or aquifer. While some uses, such as irrigation or even repeated withdrawal for drinking water, can wholly deplete a stream, other uses like repeated use for thermal cooling, will reduce flow only slightly.

In summary:

(a) Uses vary according to the availability and economic feasibility of substitutes;

(b) Uses are increasingly multiple;

(c) As uses multiply, so do the possibilities of altering water quality;

(d) Consumptive depletion of available supply varies according to use and available technology, and in extreme cases local supply can be completely dissipated.

How societies choose to use water and what technology they apply reflect individual and public attitude in appraising resulting costs and benefits.

B. Methods of Projecting Water Demand

The term "water demand" has an economic connotation. It means the amount of water or water-related services that would be used at a given price. But in contrast to most other commodities, there is no easy way to establish reasonable levels of water demand and supply through pricing policies.

It is a major task of local, regional and national water organizations to strike a suitable balance between supply and demand while taking price/demand relationships into account. Fundamental to this process and to the international examination of what needs to be done in managing the world's supply of water is the way in which demand is forecast or projected.

A first step is to estimate current use. The next step in planning for future management or conservation is to estimate how additional or different use will affect future demand and then establish a rational service level. For example, given finite resources, it may be necessary to evaluate whether it is preferable to serve more people at low-service levels (with standpipes and latrines), or alternatively serve less people (with house connexions having unrestricted water use and sewer systems).

In general, demand for water can be projected in aggregate terms. In Hungary, for example, the range of demand was projected to the year 2050 on the basis of historical relationships between *per capita* aggregate use and gross national product.

More detailed studies require examination of each of the categories of use outlined in table 4 at the national level, or even for smaller areas such as basins and sub-basins. To do this, the most rudimentary method is extrapolation of a rate of change observed over a given past time period. This method is widely used and assumes no change in either the socio-economic factors that motivate demand, or in prevailing technologies and policies. Extrapolation therefore rarely yields satisfactory results, except in the short term in some instances and under conditions of abundant supply.

Apart from extrapolation, there are numerous analytical models that examine the factors influencing a particular use and their interrelationships. Demand may thus be related to population, food consumption, industrial activity, technology, costs, political objectives and numerous other variables. Typically, such a projection forecasts the form and size of a future economy, assigns some water requirement per unit of expected output, and revises the expected usage in light of projected costs. These methods vary greatly in their sophistication and in the extent of the required data base. Using them, many projections are made that indicate how much water will be required for particular areas at particular times. The specific method used will depend upon the particular use being studied.

All these projections for cities, basins, nations, continents and the globe need to be interpreted with great care. The data base is often meagre. Frequently assumptions are made about such matters as population, industrial processes or farming practices that may change radically over a period of time. Since these projections do not rule out extrapolation, they help specify the range of uncertainty attached to each assumption. In this respect, they lay the groundwork for informed decisions concerning which policies and technical measures may be most appropriate to guide demand in the future. For this purpose, they are fully useful only when cost/price considerations enter into the analysis. It may, for example, be highly misleading to estimate industrial cooling water withdrawal needs without taking into account the costs of providing increased supplies. In this connexion, one further consideration is the incremental cost of sewer systems and waste disposal/pollution control associated with high levels of water consumption.

The following subsections summarize what is known about total water uses for each component of demand, and indicate the status of projections for future demand. Chapter IV then outlines the chief considerations in supply/demand relationships. Because of gaps in data and incomplete analysis, it is not possible to present a comprehensive global picture of water use and demand. It is practicable, however, to sketch the main features of use and show what information, analysis and judgement would be desirable if we were to make reasonable appraisals of the supply/demand situation for any basin or aquifer.

C. *Domestic Use and Demand*

To a person living in a semi-arid land, domestic water use may mean a few litres a day, mainly for drinking and cooking and excluding requirements for washing and bathing. In small communities in non-industrialized countries, domestic use may, in addition, include bathing and washing needs. In higher income societies, watering of lawns and kitchen gardens is common. In middle- and upper-income sections of large cities, household appliances, swimming pools and the washing of automobiles considerably increase domestic demand. A farming household may also use its supply to water livestock and irrigate a small garden.

Municipal supplies rarely provide water exclusively for drinking and other household uses: they also cater to the needs of commercial districts, small industrial establishments, and public uses such as street cleaning, watering of public gardens and parks, public baths and fountains, and firefighting. Commercial industrial and public uses may claim 5 to 50 per cent of the total pumpage in an urban supply system and may sometimes total several times the household withdrawal.

The quantity of water used in a household is related to the quality of living. For broad purposes, domestic water may be classified as meeting these needs: drinking water for survival; personal hygiene; basic comfort; positive well-being. The total amount used ranges from 3 to 700 litres *per capita* daily. Lawn watering may account for one half of total use in a middle- or upper-income household. As shown in Fig. 2, the range of use is set according to whether the water is carried from the source, provided by a single tap in or near the household, or supplied by multiple taps. Within these limits, the actual volume consumed by households is influenced by income, climate, culture and a variety of other factors, including the efficiency of the delivery system. In some urban areas, as much as one half of the water stored and pumped is lost through leaks in pipes and faucets. In such cases, the true average daily *per capita* consumption is only half the apparent consumption; also, twice as many people might be supplied without increasing the resource if leaks and wastage were controlled.

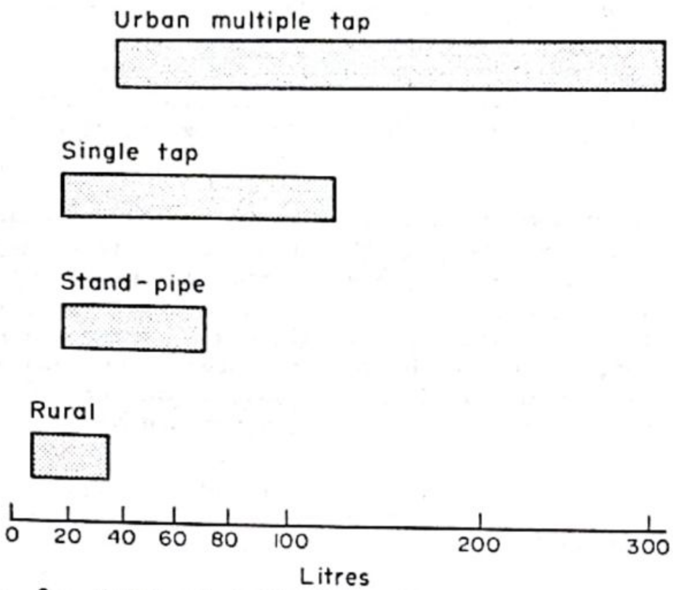

Fig. 2. Range of daily domestic water use *per capita*
Source: A.U. White (1976).

