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man's influence on the hydrological cycle

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man's influence on the hydrological cycle

A draft report of the Unesco/FAO Working Group on the International Hydrological Decade

Water Resources and Development Service
Land and Water Development Division

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME 1973

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MAN'S INFLUENCE ON THE HYDROLOGICAL CYCLE

CORRIGENDA

page 13, paragraph 2, line 7, delete:
"appear to be lowest in the tropics"

page 70, after "Netherlands", add:
"Sweden   Dr. Anders Rapp, Department of Physical Geography,
P.O. Box 554, S-571 22 Uppsala"

FOREWORD

Among the activities of the International Hydrological Decade 1965-1975, launched by Unesco, was the creation of a number of working groups, made up of scientists of international reputation, which were to examine areas in hydrology of particular urgency and importance for mankind. The Working Group on the Influence of Man on the Hydrological Cycle was one of these groups. FAO has been responsible for providing the support and technical secretariat for this group. Its first report* was published in 1972. The group then decided that this report should be complemented by another having a different approach to the subject. The present work is the result.

The key to this volume is the fact that man's efforts to control the world's water cycle invariably involve factors other than hydrology and engineering: ecological, sociological, economic, cultural and political considerations and forces. This may seem to be an obvious truth, but, like much common sense, it is all too often ignored in practice, with results that are sometimes very different from those intended by planners and technicians.

The views expressed in this publication are, of course, those of the contributors and not necessarily those of FAO.

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* "Influence of Man on the Hydrological Cycle: guidelines to policies for the safe development of land and water resources" appeared in Status and Trends of Research in Hydrology 1965-1974, Unesco, Paris, 1972.

THE AUTHORS

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MAN'S INFLUENCE ON THE HYDROLOGICAL CYCLE

CONTENTS

INTRODUCTION

In writing this book the authors have had two kinds of readers in mind. The first is the economic or political decision maker who is neither a specialist in water sciences nor has the time to study long and learned works, and the second is the student or the interested layman who wants to obtain an insight into the place of water in nature and the consequences of the decisions on its use - and misuse - being made on his behalf.

Every-day decisions by politicians and economists affect our water resources more than we may realize. For example, if a new plastics industry is to be created it may require 1 000 to 2 000 tons of water for each ton of product, most of which will be returned to a river as polluted effluent. Or, if the decision is made to boost agriculture in a dry zone by constructing an irrigation scheme, can we afford the loss of 1 500 to 3 000 tons of water for each ton of wheat? Or, again, if forests are to be cleared to provide land for farming, will the springs dry up, the floods increase and the river become unnavigable?

The situation in which water resources are affected by man's actions is further complicated by the wide range of needs for water. Primarily water is an essential requirement of life, but it is also an indispensable dynamic agent. In nature it transports the eroded material from mountains and forests to the plains and the sea; man uses it to carry away his wastes, and to produce electric power. It is also used for navigation, it produces food, and is a source of recreation. In many cultures water has a religious significance. This key element of the environment has so many uses for man that it is not surprising that these uses sometimes conflict. In the past, when the growth of demand for water was small in relation to untapped resources, the conflicts between different requirements were generally of only local concern. The situation has now changed.

So long as man was a relatively insignificant element in the whole balance of nature his power to disturb this balance was small. Now, however, his technology is becoming so powerful that he can bring great changes on continental and even global scales, and the need to foresee the consequences of his actions has become a condition for survival.

This book consists of three parts prepared by different specialists with long experience in hydrology and water development problems. The authors cross-checked and criticized each others' work. Each part is a review of one aspect of the broad problem of the influence of man on the hydrological cycle. While the papers were written so as to be self-contained contributions to the understanding of man's relations with water, they are nonetheless presented in a logical sequence, starting with a description of the physical components, followed by a review of the interactions between these components and man, and ending with a discussion of the human obstacles to successful water control.

Part One shows how the heat of the sun supplies the enormous energy needed to keep the cycle turning. Some 500 million million tons of water are raised annually from the surface of the earth to the atmosphere, to be redistributed around the globe as vapour and return as rain, hail and snow and begin the cycle again. The physical, chemical and biological roles of water in the environment are also described in this section.

Part Two discusses the many ways in which man's actions affect the hydrological cycle. Illustrations are given of unexpected and often far reaching results of man's utilization of water. For example, irrigation without drainage has reduced great areas of once fertile land to barrenness, and parts of the Baltic sea affected by industrial and urban wastes are approaching lifelessness. To meet the challenges of water management new concepts in basin-wide planning together with more flexible systems for water control are now being applied. These are illustrated with examples from Europe and Asia, and a case is included of how river pollution has been reversed.

Part Three analyses the obstacles in man himself to the realization of his goals in water development. This section of the book shows that water development planning must be adjusted as much to human as to technical problems. It is the overlooking of this truth that has reduced many apparently good water development schemes to failure.

It is the authors' belief that the future needs of mankind for water will be met only through a sympathetic understanding of the role of water in nature, of the relations between water and man, and of the obstacles to its successful control that lie within man himself.

Part One

THE NATURE AND COMPONENTS OF THE HYDROLOGICAL CYCLE

by James C.I. Dooge

Contents

Page

Contents

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THE GENERAL WATER CIRCULATION

THE WATERS OF THE EARTH

Though crude quantitative estimates of the principal elements of the hydrological cycle have been made at various times over the past three hundred years, it is only in the past fifty years or so that attempts have been made to estimate the total amount of water in the hydrosphere and the quantities involved in the general circulation of water on earth. Some of the elements of these computations are still subject to uncertainties and even the most recent estimates differ somewhat among themselves. The figures quoted below are intended only as indications of the orders of magnitude involved and not as precise scientific estimates. The figures used are taken from recent publications by Barry (3)*, Lvovitch (4 and 5) and Szesztay (6).

* Numbers in parenthesis refer to the list of references at the conclusion.

The total amount of water in the hydrosphere has been estimated at about 1 500 million km^3.. One way of envisaging this quantity is as a uniform depth of about 3 000 metres over the entire surface of the earth. Table 1 summarizes the general distribution of the water of the hydrosphere among different types of water. Practically all of this water (estimates vary between 93 percent and 97 percent) is contained in the oceans and salt seas. Of the fresh water resources of the earth (i.e. about five percent of the total water), the proportion stored in the form of snow and ice or permafrost - and thus not readily available for use - has been estimated as about three quarters of the total fresh water. About half of this frozen fresh water is contained in the polar ice caps.

TABLE 1

Approximate distribution of water in the hydrosphere

Type of water	% of total water	% of fresh water	% of available water (i.e. fresh and unfrozen)
TOTAL:			
Salt	95		
Fresh	5		
FRESH:			
Frozen	4	80	
Liquid	1	20	
FRESH LIQUID:			
Groundwater	0.99	19.7	99
Lakes	0.01	0.2	1
Soil	0.002	0.04	0.2
Rivers	0.001	0.02	0.1
Atmospheric	0.001	0.02	0.1
Biological	0.0005	0.001	0.005

Consequently, only about one percent of the total water in the hydrosphere is in a form that can be readily and economically exploited by present-day technology. Of this available water, 99 percent is in the form of groundwater (about half of which may be more than 1 000 metres below the surface) and only about one percent is in the form of surface water stored in lakes. The amount of water held in the soil above the groundwater has been estimated as about one fifth of the amount stored in lakes and the amount in rivers as about half again.

The total amount of water vapour stored in the atmosphere has been estimated at about equal to that stored in the rivers namely about one-fiftieth of one percent of all fresh water. The final element of the water resources of the earth is the water contained in the biomass or biosphere, which can be guessed as being of the order of one thousandth part of one percent of the total fresh water resources. More than 99 percent of this biological water is represented by the vegetation cover. Though the estimated amounts of water in the atmosphere and in the biosphere are relatively insignificant, they play a key role in the movement of water through the hydrological cycle.

THE GLOBAL WATER BALANCE

In hydrology the main interest is focussed on the transfer of water from one of the forms listed in Table 1 to another. Since the total amount of water is constant, this transfer must consist of a continuous cycle or series of cycles. We are concerned in the present section with the major circulation cycle which operates on a global scale. The movement of water in this cycle, and in the smaller cycles which short-circuit it, is possible because of the supply of energy in the form of incoming radiation from the sun to the earth and its atmosphere. Table 2 shows the elements of this global circulation expressed as millimetres of depth in one year over the appropriate surface concerned, and Figure 1 shows the elements of the hydrological cycle over a catchment area of limited extent.

TABLE 2

The Global Water Balance (Lvovitch 1971)

(All figures in mm depth of water per year)

	Precipitation (mm)	Evaporation (mm)	Runoff (mm)
Earth	1 030	- 1 030	-
Oceans	1 140	- 1 251	+ 111
Continents	760	- 480	- 280

In any segment of the hydrological cycle, the fact that water is neither created nor destroyed is reflected in the equation of hydrological balance:

(inflow) - (outflow) = (change of storage)

In a first approach to the global water balance the change in storage from year to year is taken as negligible so that the annual inflow is taken as equal to the annual outflow.

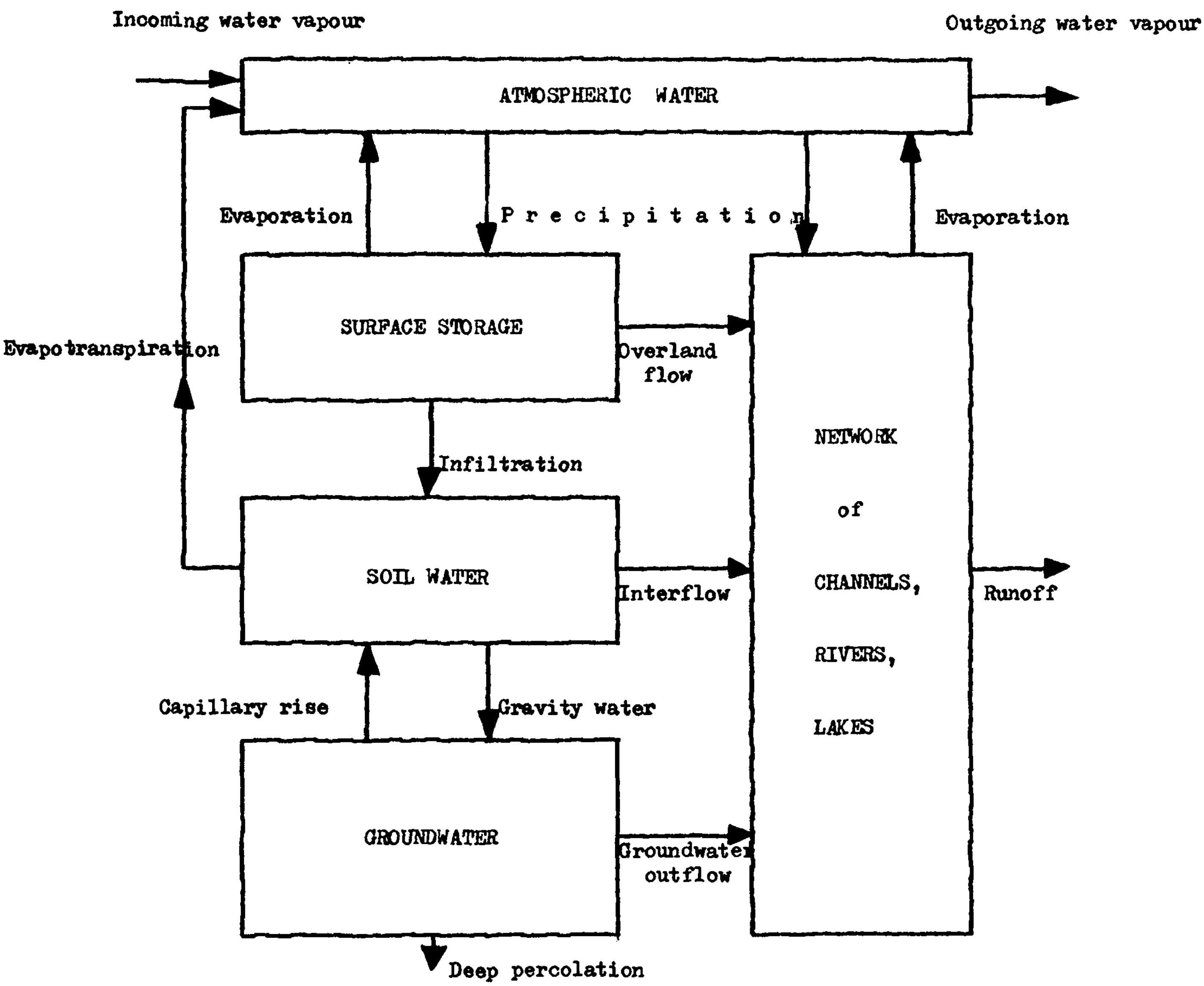
In fact, there will be a change of storage from year to year because there will be a change in the amount of water stored as surface water or as groundwater or in the icecaps or in the oceans. Whether or not such changes in storage can be neglected in our calculations depends on the purpose of the calculations. In many cases we are obliged to neglect changes in storage because we cannot measure them.

The total amount of precipitation on the surface of the earth has been estimated as 520 000 km^3 (i.e. 520 x 10^{12} m^3) per year. Since the amount of moisture retained in the atmosphere is extremely small, this is also the figure for the total annual evaporation from the earth's surface to the atmosphere. This quantity can also be expressed as about 1 030 millimetres depth over the whole surface of the earth which is the figure that appears in the first line in Table 2.

If however we consider the world's oceans only, the annual precipitation has been estimated at 410 000 km^3 or 1 140 millimetres over the ocean surface and the annual evaporation as 447 900 km^3 or 1 251 millimetres over the surface of the oceans. Assuming that the circulation is in equilibrium (i.e. the level of the oceans remains unchanged) this excess of evaporation over precipitation will exactly balance the runoff from the continents into the oceans. The latter can be entered in Table 2 as 111 millimetres depth over the ocean surface.

FIGURE 1

THE HYDROLOGICAL CYCLE
OVER A CATCHMENT AREA



The water entering the atmosphere over the oceans as a result of the excess of evaporation over precipitation is carried by the general circulation of the atmosphere over the continental land areas where the evaporation is very much lower than over the oceans. Table 2 shows the estimated figures for the continents as 760 millimetres of precipitation and 480 millimetres of evaporation per year. This leaves an excess of 280 millimetres of depth calculated over the continental land surface which runs off to the ocean.

The reasons why the figures for runoff are not equal in Table 2 are that the values are expressed as depths over the respective surface areas and the surface area of the oceans is about two and a half times the surface area of the continents. In each case the volume of runoff is of the order of 41 700 km^3.

As already mentioned, the estimates given above are approximate only and are subject to revision. Research on the world water balance is continuing (notably in the U.S.S.R.) and more reliable estimates may become available in a few years' time.

CONTINENTAL AND REGIONAL BALANCES

The amounts of precipitation and evaporation vary over the earth's surface. Estimated figures of precipitation, evaporation and runoff in millimetres are given in Table 3 for the different continents. It should be noted that Australia here refers to mainland Australia and excludes Tasmania, New Guinea and New Zealand.

TABLE 3

Water Balance of Continents (Lvovitch 1971)

(All figures in mm depth of water per year)

Continent	Precipitation (mm)	Evaporation (mm)	Runoff (mm)
Europe	734	- 415	- 319
Asia	726	- 433	- 293
Africa	686	- 547	- 139
N. America	670	- 383	- 287
S. America	1 648	- 1 065	- 583
Australia	440	- 393	- 47
Average	834	- 540	- 294
Greenland			- 180
Antarctica			- 250
Average for all Continents	760	- 480	- 280

The average continental precipitation, evaporation and runoff are close to the world average in the case of Europe, Asia and North America. In the case of South America, continental water balance estimates indicate that the precipitation is more than twice the world average and in the case of Australia that precipitation is only 60 per-cent of the world average. Because of the variation of evaporation opportunity with precipitation, these continents also show values of annual evaporation respectively above and below the average for the continental land areas. The excess of precipitation over evaporation, i.e. the resulting runoff, for South America is ten times that for Australia. In the case of Africa the evaporation is about average but the precipitation is below average and as a result the runoff is only about half the world average.

Water balances can also be studied for regional areas. In this case the general storage equation, i.e. (inflow) - (outflow) = (change of storage), is still applied but the terms are sub-divided in order to attempt to give a more detailed picture of what is occurring. Thus, an attempt is made to distinguish between open water evaporation and transpiration (i.e. the transfer of water from the soil to the atmosphere by plants), between surface water runoff and groundwater runoff and also between surface water storage, soil water storage and groundwater storage. Such regional water balances have been undertaken in connection with the International Hydrological Decade by a number of national committees.

The storage and transport of water in individual catchment areas (see Figure 1) is also studied both from the point of view of scientific enquiry and also to provide the basis for large scale projects of hydraulic engineering. In such cases the change in storage from year to year is often appreciable and must be taken into account.

INDIVIDUAL HYDROLOGICAL PROCESSES

PRECIPITATION

Precipitation from the atmosphere to the surface of the ground and to the free water surfaces in the channels, lakes and rivers will only occur under certain conditions. The three conditions necessary for such precipitation are: (a) the cooling of the incoming air until it is super-saturated with water vapour; (b) condensation (i.e. the conversion of water vapour to liquid water in the form of cloud droplets) which requires the presence of tiny nuclei; and finally (c) the coalescence of water droplets or of ice crystals to form particles which are large enough to fall to the ground as rain or snow.

The cooling of moist air to a sufficient extent to produce condensation in appreciable amounts occurs when the air is lifted. Rainfall can be classified according to the lifting mechanism into: (a) orographical rain where the lifting is due to flow over a mountain barrier; (b) frontal rainfall where the lifting is due to the relative movement of two large air masses; and (c) convective rainfall (i.e. thunderstorm rainfall) where the lifting is due to local heating of the ground and a consequently violent uplift of air over a localized area.

Rainfall is measured by a network of rain-gauges and is usually recorded on a daily basis. In remote areas, only monthly values are measured due to difficulty of access. Rainfall is continuously recorded at selected special sites.

EVAPORATION AND TRANSPIRATION

Evaporation is the process by which a liquid is changed to a vapour or a gas. Evaporation will take place from a water surface when the atmosphere above it has a relative humidity less than 100 percent. The prime energy source for evaporation from water is solar radiation. The amount of evaporation is affected by wind speed and by the degree of turbulence in the air above the evaporating surface, as well as by the vapour pressure difference between the water surface and the unsaturated air above it.

Transpiration is the process by means of which water passes through a living plant into the atmosphere as water vapour. A plant transpires during the growing season about a hundred times the amount of water which is present as biological water in the plant at any one time. This transfer of water from the soil through the plant roots and the plant body to the plant leaves and thence to the atmosphere is consequently an important component of the hydrological cycle in the case of the vegetated areas which are the areas most subject to the influence of man.

The term evapotranspiration is often used to indicate the combined amount of water evaporated from the soil surface and transpired from the soil moisture storage through vegetation. The term potential evapotranspiration is used when the water supply available to the plant is not limited. The rate of a potential evapotranspiration is essentially the rate at which water can be converted from liquid to vapour by the heat energy available.

If the water supply in the soil is limited, the amount of actual evapotranspiration will be less than the potential value. The amount by which the evaporation rate is reduced and the way in which the reduction rate varies with decreasing moisture content is a subject of controversy.

Evaporation and transpiration in a given catchment basin may be measured or may be estimated on an indirect basis. Measurements are made of the evaporation loss from pans of standard size but these values must be multiplied by a pan coefficient to obtain what is in effect an estimate of lake evaporation. Devices known as atmometers are sometimes used which consist of a tube of water separated from the atmosphere by filter paper or a porous plate. These are even less reliable than pans as evaporation estimators. Evapotranspiration can be measured for a given soil and crop coverage by means of a lysimeter. This is an isolated block of soil which can be weighed to determine the change in moisture content and this value used in conjunction with the measured precipitation and deep percolation to determine evapotranspiration as a residual in the hydrological storage equation. A number of methods have been proposed for the estimation of potential evapotranspiration from measurements of climatic variables such as temperature, radiation, wind speed, relative humidity and so on.

INFILTRATION AND SURFACE STORAGE

Infiltration is the movement of water into the soil through the surface of the ground. To the hydraulic engineer who wishes to replenish his storage of surface water it appears as a loss, while to the agriculturalist who wishes to replenish the supply of soil water available to plants it appears as a gain. When rainfall commences after a dry period, the infiltration into the soil occurs at a relatively high rate but as the rainfall continues the rate of infiltration decreases with time and ultimately reaches a constant value. The rate of initial infiltration depends largely on the state of the soil, varying directly with the soil moisture deficit. Infiltration rates also depend on the type of soil, being higher into sandy soils than into clays. The ground cover also affects infiltration rates, the highest rates being obtained for forest cover and the lowest rates for bare, compacted soil. The infiltration rates for permanent pasture and for cropped land lie between these two extremes but the actual values will depend on the nature of the pasture and on the cropping practices. In general it may be said that the better the agricultural practices used, the higher is the rate of infiltration.

