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Centre for Protection and Improvement of Environment (Berlin) of the Ministry of Environmental Protection and Water Management of the German Democratic Republic in cooperation with the Technical University Dresden

Subject II: Ecological fundamentals of production systems

STUDY MATERIAL

elaborated by a team of authors under W. BASSUS

Volume One

II. 1. Biological fundamentals of production

- Basic problems of the ecology of terrestrial ecosystems
- Basic problems of the ecology of aquatic ecosystems
- Fundamentals of primary production
- Production of useable biomass and strategies for its utilization
- Influencing the productivity of ecosystems

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- Soil genesis
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II. 3. Water as production factor

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- Interrelations soil-water-plant
- Irrigation and drainage
- Water quality, water treatment, drinking water supply

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II.3. Water as a production factor

Abstract

"Water is essential for human survival; the terrestrial eco-system cannot function without it. In addition to drinking and personal hygiene, water is needed for agricultural production, industrial and manufacturing processes, hydroelectric power generation, waste assimilation, recreation, navigation, enhancement of fish and wildlife, and a variety of other purposes. When a resource is used for so many diverse purposes, it is important that it be developed and used rationally and efficiently".

Mostafa Kamal TOLBA, Executive Director UNEP

With the increasing use of water resources and change of the natural hydrological regime of surface and groundwater the vulnerability of society with regard to fluctuations in supply due to climatic variability is likely to increase. It is, therefore, important to know more about the relation climate - hydrology - water resources, taking into account man's influence on the hydrological cycle. Fundamental principles of weather, climate and water balance are discussed in chapter 3.1. Groundwater is the main resource for drinking water supply. Important problems are the hydrologic properties of aquifers and contaminant migration into subsurface waters (chapter 3.2.). Surface water is the main resource for irrigation and industrial water supply. Measurement, analysis, prediction and simulation of streamflow (surface runoff) are important problems of water resources assessment, monitoring and management (chapter 3.3.). Water is an important factor in the relationship climate, soil and vegetation (chapter 3.4.). In many countries irrigation and drainage are a vital necessity for agricultural production (chapter 3.5.). As more water is used, more waste products are being discharged to water bodies, which reduces the water quality and thus water available for future use. Problems of water quality, water related diseases transmitted by insects

or other vectors, water treatment for drinking water supply and waste water treatment are discussed in chapter 3.6. The water problems may be solved only by reliable assessment and monitoring of water resources and demands (chapter 3.7.).

II.3.0. Introduction

Water holds a unique position among various natural resources of our planet. The ever-lasting process of the hydrological or water cycle implies a unity of natural water all over the world. The hydrological cycle involves all kinds of water resources, i.e. water of the atmosphere, ocean, earth's crust and biosphere.

The relationship between climate and the water-resource system on the earth is unique in the sense that parts of the hydrological cycle, namely precipitation and evaporation, are at the same time inherent parts of the climate and important characteristics of it. Furthermore, the hydrological cycle is the very basis of water resources. It is possible to consider hydrological processes as a transfer function from the climate system to the water resource system and vice versa, the function being under different circumstances part of either one of the two systems. /1, 2, 8, 9, 10/.

Water, as an essential factor of life, is also the most manageable natural resource. This renewable resource is capable of diversion, transport, storage and recycling. Because of these properties water is very useful 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 under consideration of the other courses of action which would be excluded.

An intense development of industry and agriculture, population growth, cultivation of new land have resulted in a great increase in water use all over the world, and in the change of the natural hydrological regime of water bodies.

There are no large rivers in densely populated areas where runoff is not affected by man's activity to some extent. Today water consumption makes up about 3,000 km^3/year while it was 400 km^3/year at the beginning of this century. Evaluation of the amount of "irretrievable" water losses (i.e. water lost by evaporation, transpiration or as part of a final product, that is water which does not return to the water source) is one of the most important topical problems in water resource assessment and water management planning. These processes cause a decrease in water amount which might be used for other needs within a particular river basin.

Man's activities have an even greater effect on the quality of water in rivers, lakes, reservoirs and aquifers. Today a pronounced deterioration of water quality is observed in many rivers, lakes and aquifers all over the world. The objective of mankind is to reduce the amount of the progressive irretrievable water consumption to maintain the proper water quality in rivers and lakes, to prevent water deficit and loss of soil fertility. The only way out is the development and planned realization of measures on the rational use of water resources available and their protection against pollution and depletion. This problem may be solved only by a reliable and properly organized assessment and monitoring of water resources and demands. Data on water resources and their use, on the hydrological regime of water bodies and their chemistry are the basis for any present and future planning of water resources development, project, construction and operation of numerous hydraulic-engineering structures on rivers, lakes and reservoirs and development of land use practices /1, 3, 5, 6, 8/.

II.3.1. Climate and the hydrological cycle

II.3.1.1. Weather and climate

II.3.1.1.1. Fundamental principles

Introduction

The atmosphere of the earth is an important environmental factor. All people, animals and plants are highly influenced by the atmospheric air, and the atmosphere can be consciously influenced by man.

Meteorology is the science of the air and the atmosphere. Applied meteorology is most important for ecological purposes. Branches of applied meteorology are:

- hydrometeorology
- biometeorology (agricultural meteorology, forest meteorology, human biometeorology)
- technological meteorology (constructional meteorology, industrial meteorology, transport meteorology).

Weather: the atmospheric conditions at a definite moment or during a shorter period.
Climate: the totality (synthesis in time) of all weather conditions over a longer period (20 to 50 years)

Radiation

Radiation laws:

- Radiation as a function of the temperature of the emitting body $R = \sigma \cdot T^4$

  R emitted radiation (W/m^2)
  T absolute temperature (K)
  σ constant value ($= 5.67 \cdot 10^{-8}\ W/m^2 \cdot K$)

- Influence of temperature on the wavelength of radiation

$$\lambda_{max} \cdot T = c$$

λ_{max} - wavelength of maximum energy
T - absolute temperature (K)
c - constant value (= 0.29 cm K)

Two different radiation fluxes can be found in the atmosphere, solar radiation and terrestrial radiation. Solar radiation is a shortwave radiation. The surface of the sun is very hot (6,000 K), consequently, λ_{max} will be small. Contrary to this, the radiation of the earth and of the atmosphere (terrestrial radiation) is a longwave radiation, because the temperature of these bodies is low (-100 to 100 K).

<u>Solar radiation:</u>

$$R_{solar} = R_{solar\ beam} + R_{sky} - R_{reflex}$$

$$R_{global} = R_{solar\ beam} + R_{sky}$$

The ratio R_{reflex}/R_{global}, e.g. the reflectivity of the earth's surface, is called <u>albedo</u>. Water surfaces and forests show low albedo values (5 to 20 %), fields medium values (15 to 30 %), snowcover high values (60 to 90 %).

<u>Terrestrial radiation:</u>

$$R_{terr} = R_{counter} - R_{outgoing} - R_{reflex\ (Long)}$$

$R_{counter}$ of the atmosphere is emitted by dust particles, clouds, water vapour, carbon dioxide, and ozone. $R_{outgoing}$ is emitted by the earth's surface. $R_{reflex\ (long)}$ is the reflected longwage radiation.

Net radiation: Net radiation is the sum of all shortwave (solar) and longwave (terrestrial) radiation components.

Wind

Wind direction is the direction, where the wind comes from. Wind velocity rises with increasing height above the earth's surface.

Wind systems in tropical climates: North east winds prevail north of the equator, south east winds south of it, especially over oceans. At the equator these "trade" winds form the intertropical convergence zone (ITC).

South west winds are observed near the equator over the continents during the summer season. They are the monsoon winds.

High wind velocities can be found on the summits of mountains, over open fields and in the countryside, low winds in valleys, forests and towns.

Wind is not an even, parallel, constant flux of air. It comprises pulsations and eddies. This wind property is called turbulence. Turbulence causes exchange processes of heat, water and trace substances. These turbulent transport processes are directed both horizontally and vertically.

Heat balance

The equation of heat balance of the earth surface is:

$$R = H + S + ET' \quad (W/m^2) \tag{1}$$

R radiation
H convective heat flux
S soil heat flux
ET' evapotranspiration (expressed as energy quantity).

Net radiation (see 1.1.2.) is the input quantity of the heat balance of the earth's surface. This input is subdivided into 3 parts:

The <u>convective heat flux</u> is the heat exchange between the earth's surface and the atmosphere. By day the air is heated by the earth's surface and ascends. By night, a heat flux from the atmosphere to the surface is observed.

The <u>soil heat flux</u> is the heat exchange between the interior of the soil and the earth's surface. By day, the heat flows from the warm earth's surface to the cold deeper layers, by night vice versa from the interior of soil to the cooler earth's surface. The long-term mean of soil heat flux will be 0.

<u>Evapotranspiration</u> of water is a process requiring a certain supply of heat. In order to evaporate a certain amount of water ET the amount of heat ET' is required:

$$ET' = r \cdot ET \qquad (2)$$

r heat of evaporation (2,500 kJ/kg)

Evapotranspiration appears both in heat and water balance equations. It forms the link between heat and water balance. If man causes changes in heat balance, then corresponding changes in water balance will automatically result (and vice-versa).

II.3.1.1.2. <u>Climate and ecosystems (examples)</u>

<u>Comparison of forests and fields</u>

In tropical countries large forest areas are transformed into agricultural tracts. This causes the following meteorological changes:

The <u>net radiation</u> of the landscape decreases, forests have a higher net radiation than open fields. This phenomenon is attributed, first, to the lower albedo of forests and, second, to the lower surface temperature of forests during day time.

The <u>convective heating</u> of the air is increased. In fields the vegetation cover of which is thinner than that of forests solar radition is converted into convective heat in a small volume. This leads to a more intensive surface heating and an increase in air temperature.

The evapotranspiration of forests is higher than that of fields due to increased net radiation and reduced convective heat flux. Therefore the evapotranspiration of the landscape generally decreases by deforestation. This occurs, above all, in the peripheral areas of the tropics.

The wind velocity is increased to a high extent over fields. Consequently, the wind erosion (whirling up of dust) of the ground increases, in particular, during periods when the agricultural tracts are bare of any vegetation. The turbidity of the atmosphere increases correspondingly.

In order to maintain the favourable climatic influence of forests the establishment of shelterbelts is recommended. As regards the windbreaking effect, the effected range of shelterbelts on the windward side has an extension equalling 5- to 10-fold tree height, on the lee-side about the 20 to 30-fold tree height. The turbulence of the wind exerts influences on the extension of the effected range of shelterbelts.

On the high-altitude mountains of the tropics, at an altitude of about 2,000 to 3,000 m, forests filter large amounts of water out of the clouds as fog precipitation (see 1.3.1.). These "cloud forests" must be preserved by all means, as they are of great significance for water management, forestry and protection against soil erosion.

Agricultural measures

The plant density influences the climatic conditions over agricultural crops. Different vegetation covers may have different albedos. The level of soil albedo depends on the density of the cultivated plants. Light-coloured soils make the albedo increase if the density of the vegetation cover decreases. For instance, overgrazing influences the albedo (destruction of the vegetation by animals trampling on it or eating it). In the Sahel zone (southern border of the Sahara Desert) the reduced density of plants caused an increase in the albedo leading to a fall in temperature, hence to a decrease of thermal upwinds, cloud formation and precipitation. This means, that the drought is favoured.

Irrigation measures influence not only the water balance, but also the heat balance of the irrigated area. The convective heat flux from the earth's surface to the air is reduced. Contrary to this, evapotranspiration is increased in the tropics.

Drainage has the opposite effect of irrigation. The albedo is likewise influenced by melioration measures.

Intermediate cultivation also exerts climatic influences. The annual evapotranspiration is increased, whereas the convective heating of the air is decreased. Intermediate cultivation prevents, however, the whirling up of dust and the increase of the atmospheric turbidity. Changes of albedo and, consequently, of net radiation are possible as a result of intermediate cultivation.

Town climate

The climate in towns is, in principle, characterized by the following basic features as compared with that of the countryside:

- deteriorated air quality (due to industry and traffic)
- reduced solar radiation (partially with increased short-wave radiation input and increased net radiation)
- lower wind velocity .

- higher temperatures, particularly in the evening
- reduced evapotranspiration
- increased convective heat flux
- increased precipitation

In the hot humid tropical climates protection against sultriness and heavy rain is recommended by constructing wide streets, light pierced walls, projecting roofs and verandas. In the hot dry climate of the subtropics protection against solar radiation and sandstorms can be provided by narrow streets, thick walls and shadowy courtyards.

Climate and man (human biometeorology)

For classifying the great variety of atmospheric influences on man, the following groups of effects are applied:

Air quality: The situation is particularly favourable with regard to the innertropical climate, where frequent rains and high air turbulence clean the air. The hot dry subtropical climate is less favourable, because the intensive solar radiation promotes the formation of smog and turbulent exchange processes are less pronounced.

Heat balance: Radiation, wind velocity, temperature and humidity control the heat balance of the human body. If the heat flux from the human body into the atmosphere is too small, sultriness will result. Sultriness is a typical feature of the innertropical climate, but not of the subtropics. Radiation and wind can be influenced by trees and buildings.

Radiation: Excessive solar radiation may be prevented by trees and artificial sunshades.

II.3.1.1.3. <u>The atmospheric components of the water cycle</u>

Precipitation

The quantity of precipitation depends on two factors: first, on the vertical wind velocity and, second, on air humidity. However, the decisive factor is the vertical wind velocity. Upwinds lead to cooling of air, condensation of water vapour, formation of clouds and precipitation. Upwinds are caused by cyclones, convergences, relief and friction effects on the air stream. The relief effect explains the fact that the amount of precipitation rises with increasing altitude. Furthermore, an intensive convective heat flux favours thermal upwinds.

The innertropical climate is evermoist. However, two peaks can be observed during the annual course of precipitation. They result from the changing position of the ITC.
In the external tropics rain falls during the summer season, when the ITC has its greatest distance from the equator. The monsoon climate is the most important example for this. The subtropical dry zone shows very low precipitation values including deserts and steppes. Finally, the external subtropics are characterized by rainfall during the period of low sun height.

For hydrological purposes the measuring error of the precipitation gauge has to be taken into account. It depends on the microclimate at the measuring station and is caused by wind (sweeping effect, the number of raindrops entering the gauge is too small) and evaporation losses from the interior walls of the gauge. In temperate climates the error for rain amounts to about 10 %, in subtropical climates it may be over 20 %. Unfortunately, up to now there is not enough information available concerning the measuring error in tropical climates.

<u>Fog precipitation</u> is observed in forests in foggy climates - This type of precipitation has to be taken into account in tropical mountain climates. The Kilimanjaro is a well-known example.

<u>Dew</u> plays an important role in the water cycle of dry subtropical climates.

When precipitation hits the plants, it is subdivided into 3 components <u>throughfall</u> T, <u>stemflow</u> S and <u>interception</u> I:

$$P = T + S + I.$$

The quantities of these terms depend on the properties of leaves, twigs, branches and stems. The interception of a spruce forest amounts to about 25 %.

<u>Areal mean values</u> of precipitation can be calculated by different methods. The simplest method is based on the arithmetic mean. The isohyetal method requires the construction of lines of equal precipitation and planimetering the area between the isohyets. The Thiessen polygon method uses special polygons constructed around the measuring point and the corresponding area inclosed by the polygon.

Evapotranspiration

Evapotranspiration (ET) is the water transport process from water, soil and plants into the atmosphere. It can be subdivided into three components:

$$ET = E + T + I \qquad (3)$$

<u>Evaporation E:</u> The water transport from waters and from fallow soil into the atmosphere.

<u>Transpiration T:</u> The water transport from the interior of the plants into the atmosphere caused by the living processes of plants.

Interception I: The water transport from plant surfaces into the atmosphere caused by the precipitation catching process (see Precipitation).

The process of evapotranspiration requires heat supply (see Heat balance).

In order to separate the atmospheric influences on evapotranspiration from those on soil and plants the term of potential evapotranspiration is defined. Potential evapotranspiration ET_p means the upper limit, i.e. the maximum value of real evapotranspiration ET_r. ET_p occurs whenever the process of evapotranspiration is not limited by deficient water supply in soil and plants, in other words, whenever the soil is saturated with water. For instance, in deserts ET_p is very high, but ET_r is very low as there is no essential water supply. For water surfaces ET_p and ET_r are equal.

ET_p depends on radiation, wind velocity and air humidity. Dry winds cause large values of ET_p. In subtropical countries ET_p is higher than in the inner tropics because of the long duration of solar radiation and low air humidity.

ET_p can be obtained by calculation formulas (PENMAN, TURC) or by measurement of the water level in evaporation pans.

ET_r depends on ET_p, soil moisture and plant mass. ET_r approaches ET_p, when precipitation increases to an unlimited extent. ET_r approaches precipitation, when ET_p increases to an unlimited extent. Contrary to the behavior of ET_p, ET_r is higher in the innertropical climates than in the subtropics. This is due to the high amount of precipitation in the inner tropics.

There are some methods by which ET_r can be determined:

- water balance of catchments
- heat balance of the earth's surface (see Heat balance)

- turbulent exchange in the atmosphere (see Wind)
- lysimeters
- calculation using ET_p and precipitation or soil moisture (for example the BAGROV method)

II.3.1.2. The hydrological cycle and the water balance

II.3.1.2.1. Water and climate

The fundamental hydrological phenomenon is the hydrological cycle, the continual changes in the state and location of water under the influence of radiation of the sun and gravity.

The hydrological cycle is regarded as a closed water circulation system on earth. As shown by Figure II.3-1, this cycle can be split into three main phases: Precipitation, evaporation and runoff (surface and subsurface). In each of these phases, water transport, temporary storage and a change of state occur at different points (Fig. II.3-2). Storage, or the mean retention time, differs widely in duration at the different points and ranges from 10,000 years in the polar ice caps and 2,500 years in the oceans down to 9 days in the case of atmospheric water and 12 days in the case of river water (7).

The majority of processes involved in the hydrological cycle are of periodic stochastic nature. The periodicity is of physical origin due to astronomical cycles; the stochastic behaviour is caused by the various sources of coincidence in, on and around the earth, particularly by changes in the permeability of the atmosphere.