1. *Quality of supply and its effect upon health*

Quality of supply is critically important to human health. Biological pollution through fecal contamination is the cause of morbidity due to water-borne diseases, which as a group rank first among all other kinds of disease in less developed regions. In certain parts of some countries, naturally occurring substances which are deleterious in excessive concentration such as nitrates, fluorides and toxic substances such as arsenic have a strictly local distribution. Pollution of water by indiscriminate discharge of synthetic organic chemicals is cause for grave concern in highly industrialized and developing countries alike. While some of these chemicals are acutely toxic, their effects however can sometimes be remedied. Of greater concern are the long-term teratogenic, mutagenic and carcinogenic effects of pollutants. Their full effect on human health is known only for a few groups of substances.

To protect human health, water used for drinking and for preparing uncooked food should, as a matter of public policy, be free of pathogenic organisms and toxic substances. So that consumers will not use less safe sources, public water supplies should also preferably be attractive to sight and taste. Guidelines for water quality are presented in the WHO publication *International Standards for Drinking Water* (3rd edition).

In connexion with public policy, the optimal requirement for domestic water is that a supply should be available daily and conveniently, at reasonable cost while meeting the criteria mentioned above.

2. *Quantity required*

The quantity of water required domestically varies with local circumstances, the method of excreta disposals, and is income elastic. It is common to design new community supplies for delivery of an average of 100-350 litres *per capita* for house connexions, and 10-25 litres daily for people using public stand-pipes. In rural areas, the design figures used by government agencies differ according to the likelihood and availability of natural sources. In general, water consumption increases as the standard of living increases.

3. *Existing and proposed community water-supply and excreta disposal levels*

In 1972 the twenty-fifth World Health Assembly adopted the following targets for community water supplies in developing countries, to be achieved by 1980:

In urban communities:

60 per cent of the population to be served by house connexions

40 per cent of the population to be served by public stand-pipes

In rural areas:

25 per cent of the population to have access to safe water

Bearing in mind prospective population growth, this would mean that the additional people to be served by 1980 as part of the Second United Nations Development Decade would be:

255 million by house connexions

135 million by public stand-pipes

274 million by rural improvements

This would still leave some 822 million people in rural areas without access to safe water.

In 1976, the World Health Organization (WHO) conducted a survey to determine progress achieved in reaching the 1980 targets. The results show that at the end of 1975, the following service levels have been achieved:

In urban communities:

57 per cent of the population is served by house connexions;

20 per cent of the population is served by stand-pipes;

76 per cent of the population (445 million) is adequately served.

In rural areas:

22 per cent of the population (310 million) has reasonable access to safe water.

The total urban and rural populations served are 35 per cent (755 million).

The WHO survey revealed that the following population had excreta disposal facilities, either through public sewers or household systems:

Urban communities	- 75 per cent (435 million)
Rural communities	- 14 per cent (195 million)
Total, urban and rural	- 32 per cent (630 million)

It is evident on the basis of the mid-decade review that there has been an increase not only in the gross number of people provided with water supply and excreta disposal facilities over the five-year period 1971-1975, but also in the percentage of the urban and rural populations served. In other words, progress in the provision of these services has more than kept pace with population growth in the urban and rural sectors. As this survey covered nearly 90 per cent of the total population of the developing countries (excluding China), it would not be unreasonable to assume that this progress applies to the developing countries taken as a whole. However, as the over-all goal for the end of the decade is for over 90 per cent of all urban populations to be supplied with safe water either inside their homes or from public standposts, it can be readily appreciated that in spite of the progress achieved, a major effort is still required to meet that goal. Practically all the data presented are estimates. The bases on which estimates were made vary. Concerning estimates of numbers of people served, countries have better information on community water supply services than on excreta disposal services and have better data on the urban than on the rural situation. The inherent difficulties in accumulating this type of basic information from different sources within a country for use in preparing estimates should serve as a note of caution in interpretation.

The survey also showed regional differences in progress. Taking this into account, member States endorsed at the twenty-ninth World Health Assembly in May 1976 the regional targets proposed by the Director-General of WHO for community water supply and excreta disposal in the developing countries to be strived for as a minimum by the end of the Second United Nations Development Decade and recommended, *inter alia,* that member States establish and periodically review feasible programme targets in community water supply and excreta disposal. If regional targets are to be achieved, it will mean that by 1980:

In urban areas:

68 per cent of the population to be served by house connexions

23 per cent of the population to be served by stand-pipes

38 per cent of the population to be served by public sewers

56 per cent of the population to be served by household systems

In rural areas:

36 per cent of the population to have reasonable access to safe water

24 per cent of the population to have excreta disposal facilities

These targets imply far greater financial resources for improving service levels in urban areas where relatively high levels already exist and further improvements are costly. In view of resource limitations, individual countries may well decide to modify these targets and attempt to provide lower levels of service (stand-pipes instead of house connexions) to a larger number of people.

4. *Delay and cost of improving domestic supply and excreta disposal*

A unified attack upon problems of providing rural water service has been launched by a consortium of organizations including WHO, the World Bank, United Nations, UNDP, United Nations Children's Fund and the International Development Research Centre. Still, the basic questions raised by this discussion are: Why have improvements in domestic water supply moved so slowly? What can be done to speed them up? Among the reasons often given for the slow pace of development are: shortage of funds; shortage of trained manpower; weakness in national programmes; difficulties in system operation and maintenance; inadequate legal frameworks; insufficient involvement of potential users.

In the WHO survey, the *per capita* cost at 1970 price levels for new community water supplies under government auspices was found to range on the average over large areas from $15* to $55 *per capita* for house connexions, from $9 to $30 for public stand-pipes, and from $6 to $24 for rural supplies. Similar *per capita* costs were used for excreta disposal. Where community participation in projects is substantial, the costs can be reduced. But the total funds required to meet the Second Development Decade are still immense.

Adjusting the above *per capita* cost figures for inflation, WHO estimates that the funds required to meet the revised 1980 targets amount to $12 billion for urban house connexions, $2.5 billion for urban stand-pipes and $6.5 billion for rural water supply. An estimated $13 billion is needed for urban and $2 billion for rural excreta costs.

These estimates are probably far below the actual expenditures which will in fact be required. In this connexion, a recent World Bank calculation of costs to meet 1980 goals for Latin America under the Santiago declaration for both water supply and excreta disposal, placed investment needs at $16 billion over a five-year period. Only about $5 billion of this would be investment for water supply: this reflects both the customary 1 to 2 ratio of *per capita* urban water supply and excreta disposal cost and also the need to accelerate investments in heretofore neglected excreta disposal. This level of investment would be roughly four times the actual expenditure in Latin America for water supply and waste disposal during the first five years of the decade.