If during a storm the rate of precipitation exceeds the rate of infiltration plus the rate of evaporation — the latter will be small due to the humid atmosphere — then water will be stored on the surface of the ground. If the ground surface is uneven, the water will collect in the hollows and in this case is known as detention or depression storage.

If the precipitation continues long enough, all of this detention storage will be filled and the continual build-up of water on the surface of the ground will lead to what is known as overland flow. This consists of flow over the surface which will gather in elongated surface depressions and flow with the slope of the ground towards the nearest open drains or ditches. Under continued constant precipitation, the rate of overland flow will increase until it balances the excess of precipitation over infiltration and evaporation.

In the case of a catchment basin which is covered by forest or heavy vegetation, some of the precipitation is intercepted by the vegetation and held in storage on its foliage. In the case of an urbanized catchment, much of the precipitation will fall on roofs, roadways and similar impervious surfaces. In this case there is no infiltration through such surfaces. Surface storage builds up rapidly on roofs and roadways and then flows off into gutters before being collected either in open drains or in underground drainage systems.

Following the end of rainfall, the surface storage is depleted by overland flow, infiltration and evaporation until the excess surface storage is exhausted. The water held in depression storage continues to infiltrate and is also subject to evaporation. Water stored on the leaf surface of trees and other vegetation or on undrained impervious surfaces is also subject to subsequent evaporation.

SOIL WATER

Soil is capable of holding a certain amount of water against gravity by means of the capillary forces which exist at the air-water interfaces in the unsaturated soil. The maximum amount of water which can be held in this way against gravity by a given soil is known as its field capacity. It is this capillary water which is available to plants and from which they derive not only the water for body building but also the very much larger amounts used in transpiration.

In dry periods, the amount of water in the unsaturated soil will be reduced by evaporation and transpiration. As the amount of moisture in the unsaturated soil becomes less and less due to such transpiration, the suction exerted by the soil on the soil water becomes greater and greater. Eventually this soil suction is so great that the plants are unable to extract the water from the soil and we get the phenomenon known as wilting. It is the amount of the difference between the moisture contents at field capacity and at wilting point that is available for plant use. If infiltration occurs into a soil in which the moisture content is less than field capacity, the effect of such infiltration is to restore the soil to field capacity before there is any appreciable drainage of water from the unsaturated soil to the groundwater (or saturated zone).

In most soils the upper horizons of the soil are more permeable than the lower. In such cases, infiltration may occur readily into the upper layers of the soil restoring it quickly to field capacity. If the lower layers of the unsaturated zone are relatively impermeable, continued infiltration may build up the water content in the upper layers beyond field capacity towards saturation. In this event, there will be a lateral flow in the upper layers which will find its way into the surface drainage system. Such flow is known as interflow or through-flow.

In some cases all of the relatively permeable upper layers will become saturated and the interflow will be accompanied by some overland flow. Even when this does not occur, it is difficult, except under research conditions, to distinguish between overland flow and interflow and the two of them are usually bracketed together and described as surface runoff or direct storm runoff or quick response runoff or some similar term.

In the case of swamps the general picture is somewhat altered. The upper layers of the soil are saturated for most of the year so that the water-table is immediately below the surface and there is virtually no soil water storage in the ordinary sense of the word. The upper horizons of the soil are frequently highly organic in nature and the characteristic swampland vegetation occurs. Swamps can also occur which are essentially shallow lakes choked by sediment and vegetation.

GROUNDWATER

Underground water which fully saturates the soil is known as groundwater and the upper surface of such a body of water as a water-table. Water in the unsaturated zone in excess of field capacity is known as gravity water since it percolates downwards under gravity towards the water-table and the groundwater reservoir. In some cases there occurs what is known as a perched water-table. This happens above a relatively impermeable layer where the water collects in sufficient quantity to saturate the soil and remains in storage since it is deeper than the root level of the surface vegetation. Under very dry conditions, the suction in the upper layers of the soil may be sufficient to induce a capillary rise of water from the water-table (either perched or permanent) and so make it available for transpiration by plants or evaporation from the soil surface.

When the level of the groundwater is high enough relative to the drainage system of the catchment basin, groundwater will enter the drainage channels and contribute to the runoff as spring flow. In humid and temperate areas, this spring flow or base flow provides the long sustained flow during the dry periods. Where the groundwater level is low or groundwater is absent there will be no base flow and the streams of the catchment basin become ephemeral, i.e. carry water only for a short period after rainfall. Groundwater may also be lost from the basin by deep penetration through permeable rocks.

CHANNEL AND LAKE STORAGE

The surface drainage system transports the water from all parts of the catchment basin to its outlet. The channels which combine to provide such a system all perform the same function but may be widely different in appearance. They may consist of small elongated depressions in the surface of the ground or drainage ditches or small streams or rivers or lakes.

Lakes — and to a lesser extent rivers — exercise an appreciable storage effect on the flow so that the outflow at the outlet from a lake (or at the downstream end of a river reach) will have a lesser peak and a longer duration then the inflow. In the case of lakes — either natural or manmade — this storage effect can be very great even when the outlet is not artificially controlled.

The water stored in lakes is measured by recording the surface levels and relating these levels to the volume stored on the basis of a survey of the lake topography. In the case of streams the relation between water level and flow is determined from a rating curve based on a number of flow measurements made in the field.

The main channel or river or lake to which a catchment area drains may, however, also drain other upstream areas as well. Flow conditions in the latter areas may well affect the catchment under consideration. If the channel or river storage is increased due to a flood originating in an upstream area, the increased level will reduce the groundwater discharge and may produce flow from the river channel to the groundwater reservoir, thus creating what is known as bank storage. Further rises may result in the reversal of the direction of interflow and, if the river should overflow its banks, some of the water in the channel storage would flow out over the land as surface storage. During the recession of the flood from the upland area, the water from the flooded area would flow back again across the surface of the ground into the channel system and the water from bank storage would return more slowly from groundwater storage to the drainage system. Needless to say, the provision of such additional storage would have the effect of reducing the peak and increasing the duration of the floods in the main river channel.

SNOW AND ICE CONDITIONS

Under conditions of snow and ice, the above picture is somewhat modified. In a permanently glaciated area, water is stored on the surface of the ground in the form of the glacier or ice cap. In the winter season, the accumulation or water input will exceed the rate of water output or ablation; conversely, in the summer season, the ablation rate will exceed the accumulation rate. If the accumulation rate is greater than the ablation rate over the whole year, the glacier will grow; if it is less, the glacier will decrease in size. The upper end of a large glacier, at which the annual accumulation exceeds the annual ablation, is called the accumulation zone and lower end, at which the annual accumulation is less than the annual ablation, is called the ablation zone. In a glacier in equilibrium, the water equivalent of ice flowing through the body of the glacier from the accumulation zone to the ablation zone will be equal to the net accumulation in the upper zone and also equal to the net ablation in the lower zone.

A seasonal snow cover also represents a case of substantial surface storage of water. In many continental temperate areas, the water stored during winter snowfall is the main source of water supply for domestic, agricultural and industrial purposes during the ensuing summer. The runoff due to spring snowmelt is responsible for the maximum floods in many areas. Since the snowmelt depends on the availability of heat energy to convert the water from solid to liquid the timing and duration of such snowmelt floods depend on the energy budget of the catchment area.

THE WATER CYCLE AND THE ENVIRONMENT

Besides being essential for life, water has many secondary effects on the human environment. Some of the more important of these effects are discussed below. They are grouped under the headings of physical effects, chemical effects and biological effects. The main physical effects of the water moving through the hydrological cycle are its key role in the energy balance of the earth and its great importance in landscape formation. Water is the most active agent in the shaping of the natural scenery that surrounds us. The main chemical effects of water movement result from interaction between soil water and both soil particles and the parent bed rock. Since water is essential for all forms of life, interference with either the quality or quantity of water in any area must have important consequences for the populations of various types of organism in the area.

Since water is so widespread, to discuss all the relationships between water and the human environment would carry us too far afield. Accordingly in the following sections no attempt is made to deal in detail with the various phenomena but rather attention is drawn to some important effects which may result from the modification of the hydrological cycle in any area due to human activity.

PHYSICAL EFFECTS

The energy supplied by the sun to the earth is redistributed by means of the hydrological cycle as well as by the general circulation of the atmosphere. Net radiation available at the earth's surface varies greatly with latitude. In the absence of the general atmospheric circulation and the general oceanic circulation the temperature in the tropics would be higher and the temperature at the poles lower than is actually the case.

The nature of the surface greatly affects the radiation. The proportion of incoming radiation reflected back into space (known as the albedo) is about five to ten percent in the case of the oceans, 15 percent in the case of meadows, 20 percent in the case of crops, 30 percent in the case of desert and 85 percent in the case of snow. The average albedo for the earth's surface is about 40 percent.

It is clear from the above figures that the oceans absorb more than their share of energy. Part of this surplus is returned to the atmosphere since energy is used up in evaporation and released later when the water vapour is condensed as cloud droplets. Without the evaporation-condensation-precipitation cycle, the temperature regime of the atmosphere and consequently of the whole planet would be greatly different.

The energy available due to net radiation at the surface of a body of water or of land (corrected for lateral inflow or outflow of heat energy) is used either as latent heat for evaporation or as sensible heat which is either transferred to the atmosphere or stored in the water or soil. Over the oceans 90 percent of the available energy is used for evaporation while over the land only an average of 50 percent of the available energy is used for evaporation. In Europe and North America the proportion is 60 percent while in Australia with its high percentage of desert the proportion falls to 30 percent.

Since the water balance and the energy balance of the earth are so intimately related, any substantial change in one will be reflected in the other. A change in the albedo of a surface would, for example, change the energy available at the surface. Similarly, a change in the amount of water available for transpiration would affect the temperature of the soil. Mammoth engineering projects have been talked about which would modify substantially the heat balance of the earth and hence the operation of the hydrological cycle. On a smaller scale urban and industrial development alter considerably the thermal regime of the neighbourhood.

Water plays a key role both in the formation of soil and in its erosion. Thus hydrolysis is the dominant weathering process in the case of igneous rocks, while solution is of prime importance in the case of many sedimentary rocks and hydration is of great importance in the weathering of clays. Even under arid conditions, occasional rain storms and dew formation play a significant part in the weathering of rock and soil. Rates of weathering depend on such factors as the nature of the bed rock, climate, local topography and biological action. In the humid tropics, weathering can take place down to considerable depths, sometimes of the order of a hundred metres.

Following the disintegration of rock, water continues to play a key role in determining the nature of the soil which is ultimately formed. The effects involved are both physical and chemical. The downward percolation of water through the weathered material and the chemical reaction with it produce clay minerals both by dissolution from the parent material and by synthesis. Studies have shown that the clay content in the soil increases with the mean annual precipitation when other factors are approximately equal. The higher the mean annual precipitation the higher is the amount of organic material in the upper horizons of the soil. Similarly the higher the annual precipitation the greater will be the depth to the zone at which appreciable accumulation of calcium carbonate occurs. With less annual precipitation, the downward percolation of the water is not sufficient to carry away these mineral salts. Occasional upward movement of alkaline groundwaters may cause such salts to accumulate close to the surface.

Water also plays the major part in the removal of soil particles from the land surface. Through rainfall impact and the flow of water over the surface, hillside material is detached and carried downstream. A high erosion rate tends to occur in areas where there is a lack of plant cover. Certain measurements in the South Western United States indicate that the erosion rate will increase up to a mean annual rainfall of about 300 millimetres and decrease for higher rainfalls due to the increased vegetation cover.

Although the rate of soil erosion is closely related to rainfall it must be borne in mind that total annual rainfall is not always a useful measure of the erosion hazard. In many countries having alternating dry and wet seasons the first rains fall upon bare ground or sparse vegetation. It usually takes from six to ten weeks before the vegetative cover is sufficiently full to afford soil protection. The rainfall during this period both in depth and intensity, is far more critical than the total annual rainfall. Erosion rates are also affected by humidity, elevation and ground slope. In regard to the last factor, it would appear that the rate of erosion increases with slope up to an angle of about 45° and then decreases for still higher slopes.

The sediment eroded from hillsides is carried downstream by the channel system and is subject to deposit and scour in various parts of that system. Ultimately it becomes part of a delta formation at the outlet of the river system. In the uplands there is a net loss of soil due to erosion, at intermediate elevations there is an approximate long-term balance between soil formation and erosion; while in the lower reaches of rivers there is a net accumulation of fertile soil in deltas.

While the overall rate of erosion from the land surface of the earth — estimated at about 0.03 metre per thousand years — may not appear serious, localized high rates of soil erosion can have devastating effects. With adequate vegetal cover, there is an equilibrium between the rate of soil formation and the very slow rate of soil erosion. If the vegetal cover is damaged (by fire or by deforestation or overgrazing or cultivation) the equilibrium is disturbed and soil erosion will commence. The most serious consequence is that the process may become cumulative.

Raindrops falling on bare soil have a high erosive capacity and sheet erosion will commence. As the process continues the runoff collects in shallow depressions and rivulets where its erosive and transporting powers are enormously increased. As time goes on the rivulets become gullies and the gullies become deeper and deeper sometimes resulting in the removal of all the top soil from the area affected.

The loss due to the removal of soil from the upper areas is not the end of the story. The particles carried in suspension will be transported by the stream and if they enter a natural or manmade lake they will tend to settle out as a result of the reduction in the velocity of the flowing water. In this way reservoirs built for various purposes can be silted up to such an extent that the greater part of their storage capacity is occupied by sediment deposits.

The form of hill slopes and of the channels of the river system are the result of the response to the effects of the water flowing through the system. In the case of rivers in alluvial beds and banks, the condition represents an equilibrium in which the amount of suspended material received at the upstream end of any reach is transported through the reach. Any change in the hydrological cycle which effects this particular river reach may result either in the deposition of the suspended material or in the erosion of the bed and banks. The geomorphology of rivers and of slope developments and of drainage patterns is a complex process. Some of the principal conclusions reached may be studied in works such as those by Morisawa (20) and by Leopold, Wolman and Miller (21).

CHEMICAL EFFECTS

Water moving through the hydrological cycle carries solids and gases in solution. A systematic account of the solusphere of dissolved material has been given by Rainwater and White (22) in which they show in diagrammatic form and list in a table the various transport processes, alteration processes and conversion processes relating to the mineral solutes in the hydrological cycle. Carbon, nitrogen and sulphur, all important elements for living organisms, are volatile as well as soluble and hence can move through the atmosphere and perform complete cycles similar to the water cycle (23).

Rain falling on the surface of the ground contains certain gases and solids in solution. Water passing through the unsaturated soil moisture zone picks up carbon dioxide from the soil air and thus becomes more acid. This acid water, coming in contact with soil particles or bed rock, takes certain mineral salts into solution. If the soil is well drained, the eventual groundwater outflow may contain a substantial amount of dissolved solids. Table 4 shows estimates of the runoff from the continents and of the total dissolved solids carried to the oceans by the rivers.

TABLE 4

Annual Discharge of Minerals from Continents (Livingstone 1964)

Continent	Average Annual Runoff m^3/s	Dissolved solids parts per million
Europe	70 000	182
Asia	352 000	142
Africa	184 000	121
N. America	144 000	142
S. America	254 000	69
Australia	10 000	59
Oceans	-	35 000

Table 4 is based on data from Livingstone (24) who estimated that a total of 3 905 metric million tons of soluble material is carried annually from the continents by flowing water.

In certain regions the drainage system has its final outlet in an inland sea rather than the ocean. In such cases this inland sea will adapt itself so as to maintain the water balance of its drainage area and the storage in it will increase or decrease according as the runoff to it is greater or less than the evaporation from it. Since the evaporated water does not contain any dissolved solids, these remain behind in the inland sea and its salt content will gradually increase. Diversion of streams into an area draining to an inland sea may improve or damage the quality of the water and its suitability for use, depending on whether the diverted waters have a salt content less than or greater than the average for the original catchment area.

If soil water is moving upward in liquid form and being evaporated at the surface dissolved salts can also move upward in a soil profile. Salts harmful to plant growth can accumulate near the surface even where the water-table is one or two metres deep. When irrigation water is added to a soil, the water is transpired but any salts in the irrigation water are left behind in the soil. If the drainage system is adequate and sufficient excess water is applied, as is common practice, these salts will be taken into solution by the percolating water and carried away by the drainage system. In the absence of adequate drainage the salts remain in the soil and may accumulate to such an extent that they affect plant production.

In certain instances, the high mineral content of waters is an advantage and the waters are used for medicinal purposes. In other instances the high mineral content may militate seriously against the beneficial use of water for domestic and industrial purposes.

BIOLOGICAL EFFECTS

Water whether in the form of surface storage, soil moisture or channel storage supports a variety of living organisms. The hydrological cycle is thus of great importance in problems involving the biosphere (23 and 27). Under undisturbed conditions, the population of organisms in the soil or in the surface water is the result of an ecological equilibrium. In many cases this equilibrium is a very delicate balance and even small changes in the quantity or quality of water flowing can result in considerable changes in the number or type of organisms present in a given location.

The thin cover of soil, which we saw earlier was largely due to weathering by water, supports not only vegetal cover but a wide variety of micro-organisms. These act on complex organic material and reduce it to simpler organic forms and ultimately to a mineral form. Their action on the surface layer of the soil is beneficial and results in the development of humus which is the organic detritus of decayed vegetation. Humus has a considerable effect on the hydrological cycle, since the existence of an appreciable layer of humus results in a relatively high rate of infiltration. Since infiltrating water normally percolates downward toward the groundwater table, and the micro-organisms are concentrated on the surface layers where there is an abundant food supply for them, the habitat of the soil micro-organisms is confined to the unsaturated zone.

A fresh water environment is less harsh than an air environment for plant and animal life. Water, whether in the form of standing water (lakes, ponds, swamps or bogs) or in the form of running water (streams, springs or rivers) is the habitat for a wide variety of organisms showing the same complexity of food relations as the inhabitants of the land surface. Some standing waters tend to fill in as a result of physical and biological development, so that we have an ecological succession from open water to shallow water to emergent vegetation to bogs. At each stage of the development, there will be a particular population complex of organisms which will be in balance in relation to competition for food and form part of a relatively stable food chain. Interference with the natural hydrological cycle in such areas can result in either the destruction of a given type of organism or the explosive growth of another or may tend to accelerate (or to slow down) the development from one type of environment to another.

Moving water systems have their own types of organism and their own environmental features, some of which are not shared by lake communities. Again any disturbance of the system and in particular any conversion of a running water system to a standing water system will result in a change in the biological community (28). For example, under primeval conditions, a stream might flow through a wooded valley possibly interspersed by swamps. Thus most of the surface of the water would be relatively shaded and would therefore be populated by plants which would be more at home in shade than where more exposed to sunlight. Such streams would have a relatively low productive ability in terms of plant material. The clearing of the banks of the streams would produce a quite different environment which would soon develop a new population mixture of organisms.

Many examples can be cited of cases where fish populationsdisappear from streams for a variety of reasons. Both communities in developing countries who look to good fishing waters as a source of nourishment, and communities in developed countries who also look to such waters as a recreation amenity, suffer damage from such a loss. To maintain a fish population, a stream must have an adequate supply of water at an appropriate temperature, an adequate supply of dissolved oxygen, a source of food supply for fish which may consist of several levels in a food chain, easy access to adequate areas of spawning beds to facilitate reproduction and a number of other environmental factors. Interference with any of these even for a short time can destroy or limit the fish population or may cause them to seek a more favourable habitat elsewhere.

POLLUTION

The use of the water circulation as a vehicle for the disposal of waste materials upsets the natural balance. It is clear that the introduction of toxic materials into the soil or into rivers or other drainage channels may seriously affect the organisms present. Since the introduction of pesticides in agriculture the problem of toxic wastes is now a rural as well as an urban problem. Some of the resulting effects are, however, not direct and might easily be overlooked. Thus the introduction of certain material into a river channel or a lake might not be toxic to fish but might have the effect of killing off the organisms on which the fish depend for food. Such a polluting substance would have the effect of reducing the fish population of the river or lake even though the material was not directly toxic to the fish themselves. Abatement of pollution may be achieved by dilution, i.e. by increasing the volume of clean water available in the stream by water management or by anti-pollution actions such as installing purification plants or by effluent control.