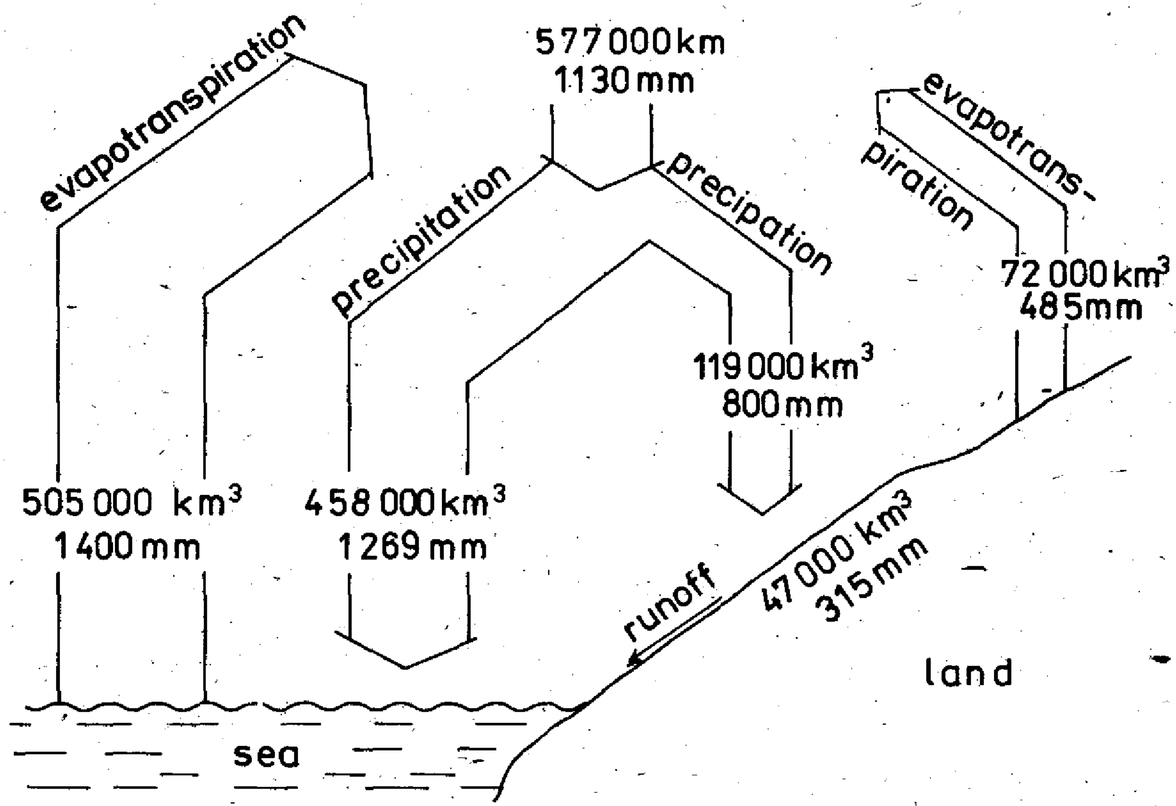


Fig. II.3.-1 Hydrological cycle and global water balance

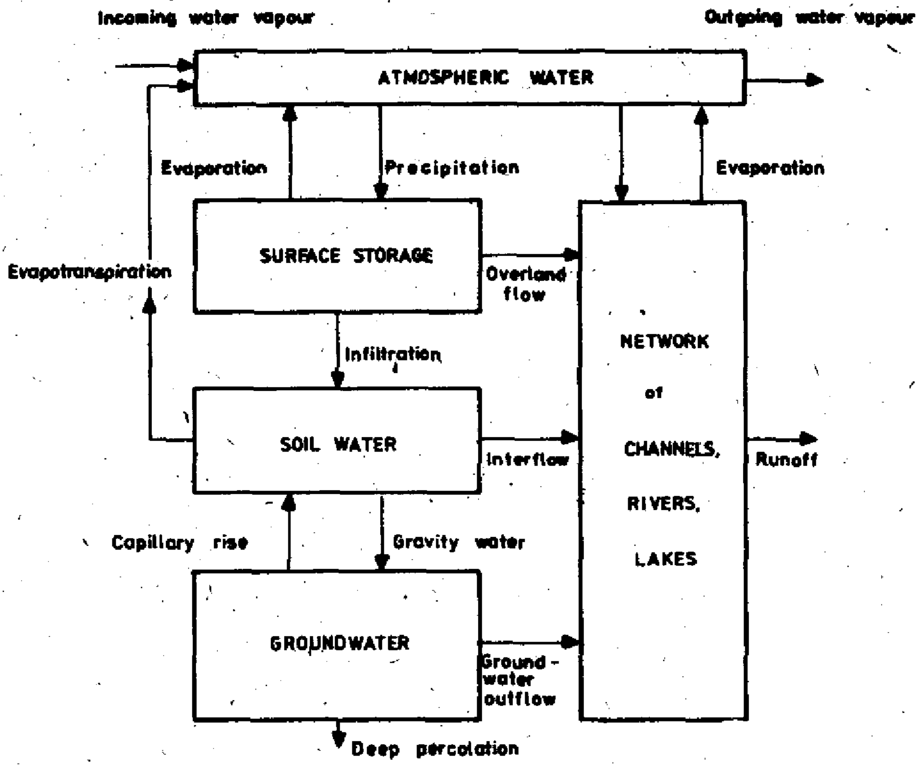


Fig. II.3.-2 THE HYDROLOGICAL CYCLE OVER A CATCHMENT AREA /FAO 1973/

II.3.1.2.2. Water balance

The quantitative description of the water cycle leads to a water balance in which the water balance quantities, i.e. precipitation P, evapotranspiration ET, runoff R and change in storage ΔS, are balanced in the form of a simple continuity equation, the water balance equation:

$$P = ET + R + \Delta S \qquad mm/\Delta t \qquad (4).$$

The water balance quantities are generally stated in mm water column related to a defined area and a defined period of time. Part of the precipitation falling on a region flows off above and beneath the surface of the earth under the influence of gravity. The runoff from an area during a defined period is, assuming that distribution is even, called the runoff depth (R) and is expressed in mm water column per unit time, e.g. in mm/a, mm/d, or mm/h. The runoff resulting from the precipitation in the region concentrates in the stream channel network and runs off through the discharge cross section. The volumetric flow per unit time flowing through the cross section of a river is called the discharge (Q) and is measured in l/s or m^3/s.

Since subsurface water can also flow out of a drainage area, the total volumetric flow per unit time leaving the drainage area, either above or below the ground, through the cross section of the valley at the measuring point or, below the ground, at other points is denoted as runoff (R). The term "runoff" will be used to describe both the process typical for this quantity in the water balance and for the volumetric flow in the sense described above.

Water balances are elaborated for defined regions which, in some cases, are identical to the natural river basins. A drainage basin (A_E) measured in km^2 can be assigned to each river cross section. A drainage area is the size of the area, measured after projection onto a horizontal plane, of a region in which the discharge flowing through a defined river cross section originates. It is bounded by basin divides. The

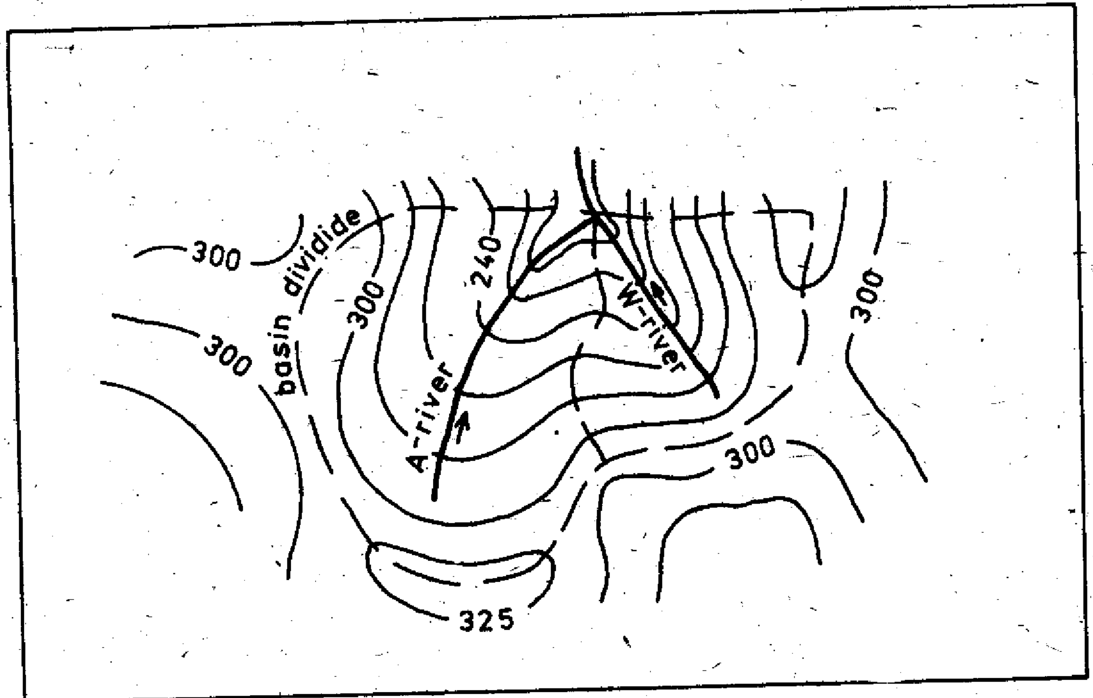


Fig.: II.3.-3 Surface drainage areas for rivers A and W

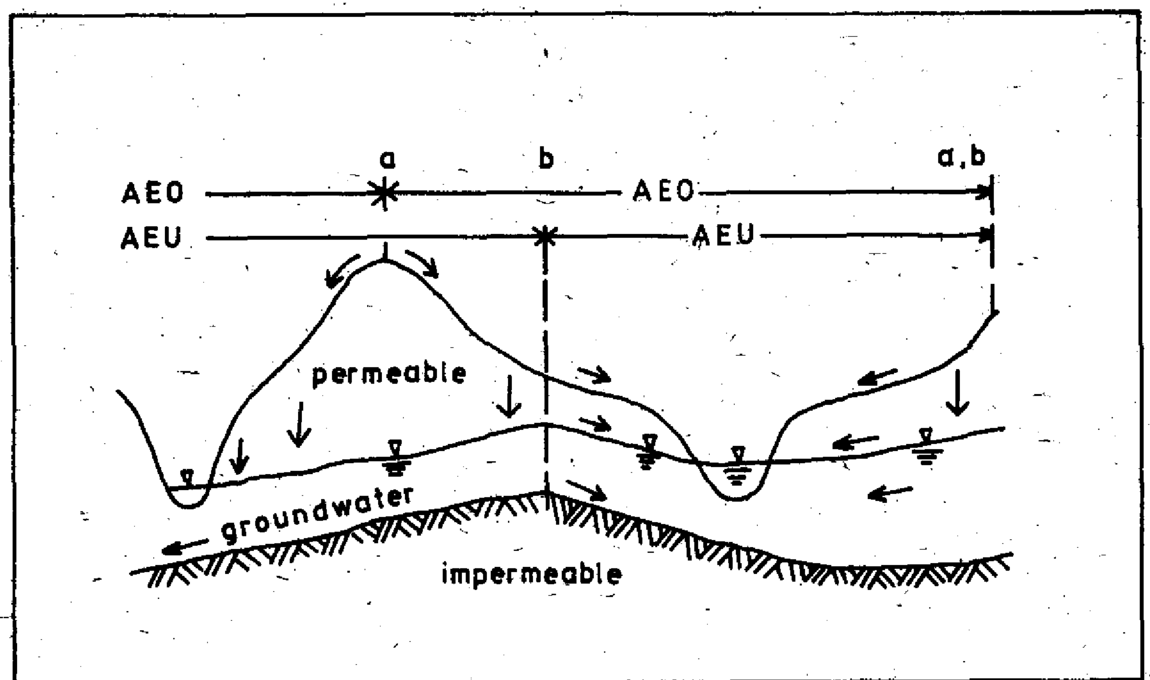


Fig.: II.3.-4 Surface and subsurface drainage area
a) surface b) subsurface

water divides can be constructed on a topographical map with contours (isohypses). The basin divide runs at right angles to the contours, beginning at the river cross section (Fig. II.3.-3.). The water divide constructed on a topographical map borders only the surface basin, whereas the groundwater runoff is governed by the subsurface basin. These two basins are not always identical (Fig. II.3.-4.) /11, 12, 14/.

II.3.1.3. Fundamentals of hydrology

II.3.1.3.1. D e f i n i t i o n

Hydrology is the science that deals with the processes governing the depletion and replenishment of the water resources of the land areas on the earth and treats the various phases of the hydrologic cycle.

It starts with the observation and measurment of certain physical phenomena, analyses their relationships, and aims at the discovery of their underlying causal structure. Thus, hydrology not only describes what happens in the various stages of the hydrologic or water cycle, but it also tries to explain how and why things happen.

II.3.1.3.2. Basic physical principles of hydrology

Two basic principles govern the amount and distribution of water on the earth:

1. Mass conservation

2. Energy conservation

The principle of mass conservation can be illustrated by the hydrological cycle or by the water budget for an arbitrary volume of soil with surface area A and depth d (Fig. II. 3.-5.). We can write the conservation equ. for a period of time t:

$$P + W = \underbrace{Q_S + Q_B}_{Q} + \underbrace{\Delta D + \Delta G}_{S} + U + ET \quad mm/\Delta t \qquad (5)$$

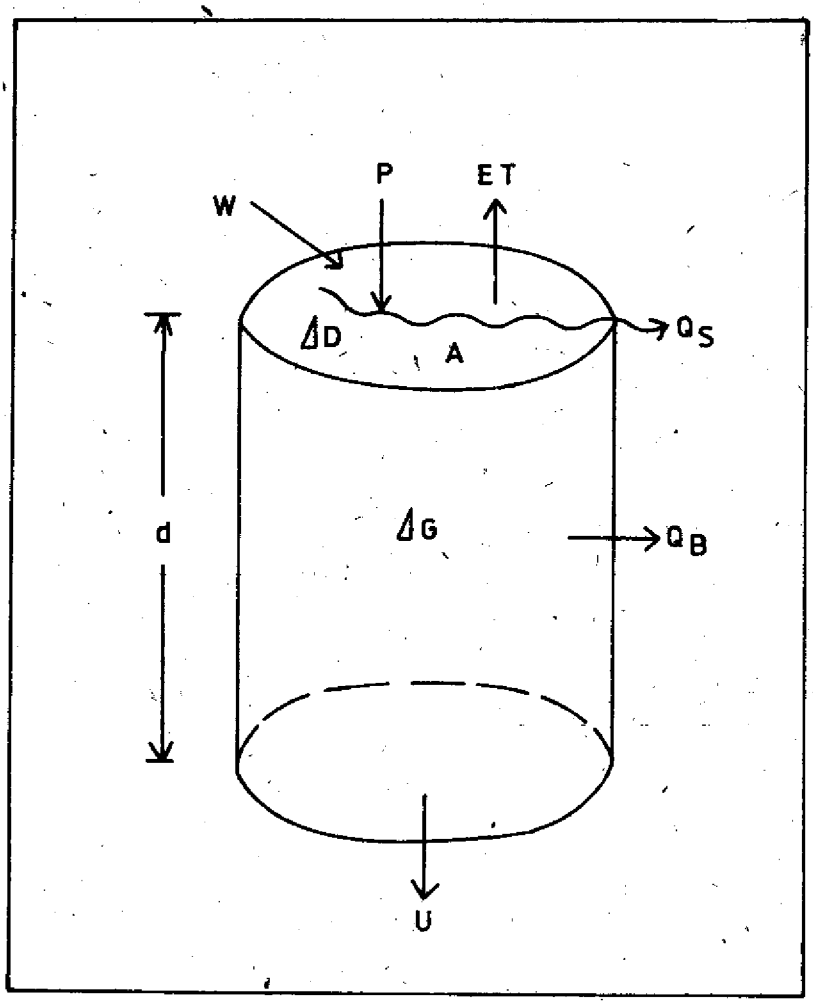


Fig.: Principle of mass conservation
II.3.-5

P - Precipitation

W - Water imported by man

Q_S - net surface runoff (surface runoff leaving A less surface runoff entering A)

Q_B' - net lateral outflow (groundwater, unsaturated flow)

Q - net total basin runoff

ΔD - increase in surface storage (depression and detention storage)

ΔG - increase in soilwater and groundwater storage

ΔS - increase in basin storage

U - net vertical outflow in soil or rock (deep percolation)

ET - Evaporation and Transpiration

If we can neglect water import W and deep percolation U then we obtain for the catchment area or river basin the water balance equation (4) with Q = R.

The amount of evapotranspiration at any site is controlled by the supply of energy and water from the atmosphere and their transformation by the soil, and by the vegetation characteristics of the site. This transformation of energy and water by the atmosphere determines the amount of actual evapotranspiration ET in equ. (4). Equ. (1) and (4) are linked by the evaporation terms.

For the conservation of energy at the layer of soil and air in which plants grow the following equation holds, expressing the relation:

Net rate of incoming energy per unit area = net rate of outgoing energy per unit area

$$R_s\ (1-\alpha) = R_L + r.ET + H + S \quad W/m^2 \text{ or } J/cm^2 \cdot \Delta t \qquad (6)$$

with $R = R_s(1-\alpha) - R_L$ and R given in equ. (1), flux density of total short wave radiation of the ground surface R_s, albedo of the ground surface α, net flux density of long wave radiation R_L. ET' is converted by equ. (2).

The potential evapotranspiration can be calculated by

$$ET_p = \frac{R}{r \cdot \varrho} \quad \frac{J/(cm^2 \cdot a)}{J/g \cdot g/cm^3} = \frac{cm}{a} \qquad (7)$$

Changes in heat storage in the vegetation and the heat used in photosynthesis have been ignored in equ. (6). They would be about 1 % of R_s. The magnitude of the terms in equ. (6) may vary substantially. If the soil surface is wet or covered by actively transpiring vegetation, most of the available solar energy may be used to evaporate water. If the soil surface is dry, most of the incoming energy may be used to heat the air.

II.3.1.3.3. Quantitative description of hydrological systems

The natural reference systems used in hydrology are drainage areas, catchments and river basins. The quantitative description of hydrologically relevant basin properties forms an important basis for the analysis and modelling of the hydrological processes taking place within a river basin.

Hydrological watershed models incorporating parameters which are measurable or can be derived from the basin properties permit conclusions to be drawn regarding the progress of hydrological processes which have received no or only little attention and enable predictions to be made regarding the effects of changes in the basin properties on the hydrological processes.