The costs quoted in the previous paragraphs are based on very rough approximations and are merely indicative of what will be required. They illustrate, nevertheless, possible cost trends. In addition, they show the options available in making investment decisions. The costliest option is water supply by house connexions and excreta disposal by sewer system. Respective *per capita* costs of these vary from $50 to $100 and from $80 to $200. In contrast, stand-pipes and latrines or pit privies cost from $10 to $35 and $5 to $10 *per capita*, respectively.

Obviously the choice of service level has a significant impact on how many people can be served. In general, it would be preferable to provide low-level service so that the maximum number of people could benefit. Service levels could then be upgraded as investment funds become available and as standards of living increase.

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* The symbol ($) refers to United States dollars unless otherwise stated.

Even if funds of the above-mentioned magnitude were available, the mounting of construction programmes to meet these goals would place heavy demands upon the existing small pools of trained personnel and equally heavy demands upon the capacity of national and municipal organizations to mobilize the affected population, given lack of information and lack of community concern. The difficulties are especially acute in rural areas and in the expanding shanty towns of tropical cities.

The volume of water needed to meet the required minimum of the Second Development Decade is not large in comparison with available run-off. The populations in need have a supply of a sort, much of it inadequate in volume and virtually all of it subject to some degree of health hazard. The problem is how to arrange for suitable storage, treatment and distribution, at costs that users can afford and by means that are appropriate to local supply and local socio-economic conditions.

D. *Industrial Use and Demand*

The economic development of a country and its applications of technology, influence the use and demand of water for industry to an even greater degree than they influence the use of water for domestic purposes.

Lacking global statistics, industrial use of water as a per cent of total withdrawal can only be outlined in relation to the experience of a few nations. See Fig. 3.

1. *Major industrial uses of water*

The major uses of water in industry are for: cooling; processing; boiler water; and general purposes, including drinking, air conditioning and cleaning. Cooling is the principal purpose of withdrawal and commonly accounts for as much as 60 to 80 per cent of total industrial withdrawal; this is the reason for the heavy use of water by thermal electric power generating plants.

Industry may draw upon saline, as well as fresh, surface and ground supplies. Process water may enter the product itself as in beverages, or alternatively, serve to wash, float or transport products in manufacturing.

A few industries account for two thirds or more of all industrial use. The chief users are primary metals, chemical products, petroleum refining, pulp and paper products and food processing. (See table 5.)

The way in which water intake and waste of these industries may vary for a given unit of volume is presented in table 5. It is not unusual to find some industrial plants withdrawing 5 to 20 times as much water as other plants for the manufacture of the same product. The principal reason for this range is the degree of in-plant recirculation within the plant. The volume of waste load in water is not well assessed, and the figures given in table 5 show only estimated averages for one country.

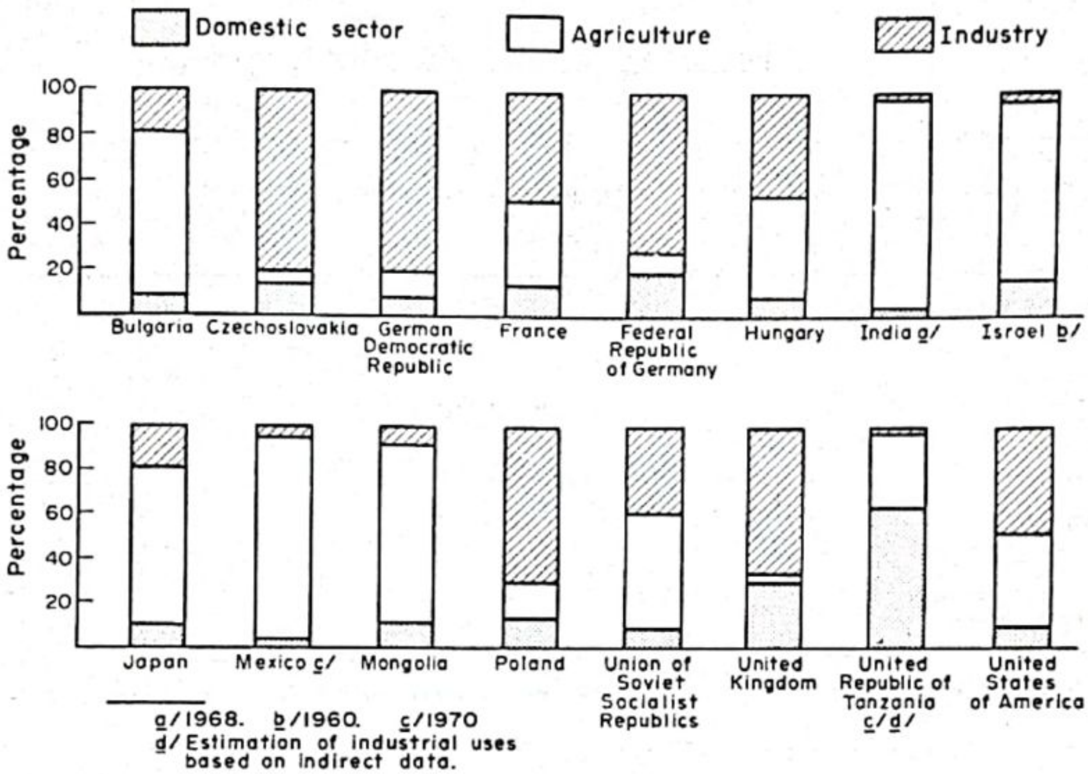

Fig. 3. Distribution of withdrawals among major categories of water uses, selected countries, 1965.

Source: *The Demand for Water: Procedures and Methodologies for Projecting Water Demands in the Context of Regional and National Planning* (UN publication, Sales No. E.76.II.A.1).

2. Consumption and waste

The critical considerations in industrial water use are: how much water is taken in, how much is consumed, and how much and what kind of waste is discharged since this can gravely affect human and environmental health.

Consumptive use rarely exceeds 20 per cent of withdrawal. In the case of steam power generation, consumptive use is less than 2 per cent and has been decreasing steadily during recent decades. The waste discharge affects the quality of the receiving water - the precise effect depending upon flow and quality of the receiving water, its temperature and a variety of other conditions.

As outlined in Fig. 4, once water enters a manufacturing plant, it may be used for one or a combination of purposes. The waste may be treated within the plant or disposed of in a variety of ways. The volume and quality of industrial waste can usually be improved through process design, in-plant recycling and improved plant housekeeping procedures.

TABLE 5. Water intake and waste load in selected industries.

Industry and selected product	Unit	Litres of water withdrawn per unit (range of reported uses)	Pounds of 5-day BOD per 1000 gallons process water discharge (USA)
Primary metals:			
steel	Ton	8000-61,000	...
Chemical:			
soap	Ton	960-37,000	16.70
Petroleum:			
gasolene	Kilolitre	7000-34,000	2.50
Pulp and paper:			
paperboard	Ton	62,000-376,000	2.21
Food processing:			
sugar beets	Ton	1800-20,000	9.16

Sources: Wollman and Bonem, 1971; country reports submitted to the United Nations, 1957-1968.