The introduction of non-toxic waste material into lakes and rivers can subsequently have adverse effects on the quality of the water in the lake. In such cases the wastes (inorganic and organic nutrients) stimulate the growth of aquatic flora and fauna beyond the capacity of the water at low levels or flows to supply the oxygen required for the normal processes of growth and decomposition. The plant and animal life may then die, and processes of anaerobic decomposition (with the production of unsightly scum and noxious gases such as H_2S) take place. Such an enrichment of the lake is known as eutrophication and is a severe problem in many countries (29, 30 and 31).

The nature of the hydrological cycle in a particular area can have a marked effect on the presence or absence of pathogenic organisms which are harmful to man or animals. The use of river channels or lakes for the disposal of human or animal wastes facilitates the transmission of water-borne diseases. Many active pathogenic micro-organisms require water in some form to enable them to be transmitted from one host organism to another. Hence the importance of the water route in the control of infectious diseases. In some cases, the long-term storage of impounded water prevents the survival of these organisms since they are at a considerable disadvantage in an environment which is quite different from the intestinal tract which is their normal habitat. In other cases the presence of a body of water or of swampy ground will provide ideal conditions for a certain part of the life cycle of a parasite and thus may cause an explosive increase in the number of such parasites. Thus there is no simple rule that applies to all cases. On the other hand the reverse process of eliminating shallow lakes and swamps is used to control the vectors of such diseases as malaria.

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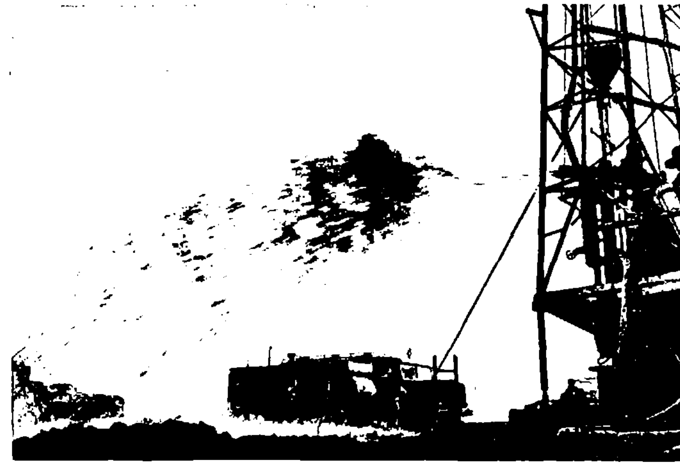
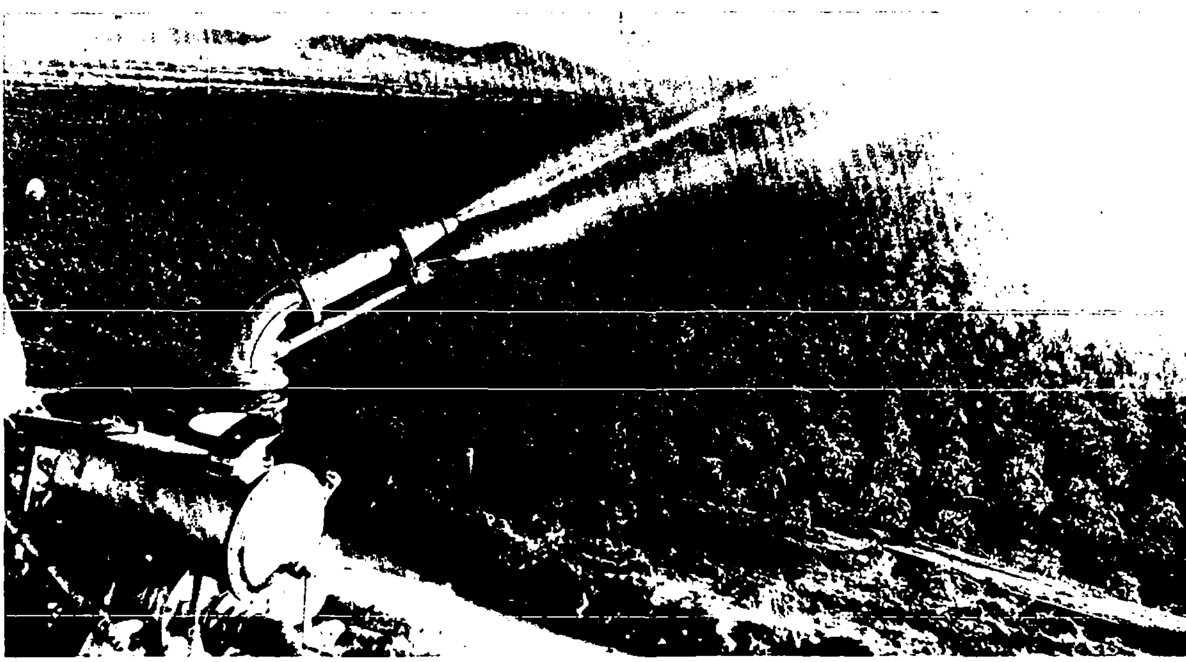
Land and Water

During heavy rain unprotected soil is subject to vigorous loosening and lifting by the raindrops. The loosened or detached particles are then easily eroded by flowing water.





Testing a borehole (top right) in a semiarid region of Syria. Sprinkler irrigation (centre) is the most efficient way of irrigating land which is either uneven or made up of highly permeable soils, but it can be expensive. Furrow irrigation (right) using syphon inlets is a simple and efficient way of controlling water distribution on gently sloping land in which the soils are not too permeable. Usually, this method requires some land levelling. Agriculture is by far the heaviest user of water. As water demands rise the tendency is toward more efficient irrigation techniques.

The Persian wheel (top) worked by leg-power by an Indian farmer, the Archimedes screw (right) and the shaduf (left) used to irrigate fields in Egypt, are ancient labour intensive devices for lifting water.

The Estero Real delta in Nicaragua mapped by side-looking radar (SLR), a remote sensing process still under development,which combines radar and photography. From an aircraft, the radar inspects the ground to the side, but electronic modification gives simulation of a vertical view. Among the virtues of SLR: it is completely independent of daylight and penetrates haze and cloud cover and so can be used at any time, and shadowing effects resulting from side illumination enhance the relief. SLR is one of several remote sensing techniques with application to hydrology. (Photo courtesy of Hunting Surveys Ltd.)

Part Two

BALANCING THE EFFECTS OF MAN'S ACTIONS -
ON THE HYDROLOGICAL CYCLE

by A.B. Costin and James C.I. Dooge

Contents

Contents | Page

Contents Page

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TOWARDS MORE LOGICAL WATER USE

Water, besides being essential to life, is also the most manageable of the natural resources; it is capable of diversion, transport, storage and recycling. And these properties give to water its great utility for man. Its quality and distribution in time and space are highly variable, but the total amount of usable water remains constant. Thus, man is faced with a wide range of choices in managing his water resources. At the same time, however, many of these choices are mutually exclusive. Therefore any proposed course of action involving water resources should not be made in isolation but in full awareness of associated hydrological and ecological effects, and of the other courses of action which would be excluded. In short, man should balance his actions with respect to the hydrological cycle so that a given amount of water can serve his various needs without undesirable side effects.

In any new situation how is man to decide how best to develop some part of his water resources? Case studies of past events describing only the action and its effects are of limited value, both because each situation is unique and because the mode of action is not defined. But logically-based decisions are possible if consideration is given to the effects of specified courses of action on the relatively few components of the hydrological equation, both singly and in combination. Confidence in this approach stems from the ability to predict, at least qualitatively and semi-quantitatively, what the consequences of alternative strategies may be. An approach based on considerations of the hydrological components permits of a relatively systematic treatment of water problems with reproducible predictions that cannot at present be obtained otherwise.

To assist in understanding the processes and examples of interactions which are to be described, it may be useful to give some explanation of the hydrological cycle and its components. For further details the reader should refer to Part One.

The hydrological cycle implies that water, unlike solid minerals such as iron or lead, is in constant movement from place to place and from one state to another. However, since it is neither lost nor gained in the earth as a whole, this movement must be cyclic. In this cycle the water changes state from gas to liquid and back again, but it can never be "lost". The cycle can conveniently be taken to start with the condensation of water vapour in the air and its precipitation on the earth as rain or snow. In the full cycle water runs over or through the earth to the oceans from which it is evaporated to become water vapour again, though within the major cycle there are a number of possible short-cuts. For example, water may evaporate from the surface of the ground, or even from rain drops during their fall, and never reach the sea, or rain may fall directly on the sea and be evaporated back again without benefiting the land areas.

Sometimes it is more useful to look at the hydrological cycle not from the point of view of the changing processes acting on a drop of water but from the point of view of the effect on an area of land. In this case the cycle is better thought of as a water balance: what goes in must come out or cause a change in storage. This balance can be written as an equation in the following terms:

$$P = I + \Delta S + Q + E + \Delta W + V$$

where P is precipitation, I is interception, ΔS is change in surface storage, Q is surface run-off, E is evapotranspiration, ΔW is the change in moisture content of the soil and V is deep drainage. In practice, the equation is often simplified by disregarding interception and changes in surface storage. This is because measurements of evapotranspiration usually include all or part of the evaporation losses of intercepted moisture; and most of the moisture in surface storage is partitioned into evaporation, surface run-off and the soil moisture store. It should be realized that most of the components interact with other components, and with water in other states, including water storages, rivers, lakes and the sea.

So far in this discussion we have considered only the cyclic movement and the balances of quantities of "pure" water. However, water has the vital ability of dissolving other substances and carrying them in solution, as well as of transporting solid particles as long as it is in movement. Therefore we must at all times think not only of the quantity but of the quality of water. This opens up a whole new range of processes and problems, some natural, some man-induced. While mineralized groundwaters have long been known – and utilized at spas and resorts, before the industrial revolution the quality of surface water in rivers and lakes was generally excellent. With the growth of advanced industrial processes and large cities water has been increasingly used as a means for disposing of waste, until today some natural streams are used by man as little more than drains for the disposal of effluent. Convenient as this may be for the disposers, it has now become a major hazard and source of concern and often outrage among water users downstream. The feasibility of purifying polluted water depends on the type and degree of the pollution and the cost which the use can bear. Similarly, the increasing development of land for agriculture has been associated with changes in the quality and quantity of streamflow. Therefore throughout this book the twin standards of quality and quantity must be taken together.

THE COMPONENTS OF THE HYDROLOGICAL CYCLE RELATED TO LAND USE

Most of the hydrological research into the effects of land use has been concerned with empirical relations between, say, clearing vegetation from the land and consequent changes in surface water run-off, without identifying which of the hydrological components have been most affected or are most responsible for the changes in run-off. Analysis of hydrological changes in terms of components is essential if investigations are to have generality. The main effects of land use on individual components are outlined below.

PRECIPITATION

There is much confusion in the literature as to whether precipitation can be influenced by land use. Two main situations can be identified: one in which most of the precipitation occurs as rain, and the other in which it occurs mainly as wind-blown snow, cloud or fog. In the first and most widespread case, there is no apparent effect of land use on the amount of precipitation. But under the latter conditions, surface roughness effects associated with vegetation can be important in influencing both the amount of precipitation (impingement precipitation) and the timing of subsequent streamflow. The presence of groups of trees, or of similar roughness elements such as wind fences, has been shown to increase the catch of wind-blown snow and, under special conditions, of moisture from cloud and fog.

WHEN MOISTURE IS INTERCEPTED

A great deal of work has been done on the effects of clearing and thinning vegetation and of afforestation on interception. Until recently, the interception of moisture by foliage was considered to be a loss to water yield, but it is now known that evaporative losses of intercepted moisture are at least partly offset by reduced transpiration. In general, therefore, land use changes do not produce large hydrological changes due to interception effects. The main exception is where there are frequent light falls of rain which keep the foliage wet and promote evaporation at free water rates; under these conditions the combined evaporation losses may be considerably greater than transpiration would have been during the same period, had the rainfall all entered the soil. Furthermore, there do not appear to be any consistent differences in interception capacity as between forests, pastures and crops. The effects are variable depending on the characteristics of the precipitation. Boughton (2)* reviews much of the relevant information on this subject.

WATER STORAGE ON THE SURFACE

Surface storage can be divided into depression storage, contributed mainly by irregularities on the ground surface, and detention storage, consisting mainly of the film of moisture on the soil, surface litter and surface vegetation at the time when overland flow just begins. Depression storage and detention storage are sensitive to land use practices which influence the amount of surface roughness. Such practices may be mechanical — contour cultivation — and vegetative — maintenance of dense ground cover. On gentle slopes, depression and detention storage of up to 8 mm may occur. Although part of such storage may be lost by evaporation, much of it may infiltrate into the soil. Measures aimed at increasing depression storage, for instance soil conservation works or, conversely, its reduction, as with finely-cultivated seedbeds, can thus be important in the distribution of rainfall between surface run-off and the soil moisture store. In the former case, accelerated soil erosion may occur.

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* Numbers in parenthesis refer to the list of references at the conclusion.

SURFACE RUN-OFF

The characteristics of the soil which control surface run-off of water into streams and rivers are of major hydrological importance in view of the fact that the soil is usually the largest reservoir of moisture and because of the direct relationship between surface run-off and soil erosion. There is a wide range in infiltration capacities of different soils (1 mm to 100 mm per hour) and for many soils this capacity can be affected by land use. First of all there are surface roughness effects influencing surface storage. As already mentioned, these can be modified by vegetative and mechanical means. Then there are soil properties themselves, particularly structure and aggregation, which favour the existence of the large pores (macro-pores) and channels important for the rapid entry of water into the soil. And there are the biological effects of type and depth of root development and of soil fauna which also influence macroporosity and drainage.

In view of the importance of infiltration in relation to soil erosion, its direct measurement should be made together with rainfall intensities in an area as a guide to acceptable practices of land use. Supplementary determinations of "minimum cover standards" should also be made to determine the necessary amount of ground cover, mainly litter and surface vegetation, which should be retained on the soils in different areas to minimize surface run-off and soil loss from the storm rains.

SOIL WATER STORAGE AND EVAPOTRANSPIRATION

Soil water storage reflects both the retention and transmission properties of the soil, and these are a function of the depth, stoniness, porosity and density characteristics of the various horizons. Most of these properties are fairly insensitive to land use except in the case of severe erosion with gross soil losses. However, the amount of unfilled soil moisture storage or moisture deficit is greatly influenced by the evaporation characteristics of the vegetation which, of course, is sensitive to and often dependent on the type of land use.

Vegetation can be examined in terms of several properties relevant to evapotranspiration. Type and depth of root system is generally the most important of these, but radiation characteristics, canopy roughness and diffusive resistances of the foliage to water vapour may also be significant. Greater attention should be given by water managers to the determination of evapotranspiration characteristics of different types of plant cover. There is already considerable information on root effects, and the extent to which different types of root system explore the soil for moisture. This information, together with meteorological data, permits approximate estimates to be made of the changes in run-off or groundwater level which can be expected from given changes in vegetation. For example, H.L. Penman used a variable root constant for the Stour catchment area in England to allow for root differences between grasses, trees and riparian vegetation. On shallow soils, or on soils in very humid environments, the hydrological effects of different types of root system cannot develop; in the first instance, because virtually any type of root system utilizes all of the limited amount of soil water and, in the second case, because soil moisture is non-limiting (i.e. always sufficient for full plant growth), whatever the character of the root system.

DEEP PERCOLATION

The extent, if any, of the movement of precipitation into deep percolation and groundwater, from which it may reappear in swamps, springs, lakes, rivers and the sea, depends on the nature of the changes in the other hydrological components or soil properties discussed above. For example, measures which increase infiltration and reduce evapotranspiration will increase the amount of moisture potentially available for deep drainage. Conversely, increased evapotranspiration as may result from replacing shallow-rooted with deep-rooted vegetation may reduce the amount of water available for deep percolation.

CONTROL OF HYDROLOGICAL PROCESSES

Some examples will now be given of the ways in which man can interfere with the hydrological cycle and change its course for his own benefit or, as it also turns out not infrequently, to his eventual disadvantage. Most of these hydrological influences are still the subject of research or technological development at the present time. Nevertheless, some of them cannot be ruled out on a long-term basis as possible means of modifying the human environment.

WEATHER MODIFICATION

During the past twenty years a number of experiments have been carried out in various parts of the world on ways to increase precipitation on the land surface (4). Most of these have been concerned with cloud seeding, i.e. the use of dry ice or silver iodide in order to provide nuclei for condensation and coalescence of moisture in clouds which were deficient in the nuclei necessary for these processes. Such seeding may only produce precipitation if the other conditions for precipitation are present; in some cases there is even the evidence of a decrease in the precipitation (5).

Though results to date indicate a degree of success with certain types of clouds, it is too early to state categorically that cloud seeding is capable of increasing precipitation over a wide area. Increases of 10 to 15 percent have been reported but there is a dearth of scientifically controlled experiments. Only the future will reveal whether man can induce economically either a significant redistribution of precipitation or an appreciable increase.

Field tests have also been made in the overseeding of clouds by inserting such an excessive concentration of artificial ice nuclei that none of the resulting crystals can coalesce to a size which would enable them to reach the ground as precipitation. Other experiments have aimed at reducing the size, and therefore the resulting damage, of hailstones, which in certain parts of the world may be as large as eggs or even tennis balls, causing great destruction to crops, livestock, motor vehicles, buildings, etc.

Up to now the question of large-scale future changes in climate over the earth has been a subject of conjecture rather than prediction. Precise data have been scarce and the interacting factors which influence climate have complex relationships which are difficult to comprehend. But the necessary data are now beginning to emerge and this difficult subject is becoming more clear. Recent studies are producing significant, thought provoking and, of course, controversial, facts and opinions.

Inadvertent Climate Modification, an international report issued by the Massachusetts Institute of Technology (6), takes up the question of how the earth's heat balance is being influenced and what this may mean. The report says:

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> Until quite recently it has been assumed that man could not compete directly with nature in the release of heat on a large scale, but now we must take a further look at this matter as we realize the implications of a doubling of the present world population of 3.6 billion by the year 2000, coupled with an expectation of more energy to be used per capita. The production of energy of all sorts is rising at a rate of from 5 to 6 percent per year for the world (5.5 percent per year is equivalent to a factor of 5 in 30 years, or by the year 2000 A.D.). There may eventually be industrialized areas of 10^3 to 10^5 km^2 where the additional input of energy by man will be equivalent to the net radiation from the sun; and on a continental scale the present insignificant contribution may rise to one percent of the continental net radiation average after about 40 years.

Among the report's conclusions are the following:

The most sensitive surface state appears to us to be the ice and snow, particularly arctic sea ice, because of the large change of albedo accompanying a change in its area and the relative ease of modification. Inadvertent change in the next four decades will be mainly of regional importance. However, over the only somewhat larger time scale of the next century we recognize a real possibility that a global temperature increase produced by man's injection of heat and CO_2 into his environment may lead to a dramatic reduction or even elimination of arctic sea ice. Further, there is a possibility that deliberate measures to induce arctic sea ice melting might prove successful — and might prove difficult to reverse should they have undesirable side effects.

The example of the arctic sea ice is an interesting illustration of the sensitivity of a complex and perhaps unstable system that man might significantly alter over the next few decades by making relatively small modifications in the earth's present heat balance. Some models indicate that a few degrees C increase in average temperature of the Northern Hemisphere might begin a melting of the arctic sea ice.

Some studies indicate that large areas of open arctic sea would tend to cause melting of the remaining sea ice, with the eventual result that it would disappear entirely. Once gone, it probably would not readily freeze over again. The melting of the arctic sea ice would not affect ocean levels. The changes in climate — especially in the Northern Hemisphere — which would occur after the arctic sea ice melted are unknown, but they might be large and include changes in precipitation, seasonal temperatures, wind systems, and ocean currents. The possible effects on the Greenland ice cap are likewise unknown — whether it would increase because of an increase in precipitation or begin to melt, and how long it might take for such changes to occur, although we believe any such changes would take many centuries. A start has been made in studying, by the use of models, the sensitivity of arctic sea ice to temperature changes.

With respect to man's impact on land surfaces, we have considered possible effects of the heat release resulting from all man's activities in energy conversion — "useful" as well as "waste" energy eventually finds itself heating the environment. We see the possibility of climatically significant changes on a regional scale in the near future. On the local scale, this influence is already very large. Local and regional scale effects are amenable to study by existing climatic models.

Finally, we have considered man's manipulation of groundwater and his use of surface waters. These produce large local climatic changes, for example when an irrigated region becomes cooler. On a global scale the effects are principally upon albedo and on altering the amount of evaporation that takes place. We suggest that these effects could be studied with the use of existing models, but it seems that most of the work remains to be done. In particular, the climatic impact of deforestation of tropical jungle, which seems to result in sharply reduced evaporation and increased local heating, requires study.

We note that "mining" of fossil groundwater is leading to loss of a non-renewable resource, and note that this and inadvertent tapping of other groundwater supplies may be depleting them to the extent that they may be causing the recent rise in sea level.