The system of waters (river basins) caused by fluvial erosion and denudation processes can be considered as open dynamic systems which endeavour to reach a steady state of operation (Fig. II.3.-6). An open system imports and exports energy and

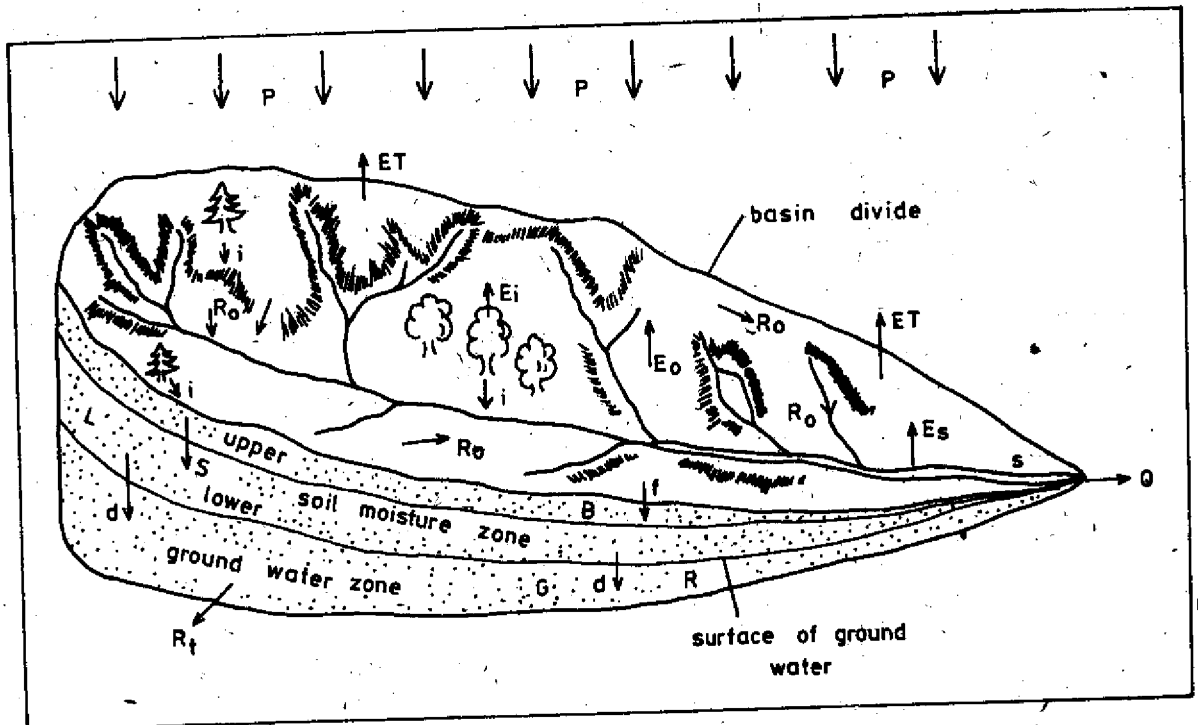


Fig.: A drainage area system
II.3.-6

matter across the system boundaries. It must continually convert energy to maintain this process. Erosion, the transport of matter, and material conversion processes cause the continuous movement of matter out of the basin. In particular, excess precipitation water and minerals leave the system as water and matter discharge through the outlet cross section. The potential energy of the site is converted into the kinetic energy of water and matter and into heat.

Quantitative geomorphological methods are used for the analysis and quantitative description of the river basin structures. We distinguish in a river basin between <u>three main vertical subsystems:</u>

- surface system (ground surface and vegetation, stream channel system and lakes (open waters), land use);
- soil system (aeration zone);
- groundwater system.

Quantitative geomorphological methods are used for the analysis and quantitative description of the <u>geomorphological structure</u> of the surface system:

- stream-channel system (concept of stream orders, stream lengths)
- basin areas
- slope values (channel slope, ground-surface gradients, mean slope of the basin area)
- basin shape
- land use (vegetation, urbanization).

Soil science provides the description (parameters) of the soil system and hydrogeology provides the quantitative description of the groundwater system of a basin. Methods to be applied depend on the objective and scale of the analysis.

II.3.1.3.4. Main hydrological processes in rainfall-runoff relations

Main phases and subsystems

The main hydrological processes are parts of the transformation of precipitation into runoff. In this transformation we distinguish between three main phases:

1. Runoff formation in the basin (land phase)
   How much of a storm rainfall or snowmelt runs off immedeately as direct runoff?
2. Runoff concentration (discharge formation in the stream channel system of the runoff forming basins, channel bed phase) - What is the time distribution of the runoff at the catchment outlets (shape of the hydrograph)?
3. Discharge process in the channel system (flood propagation or wave attenuation phase)
   What is the deformation and flow velocity of downstream flood hydrographs?

The three subsystems resulting from the vertical subdivision of a river basin mentioned above contain three main runoff components:

1. Overland flow or surface runoff (sheet flow, rill flow, quick return flow).
2. Interflow (lateral flow component in the soil).
3. Groundwater flow or discharge (base flow).

The catchment area using a horizontal subdivision comprises three different runoff contributing areas:

1. Open water surfaces (rivers, lakes, reservoirs)
2. Wet or saturated areas, impervious surfaces (quick return flow)
3. Retention areas (infiltration and groundwater recharge).

The size of the different runoff contributing areas is variabel. It depends on the saturation degree of the basin (soil moisture, groundwater tabel). In most cases the surface runoff originates from areas 1 and 2 only (Fig. II.3.-7).

Infiltration and surface storage

Infiltration is the movement of water into the soil through the ground surface. As snow melts or rain falls the soil infiltration governs the amount of water that will enter the soil and thereby greatly effects the amount of surface runoff. The maximum possible infiltration intensity of a given soil under definite moisture and other conditions is called infiltration capacity f_c. If the actual infiltration intensity is f_i, then $f_c \geq f_i$.

When it rains after a dry period, the rate of infiltration into the soil is relatively high. During this first phase the infiltrating rainfall saturates the soil and the infiltration rate is equal to the intensity of precipitation, if $PI < f_c$. But as the rainfall continues, the surface soil becomes saturated at the time tp (ponding time), when the rainfall rate starts to exceed the rate to which the soil will accept water (i.e. the start of the effective rainfall) and the rate of infiltration decreases with time and ultimately reaches a constant value (Fig. II.3-8).

Thus, if the rainfall infiltration is of such an intensity and duration as to result in surface runoff, it can be divided into two phases.

(1) The unsaturated phase without surface runoff at $t < tp$
(2) The saturated or recession phase as $t \geq tp$, when surface runoff is generated.

If the intensity of infiltration t_i is equal to the infiltration capacity f_c, then we have no unsaturated phase, and surface runoff is generated from time $t = 0$ (Fig. II3.-8).

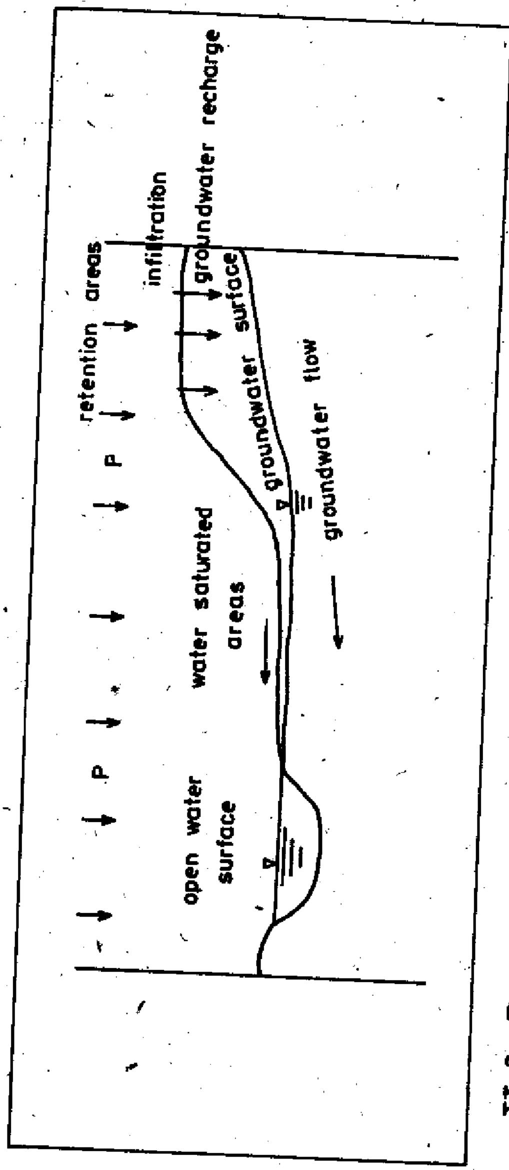
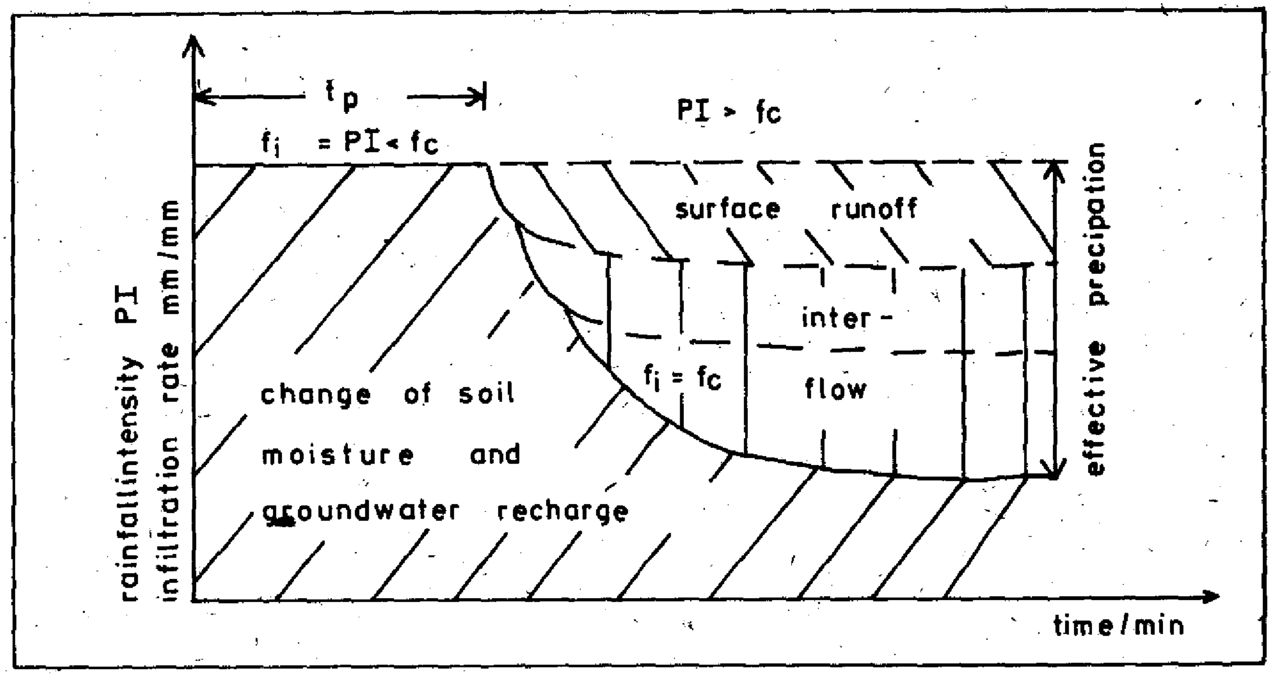


Fig.: II.3.-7 Different runoff contributing areas



FigII.3.8 Infiltration in the case of constant rainfall intensity

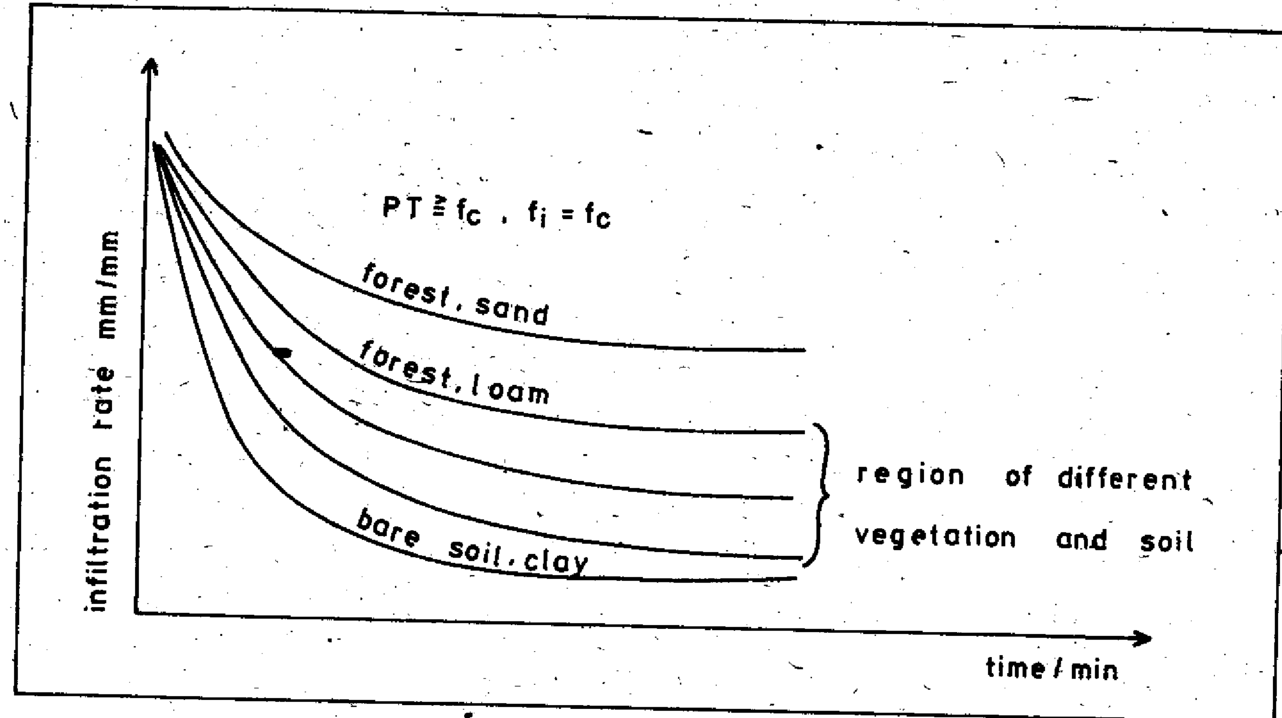


Fig.:II.3.9 Infiltration curves

The rate of infiltration mainly depends on the rainfall intensity, the state of the soil varying directly with the soil moisture deficit, the type of soil being higher into sandy soils thant into clays. Infiltration rates also depend on the vegetation, the highest rates being obtained for forest cover and the lowest for bare, compacted soil (Fig. II.3.-9). Soil compaction by machinery and the trampling of livestock decreases infiltration. The porosity and poresize distribution of the soil substantially effect infiltration rates. The most important parameter for the infiltration process is the relation of rainfall intensity PI to the saturated hydraulic conductivity of the soil, K. If the rate of precipitation exceeds the rate of infiltration, water will be stored on the grand surface (detention or depression storage).

If all of this detention storage is filled, the excess of precipitation over infiltration and evaporation will flow over the surface with the slope of the ground towards the nearest open drains or ditches (overland flow).

Infiltration theory based on the theory of unsaturated flow or two phase flow in porous media has provided a basis for understanding infiltration behaviour /1, 6, 10/.

Soil water movement

The water will move in the soil in response to molecular, capillary and gravitational forces. The movement of water in the larger soil passages is governed by gravitational forces. The water in transit is called gravity water. The unsaturated soil is capable of holding a certain amount of water against gravity by means of the capillary forces. The maximum amount of water which can be retained against the force of gravity and represents the storage capacity of capillary water is called the field capacity FC of the soil. The amount depends upon the soil texture. Plants can not utilize all of the capillary water stored in the soil. The lower limit of utilization of the soil moisture is called the permanent wilting point (PWP). The difference between the soil water content at field capacity and the wilting point represents the available water (AW) for transpiration and body building of vegetation (Fig. II.3.-10). In most cases the lower layers of the soil are less permeable than the upper. Therefore the infiltrated water is stored beyond field capacity towards saturation above layers with low permeability. This causes a lateral flow component in the upper layers which is known as interflow. Since, in most cases it is difficult to distinguish between overland flow and the quick component of the interflow in upper layers, the two components are combined and described as surface or direct storm runoff /1, 14/.

Groundwater recharge

Infiltrated water which percolates downward in the unsaturated zone and arrives at the water tabel of the groundwater is called natural groundwater recharge. The groundwater can be regenerated naturally only from precipitation as a result of the natural groundwater recharge or by seepage from surface waters as a result of bank filtration. The groundwater recharge is only partly compensated for by artificial renewal for water supplies. The remainder returns to the surface part of the hydrological cycle by means of evapotranspiration and subsurface runoff which ultimately discharges into a surface water body. The planning and the exploitation of groundwater resources available require the determination of the long term means and the variations in natural groundwater recharge. For lowland regions and plains where the groundwater table is deep and there is no significant surface runoff, we can regard the runoff $\overline{R}$ as identical to the groundwater runoff which, in turn, corresponds to the long term natural groundwater recharge $\overline{GWR}$.

Thus, the water balance equation for long term means

$$\overline{R} = \overline{P} - \overline{ET}$$

applies in the form

$$\overline{GWR} = \overline{P} - \overline{ET} \qquad mm/a$$

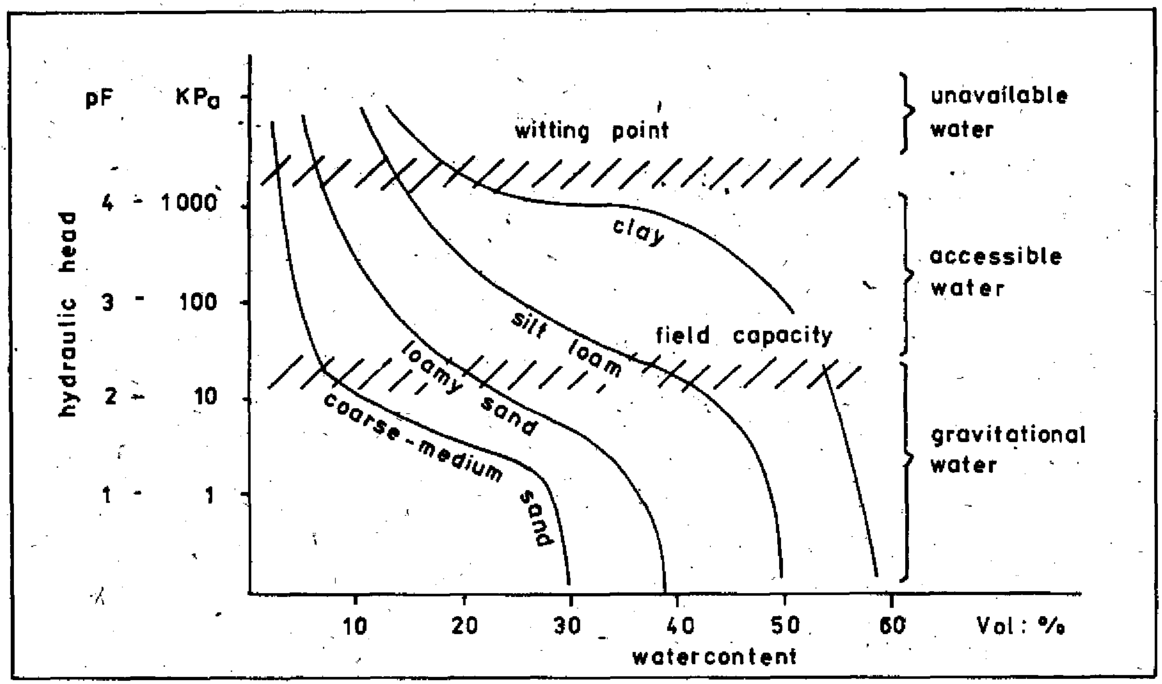


Fig.II.3.10 Waterretention curves for different soils

The mean natural groundwater recharge represents the upper limit of the available natural groundwater. This quantity may be raised for restricted periods by taking water from the static groundwater resources on the condition that these resources will be replenished by surplus natural groundwater recharge during periods when extraction rates are low.