3. *Cost of water and waste disposal*

Cost and convenience are important determinants of what processes are used for water intake, treatment, recirculation and waste discharge. But the cost of water itself usually represents a very small proportion of aggregate industrial costs. For the five most important water-using industries mentioned above, water may represent from 0.005 to 2.58 per cent of total manufacturing costs and rarely exceeds 1 per cent. In many areas, the problem of waste disposal is more limiting to financial and technical growth than the problem of obtaining adequate water supply.

4. *Effects of industrial growth upon water quality and quantity*

Industry is expected to grow at an 8 per cent annual rate in the Second United Nations Development Decade. How this growth will change the use and quality of water will depend upon the cost of obtaining suitable supplies and, above all, the standards Governments set for quality in receiving waters.

Further sophistication in manufacturing techniques will stimulate further measures for quality control and in-plant waste treatment. Such increased sophistication will also undoubtedly multiply the variety of synthetic organics and other effluent wastes. The future demand for water for industry is likely to be affected by competitive agricultural and domestic demands as world population increases.

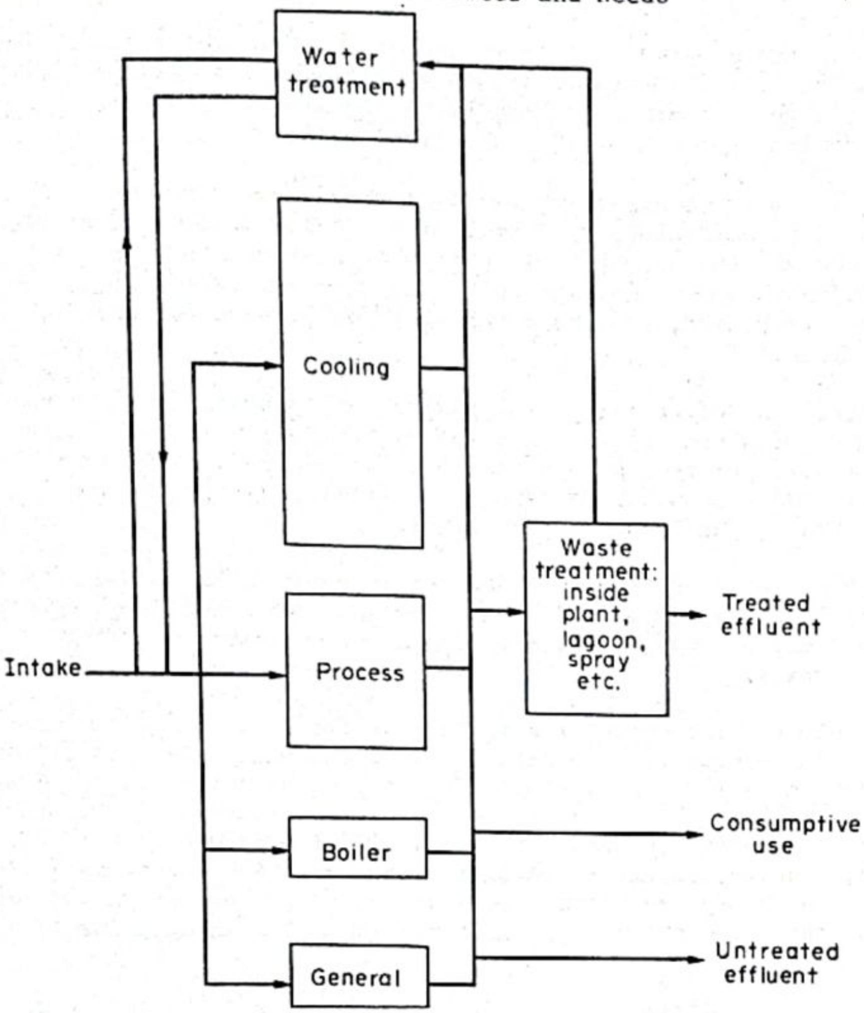

Fig. 4. Flow of water in industrial use.
Source: Modified from Blower and Sewell (1968).

E. *Agricultural Use and Demand*

As world population grows, so does the need for increased food production. A reliable and increased supply of water is essential to sustain this growth. This requires better use of rainfall and better conservation of water for crop and livestock production. Where it is necessary to increase yield from arable land, or to extend agricultural production to marginal or arid land, irrigation is required.

Agriculture is the largest user of water, accounting for some 80 per cent of world consumption, mainly through irrigation. In addition vast areas use rainfall as the principal source of water for crops. Approximately 200 million hectares of land were irrigated in 1970, almost half of this in developing countries where food needs are especially acute.

Because of wide differences in soil, climate, crops and irrigation methods, to mention only a few variables, it is impossible to establish any norm for irrigation water supply. And it is often difficult even to define an "irrigated" area. Levels of water reliability and frequency of flow provide a guaranteed, unrestricted supply in some areas. In others, there may be only an occasional seasonal flooding which in a bad year may not even reach all the land prepared to receive it, although that same land may be classified as irrigated since its productivity depends upon an outside source of water supply.

As a consequence, there is no agreed-upon set of standards to determine how much water is needed for efficient crop production or how much water should in fact be applied. Nor are there comparable data showing the extent to which treated sewage effluent is used for agricultural purposes. (Where treated sewage is used for irrigation, it should normally not be used for crops that are to be consumed raw.)

While it is difficult to define irrigation *per se*, any planned development still requires an ensured controlled water supply to the crop. The quantities and acceptable standards of reliability of supply are determined by local climatic, agronomic and economic conditions, and water requirements are therefore established at the local project level.

The estimates in table 6, land irrigated and harvested in 1970, reflect approximate assessments of irrigation of all sorts. They do not reveal the degree to which the same land may be cropped twice during a year, or may be harvested only in favourable years.

Applying an index of crop intensity as a measure of irrigated land that is harvested, the Food and Agriculture Organization of the United Nations (FAO), calculated the crop intensity for developing economies shown in table 7. These indices, ranging from 65 to 132 per cent are especially important in relation to the proportion of potentially arable land that is already under cultivation. Global statistics, however, do not reflect the wide variations among individual countries, some of which may have little remaining land for expansion and may therefore increase farm production only by increasing yield in existing farmland.