* * * * *

REDUCING EVAPORATION AND TRANSPIRATION

Direct control of evaporation from open water surfaces has been attempted by use of monomolecular films on the surface (7 and 8). These monomolecular layers are only a single molecule thick in contrast to such films as oil slicks which are about a hundred times as thick. The most suitable materials for this purpose are the long chain molecule fatty alcohols such as hexadeconal. They have the effect of offering resistance to the passage of water molecules into the atmosphere but do not prevent the passage of oxygen molecules from the atmosphere into the water in order to redress any oxygen deficit in the stored water which would be harmful to fish and other life. To be suitable as an evaporation suppressant, a material should be non-toxic, should form and maintain a continuous film over the water surface, be relatively impervious to water, and be convenient and economical to apply to the water surface. Field tests have also been made using rafts of floating plastic balls and floating sheets of plastic and similar physical coverings.

As in the case of the artificial stimulation of precipitation, tests so far give a response which is significant enough to encourage further study but not yet sufficient to be a practical proposition for widespread application in the field. However, reductions in evaporation of the order of ten percent have been obtained in large-scale field tests with monomolecular layers. One of the difficulties of monomolecular layers is the tendency of the layers to break up under wind action on the water surface. For this reason they are somewhat more successful in small bodies of water such as farm ponds than in large lakes or reservoirs.

Some work is also being done on the use of shelter belts around bodies of open water which have the effect of reducing the wind speed across the water surface and hence the evaporation from it.

Efforts have also been made to control the transpiration of plants where such transpiration is a heavy charge on the water budget. Experimentation with chemicals similar to those used for evaporation suppression have been made by spraying plant leaves with solutions of atrozine, thus causing a partial closure of the stomata. But caution should be exercised as anti-transpirants also reduce plant growth and some are potentially toxic both to plants and animals.

Another example of attempts to control transpiration are programmes for the elimination of phreatophytes. The latter are plants which depend for their water supply on groundwater within reach of their roots and which transpire considerably more water than other vegetation in the same environment. Such plants can be responsible for losses of water greater than the losses from a large reservoir. However, unless they are replaced by other vegetation the removal of such water-loving plants will probably not be successful as many of the species have a great capacity for regeneration; nor may it be desirable when weighed against the possible disadvantages such as loss of soil stability, wildlife habitat and increased salinity (9 and 10).

CONTROLLING SOIL WATER MOVEMENT

Recently advances have been made in the utilization of very sandy soils by the creation of an impervious bituminous membrane at a pre-selected depth to prevent deeper percolation of rain and irrigation waters. The form of artificial interference with the infiltration component of the hydrological cycle has resulted in considerable increases in crop yields under a fixed amount of rainfall or irrigation in dune areas.

During the last decade further improvement was introduced into the system by spraying not only oil but combined seed, fertilizer and coating material to which a moisture-retaining and swelling clay mineral called montmorillonite is sometimes added, which greatly increases the moisture-retaining capacity of the sand. The plant nutritive substances are retained on the surface of the montmorillonite and are therefore not washed away by rain, thus permitting large doses of plant nutrients to be stored on the clay as long-lasting fertilizers. Many other types and combinations of these are used now in large-scale application.

INCREASING THE AVAILABLE WATER THROUGH ENGINEERING

From prehistoric times, man has interfered with the natural conditions of water. At first, water was extracted only in small quantities for consumption, for transportation over short distances, and for the disposal of small quantities of the waste products of human activity. This interference grew in scope and as it grew its effects were increasingly felt.

Long-range historical studies have shown that most civilizations and empires which were founded on irrigated agriculture have eventually crumbled and lost their predominance. While the immediate reasons were often human - political changes, wars, invasions, plagues - the principal physical causes for the ultimate failure of almost all of the irrigation systems were these:

- Salination of the soils due to improper drainage and consequent high water-table;
- Failure of river diversion works because of erosion in the main channel which lowered the water levels at the source;
- Failure of the river diversion works because of silt deposition raising the levels of the irrigated fields;
- Sedimentation of the storage reservoirs.

It should give the modern planner considerable cause for concern that large-scale irrigated agriculture has rarely been permanent and that its predictable failures have had a close causal relationship with the disappearance of once-mighty nations (16).

The major works of modern hydraulic engineering are a feature in both developed and developing countries and represent gigantic efforts by man to improve his environment and the human condition (17 and 18). Though some of the interferences of these works with the hydrological cycle are deliberate and are the principal objectives of the works, other indirect effects are not always clearly recognized by those decision-makers responsible for evaluating alternative proposals for development. The effect of such works on the aquatic environment has been summarized by Dill, Kelley and Fraser (19).

Some typical projects are discussed below from the point of view of their modification and interference with the hydrological cycle.

IRRIGATION AND THE DANGER OF SALINITY

Irrigation is essentially an attempt to make up for the deficiencies of natural precipitation. Spray irrigation in particular can be considered as artificial precipitation. Furrow or basin irrigation can be considered as an artificial provision of surface storage which will infiltrate into the ground in the same way as ponded rainfall.

Since the objective of irrigation is to grow crops which could not be grown in the natural state, one direct result of the operation is an increase in transpiration. If irrigation water is taken from outside the catchment basin and only enough is added to provide for additional transpiration, there will be no effect on the water budget of the area. There is, however, an effect on the soil which may have serious consequences. The irrigation water applied to the soil contains mineral salts, the vast bulk of which are left behind in the soil. Unless the soil at some time during the year contains some gravitational water which percolates downwards to the groundwater reservoir the build-up of these salts in the soil may be dangerous to plant growth.

Since it is difficult, under practical conditions, to determine the exact water requirement of a crop, there is a tendency for the farmer to make sure that there is enough water for plant growth by supplying more than an adequate amount of irrigation water. The water not required for transpiration or maintaining the field capacity of the soil will percolate down, thus giving a recharge to groundwater that was not present in the natural condition. Unless the drainage outlet of the groundwater to the channel system is improved the result will be a gradual rise of the groundwater level. Such a rise is liable to bring about not only waterlogging of plants but ultimately the development of a saline soil. This is due to the fact that evaporation, whether directly from the soil through capillary rise of groundwater, or by transpiration through plants, is the conversion from liquid to vapour of pure water, the salts being left behind to accumulate in the soil unless proper drainage is assured.

In the past these side effects of irrigation were not always understood or allowed for in the design of irrigation schemes. For example an air survey in 1952-54 of the Indus irrigation schemes showed that out of a total of 18.6 million hectares 24.3 percent was affected by waterlogging and about 34 percent suffered from salinity; and ten years later it was estimated that the rate at which productive land was being damaged by salinity was still rising and had reached 40 000 ha per year (20). The rehabilitation of these lands is now in hand but it is a long and slow process.

Even if these difficulties are overcome by an adequate drainage system and the application of sufficient water to enable percolating water to remove the excess mineral salts, an irrigation scheme will result in an outflow of more or less saline water from the area. If the degree of salinity is high or the amount of water drained in this way is large it may create difficulties for downstream users of the water.

DRAINAGE

In humid areas, where the ground surface is waterlogged either permanently or intermittently, drainage works are frequently undertaken in order to improve agricultural production or to eliminate conditions conducive to the spread of certain diseases or to reduce transpiration. In some cases, the drainage works are designed to facilitate the conveyance of the water from the surface of the ground or from the soil to the existing elements of the channel network which are then able to carry the outflow away. In other cases, the channel network itself must be improved so that water can more readily travel from soil in the form of interflow or from the groundwater in the form of groundwater flow.

On a still larger scale are major works of river improvement, which are aimed at giving an outfall for an improved channel network or at preventing the overbank flow or flooding of the land during times of heavy rain.

The main effect of ordinary drainage works is the lowering of the water-table and the creation of an appreciable zone of unsaturated soil moisture storage in areas where little or none existed before. The primary hydrological result of such an effect is that the volume of infiltration into the unsaturated soil is increased.

In the case of most swamps, the surface layers of the soil are highly organic. Following the lowering of the groundwater table due to drainage, such organic soils are subject to oxidation and consequent subsidence of the ground surface. Due to this effect, many attempts at the drainage of swamp lands have been negated by subsequent lowering of the elevation of the land surface. This can be minimized by a careful control of the groundwater level. Swamps, which are essentially lakes choked by vegetation, tend to trap sediment carried down from upland areas. If such lakes are cleared of vegetation and their outlets opened up such sediment will be carried further downstream where it may have damaging effects.

WETLANDS MAY BE BETTER LEFT ALONE

The elimination of swamps and flooded flat lands is not always an unmixed blessing. From the point of view of flood control these areas provide a storage volume which reduces the peak of the flood coming from upstream. There is little point in draining a swamp at great expense and afterwards building a dam somewhere else in the area in order to provide a reservoir which will replace the attenuating effect previously exercised by the swamp on major floods. The drainage of swamps or flood lands may also destroy valuable fishery resources — especially important in tropical countries. The conservation of certain types of wildlife and fisheries depends critically on the preservation of areas of wetland which provide a natural habitat for such species, the economic value of which is rapidly increasing due to the growth of large cities, loss of wild land in many parts of the world and the increasing importance of tourism.

RESERVOIRS MEAN EVAPORATION

Dams, of a wide variety of sizes, are built to impound water so that an excess of water available at certain times can be stored and used at other times when natural flows are insufficient. Dams vary from farm pond embankments constructed by an individual farmer to hold water for his stock, to small detention dams intended to check floods in upland areas, up to large dams which are parts of integrated water resource systems designed to develop whole regions by providing for irrigation, power, water supply, low flow augmentation and other purposes.

There may be a conflict between the individual interests of potential users of impounded water. It may be necessary to harmonize the set of varying objectives by a multi-purpose development which is imaginatively conceived and rationally evaluated (17). Conflicts between different users and between the interests of upstream communities and downstream communities must be reconciled in the light of higher-scale objectives that optimize the welfare of the whole region. In both developing and developed countries, there have been instances of prestige projects based on a small number of large dams where a larger number of smaller dams would have produced greater overall benefits. Apart from the conflict between the various types of benefits from impoundment, there is the serious problem of secondary effects resulting from it (35).

In all cases, one of the main effects of such impoundments is an increase in evaporation. In areas subject to high net radiation, the economy of the construction of a reservoir for multi-purpose development may well hinge on the evaporation from the surface of the reservoir. It is in such areas that the application of evaporation suppression by surface layers of some kind, when this technique is properly developed, would be most beneficial. There is little use in spending money to accumulate scarce water resources in a position from which they are readily lost to the atmosphere.

The second main effect of impoundment is to smooth out the variation in flow. If part of the volume of the reservoir can be kept empty, it can have a marked effect on the control of floods and on the augmentation of flow downstream of the reservoir during dry periods.

SIDE EFFECTS, GOOD AND BAD

Certain other effects also result from the impoundment of water. The creation of a reservoir results in the build-up of groundwater levels surrounding the reservoir and a good deal of water may be stored in such groundwater in certain cases. A reservoir also tends to remove sediment in suspension from the water entering the reservoir. This may be good or bad or even both at once. The loss of useful storage space in the reservoir is of course harmful to those interests requiring water storage — for example water supply in drought periods or flood reduction. But the reduction in sediment load may be beneficial to users downstream, though this is not always the case as the cleaner water may have more power to erode its channel than the sediment-charged water. An interesting, though admittedly unusual example of the positive benefit of sediment in a reservoir is found in one desert country where the silt-covered reservoir floor is cultivated as the water level falls to form a productive new area of annually "flood-irrigated" land in a region where the rainfall alone is quite inadequate to support agriculture.

The impoundment of water in reservoirs has beneficial effects on the quality of the water. Variations in the chemical quality are smoothed out by storage and long-term storage may produce a very marked improvement in the bacteriological quality of the water. However, here again there is no simple rule for in certain conditions of reservoir shape, temperature and wind conditions, the water in a reservoir can become stratified and while the top water improves in quality, the bottom water may deteriorate in oxygen content with the development of undesirable anaerobic processes and obnoxious gases such as hydrogen sulphide.

BIOLOGICAL CHANGES IN DIVERTED WATER

The diversion of water rarely has direct effects on the hydrological cycle but indirect effects can occur. Water diverted or abstracted from channel flow, or from groundwater, or from natural lakes will be returned in approximately equal quantity to some other part of the cycle, though in some instances the return of the water may be to a catchment basin other than that from which it was drawn. Even if returned to the same basin, the abstraction and return points may be widely separated and there is obviously an effect on the flow in the intervening reach. Such reduction of flow in the normal stream channel can have severe effects on its living aquatic resources. Not only their living space but their spawning and nursery grounds and food producing zones are reduced unless adequate compensatory flows are provided.

USES AND ADVANTAGES OF GROUNDWATER

The abstraction of groundwater and the return of the water used to the surface drainage system represents either a by-passing of the groundwater flow, or else the mining of deep groundwater storage which would otherwise not be part of the hydrological cycle. In the latter case, the abstraction will result in a permanent lowering of the groundwater table and a slight increase in the waters of the ocean. There is some evidence to suggest that this is occurring on a world scale. The lowering of the groundwater tables has effects other than the removal from storage of groundwater that is not being replenished. In coastal areas the lowering of the water-table may result in the intrusion of salt water thus altering the hydrological balance in a most undesirable way.

In recent years the artificial recharge of groundwater by surface water has been studied and applied in the field (22). This represents the diversion of water from the surface drainage system into the soil and ultimately into the groundwater reservoir. The effect of such diversion is to reduce the amount of evaporation from the free water surfaces and to smooth out the natural variations in flow by means of the large groundwater reservoir. In many cases it will also have the effect of improving considerably the quality of the water.

Groundwater recharge is becoming an increasingly important form of water storage. The prerequisite conditions are an aquifer suitable for storage, and a pervious spreading area. Where the aquifer is overlain by an impervious layer the recharge can be accomplished through wells or bore-holes. These are some of the advantages of the underground water storage over surface reservoirs:

- No evaporation losses;
- No sedimentation problem;
- No valuable land flooded;
- No hazards related to flood and spillway capacity;
- No unnecessary expense for flood protection by elaborate spillways;
- No health hazards associated with impounded water;
- Can serve as an underground barrier to sea water intrusion;
- Does not require large long-term investment before first benefits can be realized;
- Susceptible to progressive development.

The rise in groundwater levels due to irrigation which was mentioned previously is in reality a form of unintentional groundwater recharge. As noted, it can have harmful effects if the water level rises almost to the surface, but if the groundwater lies sufficiently deep not to limit plant growth and if the quality remains within acceptable limits, then the addition to groundwater of deep percolation from irrigation is a net benefit to the groundwater reservoir.

Examples of the depletion of groundwater through over-use are well known. This over-use can result in falling yields from wells, the drying up of springs, which are the natural overflows of groundwater reservoirs or, if near the coast, in the intrusion of sea water into the fresh water reservoir with serious results. The way in which Malta deals with sea water intrusion through special legislation is mentioned by Prof. Finkel on page 57. These effects have been found where the rate of withdrawal of groundwater was not in harmony with the groundwater balance of the hydrological cycle. The concept of "safe yield" was developed to signify the rate of abstraction from a groundwater reservoir that could be maintained indefinitely. Recently however it has been accepted that groundwater "mining" — abstraction greater than replenishment — may be justified in some cases. An example is described in the report (23) of a recent survey of a part of the Sahara lying in Algeria and Tunisia. The area covered 780 000 km2 where the average annual rainfall is less than 100 mm, though the annual average has little meaning in a climate where several consecutive years may be dry and then two or three years "average" rainfall may fall in two or three days. The present rate of groundwater recharge (which was also equal to the outflow rate until the last 20 years when exploitation by deep drilling began) is equivalent to about 33 m^3/sec, but the total reserves of these great aquifers, filled during the pluvial Quaternary period, amount to some 60 000 km^3 (or 60×10^{12} m^3) of water, or enough to supply 1 000 m^3/sec for two thousand years. As the report comments, "The limiting factor for the agricultural development of an additional 50 000 to 100 000 ha (more than tripling the present area of oases) is not water, but the amount of funds that can be allocated".

DESALINATION

The process of desalination represents another short-circuiting of the hydrological cycle. Instead of the water in the ocean being evaporated, transported over the land, precipitated, conveyed to the channel system and then abstracted for use, sea water can be desalted in an industrial plant network as fresh water. In a similar fashion brackish groundwater can be made fit for human consumption, livestock, or industrial use. As a result of considerable research and development, the cost of desalination has been considerably reduced but for most purposes the process is not yet economically practical except where the cost of alternative supplies of fresh water is very high (24).

The most commonly used methods of desalination belong to one of two groups: methods based on distillation and methods based on membrane techniques. The distillation techniques are of course analogous to the natural process of evaporation from the salt water of the ocean into the atmosphere and its recondensation as fresh water in the clouds. The techniques vary from solar distillation under glass to complex multistage flash distillation plants. Membrane techniques depend on either the ability of certain membranes to permit the passage of water molecules and restrict the passage of mineral ions; or on the use of stacks of membranes half of which facilitate the passage of only positive ions and the other half of which facilitate the passage of only negative ions.

EFFECTS OF AGRICULTURAL AND FORESTRY PRACTICES

The effects of forest clearance and of tree planting on the hydrology of catchment basins has been studied and discussed for many years (35 and 36). Because of the difficulties inthe measurement and experimentation in this particular field, apparently conflicting results have at times been reported.

The effects of forests on the hydrological cycle illustrate the complexity of interacting hydrological processes. These effects can be broadly classified into effects on:

- precipitation
- evaporation
- surface flow and infiltration

FORESTS AND PRECIPITATION

It is now generally agreed that the presence of a forest cover in comparison with alternative vegetation does not affect the total amount of precipitation. However, there are local exceptions such as "occult" or "impingement" precipitation, and the interception of wind-blown snow.

Occult precipitation is due to the collection on tree crowns and stems of fog-sized droplets moving horizontally into the vegetation. Other phenomenon are condensation of water vapour as dew on leaf surfaces, or freezing to form deposits of rime.

The effects of forests on interception of snow have been extensively studied in Russia. Records of precipitation and streamflow for groups of catchments in the European territory of the U.S.S.R., show that under the special conditions of this environment forest cover gives a higher water yield than does farmland. The special conditions are (a) that most of the annual precipitation occurs as snow, (b) the major run-off events in each year are due to snowmelt, (c) the roots of the forest trees are confined to a shallow layer of about one metre depth. In an Australian study (38) at the time of maximum snow accumulation in spring, the forest areas contained up to twice as much snow-water as the deforested areas. Estimates indicate that reforestation of the formerly forested country would increase its snow-water content by about 70 percent. Afforestation or equivalent wind-fence treatment of the whole of the subalpine section of the catchment could increase its snow-water content by an overall 17 percent. It is not known to what extent the differences in snow-water content between the forested and treeless areas reflect the blowing off of snow into lower catchments or its loss by evaporation en route. However, the fact that more snow accumulates in the higher catchment and lasts longer where there are trees is significant for the generation of high-level hydro-electric power and for helping to even out streamflow. Snow management through vegetation is now being applied in several parts of the world. Of course, strategic afforestation and the construction of snow fences have been used in Europe and North America for many years for the control of avalanches and of the drifting of snow across highways.

FORESTS AND EVAPORATION

Under most climatic conditions, however, the effect of forest cover is to promote a higher rate of transpiration and hence to reduce the volume of total run-off. Accordingly, the removal of forest cover would normally have the effect of increasing the total run-off due to the reduction in evapotranspiration and also of increasing the flood peaks due to the decrease in infiltration capacity. The increases in water yield following forest clearances which have been measured in the field have been variable in amount. However, it would appear that the increases are approximately proportional to the percentage of area cleared and are in all cases less than an equivalent depth of 350 millimetres of water per annum for total clearance, or a corresponding amount for partial clearance. In cases where adequate drainage is not available, the decrease in transpiration may result in a rise in the groundwater table which can cause serious problems if the groundwaters are saline.

Cumulative effects on groundwater may occur as a result of changing vegetation patterns and associated rates of evapotranspiration. An example of groundwater rise following clearing of vegetation is the Callide Valley in Queensland, Australia, which was originally covered by dense forest and scrub (2). Vegetation maps of the area in 1921, 1945 and 1961 document the progressive clearing, and records of groundwater levels in the area show subsequent rises where clearing occurred. Rises up to ten metres in groundwater level have been recorded. In Western Australia the clearing of eucalyptus forests for shallower-rooted pastures and cereals has led to increased salinity in lower sites in the landscape. The soils affected have a considerable amount of salt in the subsoils due to a long period of accumulation of oceanic salts; but, under the original vegetation, with relatively high evapotranspiration and little excess water for seepage, the salt tends to remain at depth and fairly evenly distributed over the landscape. However, with reduced evapotranspiration, some unused soil water is available for down-slope seepage. Thus excess water carries salt with it and concentrates it in valley bottoms and around hillside springs. Describing a similar situation in Victoria Downes (39) writes "It would appear that the most likely way to re-establish a hydrological balance would be a return, not necessarily to forest, but to an improved pasture-savannah woodland formation with sufficient trees to dry out the sub-soils during the summer and ensure complete use of the water where it falls and soaks in".