When planning measures for extracting groundwater in substantial quantities, the hydrological situation must be used as a starting point to determine the yield of the strata and rocks containing the groundwater by means of geohydrological measurement and calculations. Water balance calculations must then be performed to ensure that the groundwater recharge obtained from precipitation or by bank filtration will be equal in magnitude to the water extraction. Furthermore, it is necessary to estimate the effects on surface runoff as a result of seepage due to bank filtration and as a result of the reduced discharge of groundwater into surface waters /11, 12, 15, 16/.

II.3.2. Groundwater

Groundwater, i.e. underground water which fully saturates the soil, is the most important resource for drinking water supply in several countries. The upper surface of such a body of water is known as water table. When the groundwater level is high enough relative to the drainage system of the catchment basin, groundwater will enter the drainage channels and contribute to the runoff as base flow. In humid and temperate areas, this 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 basin carry water only for a short period after rainfall (ephemeral streams).

Groundwater may be lost from the basin by deep penetration through permeable rocks. A natural formation which yields its water easily is called an aquifer /11, 12, 15, 16/.

II.3.2.1. Hydrologic properties of aquifers

The main hydrologic properties of porous media are:

Porosity - the ratio of pore volume to the total volume of a given sample of material and

Permeability - measure of the ease with which fluids pass through a porous material.

Since the resistance to the flow of water is related to the size of the individual pores, the void ratio really does not precisely describe the soil material. The coefficient assigned to scale the permeability is called the "Intrinsic Permeability". A porous medium has an Intrinsic or Specific Permeability 'k' of unity if it will transmit a unit volume of water at unit viscosity within a unit time through a cross section of unit area under a unit hydraulic gradient:

$$k = \frac{Q \cdot \nu}{A \cdot \varrho \cdot g} \left(\frac{dh}{dx}\right)^{-1} \quad \text{in } m^2 \qquad (8)$$

Where Q is the fluid volume discharged per unit time through a porous medium of cross-sectional area A, ν is the kinematic viscosity of the fluid, ϱ is the fluid mass per unit volume, g is the acceleration due to gravity, and dh/dx is the hydraulic gradient in the direction of flow. 'k' is a property of the porous medium and is usually expressed in darcys (1 darcy = $0{,}987 \times 10^{-8}$ cm^2). The hydraulic conductivity is a property of both the medium and the viscous properties of the water. The porous medium has a Hydraulic Conductivity of unit length per unit time, if it will transmit a unit volume of water at the prevailing viscosity μ in a unit period through a unit cross section of porous medium under a unit hydraulic gradient:

$$K = \frac{k \cdot \varrho \cdot g}{\mu} = \frac{Q}{A(dh/dx)} \quad \text{in } m/s \qquad (9)$$

Bernoulli energy theorem

The potential function governing the groundwater flow in porous media is, in units of energy per unit fluid mass:

$$\Phi = g \cdot z + \int_{p_0}^{p} dp/\rho \;+ 1/2\, v^2 \qquad (10)$$

Where Φ is the hydraulic potential at a given point, z is the elevation of the given point above datum, p is the gauge pressure (i.e. absolute pressure minus local atmospheric pressure) at the point, p_0 is the atmospheric pressure, and v is the fluid velocity. The kinetic energy term $1/2\, v^2$, is usually negligible for the case of fluid flow through porous media.

By defining $h = \Phi/g$ and setting $p_0 = 0$ (i.e. local atmospheric pressure = zero gauge pressure) and letting $p = \rho \cdot g \cdot \psi$, i.e. neglecting the variation of ρ with pressure, the Bernoulli energy theorem may be rewritten as:

$$h = z + \psi \qquad (11)$$

Where h is the hydraulic or piezometer head, z is the elevational head and ψ is the pressure head. Therefore the water level, h, measured in a piezometer placed at a point of elevation z is the sum of the heads due to the elevation and the hydraulic pressure at that point.

Darcys law

This principle relates the velocity in the porous medium to the hydraulic conductivity and has already been stated in (8):

$$q = - K_x \cdot \frac{dh}{dx} \qquad \text{in } m^3/m^2 \cdot s \qquad (12)$$

Where q = Q/A in (8) and is known as the Darcy or filter velocity or the specific discharge, and K_x is the hydraulic conductivity in the x direction.

The mean velocity of water in the pore (average pore-water or groundwater velocity) $\bar{v}$ must also consider the porosity n of the formation:

$$\bar{v} = \frac{q}{n} = \frac{-K_x}{n} \frac{dh}{dx} \quad \text{in m/s} \qquad (13)$$

To determine $\bar{v}$ the effective porosity n_e is often used which may be defined as that volume of water, as a percentage of the total fully saturated void space, which can drain from a saturated sediment or rock under gravity.

The pore-water velocity $\bar{v}$ is responsible for the transport of contaminants within an aquifer /11, 12, 15, 16/.

The transmission of groundwater in many major aquifers is not by intergranular flow through pores but by 'fracture or fissure flow' through systems of separated planar or semi-planar surfaces. The frictional resistence to flow through such fracture systems may be considerably less than through an equivalent length of aquifer in which intergranular flow occurs, consequently fracture permeabilities may be significantly greater than intergranular permeabilities/15/.

II.3.2.2. Contaminant migration into subsurface waters

Groundwater contaminants may enter an aquifer in various ways (Fig. II.3.-11) /12/:

1. Contaminants deposited in bulk on the ground surface may enter water-table aquifers by vertical infiltration. Liquid contaminants may infiltrate directly. The soluble components of solid wastes tend to become dissolved in rain water or irrigation water and to percolate to the aquifer.

2. Other contaminants may enter the subsurface from contaminated surface waters, where the water levels of rivers or lakes are higher than the local water table. Under natural conditions this situation is uncommon. The pumping of groundwater may, however, lower the water table and consequently encourage the in-

Table II.3.-1: Probable effect of various processes on the mobility of constituents in subsurface waters contaminated by waste disposal, UNESCO (1980) (Modified from Langmuir (1972)).

Physical Processes

Dispersion - Causes dilution of wastes. The dispersive capacity of a porous or fractured medium is directly dependent on the ground water velocity and the heterogeneity of the aquifer materials, and is inversely proportional to the porosity.

Filtration - Favors reduction in amounts of substances associated with colloidal or larger-sized particles. Most effective in clay-rich materials. Least effective in gravels or fractured or cavernous rock.

Gas movement - Where it can occur, favors aerobic breakdown of organic substances, and increased rates of decomposition. Constituents mobile under oxidized conditions will then predominate. Restriction of gas movement by impermeable, unsaturated materials or by saturated materials, can produce an anaerobic state, and reduced rates of organic decay. This will mobilize substances soluble under anaerobic conditions.

Geochemical Processes

Complexation and ionic strength - Complexes and ion pairs most often form by combination of ions including one or more multivalent ions, increase in amount with increased amounts of ions involved. Ionic strength is a measure of the total ionic species dissolved in ground water. Both ionic strength and complexation increase the total amount of species otherwise limited by processes such as oxidation, precipitation, or adsorption.

Acid-base reactions - Most constituents increase in solubility and thus in mobility with decreasing pH. In organic-rich waters, the lower pH's (4-6) are associated with high values of carbonic acid and often also of organic acids. These will be most abundant in moisture-saturated soils and rock.

Oxidation-reduction - Many elements can exist in more than one oxidation state. Conditions will often be oxidized or only partially reduced in unsaturated soils and ground water recharge areas, but will become reduced under saturated conditions when excess organic matter is present. Mobility depends on the element and pH involved: chromium is most mobile under oxidizing conditions, whereas iron and manganese are most mobile under those reduced conditions in which dissolved oxygen and H_2S are absent.

Precipitation-dissolution - The abundance of anions such as carbonate, phosphate, silicate, hydroxide, or sulfide may lead to precipitation especially of multivalent cations as insoluble compounds. Dilution, or a change in oxygen content where precipitation has involved oxidation or reduction, may return such constituents to solution.

Adsorption-desorption - Ion exchange can withhold, usually temporarily, cations and to a lesser extent anions, on the surfaces of clays or other colloidal-sized materials. Amounts of adsorbed metal cations will increase with increasing pH. Molecular species may be weakly retained on colloidal-size materials by physical adsorption. The much stronger binding forces due to chemisorption result in the formation of surface compounds involving metal ions and mineral grains. Depending on the nature of the adsorption bond adsorbed species may return to solution when more dilute moisture comes in contact with the colloidal material.

Biochemical Processes

Decay and respiration - Microorganisms can break down insoluble fats, carbohydrates, and proteins, and in so doing release their constituents as solutes or particulates to subsurface waters.

Cell synthesis - N, C, S, and P, and some minor elements are required for growth of organisms, and can thus be retarded in their movement away from a waste disposal site.

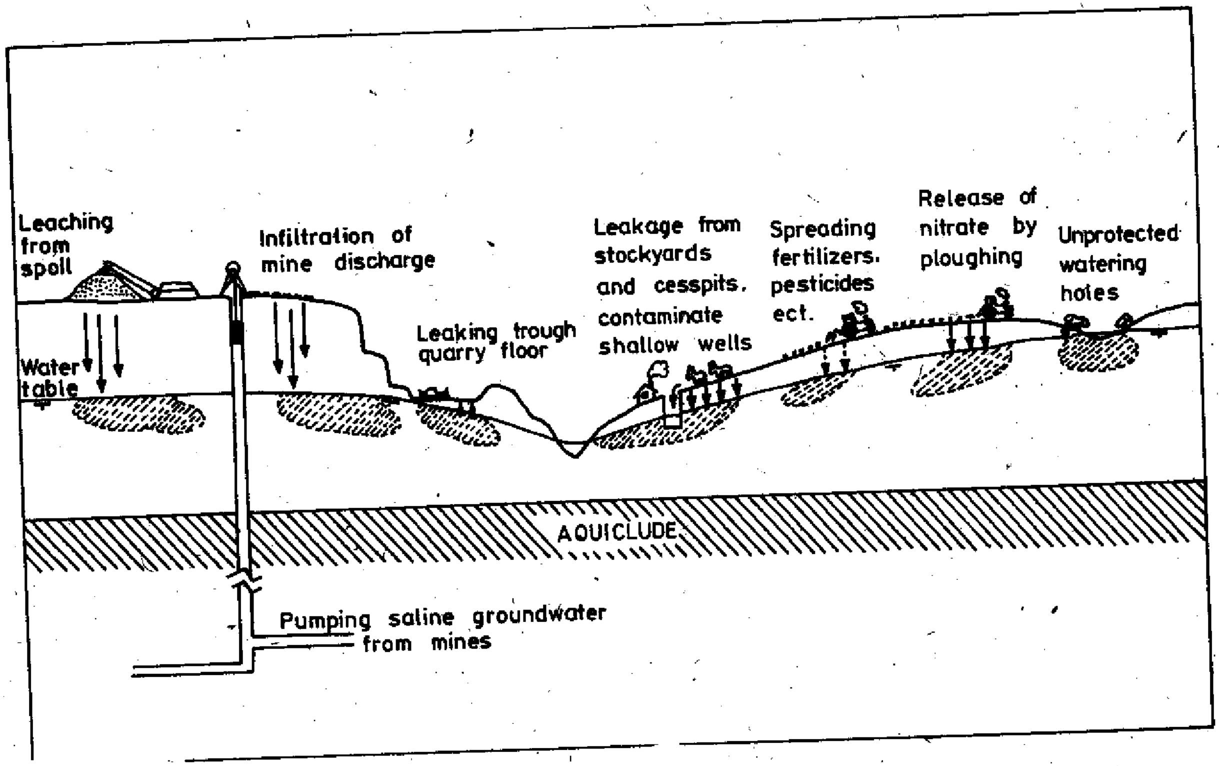


Fig. II.3.4 Sources of contamination from agriculture and mineral exploitation (UNESCO 1980).

filtration of polluted surface water into aquifers. A similar situation can develop along coastlines, where the intrusion of salt water into fresh-water aquifers may be a consequence of overpumping /16/.

3. Contaminants may migrate into aquifers due to the hydrogeologic effects of man's activities, e.g.
a) waste-water storage lagoons or tanks on the surface;
b) clarification basins dug into the ground;
c) subsurface storage tanks, oil and gas pipelines;
d) disposal wells.

4. Finally, contamination may increase at depth due to the interaction of foreign or exotic materials and surface or subsurface waters. For example, water-logged sand, clay and gravel pits and abandoned mines may become filled with wastes. As a result of the disposal of large amounts of rubble from buildings (e.g. after the Second World War) the sulphate content of groundwaters may increase because of decomposition of plaster /12/.

Main human activities generating contaminants are
- agriculture (inorganic and organic fertilizers pesticides, livestock, silage)
- mining (solid and liquid wastes)
- household, commercial and industrial solid wastes
- household, commercial and industrial liquid wastes (raw sewage, septic tanks, sewage treatment, sewage sludge, storm water drains, various industrial wastes).

II.3.3. Surface water

Surface water is the water flowing in torrents, rivers and streams and the standing water in ponds and lakes. Surface water and groundwater are closely coupled in most cases. Surface water is the main resource of water supply for industry and irrigation. A natural stream or a lake close by are the most economic source of water for a city. To judge the suitability of the surface water we have to apply two criteria:

- the dependability of the flow, and
- the quality of the water.

Since the quality and/or dependability of surface water often is insufficient for drinking water, the main source for the latter in general is groundwater.

Without storage capacity, the water demand of the city plus downstream riparian requirements should be less than the low flow occuring with a given probability. Important factors in the dependability of stream flow are the size of the drainage area, the climate and the characteristics of the drainage basin. The larger the drainage basin and the wetter the climate, the larger the dependable flow.

If the dependable flow of a river basin is insufficient to satisfy the estimated demand, but the average flow is ample, the demand may be met by constructing a reservoir.

II.3.3.2. Factors influencing the surface runoff

The hydrologic regime of a stream is the result of the formation and concentration of runoff in its basin. The characteristics of the basin are the main factors influencing the surface runoff. They may be devided into two groups; geographical factors and geomorphological factors.

Geographical factors

- Climate (precipitation, radiation, heat, air motion, evapotranspiration)

The velocity is measured on several points by counting the number of revolutions of a current meter during a short time period.

Discharge measurements are needed for different water stages of the river to construct the rating curve of the river profile. This is the relation between water stage H and discharge Q. The individual discharge measurements may deviate from a mean relation Q = f (H), because of insteady flow, variing aquatic growth with season, influence of variable back water, changes in cross section.

Other discharge measurement methods are trace methods, indirect methods, acoustic flow measurement.

II.3.3.3. Streamflow calculations

To assess the quantity of water available in a stream generally the following levels of streamflow data are utilized: mean annual runoff, the mean monthly discharges, and the mean daily discharges.

Methods of calculating stream flow are based on the following main considerations. WMO (1975).

a) Variations in natural river flow during the relatively short period of hydrometric observations and the existence of the planned structure are assumed to be random variations about a stable mean regime;

b) There is a general pattern of flow variations by season, in accordance with the annual cycle of the earth's rotation around the sun;

c) The annual maximum and minimum discharge obey the general law governing the probability distribution of random values of varying magnitudes.

- Soil (mineral composition, granulation, nutrients)
- Vegetation (vegetation cover, plant physiology)
- Man's activities (land use, artificial reservoirs)

Geomorphological factors

- Size and shape of basin
- Stream-channel system and stream lengths
- Basin slope (mean ground surface slope)
- Character and slope of the stream (upper, middle and lower reaches)

There are a great number of factors influencing runoff, they are interconnected and often counteracting.

II.3.3.4. Measurement and analysis of river discharge

For the assessment of available water resources and for hydrological analysis the measurement of water stages (river, lake and reservoir stages) and the discharge of rivers is extremely important. The site for measurement should ensure a stable relation between the stage and the discharge and an easy measurement of the flow. WMO (1980).

For measuring the stage manuel (non-recording) and recording gauges are used. The staffgauge is most common among the non-recording gauges. It consists of a graduated plate fixed in the stream or on the bank or on a structure, i.g. bridge. Recording gauges can be classified by the stage detection method (float, hydrostatic pressure) and by the mode of recording (continuous line on graph paper, sequence of punches of a digital stage recorder).

The most common method of discharge measurement is the "area-velocity-method" using the continuity equation

$Q/m^3 \cdot s^{-1}$	=	A/m^2		$v/m \cdot s^{-1}$
discharge through a cross section	=	wet cross section area	x	average stream flow velocity

II.3.3.4.1. Mean annual runoff

The maximum potential quantity of water available from a basin in the long run is given by the mean annual runoff Q. Therefore the long-term mean discharge of a stream is of fundamental importance for a surface water inventory. It is also used as a unit in terms of which the annual runoff of current years and the amount of runoff in individual seasons are expressed. The value of mean annual runoff does not give an idea as to how much the runoff in individual years can differ from the average. But, the greater the variability of annual runoff the more difficult and expensive becomes the management of water resources. Therefore, such deviations are of practical importance. The basic measure of variability is the square root of the variance called the standard deviation. To enable comparison of runoff variabilities for points with different values of annual runoff, the dimensionless coefficient of variation is prefereable. WMO (1973).

Probability distribution of mean annual runoff

The mean and the coefficient of variation alone are not sufficient for answering such questions as what is the probability of the annual runoff not exceeding 50 % of the mean. To solve water management problems we need the probability distribution of annual runoff.

Probability curves of river flow are described with sufficient accuracy by three parameters:

the mean annual flow, the coefficient of variation and the coefficient of skewness.

Three properties of runoff probability distribution can be derived from the physical nature of runoff:

- its shape is asymmetrical (skew)
- the distribution is limited in one direction (lower tail) and unlimited in the other (upper tail)
- the absolute lower limit is zero.

The measure of asymmetry (coefficient of skewness) is an important characteristic of distribution shape, but it is very difficult to estimate the exact coefficient of skewness from the available data series. As annual runoff of most rivers seems to exhibit positive skewness this has become an a priori assumption for annual runoff distributions. Positively skewed models, like gamma and log-normal types, are often applied. These two-parameter distributions do not require the coefficient of skewness to be calculated from the data and can be fitted just on the basis of the mean and the coefficient of variation. The coefficient of skewness Cs is a function of the coefficient of variation Cv.

$Cs = 2\ Cv$ for gamma distribution, and

$Cs = 3\ Cv + Cv^3$ for log-normal distribution.

Mainly rivers with large storage capacities in their basin have much smaller values of Cs. To achieve flexibility in skewness a power transformation or a location parameter c is introduced. In the first case a variable $a \cdot Q^b$ (where a and b are parameters that can be expressed in terms of Cs) rather than Q, is assumed to be gamma distributed. In the second case it is assumed that a variable $Q - c$ rather than Q possesses the gamma or log-normal distribution. The gamma distribution with a location parameter is known as a Pearson type III model.

For fitting of distribution models the data can be plotted on probability paper with a special abscissa scale where a certain type of distribution function appears as a straight line which is fitted to the plotted points of annual data arranged in order of magnitude. Objective methods of fitting are the method of moments, the method of maximum likelihood, the method of least squares, and the quantile method. These methods are not very accurate.

