Chapter 2

WATER AND ITS FUNCTION IN SOCIAL SYSTEMS

2.1 CATEGORIES OF WATER UTILIZATION

Water use includes all individual and collective activities of human society which affect water resources and change their quality and quantity. The beneficial utilization of water depends, as does its natural functions, on the water properties. Water uses include

(a) in-stream (navigation, hydropower generation etc.) and on-site (ponding etc.) uses, without withdrawing water from the resources,

(b) water withdrawal, i.e. diversion of water from the surface or groundwater resource

- local, i.e. on-site use in the neighbourhood of the resource,
- collective mass use by means of complicated supply, distribution and drainage (sewerage) networks.

The method of water use and distribution depends especially on the degree of development and organization of the social system. It becomes systematic as a consequence of agricultural, social and industrial development, gradually creating more extensive and complicated networks for water conveyance, distribution, use and drainage.

From the beginning water has been the basic need and precondition of human existence, but gradually it has also become a raw material which has been turned into a means of development in itself. An efficient water use in an organized society is managed by means of licences and concessions. Generally, no licence is required for non-organized small-scale water withdrawals and in-stream uses, especially individual, on-site washing, bathing etc., which is considered as a general use of water (Tab. 2.1).

Water supply includes all organized activities for the use of withdrawn water. Its purpose is to ensure the necessary water quantity of the required quality at the requested place in terms demanded by water users, i.e. by the

(a) population (municipal and rural demand),

(b) agriculture and forestry,

(c) industry and infrastructure (especially energetics and transport).

The functions of water can be categorized as natural and social i.e. water demands - in-stream, on-site uses and withdrawals. The relevant categories of water demands have a characteristic impact on water quality and quantity (Tab. 2.2).

TABLE 2.1

I Natural functions	II In-stream uses	III Withdrawals	
Soil moisture conservation, soil transformation	Groundwater table & soil moisture regulation HC	Drinking & cooking HQ	Urban and rural water requirements
Transport of biogeoelements	Waste transport & disposal HV, LQ, HP	Other domestic uses HQ, HP	
Biological functions	Fish and wildlife SR	Public uses HQ, HP	
Regulatory climatic functions	General utilization LC	Heating, steam power, boiling, climatization HP, HC	
Aesthetic enjoyment	Water transport public & goods	Processing HP	Industrial & infrastructural water requirements
Other environmental functions	Hydropower generation HV, LQ, LC	Cooling HV, LQ, HC	
	Recreation & water sports LC	Mining & hydraulic transport HP, LQ	
		Other industrial & agricultural uses LV	
		Irrigation HV, HC	Agricultural water requirements
		Processing HP	
		Livestock & poultry breeding HP	
		Fish & water fowl breeding	

Categorization of natural function of water and of water utilization. Abbreviations:

Consumptive use	HC - high	LC - low
Quality requirements	HQ - high	LQ - low
Impact on water quality	HP - high	LP - low
Volume requirements	HV - high	LV - low
High space requirements	SR - high	

2.2 WATER REQUIREMENTS AND WATER CONSUMPTION

The term water resources refers to the exploitable surface water and groundwater in a defined water management unit (e.g. catchment basin). Because of their periodic annual replenishment, the most suitable unit for their definition is the m^3 per year (dry, wet, mean) which leaves the relevant water management unit. The static interpretation is the amount of surface water or groundwater (m^3) within the water resource.

TABLE 2.2

Quantity	Water quality (properties)	Other factors
Volume	physical	water table width
(m^3)	chemical	riverbed width
Discharge	biochemical	channel depth
($m^3.s^{-1}$)	biological	groundwater table depth
Runoff ($m^3.s^{-1}$)	(physiological)	water table fluctuation
- total yearly	bacteriological	velocity of flow
- seasonal	radiological	sediment transport
- average	organoleptic	icebound regime
- minimum	(sensorial)	accessibility of shores
- maximum	psychic	utilization of the riverside
- minimum	medical (sanitary)	shore vegetation
- fluctuation		bank protection

Basic parameters of water occurrence and factors determining the possibilities of water utilization.

The amount of water diverted from the water resource in a given period is the water withdrawal ($m^3.s^{-1}$, m^3 per year). The water withdrawal is the input of the water supply system. The quantity of water returned to water resources after use (with a changed quality) is return flow. It forms the output from the supply and drainage system. The quality of the return flow is inferior in comparison with the quality of the withdrawal due to the processes of water use.

A given water requirement is the amount of water which is necessary for the undisturbed course of any natural or technological process. It includes water consumption (consumed flow), i.e. the difference between water withdrawal and the net return flow, that consists of consumptive use and losses. The consumptive use of water represents that part of the water consumption which, in the course of the natural or technological production process, becomes an integrated part of

(a) the product or

(b) the by-product or the waste matter.

The water loss represents that part of the water requirement, water consumption, water withdrawal or water resource which returns into the hydrologic cycle in the form of seepage, leakage, percolation, evaporation etc. Losses may be either

(a) productive, i.e. indispensable for the course of the production process (e.g. evapotranspiration for the agricultural production), or

(b) non-productive, a part of which is

- inevitable, i.e. losses which cannot be supressed in a rational or economic way, and the rest is
- the wastage, i.e. water that escapes from the resource, the supply system or the production process without being used.

The consumptive use (consumed flow) can be expressed by the following simple equation

$$C = W - (F - B) \qquad (l.s^{-1},\ m^3.s^{-1}) \qquad (2.1)$$

C - water consumption

W - water withdrawal

(F - B) - net return flow

F - return flow at the end of the sewerage system

B - undesired inflow into the sewerage system (drainage of groundwater, conveyed springs etc.)

From the foregoing terminological description it also follows that

$$C = \sum_{i=1}^{3} U_i + \sum_{i=1}^{4} \Delta_i \qquad (l.s^{-1},\ m^3) \qquad (2.2)$$

U_1 - consumptive use by means of the product (e.g. fruit)

U_2 - consumptive use by means of the by-product (e.g. trunk, branches, leaves)

U_3 - consumptive use by means of the waste material (e.g. weeds)

Δ_1 - productive losses (e.g. evapotranspiration) (Δ_p)

Δ_2 - non-productive inevitable losses (e.g. leaching, seepage in irrigation piping) (Δ_i)

Δ_3 - non-productive evitable losses caused by the state of system or by the insufficient technology e.g. seepage and evaporation in irrigation canals) (Δ_e)

Δ_4 - non-productive wastage caused by wrong operation (Δ_w)

The return flow, except for the undesired inflow into the system, which was used in the production processes and occasionally also water which was necessary to dilute this water from the production processes with the aim of achieving the desired water quality of the waste water before returning it into the water resources can be expressed as follows

$$F = F_1 (+ F_2) + B \qquad (l.s^{-1}, m^3) \qquad (2.3)$$

F - return flow (diluted waste water)

F_1 - waste water from the production process

F_2 - dilution water

B - undesired or occassional inflow into the system.

The consumptive use of water entering the product is thus the key constituent of water requirements. The quality of the product depends on the technology, which also determines the consumptive use of the water entering the by-product or the waste material, upon which the economy of the production also depends. The economy of the production process, from the water management point of view, can be improved by decreasing the amount of waste material, or by decreasing the size of the product, if possible.

From the point of view of the balance of water resources and needs the most important problems are the changes in the water quality and also the place of discharge of the return flow and the return of losses into the water resource (Fig. 2.1). Consequently losses can be classified in the following way:

(a) return losses which enter

- the same water resource from which the water was withdrawn Δ_{r1}
- other water resources in the same catchment basin Δ_{r2}
- water resources in some other catchment basin Δ_{r3}

(b) non-returnable losses (evaporation and evapotranspiration) which escape from the relevant resources and enter the atmosphere. Δ_n

Water consumption, defined as the difference between the withdrawal and the return flow, can thus be expressed as follows:

$$C = \sum_{i=1}^{3} U_i + \sum_{i=1}^{3} \Delta_{ri} + \Delta_n \qquad (l.s^{-1}, m^3) \qquad (2.4)$$

The mathematical definition of water consumption varies according to the water balance of different systems. From the point of view of the particular water resource, the water consumption C_r does not contain the first return loss - the return loss entering the water resource from which the water was withdrawn

$$C_r = \sum_{i=1}^{3} U_i + \sum_{i=2}^{3} \Delta_{ri} + \Delta_n \qquad (l.s^{-1}, m^3) \qquad (2.5)$$

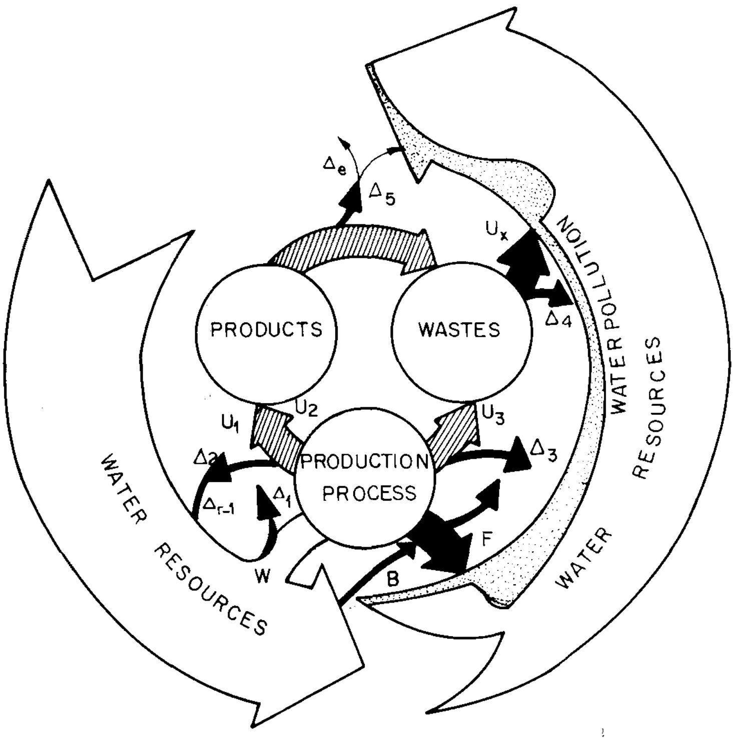


Fig. 2.1. Schematic representation of water use after physical diversion during an industrial or biological process, which results in production, accompanied by consumptive use by the product U_1, by-product U_2 and waste material U_3 as well as by water losses $\Delta_{1-n}t$. The use of the product, resulting in its change into wastes and the decomposition of wastes can lead to water recovery U_x: Waste waters from the production process as well as the leached wastes cause water pollution.

From the point of view of the catchment basin, the value of the water consumption C_b includes neither the first nor the second return loss

$$C_b = \sum_{i=1}^{3} U_i + \Delta_{r3} + \Delta_n \qquad (l.s^{-1}, m^3) \qquad (2.6)$$

From the point of view of the hydrologic cycle, the water consumption C_c is formed only by the consumptive use:

$$C_c = \sum_{i=1}^{3} U_i \qquad (l.s^{-1}, m^3) \qquad (2.7)$$

The consumptive use is

(a) short-term (transient, lasting several days or years)

(b) long-term (also from the point of view of geological time) or lasting (stable chemical links).

Therefore

$$C_c = \sum_{i=1}^{3} U_i \cdot f_i \cdot t^{-\frac{1}{n_i}} \qquad (2.8)$$

f_{1-3} - variables

t - time

n_{1-3} - coefficients of the time effect

The mentioned general process not only occurs in the course of the municipal, rural, industrial and agricultural water supply, but also during the natural production process of different biological functions and during the development of cellular matter.

Waste matter from the natural and technological processes, also formed by the utilization of the products, usually disintegrates and releases water which also enters the hydrologic cycle. The growing of cellular matter such as wood, peat, coal, oil etc. causes long-term consumptive use. The increase in quantity of cellular matter may theoretically result in the consumption of all the water resources available in a certain area, but the homeostasis, i.e. the dacay of cellular matter etc. limits this undesired development.

Water requirements and water consumption in the course of agricultural and industrial processes may be distinguished as

(a) minimum,
(b) optimum,
(c) non-economic.

Minimum water requirements or minimum water consumption during a specific production process can be achieved under special conditions, e.g. in laboratories. The water-saving technology which achieves the minimum water requirements may differ from the technology which achieves the minimum consumption of water, and both can be unsuitable from the point of view of the total production cost.

An optimum water requirement and optimum water consumption are attained when the product of desired quality is produced under the conditions of minimum total social effort, i.e. from the point of view of the national economy, by applying an optimum technology. The non-economic water requirements and water consumption exceed this optimum value.

Low losses and optimum water consumption are indispensable preconditions for any efficient industrial technology. Low water requirements depend primarily on the degree of recirculation. An efficient water resources management policy is based on a decrease in water consumption and an improvement in the waste water quality.

The prevailing, productive, non-returnable losses form the indispensable precondition for the efficiency of agricultural processes. The efficiency of water utilization in agriculture can be followed up, first, on the basis of the ratio of the productive evapotranspiration and non-productive losses

$$x_e = \frac{\Delta_1}{\sum_{i=2}^{4} \Delta i} \qquad (2.9)$$

and, second, on the basis of the ratio of the consumptive use entering the product and the consumptive use of the other cellular matter:

$$x_u = \frac{U_1}{U_2 + U_3} \qquad (2.10)$$

2.3 IN-STREAM AND ON SITE WATER USE

On-site uses, such as soil moisture conservation, flood loss management, the maintenance of swamps, dambos and other wetlands are closely interconnected with the natural functions of water. In-stream uses such as hydroelectric power generation, navigation, recreation, water sports and waste disposal are closely connected with the social functions of water. In-stream uses are characterized by insignificant consumption. The only water consumption mainly consists of losses. For these uses the volume of water is important, and not the discharges. The applicable unit of measurement is m^3. The water consumption consists of return losses Δ_{r3} which enter other catchment basins and non-returnable losses $_n$:

$$W = V + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \qquad (m^3) \qquad (2.11)$$

$$C = \int_0^t \Delta_{r3} \quad \int_0^t \Delta_n \qquad (m^3) \qquad (2.12)$$

V - volume of water necessary for the in-stream or on-site use of water

W - total water requirements

These equations can be extended to express the natural functions of water in the following way

$$W = V + \int_0^t (U_1 + U_2 + U_3) + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \ (m^3) \qquad (2.13)$$

$$C = \int_0^t (U_1 + U_2 + U_3) + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \ (m^3) \qquad (2.14)$$

Losses due to the in-stream use of water should be considered as the difference between the values before use and the values of losses occuring during in-stream use. These losses consist of leakage and conveyance into other catchment basins as a result of beneficial operation, and of evaporation and seepage due to the extended water table and enlarged river channel, when necessary for the relevant use.

2.3.1 Waste Disposal

The hydrosphere is used for waste disposal and enables, primarily in water courses, the transportation and removal of wastes. Waste waters and waste materials which are conveyed into surface and groundwater bodies enter the natural processes of the generation of water quality, enabled by the thermal, chemical and kinetic energy of water, by the thermal and chemical energy of the riverbed, and by the thermal and luminous energy from the environment of this system.

TABLE 2.3

Physical	Processes Chemical	Biochemical, biological
warming - cooling	neutralization	aerobic disintegration
disintegration	oxidation	anaerobic disintegration
mixing, dispersion	reduction	assimilation
dillution	coagulation	dissimilation
sedimentation		biological filtration
adsorption,desorption		adsorption of low organism
washing away		by higher ones
oxygen exchange		decay of living matter
oxygen diffusion		

Categorization of basic processes of water self-purification.

The erosion, fall-out and waste disposal results in an increase in bed load, suspended load and dissolved matter along the water course. But a complex of other physical, chemical, biochemical, biological and bacteriological processes as a manifestation of the homeostasis in nature further changes the water quality. Self-purification processes accompany the water pollution process in the course of sediment transport and erosion processes, resulting in the destruction and melting of erosion products, waste material and fall-out (Tab. 2.3, Fig. 2.2).

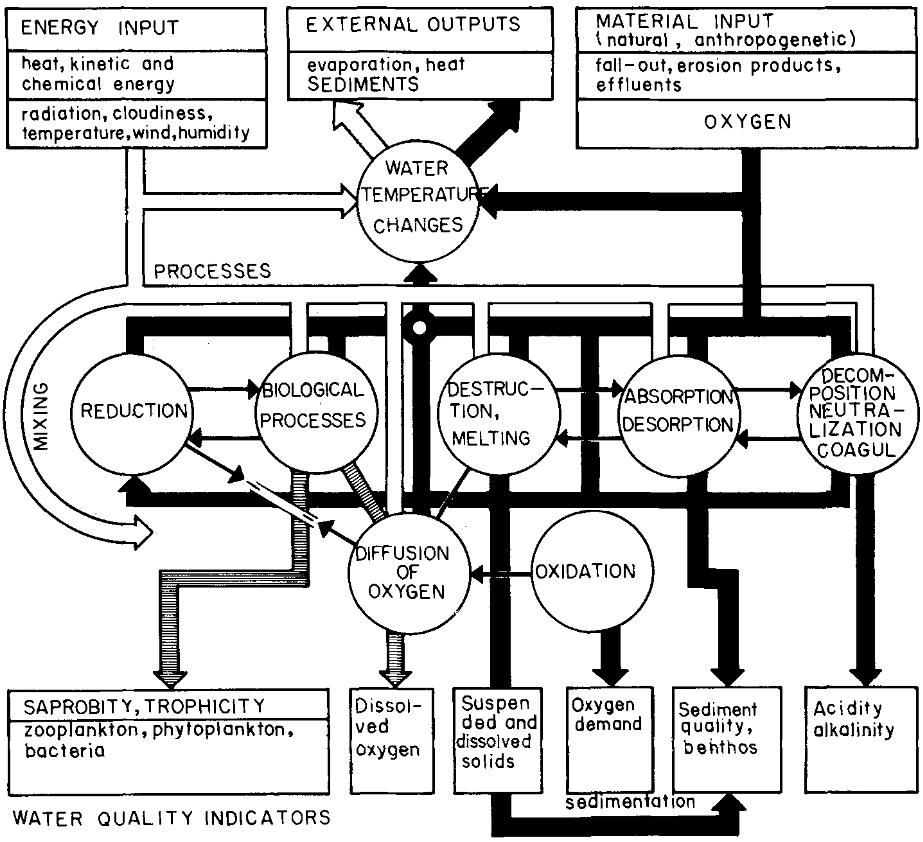


Fig. 2.2. Schematic representation of water self-purification process, a subsystem of biogeochemical cycles. Input consists of matter and energy, output is formed especially by sediments, benthos, water vapour, heat and water quality, characterized by a set of indicators.