In the Gambier Plain of South Australia there are differences in groundwater recharge between forest plantations and grassland cover. Under the conifer plantations evapotranspiration rates are sufficiently high to prevent any excess of soil moisture being available for seepage and groundwater recharge. By contrast, under grassland with a lower evapotranspiration, there is an annual recharge of groundwater of about 80 to 100 millimetres. The current rapid increase in the use of groundwater resources in South Australia gives importance to the need to consider the hydrology as well as the more obvious economic aspects of replacing grassland by forest in this type of environment.

FORESTS, INFILTRATION AND EROSION

High infiltration rates, with a corresponding reduction in surface run-off and soil erosion, are features of most forests in good condition. These attributes are due to the relatively stable and porous structure of the forest soils, and to the protection of the soils by the leaf mould and ground cover. High infiltration also increases the opportunity for recharge of groundwater, with the result that the flow of springs and streams tends to be more sustained; however, as noted above, total flow may be less due to the usually higher rates of evapotranspiration from forests than from most other types of vegetation. In areas of snowfall, forests further sustain streamflow by delaying the melting of the snow.

These favourable conditions for infiltration which exist under many forests (the relatively stable soils, the protective ground cover and leaf mulch, and the usually higher rates of evapotranspiration) tend to operate in the same direction to minimise soil erosion as well as surface run-off. There are many instances of slopes steeper than the equilibrium slope for the soil becoming unstable after the forest cover is removed. Extensive mass movements may result, sometimes soon after clearing, but sometimes many years later, after the original root system and surface cover have rotted away.

However, it should not be thought that tree cover itself is an insurance against surface run-off and soil erosion. Removal of the ground cover and leaf mulch, as by grazing or fire, may have serious consequences. An example of the effects of a forest fire in Australia is given by Brown (40), based on measurements of streamflow and sediment load before and after a major fire which severely burnt a steep forest catchment. After the fire, sheet erosion was immediately observed, resulting in sediment loads up to 400 times greater than before. The effect of the fire on flood flows is illustrated by comparison of two similar storms over a small catchment, one before and one after the fire; in the former a rain of 12 mm produced a peak flow of only 0.34 m^3/sec while in the storm after the fire a rain of 8.5 mm caused a flood exceeding 9.5 m^3/sec.

POPULATION AND DEFORESTATION

Forest clearance may be a result of increasing population pressure. In one area of south east Asia the climax vegetation of tropical monsoon rain forest is being cut both for fuel supply and for shifting cultivation (41). Although regulations exist against such cutting, it is difficult to enforce them in areas where the families cannot afford imported kerosene, and need the land to farm. Although in the short term their needs can be met from forest clearance, in the long term this solution is inadequate. The natural yield of wood for fuel of these forest lands is reduced to a third or less after primary deforestation, and the damage to the land is permanent since without protection the friable sandstone and shale soils are eroded to bedrock. The resulting increased supply of sediment to the rivers has disturbed the natural balance between the channel shape and transporting power of the rivers and the sediment load. Stream channels have become unstable and typical bed widths have increased over the last 30 years from 50 to 500 m; shifting sandbanks are hindering navigation on major rivers. Former observations of sediment load suggest that the soil loss in one basin of 600 km^2 increased from 0.3 mm per year in 1910 to 0.7 mm per year in 1950 and on the present trend may reach 16 mm per year by 1990. This last figure represents one percent of the volume of the run-off, a figure which has already been observed in another basin. That these increases are due to forest destruction can hardly be doubted. The farmers are aware of the problem but rightly ask — What else can we do? The problem thus changes from a technical one to a human one.

There is nothing new about the awareness of the effects of deforestation among observant and responsible people. Recently the report of a British civil servant in Burma, E.W.D. Jackson, was brought to our attention. Written in 1935, the report warned of the accumulation of sediment in Meiktila Lake, an irrigation system with a unique history.

"The Meiktila Lake", reported Mr. Jackson, "is without doubt the most successful irrigation work constructed in the time of the Burmese kings, and remains substantially unaltered since the day it was completed some 900 years ago." It was more than an irrigation work; it was a historic monument "regarded with feelings of pride and deep sentiment by every Burman." After nine centuries, it had begun to silt up. Today, in a time of concern over environmental damage, Mr. Jackson's report is of particular interest. The following is an excerpt from it.

* * * * *

It may well be asked why the engineers in charge of the Lake have been tackling the silting problem at the wrong end.

If the trouble is due to silting, why let silt get into the lake in the first instance?

In the time of the Burmese Kings there was no such trouble. The Lake was famed for its clear water, in which even weeds did not grow. The bunds were never in danger of breaching — the only recorded breach was due to a cut made by the Chinese army which invaded in the 15th century.

If the Lake could last nearly 900 years under Burmese rule without silting up, what change of conditions has occurred under British rule to place the Lake in such grave danger within recent years?

The replies to these questions may not make entirely pleasant reading, but nothing is to be gained by evasion, and a frank statement of the facts will facilitate the consideration of the whole problem.

In the time of the Burmese Kings there were very strict laws enforced in connection with the administration and control of the Meiktila Lake. One of these laws in particular was enacted with the dual intention of ensuring a good regular supply of water and preventing the entrance of silt into the Lake.

No person, on pain of death, was permitted to cut any jungle or to clear any land for any purpose whatsoever within two miles of the bank of a stream in the catchment area.

The Burmans knew that in closely afforested areas there were usually ample supplies of subsoil water, which was of course very desirable in the streams feeding the Meiktila Lake.

It was also a matter of common knowledge, based on ordinary observation, that the protection of wide strips of land by forest, undisturbed jungle and grass would prevent eroded soil from being swept into the streams and carried down as silt during the rainy season.

Under the British administration many harshly enforced Burmese laws became obsolete, and unfortunately the laws concerning the Meiktila Lake were amongst them.

The engineers were given the Lake itself to look after and improve. The catchment area was not placed under the control of the Irrigation Authorities (who, it must be confessed, did not in the light of the technical knowledge of those days, concern themselves very greatly about what might occur in the areas above the Lake), but was thrown open to cultivation to a great extent, and in parts worked as a reserve forest for purpose of revenue.

The natural result has been that the land in the catchment area has been cleared, especially the rich strips of virgin soil along the banks of streams, and the effect of the climate has accelerated surface erosion to such an extent that the situation is now one of the utmost gravity.

* * * * *

In the years since 1935 great developments in irrigation and drainage have been achieved throughout the world. How many more situations of similar gravity have also been created as a part of such development?

GRASSLAND, GRAZING AND WATER

The hydrological effects of grassland practices depend greatly on the climate and on the level of grassland management. Generally, a permanent grass cover has an effect on the elements of the hydrological cycle which is intermediate between that of forest or dense scrub and that of bare soil or land cultivated for crops. Thus, for example the water yield and the tendency to erosion will be greater than for forest cover but less than for ordinary farm land on comparable topography. The higher the level of grassland management, the closer will the hydrological characteristics of the grazing area correspond to those of good forest cover.

In semi-arid areas, mismanaged grassland is particularly liable to produce high flood peaks and relatively large amounts of soil erosion. In these areas the native grass cover tends to be seasonal and at times offers minimal protection to the whole of the soil surface. Thus the amount of livestock which can be supported by such grazing land on a long-term basis may be quite limited. Over-grazing of the area will intensify the problems of surface run-off and erosion.

The over-grazing of grassland can also result in a hydrological change due to the compaction of a surface with inadequate cover due to the trampling of the grazing animals. This phenomenon is just as likely to occur in humid as in arid areas and it further decreases the amount of infiltration and increases the amount of surface run-off and the liability to surface erosion.

Good management of the pasture is not only of benefit for hydrological control but is also in most cases capable of giving better economic returns. A poor situation can be radically improved by treating the grass as a crop, i.e. by sowing good varieties of grasses and legumes, by applying whatever fertilizer is necessary to make up natural deficiencies and by controlling grazing so that the surface cover is not impaired. H.C. Pereira, in a report to the International Hydrological Decade Working Group, (1) has given examples from a number of climatic areas throughout the world of the effects of improved grassland management. In these cases, the stock carrying capacity of the pastures was increased several fold and both the flood run-off and surface erosion were very markedly reduced and in some cases virtually eliminated.

It should not be forgotten that the improvement of grasslands (or the replanting of land to forest) by reducing the run-off may affect the water supply position of downstream users. It should be recognized that the planting of land to trees or grass to prevent the filling of a downstream reservoir with silt may accomplish its purpose but at the same time may reduce the chances of filling the reservoir with water.

The effect of a pastoral economy on water quality should not be ignored. With increasing standards of grassland management and an integrated economic development of a region, the wastes from some intensive agricultural activities may become significant. With open range grazing, animal wastes do not present a pollution problem and indeed are beneficial to the soil. However, the concentration of animals in confined feeding areas, either for winter feeding or before disposal, can give rise to quite serious problems if the waste from these areas is discharged to streams or percolates rapidly to groundwater. If factories for the processing of animal products are located in rural areas, the treatment and disposal of the wastes from such units can be a serious problem (42). The successful use of spray irrigation of industrial wastes on grasslands indicates that an integrated solution to such problems is possible in certain instances without further endangering the quality of the water resources of the region.

THE EFFECT OF DIFFERENT FARMING METHODS

As in the case of grassland, good management of land under crops and improved agricultural practices are the best counter-measures against the dangers of erosion (43 and 44). Contour ploughing and the use of banks and terraces will break up overland flow and promote infiltration. The use of appropriate fertilizers will produce a denser crop cover which will have the effect of protecting the soil surface and improving soil structure. Proper farm management of arable land can promote infiltration rates as high as those occurring on pasture.

Field records are available for the U.S.A. covering the effect of land use in agricultural practices over the past fifty years (44). These records show that, when types of farming use are ranked in order of decreasing infiltration and increasing surface run-off, the order is as follows: continuous grassland, hay crop in a rotation, row crop in a rotation, continuous row crops. The results also show that deep tillage gives higher infiltration and lower surface run-off and soil loss than unimproved practice and that contour ploughing gives still higher infiltration rates and still lower surface run-off and soil loss.

Some improved agricultural practices may have deleterious effects on water quality. The use of insecticides and herbicides to improve crop yield and hence surface cover may result in residual amounts of these pesticides being carried away in the drainage water. The very qualities which make these chemicals useful as pesticides, namely their wide range of toxicity and their high persistence, make them potentially dangerous when they get access to stream systems. They may then interfere with the life of the stream or kill fish. The high use of fertilizers can also give rise to problems in water quality. Residual amounts of nitrogen and phosphorous applied for the enrichment of the soil may find their way through drainage to the stream channel system where they are responsible for the nutrient enrichment, or eutrophication, of the rivers or lakes. The enrichment of lake waters in this way has given rise to serious problems in many parts of the world (45, 46 and 47).

EFFECTS OF URBANIZATION AND INDUSTRIALIZATION

Most of the inhabitants of Western Europe live in towns and cities with more than 5 000 inhabitants. Accelerated growth of cities is characteristic of virtually all developing countries. Though only about one percent of the habitable land area is occupied by towns, it has been estimated that by the year 2000 half of the world's population will live in urban areas. Urbanization represents one of the major human interferences with the hydrological cycle.

Urbanization affects the hydrological cycle in a number of ways. Firstly it represents a particular form of land use and surface cover; secondly the microclimate in an urban neighbourhood is modified by the form of urban structures, by changes in the heat balance and other effects; thirdly the disposal of urban and industrial wastes has a marked effect on the quality of water in the cycle. These problems have been studied in the U.S.A. in particular (48 through 52) and an international review of the present situation is currently being prepared by a study group under the IHD.

The effects of industrialization have many features in common with those of urbanization even when the industrial plant is located in the open countryside. Similarly large-scale mining has effects on water quality that are comparable to those produced by industrial wastes.

INCREASED PRECIPITATION AND CITY GROWTH

It is only in recent years that the effect of urban complexes on precipitation has been studied but some information is now available (51). It would appear that the development of a large urban complex tends to increase the total precipitation in the area by an amount of the order of about ten percent. There is some evidence that the number of thunderstorms is increased but there does not appear to be an appreciable effect on the occurrence of very heavy rainfalls. The increased precipitation as a result of urbanization has been attributed to various factors including the addition to the atmosphere of condensation nuclei due to the emission of smoke, increased turbulence in the atmosphere due to the presence of buildings, to heat transfer effects, and to the presence of additional water vapour arising from the urban complex. There is insufficient evidence as yet to draw any firm conclusions in regard to these various factors. The situation in regard to the effect of urbanization on precipitation is similar in a number of respects to the whole question of inducing precipitation by cloud seeding.

Compared with open country there is usually less evaporation and transpiration from an urban area, the amount depending on the presence of parks and lakes and reservoirs. Even where open water occurs within the boundaries of an urban area, there is probably a reduction in evaporation due to the reduced amount of available radiation at the water surface in the city environment and due to the reduction of wind speed in a built-up area. However, in semi-arid and subhumid environments where there is extensive development of parks and gardens which have to be kept watered, evaporation may be greater than under natural conditions.

URBANIZATION MEANS LESS INFILTRATION AND MORE SURFACE RUN-OFF

The principal effect of urbanization is the replacement of most of the ordinary land cover by impermeable surfaces, such as buildings and streets. Precipitation falling on these surfaces is carried to the surface drainage system across roofs and road surfaces and through gutters and drain-pipes. By definition, the run-off from impermeable surfaces appears as surface run-off and consequently reaches the streams more rapidly than water which infiltrates through a permeable surface to emerge later as interflow or groundwater flow. Thus the peak of surface run-off may be increased following urbanization by a factor of five to ten times with a corresponding reduction in the time to the peak outflow. Following urbanization, increases of this magnitude are found in the case of the relatively frequent storms that would recur once a year or so.

Since the amounts of infiltration and transpiration are reduced, the total surface water yield from an area increases after urbanization. However, all of this increased yield usually cannot be used beneficially by downstream consumers since much of it would be in the form of storm run-off which in many cases could not be readily used because of the high cost of storing these flood flows for later use. The fact that infiltration to the soil and groundwater is reduced means that the sustained base flow during dry periods will be less at a time when additional water would be most valuable. The fall in groundwater levels as a result of the great reduction in infiltration following urbanization and heavy groundwater abstraction for city water supplies can result in severe subsidence of the land with consequent serious damage to buildings, and land subsidence due to excessive groundwater lowering has already become a serious problem in many parts of the world (53).

While the covering of an area by roads and buildings prevents the continual long-term erosion of the soil, very serious problems may arise due to the soil erosion during construction operations. The soil erosion during the development of a sub-urban area can be as catastrophic as the clearing of a forest on a steep soil slope. Such erosion affects not only the immediate area but has the usual deleterious effect on the downstream water. In the case of urban areas, soil eroded from a development site may be deposited downstream in channels or culverts intended to carry flood waters and may tend to block these flood outlets. On a larger scale, the construction of a road or a railway at the toe of a slope may upset the equilibrium of the whole slope and be responsible for a massive soil movement or for landslides which would not have occurred under the pre-urban conditions.

The main effect of urbanization and industrialization on the hydrological cycle is, however, on the quality of water. In the early stages of urbanization or industrialization the polluting effect of the wastes may not be serious if their volume is negligible compared to the dilution effect of the streams or lakes into which they are discharged. However as the population of a town or the productive capacity of an industry increases, the quality of the receiving waters will deteriorate and may reach an extremely serious condition before any efforts are made to remedy the situation. The problem is intensified when a river which acts as a dumping ground for the waste of one town is the source of water for another further downstream.

WATER QUALITY AND POLLUTION

Pollution may be defined as any alteration in the composition or condition of water directly or indirectly as the result of the activities of man so that it thereby becomes less suitable for use. Pollution may be of several kinds, e.g. physical, inorganic, organic, or biological. The most common physical manifestations of pollution are colour, turbidity, temperature, suspended matter, foam, radio-activity and acidity or alkalinity. Inorganic chemical pollution may be harmful because of the presence of minerals which are toxic to some forms of life. Organic chemical pollution arises due to the presence of carbohydrates, proteins, fats or other organic substances found in domestic and industrial wastes. Biological pollutants consist of living plants and animals which affect the quality and the beneficial use of water. Some biological pollutants are classed as primary pollutants; these are organisms which are added directly to the water and have a harmful effect on it. They include the pathogenic organisms which are responsible for the spread of waterborne diseases. Secondary pollutants represent organisms which occur naturally in the water environment but which interfere with the beneficial use of water either by their normal processes or by the stimulation of these processes as the result of human activity.

The physical aspects of pollution are described in Part One. The point to be made here is that pollution is one of the most serious influences of man on the hydrological cycle, and one that has cumulative and far reaching effects that may not be realized in the early stages of the process. Waters can become foul through eutrophication (see page 16) and deoxygenation can destroy the natural aquatic life. The growing magnitude of this problem in many parts of the world is illustrated by the fact that measurable deoxygenation is now occurring even in some of the seas. In the Baltic Sea, according to reports from the International Council for the Exploration of the Sea, as reported in the New Scientist (55):

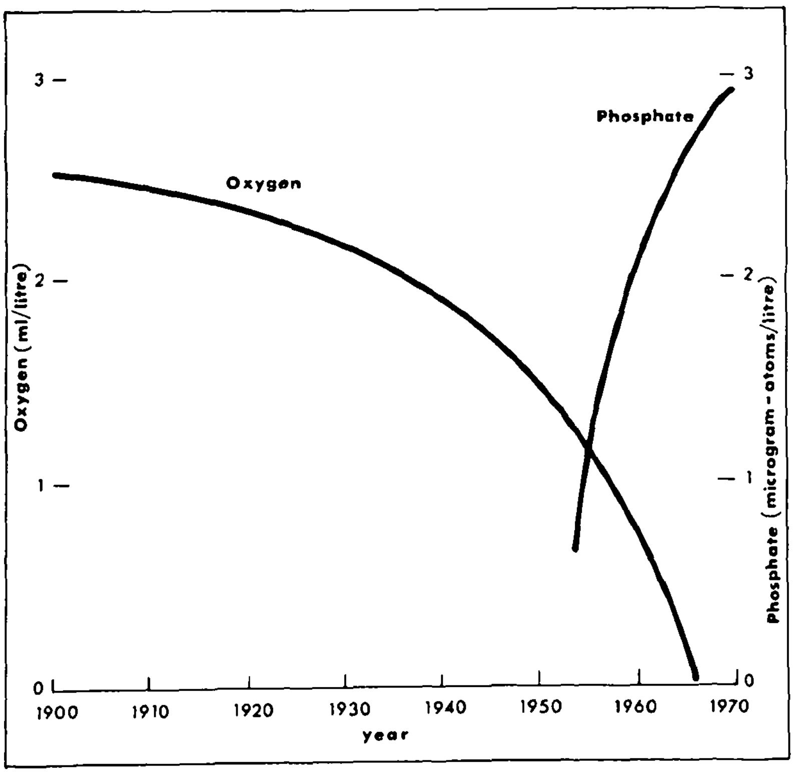
"... oxygen and phosphate levels of the deep waters have, respectively, decreased and increased to such degrees that the bottom of the sea will soon be lifeless, just like the Black Sea at the present time.

"Baltic marine stations have recorded data on the concentrations of dissolved oxygen and phosphorus in the deep waters for relatively long periods... The situation in the Landsort Deep, south of Stockholm, is illustrated here (Figure 1). The measurements show an almost exponential decrease in oxygen from values of about 30 percent saturation in 1900 to values which are barely measurable in the 1960s. The latest observations — in November 1968, and January 1969 — show that H_2S is now present in the Deep, a consequence of complete deoxygenation and the development of sulphate-reducing bacteria in the water."

"The data on sewage and industrial waste contamination... show that the amount of phosphorus which pollution tips into the Baltic is roughly equal to the amount discharged naturally by streams and water exchange. As elsewhere, the added supply is due to a fairly recent extension in the use of fertilizers and phosphate-based detergents."