A plot of a fitted distribution function is the final practical objective of distribution fitting giving the values of annual runoff of desired probability. WMO (1973).

Time-dependent behaviour of annual runoff

A sequence of annual runoff data is called a time series. It is a special feature of hydrologic time series that they show high variability and large scale random variation about a mean value. A time series may be marked by a superposition of random, cyclic and trend components. It is extremely difficult to decompose the composite time series into its components, but there may be a relationship between the various components and basic physical laws.

It is important to know the pattern of time fluctuations for long term hydrological forecasting, long-range planning in water resources and design and operation of flow regulating reservoirs.

If there is no trend in the sequence of annual runoff data, or it has been removed, the series can be regarded as a discrete stationary stochastic process. Its stochastic behaviour is characterized by the autocorrelation function, which can be estimated by the correlation coefficient between the pairs of annual runoff values k years apart

$$r_k = \frac{\sum (Q_i - \bar{Q}_n)\ (Q_{i+k} - \bar{Q}_n)}{n \cdot \sigma^2}$$

where σ is the variance. In a finite n-term series the above summation can be carried out from I = 1 to i = n - k. With increasing k the reliability of r_k decreases.

If no reliable inference can be made about r_k, k = 2, 3, ... but r_1 is significantly different from zero, the series can be fitted by first order Markow chain

$$Q_i = r \cdot Q_{i-1} + RE_i$$

with the autocorrelation function

$$r_k = r_i^{\ k}$$

Where RE_i is a random element whose distribution is a function of that of Q . WMO (1973).

Simulation of series of annual runoff

The real time-pattern of future fluctuations of the stochastic series of mean annual flow cannot be predicted. But in water resources planning and management decisions are necessary taking into account time horizons of several decades. A way out of this dilemma is to test a given decision on a large spectrum of possible future runoff fluctuations thus obtaining a multitude of different outcomes from which the probalitiy of the desired outcome can be assessed. Using a mathematical model for the time series of annual flow, like the first order Markov chain, one has to simulate by computer a large number of possible variants of the future runoff series and try out the intended water management policy on each of them. As a result of this application of the Monte-Carlo-Method a number of possible outcomes is obtained from which the needed information can be extracted. Stream flow simulation is described by FIERING (1967) and DYCK and others (1980).

II.3.3.4.2. Mean monthly river flows

There are many water resources management problems for which the knowledge of the annual runoff is not sufficient (irrigation projects, low-head water power development with small flow regulation capactiy, water pollution in a stream with a constant input of waste water ....). In such cases mean monthly flows are used for describing sub-annual distribution of runoff. Frequency distributions of runoff and its parameters can be obtained for each month in the same manner as described for annual runoff. All parameter are influenced by the periodic component in the series of mean monthly flows. It is therefore a much more complex stochastic process than a series of mean annual flows.

For simulation of time series of monthly flows a twelve fold linear regression model can be used as shown by DYCK and others (1980). It requires to specify the 12 distributions of monthly flows and the 12 correlation coefficients between the flows of successive months.

II.3.3.4.3. Mean daily river flows

Mean daily flows are the basis for computation of mean monthly and annual flows. They are used for planning, design and operation of water supply from unregulated streams, waste water dilution, on-river water power installations, and navigation. By plotting in descending order mean daily flows from the entire period of record and rescaling the time base of the plot to be equal to 365.25 days we obtain the basic duration curve. The value of flow rate corresponding to a certain number of days m, on this curve, then gives a mean daily flow which is exceeded, on the average, during m days of a year. The duration curve can be used when dealing with the above mentioned water management problems /WMO (1973)/.

II.3.4. Interrelations soil-water-plant

II.3.4.1. Introduction

The relationship between vegetation and climate figures among the most difficult ones in ecology. It has occupied researchers since the establishment of agricultural societies. Vegetation uses solar energy and water to convert carbon, nitrogen, phosphorus, and other elements into plant tissue. The carbon diffuses through pores in the leaves as carbon dioxide, while the mineral flow in aqueous solution from the soil through the roots.

Plant growth can be looked at as a system consisting of three parts: soil, plant and atmospheric conditions (water and energy supply). When assessing the water demand of a plant each of the three components must be taken into account. For the estimation of expected crop yield we need:

- assessment of potential evapotranspiration, which reflects the energy supply by solar radiation
- assessment of reduction of actual evapotranspiration with decreasing water availability (soil moisture)
- a procedure for balancing the soil moisture to assess the actual available soil moisture.

II.3.4.2. Terminology of plant water demand

The terms Evaporation E, Transpiration T, Evapotranspiration ET (see 3.1.1.3.) are specified for different objects:

Eo : evaporation of an open water surface [mm/d]

ETo : evapotranspiration of an area with optimal supply of water and nutrients grown with equally high short green grass [mm/d] used as reference crop for the determination of the potential evapotranspiration of a definite crop (Unit ETp)

ETp : potential evapotranspiration of an area covered with a definite crop species, dependent on the stage of plant development

ETa : actual evapotranspiration, dependent on the availa soil moisture, atmospheric conditions, and the soil and crop characteristics

The critical hydraulic properties of soil vary widely with textural class. They can be characterized by

n total porosity, equal to the volume of voids/volume of soil;

n_i inactive porosity, equal to the void fraction not participating in soil water movement under normal potential gradients,

n_e effective or active porosity, equal to $n(1-n_i)$.

Apart from the terms Field Capacity (FC) and Permanent Wilting Point (PWP) in Vol % or mm/dm soil column we use the following terms to describe the water in the soil:

Θ : water content (soil moisture) of a soil in volume per cent [Vol %] or in mm

Ψ : soil water potential or suction in Pascal or bar

For the region between PWP and FC (Fig. II.3.-10) we have approximately the relation

$$\Psi = a \cdot \Theta^{-b} \qquad (1)$$

with a, b soil specific constants.

Θ_u: useable soil moisture in [mm/dm] or [per cent]
$\Theta_u = FC - PWP$

Θ_a: available soil moisture [mm/dm]
$\Theta_a = \Theta - PWP, \quad 0 \leq \Theta_a \leq \Theta_u$

Z_r: depth of root zone [dm]

Θ_e: effective useable soil moisture of the crop [mm]
$\Theta_e = \Theta_u \cdot Z_r$

II.3.4.3. Determination of the potential crop evapotranspiration ETp

For the calculation of the plant water demant field experiments should be performed. If such data are not available we can use ETp as a measure for the water demand. The procedure is as follows:

1. Determination of potential evapotranspiration of short green grass ETo

In its instructions FAO (1975/77) recommends several procedures. The best known are those of PENMAN (1948), BLANEY/CRIDDLE (1947) and TURC (1961).

2. Determination of the specific potential evapotranspiration of a plant ETp

Each plant species shows a specific behaviour regarding temporal development of growth and resultant maximum possibility of transpiration. Plant water use can be described by a species-dependent crop coefficient K_c, which is the ratio of potential crop evapotranspiration to the potential evapotranspiration of a reference crop

$$ETp = K_c \cdot ETo$$

The value of K_c will vary with plant species and with the stage of seasonal growth cycle. FAO (1975/77) published K_c - functions for most crops.

II.3.4.4. Assessment of actual evapotranspiration

The decrease of soil moisture results in a decrease of the evapotranspiration rate. The amount of this decrease is variable and depends on many soil, plant and climate factors. The interdependence of these factors and the degree of its influence on evapotranspiration is a point of international discussion and research.

For the assessment of direct interdependence of actual evapotranspiration ETa, potential evapotranspiration ETp and available soil moisture several models have been proposed. Most of them give the relative evapotranspiration ETa/ETp as a function of soil moisture

$$\frac{ETa}{ETp} = f(\Theta) \qquad (2)$$

Examples are the following models:

MINHAS, PARIKH and SRINIVASAN (1974) propose the following class of functions

$$f(\Theta) = \frac{1 - e^{-\gamma \cdot \Theta}}{a - 2e^{-\gamma \cdot \Theta_{max}} + e^{-\gamma \cdot \Theta}} \qquad (3)$$

with Θ_{max} availables soil moisture at field capacity, γ free parameter.

NORERO (1969) uses the relation $ETa/ET_{max} = f(\Theta)$ with

$$f(\Theta) = \frac{1}{1 + \left(\frac{\Theta_c}{\Theta}\right)^{b.K}} \qquad (4)$$

ET_{max} is the maximum possible ET under given conditions, if soil water is taken as a non-limiting factor. K is the coefficient of proportionality given for different crop dependent on ETp, Θ_c is the soil moisture content [Vol %] for which ETa = 0.5 ET_{max} BAGROV (1953) developed the differential equation for annual means

$$\frac{d\,\overline{ETa}}{d\overline{P}} = 1 - \left(\frac{\overline{ETa}}{\overline{ETp}}\right)^{n} \qquad (5)$$

with n as parameter of efficiency, characterizing the efficiency of water supply ($\overline{P}$) and energy supply ($\overline{ETp}$) at a site with given soil and vegetation.

For the computation of the actual water balance we have to take into account the change in storage. Therefore, equ. (5) is modified

$$\frac{ETa}{ETp} = \left(1 - \frac{dETa}{d(P+\Delta s)}\right)^{\frac{1}{n}} \qquad (6)$$

Dynamic geohydrological models have been developed for the computation of actual monthly water balance values specific to a given site. From this models water fluxes and water content for the different soil layers of the aeration zone are obtained, DYCK (1980). These models can be used for the computation of the actual water balance and for the planning, design and operation of irrigated areas.

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II.3.5. Irrigation and Drainage

II.3.5.1. Introduction

Irrigation and drainage of agricultural areas have been known for about 4,000 years. Mainly in comparatively densely populated and rain-deficient regions extensive irrigation systems were built, which constituted the basis of the prosperity of the people who lived there.

A good example of the close relation between the development of the irrigation techniques and the wealth of a society is known from Mesopotamia, the region between the Euphrates and Tigris rivers. The development of the irrigation and drainage agriculture for about seven millenniums ensured a flourishing society. The destruction of the irrigation systems by catastrophic floods together with soil salinization initiated the downfall of societies and cultures.

Whereas irrigation serves to get higher returns in agriculture in arid regions, land drainage is the removal, by artifical means, of water excess from the soil or the land surface, its objective is to make the land more suitable for use by man.

In agriculture, it aims to increase production, to sustain yields, or to reduce production costs. In many countries drainage has always been a vital necessity for the cultivation of land otherwise unarable; for the improvement of moisture to make the cultivation of a greater variety of crops possible.

II.3.5.2. Irrigation

II.3.5.2.1. Origin and Quality of Water

The water used for irrigation is taken from the natural running or stagnant waters. Surface and groundwater are differentiated. Wastewater and brackish water are more and more used for irrigation too.

Surface water: Surface waters are classified into stagnant and running waters according to the water motion. Streams, rivers, brooks, ditches and canals are running waters. Mainly in arid regions their rate of flow may vary considerably, and especially in periods of increased water demand smaller water courses may completely dry up. Stagnant waters are natural or artifical waters. Artificial water-reservoirs have been known since the beginning of irrigation agriculture. In arid regions mainly cisterns and earth basins are available, which serve for collecting rainfall. Retention basins and storage lakes at running waters are also very important.

Groundwater: Groundwater supplies a large and continuously increasing share of the irrigation water. The potential tapping is determined by the recharge of groundwater, which amounts to only 2 ... 5 % of the rainfall in arid regions. Groundwater can of course, be used by tappings of springs; as a rule, however, wells (dug or drilled wells) are necessary for water supply. Kanats for water supply are common in the Middle East, e.g., about three million hectares of agricultural area are irrigated with water from kanats.

Wastewater and brackish water: In industrial agglomeration areas and in the neighbourhood of large towns waste water is used in the irrigation agriculture, too. In addition to the utilization of wastewater, attempts are made to increasingly use saline waters for irrigation. There is the danger, however, that due to the salinization of soil total irrigation areas will become unavailable for agricultural use for short or long periods of time. Today the desalinization of water for irrigation is still too expensive and confined to a few examples.

3.5.2.2. Delivery, feed, measurement

In the classical irrigation agriculture water is brought to the areas to be irrigated usually by a natural slope. In many cases, however, it is necessary to lift water from a canal or a feeding ditch. This applies in particular when water cannot be taken in at the upper course or if an elevated terrain is to be irrigated.

Plants driven by man power, draught animals, wind power, hydro-power, electric motors or internal combustion engines are used for water supply. In many regions of the Earth plants driven by man power or animal power are still very important.

The measurement of the water quantity is necessary for an economical irrigation. Depending on the discharge and the technical facilities available it is either carried out in open conduits, by means of measuring weirs or by flow measurements in pipe lines.

The feed of water has a decisive function as the link between water supply and water distribution. The efficiency of irrigation systems is determined largely by the quality and serviceability of all feeding systems, because they influence the water losses essentially.

Water is fed through canals with or without lining or pipe lines. The canals can be sealed with clay materials, concrete, masonry, foils or chemicals (e.g. bitumen sprayed on). As a rule, the feed through pipe lines necessitates a higher expenditure on construction and higher maintenance costs. Water losses are minimized, which may be decisive mainly at longer feeding distances.

II.3.5.2.3. Water distribution

In the irrigation agriculture the water distribution is decisive for success. A water distribution system is needed by means of which the water quantity required for the optimum developement of plants can be fed into the areas under cultivation at any time.

The systems are classified into types, this is according to their purposes.

Moistening irrigation serves to supply water in order to increase soil humidity, especially to guarantee an optimum growth of plants during dry periods. This is the most frequent kind of irrigation.

Storage irrigation means to increase the soil humidity during humid periods when water is available. During dry periods plants tap water from this artifical storage. By fertilizing irrigation the soil is supplied with an effective quantity of plant nutrients together with the irrigation water. The irrigation by river water which is rich in sludge (e.g. in Egypt due to the overflowing of the banks of the Nile river before the Aswan dam was constructed) can be classed with fertilizing irrigation.

Frost precaution irrigation is intended to prevent frost damages. It is confined to special cultures (vine, fruit) and is of local importance only.

In the course of millenniums, a large number of irrigation techniques have been developed. There is no irrigation technique which is ideal and adequate to all conditions and requirements. The choice of the technique must always aim at achieving an optimum state with due regard to soil conditions, the financial means and other characteristic features.

The irrigation techniques are difficult to systematize, because different classifications are used in different language areas and fields of application. The following table shows the most important irrigation techniques in German, English and French.

	German designation		English designation		French designation
Stauver-fahren	Flächenüberstau	surface methods	controlled flooding	sub-mersion	irrigation par submersion
	Beckenbewässerung		basin irrigation		irrigation par cuvettes
Riesel-verf.	Landstreifenbewässerung		border strip irrigation	ruissell-ement	irrigation par planches
	Furchenrieselung		furrow irrigation		irrigation par sillons
Stau-verf.	Furcheneinstau		- " -	infiltr.	irrigation par rigoles d'infiltr.
	Winterflurbewässerung		subirrigation		irrigation souterraine
	Tropfbewässerung		drip irrigation		irrigation goutte à goutte
	Beregnung		sprinkler irrigation		irrigation par supersion

The choice of the suitable irrigation technique depends on a large number of local and social conditions, e.g.

- soil (physical properties, topography)
- water (demand, necessary dosage, physical and chemical properties)
- crop type and properties
- expenditure on construction and operation.

The efficiency of irrigation is an important characteristic when planning an irrigation system. It expresses the ratio of the water taken up by the plant and the water quantity having been made available. A distinction is made between the efficiency of the total system, the efficiency of the water supply, the efficiency of the supply to the fields and the efficiency of water distribution.

The efficiency of different techniques may differ widely; in general, the following efficiencies of distribution can be expected: for surface irrigation 0.5 - 0.6, for spray irrigation 0.65 - 0.75. The efficiency of the supply and distribution systems is considerably influenced by exact dimensioning.

II.3.5.2.4. Planning and control of irrigation

Before any new irrigation system is constructed, it has to be checked whether climate and soil necessitate irrigation. Due regard should be given to economic criteria and the surplus yield of irrigated cultures should considerably exceed the labour and the construction and operating costs.

So far, there is no theoretical foundation which takes into account all requirement and conditions for determining the water-yield relation.

The planning and control of irrigation systems require a high degree of interdisciplinary co-operation between agronomists, engineers and economists who have to be assisted by meteorologists, pedologists and hydrologists. Experience teaches us that failures often occur in case of a purely technical approach to the complex problem.

The control of irrigation systems can be done according to

- plant-physiological criteria
- soil-physical criteria or
- climatological criteria.

The choice of a suitable regulation and control depends on the available measuring devices, the demands made by the crops or plantations to be irrigated/ the climatological factors and other factors.

The price of the irrigation water, which may considerably influence the economic aspect must be taken into account.

II.3.5.3. Land drainage

Land drainage is very old practice. Especially in the Netherlands, with much of its low-lands lying below the sea or river level, drainage has always been a vital necessity. The development of drainage all over the world was paralleled by a better understanding of the principles of drainage, upgrading it from a practical method based on experience and skill into a science based on the complex interrelations between the hydrological, geological and agronomical conditions. In the nineteenth century the French hydrologists Darcy and Dupuit were the first to formulate the basic equation of groundwater flow through porous media and to apply it to flows to wells. In the thirties Hooghoudt followed by Childs, Connan, Ernst and other wellknown scientists dealt successfully with drainage problems, but when drainage problems are applied in practice, we still face a number of limitations. These limitations are a consequence of the wide variability we encounter in nature when dealing with soils and plants.

We face a lot of questions like: how to characterize a soil profile and how to measure a physical soil constant? All these factors contribute to an inevitable inaccuracy which has to be accepted when working in land drainage. Therefore, the statement made by Cloude Houston in 1961 is still valid: "Although excellent progress has been made in recent years in developing drainage criteria and investigational tools, it still takes good judgement, local experience, and trial and error - along with a thorough understanding of the basic principles - to design a successful drainage system."

II.3.5.3.1. Hydrogeology and drainage

An area drainage problem is closely related to its geomorphological and geogenetical conditions. The presence or absence of layers with good water-transmitting properties, of barriers and springs and the relation between groundwater and surface water will affect the water conditions in or near the rootzone.

For hydrological purposes the layers are classified as:

- pervious
- semi-pervious
- impervious

A layer is said to be pervious if its resistance to vertical flow is small. It may generally be neglected, so that only the energy losses caused by horizontal flow must be taken into account.

In a semi-pervious layer the horizontal flow rate over a longer distance is negligible, but vertical flow cannot be neglected due to the relatively small thickness of the layers.

The layers containing groundwater combine into aquifer systems. These systems should be relatively simple in order to enable a mathematical treatment of ground water flow problems and should belong to one of the following types:

- confined
- semi-confined
- unconfined

An unconfined aquifer, or phreatic or watertable aquifer, consists of a saturated part which is underlain by an impervious layer. A confined aquifer consists of a completely saturated layer whose upper and lower boundaries are impervious layers. Confined aquifers are rare in drainage problems.