The indispensable precondition for the destruction and transport of this material is a surplus of kinetic energy (see Chapter 1.6). A lack of kinetic energy causes sedimentation, the most basic of the physical self-purification processes. Sedimentation is governed by Stokes's law:

$$w = 0,01 \; . \; \sqrt[n]{\frac{d \; . \; (\gamma - 1000)}{a}} \qquad (m.s^{-1}) \qquad (2.15)$$

w – vertical sedimentation rate $(m.s^{-1})$

d – diameter of sedimented particles (m)

γ – unit mass of particles $(kg.m^{-3})$

a, n – coefficients of size, depending on the diameter of particles

$d < 0.002$ m – $n = 1.2$; $a = 0.07$

$d > 0.002$ m – $n = 2$; $a = 0.064$

Sedimentation is accompanied by coagulation and melting and results in a decrease in the content of chemical matter in water and in an increase in the sediment volume.

Another basic process of self-purification to occur as a result of the contact of water with the air is the acceptance and diffusion of oxygen. Oxygen enters water not only from the air, but also as a product of the biological processes of plants and of phytoplankton. The content of dissolved oxygen in water is limited by temperature, barometric pressure and by the content of oxygen in the air above the water surface:

$$c_b = 0,373 \cdot \frac{B}{H} \qquad (g.m^{-3}) \qquad (2.16)$$

c_b – dissolved oxygen balance in water, when the oxygen content in the air equals 21%

B – barometric pressure (Pa)

H – Henry's constant, depending on water temperature (Pa– Tab. 2.4).

TABLE 2.4

Temperature (^{o}C)	0	5	10	15	20	25	30
H (10^3Pa)	2.57	2.95	3.32	3.69	4.05	4.44	4.81

Henry's constant H for the determination of the oxygen content in water in dependence on water temperature.

Chemical processes of self-purification, decomposition, coagulation, neutralization as well as absorption and desorption consume the dissolved oxygen, resulting in an oxygen deficiency, expressed by the difference between the actual oxygen content and the oxygen balance which corresponds to the relevant temperature.

The rate of the natural liquidation of this deficiency depends expressly on the temperature, and on the current velocity and depth of the water. Streeter-Phelps (1925) prove that the process of reaeration is quicker in shallow river beds with a higher current velocity:

$$\frac{D_t}{dt} = K_2 \cdot D_t$$

$$D_t = D_o \cdot e^{-K_2 T} \qquad (2.17)$$

$$K_2 = 1,047^{(T-20)} \cdot K_{2(20)}$$

D_c - oxygen deficiency at the beginning of the reaeration $(g.m^{-3})$

D_t - oxygen deficiency during the reaeration $(g.m^{-3})$

t - time (d)

K_2 - coefficient of reaeration at the temperature T (d^{-1})

$K_{2(20)}$ - coefficient of reaeration at the temperature of 20°C (Tab. 2.5) (d^{-1})

T - temperature (°C)

TABLE 2.5

Type of water course	Coefficient K_2 (d^{-1})
Shallow brook	0.50-0.80
River:	
velocity of flow>0.5 $m.s^{-1}$	0.30-0.80
<0.5 $m.s^{-1}$	0.20-0.25
Reservoir	0.05-0.15

Coefficient of reaeration K_2 at 20°C according to Zhukov (1964)

In the course of physical and chemical processes the suspended matter is swallowed down by water organisms. The absorption of this matter into the nutrition chains of destruents, consumers and producers changes the living organic matter into anorganic matter and vice-versa. Most of the mentioned processes are aerobic, i.e. require the presence of oxygen. Anaerobic processes, i.e. processes without oxygen, occur especially near the bottom, in the mud.

The rate of the biochemical decomposition of organic matter depends on the enzymatic systems of the relevant organisms, i.e. their ability to decompose certain organic matter, or on their ability to create such systems after a short period of adaptation. The process of biochemical oxygen demand during biochemical decomposition can be described by the equation of kinetics of the 1st order

$$L_t = L_o.(1 - e^{-K_1 t}) \qquad (g.m^{-3}) \qquad (2.18)$$

$$K_1 = 1,047 (T -20) . K_{1(20)}$$

L_t - biochemical oxygen demand in the period t (BOD) $(g.m^{-3})$

L_o - the initial value of the biochemical oxygen demand $(g.m^{-3})$

K_1 - coefficient of deoxygenation at the temperature T (d^{-1})

$K_{1(20)}$ - coefficient of deoxygenation at 20°C (d^{-1})

The change in the value of the oxygen deficiency during the processes of reaeration and deoxygenation, i.e. during the biochemical disintegration of organic matter, can be expressed by the differential equation

$$\frac{dD'_t}{dt} = k_d \cdot L_t - K_2 \cdot D'_t$$

$$D'_t = \frac{K_1 \cdot L_o}{K_2 - K_1} \cdot (e^{-K_1 t} - e^{-K_2 t}) + D_o \cdot e^{-K_2 t} \qquad (2.19)$$

D'_t - oxygen deficiency at the moment t for the simultaneous reaeration and biochemical disintegration of organic matter.

The decrease in the oxygen concentration and the increase in its deficiency as a consequence of the simultaneous reaeration and deoxygenation lasts until the critical moment at which the rate of the biochemical oxygen demand and the rate of the oxygen input become equal. After reaching this critical moment, the concentration of oxygen rises to the original value, following the curve of the oxygen content. If the concentration falls below the critical limit, the organisms die (Fig. 2.3).

The beginning of this process is accompanied by a decrease in the variety of biological species, characteristic for the degree of oligosaprobity, due to qualitative and quantitative changes in the littoral and benthic fauna, and in the plankton and fish species.

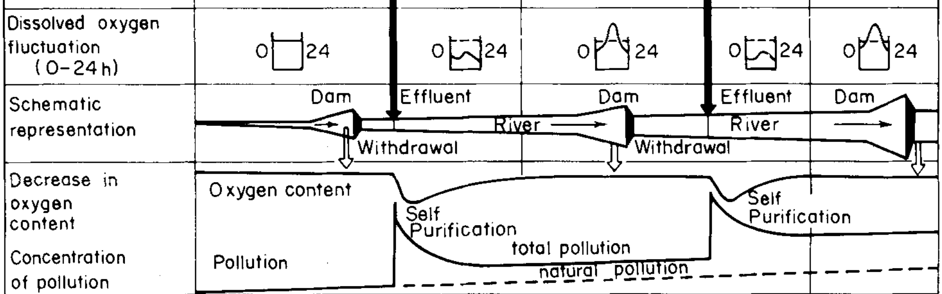
Consequent changes in the water properties include the change in its colour, the decrease in turbidity, the decrease in the oxygen content, especially in the hypolimnion of reservoirs etc. A further surplus of nutriment supply then causes a deterioration in the water quality as a result of the development of some organic species (Anabaena, aphanizomenon flos-aquae etc.). The result of their disintegration after extinction is an exhausted oxygen content.

Water pollution which occurs at the same place changes in time and depends on the pollution regime, the relevant discharges, the morphological factors of the river channel, the climatological factors and the coherent course of the self-purification processes.

Water pollution can also be defined as a complex of processes whose result limits or makes impossible the beneficial use of water. The natural pollution of surface water is generally low - the water quality varying within the limits of the 1st or 2nd class of water quality - unless it is severely deteriorated by higher quantities of suspended matter (especially by washed soil particles after heavy rainfall, or by high contents of salts as a result of salt plugs in the river channel or high evaporation - Tab. 1.24).

The character of water pollution which is caused by the industrial, agricultural and other activities of human society and by urban effluents differs from

Feasible for	Drinking water supply	Water supply	Economically unfeasible for drinking water	Water supply for industry	Economically unfeasible for drinking water
Section	A	B_1	C_1	B_2	C_2



Characteristics	Without anthro — pogenetic pollution	Primary pollution	Secondary pollution	Primary pollution	Secondary pollution
Prevailing pollution	Natural	Waste waters in high concentration	Natural waste waters in low concentration	See B_1	See C_1
Prevailing processes	Physical	Heterotrophic biological oxidation, reduction, destruction of dead organic matter	Autotrophic, biological production of living matter	See B_1	See C_1
Saprobity	Oligo-saprobity β-mesosaprobity	Meso-Poly-saprobity	β-mesosaprobity α-mesosaprobity	See B_1	See C_1

Fig. 2.3. Schematic representation of the course of the main characteristics of the self-purification process in the longitudinal profile of a water course with a cascade of reservoirs. Both natural and anthropogenetic pollution increases downstream. A characteristic curve of oxygen demand appears below the effluents.

that of natural pollution. This pollution considerably changes the chemical and biological properties of the water, and also the type of the relevant chemical, biological and other processes. A decrease in water quality below the 3rd or 4th class is a frequent consequence as well as eutrophosation, resulting in a decrease in the biological quality of water, reaching a maximum of β- mesosaprobity (Tab. 1.24, 1.30).

The self-purification process, like any manifestation of natural homeostasis, is stimulated by feedbacks. But the state to which the system returns is not necessarily the same as the original one. The lack of energy or matter makes such a return impossible and results in an irreparable change in water quality which may limit or exclude its beneficial use. The acceptable quality of water in a water resource can be expressed for any particular use by a set of indices.

All these chemical, biochemical and biological processes occur in the environment of the running water. Suspended matter and floating debris of both natural and anthropogenetic origin are carried away by tracting forces of the flowing water. Solid wastes in the stream channel and the bed load start to move when the drag forces exceed the friction forces. The balance of these forces is expressed by the equation

$$F_s \cdot \gamma \cdot g \cdot \frac{v_o^2}{2g} = V_s \cdot \gamma_m \cdot f \cdot g \qquad (2.20)$$

F_s – surface of the particle under the action of drag forces (m^2)

γ – unit mass of water ($kg.m^{-3}$)

v_o – bottom current velocity ($m.s^{-1}$)

V_s – volume of solid waste/sediment particle (m^3)

γ_m – unit mass of the particle ($kg.m^{-3}$)

f – coefficient of friction

g – gravitational constant ($m.s^{-2}$)

The current velocity, the size and shape of the particles of natural and anthropogenetic origin as well as their unit mass is not uniform throughout the cross section. For practical reasons the beginning of the motion of a significant quantity of sediments is important, which depends on a critical velocity corresponding to a critical discharge at which the above equilibrium (Eq. 2.20) is disturbed. The critical bottom current velocity which characterizes the start of the motion can be derived from the above equation as follows

$$v_c = \left[\frac{2g \cdot d_e \cdot (\gamma_m - \gamma) \cdot f}{\gamma}\right]^{\frac{1}{2}} \qquad (2.21)$$

v_c – critical bottom current velocity, characterizing the start of the sediment motion

$d_c = \frac{V_s}{F_s}$ – characteristic effective size of the particles

The discharge corresponding to this critical bottom current velocity in the conditions of most sustained river beds is often the discharge exceeded 50% of the time, i.e. Q_{180d}.

The water quality due to the course of sediment movement and the dilution of waste waters depends on the discharge but in direct relationship with:

(a) soil-erodibility rate, dependent on precipitation, and

(b) soil-solubility rate, dependent on the intensity of the surface runoff,

(c) geological, soil and soil surface factors incl. the type of the vegetative canopy, its state and season,

(d) hydrometeorological, seasonal and purely random influences, e.g. the changes in water temperature, the intensity of solar radiation, the intensity of the longitudinal mixing which determine the whirling and transport of sediments and wastes as well as the course of natural processes of self-purification,

(e) anthropogenetic activities, i.e. the pollution regime.

The pollution regime depends on the type of polluters in question, which may be

(a) accidental (pollution from pipelines, transport vehicles and their freight, breakdowns etc.),

(b) systematic

- spot pollution (point pollution), i.e. pollution from communities, localities, townships, towns, industrial and agricultural estates, infrastructure, sanitary, school, recreational and other facilities,
- areal pollution, i.e. washed soils and fertilizers, pesticides, dumps etc.

In addition to this organic and anorganic pollution may be distinguished, the first being mostly better coped with during natural processes.

Spot pollution, with the exception of dumps, occurs immediately. Areal pollution, which may also include pollution from dumps, is generally delayed and depends on the rainfall, and on the overland and groundwater flow occurrence. In this connection the relevant delay may depend on meteorological factors, but may also appear almost independently.

Water pollution which occurs at the same place changes, therefore, in time. The water quality in surface courses which results from the pollution and natural self-purification processes is a function of space and time

$$q_{1-n} = f\,(Q\ ,\ x\ ,\ y\ ,\ z\ ,\ t) \qquad (2.22)$$

q_{1-n} - water quality indicators $(g.m^{-3})$

Q - discharge $(m^3.s^{-1})$

$x,y,z,$ - coordinates : x - distance in the longitudinal profile (from the point of pollution) (m)

y - location in the cross section of the river bed (m)

z - depth of the sampling (m)

t - time (date,hour)

Under a simplified approach primarily in the proximity of the sources of pollution the concentration of diluted matter can be considered as a representative factor of the water quality:

$$q_1 = a + \frac{b}{Q} \qquad (g.m^{-3}) \qquad (2.23)$$

q_1 - total concentration of dilluted matters in water

Q - discharge ($m^3.s^{-1}$)

a - concentration of the basic natural pollution, often independent of the discharge ($g.m^{-3}$)

b - pollution (input of wastes) ($g.s^{-1}$)

In many practical cases pollution grows with discharges and the degree of dependence of the concentration of pollution on discharges is linear

$$q_2 = a + d \cdot Q \qquad (g.m^{-3}) \qquad (2.24)$$

or bilogarithmic

$$\log q_2 = \log a + d \cdot \log Q \qquad (2.25)$$

The changes of the organic pollution indicator, i.e. of the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD), can be expressed by the regression formula

$$q_3 = q_b + \frac{A}{Q} + \frac{B}{Q} \cdot 10^{-K_1 t} \qquad (g.m^{-3}) \qquad (2.26)$$

q_3 - biochemical or chemical oxygen demand

q_b - basic value of the biochemical or chemical oxygen demand, dependent on the characteristic of the catchment basin ($g.m^{-3}$)

A - organic pollution, non-degradable by self-purification processes ($g.s^{-1}$)

B - organic pollution, degradable by self-purification processes ($g.s^{-1}$)

K_1 - coefficient of deoxygenation (d^{-1})

t - regression time, i.e. the time of advancement of the pollution from the sources of pollution to the analysed profile, depending indirectly on the discharge

$$t = \frac{r}{Q^m} \qquad (d)$$

r , m - coefficient of the pollution advancement

Suspended matter and the bacteria (coli) can be quantified by the equation

$$q_4 = a + \frac{b}{Q} + d \cdot Q \qquad (g.m^{-3},\ pc.m^{-3}) \qquad (2.27)$$

a - quantity of suspended matter or bacterium coli from waste waters ($g.s^{-1}, pc.m^{-3}$)

The changing inputs of the self-purification process and its changing intensity result in the changing intensity of the pollution and in variations in its concentration. The change in concentration may often be expressed by the equation

$$q_i = a + \frac{\beta \cdot b}{Q} \qquad (g.m^3) \qquad (2.28)$$

q_i - concentration of dilluted matter in the profile i

a - concentration of the basic natural pollution, independent of the discharge (g.m^3)

b - concentration of the spot pollution, changing with the discharge (g.m^3)

Q - discharge ($m^3.s^{-1}$)

β - reduction coefficient $\beta = f\,(x\,,\,Q\,,\,T\,,\,h\,,\,v)$, depending on the distance x from the source of pollution, discharge Q, water temperature T, average water depth h in the river channel, flow velocity v.

On the basis of the foregoing formula the probable deviation of concentration at the same place for one single source of pollution is as follows

$$\varrho_i = \varrho_o + (\,c_Q + c + c_b\,)\,.\,\beta^{-2}\,.\,b^{-2}\,.\,Q^2 \qquad (g.m^{-3}) \qquad (2.29)$$

ϱ_i - deviation of concentration in the profile i

ϱ_o - deviation of the basic pollution (g.m^{-3})

c_Q , c_β , c_b - coefficient of the variation of the discharge, of the reduction coefficient and of the spot pollution

The hydrometeorological and anthropogenetic inputs of the self-purification system are matter and energy. The output is not only the water quality and sediments, but also evaporation and external temperature, i.e. factors which influence the microclimate.

2.3.2 Inland Water Transport

Navigable or canalized water courses including reservoirs and canals form an infrastructure for the transportation of goods and passengers (public, occasional transport including recreation). The current importance of inland water transport is primarily a result of its energy and manpower saving technology, especially with regard to its role in conveying individual types of cargo, which is mainly general, liquid, bulk, heavy, spacious and containerized, such as grain, fodder, timber, cellulose, stone, gravel, sand, building materials, ore, coal and coke, oil and oil products, chemical products, fertilizers and piece goods.

European waterways can be classified into six classes depending on the size and capacity of goods-carrying inland-waterway vessels (Tab. 2.6). The parameters of waterways are derived from the size of the typical motor cargo vessel

TABLE 2.6

Class	Capacity (t)	Class	Capacity (t)
I.	250 - 400	IV.	1000 - 1500
II.	400 - 600	V.	1500 - 3000
III.	650 - 1000	VI.	> 3000

Classification of European waterways.

and motor-driven tug. Two categories can be distinguished on the basis of the biggest vessel

(a) European - vessel E (82 . 11.4 m)

(b) Local - vessel L (41 . 5.7 m)

The admissible draught on a canalized water course depends on the water stage:

$$T = H_g - H_d - M \qquad (m) \qquad (2.30)$$

T - admissible draught of the vessel (m)

H_g - gauged water stage (m)

H_d - difference between the maximum draught and the gauged water stage (m)

M - margin - safety distance between the vessel bottom and the channel bottom

In the case of inland waterways with a fluctuating water table, the draught characteristic corresponds to the draught secured during 240 days in a hydrologically mean year.