Changes in agriculture may modify crop-water needs. For example, the introduction and expansion of modern crop varieties create a demand for improved water supply both in quantity and in timely application so that the greatest potential of the new crop will be realized while taking into account other related inputs such as fertilizers. Mechanization of agriculture may call for changes in field layouts, planting and harvesting techniques, with resulting influences on the methods and timing of irrigation patterns of water demand, and most important, total water use. Such use could either increase so as to support intensified cultivation, remain unchanged, or even decline through better water management. Improved technologies for the reclamation, re-use and recycling of water may also reduce demands for new sources to some extent. An important concept in water management for the future is the increasing of crop production with poorer quality water, thus making use of a resource previously rejected as unsuitable.

To arrive at the estimates of gross water demand presented in table 6, FAO assumed the demand to be 700 millimetres of water per crop season where the staple food is a dry-foot cereal and 1500 millimetres where it is rice. These values are presumed to be the total quantity needed by the crop, whether supplied from rainfall or irrigation, with typical losses associated with storage, conveyance and application taken into account. Still, part of the water lost in application in one area may well become a source of supply elsewhere through seepage, return flow and ground-water recharge. For this reason, FAO

TABLE 6. Estimated Irrigated Harvested Areas and Gross Water Demand, 1970

Region	Irrigated harvested area (millions of hectares)	Gross water demand (billions* of cubic metres)
Africa (excluding Egypt, Libyan Arab Republic, Sudan)	2	14
Latin America and Caribbean	8	59
Near East (including Egypt, Libyan Arab Republic, Sudan)	16	109
Asia (excluding China and USSR)	75	899
Asia (China and other centrally planned countries)	78	1167
USSR and Eastern Europe	14	95
North America, Australia and Oceania, Western Europe	33	228
	226	2571

Source: FAO report for the World Food Conference, 1974.

* The term "billion" means a thousand million.

TABLE 7. Cropping Intensity of Irrigated Land and Cultivation of Potentially Arable Land in Developing Market Economies.

Region	Irrigated land cropping intensity (percentage)	Potentially arable land under cultivation (percentage)	Irrigated land (millions of hectares)
Africa	98	44	02
Latin America	82	28	10
Near East	65	89	24
Far East	132	84	57

Sources: Food and Agriculture Organization of the United Nations, *Indicative World Plan for Agriculture* and the report to the World Food Conference, 1974.

notes that the totals given in this estimate of 2570 x 10^9 cubic metres, probably greatly exceed the actual use of water by the crop. Other recent estimates have placed projected global irrigation use as low as 1400 x 10^9 cubic metres for 1967 (Holy 1971), and as high as 2300 x 10^9 cubic metres for 1965 (Lvovich 1973).

From a technical standpoint, it is questionable whether the present-day demand for irrigation truly represents a sound starting point for future projections. Irrigation efficiencies are often so low as to be harmful as well as wasteful, and current irrigation water use does not therefore necessarily reflect real water needs. To project water demand by extrapolating past usage for new land is to ignore the opportunities for increased efficiency of use.

Improved water-application efficiency, better over-all water management and the rehabilitation of outmoded water schemes may rapidly achieve local savings of water. However, no general criteria can be formulated to evaluate such local benefits: a loss of water from one project may constitute a source of supply to a downstream user. Only a basin-wide hydrological and economic analysis will identify when savings arising from increased local efficiency are in fact providing a real asset for expanded use.

A review of experience at the basin or project level indicates two widespread and counter-balancing trends in irrigation use.

In some areas, a wise selection of the crops to be produced, better canal linings, better on-farm management, the introduction of spray or trickle application techniques, revision of water-allocation practices and readjustment of water rights have all helped to improve the efficiency of water use. (At the same time, it is not uncommon to find that 70 to 80 per cent of the water delivered to a canal system does not reach the crops. And while the average water consumption per hectare has been decreasing in recent years, this decrease is a very slow process in many areas.)

But in other areas, irrigation schemes are deteriorating through reductions in productivity or outright abandonment of land because of water-logging, salinization and alkalinization, unsuitable drainage and over-application or under-application of water. Return flows may become so salty, as in the lower Colorado, that downstream irrigators must have the waters desalted to render them usable.

In still other areas, urbanization destroys productive land as fast as new projects are built. In upstream locations, the effect of increased on-site use of precipitation is a reduction in downstream flow.

Proper assessment of the global situation must await the completion of the FAO Perspective Study for World Agriculture Development and the proposed World Survey of Water Resources and Irrigation. The magnitude of demand for irrigated land in the near future has been outlined in the Indicative World Plan for Agriculture, in which the over-all objective is to increase the 1970 harvested area by 43 per cent by 1985 in the developing countries.

Other essential agriculture needs, including rural domestic uses, make relatively small demands on over-all water resources. Water demand for livestock, for example, is estimated at about 62 x 10^9 cubic metres per year for 1700 million animal units, and this allows 100 litres per day per animal unit to cover all water needs. Fisheries represent a small volumetric use which is highly remunerative in yield per unit of water consumed.

Roughly three-quarters of the land and water development costs projected in the Indicative World Plan are for irrigation and associated drainage, but the Plan also stresses the great importance of seeds, fertilizers, crop protection, soil conservation, land reform, mechanization, educational assistance, credit, marketing and trade policies.

The cost of irrigation works and associated drainage varies with local conditions. Per hectare costs are mounting progressively as readily accessible soil and water approach full development. Planning and execution time will depend upon the difficulties presented by any particular scheme.

It has become evident that if an irrigation project is to achieve its aims of improving agricultural production and livelihood without environmental deterioration, the engineering works must be accompanied by appropriate credit, transport, housing and related activities. What is more, new irrigation planning is increasingly obliged to find means of developing the water resources of an entire basin or management area so that they may serve multiple purposes, including industry and hydroelectric power.

F. *Hydroelectric Power*

Hydroelectric power generation can be combined with numerous other instream uses. Usually it is organized as part of energy systems that utilize thermal generation.

We can estimate the theoretical potential of falling water to produce electricity, either on the basis of average stream flow (the river gradient) or on the basis of an assured amount being available for some portion of time. This latter amount will vary according to the seasonal character of run-off.

The installed capacity to capture hydroenergy is concentrated for the most part in Europe (including the USSR), North America, Japan, China, India and Brazil. In some countries (Brazil, Canada, Morocco, Norway and Uganda, for example), hydropower accounts for as much as 80 to 90 per cent of all power generated. Elsewhere, the installations may be tied in with thermal-generating units, and are often reserved to meet peak demand. Hydropower provides about half of electric power production in Japan, and about 15 per cent in the United States.

Often hydroelectric storage facilities are also used for irrigation programmes, navigation, domestic water supply or aquatic habitat. Thus, the development of hydroelectric power is often linked to multipurpose programmes. Hydroelectricity plays a key role in the development of the Dez, São Francisco and Volga basins.

Construction costs per unit of generating capacity have tended to rise as the most promising sites have been exploited. But with the recent rise in the cost of other energy producing materials, many sites that were formerly regarded as economically unfeasible for development, may now become economically viable.