FIGURE 1

THE BALTIC SEA
APPROACHING LIFELESSNESS



Changes in the Landsort Deep, south of Stockholm, since 1900 as a result of industrial and urban effluent discharged into the sea. Deoxygenation and the build-up of hydrogen sulfide were aggravated by the closed nature of the Baltic. (See page 40)

METHYL MERCURY POISONING

Another example, in this case involving biochemical effects associated with sedimentation, is methyl mercury poisoning in aquatic organisms and man (56). Inorganic mercury compounds are used in many industries, for example, as fungicides in the pulp industry and, until recently, it has been taken for granted that no harm results from the discharge of these inorganic, apparently inert compounds. But it has now been shown that these seemingly innocuous forms of mercury are converted by bacteria into organic methyl mercury, which is one of the most potent, persistent and insidious poisons known. The bacteria are eaten by plankton, which in turn are eaten by fish, and these may be eaten by man. The methyl mercury, becoming increasingly concentrated through the food chain, is bound by haemoglobin in the red blood cells and passes to the brain, where it causes selective and irreversible damage. The poison can also pass through the placental barrier into the foetal brain and blood. The first recorded cases of poisoning, only now being properly understood, were from Japan, with more than 240 cases, including more than 50 deaths, between 1953 and 1970. Contaminated fish and wildfowl occur in Swedish freshwater lakes and in the Baltic Sea. Mercury pollution has now been reported in Canada and the U.S.A., and it doubtless occurs in many other parts of the world.

THE THAMES: PUTTING POLLUTION INTO REVERSE

Today there are innumerable examples of the effect of domestic, industrial and agricultural effluents on the pollution of waterways. The pessimists see little hope of improving water quality in areas of high population and industrial activity. But the example of the River Thames, formerly one of the most polluted rivers, illustrates that water quality can be improved despite increasing population and industrialization. The following account is from Wheeler (57).

* * * * *

Only 12 years ago the lower Thames was so heavily polluted that for several months of the year it was normal to fail to detect any dissolved oxygen in its water. The river literally stank, partly perhaps from the waste material released into it, but most of all from the generous production of hydrogen sulphide by the reduction of sulphates in the prevailing anaerobic conditions. Fish were simply not seen, and the only species which was known to live in the metropolitan Thames was the eel — a very resistant animal by any criterion.

Today the lower Thames is markedly cleaner. Dissolved oxygen is present in the river at all times of the year, and the disgusting smell is no longer noticeable. Most interesting of all, fishes have returned to the river in numbers. The list of species found in the river has now passed the 50 mark. Some of these are represented by single specimens only, but of others hundreds have been caught and examined. Moreover, they have been captured at various sites along the river and at all seasons of the year, and it seems legitimate to conclude that fish are today living along the length of the river.

Fishes are not the only animals to have returned to the Thames in numbers; many aquatic invertebrates are now found where previously the only animal to be seen was the mud burrowing oligochaete worm, the blood-red Tubifex tubifex. Upstream of London, fresh-water organisms have become abundant in places; downstream marine animals are re-invading the lower reaches. Fish-eating birds, such as common terns, can now be seen fishing in the lower reaches.

The causes of this dramatic reversal of the polluted condition of the river are varied, but can be summarized in the phrase pollution control. Strict control by the Port of London Authority of polluting discharges from industrial users, ships, and local authorities, coupled with the rebuilding by the London County Council (now the Greater London Council) of the major sewage outfall at Crossness, have resulted in this improved condition. The recovery of the Thames has been a heartening sign. But it has wider implications, for in these days of polluted rivers and a worsening environment it shows that aquatic pollution can be overcome in a relatively short time. It seems that the two important factors in the control of pollution are a large purse and, above all, the determination to improve conditions. In the recovery of the lower Thames we have surely a lodestar which could be followed by pollution control authorities the world over.

* * * * *

The example of the River Thames shows that, in fact, technical knowledge is available to enable us to treat both domestic and industrial wastes so as to minimize their adverse effects on the receiving waters. What is usually lacking are the institutional procedures, the laws and the capital to ensure that the abstraction and return of water to the hydrological cycle are organized in a manner that is at one and the same time rational and in the public interest, and fair to private individuals. There are conflicts of many types in this situation - quite apart from the obvious conflicts between competing private interests or between private interests and the public domain. For example, a planning authority will have to balance the benefits of increased industrial employment in a region against the effect of the new industry on the quality of the waters of the region from the point of view of public health and nuisance and amenity. This can give rise to particular difficulties in developing countries, where the temptation to attract foreign capital may result in the toleration of industrial waste effluents which are exceedingly harmful to the environment and to other users and which would not be tolerated in the country of origin of the particular industry concerned.

INTEGRATED WATER RESOURCES PLANNING

The various consumptive uses of water for domestic, industrial and agricultural purposes have almost always received priority over uses for recreation and wild life and the many components of "quality of life". Although these consumptive uses will continue to be of major importance, there is a growing awareness of the need for broader and more careful planning in the development and use of water resources. In the past, most of the negative (and occasionally positive) effects of consumptive water use on wild life, recreation and human values have been mainly unplanned. We now know enough, in principle at least, to anticipate most of the effects of proposed water development projects, so that desirable effects can be maximized and the undesirable ones reduced; unfortunately this knowledge is not always applied at the right place and time. For example it is expected that the benefits of a certain large dam may be partly offset by changes in the regime of silt carried by the river, causing sedimentation in the reservoir itself and reduction in the natural fertilization by river-borne silt of soils downstream; other adverse effects may be the spread of water-borne disease, erosion of the coast and a diminution of coastal fisheries. It is now thought that most of these adverse effects could have been minimized (58). It is important that such projects, whilst not always maximizing the "uneconomic" values at the time of the major development itself, should at least anticipate them so that future needs can be met. All possible effects should be foreseen. The following account, from a paper by Talbot and Challinor (59) summarizes the major ecological problems associated with the various development and resettlement projects of the Mekong Scheme.

THE MEKONG

The Mekong is one of the world's largest rivers, some 2 400 km long, with a drainage area of over 600 000 km^2 extending into four countries (62). Its annual cycle includes a five-month flood season, inundating vast areas of lowlands, and a dry season during which parts of the river may become almost stagnant.

* * * * *

This annual cycle of inundation provides the set of conditions in which the soils, and native flora and fauna, have developed or adapted. To a large degree the same is true of the human population. Over 25 million people in the lower Mekong Basin have a way of life adapted to the annual flooding, and rely on the annual ebb and flow of the water for irrigation of their crops as well as for provision of the fish which provide nearly all of their meat protein.

The Mekong Basin Development Programme is one of the most ambitious and largest development programmes ever attempted. In general outline, the programme would involve a series of 40 to 50 main stream and tributary dams, with the major objectives of power production, flood control and irrigation. Overall co-ordination is to be provided by the Mekong Committee established by the United Nations Economic Council for Asia and the Far East, and technical assistance and other support has been provided or pledged by nearly 30 nations and a dozen international organizations.

The major ecological consequences of development projects in the Basin will stem from three main groups of factors: firstly, the downstream consequences of altered river flow when dams are constructed; secondly, the consequences of impoundment, i.e. the creation of lakes when dams are constructed; and thirdly, the consequences of resettlement, irrigation, and other changes in land use.

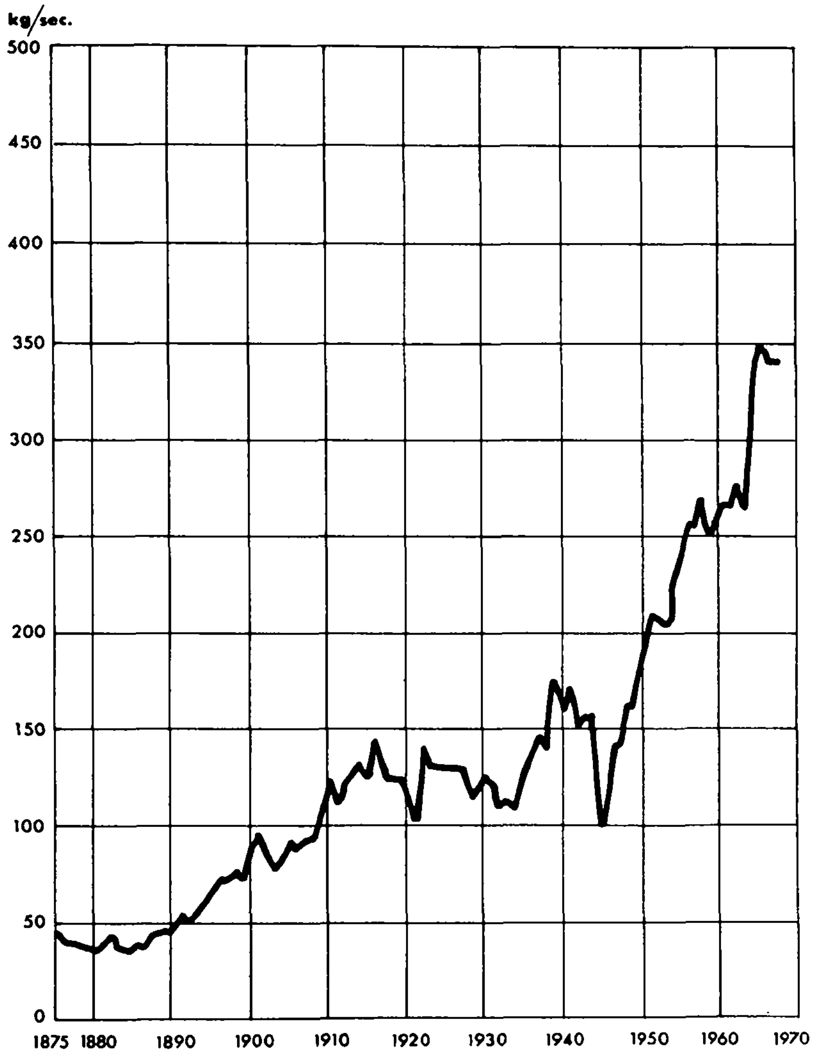
* * * * *

The construction of dams will result in a nearly uniform year-long stream flow. This will profoundly affect the life cycles of riverine fish and may even cause the extermination of those with inflexible requirements. It will also largely cut off the floods which today provide the water for the traditional form of irrigation. Compensating systems of water supply and irrigation must be provided. Moreover the annual floods are a source of nutrients to downstream irrigated farms. Limiting silt deposition by the construction of dams will effect soil fertility and alternate methods of fertilizing farm land will have to be planned, taking into account resource availability, transportation, and other economic factors.

The new lakes caused by the dams will also pose health problems. The creation of many miles of new shore line will almost certainly create a good habitat for various disease parasites or their hosts, such as schistosomiasis and filariasis, which can create a potentially critical condition for the local human population. Schistosomiasis already exists in several parts of the Mekong Basin... Experience from other water development projects in the tropics indicates that unless some effective means of control can be found, the execution of the Mekong Project will almost certainly result in the spread of schistosomiasis throughout the basin. Resettlement and cultural change for large numbers of people cultivating the fertile valley bottoms which will be inundated pose further human and economic problems.

FIGURE 2

POLLUTION OF THE RHINE



The average annual load of chloride in the Rhine River since 1875 as measured at Lobith where the Rhine enters the Netherlands. (Source: Netherlands Institute for Water Supply)

DIKES AND THE DUTCH

Of all the old world countries the Dutch are perhaps the people with the largest experience of tireless grappling with the hydrological cycle. The main reason is their historic fight against floods — from both landward and seaward — due to their lowlying land, much of it below sea level. But of recent years they have, for another reason, faced the increasingly threatening man-made problem of pollution (see Figure 2). It is particularly worrying to the Dutch since the Netherlands lies at the downstream end of the Rhine River, on which they rely for much of their water supply, but the pollution comes from great industrial and mining complexes in other countries upstream over which they have no control. Between a polluted Rhine from upstream, the intrusion of salt water into rivers and canals from the sea, and the brackishness of much of their natural groundwater, the Dutch would seem to be in an unenviable position. The key to the planning with which they are combating these dangers is an integrated water management system with a wide degree of flexibility in operation. For example, the same linkage of canals connecting the new lakes of the Delta Plan, the Ysselmeer and the rivers can be used in both directions, for storage of good quality river water at times of high flow and for strategic flushing of saline waters and supply to domestic and industrial needs at other times. Another aspect of the Netherlands' situation that is of particular significance is the changing emphasis from water quantity to quality and its relation with flow regime. A few years ago, water engineers paid relatively little attention to the problems of sustaining streamflow. But with the growth of water quality problems, of which salinity is only one, it is being found necessary to control the often episodic occurrences of poor quality flows by increasing low flows. Provision for this facility in water supply systems is proving to be one of the most effective means of quality control. It should be carefully planned as a major component of large water supply schemes.

THE CHALLENGE OF WATER MANAGEMENT

Everything that we have said thus far should indicate the complexity of making decisions about hydrological works.

In the past, when water resources were generally plentiful in relation to man's needs and man could make changes in the cycle only on a relatively small scale, lack of knowledge of the hydrological cycle and the inter-relationships of its components was not serious, and any unfortunate side effects of development schemes could be regarded as a reasonable price to pay for the benefits achieved. Now, however, with a rapidly accelerating pressure on the world's limited water resources, and powerful developments in technology on a scale undreamt of in the past, man's ability to achieve harmful, as well as positive, results is also greatly increased, and the safe margin for error is correspondingly diminishing.

In the past people involved in making decisions about dams, drainage projects and irrigation systems often based their actions on what appeared to be a similar situation elsewhere, reasoning that if something worked in one place it would work the same way again in their particular circumstances. Sometimes it did, but very often it did not. Today most hydrologists are well aware of the dangers of going about water management by this essentially unthinking process.

Logic, however, is frequently overruled for reasons of expediency, as illustrated in Part Three. For example, many governments want big dams because they are national status symbols as well as dams. So decision makers may convince themselves — or decide on the basis of expediency — that because a big dam worked in some other country it will work in theirs.

This sort of approach is not always the result of political expediency. The decision maker and his technical assistants may have their eyes so close to individual projects that they render themselves incapable of remaining aware of the numerous interreactions of components and processes in the hydrological cycle in the entire area they are dealing with and beyond. How can they, then, foresee all the effects that may be forthcoming?

Fortunately there is in fact only a very limited number of hydrological components in any given circumstance. These few components come together to form a limited number of circumstances; and it is these components and processes in various combinations that together make up each hydrological situation.

This paper has aimed at demonstrating the "unity in diversity" in hydrology. It is a unity resulting from the fact that water corresponds to that most primary definition of matter: something that can neither be created nor destroyed, but only be transformed into some other form of itself. And this is also what makes the wise management of water so fascinating a challenge for those who are called to manage it.

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Man and Water

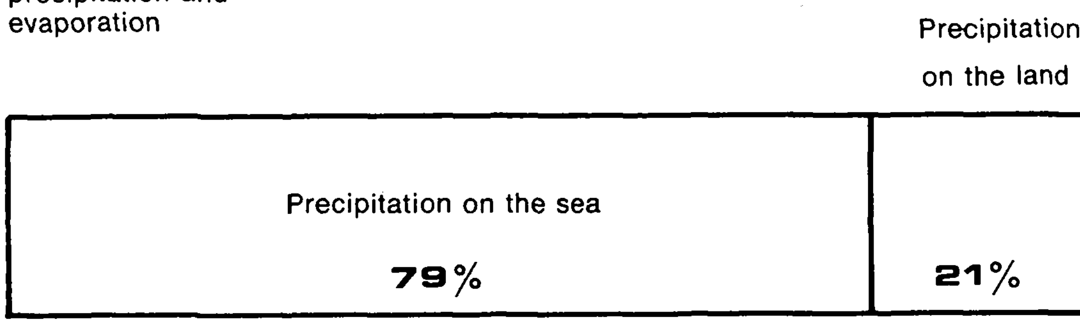
Works such as India's Rajastan Canal (above) and Iran's Farahnaz Dam (right) represent complex and expensive efforts at bringing vast amounts of water under controlled use. Aside from obvious problems of financing and construction, there are numerous technical, social and economic activities associated with such projects which are less spectacular but just as vital for the successful outcome of water development schemes. For the Rajastan Canal project soil maps were prepared for an area of some three million acres, and educational programmes are planned for farmers unaccustomed to working irrigated land.

Extreme erosion (top, left) in the Anatolian plateau of Turkey resulted from deforestation and poor agricultural practices over long periods. The Bokod River (top, right) in the Philippines carries thousands of tons of sediment per year, eroded from deforested hillsides by heavy tropical rains, into the Ambuklao Reservoir where it decreases the storage capacity. A sink hole located in an amphiteatre-like setting in Greece collects rain water which drains away to recharge the groundwater aquifers.

Surface salt (right) caused by waterlogging due to lack of drainage. Thousands of hectares are going out of production each year through salt accumulation in the soil in areas where people are not yet alive to the dangers of inadequate drainage. Rice terraces in Western Java (below) are part of an ancient peasant tradition of careful land and water management that is in balance with nature.

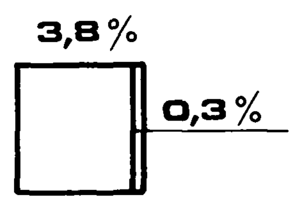
THE HYDROLOGICAL CYCLE

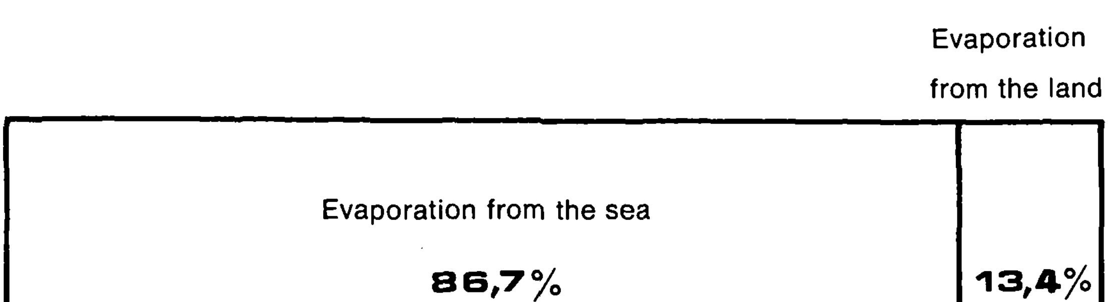
A continuous exchange of water through precipitation and evaporation



Water Potentially Controllable and Controlled by Man

Of the total annual world precipitation 79 percent is lost to man immediately since it falls on the sea. From the remaining 21 percent falling on land, 13.4 percent is lost as a result of evaporation, leaving 7.6 percent to run off in the rivers of the world and through the ground. Of this amount it is estimated that half is beyound the control of man. Of the other 3.8 percent which is potentially controllable by man 3.5 percent is not controlled at present, leaving the amount of water actually under control at only 0.3 percent of the total annual precipitation. For the most part the unused but potentially usable supply is located far from where it is most needed. To meet future demand for water without harmful effects will require that the necessary large scale investments and engineering are based upon knowledge and understanding of the place of water in the whole environmental equilibrium.





Part Three

HUMAN OBSTACLES TO THE CONTROL OF THE HYDROLOGICAL CYCLE FOR THE BENEFIT OF MAN

by Herman Finkel

During the past 30 or 40 years the world has witnessed a significant number of water development projects which have fallen short of expectations even though they were designed and constructed to high technical standards. What went wrong? Hindsight and closer analysis reveal that the causes for failure in one after another of these projects were a series of non-technical human obstacles which had been ignored or inadequately solved. An appreciation of human limitations in hydrological development work, therefore, is needed if we are to avoid making the same mistakes in the future.

These human obstacles can be put into nine classifications:

These nine areas will be presented in terms of the levels on which they occur - international, national, regional, local and individual - and related to the objectives of water development.

INSTITUTIONAL AND ORGANIZATIONAL PITFALLS

Many of the resource development projects in developing countries are planned and supported by international agencies such as the United Nations family of organizations, the Development Banks and the bilateral aid programmes of the developed industrial countries. The question of establishing priorities among various types of projects is of primary importance. It is inevitable that non-technological factors weigh heavily in the balance. These may include political, historic and nationalistic considerations, as well as the subjective feelings of loan officers. The resulting decisions may be, if not incompatible, often divergent from the true needs of countries involved. Countries contributing to multilateral aid are naturally entitled and even expected to direct foreign aid into channels most beneficial to their own interests. Even from this point of view, only the passage of considerable time can verify or discredit the wisdom of their decisions.

The existing network of international aid organizations is inadequately developed. There is, on the one hand, a multiplicity of agencies treating similar problems in certain parts of the world, and a great paucity of institutions in other areas. The organizational pattern abounds in bilateral, trilateral, multilateral, regional, continental and world-wide groupings. Coordination and cooperation between them is sometimes inadequate. On the other hand, the recipient countries differ enormously from each other in the extent of their associations with these various agencies. This variation is not always proportional to their development needs. In two neighbouring countries of Southeast Asia, one has a plethora of international representatives actually competing with each other in the selection of loan-worthy projects, while the other is more or less "going it alone". Similar examples are to be found all over the developing world. The reasons often have to do with quite complex and not easily perceived combinations of political, economic and social factors. In fact, similar situations exist among the many bilateral aid programmes.