The network of inland waterways includes

(a) river channels (natural, improved - trained, canalized)

(b) canals (artificial water courses).

The basic parameters of these waterways, i.e. those which determine the carrying capacity, include the breadth and depth of the fairway, the corresponding minimum size of the cross section, and the velocity of the flow. The other main dimensions determine the fluency, methods of operation, speed and safety of transport.

The criteria for an assessment of the minimum dimensions are as follows (Fig. 2.4):

(a) minimum breadth of the fairway along straight stretches (at the level of bottom of the typical vessel):

$$B = 2\,b + 2\,b' + b'' \qquad (m) \qquad (2.31)$$

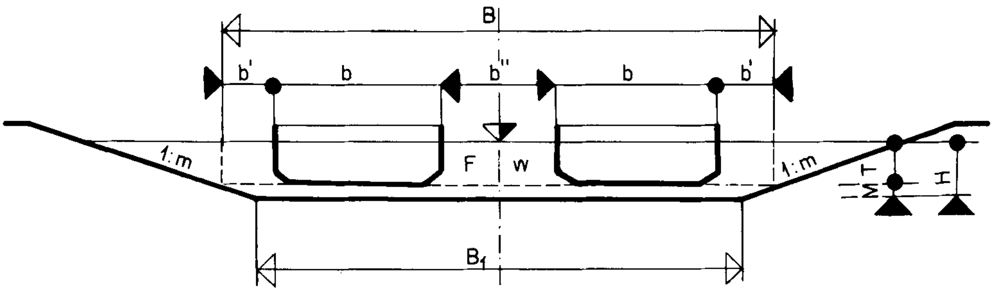


Fig. 2.4. Schematic cross section of an inland waterway. The relevant parameters are to be derived from the parameters of the typical vessel.

B - minimum breadth of the fairway

b - vessel width

b' - board space

b''- space between vessels

(b) minimum breadth of the fairway in a curved stretch

$B' = B + e$ (m) (2.32)

e - extension in curves

$c = \frac{L^2}{2R} - \frac{A}{R}$

L - overall length of the typical vessel formation

R - perimeter of the curve

A - coefficient of the extension ($= \frac{L^2}{2}$) (m^2)

(c) minimum depth of the fairway

$H = T + M$ (m) (2.33)

T - draught of the typical vessel

M - margin - safety distance between the vessel bottom and the channel bottom (0.3 - 0.5 m)

(d) minimum cross section, limited by the water level

$F = n_p . p . r . T . b$

n_p - hydraulic characteristic of the waterway $n_p = \frac{F}{f} = 5\text{-}7$

f - cross section of the typical vessel

p - number of vessels coupled side-by-side

r - reduction coefficient: two-way stretch $r = 1$
one-way stretch $r = 0.6$
waterway tunnel $r = 0.5$

(e) admissible velocity of the flow

$$v_{max} = \frac{Q}{F + \Delta F - p \cdot b \cdot T} \quad (m.s^{-1}) \qquad (2.34)$$

Δ - enlargement of the minimum cross section corresponding to the discharge Q

v_{max} - velocity of flow

The design speed of vessels should be

$$w = 0.55 \cdot \sqrt{g \cdot H} \qquad (2.35)$$

The velocity of flow is limited by the following equations

$$v = 0.5 \cdot w \text{ , i.e. } v = 0.275 \cdot \sqrt{g \cdot H} \qquad (2.36)$$

but also by $v \leq v_{max}$

The flow velocity not only determines the speed when loaded (10 to 400 km per day), but also the operation capability and manoeuvrability of vessels and articulated formations, as well as the necessary energy input and fuel consumption. The required speed of vessels in relation to the channel cross section influences the backflow and thus the erosion rate.

(f) routing of the fairway:

The routing of the fairway including its extension in curves determines the speed, fluency, safety, method of operation and the energy consumption of the inland water transport. The straight route is most suitable: two limits exist for the value of the perimeter:

- the minimum perimeter, securing fluent and safe operation without any significant restrictions,
- the exceptionally acceptable perimeter, requiring limited speed and thus reducing the fluency of operation (Tab. 2.7).

The exceptionally acceptable perimeter has to be used in built-up areas, deep narrow valleys and natural river beds.

Secondary characteristics of water courses which have an impact on the course and safety of transport operation, the operation time and period, interruptions to operation, its restriction to some 220 to 340 days a year and the different technical measures employed include

- flood occurrence

- periods of low discharges in non-canalized rivers
- ice-bound regime
- meteorological factors, especially fog and strong wind occurrence
- maintenance, repair and reconstruction work, especially in the case of one-way stretches
- technologically unsuitable and obsolete constructions, such as locks and weirs.

The freight turnover of a waterway depends on the stretch with the lowest freight capacity, i.e. on the locks in the case of double-way canals. The capacity of a one-way canal is generally smaller than that of the lock. The freight turnover of the lock can be expressed by the formula

$$K_d = \left(\frac{24}{t_n} - n_d \right) . m . d . W . \frac{a}{b} . \frac{t}{24} \quad \text{(t per year)} \qquad (2.37)$$

t_n - duration of the operation cycle (lockage) (hours)

n_d - number of vessels per day

d - duration of the transport season (days)

m - number of simultaneously locked vessels

W - carrying capacity of one vessel (medium) (t)

a - coefficient of capacity utilization (0.7-0.9)

b - coefficient of the uneven utilization of the waterway (1.25-1.75)

t - average number of operating hours per day (12-24 h)

The volume of water needed for one lockage is

$$V_1 = F . h \pm W = s . d . h \pm W \quad (m^3) \qquad (2.38)$$

and for the slant walls of the lock

$$V_1 = (s + 2 h . tg\delta) . d . h \pm W \quad (m^3)$$

V_1 - volume of water needed for one lockage (m^3)

b - lock width (m)

a - lock length (m)

h - head (m)

δ - slope of the lock walls (^{o})

The plus sign before the value of the carrying capacity is used for the passage upstream, because water in the lock has to be replaced after its departure from the lock. The minus sign is used for the passage downstream. When technical measures safeguard reciprocal lockage in both directions, only 50% of the volume is needed

$$V_2 = \frac{1}{2} \cdot V_1$$

and, therefore for practical cases

$$V = k \cdot a \cdot b \cdot h \qquad (m^3) \qquad (2.39)$$

k - coefficient of operation coordination (1 k 0.5)

The freight turnover in a complicated network of inland waterways has to be expressed by a more complex formula

$$K_a = \frac{\eta \cdot d \cdot t \cdot m_s \cdot W_s \cdot (w_m + w_n)}{2 \cdot (p_m - p_n) \cdot t_1 + 2\, p_n \cdot t_2} \qquad \text{(t per year)} \qquad (2.40)$$

η - coefficient of the uneven utilization of the waterway throughout the year

$m_s \cdot W_s$ - annual average of the carrying capacity of simultaneously locked vessels

w_m , w_n - utilization of the carrying capacity in either direction (%)

p_m , p_n - percentage of vessels in either direction

$p_m + p_n = 100\%$, $p_m - p_n > 0$

t_1 - duration of one lockage if lockage in the same direction follows $(= 2 . \sum_{i=1}^{6} t_i - t_3 - t_6)$ (hours)

t_2 - duration of one lockage if lockage in different direction follows $(= \sum_{i=1}^{5} t_i$ - Tab. 2.7)

Bearing this in mind, the annual water requirement for a lock is

$$R_a = \frac{2 \cdot K_a \cdot (p_n \cdot V_2 + /p_m + p_n/ \cdot V_1)}{m_s \cdot W_s \cdot (w_m + w_n)} \qquad (m^3 \text{ per year}) \qquad (2.41)$$

The operation of locks is an inherently in-stream use, but using water in this way results in a loss of its potential energy both in the passage upstream and in the passage downstream:

$$J_u = h \cdot (a \cdot b \cdot h + W) \cdot \gamma \qquad \text{(kgm)} \qquad (2.42)$$

$$J_d = h \cdot (a \cdot b \cdot h - W) \cdot \gamma \qquad \text{(kgm)}$$

J_u - loss of potential energy in the passage upstream

J_d - loss of potential energy in the passage downstream

γ - unit mass of water (kg.m^{-3})

The passage upstream decreases the energy consumption (i.e. also fuel consumption), the reverse operation of locks for the passage downstream has no effect on fuel consumption.

TABLE 2.7

Symbol	Operation	Duration (s)	Velocity (m.s^{-1})
t_1 t_5	drift in drift out $t_{1(5)} = \frac{L_k + (5-10).B_k}{r}$	see formula	r_1=0.6-1 r_5=0.8-2.2
t_2	opening and closing the upper gate	60-120	
t_4	opening and closing the lower gate	60-120	
t_3 t_6	filling the lock emptying the lock $t_{3(6)} = \frac{h}{v}$	300-900	v=0.02-0.06

Duration of one operation cycle of a navigation lock with two-way traffic. Symbols are in text.

The water requirements for inland navigation are determined by the size of the largest lock, i.e. in the case of unified horizontal dimensions by the volume of the lock with the highest head incl. relevant water losses. These water requirements can be reduced by

(a) two grouped locks
(b) water-saving tanks
(c) pumping
(d) vessel lifts, canal inclines, water slopes.

The first two technical measures reduce the water requirements and simultaneously increase the duration of lockage. Pumping and mechanical lifting equipment can shorten this operation, but, unless a counterweight is used, this is energy-demanding.

By grouping two locks, i.e. by emptying one lock into another, water requirements can be reduced by 50%. During routine operation of grouped locks, the duration of the lockage is shortened by closing the valve before equalizing the water levels, thus increasing the water requirements to the average value

$$R_a = 0{,}53 \cdot k \cdot a \cdot b \cdot h \qquad (m^3) \qquad (2.43)$$

k - coefficient of the operation coordination $(1 > k > 0.5)$

The effect of water-saving tanks on reducing water requirements depends on their size, number and technical arrangement (Tab. 2.8). The water requirements of a lock with water-saving tanks of the same size

$$R_s = \left[1 - \frac{n}{n + 1 + x + \frac{2}{y}}\right] . a . b . h \qquad (m^3) \qquad (2.44)$$

n – number of water-saving tanks

$x = \frac{a.b}{U}$ – ratio of the size of the lock to the size of the tank

$y = \frac{h_n}{h_o}$ – ratio of the water strata h_n for particular tanks and of the difference of water tables h_o reached at the moment of the commencement of filling up from the next tank for time-saving reasons

TABLE 2.8

Number of reservoirs	Full levelling of water tables ($y = \infty$)		Partial levelling of water tables ($y = 10$)	
	requirements $V_s : V_o$	Ratio of duration $t_s : t_o$	requirements $V_s : V_o$	duration $t_s : t_o$
1	0.666	1.225	0.687	1.145
2	0.5	1.414	0.523	1.276
3	0.4	1.581	0.423	1.395
4	0.333	1.732	0.355	1.505

Decrease in water requirements and the extension in duration of one operation cycle of a navigation lock with water-saving reservoirs, their area being equal to that of the lock.

The following formula can be derived for the duration of the filling up of the lock with water-saving tanks

$$t_s = t_o . \frac{1}{\sqrt{n + 1 + x + \frac{2}{y}}} . \frac{n}{1 + x} . \left[\sqrt{1 + x + \frac{1}{4}} - \frac{1}{2}\right] + \sqrt{1 + x + \frac{2}{y}} \qquad (hrs) \qquad (2.45)$$

t_o – duration of the filling up of the lock without water-saving tanks (hrs)

Water requirements for lockage restrict other in-stream uses, e.g. for hydropower generation, and should only be considered when the natural supply by river discharges is not sufficient. Water losses of navigation operation are caused by

(a) leakage of gates and valves

(b) seepage of the bottom and the banks of the canal

(c) evaporation from the free water surface and the increased evapotranspiration from banks affected by the impounded water.

The losses through the leakage of gates and valves depend on their construction, type of seal and technological state as well as on the lockage frequency. Their value fluctuates between 3 and 5 $l.s^{-1}$ for 1 m of head for locks 12 m wide. Higher values correspond to a higher frequency of lockage.

Inland water transport does not make any important requirements on water quality, except recreational passenger transport, whose success is closely interconnected with the quality of water. Water pollution from inland navigation is mainly caused by the liquid fuels used in vessels, chemical products incl. hydrocarbons and other dangerous substances transported as cargo, solid wastes, degassing, washing and ballast water, but especially by accidental spillage during loading, unloading and transloading.

2.3.3 Water Power Utilization

The potential energy of water can be converted into pressure energy by concentrating the head and discharge and into kinetic energy by passing the concentrated discharge through water engines. The value of the electric energy generated from this kinetic energy reaches

$$N = \frac{\eta . \gamma . Q . H}{102} = 9.81 . Q . H \quad \text{(kW)} \qquad (2.46)$$

Q - discharge ($m^3.s^{-1}$)

H - net head (without intake losses) (m)

η - coefficient of efficiency (turbine, gears, generator)

γ - unit mass of water ($kg.m^{-3}$)

N - power generated (kW)

To extract the maximum power and energy at the optimum cost the design criteria focus on the choice of the location, design discharge and head, lay-out, size and number of units etc. by suitable numerical techniques. This approach embodies an optimization of the power output/cost-benefit ratio etc. on the basis of a realistic operation of the plant, in the framework of the topographic/ hydrological situation and power market demands.

The specific advantages of hydropower plants open up favourable possibilities of application as

- run-of-river plants (in the original river bed or in a bypass canal, using discharges which are available without considerable storage),
- storage plants (using reservoirs for water accumulation and thus affording the possibility of peak power generation)
- pumped-storage plants (repumping accumulated water during a surplus of energy in the network and generating power during peak demand)

- tidal power plants (utilizing the head and flow produced by the tide)
- power stations using the energy of waves (not feasible yet).

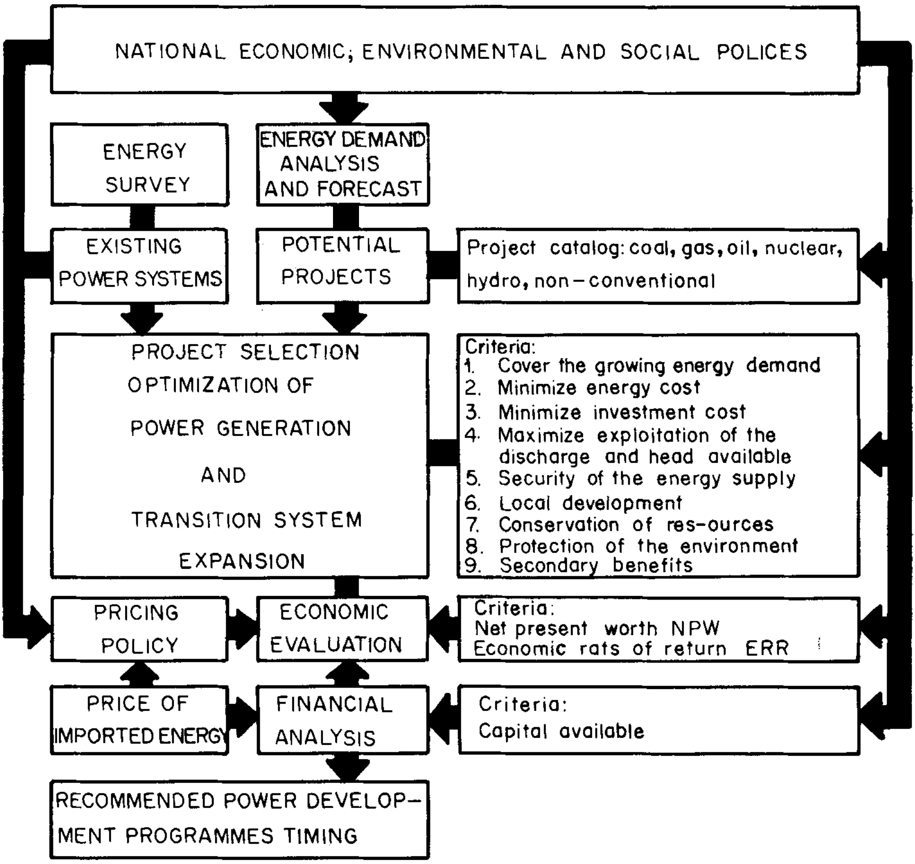


Fig. 2.5. Block diagram for the project selection, optimization of power generation and transition system expansion in the framework of national economic, environmental and social policies.

Hydropower is the only dependable renewable source of energy and offers, in addition in comparison with thermal and nuclear power, as well as with the unconventional energy options, the following basic advantages:

- flexibility of operation,
- possibility of multipurpose utilization,
- high reliability and long service life,
- positive or almost negligible environmental impact (if environmental factors are accordingly taken into account during the design and operation),
- low operating costs,
- possibilities of using local materials and labour.

The following indicators affecting the choice of the optimum design discharge and head have to be considered with a possible environmental impact of the power plant layout:

- unit cost of energy (kWh) should be competitive with other energy options,
- installed capacity (kWh) should be optimum for integration into the network power market,
- energy output in the period or season of maximum energy demand (kWh) should be optimum.

Available simulation models have the capability of simulating any hydropower plant or electrical system. Computations may be performed at a desired level of accuracy consistent with the availability of the input data. These programs may be used to determine hydropower potential, to optimize design discharges, heads, dam heights and reservoir sizes, to study the feasibility of new developments and their impact on existing systems, effects of changes in operational procedures in existing systems etc. (Fig. 2.5).

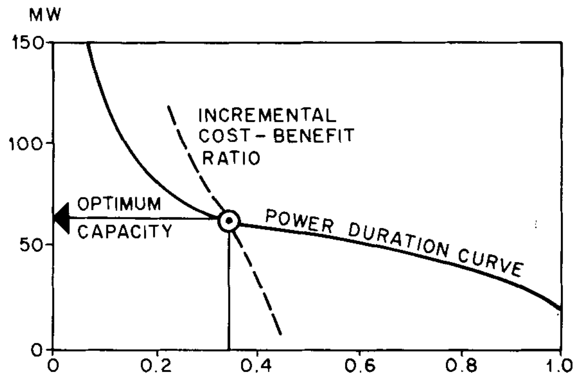


Fig. 2.6. Selection of the optimum capacity of a hydropower plant by superimposing the incremental cost-benefit ratio function on the power duration curve according to Fahlbusch (1983).