The growing industrialization of the developing countries will increase the demand for electric power, and this will require a careful scrutiny and evaluation of remaining hydro-sites.

TABLE 8. Continental Totals of Hydraulic Energy Resources and Current Use.

Continent	Potential available resources 95 per cent of time (thousands of kilowatts)	Potential output 95 per cent of time (millions of kilowatt hrs per year)	Current installed capacity (thousands of kilowatts)	Current annual production (millions of kilowatt hrs per year)
Africa	145,218	1,161,741	8,154	30,168
Asia	139,288	1,114,305	47,118	198,433
Europe (including USSR)	102,961	827,676	135,498	505,317
North America	72,135	577,086	90,210	453,334
South America	81,221	649,763	18,773	91,415
Oceania	12,987	103,897	7,609	28,897
World Total	553,810	4,434,468	307,362	1,307,564

Source: United States National Committee of the World Energy Conference, *Survey of Energy Resources, 1974.*

Not only has the competitive position of hydroelectric power been enhanced by recent increases in the cost of fossil fuels but the fact that it does not produce organic or heat pollution commends it in areas where water quality is threatened.

While the storage capacity of some reservoirs is threatened by silting and the permanence of supply may be dependent upon the preservation of appropriate land use and contingent on upstream development, the relative permanence of the water supply places hydro-projects in a unique position among potential energy sources.

It has been pointed out that hydroelectric power is often combined with other in-stream uses. While some of the uses of a multipurpose project may be complementary, others may in fact be competitive. The intake for a drinking-water supply, for instance, or the diversion structure for an irrigated system can often be located downstream from the hydro-station so that the energy in the water can first be used to generate electricity. On the other hand, the provision for flood control in a reservoir usually means reserving a considerable amount of storage to lop off flood peaks. This reduces the gross head on the turbine and hence reduces the power output.

Not all the theoretical hydro-potential of a river basin can necessarily be developed unless the site is suitable for dam construction, i.e. sound foundations and abutments that are reasonably impervious to seepage; further, the reservoir perimeter must be reasonably free from low areas which would allow overflowing to other drainage basins. Also of great importance is the need to proportion the size of the hydro-development and its generating capacity to the size of the power system it will feed. For an electrical system of any given size, the increment of new capacity must lie within a given range if it is to be economically feasible.

Ideally, the exploitation of any source of energy should be based upon an analysis of all alternative sources so that each may be given a priority for development. Development of hydroelectric power should therefore be analysed in the context of a country's total energy resources. Such analysis not only requires the least cost solution in meeting energy needs, but also that these needs should be evaluated in terms of their net value to the society as a whole. In practice, this would require that pricing of basic fuels should also be based upon their true economic costs.

Once priorities for the development of various types of energy have been established, and the role of electric power in meeting the country's needs has been determined, the next step in planning is to formulate the most efficient mix of investment in hydro, conventional thermal, nuclear and so forth. Where appropriate, a distinction is made between time-of-day and seasonal variations in production and consumption so that the incremental costs of supplying power are reflected in pricing policy. This means that data on hydro potential only has value when viewed in the light of its actual costs and benefits. If alternative forms of generation of electric power are cheaper, or if for any reason demand in a particular country or region does not justify its exploitation in the foreseeable future, the value of data on potential hydro resources is correspondingly reduced.

G. *Water-borne Transportation*

Inland waterways make use of natural streams and lakes or artificial channels. In such great inland water systems as the Rhine, Seine, Danube, Elbe, Nile, Volga-Don, Ganges-Brahmaputra and the Mississippi, storage reservoir evaporation, maintenance of low-water flows and lock operation make the most demand on the resource.

Barges carrying as much as 3000 tons with drafts of 2.5 metres are found on European waterways, and drafts of up to 3-4 metres in North America.

To the extent that regulation of dry season flow is required for minimum operating depths, navigation channels compete with other uses. Their design and operation, however, can be made compatible with the competing demands of hydroelectricity, domestic water supply, irrigation, recreation and waste disposal.

Advances in the design of locks, lifts and inclined planes have reduced the amount of water required to elevate or lower water craft. Further, improvements in the design of barges enable larger cargoes to be handled at lower cost.

These technical improvements have, in themselves, improved the competitive position of water transport *vis-à-vis* road and rail. In addition, two other factors have led to an increased interest, if not a renaissance, in water transport in certain regions. First, recent sharp inceases in energy costs have enhanced the physical efficiency of water as a means of transporting petroleum, coal, minerals, metals, grain and other bulk products. Secondly, the relatively low levels of air, water and noise pollution inherent in water transport make it possible to combine navigation with multipurpose water management schemes involving wildlife conservation and water recreation facilities. As a result, there is a renewed and growing regional and interregional interest in water-borne transportation.

H. *On-site Uses*

Streams and lakes are used for flood conveyance, inland fisheries and recreation as well as for hydroelectric power and navigation.

Fisheries and recreation uses are highly dependent upon the physical, bacteriological and chemical quality of water. In turn, water quality is affected by both point discharges from domestic, industrial and irrigation users, and by non-point flows from forests, fields and grazing lands.

1. *Flooding conveyance*

A natural function of all stream valleys is to carry the peak discharges that occur seasonally or at rare intervals. All forms of water management must allow for these flood flows.

Where the inundated land is potentially useful for crops, transport or city purposes, communities have the option of:

(a) Accepting occasional or periodic loss of property and life;

(b) Trying to control flood flows by engineering works;

(c) Reducing flows by upstream land treatment;

(d) Modifying building and land use to reduce vulnerability to loss;

(e) Sharing the burden of flooding through relief and insurance schemes.

On a world scale, the average annual *per capita* property damage from flood is estimated to be increasing, as is vulnerability to catastrophic damage caused by exceedingly rare floods with a probable recurrence of, say, 100 to 1000 years. Urbanization generally increases peak flows. And poor use of land has effects of even greater magnitude throughout the developing world.

Engineering works for power, irrigation, navigation and other purposes, can in some places be combined with flood control. Warning systems, building design, land use plans and regulations can be integrated to reduce vulnerability to loss.

2. *Inland fisheries*

About 13 per cent of the total world fish catch (63×10^9 metric tons) is drawn from fresh water. Unlike marine fisheries, which have shown marked declines in catch and over-fishing of table-grade fish since 1970, fresh-water stocks are stable or increasing.

The demand for fish as a food supply is intensified by the shortage of other sources of animal proteins, minerals and vitamins. Fresh-water fish production thus plays a small, yet significant, role in helping meet increasing food needs. In multiple-purpose water planning, provision for fish production is of growing importance.