MINISTRIES IN CONFLICT

On the national level of decision making for development the first and most obvious functional conflict stems from the separation of responsibility for different aspects of the project between the various ministries of the government. While the construction was probably handled by a ministry of public works or water resources, the subsequent settlement of the land and the actual management of the project may become the target of conflicting claims between the ministries of agriculture, land reform, development, social welfare, education, electricity, and several others. If the scope of the project is sufficiently great, the solution often chosen is to establish a separate development authority for the management of the project in all its aspects, either under a single ministry, or as a separate agency responsible directly to the chief executive. This step, while seemingly simple and logical, is fraught with organizational problems which evoke sharp conflicts with other national agencies of long standing which may claim both the prerogatives and the skills to deal with various phases and aspects of the programme. The resolution of these conflicts, and the formation of smoothly working and efficient valley development authorities have taxed the abilities of the most experienced planners and the most seasoned national politicians.

The solutions in different countries have varied from one extreme to another. In some cases a strong central government leader has been able to create a self-sufficient, independent valley development authority which assumes full responsibility for all aspects of the project including such matters as selection of the settlers, farm planning, agricultural extension, water distribution, land distribution, schools, health, transportation, etc. In other countries a broad roof-organization is formed which loosely coordinates the specialized activities of the different government bureaus or ministries, while retaining overall control mainly through the management of the annual budget. In still other countries, the complexity of the organizational problems have been too great to surmount, especially when aggravated by interministerial warfare and the conflicting ambitions of several strong personalities. In these cases the projects either never got started, or foundered in their early stages. The importance of these institutional and organizational factors to permanent and successful operation cannot be overemphasized.

Even when the institutional and organizational obstacles have been allowed for in the planning, the success of the enterprise may be still very much in doubt. A critical factor is the ability of the local organization to function effectively. Mechanisms must be created to distribute and control the use of the water. Supplies must be made available to the producers. Storage, transportation and marketing facilities must be organized. Accounts must be kept. The work must be planned and directed from year to year, month to month, and even day to day. Taxes must be levied and collected. Public services must be organized and maintained. The forms of the local organization are many and pitfalls are equally numerous. The inner workings of a cooperative, for example, are fraught with difficulties, especially in countries which do not have a strongly developed cooperative tradition. The interests of efficiency often demand that decisions be taken quickly and forcefully by a single manager, or small managerial group. This may come into direct conflict with the democratic process postulated as fundamental to the functioning of a cooperative society. Drainage or soil conservation districts may suffer from catering to the wishes, alternatively, of the many or the few. Division of responsibility, and unclear lines of authority may hamper the work of the local government. Ambiguous or overlapping definitions of function between the local representatives of the national ministries may cause difficulties. The advisory functions of instructors and extension agents may be confused with the regulatory functions of watermasters, inspectors and controllers, thereby obliterating the important difference between suggestions and commands. In short, a great deal of careful thought tempered by local experience is necessary to overcome the human obstacles at this level.

INTERNATIONAL WATER LAW REMAINS INADEQUATE

There are a number of hydrological problems encountered all over the world, the solution of which is frustrated by the lack of adequate international legislation and enforcement. In some cases the solution is a matter of convention between two or more countries concerned. Others require a regional or world agreement. The efficaciousness of world agreements, however, is greatly dependent upon the current status and prestige of the force of international law. The following are some illustrations of this type of problem:

- Regulations concerning the use and protection of boundary lakes and rivers, and of streams passing through several countries successively.
- Regulations against pollution of coastlines and international waterways by passing vessels.

- Regulation against pollution of international waters by dumping of wastes from the shores.
- Regulation of aquifer pumping near international boundaries.
- Flood control in valleys forming international boundaries.
- Flood, erosion and pollution control in watersheds whose upper portion lies in one country and whose lower portion lies in another.

Many of the problems have been amply treated in a series of declarations and resolutions adopted by various international legal institutions (1).* One of the earliest is the Madrid Declaration (1911) which very briefly declares the rights of countries sharing an international body of water to utilization of the resource providing that no serious injury or harm is caused to the neighbouring country. A fuller statement of this doctrine with specific reference to the development of hydraulic power is found in the Geneva Convention of 1923 which relied upon the League of Nations to adjudicate disputes. With the failure of the League of Nations it is presumed that this convention was subsequently ignored. There followed a series of declarations and resolutions each of which elaborated upon the control and exploitation of international waters (aside from navigation).

The wide range of treaties and statutory instruments dealing with these problems can be seen in a compilation of "Legislative texts and treaty provisions concerning the utilization of international rivers for other purposes than navigation" put out by the United Nations in 1963 (2). Many of these legal instruments have resulted in effective trans-national management of shared water resources, and in the establishment of permanent international river commissions and boundary water commissions.

However, the distinct "neighbourhood scope" which is characteristic of most agreements on water also tends to prevent the formulation of world-wide rules of law irrespective of local circumstances. While there have been numerous attempts at drafting general principles through universal conventions (such as the 1923 Geneva Convention on the Development of Hydraulic Power Affecting More Than One State) and declaratory resolutions (from the 1911 Madrid Declaration of the Institute of International Law to the 1966 Helsinki Rules of the International Law Association), none of these can be said to have found universal acceptance, and the law of international water resources is still listed as "future business" on the agenda of the UN International Law Commission.

At the same time, in spite of occasional references to the International Court of Justice in some water treaties, most of the case law relating to international water resources is based on ad hoc decisions by arbitration tribunals whose future binding force as legal precedents is open to speculation. The fact that several bilateral and regional agreements depend for their interpretation and implementation on general international law (e.g., for the determination of compensable damage) underscores the urgent need for basic principles. So does the total lack of applicable rules in areas where international water resources are only now being developed, or where technological advances are beginning to raise new international problems (as in the case of cloud-seeding to tap atmospheric water resources).

The codes for international control of water utilization and protection are thus seen to exist. Their effectiveness and general acceptance is another matter.

NATIONAL LEGISLATIVE PROBLEMS

Control at the national level is easier than at the international level, but even so national legislation governing the various aspects of man's control of the hydrological cycle is highly developed in only a few countries. The recognition of flowing surface water as a national resource is fairly well established in some countries, but it is often highly qualified and modified by existing riparian rights which may not serve the best public interests. Established and legitimate water rights may conflict sharply with each other, as for example the claim to a limited water supply on the part of

* Numbers in parenthesis refer to the list of references at the conclusion.

urban, industrial and agricultural interests. In some countries where specific water legislation is not highly codified, there may nevertheless be a body of common law and custom inherited from the former mother country which serves as a legal guide to the conflicting claims.

In a survey of African states [1], it was found that 26 countries adhered to the Roman water code as accepted in France, Spain, Portugal, the Netherlands, Belgium and Italy. An additional 15 followed the English Common Law. In 24 countries the basic principles of Islamic water laws are observed despite the existence in some of these countries of more recently written western water laws.

It is an unfortunate fact that the once imperial countries such as Britain, France, Belgium and The Netherlands are themselves located in a temperate region of mild summer rainfall and frozen winters. Their former colonies which have inherited the traditions, precedents and court decisions of the mother country are generally located in distinctly different climatic regions, such as arid, semi-arid, tropical, winter rainfall, etc. It is consequently necessary for the newly independent countries to evolve their own doctrines of water legislation more suitable to the local conditions [3]. An exception to this is Spain which has extensive semi-arid regions requiring irrigation. Consequently the water laws of most South American countries are strongly oriented toward protecting water rights even more than the rights to land ownership. It is recognized by most of the water codes in that continent that land without water is fairly useless [4].

A notably underdeveloped aspect is the legal control of the pumping of groundwater. In relatively few countries has groundwater been officially declared part of the public domain, regardless of the ownership of the land surface. In a study entitled "Groundwater Legislation in Europe" put out by FAO in 1964, the codes of 23 countries were analysed. In all of these except four (Israel, Romania, Turkey and Yugoslavia) the rights to exploit the groundwater belonged to the owner of the land. In these four countries groundwaters are declared to be part of the public domain. On the other hand, in a review of water legislation in nine countries in Asia and the Far East [5] it is shown that in four of them, Brunei, Burma, Taiwan and Thailand, groundwater is considered to be the property of the state. In Afghanistan, Iran, Japan, New Zealand and the Philippines the groundwater ownership goes with the land ownership.

As a result of inadequate legal control, therefore, together with the increasing availability of diesel and electric power, pumping systems are being operated at a rate inconsistent with the conservation of the aquifer, and serious problems are being created such as the irreversible intrusion of sea water into the wells.

In at least one country, Malta, there is legislation which guards against sea water intrusion as a result of water table levels falling below a certain point, for instance during droughts. The law forbids pumping of groundwater at such times if there is evidence that salinity is increasing dangerously. Such forsightedness is rare, however.

Another sphere where current legislation falls far behind the needs of many countries is the control of water pollution. Sewage, industrial wastes, salinity, sedimentation, organic and pathogenic pollution are rampant in many parts of the world where good quality water is a precious resource. The preparation of suitable legislation should be the joint effort of lawyers and hydrologists, based, as much as possible, on a background of incontrovertible facts rather than on emotional appeals. The solutions are, however, far from simple, as short-term economic benefits and the interests of specific pressure groups must be weighed against long-term social and public good.

The mechanisms of the legal process create another type of obstacle which varies considerably from country to country. On the one hand some governments must struggle patiently to achieve a consensus of many parties in a coalition government before suitable laws can be enacted. In other countries the problems may be solved - but not necessarily in the best way - by the signature on a presidential decree.

LAWS AND LAW ENFORCEMENT

A final obstacle to legal control - and this applies not only to water - is that it is very difficult if not impossible to impose control against widely accepted opinions and powerful interests. "Shoot the gendarmes" is the reaction in one country when these gentlemen appear on the scene to enforce the water law, and in another country the fine for drilling a well without permission in a controlled area is commonly regarded as an unavoidable part of the cost of a new well.

The legal instruments for the regulation of man's multifarious influences on the hydrological cycle are usually created on the national level, by means of laws or supreme decrees controlling water rights, diversion, pumping, pollution, land-use, forestation, etc. However, in many countries such authority is extended to lower levels such as district and municipal councils, valley authority organizations, and cooperative managements. Such authority is usually constrained by the national laws only in the broadest possible terms. The local authorities often control such items as water quotas, water price, dumping of wastes into a stream, crop quotas, coastal aquifer pumping control, land confiscation for canal right-of-way, and, most important, the levying and collecting of taxes. This in itself is not, by definition, an obstacle, since it can be argued that the local authorities are closer to the individuals concerned and have a more intimate appreciation of the problems. However, local councils vary tremendously in their ability to legislate wisely, and they may be exposed to undue pressure from strong individuals or special-interest groups. Moreover, their capacity to enforce decisions may be much weaker than required. In many countries there is no tradition of strong, independent, democratically controlled legislative councils at the local level. The extreme centralization of authority in the national government, or in the chief executive residing in the distant metropolis, may tend to make the provincial leaders timid, docile, apathetic, or unwilling to assume more assertive roles of responsibility. On the other hand, a more agressive, self-confident local leader may evoke in the hearts of his constituents feelings of anxiety and mistrust.

ECONOMIC AND FINANCIAL CONSIDERATIONS

The support of worthwhile projects by the international agencies is currently hampered by the shortage of sufficient funds. The principle source of these funds is from the so-called developed world which today represents about one third of the total world population. At the 1970 level this sector was contributing $ 13.6 thousand million p.a. to development work in the countries representing the other two-thirds of the world population. The GNP of the affluent nations is 80 percent of the world total, whilst the poorer two-thirds produce only 20 percent. The gap continues to widen. The projected per caput GNP figure for 1980 averages $ 245 in the developing world, and $ 3 280 in the developed world, as compared with $ 175 and $ 1 964 respectively in 1968 (6).

Despite its affluence, there are no signs that the developed world will increase considerably its contributions to development work in the coming years. It is predicted that international funds for this purpose will continue to fall far below estimated needs, while there remains little hope for many of the developing countries to finance their development projects from their own national incomes. This, in a nutshell, is a most formidable human obstacle on a world scale. It would be sufficient to plunge many planners into abysmal despondency were they not, by the nature of their profession, inveterate optimists.

THE POWER OF THE BUDGET MAKERS

Once a water development project has been submitted to a government it must be weighed against alternative projects, often of completely different types. It is usually not difficult to establish priorities among a list of water projects, all of which have sound engineering and economic analyses. But the choice between a water project and, for example, a hospital, a jet airport, or a palace for the president, requires a completely different kind of economic approach. Difficult choices must be made between immediate versus long-range benefits, small scale profits to a large sector of the population versus massive benefits to a small but more productive sector of the society, benefits of an intangible nature such as status symbols and prestige versus unseen, unheralded improvements of the infra-structure. The accepted reaction to this complex of problems is to establish a national planning office. However, careful studies of the national long-range plans of a great many countries have revealed that there is virtually no relationship between the five and ten year goals of the national planning offices, and the works actually undertaken and completed. There are a great many interesting reasons for this discrepancy, but it can be asserted with reasonable confidence that in most countries there is only one instrument of national, short range planning which is closely linked with the actual programme of implementation, and that is the governmental budget. Priorities determined at this point become completely relevant to reality, since the decision is not economic but financial.

The financial obstacles or limitations to hydraulic projects are generally understood and need little elaboration. They usually occur in two forms. The first is in the regular operational budget which contains appropriations for hydrological and climatological data collection, research, studies, and the enforcement of laws concerning water use and pollution, etc. These items are invariably small fractions of the total budget, and unfortunately, hydrologists have in most countries been able to exert little influence in having them increased. The second form is in the development budget, which contains special appropriations for specific water projects often linked to financing from outside and international agencies. Here the decisions regarding priorities are made on the basis of a wide spectrum of pressures, political, regional, ethnic, economic, sectorial, etc. Too often the long range effect of the specific project upon the hydrological cycle is very low on the list of criteria. Thus, for example, in a Middle East country a marshy peat bog lying upstream of a great fresh water lake was drained and put under intensive agricultural cultivation with substantial immediate economic returns. But the excess of nitrates which were eventually released from the decomposing peat are now threatening to destroy the fresh water lake completely. Only in the face of impending disaster are priorities of this type hastily revised, in the hope that it will not be too late.

Another very important problem in the realm of finance is that of phased or progressive development. Some projects are of such a nature as to require the entire investment to be completed before the first gains can be realized, as in the following example:

The river "M" forms the boundary for 100 km between two African states. On the joint request of the two states the UNDP financed a feasibility study for a river development project. The study was intended to lead to integrated development having the following four elements:

- agriculture: irrigation development of 50 000 ha;
- hydro-electric production;
- river control to minimize flood damage;
- construction of a storage reservoir.

The estimated cost of the development project was $ 96 million.

Initially the project was oriented towards the construction of the storage reservoir and the production of electricity but the need for economic viability necessitated that it have a more integrated character. At the same time it was found that the agricultural development part, which represented slightly more than half of the cost, suffered from a number of handicaps of which the most important was the lack of knowledge among the peasants, of whom there were about 100 000, of how to go about agriculture on irrigated land. Other difficulties also existed such as insufficient basic information on hydrology, geology and ecology as well as problems of water-borne diseases.

Today the two states have envisaged as a first step a more modest project, that is to say a pilot scheme which would consist of the construction of a reservoir and the development of 2 000 ha of irrigated agriculture. A new request for this pilot scheme is in course of preparation.

The point is that the sounder projects are those in which modest profits may be quickly realized from relatively small investments. These in turn can be partially reinvested for additional stages until the entire project is complete.

THE FINANCIAL TROUBLES OF VALLEY AUTHORITIES

The success of the regulatory functions of local governments is limited by its financial means at their disposal. Unfortunately there is a general tendency all over the world for local, district and regional valley development authorities to be insolvent. This need not be taken as an indication of worldwide incompetence and mismanagement at these levels of government. It may stem more from the nature of the work, which is concerned with operation, maintenance and regulation, rather than planning, design and construction. In the budgeting of development projects, the design and construction always enjoy the higher priority, while little if any financing is systematically provided for maintenance and operation. Grants and international loans are limited in amount and period of repayment. It is usually assumed that after an initial period the project, if sound, will be able to carry itself. There have been many beautiful university buildings built in various parts of the world which function at a fraction of their intended capacity and level for lack of current funds for staff and materials. The same is true for land and water development projects. If success is to be assured their operating needs must be taken more fully into account in the initial financing of the project.

The question then arises as to who should pay for the operation and maintenance of a scheme. In some countries these costs, as well as those of design and construction, are paid in perpetuity from central government funds. This may not be desirable, however, for three reasons: 1) as development schemes multiply an unreasonable burden is placed on central government funds, 2) control is more effective at the local level if operation and maintenance are paid by those who directly benefit, and 3) a proper system of water rates is an incentive to farmers to improve the efficiency of water use; uneconomic use of water has been recognized in a number of countries as one of the main causes of disappointing returns from irrigation schemes.

LEFT OUT OF THE BUDGET : THE INDIVIDUAL

The works included in a comprehensive water project are generally of three types. There are the central elements, which are built and financed by the national authority; certain lesser works together with operation and maintenance, handled by regional or local authorities and, finally, there are the numerous, but important small works which each individual is often expected to accomplish alone. Examples of the last are land levelling and preparation, furrowing for water distribution in the fields, terraces and erosion control measures, roof catchment works, cisterns and small surface tanks, cesspools and septic tanks. The financing of many of these small measures is, for most rural people, beyond their capacity. Consequently, much of the work is either never done, or else it is done once, usually poorly, and then allowed to fall into disrepair. If these tertiary works are to be accomplished successfully, it is often necessary to establish a system of supervised, low-cost credit. Funds for this most important item are either inadequate, or overlooked completely in many projects.

LAND TENURE : A NATIONAL DILEMMA

Land tenure is one of the major stumbling blocks for large land and water development projects. In the case of the irrigation of a new area, devoid of previous private ownership, the problem is simpler since sizes and boundaries of the plots can be planned initially as part of the project. The land tenure system proposed must, however, fit in with the prevailing land holding systems of the country, or else special legislation must be provided to cover the innovations. That this is by no means easy can be imagined from the case of a South American project where a reservoir had been completed and filled with water for five years while the national legislature struggled with several versions of a land tenure and colonization law, each proposed by a different political party. In a similar, uninhabited area in southwest Asia as the water supply system - pumping from a dense network of deep wells - was being completed, unauthorized settlers moved in and claimed squatters' rights. The lack of previously established land ownership procedures prevented control of this unregulated invasion.

An even more difficult problem is encountered in a water development project in which there is existing settlement and land ownership. If the pattern of ownership is highly fragmented by the laws of inheritance into an impossibly large number of small holdings, national legislation may be required to enable consolidation and reparcelling. At the other extreme lie the huge estates, the latifundia, which may claim so great a portion of the project area as to negate the socio-economic benefits expected from the project. In this case reasonable laws and procedures must be developed for land confiscation with appropriate compensation to ensure peaceful transition from the old to the new form of settlement. The lack of provision for such procedures has in some cases led to the virtual failure of the project to achieve its stated aims and in other cases to violence and bloodshed.

BIG ESTATES VERSUS SMALL HOLDINGS

Whereas there is an almost infinite variety of land tenure patterns in the regions of the world, there are a few recurring prototypes which represent the chief obstacles to any programme of land and water development. At one extreme there are the multitudinous holdings of the small family units relentlessly driven to further fragmentation by immutable tradition and inheritance laws. The sizes of the plots are far below the minimum needed for economic efficiency. The problems of water distribution and control for purposes of irrigation, drainage and soil conservation are hopelessly complex. At the other extreme lie the great tracts of land held in estate ownership. These may be economically efficient, although not necessarily. The wide boundaries of large parcels of land facilitate every type of water control effort. However, because of their relative wealth and power the owners of extensive areas are far less amenable to interference and control by local government authorities. Proposed measures which do not yield an immediate profit to the owners may be met with intractable opposition. Furthermore, many estates are the property of absentee owners or impersonal corporations, and are managed by hired agents whose incentive to show a profit may understandably overshadow their appreciation of long-range social goals such as water conservation and environment protection.

An intermediate pattern, which is in its own way no less of an obstacle, is the combination of a few latifundia and many minifundia in the same region. The former represent an extremely small number of owners and contain most of the land. Their contribution to the total production is usually proportionately great. The many smallholdings together form a small fraction of the total land, held by the majority of the rural population. The conflicts between the objectives of these two groups are almost irreconcilable. Decisions taken democratically at the local or district level could be intolerable to the large owners to the same degree that arbitrary measures favouring the estates would be repugnant to the peasants. An example comes to mind of a small Mediterranean country where a reservoir remained full of water and unused for years because of the inability of the many smallholders to agree with the one large plantation owner on the mechanics of the water distribution system, the irrigation quotas, and the price of water. Since the big plantation also had its own wells, the owner could afford to hold out for a long time.