A semi-confined or leaky aquifer consists of a completely saturated pervious layer covered by a layer with a water table. In many cases a vertical flow component will raise or lower the water table in the covering layer.

II.3.5.3.2. Soil and soil properties

The term soil is often vague and conveys different meanings to different people. The civil engineer, the soil physicist, the soil chemist or agronomist consider the soil as unconsolidated earth, as a porous medium, as a powder, or as the medium for plant growth.

The drainage specialist is concerned with soil properties which affect the movement of water into and through soils. The natural soil contains solid, liquid and gaseous materials. Soils supply crops with essential plant nutrients, in addition to water and oxygen for root respiration.

Other aspects of soil which have a bearing on plant growth are

- its temperature which should be favourable to plant growth;
- its mechanical resistance to the movements of roots which should not be too high;
- it should provide an environment free of chemical or biological conditions detrimental to plant growth.

II.3.5.3.3. Types of field drains

The field drainage systems may consist of one or of the following types of drains:

- open drains : ditches
- mole drains : unlined underground channels
- pipe drains.

Open drain systems have their specific advantages and disadvantages.

Advantages:	Receive both groundwater and surface water, the gradient required is much less than in pipe drains or in mole drains, they allow inspection
Disadvantages:	loss of land, weed growth and erosion is possible, the land is split up into seperate parcels.

II.3.5.3.4. Construction and materials for pipe drains

The normal procedure in constructing a pipe drainage system is to
- excavate a trench at the required depth and gradient
- install the pipes in the trench
- fill the trench with the excavated soil.

The construction may be done by manual labour or by machines. Clay, concrete, and plastic are the most common materials used in drain pipe productions.

Cover materials are applied to pipe drains for two purposes:

- to facilitate the water flow into the drain
- to prevent the entry of soil particles into the drain.

These materials are applied in bulk, in sheets or by means of pre-enveloped drain pipes.

II.3.6. Water quality, water treatment, drinking water supply

II.3.6.1. Chemical water quality problems

II.3.6.1.1. Essential constituents in water

For the purpose of this survey only a few aspects of water use, particularly of drinking water, shall be mentioned.

Among the gases dissolved in water, special significance is attached to oxygen and carbon dioxide. Clean surface waters have a relatively high oxygen content which is very near to the value of saturation. The oxygen deficit is larger in polluted waters due to the biochemical conversion of organic substances. In such cases the absorption of oxygen from the air and the oxygen formation by the assimilation activity of water plants is often not sufficient in order to compensate the consumption. Severe loss in oxygen results in dying of fish and septic processes. In contrast to surface waters, groundwaters often contain smaller quantities of oxygen. Sufficient oxygen content in the water reduces the danger of taste impairment and is necessary for the formation of a protective layer of lime and rust in the pipework. Carbon dioxide gets into the water from the atmosphere, from geological processes, and from biochemical disintegration processes. It is closely connected with the occurrence of carbonic acid and its dissociation products. Carbon dioxide has a positive influence on the water taste, it accelerates the disintegration of certain minerals, particularly of carbonate stones. Thus, carbonic acid can be assigned aggressive properties. Therefore, excessive carbonic acid must be removed when treating water, and an equilibrium between lime and carbon dioxide must be established. Due to the exchange between water and atmosphere, surface waters possess a low content of carbon dioxide, while the concentration in the groundwater may be quite high.

In the absence of oxygen, under anaerobic conditions, hydrogen sulphide can be produced by biochemical dis-integration of organic substances and by chemical processes from sulphides. This poisonous gas is characterized by a stringent odour which becomes noticeable already in small traces. It is to be eliminated by the treatment process. It should also be pointed out that sulphides oxidize under formation of aggressively acting sulphuric acid. As regards cations, mention should be made of the hydrogen ion concentration which is characterized by the pH value. The pH values of surface waters are in the neutral range while ground waters often have higher hydrogen ion concentrations and lower pH values, and thus can act aggressively.

The pH value of water is mainly specified by the concentration of free carbonic acid and hydrogen carbonates. Many metabolic changes of water depend largely on the pH value.

The anorganic composition of natural waters is characterized mainly by the rocks with which the water has reacted. The alkali and alkaline-earth minerals which are readily soluble form the major part of cation components of inland waters over a broad scope of concentration.

In general, the sodium ions outweigh the other alkali ions by more than 50 per cent. Calcium ions are adsorbed from the soil and from suspended substances of the water, so that the portion of calcium ions amounts to only approximately 10 % of the sodium ion content.

Almost all waters contain calcium and magnesium ions. They are responsible for the hardness of a given water which affects the utilization of water in many ways when exceeding certain threshold values.

The interaction of the alcali and alkaline earth cations, in general with chloride and sulphate ions, produce a salty or bitter taste of water.

In general, surface waters contain iron and manganese ions in very small concentrations only. The prescence of these elements is, however, typical for a great number of ground waters. In the presence of dissolved oxygen, iron (II) ions are readily oxidized to iron (III) oxide which subsequently precipitates as oxide hydrate with low-solubility. The absence of dissolved oxygen (groundwater) and the reaction of carbonic acid to iron containing minerals leads to a higher iron (II) ion concentrations. The iron ions can be often found in a complex compound with humic acid, partly dissolved, partly in colloidal form. These humates are very stable towards oxidation with atmospheric oxygen. Iron ions can also get into the water by way of corrosion processes. Iron ions are not harmful although they provoke an ink-like taste. The sedimentation of precipitated iron (III) oxide hydrate leads to the clogging of pipework, to which the rapid multiplication of iron bacteria is adding.

This also applies to manganese ions and iron (II) ions. Even small manganese concentrations have a negative effect on the water, and their elimination is more expensive as they are less oxidizable than iron ions. Both cations must be eliminated by water treatment.

Chloride, sulphate and hydrogen carbonate form the major part of anions contained in natural waters. Chloride ions can be found in almost all waters, and their concentrations varies very much. Due to the high solubility of chlorides, chloride ions are widely spread. Domestic and industrial waste waters can increase the content of chloride ions in a given water. This also applies to a number of other main components which have already been mentioned. Sulphate ions are also widely spread as the final product of oxidation of sulphide like minerals as well as of sulphuric organic substances. Higher contents may cause stomach and intestinal disturbances, and can do damage to concrete buildings. Concerning the negative effects on concrete factors like the density of concrete, intensity of the stagnant or flowing water, and temperature play a leading role. Reactions of carbonate stones with the dioxide dissolved in water lead to hydrogen carbonate ions. In the alcalic pH range these hydrogen carbonate ions dissociate to carbonate ions, while in the acid range, undissociated carbonic acid prevails. Water practice therefore distinguishes between free and bound carbonic acid. The establishment of an equilibrium state between these substance and the calcium ions is considered to be of great importance, in order to eliminate a possible aggressiveness of the water, and to prevent the pipework from becoming overgrown by lime precipitation.

In this connection, with waste water influx and fertilized agricultural acreage, increasing importance is attached to the addition of nitrogen and phosphor compounds with respect to the eutrophication.

Ammonia and ammonium ions are primary disintegration products of organic nitrogen compounds, e.g. hydrolysis of urea. Industrial waste waters and fertilizers are further sources of water pollution by ammonium ions. The presence of these ions is objectionable from a hygienic point of view.

Ammonium ions are oxidized to nitrate via the intermediary stage nitrite by means of micro-organisms. Like proteins, nitrate ions, as the highest oxidation stage of nitrogen during the aerobic disintegration of organic nitrogen compounds, indicate water pollutions or signalize the use of fertilizers. Although nitrate ions are comparatively harmless, nitrate is reduced to nitrite in the upper small intestine section in babies causing methaemoglobinemia which is rather dangerous. Care must therefore be taken that the excessive nitrate content is reduced during the water treatment process.

Apart from phosphorus which is organically bound, hydrogenphosphate ions are mainly found in the water. As they occur mostly in minor concentrations, a higher content is an indication for pollution, particularly introduced by fecal matter and fertilizers. Phosphorus is often the initial factor of eutrophication, in general it represents the limiting factor which is needed for the formation of biomass in waters. Already small rises in concentration may lead to mass growth of algae.

Small hydrogen phosphate concentrations are not dangerous to health. Phosphorus compounds are added repeatedly to drinking water in order to form a protective layer in the pipework.

Organic substances may have a negative influence on the water-use in various ways. Attention must be paid to poisoneous implications, deterioration of taste and surface effects. Altogether they may reduce the self-purification processes, and in extreme cases, they can stop them completely. It is quite impossible to enumerate all organic substances that contaminate waters. When considering the water load caused by waste water contents, the organic substances should hold an eminent place.

Organic water contents include in the widest sense living organisms, their metabolic products, and also inaminate substances in dissolved or suspended form. A great number of organic substances contained in a water are subject to biochemical disintegration and changes. This natural self-purification of the water is caused by the complex interaction of physical, chemical and biological processes, and leads, under certain conditions, to the mineralisation of organic substances. Water, carbon dioxide, sulphate, nitrate, and phosphate are the basic final products of these. With regard to the biochemical conversion, the organic water contents can be divided into three groups.

1. Substances which can easily be disintegrated biochemically. The organic substances of that group are mostly non-toxic, i.e. purely domestic waste water.

2. Substances which are hard to disintegrate biochemically. The substances of that group are converted only over longer periods of time, examples are cellulose waste waters, and also mineral oils.

3. Substances having a toxic effect. There is no biochemical disintegration. Chemical conversions may take place over longer intervals, a typical example are insecticides.

This roughly outlined classification must not be applied schematically. Numerous transitions are the rule. We lack knowledge about type, stability, and effect of the intermediary products formed.

The following are organic substances which have gained an important position over recent years: humic and lignine compounds, the wide spectrum of the pesticides as well as cancerogenic substances.

A number of polycyclic aromatic hydrocarbons, the cancerogenic effect of which is known, have been found in natural waters. Such substances may get into the water by means of road dust, and waste waters, and their synthesisis is also possible in the flora. They have also been found in algae and bacteria.

When disinfecting water by means of chloride, as it is often done by drinking water treatment, chloride products may be formed depending on the concentration of organic substances. Reference shall be made to the haloform compounds, which are of simple chemical structure. Chloroform is a haloform compound and its toxic effect is known. It is therefore important to learn more about the metabolic products formed during water treatment. Our knowledge on the effect of organic substances is broadened continuously. The water treatment faces new problems by the presence of harmful substances, and development of further process stages become necessary in order to supply drinking water which is clean from a hygienic point of view.

The last mentioned substances occur in water in minor concentrations as so-called trace substances, a term which is gaining ground.

II.3.6.1.2. <u>Water analysis</u>

Concentration of water compounds with the exception of a few special cases, ranges between 10^{1} and 10^{-9} g/l. The analysis of water compounds, particularly of harmful substances in the water, is therefore identical in most cases with a trace analysis. Therefore, any particularities of the water analysis have to be borne in mind when taking and preparing the sample. In the following some basic remarks shall be made.

The most exact findings of an analysis are useless unless the water sample which has been analysed is representative. Although there are hardly any ideal representative samples, any possible care should be taken not to change the properties or condition of the water sample prior to analysis.

The shorter the time between sample taking and the analysis, the more likely it is to keep any changes at a minimum. With some water compounds, particularly with gases, an analysis or at least preservation or fixing of the substances must be made in-situ, as already changes in temperature may cause changes in the water-condition. If the water analysis cannot be carried out in-situ - this could be done either in mobile laboratories or automatic stations - the water sample to be tested must be preserved in order to prevent or delay changes caused by physical, chemical or biological processes. The absence of a universal preservation substance presents problems even to the experienced analyst.

Furthermore it is of decisive importance to known whether a water investigation shall only record dissolved substances, and whether suspended matter or coarser components shall be separated prior to the test. It is for the analyst to decide whether sedimentation, decantation, filtration or centrifugation is appropriate, and whether the preparations must be enlarged, particularly when it comes to recording inorganic components by a disintegration method. Knowledge of the absorption ability of the various harmful substances of solid components and the material of the sample containers is essential, as it is known that some water compounds can be adsorbed by up to 50 % of their concentration.

Water often contains harmful substances in such minor concentrations that they can be recorded analytically only by special modern analysis methods and often even only after enrichment. The necessary concentration of various harmful substances in water requires enrichment methods earmarked for special purposes. Advantages and disadvantages of such methods are left for the experienced chemist to decide. Every enrichment method represents a decisive interference in the aqueous system to be considered when evaluating the measured values.

An exact assessment of the water quality and the necessary comparability of testing results can therefore only be achieved if all laboratories concerned apply reliable, attractive and standardized analyses methods. For this purpose a number of countries try to elaborate and recommend standard methods.

The "International Standards for Drinking Water" and the "European Standards" were set up due to the efforts of the World Health Organization (WHO). The "Selected Methods of Water Tests" have been revised by the member countries of the Council for Mutual Economic Aid (CMEA) and were published in the GDR (1). The analytical methods in this book which are based on current experience should be declared as binding for any water analysis.

In the following, problems shall be emphasized which occur in the analytical investigations of harmful substances in the water.

It is advisable to distinguish between the analytical recording of harmful inorganic and organic substances in the water, for the following reasons:

1. The number of harmful inorganic substances in the water can be surveyed but this does not apply to organic compounds.

2. Fewer new analytical problems result from the inorganic water analysis than from the analysis of harmful organic substances in the water. This has been expressed in the attempted standardization of the so-called "Selected Method for Water Tests" (1) which refers still mainly to inorganic water compounds.

Determination of inorganic water compounds

The colorimetric and photometric processes are of particular importance for the water analysis. They are preferably applied in water analysis because they can be carried out quickly and are highly sensitive to very small quantities of substances dissolved in water. The intensity of a colour which is characteristic for a given substance serves as a measure in this determination.

Colorimetric as well as photometric determination require completely clear solutions for determination. Even the slightest turbidity would result in stronger colorations. Even fibres of filter paper would cause disturbances. The basic colour of the water to be investigated must be borne in mind, too.

From the sources of error which have been pointed out, it becomes evident that thorough methodical preparations need to be made before modern physical and physico-chemical measuring methods can be applied. This does not apply to photometric methods alone. The commonly known electro-metric measuring of the pH value requires e.g. knowledge of the function, maintenance and care of the measuring electrode (glass electrode) in order to exclude very erroneous measuring results. This applies to the measuring of dissolved oxygen, too.

When it became general knowledge that harmful substances, particularly trace metal ions, were enriched via food chain causing pathogenic symptoms in human beings and animals, worldwide alarm was raised which in turn was reason to follow up the causes.

Hence, the expenditure on analytical investigations must be multiplied in order to gain new findings in this field for the protection of mankind. Bearing in mind the complexity of the task this objective cannot be achieved with the time-consuming conventional methods. Water analytics can meet these demands only if it can rely on modern measuring instruments, high labour productivity and a high sensitivity of the equipment.

Today, the atomic absorption spectroscope (AAS) presents a method which meets the demands to a large extent. It operates quickly, almost free of interferences, and is highly sensitive.

Determination of organic water compounds

Concerning the chemical analysis of organic water compounds the main problem involved is the large variety of organic water compounds, which can cause harmful implications. In addition, effects occur which are caused by the total number of organic substances found in the water. In water analytical investigations of organic substances a distinction is therefore made between sum determination methods and determination methods for individual organic substance groups or compounds.

At present, the following sum determination methods are widely applied:

1. Determination of oxygen which is needed for oxidation of organic substance in the water
   a) as bio-chemical oxygen demand (BOD)
   b) as chemical oxygen demand (COD)

2. Determination of the total organic carbon (TOC).

Each of these methods provides certain information, yet they have also a number of shortcomings. Nevertheless they continue to be applied in water analysis, because it is impossible to make a complete analysis of all individual organic water compounds. The expenditure needed would surmount any imagination, and for the major part of these substances there is no analysis method available.

Both the determination of the bio-chemical oxygen demand and the determination of the chemical oxygen demand are indirect conventional analytic methods. Only in rare cases organic water compounds are included in a complete recording. On the contrary, from the manifold experience of water practice, working instructions have been developd which render it possible to achieve optimum statements under certain stipulations, e.g. reaction time reaction temperature and reagent concentrations. Any deviation from the conditions indicated during the analysis produces results which cannot be compared. For this reason great efforts are being made to improve the conventional sum determination methods in recording the numerous organic water compounds. The parameters achieved are important approximate values when characterizing the water quality, particularly with respect to the assessment of a temporary change of the organic load. The thus achieved relative values are an important basis to assess the respective water situation. Individual substance analyses or substance group analyses can be justified only in such cases where there is a suspicion and indication of certain harmful water substances, as this is the case e.g. with industrial waste waters.

Investigations of pesticides, mineral oil, and polycyclic aromatic hydrocarbons are examples of a persistently applied analysis methodology for harmful organic substances in the water.

Even with the application of modern analyses methods, like UV, IR, fluorescent spectroscopy, and mass spectroscopy only a limited number of individual components can be ascertained in a mixture of organic substances in water which had not been separated previously. Application of mass spectrometry is said to have the highest resolution capability. One way of achieving high resolutions is by using modern chromatographic methods.

The application of chromatographic methods, particularly gas chromatography, and liquid chromatography which is still in the process of development, result in increased expenditure as it is case with all other modern analyses techniques because they imply the provision of apparatuses and trained experts.

Although it has been possible to mention only some of the most important problems which require attention and solution in the water analysis, and although such problems as routine analysis, automation with water control, and operational control were not dealt with, it has been expressed that it is up to the water analyst to make important decisions regarding the selection of the type and the number of criteria which he wants to be measured or determined in the water. He must often reduce his wish to measure everything to a degree which ensures an optimum statement combined with reasonable economic expenditure.

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Table II.3.-2: Tests Used for Characterization of Water

Esthetic	Major constituents	Trace elements	Pollutional characteristics
Taste	Calcium	Cadmium	Suspended matter
Odor	Magnesium	Chromium	Dissoved oxygen, O_2
Colour	Sodium	Cobalt	Biochemical oxygen demand, BOD
Physical	Potassium	Copper	Chemical oxygen demand, COD
Temperature	Chloride	Lead	Total organic carbon, TOC
pH	Sulfate	Nickel	
Conductivity	Nitrate	Selenium	Total organic chlorine, TOCl
	Hydrogen-carbonate	Vanadium	
Chemical		Zinc	Nitrogen
Alkalinity			Ammonia
Acidity	**Minor constituents**		Nitrate
			Nitrite
	Iron		Nitrogen (organic)
	Manganese		**Phosphorus:**
	Aluminum		Phosphate (ortho)
	Fluoride		Phosphate (poly)
			Phosphorus (organic)
			Sulfur
			Sulfide
			Sulfite
			Grease and oils
			Detergents
			Phenols
			Cyanide

II.3.6.2. Biological water quality problems

II.3.6.2.1. Water related diseases transmitted by insects or other vectors (Medical aspects)

M a l a r i a

Malaria is an acute infectious diseases caused by parasites which are transmitted by vectors, belonging to the genus Anopheles.

The incidence of illness depends on the density of vector population which is mainly influenced by the type and number of mosquito breeding places and resting sites.