3. *Recreational uses*

Streams and lakes, both natural and man-made, are often used for recreational fishing and water sports. The aesthetic use of water is a consideration here, too. Inadequate treatment of municipal and industrial wastes before discharge may diminish the attractiveness, and even the safety, of natural waters for recreational use. Though impoundments and channel works can destroy valuable aquatic habitat, with proper foresight they can also provide new habitat. Fisheries, navigation and recreational facilities can all, in favourable circumstances, be developed in conjunction with hydroelectric power.

4. *Water quality*

In industrialized countries, one important objective of water pollution abatement is to make waters safe for fishing, wildlife, sports and other water-based recreation.

This concern is related to the protection of health from pollution and leads directly to an assessment of the effects of on-site uses upstream.

The flow of erosion products from grazing lands, cultivated lands, forests and mines threatens the storage capacity of reservoirs by silting and reduces recreational activity and fishing by increasing turbidity. These effects can be countered by soil and forest conservation programmes. At the same time, nutrients from fertilized fields encourage the growth of algae in receiving waters, and the wide use of pesticides, herbicides and fungicides contributes toxic substances. The intense utilization of precipitation in fields or shifts in forestation and farming practices (including the construction of small reservoirs) may reduce run-off. In these ways, on-site uses of water may exacerbate problems of pollution.

Statistics presenting the extent of different on-site uses on a comparable basis are unavailable. However, on-site uses are increasing and are having greater effect on the suitability of water for downstream use.

I. *Summary*

Domestic water supply is hazardous to the health of at least one quarter of the world's population. To achieve minimum degrees of safety in potable water supply for the present and prospective population will require major increases in quantity and great improvement in the quality of water supply. The most urgent needs are in rural areas and in the low-income sections of tropical and semi-tropical cities.

Industrial demand, chiefly for cooling and processing in a few industries, is currently satisfied by methods which vary tremendously in volume of water withdrawn and in amount of waste returned to ground, stream or lake. As demand grows with the expansion of manufacturing, the extent to which the volume of effluent waste will vary and the quality of water deteriorate or improve will be governed by the techniques adopted for in-plant processes and waste treatment.

Irrigation demand, the largest consumptive use, is destined to increase in response to the imperative need to increase food production, both nationally and globally. Although efficiency in the use of water for crops is improving to some degree in some areas and although cropping intensity is rising, albeit slowly, water losses are still large and much irrigated land is deteriorating. Meeting new demands will involve more costly projects, greater attention to auxiliary services, and intensified competition for available run-off. It may also require locating population where water supply is more readily available.

In-stream uses will be affected by changes in water flow and quality. On-site uses are expanding, with a consequent reduction in downstream flows.

Whether at the metropolitan, basin, national or international level, these shifting demands on finite supply will only be satisfied by improved water management programmes where the demand/supply relationship and the administrative and legal structure will influence the allocation of water and the choice of technology.

IV. DEMAND/SUPPLY RELATIONSHIPS

Throughout the world, the essential water problem is how best to reconcile increasing use of a fixed supply with the needs and constraints of human society, in a way that will maintain a stable environment. Three characteristic situations emerge in this evolving relationship between constant water supply and dynamic demand.

At one extreme are the regions, countries or parts of countries with a large natural supply and a relatively low level of demand which can be satisfied without regulation of water resources.

At the other extreme are areas with scarce supply and relatively high levels of demand which are satisfied only through complete regulation of water resources.

In between, are areas where demands for water are satisfied through partial regulation of flow and quality.

In those situations where no interference in water flow is required, water management usually proceeds on a project-by-project basis within a local framework. In the intermediate situation of partial regulation, there are two principal alternatives for balancing supply and demand: increase availability of supplies, or alternatively, decrease net demand by making more efficient use of supplies at hand. In situations of complete regulation, only the demand management option is available and this may call for changes in the location of production or in the mix of products.

This latter situation develops over different periods of time depending upon the whole range of factors affecting demand/supply relationships. In the Tisza River basin (a 156,000 sq km subbasin of the Danube shared by five countries), water management began about 130 years ago and is expected to reach complete regulation in about 60 to 80 years. The Salt River basin (32,000 sq km in the United States) developed complete regulation over a 60-year period. For many areas, long-range equilibrium of demand and supply can be achieved without planning for complete regulation in the short term.

The process of projecting the relationship between supply and demand normally requires a careful examination of alternative development patterns and policies and the likely consequences of each. In addition to the basic requirements for domestic and municipal water, the projection takes into account the desired or possible activities that might require water and the likely water demand for each unit of output. Inevitably, this requires knowledge and experience from many areas: socio-economic, financial, technological, legal and administrative.

Demand/supply management presents particular difficulties in arid and semi-arid lands. The population in these regions is confronted with over-grazed and sometimes parched or even sterile pastureland; a degraded, sparse and vanishing forest; and a precarious agriculture subject to uncertain rainfalls and river flooding. These conditions are frequently exacerbated by the drying-up of surface water supplies between seasons; the problems are further compounded in cold desert regions.

In many arid areas the Sahel countries, for example, a relatively large water potential is often, in fact, available for development. The real problem, therefore, is not the lack of water resources, but rather the lack of an integrated water management policy that will help alleviate the current tragic conditions and also prevent further desertification.

Any policy for such regions must not pay heed only to the uneven distribution of rainfall and water resources over space and time; the cost of water structures and the relatively high cost of ground water exploration and development must also be taken into account. Moreover, systematic training of technicians is required to cope with operation and maintenance functions over areas with scattered population. As a result, the investment required to develop available resources in turn requires a careful appraisal of the social and economic benefits of future water use projects.

A. Socio-economic Considerations

Certain socio-economic questions are basic to the water demand/supply relationship: What are the social benefits of various demands for water and water-related services? How do these benefits compare with the social and economic costs of providing an acceptable level of supply and water-related services? Are the required funds obtainable considering other demands for investment and services in other sectors of the economy?

Optimal demand/supply relationships are often judged on monetary criteria alone. But non-monetary considerations also influence decisions about the appropriate level of water resource development when national goals include such objectives as income redistribution, improvement of public health standards and the general quality of living, income stability for small farmers, and environmental protection and improvement.

As a result, after water demands have been estimated and compared with the costs of supply, those responsible for making investment decision about water supply facilities and production facilities that use water, may well modify the initial projections. For example, plans for type and level of service for a community or district may be adjusted so as to improve a well or spring rather than providing house connexions or stand pipes.

Normally. the basic pattern of a nation's growth is not, except for agriculture, dominated by the availability or the lack of water. The distribution of activities among sub-basins or basins and the technology of water use may, however, be acutely affected by the level of water supply. This intensifies as the marginal costs of water, both for quality and quantity, increase — a common tendency as cheaper supplies are claimed, waste loads increase, and better quality is desired.

Policies for agricultural production, price controls, international trade, urban improvement or similar aims, may be reinforced or counteracted by investments in the water resources sector.