According to Fahlbusch (1983) the optimum capacity of a hydropower plant, if the objective is the maximum exploitation of energy and not the provision of peak capacity, is that value of theoretical capacity N for which the complementary cumulative distribution of power output equals the marginal benefit-cost ratio

$$\frac{\Delta C}{\Delta B} = \frac{C'(N)}{M.t_o} \tag{2.47}$$

$$\int_{N^+_{opt}}^{\infty} f(x)dx = \frac{C'(N)}{M.t_o} \tag{2.48}$$

Solving this equation for the optimum N_{opt} requires superimposing the marginal cost-benefit ratio function on the power duration curve (Fig. 2.6).

x - power output

f(x) - probability density of power output x

C(N) - annual cost as a function of capacity

M - value of energy per kWh

t_o - duration of one year in hours (8760 hrs)

ΔC - incremental costs

ΔB - incremental benefits

A hydropower development project may exhibit an incremental cost-benefit ratio of less than unity and still be uneconomical, requiring substantial investment for the construction of storage and diversion facilities, which may be largely independent of the design capacity.

The trouble-free and economic operation of power plants requires a low content of sediments (both bed load and suspended matter, especially hard minerals), a low content of floating debris and chemically non-aggressive water quality, which means that a low content of oxygen, low chemical aggressivity and a low temperature is required in order to restrict:

(a) cavitation and chemical disintegration of turbines,

(b) abrasion of pressure pipelines, spiral case, turbines, liner and other technological equipment,

(c) sedimentation in water conveyance structures.

The transport of bed-load and suspended matter requires the construction of special intake structures and silt basins. It also requires a minimum flow rate of some 1.0 $m.s^{-1}$, dependent on the characteristics of the prevailing particles, in order to avoid sedimentation in the conduit system. The design dimensions of these structures should be determined in the light of the size and density of the particles and their volume which can be allowed to enter the system.

No operational troubles caused by sediment transport occur in storage plants with a reservoir which has a sufficient trap efficiency. Run-of-river plants cope with serious sediment problem when the design discharge Q_i exceeds the critical discharge Q_s at which the bed load starts to move:

$$Q_i < Q_s \qquad (m^3.s^{-1}) \qquad (2.49)$$

In rivers with a heavy bed load transport it is useful to locate the off-take in an eroded section. If the off-take is located in a section where sedimentation prevails, it is necessary to narrow the river bed in this particular section.

The bed load transport normally needs the energy of some 50% of the discharge. To avoid sediment transport problems during a period of increased bed load transport ($Q_a > Q_s$), the hydropower station may utilize some 50% of the discharges available

$$Q_e = \frac{1}{2} \cdot Q_a \qquad (m^3.s^{-1}) \qquad (2.50)$$

even when the intake is well located.

The operation of a run-of-river plant in a river with a heavy bed load transport and fluctuating discharges is, therefore, limited in two time periods

- because of the lack of water during a period with actual discharges Q_a lower than the design discharge Q_i ($Q_a < Q_i$)
- for the transport of sediments in the period when the actual discharges Q_a exceed the critical discharge Q_s, but do not reach the double of this value ($Q_s < Q_a < 2Q_s$).

No limitation of such plant operation is required during high discharges ($Q_a \geqq 2Q_s$). But, under these conditions, the power generation is restricted by the decrease in head available:

$$Q_a \geqq 2Q_s \longrightarrow Q_e = Q_i \qquad h_a \ll h_i \qquad (2.51)$$

2.3.4 Water for Recreation

Recreation includes all activities whose social goal is to gain or recover physical and psychic forces. Water recreation does not only include bathing, swimming, fishing and other water sports, but also boating, yachting, some winter sports like skating etc., and sojourns beside the water such as camping, caravanning and other forms of short-term or weekend sojourn.

Areas rich in surface water substantially ameliorate the recreation conditions in arid, semiarid and humid climates, but do not have such a positive impact under conditions of rough climate. Water recreation may be classified as (Tab. 2.9, 2.10):

(a) everyday - reservoirs and accessible water courses, swimming pools in the proximity of dwelling areas (up to 20 km),

(b) weekend - reservoirs and water courses whose distance from relevant dwelling areas exceeds 20 km (up to 200 km)

(c) seasonal - areas of recreational character whose distance from relevant dwelling areas exceeds 200 km.

The quality of water recreation depends on

(a) water management factors,

(b) climatological factors,

(c) local factors incl. topographical and aesthetic factors.

The pre-condition for the recreational effect of a given area is the change of milieu: Relatively warm areas are pertinent for recreation in a mild climate, relatively cool areas in a semi-arid and arid climate.

TABLE 2.9

Type of recreation	Deciding factors	Type of recreation	Deciding factors
1 bathing	W1-6 & 8 K1-4, M1-6	7 yachting	W3-5, M3
2 water tourism	W1-3 & 5, K1-2, M5-6	motorboating	
3 rowing & paddling	W1, 3-5, K4, M6	8 recreational stay	W1, K1, M3
4 fishing	W1, 4-7, M4	9 skating	W6, 4, M3

Categorization of water recreation (basic characteristics of deciding factors see table 2.13).

Water quality incl. temperature is the most important factor which influences the quality of recreation in relation to the type of recreation activity (Tab. 2.10). Bathing and swimming is a supplementary activity for other recreation activities, distinguished by the highest requirements on most factors. Water temperature is not necessarily connected with climatological factors. Thermal waters may create extremely favourable conditions for recreation, especially in less favourable climatic conditions. Under such conditions the influence of climatological factors may appear of tertiary importance.

TABLE 2.11

Category of visitors	Required water depth (m)	Ideal share of the water table area (%)
Children	0 - 0.8	20%
Non-swimmers	0.8 - 1.3	40%
Swimmers	> 1.3	40%
Water jumping	3.4 - 5	min 16.25.14 m

Required water depth and the ideal share of the water table area for relevant categories of visitors to natural and artificial bathing pools.

The quality of natural bathing pools depends on the morphological and aesthetic conditions of the environment and on a favourable water depth for swimmers, non-swimmers, children and divers (Tab. 2.11, 2.12). The active area on big reservoirs is a zone near the shore, some 50 m wide.

The size of bathing and swimming pools should correspond to the length of race tracks, which are ratios of 50 m: 10 m, 12.5 m, 16.67 m and 25 m. In a swimming pool of 50.21 m, as recommended by FINA with a water depth above 1.8 m,

TABLE 2.10

Water management factors (W)	Excellent	Suitable	Marginally suitable	Unsuitable
1. Water pollution (class)	Ia	Ib	II	III
2. Water temperature °C	> 25	> 18	> 14	< 14
3. Water depth (m)	0.5 -1.6	< 1.6	> 1.6	< 0.5
4. Water table width (m)	> 20	> 10	> 5	< 5
5. Velocity of flow ($m.s^{-1}$)	< 0.5	0.5 -1.1	~1.5	> 1.5
6. Water table fluctuation (m)	< 0.5	< 2	> 2	≫ 2
7. Fish occurrence	plentiful		scarce	nil
8. Variance with other water management purposes	no	partially		yes

Climatic factors (C)	Excellent	Suitable	Unsuitable
1. Number of high summer days	> 70	> 50	< 50
2. Rainfall total in summer (mm)	< 250	< 450	> 600
3. Air temperature °C (% humidity)	21-26 (18-70)		< 18
4. Air pollution	no	no	yes
5. Noise	no	slight	yes

Morphological and aesthetic factors (M)	Suitable	Unsuitable
1. Riverbed material	sand	mud
2. Bank slope	< 1:3.3	> 1:2
3. Accessibility	good	difficult
4. Insect occurrence	no	yes
5. Aesthetic of the environment	pleasant	uninteresting
6. Services (for mass recreation)	good	poor

Categories of parameters which determine quality of recreation.

it is possible to play water polo.

TABLE 2.12

Parameter	Limiting value (maximum or minimum)
Water table width	>10 m
Minimum area of the water table	200 m^2
Velocity of flow - for adults	< 0.5 $m.s^{-1}$
- for children	< 0.3 $m.s^{-1}$
Minimum discharge per visitor and day	1 m^3
Bottom slope	<30 %
Bottom material	sand, pebble, pavement, concrete
Water temperature	> 18 °C
Class of water quality	I (max II)
Area of water table per visitor	> 2.5 m^2
Total surface area per visitor	>10 m^2

Limiting values of basic parameters to ensure good conditions for recreating at natural bathing pools.

The optimum flow rate and fluctuation of the water table not only depend on the type of recreation, but also on the morphology of the terrain: on the material of the bottom, on the slope and accessibility of the banks. An optimum velocity of flow for most activities is below 0.5 $m.s^{-1}$. The permissible fluctuation of the water table also determines the water quality (Tab. 2.13).

The physical need to bathe appears when the daily temperature exceeds 25°C. A reservoir offers good conditions for bathing whenever the number of such days is higher than 50-70 annually and precipitation in this period does not exceed 450 mm. Conditions are favourable for a recreational stay near water when the average daily temperature is above 10°C, i.e. from April to October in a mild climate.

Last but not least, the quality of water recreation depends on the quality of the air, the noise and the occurrence of insects. The morphology may create a favourable climate in a natural milieu or in a housing estate. The climatic pleasantness depends on the relation of the amount of diffused and reflected solar radiation, which influences the air temperature and humidity (Fig. 2.7).

To maintain the water quality in swimming and bathing pools, an exchange of water is required, which may be

(a) continuous,
(b) immediate,
(c) achieved by the circulation of water.

TABLE 2.13

Water quality indicators	Bathing pool	
	natural	artificial
Physical properties:		
Temperature minimum	14 °C	14 °C
optimum	21 °C	21 °C
Visibility in water	>0.5 m	> 5 m
Turbidity (SiO_2- content)	-	
depth down to 1m	-	> 2 $mg.l^{-1}$
depth down to 2m	-	> 1 $mg.l^{-1}$
Chemical properties		
Factor pH	5.5 - 9.0	6.8 - 7.1
Organic matter	-	i + 30 $mg.l^{-1}$
Chloride	100 $mg.l^{-1}$	i + 0.3 $mg.l^{-1}$
Ammonia	1 $mg.l^{-1}$	i + 0.3 $mg.l^{-1}$
Nitrides		i + 0.2 $mg.l^{-1}$
Nitrates		i + 20 $mg.l^{-1}$

Water quality indicators for natural and artificial bathing pools. i - water quality indicator of the inflow.

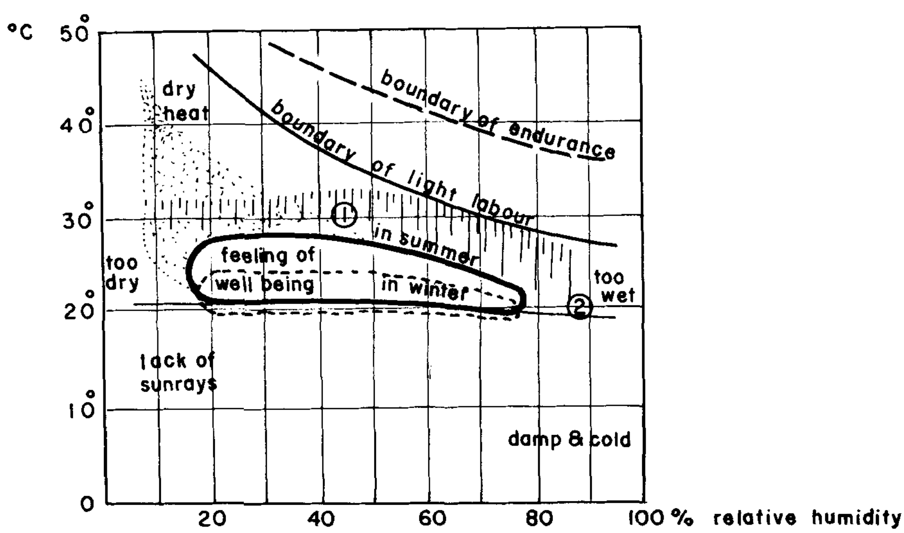


Fig. 2.7. Relation of temperature and relative humidity to attaining favourable feeling during water recreation in a mild climate. Sunshine and wind motion appear as important secondary factors: 1 - lack of air motion, 2 - lack of shadow.

Water quality standards for indoor and outdoor swimming pools approach the requirements for drinking water (Tab. 2.14). The relevant quantitative requirements include

(a) filling water R_f - its volume corresponds to the volume of the pool and of the relevant installations for water circulation etc. $R_f = V$.

(b) supplementary water R_s - compensating losses through spilling, seepage, leakage, evaporation etc.

(c) dilution water R_d - to ensure the required concentration of polluting substances, concentrated by the operation of the pool.

The quantity of dilution water for pools without water circulation can be derived from the permissible increment in the content of chlorides, measured to the permissible value of chlorides in the water resource. The specific daily pollution increment is

2 g per capita and day for outdoor and indoor swimming pools

1 g per capita and day for natural bathing pools, therefore

$$R_d = \frac{2000}{30} = 66 \text{ l per capita and day.}$$

R_d - water requirements of dilution water for outdoor swimming pools.

During water circulation a 0.25 m layer of water has to be replaced in the course of one hour. The required capacity of the water treatment plant has to be

$$R_c = \frac{A \ . \ 0,25}{3600} + R_s \qquad (m^3.s^{-1}) \qquad (2.52)$$

R_c - recycled discharge

A - area of the swimming pool (m^2)

When water is being circulated in a natural bathing pool, the recommended design discharge for the treatment plant is 0.5 m^3 per capita and day. Large swimming pools require a continuous process of circulation; an interrupted process is recommended for small pools with only a 4 hour cycle.

As a water-saving technique and in order to improve the water quality, the circulated water can be used for showers, flushing, filter washing and the cleaning of the recreational amenities.

2.4 MUNICIPAL AND RURAL WATER REQUIREMENTS

The amount and quality of water used in human settlements influences the social development of the society concerned and affects the biological development of the individual human beings. The quality and quantity of drinking water supplied to organisms has a direct effect on health.

Water supplies important minerals to organisms. The long-term utilization of the same water for drinking and cooking purposes by an individual influences the development of the organism and its hereditary signs. The amount and quality of water used for washing and bathing has a considerable influence on health conditions in human settlements.

The extent of these influences depends on the physiological adaptability and characteristic properties of man in the framework of the homeostasis of his own biological system, on the energy input and output of relevant individuals, on the supply of nutriments, vitamins and on other sanitary conditions.

The mode and frequency of the relevant organism's contact with water is a further important factor. Water demand in households, workshops and public services has different quality requirements for:

(a) drinking (and other uses resulting in internal contact of water with the human body: meal preparation),

(b) other domestic uses in contact with the surface of the human body

- physical care: washing, showering, bathing
- dish washing
- laundry

(c) using water in systems where contact with the body can be avoided

- laundry
- house cleaning and car washing
- yard and park watering, street cleaning, sewer flushing
- toilet rinsing
- fire extinguishing

(d) using water in closed systems

- heating
- air conditioning.

The supply of water of uniform quality for each of these technologically different purposes is the simplest method to safeguard all these requirements by means of one supply network. In practical cases this method may not appear as the most economic or suitable to positively influence the development of human organisms and their health.

2.4.1 Water Requirements for Drinking and Cooking Purposes

The physiological water requirements of a healthy individual reaches an average of 1.5 to 15 liters per day. The metabolic processes of each individual tend to achieve a balanced stage, depending on climatological conditions, personal weight and individual activities (profession, hobbies) and customs (drinking, eating, dressing), thus requiring a stable complementing of water losses.

The physiological water requirement of some 2.5 l per capita and day is covered 50% by food and 50% by beverages. In addition to this, a healthy organism produces some 0.3 l of metabolic water per day by processing the basic nutriments. The physiological water requirements per capita and day R_i can, therefore, be expressed by the following equation

$$R_i = f\ (w,\ a,\ c,\ h,\ f,\ m) - R_f \text{ (l per capita and day)} \qquad (2.53)$$

w - individual weight

a - activities (profession, hobbies, age)

c - climate (especially temperature and humidity)

h - personal habits (quality and quantity of drinking, dressing etc.)

f - food composition

m - metabolic function (less important)

R_f - content of water in food.

The human organism is influenced by the amount and quality of accepted water, especially if ancestors have been living in the same place for generations. The anorganic and organic constituents of water have a direct influence on the human organism, i.e. physiologically, and an indirect influence, i.e. psychically, both positively and negatively. The human organism generally, depending on its individual properties, may get accustomed to the influence of natural water constituents and their combination, or may produce relevant anti-matter. But some constituents of water, especially those coming from pollution through wastes from industry and agriculture, may cause diseases or morbid changes, namely

(a) teratogenic (may induce morbid changes of the organism)
(b) mutagenous matter (may produce hereditary changes)
(c) cancerogenous matter (may cause malignant tumours).

These matter and their function are not sufficiently known, because the reaction of any organism to such matter depends to a considerable extent on their quantity, combination and concentration, as well as on the organism's health and habits. The degree of resistance depends on the health standard, hereditary and personal resistance or disposition and age of the individual concerned.

Occasional drinking of unsuitable water may not be dangerous when the relevant harmful concentrations are low and when the relevant organisms does not contain potentially dangerous germs. The organism's own bacteria limit the development of the accepted bacteria. On the contrary, daily drinking of physiologically or sensorially unsuitable though sanitarily non-defective water which only corresponds to basic standardized indicators may cause unexpected consequences.

To achieve the healthy development of the population, it is essential to secure an everyday supply of physiologically beneficial and sensorially aggreeable water, at least for drinking purposes. If the quality of water in the pipeline system does not correspond to these criteria, it is vital to supply bottled water of physiologically beneficial quality, at least for sucklings. For this reason, it is also advisable to organise the production of all beverages using, without exception, groundwater resources of the best quality available.

The standards for water quality should be derived from the mode of contact of human organism with water, because this is

(a) regularly absorbed by the organism,

- without boiling
- after boiling, or

(b) in temporary contact with the whole surface of the organism (and may be accidentally swallowed during showering, swimming etc.)

(c) in restricted incidental surface contact with a part of the body (during washing, cleaning, sprinkling etc.)