Another problem found in certain Mediterranean countries is that created by the separate ownership of the land, the water rights and the trees. The author once visited a field where each of these three elements were separately owned, and in turn, leased to different tenants. Six people thus had to agree to the irrigation of a few olive trees which, fortunately, they did in this case.

The variations and ramifications of the land tenure problems are far too numerous to be covered in the present report, nor is it within its scope to treat the many experiments in agrarian reform which have been attempted all over the world. It must suffice here to emphasize the formidable nature of this human obstacle, and to express a note of warning that lack of sufficient attention to it may cause an otherwise excellent project to fail.

POPULATION : THE HEART OF THE PROBLEM

Population growth in developing nations constitute not merely another difficulty to be overcome; it is the central problem of development. The problem is simply that in most of the developing countries the population is increasing at an annual rate of from 2½ to 3½ percent per annum. These rates represent a doubling period of from 28 to 20 years respectively. In the face of this fact, almost any programme of resource development or control will become obsolete before it is fully realized. Be it water supply, the treatment of sewage, pumping of groundwater, control of pollution, surface reservoirs, irrigation, or any other engineering aspect of the hydrological cycle, the load will be doubled in a single generation. This does not take into account the large accumulated backlog of human needs which have long since gone unsatisfied. The enormity of this obstacle can become completely baffling and frustrating to the long-range planner. One may easily surrender to the point of view that, given the present human needs for water in all its forms, the present inadequate state of environmental control, the limited financial and human resources available for this work, and the current rates of demographic explosion, it will be impossible to catch up. Some countries and some regions are, of course, more fortunate than others. But in terms of world averages the outlook is indeed very bleak. This subject has been amply and well treated in Limits to Growth, the report of the Club of Rome(7). Little can be added to this section other than the words of encouragement: "You are not required to complete the task, neither are you free to abandon it".

The obstacle to development work presented by the spectre of uncontrolled population growth and demographic problems on the national level is essentially the same on the regional and local level, with a few important differences. The annual rates of growth found in the national statistics are averages which may, in certain local districts, be far exceeded. This aggravates the problem. Furthermore, some regions may experience large and sudden rises in population due not to natural increase but to immigration of refugees because of war, drought, earthquake, floods or economic stress. The size of transient populations may also undergo abrupt increases because of health, ethnic or political reasons, or because of religious ceremonies. By the same tokens, other regions may experience a drastic drop in numbers over a short period of time. Such fluctuations make long-range and even short-range planning of resource utilization difficult if not impossible. It is economically unfeasible to allow for such great contingencies in most projections.

INTEREST AND MOTIVATION

As already mentioned, the very limited financial contributions to the developing world from the more fortunate countries may stem primarily from limited interest and motivation. The sums devoted to foreign aid are often appropriated with great reluctance, since every country, however apparently affluent from the point of view of statistical averages, is more keenly aware of its own yet unsolved social and economic problems. Highest priority is understandably granted to internal improvements, welfare and defence. Foreign aid may even receive its share in proportion to expected benefits to be gained, such as support of the national economy by the export of equipment and skills, or by geopolitical and military benefits to the donors. It would seem that the world must still shrink considerably in size before most people will appreciate the inescapable fact that all mankind share a common destiny, and that the fate of the more fortunate is inseparably linked to that of "les misérables".

The motives which prompt a government to favour certain projects over others are often obscure or contradictory. As an economic motive, the balance of payments and foreign trade may predominate. As a prestige motive, the construction of a hydro-electric project may be chosen. From the political point of view a certain region or ethnic group may be favoured. Possibly lower on the scale of values may lie such considerations as the conservation of the natural resources for the future, and the improvement of the ecology. This lower priority is entirely understandable, given the democratic process and the desire of the leadership to gain public approbation and re-election by creating the maximum tangible benefits in the shortest possible time. The problem is further aggravated by the effects of frequent changes in national administration (by democratic means or otherwise). The new forces in power usually feel themselves constrained to reject or drastically to modify the long-range plans of their predecessors regardless of any intrinsic merit they may have possessed. There is therefore little continuity in the long-range planning process.

Interest and motivation may, on the other hand, be an obstacle not because of their lack but because of their excess. Many countries assign high priorities to specific projects because they lie in the home district of the president or one of his ministers. High motivation in certain directions on the part of some national officials may be actually caused by a certain coincidence of public and private interest.

Excessive interest and motivation may also be a characteristic of the well-meaning but over-optimistic engineer. The following is an example:

In a desert country in the Middle East a reservoir of 71 million cubic metres capacity was built for flood control and seasonal irrigation storage. The consultants estimated the useful life of the reservoir to be 90 years. However, two years after it was built, more detailed studies of the sediment trapped in the reservoir suggested that the useful life might be not more than 20 years. The original estimate was based on very few hydrological and sediment measurements, and these taken only at low flows; as a result, widely differing estimates could be made of the sedimentation rate. The promotors of the scheme had been naturally inclined to interpret the information in the most favourable light from their point of view.

We should not ignore the conflict of interest between the planners and the construction contractors. It is the ethical duty of the engineer to undertake a survey or prepare a set of designs for the best interests of his client - which is usually the public. It is, however, the legitimate right of a contractor to undertake any construction work, whether useful or not, for a reasonable profit. In the many ill-advised instances where a single firm undertakes to do the survey, economic studies, design and construction the results may be disastrous. Such a firm will hardly ever bring in a negative recommendation on a feasibility study and will tend to resist all attempts to reduce the scope of the undertaking. This also applies to government agencies.

REGIONAL, NATIONAL AND LOCAL CONFLICT

Where there is a problem of insufficient interest or faulty motivation at the district level it frequently stems from conflicts arising between regional interests and the national public good. The knife here cuts both ways. On the one hand, regional leaders may press unduly for allocation of benefits to their constituents incompatible with the national optimum needs. (An extreme case of this is illustrated by a large South American country in which a university was opened in every provincial capital where the congressional representative so demanded.) On the other hand, regional councils may have a lack of motivation and be reluctant to assume the burdens of management and control necessary to the success of the project. Regionalism is a phenomenon which has been recognized for years as an obstacle to sound national planning, notwithstanding the undoubted socio-cultural advantages of a strong and unifying sense of local patriotism.

Conflicts may also arise on the district or local level from the different interest and motivations of various sections of the population. This may be seen in the following example:

In a West African state two small reservoirs were built several years ago for irrigation development. However, the farmers were not interested in irrigated agriculture and would not take up land in the irrigable area, which lay idle. Then some city dwellers purchased land and became absentee landlords or bought land as an investment without the intention to develop immediately. The government irrigation department was so disappointed that it was prepared to give away land to farmers to show that the water could be beneficially used. It is expected that when the local farmers realize their mistake and the benefits that they could obtain from irrigated agriculture, they will attempt to force out the city people on the grounds that they have no rights in the area.

INNOVATION BY INDIVIDUALS

The response of an individual to a plan for his own improvement proposed by others can be extremely variable, in accordance with his past conditioning. In the Vicos Project in Peru a group of sociologists and anthropologists from Cornell University in the United States attempted to rehabilitate a poverty stricken community in the Andes mountains by settling them on an abandoned estate which they had acquired. They organized an extensive programme of self-help. The first reaction of the Indians was that of suspicion and distrust. It took a very long time to overcome this reaction, and this was finally accomplished by persuading one or two Indians to agree to plant the improved potato seeds offered them. The individuals who were willing to take this risk, in the face of hostility on the part of the entire group were among the very poorest and lowest of the village. Possibly they had nothing to lose. Or perhaps despair brought them to accept innovation. After this breakthrough, the project began to develop, and eventually it became a showplace. The story of Vicos could be studied with benefit by many modern planners. It gives valuable insights into problems and solutions involved in creation and maintenance of motivation for self-help among people.

A somewhat different situation was experienced by a group of missionaries in French West Africa. In an economically depressed village they attempted to introduce improvements in agricultural techniques by the use of very simple and inexpensive equipment. They began by persuading the most prosperous and successful farmer in the village to adopt the practice, in the hope that as a leader and an "opinion maker" he would establish the value of the new method in the eyes of his fellow villagers. The reaction was surprising and disappointing. The very fact that a rich man used this equipment immediately convinced the others that it was far beyond their reach. Their feelings of pessimism and hopelessness were only deepened by his actions.

On the northern coast of the West Indian Island of Dominica there is a village which lives entirely from the sale of its bananas. The plantations lie on steep hills, accessible only by a narrow winding path, and the income of the village is limited by the small number of stems which can be carried out on the heads of the villagers. Under the prodding of an enthusiastic local teacher, himself a native of the village, all the villagers engaged in the voluntary construction of an access road, almost entirely by hand labour, and for no pay. The government, which had taken no initiative in this project, eventually sent over a bulldozer to help with the heavier cuts and fills. The standard of living of the village rose abruptly as a result of this road, and the cooperative habit was extended to other improvements.

The above examples illustrate various ways in which the interest and motivation of one or two individuals may affect the course of action of a whole group, sometimes favourably, and sometimes detrimentally. Of all the problems discussed here, this one is without doubt the most fascinating and the least tangible.

The reactions of the individual should not be thought of as "obstacles" to a resource development programme. The opposite is more true. A resource development programme, or the lack of it, may be a sort of "obstacle" to the development of the individual. The placing of man as the central objective of all development work is often neglected or overlooked by the very scientists and engineers who plan the programme. The specialist may be so lured by the beauty and satisfaction of his own profession as to make it paramount in his thinking. The hydraulic engineer optimises the use of water. The economist optimises the use of funds. The agronomist optimises the use of land. Few are the specialists, even in this era of interdisciplinary team planning, who make their own special subjects subservient to the needs and rights of individuals. They are probably not to be blamed since modern society has ever less time and consideration for the individual. We are, all of us, trained to deal in large numbers.

KNOWLEDGE AND INFORMATION

THE DATA GAP AT WORLD LEVEL

Reliable information is a basic requirement for sound development planning; but all too frequently plans must be made on the basis of inadequate or inaccurate data, or indeed no data at all. Field surveys to obtain this information are the responsibility of national governments and not of international organizations. Unfortunately, the efforts, finances and priorities that most governments are giving to gathering and coordinating this kind of data are inadequate, and this is recognized in the field of hydrology.

The task of international organizations is to assist member governments in technical fields, and to collate and disseminate information. The International Hydrological Decade, 1965-1975, sponsored by UNESCO, is concentrating on various aspects of world needs in hydrological data, methodology and training, but financial resources are limited. In particular, more information is needed on surface water resources, droughts and floods, and also on groundwater, soil erosion and pollution.

WMO, FAO and other international organizations and scientific bodies are cooperating in this programme, and in other activities such as standardization in mapping. In the field of agriculture, FAO is concerned with the dissemination of knowledge on irrigation methods and efficiencies, water needs of crops, and the effects on crop yields of water shortages. But compared with this worldwide need for readily available and reliable information the resources being devoted to this essential requirement for development are sadly inadequate and, in spite of the efforts being made, progress is disappointingly small.

... AND AT NATIONAL LEVEL

The lack of fundamental information on the part of high-level decision makers is often quite incredible. Many of the developing countries are extremely large, and transportation to the remote provinces where water projects may be proposed is difficult and tedious. The well-known phenomenon of the "hydrocephalic capital city" can discourage top officials from becoming personally acquainted with the problem of the outlying districts. More than one head of a Ministry of Agriculture has never left his desk for a field inspection. Decisions are taken on the basis of information gathered by subordinates, or expatriates and presented in voluminous, indigestible reports. This is not to imply that a quick, ceremonious inspection on the part of a bureau chief is a preferable substitute to the careful accumulation of data by trained observers. There is no doubt, however, that the interdisciplinary aspects and the overall picture of a complex project cannot be fully appreciated without extended and frequent personal contact with the field.

Many national decision makers are further handicapped by simple lack of education in the fundamentals of hydrology, engineering and economics. Graduate engineers and scientists in both the developing and the developed countries are very sparsely represented in the legislative bodies and the top administrative positions of government. This probably indicates no prejudice on the part of the public against these professionals, but rather a disinclination on the part of most engineers and scientists to enter the fields of politics, government and administration. Consequently those in charge must rely on the guidance of advisers and hired consultants whose powers of persuasion, selective point of view, and special interests may mitigate against wise, overall decisions favouring the greatest public good.

A third type of problem in this category is the lack of basic data carefully collected, accurately generalized and clearly presented in accessible forms. These data may relate to hydrological factors, demography, economic factors education or any other component of the project. Too often large and costly schemes have been prepared on the basis of projections from very limited data, in which the curves were extrapolated "out the window", or by analogy to other regions which eventually prove not to have been sufficiently analogous.

Planners and engineers sometimes find themselves working with distorted data for another reason. At the national planning level many of the characteristics specific to a given region are perforce ironed out by means of statistical averages and generalizations. Consequently, programmes which are generally sound may contain certain elements which conflict with local needs and aspirations because of inadequate knowledge and faulty assumptions on the part of the planners. These pitfalls have resulted in costly disappointments and have ruined many projects.

An interesting solution to this problem was developed in one country in which the planning headquarters was moved from the metropolis to the project area. All planning personnel were also required to reside there. Construction was begun as soon as the first stage of the plan was ready. By close contact and personal observation the planners were enabled to evaluate constantly the validity of their work. Thus a constant feedback of success and failure information was put into the planning of the subsequent stages. In this manner the obstacle of inadequate knowledge of the local situation was overcome. This process illustrates two sound principles in regional development. First, planning must be a dynamic process with one stage under operation, one under construction, and one under planning, simultaneously, so that the results of the earlier stages can interact favourably upon the later ones. Second, dynamic planning must be performed, physically, on the very site of the project. The logistic difficulties and expense resulting from the application of these two principles are always justified by the greater measure of the final success.

THE ABILITY FACTOR

Clearly, the number and scope of projects in the developing countries require skilled manpower far beyond that available, both in numbers and in level of training. The problem, however, is different in the three stages of a major hydrology project, viz. planning, construction and operation. The solution to the first is often obtained by the hiring of expatriate personnel through international agencies or from private consulting firms. The second phase, construction, is usually handled by large, international contractors who bring in from abroad most of the technical and managerial skills. However unsatisfactory these solutions may be from the national point of view, they nonetheless seem adequate and unavoidable for short-term needs. In the third phase, however, that of the long-term successful operation of the project, it is difficult to rely upon expatriate personnel for many reasons. They are not available in sufficient numbers. They may lack the language and an understanding of local conditions. They are unreliable in times of international crisis or war. Their presence may discourage the training and promotion of national personnel, or arouse envy because of their higher salaries and foreign standard of living. This often becomes the achilles heel of many projects.

In the planning and funding of international development programmes, too often the training of local staff to run the project after completion is neglected. The finest plan can be reduced to naught by inability on the part of the permanent staff not only to operate and maintain it but to constantly revise and adapt the works to new requirements and conditions which are always changing. Professor A.Lepawsky(8) has reported that the Economic Commission for Europe has found "considerable lagging of water management techniques behind scientific and technological progress in the application of management methods and tools". He adds however, that management technology may presently be running ahead of manpower proficiency. If these statements are true in Europe they will surely apply to some of the less developed regions of the world. The long-range solution to the problem of creating an "ability pool" on the national level goes beyond the scope of short courses and in-service training. In most developing countries it touches the very structure and content of the schools of higher learning and the social prestige or lack of it attached to technology, agriculture and management as compared to law, medicine and the humanities, as a career.

Studies of the distribution of trained technological and administrative manpower in most countries reveal that the largest number of the best personnel are available in or near the large cities. Education and training are the passports to higher economic status and this is synonymous with urban living. Qualified staff may be brought to the more remote provinces for limited periods of time, but the likelihood of their remaining is not great. Few are the societies today which grant higher social prestige to the pioneer, farmer, rural teacher or provincial leader. As a result, the outlying districts are drained of the most able of their youth; they remain bereft of leadership in almost every branch of endeavour. Many countries are striving to combat this trend by means of increased material incentives for qualified people to return permanently to the development areas, as well as by efforts to improve the general quality of provincial life in both material and non-material ways. In doing so they are recognizing one of the most important and basic factors in agricultural development.

EDUCATION AND TRAINING

The level of knowledge and ability of the individual in a project of water development becomes a limiting factor when the techniques and operations which he is required to perform daily are of a higher level than those to which he is accustomed. For example, if pumping and sprinkler irrigation are introduced, a high degree of water utilization efficiency will be realized only after the entire farming population has undergone adequate training. Other examples are numerous and obvious in every phase of man's influence upon the hydrological cycle. Training for specific techniques, however, cannot proceed much above a ceiling fixed by the individual's level of general education. The fundamental obstacle is simply the lack of sufficient formal schooling. Beginning with literacy and simple arithmetic, and proceeding by stages through elementary school, with a certain percentage of the people following it with secondary or vocational school, and ending with the university level education for a select few, all of these stages are required to create a population capable of carrying out a complex water project. In the World Survey of Education, published by Unesco, the prevailing rates of illiteracy in many countries and the steeply angled "pyramid of elementary school enrolment", which indicates a high rate of drop-out, present a rather discouraging picture. Some countries have, nevertheless, made great strides forward in the past five years. A realistic appreciation of this obstacle can lead to a more reliable prediction of the rate of progress achievable in resource development in a given country. It can also lead to a channelling of a greater proportion of a project's funds toward training programmes for the people who are expected to live with the project.

SOCIO-CULTURAL OBSTACLES

Under this heading may be included many of the remaining kinds of human obstacles to development not already covered. They relate to the national character of a people, customs, habits and manner of thinking, and they include some of the least tangible and most difficult to assess factors of human nature and behaviour.

The following might be included as illustrative examples of socio-cultural considerations in projects dealing with water. The comparative role of the city and the rural scene in the national consciousness may be decisive in allocation of water resources. The bathing and laundry habits of certain socio-ethnic groups may have a tangible effect on the rates of water consumption to be provided for. The attitude toward human excrement varies considerably in different cultures and could influence the design of waste disposal systems, re-cycling, sewage irrigation or fertilizing of crops with untreated fecal matter. The recreational habits and needs of certain populations may affect the relative importance assigned to facilities for swimming, boating or fishing. The water-scarcity consciousness of desert tribes and inhabitants of semi-arid regions encourages the extensive use of roof collectors, cisterns, storage tanks, lined canals, "shadufs" for drawing water from the subsurface flow in a dry stream bed, and a host of other water-winning measures. In the humid climates, on the other hand, water is thought of more as a hazard than an essential utility. Houses are raised on stilts. Groundwater is lowered by drainage and pumping, terraces are built for soil erosion control and surplus runoff is channelled into waterways and diversions.

Attitudes to water vary so widely that it may be difficult for an outsider to understand the "water mentality" of a people. The obstacle may then be on the part of the visiting expert. Does he have a deep historical understanding of the people for whom he is planning? This question is often forgotten in the workaday rush to meet a project deadline. Despite the rapid world trend toward cultural uniformity, so welcomed by political scientists, and so bemoaned by anthropologists, there still remain profound differences between human groups, which may have surprising effects upon the success of a particular programme. It has been found, for example, that organizations based upon a high degree of cooperation and mutual help between neighbours are very likely to succeed among the Quechua Indian of the Andes, because of their ancient custom, dating back to the Inca Empire, of working in aylus, or "rings". African village and tribal structure may serve as a sound basis for cooperative regional water development in certain cases but not in others. Tribes with a scattered housing pattern and strong individualism, fostered by suspicion of their neighbours, must be handled in a completely different way. Clans in southwest Asia based upon paternalism and obedience to leadership of the elders will accept a completely different type of water distribution scheme than that which might profitably be proposed to Dutch farmers in the polders. No planner in his right mind would propose pig farming for the Muslims or the Jews or beef cattle ranches for the Hindus. The point is obvious but the degree to which it has been disregarded is surprising.

CONCLUSION

The first two papers of this book were concerned with the key role of water in the environment and with the effects in nature of man's actions which disturb the environmental balance. In this last paper we have looked at the attitudes and obstacles to successful water development within man himself. This is a vast subject and the treatment here has of necessity been brief. However this is the area most responsible for failures of water development projects and also the least recognized by many specialists. It is hoped that this brief treatment will arouse interest in and concern about these problems which will press increasingly on us in the future.

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Note: A list of the meanings of all abbreviations in this volume appears on the final page.

ABBREVIATIONS

CSIRO — Commonwealth Scientific and Industrial Research Organization

COWAR — Scientific Committee on Water Research of the ICSU

FAO — Food and Agriculture Organization of the United Nations

IASH — International Association of Hydrological Science

IBP — International Biological Programme

ICSU — International Council of Scientific Unions

IHD — International Hydrological Decade

Unesco — United Nations Educational, Scientific and Cultural Organization

WHO — World Health Organization

WMO — World Meteorological Organization