Situation analysis

While malaria eradication programmes had freed about 50 per cent of the population of the originally malarious areas from the risk of malaria by 1970 during the last 10 years the situation has deteriorated in several regions, especially in southern Asia and Latin America.

Malaria is again endangering not only the health of the population but also the overall socio-economic development.

The clinical picture and transmission route are characterized by an incubation interval. It lasts on the average between 10 and 40 days depending on the parasite type. After this time the parasites are capable to occupy the erythrocytes and multiply within them. This leads to fever-fits. The interval of the fever periods depends also on the parasites type. In the further course of the illness different sexual forms of parasites develop which can multiply only within the insect vector after changing the host.

Malaria is one of the most frequent tropical diseases. Only human beings are reservoirs for the parasites. Temperature, humidity, rainfall and the number of water surfaces favourable to the breeding of the vectors are the main environmental factors affecting the disease incidence. The relationship between rainfall and mosquito breeding is of fundamental importance.

Control measures

The malaria situation in an area may vary constantly. Evaluation must be a permanent feature of any malaria control programme so that it can be revised quickly to meet the changing conditions. The defence against malaria includes vector control programmes, antimalaria treatment and additional measures applied by the community:

- prevention of man-vector contact by careful selection of building sites and house screening,
- destruction of adult mosquitos by space spraying or residual spraying of insecticides,
- destruction of mosquito larvae by larvicides,
- reduction of mosquito breeding sites using water management techniques such as filling-up ponds, draining pools, planting trees, and intermittent drying and sluicing methods,
- and mass drug administration.

Antimalarials are essential for treatment of the disease and a prophylactic measure for travellers and other populations at risk. Recently the problem of resistance has become grave and may influence the efficient control of the disease by drug treatment.

In Asia the chloroquine resistance of Plasmodium falciparum has increased. The same is true to South America and some parts of the African continent.

Schistosomiasis

Schistosomiasis is a chronic disease with local and visceral manifestations caused by many species and strains of the flukeworm Schistosoma. The epidemiology of the disease depends on the biology, ecology and distribution of the parasites, their snail intermediate host and mammalian reservoir hosts.

Situation analysis

The global prevalence has been estimated to be 200 million cases. Worldwide demand for water has resulted in the spread of schistosomiasis to new areas and the overall infection rate appears to have increased.

The WHO stated in general terms that projects for water-resources development have intensified transmission in many endemic areas during the past decade.

The clinical picture and transmission route

The clinical picture results from the life cycle of the parasite. Schistosomiasis attacks when people working or playing in water expose their bare bodies to water harbouring the microscopic larvae of the disease-cercariae. The larvae burrow through the skin and pass into the blood stream where they grow into adult parasites. The adult parasites live in blood vessels of the internal organs. Eggs work their way out of the blood vessels and into the tissue of walls of the intestine or of the bladder, and finally they are excreted via urine and stool. Some eggs are accidently carried in blood vessels to the liver or lungs where they can cause severe damage. In the absence of satisfactory arrangements for disposal of human wastes eggs may enter water bodies, develop to the larval stage (Miracidium) which pentrates into an intermediate snail host for their further development to the stage of cercaria. Fever and swelling of liver and spleen are the clinical symptoms. Later it comes to chronic diseases either of the urinary tract (Haematurie), of the gastrointestinal system (Colitis), of the respiratory tract, or of the liver.

Control measures

Left untreated the disease permanently damages the vital organs and can cause death. In its early stages it is often insidious, sapping the vitality of the victim without showing serious overt symptoms.

Use of chemotherapy

Chemotherapy reduces the output of living eggs from the patients' body and thus diminishes transmission. By killing the worms in the treated individual it enables the patient to recover from reversible lesions.

In case of some drugs, the dosage required may produce side-effects in some patients and may even be occasionally lethal. Therefore the dosage may still have to be reduced below the optimum clinical level. Niridazole and hycanthene have 80 - 90 per cent success but they were believed to be potential carcinogens. Oxamniquine-tolerance is good.

Snail control

Snail control by molluscicides is a rapid and effective means of reducing transmission.

Control by environmental modification

Permanent changes can be made that have a lower maintenance cost than other methods of control. Socio-economic development may markedly affect transmission.

Provision of domestic water supply supported by health education, reduced human contact with water results in reduced schistosomias transmission.

Health education

Human attitudes towards water need to be modified. Efforts should be directed towards the groups that are at greatest risks and most involved in transmission - usually young children.

Progress in selected national control programmes

Brazil

The Spezial Programme provides for stool survey, malacological collection and chemotherapy.

Egypt

The overall prevalence was estimated at 22 per cent of the population. At present there are three applications of molluscicides per year to all branches of main canals and to all drainage systems in the area.

Venezuela

After 35 years of control programme the general prevalence has fallen from 14 per cent at the beginning to 1.8 per cent at the 1977 evaluation.

Onchocerciasis (river blindness)

Onchocerciasis is an infestation with Onchocerca volvulus, a filarial worm. Each female lives 15 - 16 years in the human body and produces about one million larvae microfilariae annually. A free living period is followed by confinement in fibrous nodules under the skin of the scalp, ribs etc. The disease is transmitted by small blood sucking blackflies belonging to the genus of Simulium (female flies), whose enimature stages - egg to pupa - live in running water (highly oxygenated). Because of the breeding habits of its insect vector onchocerciasis is distributed in river valleys and called river blindness.

Situation Analysis

The disease is estimated to affect more than 20 million people, it is widespread throughout tropical Africa and in Guatemala, Mexico and Venezuela. Recently it had been found in Colombia and Yemen. Blindness rate varies but in hyperendemic areas more than 10 per cent of the entire population and more than 20 per cent of the adults may be blind.

Clinical manifestation

Children are generally free. Adolescents are infected. The most crippling effects of the disease appear in adults. A heavy infection is acquired only after a long period of exposure to bites by infected flies and always has serious effects on the eyes. The adult worms form more or less voluminous nodules in the subcutaneous tissue. The microfilariae (life span 2 years) are found in the epidermis where they cause itching and may give rise to characteristic patches on the skin. All parts of the eyes, alone or in combination, may suffer damage resulting in blindness. Microfilariae are found in the urinary tract and other internal organs. Onchocerciasis is not a fatal disease.

Transmission cycle

The blackflies become infected when they pierce the skin of a person affected by onchocerciasis and suck in microfilariae. After passing through three larval stages they finally become free larvae capable of infecting a human host. The time required for this development cycle under tropic conditions is about 1 week. At the end of this period the fly may transmit the infection to any person it stings. An individual must receive a considerable number of infective stings before one or several couples of adult worms can develop. In the human organism the transformation of infective larvae into adult worms is fairly rapid and the microfilariae produced by the adult worms may be found in the epidermis less than a year after a person's arrival in an area where the disease is endemic.

Control of carrier flies

Use of insecticides to kill the larvae in the rivers and water courses. To have a lasting effect, these operations should cover either the whole of one isolated focus of the disease or a territory wide enough to ensure that female flies with their enormous flight range (from 20 up to 100 km in their first days of life) will not rapidly repopulate the treated areas.

Larvae control campaigns must take long enough to ensure that the parasites disappear completely from their human hosts without any treatment. This should be supported by the use of drugs to eliminate the parasites from the remaining infected persons for a certain number of years after the interruption of the transmission of the disease. For ecological aspects of the vectors see also chapter II.4.1.

II.3.6.2.2. Water-borne diseases

Natural water in rivers and streams, in wells and lakes contains a distinctive flora and fauna, and characteristic dissolved and undissolved inorganic and organic matter. Some components of the microflora are potential pathogens and therefore hazardous to the health of the community.

The access of fecal contaminants to water may add a variety of intestinal pathogens from faeces of man, from other warm-blooded animals and cold-blooded animals (fresh water fish) at any time. Sometimes pathogenic organisms will be present in water degraded by a variety of pollutional discharges from warm-blooded animals. The most common pathogens include strains of Salmonella, Shigella, Leptospira, enteropathogenic Escherichia coli, Pasteurella, Vibrio, Myobacterium, human enteric virus, cysts of Entamoeba histolytica and hookworm larvae.

The faeces of man and the sewage wastes he creates are a major source of the pathogens in water. Monitoring sewage for pathogens is an excellent tool for determining what diseases may be prevalent in the community at the moment. Human pathogens are also found to frequent the intestinal tract of the other warm-blooded animals. Among the cold-blooded animals freshwater fish may harbour human pathogens after exposure to contaminated water or food sources and carry these organisms to clean stream recreational areas.

Salmonellosis

In humans, salmonellosis most commonly occurs as an acute gastroenteritis with diarrhea and abdominal cramps. Fever, nausea, and vomiting are frequently found symptoms. The incidence of human salmonellosis is fairly low, Salmonellae are easiest to isolate from water and to relate to the pollution. The total number of Salmonella serotypes known to be pathogenic to man exceeds several hundred and their frequency of isolation from man varies from year to year and from country to country. The survival of Salmonellae is favoured by nutrient-rich wastes and low stream temperatures.

Shigellosis (dysenteria)

The symptoms of shigellosis vary from a mild transitory diarrhea to severe prostating attacks accompanied by high temperatures, vomiting and profuse bloody stools. The disease is endemic in some areas. The incidence is highest in children under 10 years of age. Summer and early autumn are peak periods.

There are at least 32 Shigella serotypes of which S. sonnei and the subgroups of S. flexneri account for over 90 per cent of all isolates from the human population. There has been a significant number of epidemics which resulted from poor drinking water quality.

The survival is relatively short (30 min - 4 days) and is reduced by aeration, high temperature, a high total bacterial population, acid pH-range, and sunlight exposure of the water.

Leptospirosis

The disease is characterised by fever, shivers, pains in the calfs, headaches, eczema at body and thigh. The disease goes through several phases with symptoms of the central nervous system and of the kidney and liver. The course of the disease is more serious when a jaundice occurres.

Leptospirosis is caused by bacteriae, which generally gain access to the blood stream through skin abrasions or mucous membranes to produce acute infections.

The annual incidence rate is less than 1 per cent. Outbreaks occur almost exclusively during the recreational season. Leptospirosis is transmissible to man from various domestic animals, animal pests and wild animals.

Leptospira enters recreational streams and lakes through direct urination of infected animals or from drainage of adjacent livestock pasture land. Transmission takes place by bathing or wading in and during occupational activities associated with polluted water. Leptospira is frequently found in slow-moving streams, canals, creeks and small lakes. Leptospira were found to survive longest in water with a pH-range between 7.0 to 7.2, low stream temperature, low salinity and a low density and composition of the micro-biological population.

Enteropathogenic Escherichia coli (E. coli)

Various serotypes frequently cause a gastroenteritis characterized by a profuse watery diarrhea with little mucus and no blood, nausea, prostration, and dehydration with a general abscence of fever. The serious diarrhea among children under 5 years, particularly of newborn children, is frequently a result of the etiologic agent, enteropathogenic E. coli.

Most urinary infections of adults are caused by pathogenic E. coli.

Water-borne enteropathogenic E. coli outbreaks have been caused by contaminated drinking water. They are also present in streams and lakes polluted with warm-blooded animal faces.

Survival of E. coli is influenced by some environmental factors including water pH, water temperature, sunlight exposure, bacterial adsorption with sedimentation and predation.

Tularemia

The tularemia pathogen usually gains access to the blood stream through skin abrasions or mucus membranes. It produces chills and fever, swollen lymph nodes and a general prostrate condition.

The infectious agent has been named Pasteurella tularense. It is not considered to be transmitted directly from man to man. The disease is spread via drinking water contaminated by the urine, faeces and dead bodies of numerous species of rodents and wild rabbits. Outbreaks have occurred by drinking water from contaminated springs, creeks, wells, and streams.

Survival of P. tularensis in water is protected by low temperature and addition of nutrients. It can last 20 to 60 days.

Cholera (Subtypes: El Tor biotype and Inaba and Og)

The bacterial pathogen Vibrio cholerae can produce a serious, acute intestinal disease that is characterized by sudden diarrhea with profuse, watery stools, vomiting, suppression of urine, rapid dehydratation, fall of blood pressure, subnormal temperature, and complete collapse. Death may occur within few hours unless prompt medical treatment is given to the patient.

The spread of cholera may be through polluted drinking water. It reflects a lack of safe water supplies and inadequate sanitation. Survival of vibrios relates sharply to various chemical, biological and physical characteristics of a given water body.

Human viruses

Increasing attention is paid to the contamination of water and soil by viruses. Viruses pathogenic to man are isolated from rivers, lakes and treated waters.

More than 100 different types are known to be excreted in faeces. More than 1,000,000 infectious particles may be excreted per gram of faeces by infected persons, whether a disease breaks out or not.

Viruses may survive for several months in the aquatic environment and may resist conventional water and wastewater treatment procedures including chlorination.

Polioviruses and Coxsackievirus B

Polioviruses can cause serious nervous system disease, depending on the virulence of the virus and age of the host. At present in countries where live poliovirus vaccine is widely used, the excreted polioviruses are usually vaccine derived. In developing countries in which wild polioviruses are prevalent infections are typically acquired very early in life when the risk of serious diesease is lowest. Most older children and mothers are thus immune. In these areas waterborne spread undoubtedly occurs and may be a significant factor in the process of natural immunisation. As sanitation has improved in some of these areas, paralytic poliomyelitis has increased, presumable because infections are delayed to older age.

Coxsackieviruses B can cause pleurodynia and pericarditis (chiefly in older persons), serious and fatal myocarditis in infants and congenital defects (chiefly cardiac) in infants born by mothers experiencing infection during pregnancy.

Hepatitis A virus

The agent of type A is now classified and called Enterovirus 72. The virus is excreted in faeces over a relatively extended period and is often spread via water. The large outbreak in Delhi 1955/56 was caused by gross sewage contamination of the water supply. The agent withstands levels of residual chlorine which kill most of the other enteric pathogens.

Gastroenteritis viruses of the Norwalk type

These viruses have recently be recognized and have been identified as the cause of large outbreaks of gastroenteritis via the water route.

Reoviruses and rotaviruses

Rotaviruses have been found to be the major pathogen of nonbacterial infantile diarrhoea throughout the world. Infection with these viruses may also account to some extend for malabsorption and malnutrition in infants especially in developing countries.

Incidence rates vary but in general rotavirus infection accounts for 20 - 40 per cent of diarrhoea cases in children up to five years of age who seek treatment in hospitals in tropical countries (40 - 60 per cent in temperate countries). Mortality rates in developing countries are not known. Rotavirus infection spreads by faecal-oral transmission. The true role of water thereby has still to be studied.

Adenoviruses

Adenoviruses are abundantly shed in faeces. Well documented instances of water-borne spread have been the epidemics of pharyngo-conjunctival fever associated with swimming pools.

For a wide range of viruses of human origin doses of ingested viruses as low as a single infectous unit are capable of inducing infection in man. Therefore the presence of even a small number of enteric viruses in a large volume of drinking water should be prevented. Enteric viruses may be spread from one person to another via faecally contaminated water and via contaminated food.

Wastewater: Large numbers of viruses of human origin are normally found in wastewaters. Virus concentration is estimated to about 10 infectious units per 1 ml raw wastewater.

Drinking water: Sources of drinking water can be heavily contaminated. The mean concentration may reach 1 infectious unit per 1 l.

Seawater: Many communities discharge their wastes into estuaries, bays, harbours and other coastal waters. They adsorb to solids and accumulate in sediments. These viruses may still pose a public health problem when using the estuarine water for recreational activities.

Soil and crops: There is an increasing worldwide interest in the re-use of wastewater for irrigation. Health hazards where application by wastewater sprinkler-irrigation is practised might be the result of virus dissemination by aerosols.

Groundwater: Soil composition and structure affect virus movement. The higher the clay content of the soil the greater is the expected removal. Fissured limestone aquifers under shallow soil allow virus to travel over great distances and can present serious groundwater contamination.

Virus monitoring

During an outbreak caused by enteric viruses, sampling should be aimed at determining whether the water supply is contributing to the spread of disease. Samples of raw water, fully treated water and tap water should be examined. The monitoring of wastewater may provide an early indication of viral infections in the community.

Routine monitoring of drinking water would be justified when large urban centres use heavily polluted rivers that carry a significant flow of sewage as source of raw water.

Recommendations

1. Drinking water should be free from human enteric viruses.

2. In the light of greater resistance of many enteric viruses to disinfection, emphasis should be given to effective disinfection of drinking water.

3. Further research is necessary into the health risks associated with viruses in the aquatic environment.

II.3.6.2.3. Parasitic Protozoa

Amebiasis

Amebiasis is a disease of the large intestine that may vary from mild abdominal discomfort involving diarrhea alternating with constipation or a chronic dysentery with mucus and blood. The infectious agent is the parasitic protozoan Entamoeba histolytica. The major source of transmission is fecal contamination of drinking water supplies.

E. histolytica is usually found at low density levels in sewage but cysts of E. h. may persist at least 150 days in good quality water.

Giardiasis

Giardiasis is characterized by a variety of intestinal symptoms, most frequently in a protracted intermittent diarrhea. The causative organism, the intestinal flagellated protozoan, Giardia lamblia is worldwide in distribution.

Amoebic meningoencephalitis

Amoebic meningoencephalitis is a fatal disease of the central nervous system caused by a pathogenic strain of the Ameba Naegleri Gruberi. The onset of symptoms begins about 4 to 7 days after water contact. Death ensues 4 to 5 days later.

The disease is associated with swimming and diving in the warm waters of small lakes and polluted estuary.

Naegleri species are among the numerous free living amebas common in soil, sewage and surface water. This pathogen is more suited to parasitic existence in nature, the aquatic host is not yet known.

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II.3.6.2.4. International standards for drinking water

International standards were first published by WHO in 1958 as an aid to the improvement of water quality and treatment. The third edition was issued in 1973. The standards have been adopted in whole or in part by a number of countries as a basis for the formulation of national standards. Since new methods are constantly being introduced and developed it is expected that standards will be revised from time to time.

The fourth edition is finished by WHO and announced for distribution to 1983. Therefore this chapter is to be supplemented at the time of gaining access to this publication.

II.3.6.2.5. Health aspects of chemical water pollution including treatment agents and processes for drinking water

L e a d

Lead can be regarded as non-essential element in health terms. Lead is dangerous to health especially for the foetus, the young infant and individuals with certain medical conditions such as increased water intake or renal dialysis.

Under some circumstances the concentration of lead in drinking water may become extremely high and severe clinical lead poisening can occur. Lead may disturb haem synthesis, may result in mild anaemia with a small reduction in blood haemoglobin. The effects of lead on the nervous system vary with the duration and intensity of exposure. Lead encephalopathy has the following major features: dullness, restlessness, irritability, headaches, muscular tremor, hallucination and loss of memory and ability to concentrate. Young children with elevated lead exposure may experience subtle neurological damage with mental disorders in their development.

Distribution of lead levels in water occur when aggressive waters get in contact with lead or when a high percentage of lead pipes is used. Lead stearate may also be extracted from plasticized PVC pipes.