(d) used in closed systems, excluding contact with the organism (air conditioning, heating, toilet rinsing, drip and subsurface irrigation).

In only one supply system is used for all the purposes of municipal or rural water supply, as is usual, the water quality should correspond to the highest quality requirements, i.e. to drinking water requirements. If such water is not available for all required purposes, sanitarily non-defective water should be used for such purposes, where contact with the organism cannot technically be excluded. The supply of the necessary amount of such water, whose value depends on local conditions, prevents the occurrence of water-borne diseases.

The level of knowledge about the biological importance of the different elements and components present in water and their combination is generally low, except the appreciation of the medical effect of some mineral waters.

Not even the effect of such basic components as calcium Ca or magnesium Mg has been sufficiently investigated. The knowledge on the effect of trace elements and especially of the synergetic or antagonistic effects of their combinations: iodin J and fluorine F, fluorine F and molybden Mb etc., is also low.

The reaction of the organism to the impact of these elements can have considerable individual or hereditary effects, also in combination with other external factors such as climate, overloading of the organism, the organism's stage of development, health state etc. Water of a different quality can be used for different purposes of domestic use and relevant quality indicators for any category of its particular use can be derived from the

(a) sanitary non-defectiveness,

(b) physiological benefit,

(c) sensorial agreeableness (Fig. 2.8).

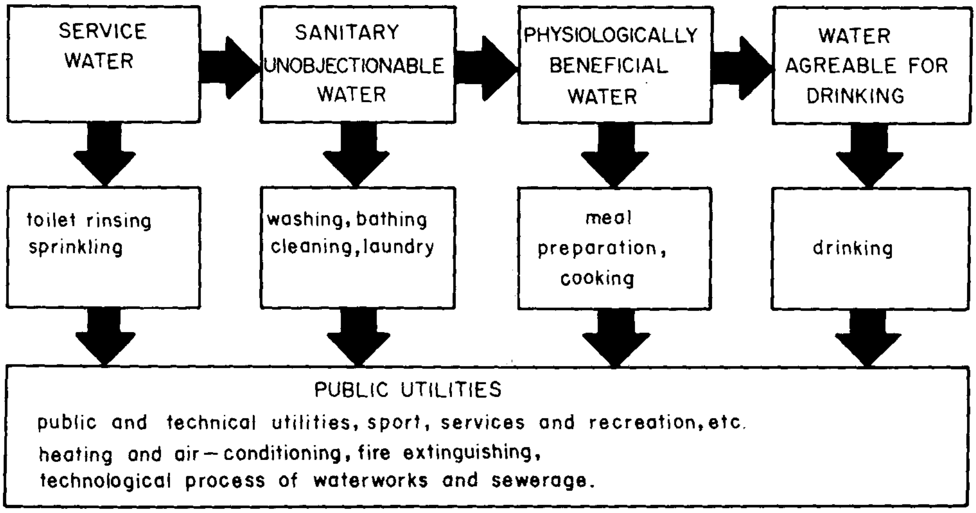


Fig. 2.8. Hierarchy of goals and requirements on water quality for municipal water supply and possibilities of water delivering water of different quality for relevant purposes.

The physiological benefit from water depends not only on its chemical and bacteriological composition, but also on its temperature, flavour and odour as the components of its sensorial properties. The quality of water in the supply network depends on the quality of raw water and can be defined by means of standards. The interstate coordination of these values is organized under the auspices of the World Health Organization and the International Standard Organization. The health and optimum development of the population can be permanently and effectively influenced through the utilization of appropriate water resources and through sophisticated water treatment (Tab. 2.14, 2.15, 2.16).

Water quality can be defined and standardized by means of indicators expressing the limiting concentrations of relevant components and other water properties with regard to their health effect. Their values have to be derived from the character and intensity of impact of the relevant components of the human organism. The number, type, methods and frequency of sampling and analytic methods are also standardized.

The relevant values can be standardized as

(a) maximum permissible values - water which exceeds these values may not be considered as drinking water (mandatory limits),

(b) recommended limits - the rate of their occasional or permanent excess has to be analyzed individually in consideration of local conditions (and officially approved).

Relevant drinking water quality requirements may differ for temporary or in-

TABLE 2.14

Selected indicators	Maximum permissible value ($mg.l^{-1}$)	
Physical: - colour	^{o}Pt 300	According to the platinum-cobalt scale
Chemical:		
a) matter influencing suitability for drinking:		
Total evaporation residium	1000	
Iron (Fe) total	50	Higher content when the ammonia content is below 0.5 $mg.l^{-1}$, due to the corrosion effect
Manganese Mn	5	
Copper Cu	1.5	
Zinc Zn	1.5	
$MgSO_4 + Na_2SO_4$	1000	
Sodium alkylbenzenesulphonate	0.5	
b) matter affecting health:		
Nitrates NO_3^-	45	Causing metahemoglobinanemia in sensitive individuals in concentration 100 $mg.l^{-1}$.
Fluor F^- derivatives	1.5	Higher concentration causes fluorosis, concentration 0.8.-1.0 $mg.l^{-1}$ are anticaretic prevention.
c) toxic matter:		
Phenol derivatives	0.002	gas works, chemical industry, volcanic waste from metal coating
Arsenic As	0.05	
Cadmium Cd	0.01	
Chromium Cr^{-6}	0.05	
Cyanids CN^-	0.20	
Lead Pb	0.05	
Selenum Se	0.01	
Total -activity	1000 $C.l^{-1}$	
d) matter indicating pollution:		
Oxidability	10.0	
Biochemical oxygen demand BOD_5	6.0	
Nitrogen N (total)	1.0	
Ammonia NH_3	0.5	
Extractable matter CCE	0.5	
Fat	1.0	

Maximum permissible content of chemicals in raw water that may be treated for drinking purposes, according to the recommendation of the World Health Organization.

dividual water supply and for permanent collective municipal and rural supply, where more strict criteria have to be applied with regard to possible infection, epidemics etc. From the metodological point of view it is possible to distinguish such indicators as

TABLE 2.15

Class	Bacteriological pollution	Bacteria coli per 100 ml	Required treatment
I.	slight	0 - 50	disinfection only
II.	medium	50 - 5000	current processes: coagulation, filtration
III.	high	500 - 50000	special treatment
IV.	excessive	>50000	water has to be used if inevitable only

Classification of raw water used for drinking purposes after its bacteriological pollution according to the recommendation of the World Health Organization.

TABLE 2.16

Indicator	Water course	Raw water	Drinking water recom.	max.
Chloride (CL^-)	400	200	20	30
Sulphide (SO_4^-)	300	200	60	
Calcium (Ca)	300	250	36	70
Magnesium (Mg)	200	125	30	60
Fluoride (F)	2.4	1.5	1.0	1.3
Ammonia (NH_3)	3	0.5	0	0.2
Nitrate (NO_3^-)	50	25	20	30
Nitride (NO_2^-)	-	-	-	0.05
Sulfate (SO_4^{2-})	-	-	25.0	50.0
Phosphate (PO_4^{3-})	-	-	0.01	0.02
Iron (Fe- total)	1.5	0.5	0.05	0.1
Manganese (Mn)	0.5	0.2	0.01	0.03
Cyanide (CN)	0.2	0.01	0.01	0.05
Zinc (Zn)	2	2	1	2
Nickel (Ni)	0.1	0.05	0	
Lead (Pb)	0.1	0.04	0	0.04
Chromium (Cr)	0.1	0.05	0.05	
Arsenic (As)	0.5	0.04	0.04	
Copper (Cu)	0.2	0.05	0	0.05
Selenium (Se)	0.1	0.05	0.003	0.01
Mercury (Hg)	0.005	0.001	0.0001	0.004
Cadmium (Ca)	0.3	0.005	0	0.005
Alluminium (Al)				0.05
Free Chlorine (Cl)			0.1	0.3
Oxygen (O_2) (min 5.0)			8.0	10.0

Selected admissible values of ion content ($mg.l^{-1}$) in water courses, surface water used for municipal water supply and in drinking water (recommended and maximum admissible values).

(a) bacteriological and biological indicators

(b) chemical and physical indicators.

Drinking water may be defined as sanitarily non-defective water when it does not cause any health troubles or diseases, even after long-term utilization.

In addition, water delivered for municipal and domestic purposes should be wholesome and palatable. Water from underground sources is preferred to surface-water delivery. Groundwater contains more bioelements important to human organism, has a stable temperature, and is less subject to contamination than surface water resources. But the very high demand for municipal water frequently precludes the exclusive use of groundwater for municipal water supply because of the limited capacity of groundwater resources.

Bacteriological non-defectiveness is an indispensable requirement. Physical and chemical indicators tend to demonstrate possible pollution in the water resource or during water purification and transport.

The term raw water refers to water from the surface or underground resource, whose quality only depends on natural factors and possible anthropogenetic pollution. Water treatment or water purification is a combination of technological processes aimed at changing the quality of raw water to the required level (Fig. 2.9).

The quality of treated water depends on the quality of raw water: not only on the content of undesirable matter not removed during water treatment, but also on the content of desirable matter which was removed during treatment or which does not appear in the raw water. For example, the lack of minerals in drinking water, characteristic for treated water from surface resources, incidentally causes heart and vessel diseases.

The basic requirement for the quality of raw water intended for municipal water supply is its non-defectiveness from the toxicological point of view and the safe running of technological processes during its purification.

The values for the maximum permissible concentration of harmful matter are gradually being defined with more precision. Particularly important is the quantity of harmful bacteria and of organic matter, whose concentration increases the probability of noxious effects. The harmfulness of this matter also depends on its combination. Unpleasant flavours and odours which are difficult to remove are another important factor.

Water treatment decreases the content of undesirable components to below the level of maximum permissible concentrations and increases the suitability of the water for transport in the pipeline network. All pathogenetic organisms, in particular the large group of Salmonella-Shigella bacteria and viruses, have to be removed by disinfection. Viruses are often resistant to current disinfection methods, including:

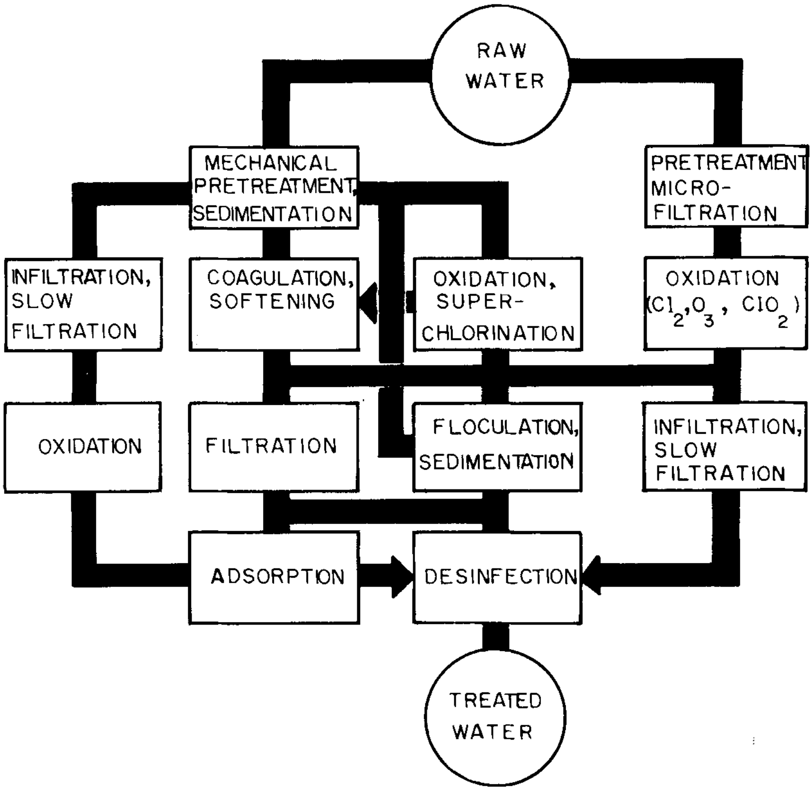


Fig. 2.9. Basic combinations of methods of water treatment for municipal water supply.

(a) physical (light-ultraviolet rays, radioactivity - γ-radiation, heat, ultrasound, electricity)

(b) mechanical (filtration, clarification, sedimentation, ultramicrofiltration, reverse osmosis, capable of removing 95-99% of bacteria)

(c) chemical (chlorination, i.e. adding of its compounds, other halogens, oxygen etc.)

(d) oligodynamic (katadynisation and other disinfection methods using various heavy metals: silver, copper and their salts).

An excess of disinfection matter, e.g. chlorine, forms a protection against pollution during transport in the pipeline network. Its extinction at the end of the network may indicate relevant pollution, which may be of pathogenetic origin. But chlorination may also produce adverse effects: trichlorine methane derivatives, produced by reacting chlorine on humine acids, currently occurring in surface waters, cause the dissemination of cancer according to Maugh II (1981).

Apart from sanitary requirements, the quality of drinking water should correspond to the requirements of economical and continuous transport in the pipeline system, not causing corrosion or clogging. The optimum water quality for this purpose depends especially on the degree of over-saturation and undersaturation with calcium carbonate $CaCO_3$. This state can be characterised by Langelier's index, i.e. by the difference between the actual pH factor of water and balanced pH_s, when the protecting alkalinity corresponds to the concentration of carbon dioxide CO_2

$$I_s = pH - pH_s \tag{2.54}$$

TABLE 2.17

Material	Concrete	Asbesto-cement	Steel & cast iron	Glass & plastics
Saturation index	0	0	0	0
Oversaturation with calcium carbonate				
- as $CaCO_3$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$
- as Ca	0.05-0.1 $mmol.l^{-1}$		0.05-0.1 $mmol.l^{-1}$	
Aggressive CO_2	5 $mg.l^{-1}$	5 $mg.l^{-1}$	5 $mg.l^{-1}$	-
Calcium Ca	-	-	16 $mg.l^{-1}$	-
Total alkalinity	0.8 $mmol.l^{-1}$	0.8 $mmol.l^{-1}$	0.8 $mmol.l^{-1}$	-
Factor pH	6,7	6.0	-	
Sulphates SO_2^{2-}	250 $mg.l^{-1}$	250 $mg.l^{-1}$	-	
Suspended matter	15 $mg.l^{-1}$	15 $mg.l^{-1}$	1000 $mg.l^{-1}$	15 $mg.l^{-1}$
COD (by permanganate)			75 $mg.l^{-1}$	

Degree of aggressivity	Rate of uniform corrosion μm per year (water temperature below 25°C)
I. mild aggressivity	50
II. medium aggressivity	50 - 150
III. high aggressivity	150

Indicators for safeguarding the stability of water quality during its transport and limiting the corrosion rate in pipeline systems. Degree of aggressivity for determining the efficiency of the water treatment process to limit the corrosion rate.

The protection of metallic pipelines has to be achieved by a certain degree of oversaturation with calcium, forming a thin internal protective. This can be achieved under conditions of a high content of the total components of carbonic acid H_2CO_3. According to Stumm (1962), in the case of a low content of these components, a granular porous matter appears instead of a compact film. The aggressivity of water depends on the character of the material it contains, and has to be evaluated on the basis of the limiting values of the pH factor, sulphates SO_4^{2-} and chlorides Cl^-. Pipes made of plastic materials and glass are chemically far more resistant (Tab. 2.17).

For the most part domestic water requirements have to be covered by warm water supply. The mass supply of warm water is often accomplished by a special pipeline network. The quality requirements for mass supply of warm water is a complex subject. Such water should correspond to drinking water standard and must not cause excessive corrosion or clogging of the supply network. The temperature of warm domestic water should be about 60°C, because higher temperatures increase the corrosion rate. Chemical indicators for warm water quality are, therefore, more complicated means of achieving the desired balance for limiting corrosion and clogging (Tab. 2.18). These criteria also include the content of magnesium Mg before warming and the maintenance of the diphosphorus oxide P_2O_5 concentration above 2 mg. l^{-1} to 3 mg. l^{-1}.

TABLE 2.18

Temperature	< 60° C	Total alkalinity	> 1.5 mmol.l^{-1}
Dissolved solids	< 1000 mg.l^{-1}	$CaCO_3$ + $MgCO_3$	> 1.5 mmol.l^{-1}
Factor pH	< 8.6	P_2O_5	2 - 5 mg.l^{-1}
Content of chlorides in dependence on $CaCO_3$+$MgCO_3$			
$CaCO_3$ + $MgCO_3$	< 4,18 mmol.l^{-1}	→	75 mg.l^{-1}
	> 4,18 mmol.l^{-1}	→	150 mg.l^{-1}
Content of magnesium Mg^{2+} in dependence on pH and total alkalinity +)			
pH <8,6	total alkalinity 1.5-4 mmol.l^{-1}		<105 mg.l^{-1}
>8.8	4-8 mmol.l^{-1}		< 42 mg.l^{-1}
Content of free CO_2 in dependence on Ca^{2+}, and total alkalinity +)			
$0 \leq (Ca^{2+}-a) \leq 0.5$	$0 \leq (a - Ca^{2+}) \leq 0.5$	$0.5 < (a - Ca^{2+}) \leq 1$	$0.5 < (Ca^{2+}-a) \leq 1.5$
mg.l^{-1}			mg.l^{-1}
≤1		1.5-3.6 mmol.l^{-1}	≤1.8
≤5	←	3.6-7.2 mmol.l^{-1} →	≤7
≤16		> 7.2 mmol.l^{-1}	≤18

Basic criteria for the quality of warm water supplied by a special pipeline network for ma$s supply: +) before warming, a - alkalinity.

2.4.2 Water Requirements for Other Domestic Uses

Water requirements for other domestic uses depend on the local conditions, especially on the

- life-style
- standard of equipment
- ratio of income and water rates
- number and age of household members.

In developed countries, the standard of equipment has the greatest influence (Tab. 2.19).

TABLE 2.19

Household equipment	Average daily water requirements (l per capita and day) block of flats	family houses
Mass delivery of warm water, central heating, bathroom	280	170
Warm water heated locally bathroom	230	140
Cold running water, shower	150	90
Outdoor wells, street faucets (without running water or flush toilets)	40	25

Average urban and rural water requirements per capita and day and their relation to the standard of household equipment.