B. Financial Considerations

Although pricing is a powerful instrument for controlling demand/supply relationships, it has rarely been used in water management. This situation may change since a gradual shift from supply management to demand management is under way in many parts of the world as a result of rapidly increasing costs of supply.

The way in which water is traditionally priced by a utility in industrialized societies — price per unit of water declining as gross use increases — can result through time in significant over-investment in water supply. Many water utilities now realize that larger consumers should pay the same price per unit for their incremental consumption as small consumers. They also realize that the price charged should reflect the investment cost of expanding the system capacity through time. If consumers are charged a price which reflects this cost, it is more likely that water-saving and water-using technology will be adopted.

C. Technological and Environmental Considerations

Every technological change has some impact on the environment and each change may have potential costs or benefits. Any projection of demand/supply relationships must allow for likely technological change, and research that fosters desirable new technologies should be built into the planning process.

1. Effects of water and non-water technologies on water supply and demand

Technological developments may contribute to better conservation of existing sources of water supply (e.g. evaporation reduction, phreatotype control, and surface water harvesting). Some may also open up new sources of supply (e.g. desalination of sea and brackish water, precipitation increase through cloud seeding, fog drip augmentation, iceberg towing). These technologies become especially relevant as a society approaches or reaches complete regulation of a region's natural supply. In these conditions, improved and usually more expensive water-use technologies are also available for achieving a balanced demand/supply relationship (e.g. advanced waste treatment for recycling and reuse, greenhouse irrigation, replacement of unlined canals by lined channels or pipelines for water conveyance).

Non-water technologies can also affect the water demand/supply relationship. Some of these exogenous technologies tend to increase future demand for water (e.g. gas production from coal, transport of solids by water slurry pipeline). Some tend to decrease further water demands (e.g. genetic development of plants to withstand drought and salinity, bioprocessing to provide food, electric power generation by use of wind and water power, cooling systems using air). The effects of others depend on local conditions (e.g. use of geothermal energy, vegetation management, oil shale conversion to liquid fuels, conversion of solar energy to heat and power).

2. *Effects of technology on health and ecology*

All water management technologies are subject to ecological constraints. Emphasis on water quality varies from country to country, and even among uses and regions within a country. Maintenance of health is, of course, a paramount concern. But the establishment of appropriate standards for limiting particular substances in water is inhibited in many instances by lack of knowledge of the effects of a particular substance on humans and other organisms in the environment. Efforts are made to regulate the discharge of poisonous industrial wastes, since many are amenable neither to waste treatment nor to water treatment, except at inordinately high cost. The "proper" level of water quality should be determined for each watercourse, depending upon the concurrent or sequential uses to which it is put. Whether effluent control policy standards should be uniform within a basin, within a country or within a multinational region will depend upon development objectives and environmental policies. For example, one basin or sub-basin may be given special status – high quality or low quality – and effluent standards applicable to industries and communities in that basin may be different from those of neighbouring basins.

3. *Effects of water management on the environment*

When stream flow regulation converts rivers to lakes or reservoirs, scenic values are changed. Also, reservoirs substantially increase evaporation from river systems, change water temperature, alter erosion around reservoir banks and trap sediment. If the full consequences of a new reservoir are to be weighed, they must place a socio-economic value on the resulting displacement of people, communicable disease hazards, the inundation of farm land, the enhanced potential for fish production and the modification of wildlife and agricultural production that was dependent on the previously existing régime. Further, important ecological effects will often result from the recreational and urban developments that often follow the construction of a reservoir system.

Large-scale drainage and irrigation projects may modify the physical environment, and generate changes in climate, soil and vegetation and, in ground and surface-water levels. A social environment may often be transformed from a rural to an urban-industrial economic system with numerous secondary environmental and social effects.

Unwise short-term decisions about river regulation may jeopardize long-term possibilities for sound development. The record of water development shows that the advances and consequences of technology can only be ignored at great potential cost to the community. At the same time, the record also shows that with proper foresight, environmental improvement can be one of the multiple objectives of water resource planning and management. Environmental policies must therefore be built into the planning of any water management development programme.

D. Administrative and legal considerations

Administrative and legal structures greatly influence water balance efficiency and under conditions of scarce supply offer important mechanisms for regulating a balanced demand/supply relationship.

As demand intensifies, large-scale regional water supply systems are often developed by the integration of several smaller river basins with the groundwater system. This tends both to strengthen national management agencies, and to establish or modify the structure of river basin or other commissions or committees.

Whenever large river basins are shared by two or more countries, the tendency towards interrelation encourages international basin management and development. Many international agreements have been signed during the past decades. But for a large number of rivers, either no agreement has yet been reached, even after many years of negotiation in some instances, or the agreements reached have little substance and prove to be ineffective in the solving of difficult problems such as pollution control and the development of large-scale facilities.

Through the powerful tools of socio-economic and monetary policy, Governments can, in effect, control the demand for and the supply of water. The form of action any Government will take in managing water resources will generally reflect the availability of financial resources, cultural and political traditions, and the priority given to water development and preservation.

V. CONCLUSION

This paper has described a condition where the global stock of water is fixed, and postulated an accelerating future demand. It is tempting in such circumstances to extrapolate demand curves for future times when they might outstrip supply. But there is little help in such an exercise.

To be sure, water demand has already exceeded supply in some areas. And there is no question that demand will have to be curbed in some instances in the near future, unless available supplies can be inceased and water management radically improved.

Rather than extrapolating from present data on the presumption that current conditions will persist, it might prove more salutary and realistic to focus attention on alternative and improved methods that will correct current carelessness or profligate practice. The crucial question is how to implement effective and socially acceptable demand management procedures before they are dictated by shortages.

Further, the basic data about water supply and its rational use is inadequate for large sectors of the land surface. Decisions about future management for such areas are riddled with uncertainty and frustrated by large margins of error in data derived from inadequate observation networks and equally inadequate modes of analysis. Also, the gap between scientific knowledge and its application is vast and widening in most parts of the world.

The opportunities for radical improvement in the socio-economic, financial, technological, administrative and legal conditions that influence present circumstances are immense. It should therefore not be taken for granted that any sector of the world's population need drink contaminated water, that industry need continue its present pattern of largely unregulated water use and discharge, that agriculture cannot alter its current pattern of irrigation loss and misuse of water, or that productive soils need be destroyed and aquifers exhausted beyond our ability to replenish them in our own lifetime.

Finally, it must be stressed that the urgent need in many areas is a matter not so much of devising new management methods, but of putting to use the technology and institutional devices which are available now. Subsequent papers will discuss how this might best be accomplished under different physical and socio-economic conditions.*

*These papers are included in *Water Development and Management*, edited by Asit K. Biswas, Pergamon Press, Oxford, 1978.