Nitrates, Nitrites and Nitrosamines

Nitrates are normal constituents of drinking water, being derived for the most part from drainage from cultivated and fertilizer-treated land and from sewage effluent. During the last years there is a tendency towards an overall increase. Nitrate levels of water supplies in rural areas tended to show a greater variability than in urban areas.

Nitrites are not usually present in drinking water, but where bacterial contamination was present reduction of nitrate could occur.

Preformed nitrosamines are rarely found in drinking water in significant amounts.

Acute effects of increased nitrate concentrations may be seen in infants, hence babies and pregnant women form the vulnerable groups. The greatest clinical hazard is methaemoglobinaemia, especially in bottle-fed babies under six months of age.

Arsenic

Arsenic in water is usually found in the form of arsenate or arsenite. The natural concentration of arsenic in drinking water varies in different areas. Drinking water can be severely contaminated through industrial operations, especially by wastewater from factories producing arsenic sulfide and leaching of arsenic from coal preparations wastes and fly ash from coal-fired power plants.

Acute effects caused by the ingestion of inorganic arsenic compounds are profund gastrointestinal damage resulting in severe vomiting and diarrhoea, moscular cramps, facial oedema and cardiac abnormalities. Subacute and long-term exposure effects mainly involve the respiratory, gastrointestinal, cardiovascular, nervous and haematopoietic systems. Exposure to arsenic has been associated with the induction of cancer.

Arsenic is mainly transported in the environment by water. In oxygenated water, arsenic usually occurs as arsenate but under reducing conditions, for instance in deep well waters arsenite predominates. Drinking water ordinarily contains a few micrograms of arsenic per litre, mainly in the form of inorganic compounds.

Mercury

The major source is the natural degassing of the earth's crust. Anthropogenic sources are probably less than natural sources. Several human activities account for substantial releases into the environment. They include the burning of fossil fuel, the production of steel, cement, and phosphate and the smelting of metals from their sulfide ore. Mercury once released in water undergoes metabolic changes. The methylation of inorganic mercury in the sediments of lakes, rivers, and other waterways and in the oceans is a key step in the transport of mercury in aquatic food chains. Accumulation of methylmercury in aquatic food chains represents a potential hazard to man by consumption of certain species of oceanic fish, and of fish or shellfish from contaminated waters.

The symptoms of poisoning by methylmercury are paraesthesia, constriction of the visual fields, impairment of hearing and ataxia. The effects are usually irreversible. The foetus is more sensitive to methylmercury than the adult.

The intake of mercury from drinking water by the general population is probably very low in comparison with intake from diet. Wellwater and drinking water from reservoirs have very low mercury levels. However drinking water in certain areas exposed to mineralized mercury deposits or from rivers in heavily industrialized areas may have high values and mercury is not removed during the drinking water treatment.

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II.3.6.2.6. Treatment agents and processes for drinking water

Water treatment is defined as including everything done to the water from the time it enters a reservoir, canal or pipe until it flows from the customer's tap.

Disinfection is one of the treatment processes to make water potable and safe for human consumption. A number of the halogenated substances found in drinking water have been identified as being formed by chlorination. Chloroform is formed by a special reaction of chlorine with resorcinol and humic substances. If bromides and jodides are present any type of trihalo-methane may be formed.

Humic substances have been identified as a major precursor of chlorinated compounds in drinking water.

Chlorine dioxide produces nonvolatile halogenated compounds but no chloroform.

Ozone is a strong oxidant and disinfectant. The chemical reactions of ozone are complex and depend upon pH. Ozone is capable of splitting water molecules to produce hydroxyl free radicals and thus of forming hydroperoxide, peroxyacids and epoxides. Chlorine dioxide is an unstable gas which must be generated at the time of use. It can produce epoxides and other oxidation products.

Substances intentionally added by treatment involve sodium ions and chlorides for water softening and aluminium, iron and silicate ions as coagulants in order to remove turbidity and organic matter from polluted water.

Health effects

Chloroform would be regarded as an indicator of other possibly dangerous matter which may have been formed by chlorination. Chloroform is considered to be a carcinogen but it is not mutagenic, whereas 5-chloro-uracil also formed by chlorination is a genetic mimic of thymine and mutagenic in bacteria.

Ozone produces epoxides and peroxyacids, which assume impertance as toxical substances.

Chlorine dioxide, the chlorite ion ClO_2 has been questioned as a potential cause of methaemoglobinaemia.

A high intake of sodim may have adverse effects on artificially fed babies and induce hypernatraemia, nephropathy and encephalopathy and it interferes with the management of patients suffering from congestive cardiac failure or hypertension.

II.3.6.3. Water treatment

A water treatment plant is generally required when opening new water resources, especiall if a central drinking water supply system is to be set up. In water treatment, efficient processes, which minimize the cost, with high operational safety must be applied in order to make different raw waters (river water, impounded reservoir water, ground-water, infiltration water) with different loads (different in number and harmful effects of water substances) suitable for human consumption and industrial use according to the quality standards. Many different processes and plants are available for solving these problems. Thorough preliminary investigations in laboratories and on a semi-technical and large-scale technical basis are required before taking the difficult decision which treatment system to apply. In this respect the raw water quality plays an important role. It is affected by:

- the development in the region concerned,
- new products, raw materials and processes which result in a new sewage composition,
- the construction of primary clarification plants which reduce the number of substances with high biodegradability in surface waters but do not affect salts and substances with low biodegradability,
- the ever growing percentage of sewage in waters; even if the sewage is treated, the natural cycle is short-circuited and the self-purification processes cannot gain full effect,
- the growing use of chemical products in agriculture and forestry which end up in the waters by the action of wind and rainwash,
- more efficient analytical methods which resulted in
  - the discovery of an ever growing number of organic and inorganic micro-contaminations and their harmful effects,
  - the knowledge that even water treatment can cause micro-contaminations, e.g. if chlorine is used for oxidation and disinfection and halogen compounds are formed.

The comprehensive problems arising in water treatment can only be solved by interdisciplinary cooperation between specialists of water treatment engineering, construction engineering, hydrochemistry, hydrobiology, hygiene and hydrology.

The following water substances are of importance to the water treatment process:

substance	significant substances	
gases in solution	oxygen, carbon dioxid, chlorine, ozone	
suspended substances	coarse and colloid-disperse suspensions	
dissolved substances	<u>inorganic substances</u> anions: NO_3, NH_4 cations: Ca, Mg, Fe, Mn	<u>organic substances</u> anionic, non-ionic, surfactants, polycyclic, aromatic hydrocarbons, lignosulphonic acid, humic acid

Water treatment includes physical, chemical and biological processes. In the water treatment technique, these processes are purposefully combined with regard to the given raw water or pure water quality.

Stages of drinking water treatment

stages	process	plant
coarse water purification	gas exchange	tubular checker cascades pressure ventilation
	screening	screens, travelling screens, micro-screens
	flocculation/ precipitation	classical settling plants sludge contact plants

fine purification	filtration	open high-rate filters, pressure filters
very fine purification and disinfection	adsorption oxidation biological process	high-rate filters reaction vessels low-rate filter, biofilter
special process: recharge of groundwater	comprehensive biological and physical treatment	low-rate filters, sand and plant basins

In addition, each water treatment plant requires sludge treatment and chemical dressing facilities. When making water suitable for industrial purposes (process water, cooling or boiler feeding water) the processes mentioned are applied either individually or in their combination with and without additional processes such as softening, desalting, oil separation and hardnesss stabilization.

The plants are set up on the basis of experiments or dimension standards.

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II.3.6.4. Sewage treatment

A central water supply requires sewerage and sewage plants. Sewage treatment is concerned with cleaning sewage conducted away from residences and industrial establishments in such a way as to exclude any toxic effects on human beings and animals especially with regard to hygienic requirements. Furthermore, it is important to extract valuable substances from the sewage (e.g. fermentation gas, humus and metals, in case of industrial waste) and to recycle the water, if there is a water shortage in the area concerned.

The amount of waste water arising varies very much according to the water supply available. In general, it amounts to some 200 litres per inhabitant daily in Central Europe. By increasing the amount of water available and improving the living standard, this figure rises continuously. The waste water composition varies very much, too. IMHOFF (1) gives the following average figures for domestic sewage:

per inhabitant	mineral substances	organic substances in g	total of inhabit.	BOD_5
settleable suspended substances	10	30	40	20
non-settleable suspended substances	5	10	15	10
dissolved substances	75	50	125	30
total	90	80	180	60

Industrial sewage contains many different substances, the number of which is continuously rising due to industrial growth. Sewage treatment basically aims to protect the waters from pollution.

The purification method to be applied depends on the quality of the water of the receiving body of water. Therefore an investigation of the selfpurification capacity is required. Self-purification is the capacity of waters to dispose themselves of organics by means of the microorganisms contained in the water. It is important, especially in densely populated areas, not to disturb the self-purification capacity by discharging too many sewage substances in a water. This includes both organic sewage substances and toxic metal ions and compounds. The conditions of a water may be controlled by means of biological longitudinal quality sections or sewage load schemes (1). As a result, the sewage plant and the degree of purification required can be determined. Municipal sewage undergoes different stages of purification:

stage 1: sewage clarification, primary treatment

stage 2: biological sewage treatment

stage 3: elimination of phosphate and nitrogen compounds

Furthermore, there are numerous processes for industrial sewage treatment (e.g. degreasing, detoxification, neutralization). With regard to the processess used the municipal sewage plants are grouped into the actual sewage treatment and the sludge treatment including fermentation gas isolation and processing.

The sedimentation basins form the heart of the primary treatment. If the sewage remains for about 90 minutes in these basins, the settleable substances are reduced by some 90 per cent. Other sewage substances are not sufficiently removed, therefore the process is, in general, followed by biological sewage treatment. As compared to self-purification in waters these purification processes are induced by microorganisms and bacteria and take place in man-made facilities within a short period of time. The BOD_5 reduction amounts to about 90 to 95 per cent and is effected in biofiltration and activated sludge plants. When activated sludge plants are used, oxygen in form of air is artificially introduced into the activated sludge tanks in order to activate the microorganisms. Many different methods are used. The 3rd stage of purification is especially used in areas where downstream waters (in particular lakes and impounding reservoirs) are used for drinking water supply. The organic sludge from the primary treatment and the activated sludge tanks is putrefied in digestion tanks. During this process the sludge decreases considerably in volume and fermentation gas is formed. After the sludge has been putrefied, it is used in agriculture.

The present knowledge enables us to clean nearly any sewage type by technological processes, although this may entail considerable expenditure. Expenditure grows exponentially with the degree of purification needed.

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II.3.6.5. Assessment and monitoring of water resources and demands

Fundamentals of systematizing water resources and water demands

The assessment and monitoring of water resources and demands includes all those - scientific, technical, economic and administrativ - activities the purpose of which is to explore and evaluate the quantitative and qualitative characteristics of water resources and demands. On the basis of a comparison between them, we have to analyze the conditions of equilibrium between water supply and demand and to decide on the necessary monitoring in each case.

Water resources and demands and the maintenance of equilibriums of water balances can only be correctly assessed if socioeconomic evaluations are included in the interpretation of demands and supplies and in balance studies. As the central issue of the rational natural resource management, methodological conditions must be created for assessing all of the essential natural and economic factors and their interrelations.

The currently changing economic importance of water and natural environment results from the social, economic and technological progress e.g. from

- the general increase of the intensity of water use
- changes in the types and levels of water demand
- extended connections between economic and natural processes and, as to the latter
- the occurrence of adverse tendencies
- the need for continuous monitoring including protection of water resources in regions with high intensity of water and land use (1, 3).

Water is present in almost all components of both, the natural and the economic-technological processes whose development is controlled or influenced by it in close interrelation - extending both in time and space - with other factors. Any control of water in any of the sub-systems - either hydrology or water use - will have an impact on the other side as well.

For proper interpretation and consideration of the manifold appearance and role played by water in the framework of water resources assessment the following tasks have to be solved:

1. A system of assessing and evaluating the countries hydrogeographic endowments, water resources and waterrelated services has to be developed with view to the interest of the whole society and the national economy.

2. A system of impact assessment has to be compiled in which the human activities modifying the hydrogeographic endowment and hydrological processes are summarized and differentiated at the same time according to the aspects of balancing demands and supplies.

3. Scenario-oriented water resources assessments that enables the decisionmaker to evaluate the benficial impact of his decisions.

<u>Socio-economic evaluation of the hydrogeographical endowments and water-related implications of interest</u>

Fig. II.3.-12 describes groups of socio-economic interest and evaluation possibilities relating to the utility and hazardousness of hydrogeographic endowments and to water management. In addition types of climatic impacts are given.

It is important to study the connection between water management and national economy and the intersectorial relations of water management. It includes the necessity to assess and evaluate all

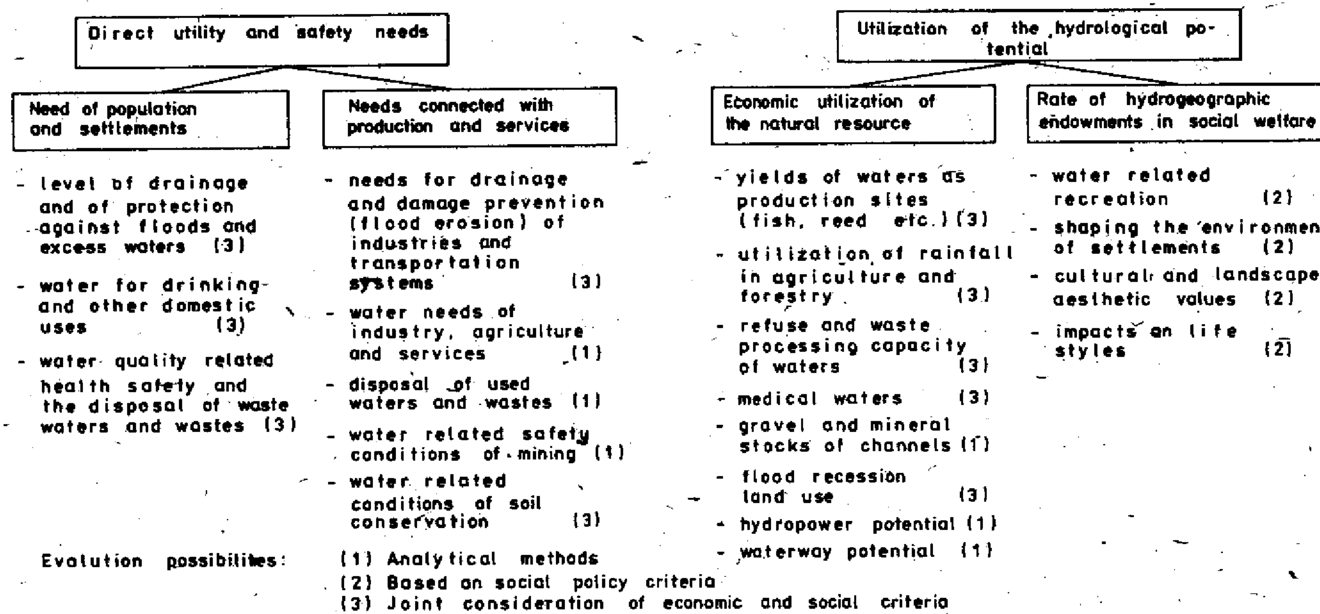

Fig.: II.3.-12
Groups of socio-economic interest and types of climatic impacts relating to hydrogeographic endowments and to water management (after Orlóci-Szesztay 1981)

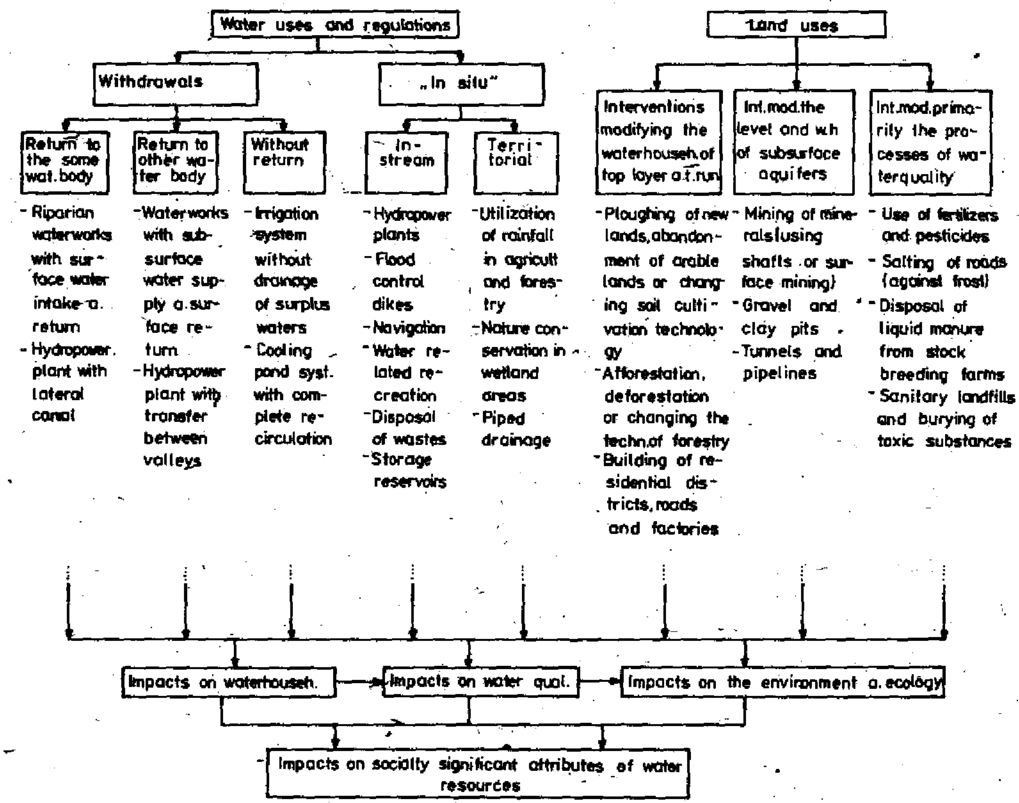

Fig. II.3.-13 IMPACT OF HUMAN ACTIVITIES ON HYDROLOGICAL PROCESSES AND THEIR FEEDBACKS ON SOCIETY
(Structural scheme with indicative examples; Orlóci-Szesztay 1981)

human activities affecting the environment and hydrological processes of the region or country, independently of the administrative or economic sector which will perform, control and plan the activity.

Fig. II.3.-13 shows the impacts of water and land use activities upon water balance, water quality, aquatic environment, economy and society. This grouping underlines that the most important human economic activities modifying the endowments and the hydrological processes do not figure, in general, among water use activities but rather among land use activities.

The most considerable changes which have taken place in the recent past in the field of water quality, water balance and aquatic environment were mainly caused by

- pollution sources associated with some types of land use (waste disposal, burying of toxic substances, application of fertilizers, disposal of liquid manure from stock breeding farms; etc.)
- activities of mineral mining (soft coal, bauxite; etc.)
- changes in the technology of soil cultivation (farming on large fields, pedological consequences of mechanized cultivation, increase of tillage depth etc.) (1, 2, 3).

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