Water withdrawals for domestic water supply generally exceed the relevant water requirements and also depend on the technical equipment and state of the supply network, as well as on its operation and maintenance. Water rates have a regulating effect, depending on the ratio of the family or individual income and its value, but only if payments are derived from current metering. It is useful to apply water pricing as a regulating factor of water withdrawals, when the total water demand reaches the capacity of the constructed supply systems, or when the water balance of the relevant area tends to be passive. Under such circumstances, lower water withdrawals decrease operating costs and delay the extension of the old supply system or the construction of a new one.

Domestic water requirements also depend on the structure of the family, on the age, sex and activities of the family members. Nevertheless, the prevailing factor is the standard of equipment. The crucial moment of a rapid increase in water requirements is reached when water use is not restricted by availability, a low standard of equipment or high rates influencing living standards.

The availability of free time may appear as the next crucial factor for a further rapid increase in water requirements. According to Holman (1961), the structure of time utilization in developed countries during the period 1950-2000 will not change considerably (except annual leave, which may restrict requirements in the critical summer period). For this reason, future water demand will not differ from present requirements, which correspond to high living standards.

Domestic water requirements (including drinking water demand, forming 2-2.5% of its value only) have to be derived from the standard of equipment, occupation and general customs, sex and age and simply defined as a function for the individual

$$R_1 = f\,(s\,,\,o\,,\,g) \qquad \text{(l per capita)} \qquad (2.55)$$

and for the household (family) members.

Defining the average per capita and day water requirements R_d as the optimum value which corresponds to the customary style of life, not including excess wastage, previous equations can be simplified by using coefficients as follows:

for the individual $R_1 = R_d \cdot k_a \cdot k_x$ (l per capita)

for the household $R_f = m.R_d \cdot k'_a \cdot k_x$ (l per household)

k_a, k'_a – coefficient of activity (profession and free time)

k_x – coefficient of unavoidable wastage

m – number of household (family) members.

The total domestic water demand is expressed by the sum

$$R_s = k_s \cdot k_x \cdot \sum_{k=1}^{N} k_a \cdot m_{ak} \cdot R_d \qquad (m^3 \text{ per day}) \qquad (2.56)$$

k_s – coefficient of losses in the supply system (< 1.15)

k..... N – category of the dwelling standard including subcategories of activities

m_{ak} – number of inhabitants in relevant subcategories

R_d – optimum water demand which corresponds to the style of life (household equipment and activities).

When analysing the necessity and economy of domestic water supply for different purposes of utilization it is possible to distinguish four categories of water quality:

A_1 – physiologically beneficial water agreeable in smell and taste (can be supplied by a special network or bottled)

A_2 – physiologically beneficial water (if not available, can be replaced by category B)

B – drinking water, as defined, i.e. sanitarily non-defective water, which cannot cause health troubles or diseases, even after long-term utilization.

C – sanitarily non-defective water. The use of water of lower quality for flushing, water and other purposes requires strict technical and hygienic measures to exclude any contact with the human organism.

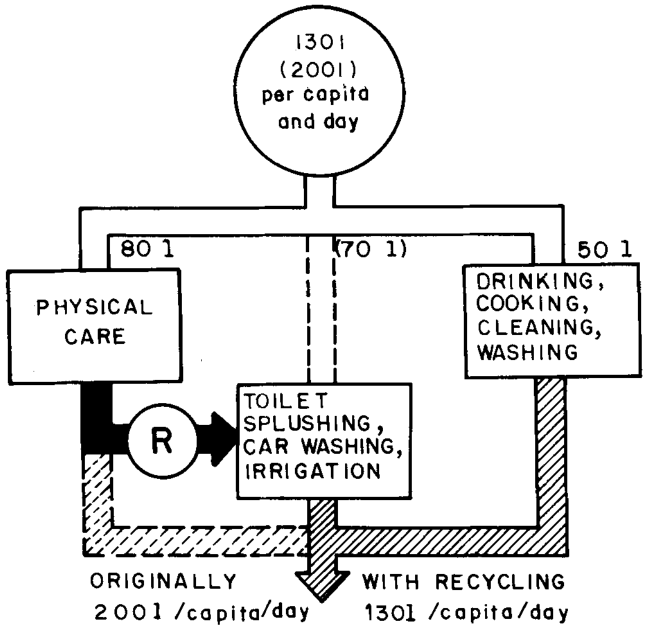


Fig. 2.10. Water-saving technologies for households. Schematic representation of possibilities of waste water segregation in household and subsequent feasibility of domestic water re-use. Traditional system in black and dotted, data in brackets.

The basic precondition for a high standard of life can be ensured by supplying 250 l per capita and day (Tab. 2.20), if used in a proper way. Supplying higher quantities only forms favourable conditions for water wastage. The same standard can be achieved by applying unconventional water-saving techniques to lower water withdrawals and/or by recycling segregated waste waters: Waste water from personal washing, bathing and laundry can be used without any treatment for toilet rinsing, garden watering and outdoor washing (Fig. 2.10).

Pollution by detergents may restrict the use of such water for irrigation. This can be precluded by using suitable detergents, namely by using detergents which have fertilizing effects and do not form carcinogen remnants. Waste water re-use in households may decrease the per capita water requirements of the highest standard of life to some 130 l per day, thus enabling the growing water demands for irrigation and street washing to be covered, in many cases without an extension of the existing water supply network.

TABLE 2.20

Component		Water requirements per capita and day (l)	(%)	Total per capita and day (l)	(%)	Water quality Harmless	Health beneficial	Agreeable to drink
Drinking	A_1	2				+	+	+
Meal preparation	A_2	3	2	5	2	+	+	-
Dish-washing	B	15	6			+	-	W
Physical care		60	24			+	-	W
Laundry (washing)		20	8			+	-	W
Cleaning		10	4	105	42	+	-	W
Toilet rinsing	C	50	20			-	-	-
Garden watering		10	4	60	24	-	-	-
Unavoidable losses	A-C	30	12	30	12			
Household total		200	80	200	80	+	+	+
Public utilities & heating		50	20	50	20	+	+	+
Urban water requirements total		250 l per capita and day						

Ideal structure of per capita and day urban water usage respecting modern style of life, but not including unnecessary wastage which does not improve the living standard. Corresponds to water requirements of garden cities in a humid climate.
Symbols: + yes, - not necessary, W warm water

2.4.3 Urban Public Water Requirements

Urban public uses of water include

(a) public and technical utilities

(b) heating and boiling (steam, heated and warm water networks) - see paragraph 2.4.2, Tab. 2.18.

(c) fire extinguishing

(d) water and waste water treatment, cleaning of water supply and sewer system.

Public and technical utilities embrace all services including cultural, schools, hospitals and other sanitary services and administration, but not industrial and agricultural production. Water use for this purpose also includes street washing and watering of gardens and parks, playgrounds and graveyards, and cleaning of transport vehicles (Tab. 2.21).

TABLE 2.21

Water requirements	Per employee daily	Water requirements	Per visitor daily
Shops, stores	60	Theatres, cinemas	5
Bar	300	Nurseries, creches	120
Restaurant, canteen	450	Kindergarten	60
Snack bar, canteen	400	Schools	25
Café, wine cellar	300	Universities	40
Services not using water for processing	80	Youth clubs	25
Dirty and dusty workshops	180	Gymnasium	60
Hairdressers	200	Sauna	250
Photographic laboratories	800	Match auditorium	3
Sales rooms	60	Travellers by rail or bus	3
Butchers' shops	80		Per one washing
Chemists	100		
Sanitary services	80		
Railway stations	60	Car washing	500 - 1000
Offices	60	Lorry, bus washing	900 - 3000
	per bed daily		per sq.m. daily
Hotels de lux	1200	Communications 1)	3 - 5
second class	500	Public spaces 1)	3 - 5
Guest houses hostels	200	Playgrounds	1 - 2
Hospitals	700	Tennis, basketball	10
Convalescent homes	250		$m^3.ha^-$ per season
Social care homes	500		
		Parks 2)	1200
		Gardens 2)	3000
		Graveyards 2)	200

Urban public water requirements: 1) 240 days a year, 2) in humid climate.

The quantity of water used for heating is relatively small and relatively unimportant for water balance computations. The quantity of water used for water treatment and cleaning the water supply and sewer system can be derived as a percentage of the total amount supplied. When using water for fire extinguishing, temporary troubles or breakdowns in the public water supply may be permitted.

Water requirements for public uses therefore depend

(1) on the area of the community (washing and watering of communication lines and other public areas)

$$R_a = \sum_{k=1}^{K} A_k \cdot R_{ak} \qquad (m^3) \qquad (2.57)$$

A_k - area washed and watered (m^2)

R_{ak} - specific water demand per square unit $(l.m^{-2})$

(2) on the number of inhabitants (per capita and day water demands in public utilities)

$$R_b = n \cdot \sum_{k=1}^{L} R_{bk} \qquad (m^3 \text{ per day}) \qquad (2.58)$$

n - number of inhabitants

R_{bk} - average per capita and day uses in relevant public utilities $(m^3$ per capita and day)

(3) on the number of public, cultural and other social utilities (on the number of outdoor visitors, requirements not included in the number of inhabitants - hotels, hostels, selected schools, sanitary, sport, cultural and transport utilities etc.)

$$R_c = \sum_{k=1}^{M} m_k \cdot R_{ck} \qquad (m^3 \text{ per day}) \qquad (2.59)$$

m - number of visitors in relevant utilities

R_{ck} - per capita and day uses of visitors in relevant public utilities.

The per capita and day requirements of the inhabitants and visitors can be estimated as the fictitious uses of relevant personnel.

The quality of water for public utilities theoretically corresponds to the mentioned four categories for domestic water uses. The quantity requirements depend on the climate, on the size of the relevant localities and on the standard of the relevant public utilities. Their total reaches some 10% of the domestic water demand for unimportant townships, 30% for big municipalities and some 50% for large cities and spas.

Water for fire extinguishing has to be withdrawn from the water supply network, from special reservoirs and/or directly from a water resource. The quality requirements for such water should safeguard the uninterrupted operation of the extinguishing equipment - i.e. preclude clogging - and also secure the basic sanitary postulates.

TABLE 2.22

Fire load (kg)	Specific water requirements ($l.s^{-1}$)	Period between the alarm and extinguishing (min)	Distance of the fire brigade (km)	Surface affected by fire Minimum	Collective dwelling (m^2)	Industry with combustible products
5	0.128	3	0.5	16	44	95
50	0.170	10	3–6	28	72	148
100	0.220	20	10–13	45	112	224
120	0.240	30	18–22	62	152	300
180	0.300	40	28	79	192	337

Parameters for determining fire water requirements: specific water requirements for different fire load and surface assumed to be affected by fire at the beginning of fire extinguishing.

A minimum volume of at least 75 m^3 or a maximum daily withdrawal of 3 hours should be reserved for fire extinguishing purposes in the reservoirs of the relevant supply network. The capacity of the water resources and intake must allow a supplementation of this volume for 12 hours in industrial estates, for 24 hours in big towns and for 36 hours in small townships.

The theoretical requirements for fire extinguishing correspond to the size of the area attacked by fire at the beginning of extinguishing. The specific water requirements, corresponding to 1 m^2 of the area attacked, depends on the structure and material, expressed as fire load. This load has to be determined by converting the amount of combustible matter present in the volume of wood of the same heating value. It is neither advantageous for economical to safeguard water for extinguishing single family houses, simple and small buildings, or small localities with water requirements which do not exceed 5 $l.s^{-1}$.

Water requirements for fire extinguishing are determined by the following formula

$$R_e = \delta \cdot A_e \cdot R_{se} \qquad (l.s^{-1}) \qquad (2.60)$$

R_e – water requirements for fire extinguishing ($l.s^{-1}$)

A_e – area attacked at the beginning of the fire extinguishing (m^2)

δ – coefficient which expresses operational difficulties during fire extinguishing (1 to 1.3, max. 1.5, depending on ventilation, evacuation of persons, types of combustible matters etc.)

R_{se} – specific requirements of water for fire extinghishing ($l.s^{-1}.m^{-2}$)

The size of the area attacked depends in part on the type of building and then on the time it takes the fire to flare up and the time it takes the fire-brigade to arrive, i.e. on the distance of its headquarters (Tab. 2.22) and on the method of the fire alarm signal. For storage tanks, silos and reservoirs the theoretical value of this area is at maximum 150% of the area which can be attacked by fire. The water pressure in hydrants should be at least 0.2 MPa.

The water requirements for water treatment cover

(a) filter washing

(b) sludge discharge of defecators and settling basins.

The water requirements for filter washing are expressed by the formula

$$R_w = \frac{f \cdot t \cdot x \cdot 100}{K \cdot V \cdot (1-e^{-It})} \quad \text{(\% of treated water)} \quad (2.61)$$

f - filter surface (m^2)

I - washing intensity ($m^3.m^{-2}.s^{-1}$)

t - time of washing (s)

x - content of suspended matter in raw water ($mg.l^{-1}$)

k - sludge capacity of the filter ($m^3.m^{-3}$)

V - volume of the filter (m^3)

Leaving aside the quantity of suspended matter in the filter, this equation can be simplified to

$$R_w = \frac{230.3 \cdot \log vt}{v \cdot t} \quad \text{(\% of treated water)}$$

v - filtration rate (%)

t - duration of the filtration cycle (hrs)

The water requirements for the cleaning of defecators or settling basins without pumping are

$$R_u = \frac{x'}{c} \cdot 100 \quad \text{(\% of treated water)} \quad (2.62)$$

x' - concentration of suspended matter which enters the space for thickening ($g.l^{-1}$)

c - concentration of suspended matter in the thickened sludge ($g.l^{-1}$)

Pumping changes the previous formula to

$$R_u = \frac{Q_w \cdot t \cdot 100}{Q_t \cdot t_1} \quad \text{(\% of treated water)} \quad (2.63)$$

Q_w - output of the sludge pump $(m^3.s^{-1})$

T - duration of sludge pumping (sec)

t - period of sludge pumping (sec)

Q_t - treated water quantity $(m^3.s^{-1})$

2.4.4 Management of Water Delivery and Disposal

The flow chart for an assessment of water requirements, as well as their projection for the evaluation of alternative scenarios and for the operational management of water withdrawals in the mass supply network, also embraces industrial and agricultural water supply including infrastructure (Fig. 2.11).

The value of the optimum water demand for population, enabling the development of a high standard of living, was derived in the previous paragraph fixed at 200 l per capita and day for domestic purposes and 50 l per capita and day for urban public uses (without recycling). These figures include a reasonable percentage of water wastage and are to be regarded as planning and operational limits which must not to be exceeded. They also contain a reasonable reserve for an increase in present water demands through

- the extended use of washing-machines,
- more frequent bathing, showering and general physical care,
- the extended use of dish washers,
- the extended practice of garden irrigation and out-door washing (Tab. 2.20).

These figures do not include water requirements for home swimming-pools or air coolers. Using the flow chart for the management of withdrawals (Fig. 2.11), these have to be reduced hierarchically depending on the socio-economic losses which occur as a consequence of the reduced water deliveries.

The course of water withdrawals which fulfill municipal and rural water demands is non-uniform. This course depends on the cycle of economic and social activities, in particular on

- the organisation of production, services and other social activities,
- the living standard, customs and cultural standards which serve to form the relevant life-style.

In the course of the year, minimum municipal water requirements occur during holidays - with the exception of holiday resorts. In Central European conditions, a noticeable minimum can be observed at the end of July and beginning of August and there is also a periodic depression during February. Maximum water requirements, which differ less from the average values than the minimum values, occur very often during October or November and sometimes also before Christmas. The weekly minimum occurs on Saturdays and Sundays. The course of water deliveries depends on economic activities on weekdays, and on the life-style during holidays. The daily minima occur at night, and the maxima in the evening, with a

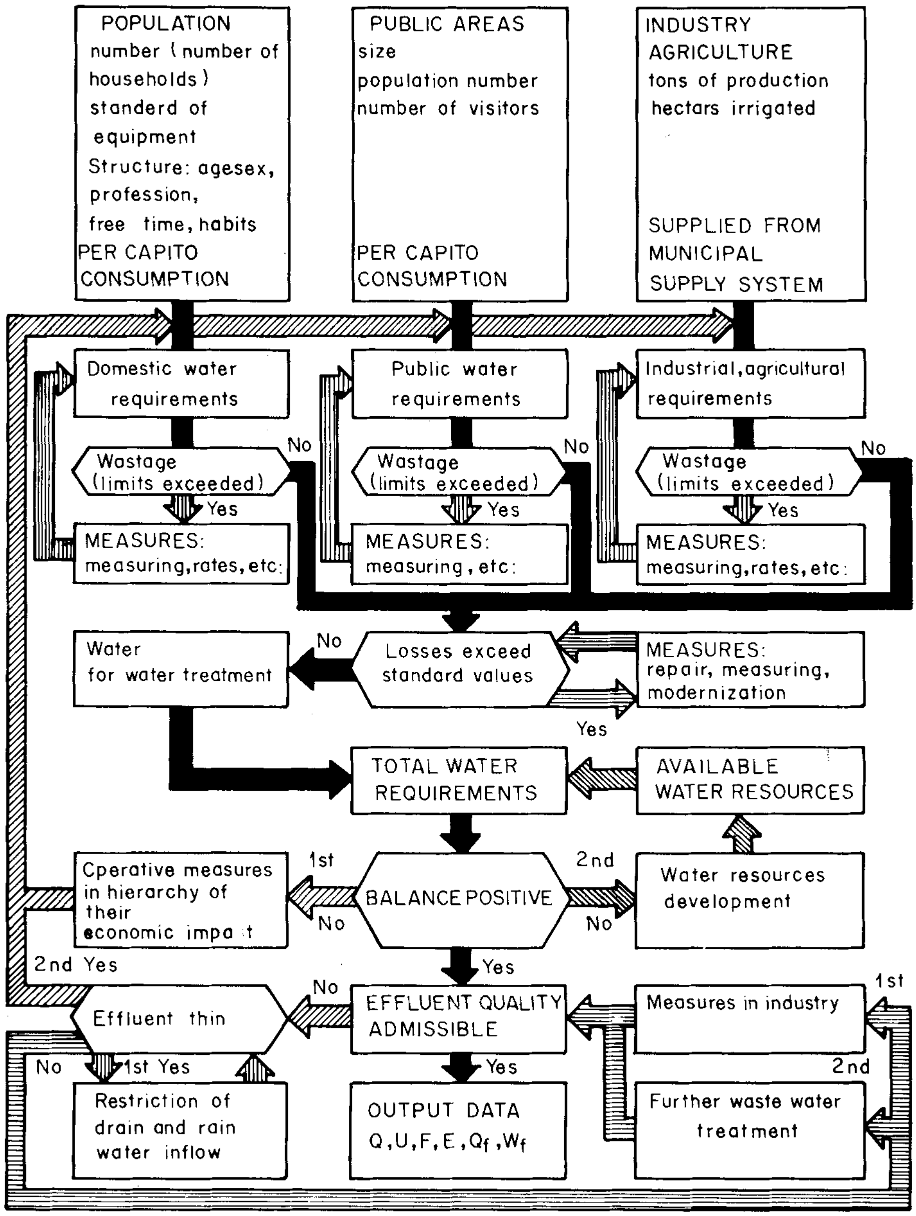


Fig. 2.11. Block diagram for determination of municipal water requirements and management of water delivery during periods of a passive balance of water resources and needs.

less considerable maximum values in the morning and at noon (Fig. 2.12).

The maximum and minimum values of water withdrawals from the municipal water supply network can be derived from the average values by using coefficients as follows:

Maximum and minimum total daily average water requirements:

$R_m = R_d \cdot c_d$ (m^3 per hour) (2.64)

R_d - average daily requirements (total of the domestic and public uses) (m^3 per hour)

c_d - coefficient of the daily non-uniformity (= 0.9 for minimum, 1.05 - 1.5 for maximum, lower values correspond to big cities, higher to small communities)

Maximum and minimum water requirements per hour

$R_h = R_m \cdot c_h$ (m^3 per hour) (2.65)

R_h - maximum daily average demand (m^3 per hour)

c_h - coefficient of the per hour non-uniformity (c_h = 0.15 - 0.6 for per hour minima, 1.5 - 2.9 for per hour maxima, likewise depending on the size of the settlement).

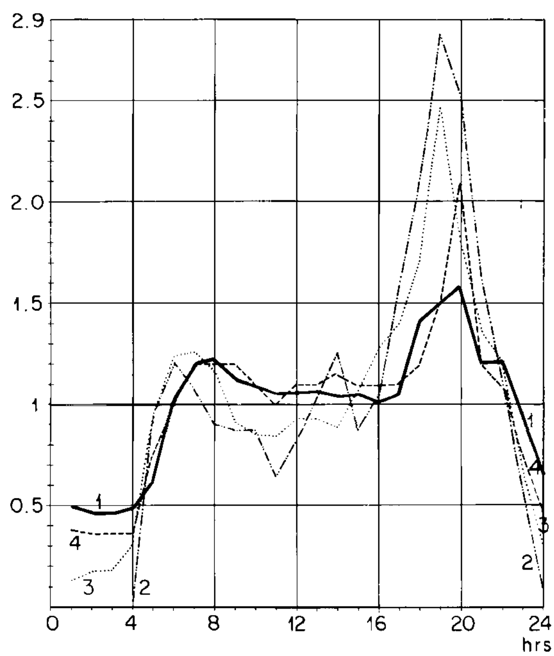


Fig. 2.12. Graphic representation of diurnal fluctuation of water deliveries in a municipal supply network and coefficients of per hour fluctuation: 1 - town with 50,000 inhabitants, 2 - district of workers, 3 - district of clerks and salesmen, 4 - average district.

Water losses which occur during mass water supply for the population are caused by

(a) wastage - i.e. in the unused release of water from the network,

(b) technical shortcomings and defects of the private indoor installations,

(c) the operation, technical shortcomings and defects in the public network incl. water reservoirs.

These losses can be classified as

(a) technically removable,

(b) inevitable losses.

The percentage of water wastage depends not only on the suitability of the relevant technical equipment, but also on the economic tools and the degree of official and personal responsibility and discipline. Technical shortcomings and defects depend especially on the technical state of the water supply network, which in itself depends on the quality of the material, fittings and other equipment, on the state and utilization of measuring equipment as well as on the quality of the workmanship, maintenance, method and duration of the operation, i.e. the age of the system.

The average water losses of the pipeline network should not exceed 10%, and at the end of the service life of the system not more than 15% of water withdrawals.

From the economic point of view water losses have two basic aspects:

(a) the general economy of water resources utilization, which can be analyzed on the basis of water balances,

(b) the cost-effectiveness of the operation of the water supply network depending on the water pricing and water metering system.

These two aspects differ in detail and often generally, as well:

A substantial part of the withdrawn water is not used beneficially, although paid for, and does not, therefore, contribute to the solution of relevant water balance problems. On the other hand, withdrawn water, although not paid for, may be beneficially used. The loss from the cost-effectiveness point of view is formed by the difference between the quantity supplied and the volume paid for. Water used for fire extinguishing, street watering and emergency water supply in cisterns is often not subject to invoicing, yet cannot be considered as a loss from the balance point of view.

Mass water supply is metered

(a) directly - by means of measuring instruments, mainly gauges and water meters,

(b) indirectly - on the basis of the energy consumption for its supply, or pump output.

The course of water delivery and water losses cannot be followed up in the necessary detail, because water supply networks are not equipped with a sufficient number of measuring devices. The manner of invoicing and water pricing, often lump sums which bear no relation to the water quantity really delivered, is not sufficiently bound to the desired real economy to supply water for beneficial uses only. The goal of the assessment of lump sums and other charges is to cover the operation and maintenance costs including profit, if required. Incoherent metering, accompanied by imperfect measuring equipment and the insufficient quantity and wrong location of this equipment, serves to create fictitious losses. Under such circumstances, water pricing does not form an effective tool for economising on water utilization.

Measures for limiting real losses in water tanks, pipelines and indoor installations include

(a) a well-equipped, prompt maintenance and breakdown service for the immediate repair of apparent and discovered troubles,

(b) the execution of repairs, reconstruction and modernization of the network in harmony with the technological development and with its technical state, especially with its corrosion, clogging and ageing,

(c) the limiting of overflow by an effective signalling and blocking system,

(d) the systematic measuring of all important withdrawals and the systematic checking of lump sums and excessive withdrawals,

(e) the utilization of water meters in a quantity which corresponds to the delivered water quantity,

(f) the adherence to the recommended terms for the callibration of water meters and periodic maintenance,

(g) the systematic checking of water losses in the supply system,

(h) the equipping of the network with really watertight valves and closures,

(i) the introduction of an effective system for checking their locking mechanism.

The measures for limiting water wastage are simple, but effective. They include:

(a) systematic water metering and the limiting of anonymous non-metered withdrawals by the installation of water meters not only for the main users, but also for housing units,

(b) an effective water pricing system, introducing water prices which increase with over-excessive water deliveries,

(c) the utilization of water meters in a quantity which corresponds to the delivered water quantity,

(d) the automatic controlling of non-metered escapes of water,

(e) the instalment of automatic stop and discharge valves, locking gear, self-activated timing devices etc.,

(f) the systematic checking of water losses in and automatic checking of escapes from the supply system,

(g) the application of devices for waste water segregation and accumulation, and secondary using of water polluted by washing and showering for toilet flushing, outdoor washing and garden watering.

Domestic sewage is to be accumulated and/or treated in order to avoid the contamination of surface and groundwater resources. It may be, under appropriate environmental conditions and depending on the required degree of control (Fig. 2.13), discharged into a body of water if a sufficient discharge with adequate dissolved oxygen is available, so that the self-purification processes would not cause any nuisance. The appropriate method of domestic waste water disposal depends, therefore, on effluent quantity and quality as well as on local environmental constraints.

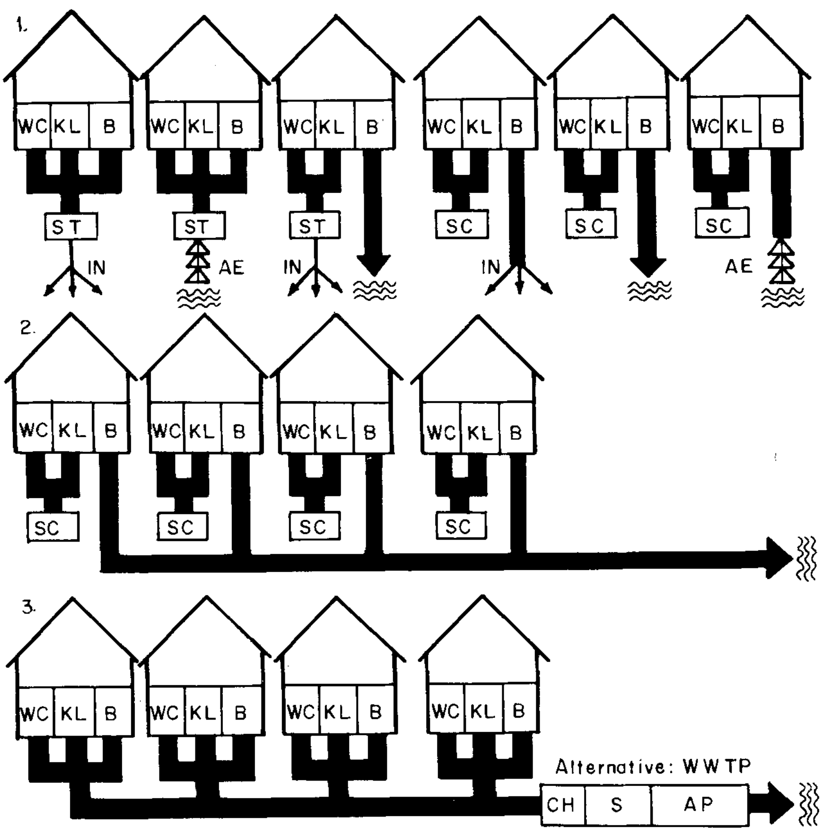


Fig. 2.13. Basic systems of domestic waste water disposal, resulting in a moderate local (scheme 1), moderate semi-centralized (scheme 2), and strict pollution control (scheme 3): KL - kitchen, scullery, laundry, B -bathroom, showers, washbasins, WC - toilet, ST - septic tank, SC - sludge container, S - sedimentation tank, CH- chemical treatment, IN - infiltration, AE - aeration, biological filter etc., AP - aerobic pond, WTP - waste water treatment plant.

2.5 INDUSTRIAL WATER SUPPLY AND RE-USE SYSTEMS

Industrial supply is enabled by industrial water supply and disposal systems, i.e. sets of structures, technological equipment such as measuring and controlling devices with associated feedbacks which secure the withdrawal and treatment of water, its distribution and circulation, as well as waste water treatment and recycling, sludge disposal and the harmless discharge of polluted water into appropriate recipients.

Process water in industry includes all water needed for

(a) processing, i.e. water entering the product and serving functional purposes,

(b) mining and hydraulic transport,

(c) cooling and air conditioning,

(d) boiling and heating,

(e) general use (cleaning, showering, drinking and other personal uses in industry).

Process water does not include water used for water power generation.

The use of water in industry is heterogeneous, and the relevant supply and disposal systems are complicated; these include

(a) open circuit operations - in one process

(b) successive re-use operations -

- of used water in other processes of the same industrial plant,
- of waste water in other plants or in agriculture,
- of municipal waste water in industry,

(c) recycling operations

- partial circulation (e.g. of cooling water)
- closed circuit operation, i.e. circulation and recycling of all waste waters (Fig. 2.14).

In the open circuit system the water withdrawal is discharged into recipient water resources after use in one process. The value of the water withdrawal W corresponds to the water requirement R, i.e. to the sum of the water entering the product or serving other functional purposes, return flow and the water losses

$$R = W = C_1 + \sum_{k=1}^{n} \Delta_k + F \qquad (1.s^{-1}) \qquad (2.66)$$

Water consumption in the open circuit system is

$$C = C_1 + \sum_{k=1}^{n} \Delta_k = W - F \qquad (1.s^{-1}) \qquad (2.67)$$

F - return flow (effluent)

C_1 - water consumption for functional purposes incl. water entering the product

Δ_1 to Δ_k - water losses in the supply, distribution and disposal system

Δ_m, Δ_n - water requirements for water/waste water treatment

The successive re-use of waste waters is characterized by the supply of water in qualities which differ from the quality requirements of the relevant produc-

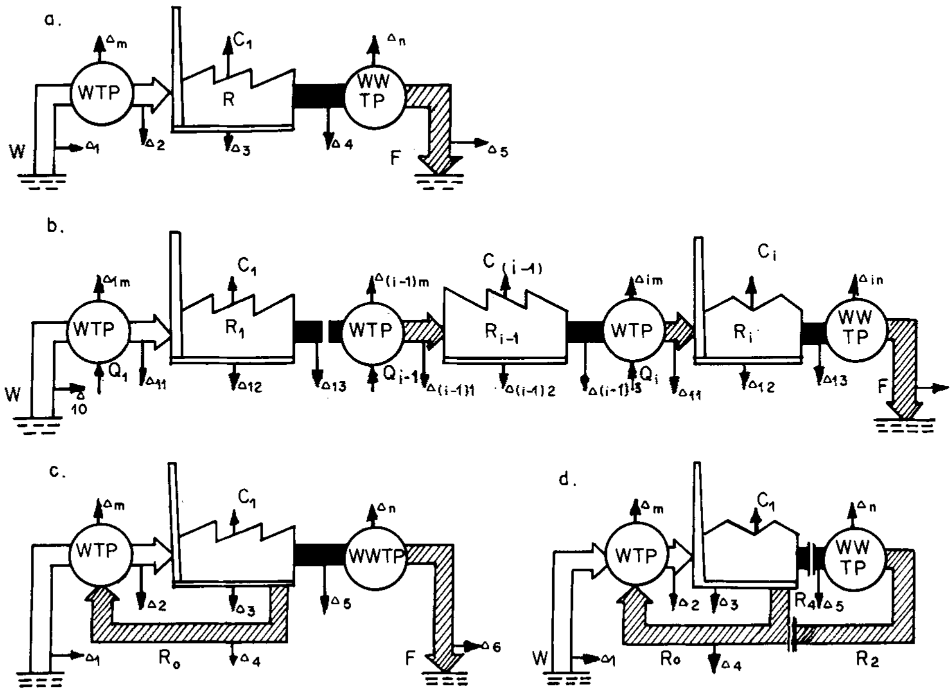


Fig. 2.14. Industrial water supply, distribution and waste water disposal systems: (a) open circuit system, (b) successive re-use system, (c) partial recycling system, (d) closed circuit system. WTP - water treatment plant, WWTP - waste treatment plant.

tion process. The basic problem of the direct re-use of water is:

(a) securing the quantity of water for successive technological processes taking into account the time schedule and hierarchy of water requirements,

(b) safeguarding the quality of the water for the following process, which depends on the quality of the preceeding one, and their schedule on the basis of the decreasing water quality, in order to economize on the water treatment e.g. by segregation of waste waters, re-use of important substances of waste waters etc.

During industrial processes, water is used

- in contact with the material or product without a thermic impact (category A) or without a thermic impact (category B)
- in closed systems without any contact with the raw material or product (category C), (Fig. 2.15, Tab. 2.23).

The criteria for water quality which safeguard successful water re-use and re-cycling are summarized by Appleyard and Shaw (1974) as follows:

(a) low content of suspended matter,

(b) low aggressivity,

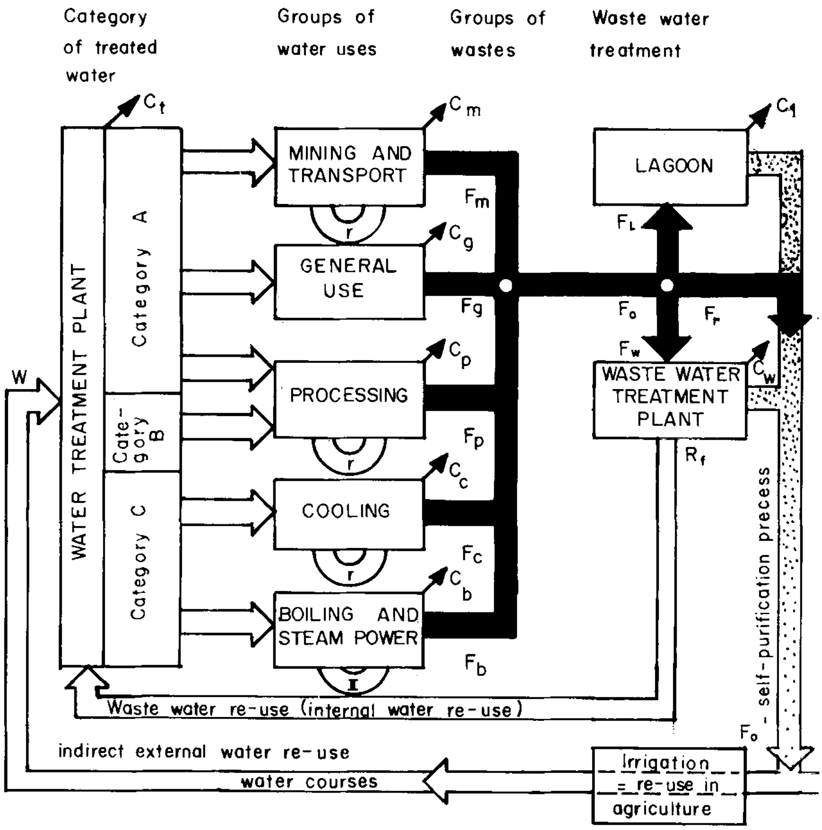


Fig. 2.15. Schematic representation of heterogeneous water quality requirements necessary for relevant groups of industrial processes. These processes result in heterogeneous quality of waste waters, that are to be treated in one waste water treatment plant and subsequently disposed of or re-used, both in industry and agriculture: r - water recycling, F_i - waste waters, C - water consumption, F - effluent, W - water withdrawal.

(c) no tendency to separate salts which are difficult to dissolve,

(d) bacteriologically reliable,

(e) no tendency to create biological deposits,

(f) suitable pH, suitable content of dissolved matter and acceptable odour.

Current water treatment processes are often inadequate when it comes to gaining water of such quality from waste water. The treated waste water contains excessive quantities of salts, including ions of ammonium and phosphorus, and a lot of organic matter, dissolved or suspended, which is bacteriologically dangerous and forms foam. If the current simple treatment processes are not capable of attaining water of suitable quality, the following physical and chemical processes should be applied:

TABLE 2.23

Water quality indicator		Water in contact with the product or with the raw material		Water without any contact with the product		
		without heating	with heating	Temperature of the medium 80°C	80-400°C	400°C
Temperature	°C	-	-	25-28	<28-40	<40-45
Suspended matter	$mg.l^{-1}$	200[1] 1000	30-45	20-30	10-20	5-10
Fat and oil products	$mg.l^{-1}$			20	10-20	10
pH		-	6.5-9	6,6-8,5	6,5-8,5	6,5-8,5
Total content Mg + Ca	$mmol.l^{-1}$	-	-	-	< 7	< 5
Carbonate content Mg + Ca	$mmol.l^{-1}$	-	-	1,2-3,5 $1,5-2,5^{+}$	1,5-3 $1-2^{+}$	1,5-2,5 $0,5-2^{+}$
Dissolved matter	$mmol.l^{-1}$			<4	<3,5	< 3
Chlorides Cl^{-}	$mg.l^{-1}$	-	-	<2000	<1300	< 800
Sulphates SO_4^{2-}	$mg.l^{-1}$	-	-	< 350	< 350	<150
Iron Fe	$mg.l^{-1}$	-	-	< 500	< 600	<250
Chemical oxygen demand						
by permanganate	$mg.l^{-1}$	10[1]	-	< 20	< 20	< 20
by bichromate	$mg.l^{-1}$	-	-	100-150	-	-
Total biochemical oxygen demand BOD	$mg.l^{-1}$	-	-	15-20	10-15	10-15
Bioelements						
Nitrogen N	$mg.l^{-1}$	-	-	50-80	50-80	-
Phosphorus P	$mg.l^{-1}$	-	-	2,5	2,5	-

Quality indicator for circulation water (+ supplementary water) according to information from COMECON (1976): [1] for flotation

(a) coagulation with low doses of ingredients in order to decrease the content of the suspended matter,

(b) sorption with active charcoal - in the case of high quality requirements,

(c) using ion exchanges - especially to eliminate the salinity and metallic ions in exchange for sodium, hydrogen and hydroxyl,

(e) reverse osmosis - for an efficient removal of organic matter and bacteria as well as of suspended and dissolved anorganic matter,

(f) electrodialysis - for the separation of dissolved matter, including acids, bases and salts,

(g) separation of foam - especially for the separation of detergents,

(h) ozonization - for disinfection and decrease in turbidity and content of organic matter,

(i) using immobilized enzymes - in order to remove dissolved organic matter including phenols and in order to decrease the content of pathogenic germs,

(j) fermentation and sterilization - to remove sulphite waste liquors etc.

The basic equations for successive water re-use are (Fig. 2.14b)

$$R_i = R_{i-1} - C_{i-1} - \sum_{k=1}^{n} \Delta_{(i-1)k} \pm Q_i \quad (m^3.s^{-1}) \tag{2.68}$$

$$C = \sum_{i=1}^{i} C_i + \sum_{i=1}^{i} \sum_{k=1}^{n} \Delta_{ik} = W + \sum_{i=1}^{i} Q_i - F \ (m^3.s^{-1}) \tag{2.69}$$

$$F = R_i - C_i - \sum_{k=1}^{n} \Delta_{mk} \quad (m^3.s^{-1}) \tag{2.70}$$

Q_i - excessive inflow that is to be diverted without use or deficit that is to be made up from other sources.

C - total water consumption

C_i - water consumption for functional purposes including water entering the product in the single process i.

Apart from the mentioned direct internal successive waste water re-use, indirect external water re-use also exists, i.e. repeated use of the same water along a river by different users, formed by the discharge of waste waters into water courses and by its successive withdrawal (Fig. 2.15). The ratio of the internal successive water re-use is as follows:

$$r_i = \frac{R}{W} \quad \text{or} \quad r_i = \frac{\sum_{k=1}^{k} R_k}{\sum_{k=1}^{k} W_k} \tag{2.71}$$

R - the total water requirements needed for relevant technological purposes $(m^3.s^{-1}, m^3)$

W - the total water withdrawals $(m^3.s^{-1}, m^3)$

The ratio of the external water re-use is expressed by the formula

$$r_e = \frac{\sum_{k=1}^{k} W_k}{Q_b} \tag{2.72}$$

Q_b - the guaranteed stream flow used for the compilation of water balances

The total ratio of water re-use is expressed by their product

$$r_t = r_e \cdot r_i = \frac{\sum_{k=1}^{k} R_k}{Q_b} \qquad (2.73)$$

Generally:

$$Q_b = Q_m + Q_r - \left[\sum_{k=1}^{k} W_k - \sum_{k=1}^{k} F_k \right] \qquad (2.74)$$

Q_m - minimum monthly discharge (98% of guarantee)

Q_r - guaranteed yield of reservoirs

The expression in brackets equals the total water consumption.

The repeated use of the same water inside a closed circuit is called water recycling. Water quality requirements call for water to be treated, at least by cooling after each cycle. In the case of an open system, part of the water quantity enters the circulation system and the rest is used once only or successively (Fig. 2.14c). Water requirements in a system with partial circulation are expressed by the sum

$$R = W + R_o \qquad (m^3.s^{-1}) \qquad (2.75)$$

The actual water requirements are substantially lower and are covered by the water withdrawal, which replaces the effluent of waste waters and feed water in order to replace losses and regenerate the water quality of the circuit

$$W = C_1 + \sum_{k=1}^{n} \Delta_k + F \qquad (m^3.s^{-1}) \qquad (2.76)$$

The water consumption is

$$C = C_1 + \sum_{k=1}^{n} \Delta_k = W - F \qquad (m^3.s^{-1}) \qquad (2.77)$$

The volume of water in the circulation system depends on the recycling rate and, therefore

$$V_o = R_o \cdot t_c \qquad (m^3) \qquad (2.78)$$

V_o - volume of water in the circulation system, whose regular exchange safeguards the regeneration of water quality

t_c - recycling rate (s)

In the closed circuit operation the effluent is limited to that quantity which enables the regeneration of the water quality (Fig. 2.14d)

$$F \doteq 0$$

The water withdrawal W in such case only covers the water consumption, i.e. the consumptive use incorporated in a product, by-product and waste material plus water losses

$$W = C_1 + \sum_{k=1}^{n} \Delta_k \qquad (m^3.s^{-1}) \qquad (2.79)$$

The intensity with which water is recycled or successively re-used depends on the type and degree of pollution. The closed circuit operation often requires complicated and expensive equipment. Water consumption in industry consists of the consumption during processing C_p , the consumption required to regenerate the water quality C_q and losses during treatment, distribution and recycling.

$$C = C_p + C_q + \sum_{k=1}^{n} \Delta_k \qquad (m^3.s^{-1}) \qquad (2.80)$$

The regeneration of the water quality includes water treatment and waste water treatment, clearing, sludge blow-off etc. During water recycling in industry, water requirements are covered by the sum of the recycled water R_o and by the supplementary water W abstracted from the resource.

The internal recycling coefficient is the ratio

$$r_i = \frac{R_o}{W + R_o} = \frac{R - W}{R}$$

The ratio of the water consumption is expressed by

$$r_c = \frac{C}{W} = \frac{C_1 + \sum_{k=1}^{n} \Delta_k}{C_1 + \sum_{k=1}^{n} \Delta_k + F} \qquad (2.82)$$

The ratio of the water consumption for closed circuit systems equals almost 1.

As was mentioned already, water consumption consists of the consumptive use by a product U_1, a by-product U_2 and by means of wastes U_3 as well as by returnable and non-returnable losses $_n$ and, therefore

$$r_c = \frac{\sum_{i=1}^{3} U_i + \Delta_r + \Delta_n}{W} \qquad (2.83)$$

The ratio of the water consumption has to be analyzed separately for the supply, water treatment and recycling system and for water entering the product, by-product and serving other functional purposes. The relevant values often depend on the season, being higher in summer due to the higher evaporation rate.

The water consumption during water supply, recycling and water treatment consists of non-productive losses only. The consumptive use during the technological process of water treatment is a pure loss from the production point of view. These losses can be reduced by technological and operational measures including maintenance, as well as by a decrease in water requirements in the production processes.

The beneficial use of water in industry can also be expressed by the ratio of withdrawal utilization

$$w_1 = \frac{W - F}{W} \qquad (2.84)$$

and by the ratio of losses

$$w_2 = \frac{W - F}{R} = \frac{W - F}{W + R_o} \qquad (2.85)$$

Basic indicators of the economy of water use in industry are the water requirements per unit of product and the water consumption per unit of such a product as well as the waste load generated per unit of production. Their values depend on each other, on water recycling and on the technology of production and of water supply. The basic interrelationships can be expressed conceptually in the form of a joint function:

$$^1R \, ; \, ^1C \, , \, ^1N \, , \, r_i = f_{1-4} \, (A \, , B \, , C \, , D \, , E \, , P_1 \, , M_{1-6})$$

^1R – water requirements per unit of production $(m^3.t^{-1})$

^1C – water consumption per unit of production $(m^3.t^{-1})$

^1N – waste load generated per unit of production $(t.t^{-1})$

r_i – internal recycling coefficient

A – combination of production process and product mix

B – nature of raw material used, which also influenced by-product production and waste material processing incl. material recovery

C – production technology including technology of waste material processing, operating rate

D – water quality (water quality indicators $q_1, q_2, \ldots . q_n$)

E – law and order, administration, the efficiency of their function

M_1 – water rates and cost of water treatment

M_2 – cost of waste water treatment and effluent disposal rates.

Water consumption, with the exception of cooling water, water for mining and the use of water in the food industry, does not generally form a substantial part of industrial water demand. Limiting water requirements serves to decrease the quantity of waste waters and water consumption, but need not necessarily lead to a decrease in the waste load generated, which depends more on the production technology.

The interrelationship between water requirement and water consumption is complicated, not only in terms of the quantity of waste water, but also of its quality, e.g. the environmental need to dilute waste water. The selection of a suitable technology from the water resources point of view requires an analysis of the combinations of water requirements, water consumption and waste loss generated per unit of production. The decision has to be taken on the basis of an economic evaluation of the environmental aspects of relevant production scenarios (Fig. 2.18).

2.5.1 Water for Processing, Mining and Hydraulic Transport

In the course of mining and hydraulic transport water comes into direct contact with the intermediate or final product without any thermic impact. During processing water comes into contact with the product or enters the product mainly as a cooling or heat-carrying material.

The quality requirements for water which comes into contact with other products without any thermic changes depend substantially on the nature, quantity and maximum size of the solid particles, which should be specified for the relevant use.

No treatment is required for some industrial uses, e.g. for the hydraulic transport of slag or coke cooling. Simple pretreatment, e.g. mechanical, is often sufficient for a considerable number of technological processes, especially for cooling, mining and hydraulic transport. During this pretreatment the content of iron Fe, manganese Mn and aluminium Al has to be reduced. Pretreatment should include processes aimed at removing ingredients which may interfere with further water treatment processes.

Water which comes into direct contact with the product by mining, beneficiation of ore, transport of ashes and coal, cleaning of gases etc., accepts pollution from the raw material or the intermediate product. It has to be treated before the new cycle of use.

Heterogeneous quality requirements on water for processing, which also depend on its transport in the pipeline system, often require the application of multigrade treatment technologies, including

(a) mechanical processes,
(b) thermic processes,
(c) magnetic processes,

(d) chemical processes,

(e) biological processes.

Chemical water treatment includes softening, decarbonization, deionization, demineralization and other processes aimed at decreasing the content of organic matter and dissolved oxygen, especially by using macromolecular ion exchangers.

TABLE 2.24

Interference agents	Negative impact on
Iron (Fe) Manganese (Mn) Humines	taste and/or colour of tee, coffee, yeast, dough, malt, beer, milk, cheese, starch, sugar, tinned food cathalytic disintegration of fats, reduction in durability of food
Calcium/magnesium carbonate ($CaCO_3$ + $MgCO_3$) 1)	taste/floculation of cacao taste of butter, other milk products, and beer turbidity/colour of alkoholic beverages, bottom sediments
Chlorides (Cl^-) 1)	taste of coffee and tea
Natrium (Na) Hydrogencarbonate	stability of vitamins
Nitrates	production processes
Oxygen (O_2) 1)	oxidation of fats, decomposition of proteins (acceleration)
Putrefactive and iron bacteria, mold fungi, dregs etc.	negative impact on taste, cause of health difficulties, disturbance in production processes

Negative impact of selected agents on food products: 1) high content

Multigrade water treatment processes combine cheap processes for removing a substantial part of the undesirable components with more expensive processes aimed at achieving the desired quality for a limited volume of water for certain single, specific process. The final product of this treatment is water of different qualities which is suitable for certain specific technological processes.

During the use of water in contact with the product and as a cooling and heat carrying medium, it is possible that carbonates, other salts, gases and organic matters may separate. In this way water is used during catching, cooling and cleaning of gases, extinguishing of coke etc. also in the food industry. The quality requirements in this group are complex and should correspond not only to the previous ones, but also to the requirements for cooling and heat carrying matter. These requirements, which are peculiar to each production process, have to be determined separately.

For the pharmaceutical and food industry drinking water is used and additional quality requirements applied for in order to safeguard the appropriate standard of these products (Tab. 2.24).

2.5.2 Cooling Water

Cooling water, which accepts and removes the excess heat during industrial production, forms some 60-80% of the water quantity needed in industry. This water undergoes thermal changes and often requires thermal treatment, including all the processes of water warming, cooling, distilling, mixing with vapour and degasifying. Cooling by water in contact with the semi-finished product as contact cooling is a part of processing.

TABLE 2.25

Losses through	Requirements of cooling water ($m^3.s^{-1}$)	Water consumption (losses)	Type of losses
Once-through systems	R ($m^3.s^{-1}$)	$\Delta_e = c_e \cdot (T_2 - T_1) \cdot R$ $\Delta_e = 0.001.(T_2-T_1+10).R$	evaporation leakage
Open circuit systems	$\frac{0.241.J}{T_2 - T_1}$	$\Delta_e = 0.002.(T_2-T_1+13).R$	evaporation (concentration) wind impact spreading, leakage, mud discharge
Closed circuit systems		$\Delta_e = 0.01.R$	evaporation (concentration) leakage mud discharge

Losses through
I. wind impact
II. spreading $\Delta_{I-IV} = c_{I-IV}.R$
III. leakage
IV. mud discharge (sludge)

J - heat diverted ($J.s^{-1}$)
T_1- water inflow temperature
T_2- water outflow temperature (^oC)
R - cooling water requirements

Water requirements and losses in different cooling systems. Water requirements in once-through systems are permanent, in circuit systems once per operation cycle.

Systems for cooling without any contact with the product are like other industrial water systems, namely

(a) open circuit systems,

(b) recycling systems

- open, when the heat is removed by the direct contact of water and air,
- closed, when the heat is removed without any direct contact with air, i.e. in a closed heat exchanger.

Cooling is needed e.g. in steam and nuclear power plants, during vapour condensation, bearing and oil cooling, as well as for the indirect cooling of gases and liquids, furnaces, kilns etc.

Water requirements depend primarily on the technological process and its temperature, i.e. on the quantity of heat J ($J.s^{-1}$) to be removed and, secondly on the type of cooling system (Tab. 2.25, 2.26). They are substantially lower in recycling systems. Closed systems prevent evaporation, thus further decreasing both water consumption and water requirements. Between 80 and 400°C air cooling is more advantageous than water cooling.

TABLE 2.26

Cooling systems	Evaporation losses at the air temperature 0° C	10° C	20° C	30° C	Losses through wind impact
Cooling towers					
- with natural draught	0.0010	0.0012	0.0014	0.0015	0.001-0.003
- air blowers					0.005
Outdoor sprinklers	0.0020	0.0024	0.0028	0.0030	0.015-0.020
Cooling ponds and tanks	0.0007	0.0009	0.0011	0.0013	0

Water loss coefficients through wind impact c_I evaporation c_e and their dependence on air temperature and type of the system.

The quality requirements for water used as a cooling medium without any contact with the product are derived in such a way as to ensure the safe and efficient operation of the system (Tab. 2.27). They may be low for open circuit systems and must be high for recycling systems, preventing especially their corrosion and clogging. The quality requirements for water used in heat exchangers should safeguard its thermostability, i.e. eliminate the growth of biomass, the separation of carbonates and other salts and gases, etc., even under conditions of multiple cycles of warming and cooling (Tab. 2.23).

A cumulation of the following suspended matter occurs in the recycled water:

(a) crystals of salts, especially of calcium carbonate $CaCO_3$ which are difficult to dissolve,

(b) the products of corrosion,

(c) microorganisms,

(d) dust and soot (especially in open systems).

Cooling water has to be treated mechanically by filtration, by alkaline clarification, by ion exchangers, or magnetically, in order to decrease the sedimentation, especially of the calcium carbonate. The sedimentation rate in a closed system is essentially lower than in an open system.

TABLE 2.27

Velocity of water flow ($m.s^{-1}$)	Permissible concentration of pollution ($mg.l^{-1}$) Continuously	Short-term
<0.01	< 5	<20
0.01-0.2	10 - 20	50
0.2-0.5	30 - 50	100

Permissible concentration of pollution in cooling water and its dependence on the cooling water flow velocity.

For the treatment of water for cooling, it is necessary to remove organic components, which are able to form porous deposits in a warm environment, thus clogging the cross profile of the pipeline system, increasing the flow rate and decreasing its heat conductivity. In the closed circuit recycling system it is not necessary to remove the infectious bacteria: this is only indispensable when the water comes into direct contact with the product or with the staff in some industrial branches, especially in the food and pharmaceutical industries.

2.5.3 Boiling and Stream Power Water

Boiling water is used as a heat carrying medium without any contact with the product and undergoes similar changes as cooling water. Boiling water and steam is used

(a) during processing,

(b) for heating and ventilation,

(c) for power generation,

(d) as warm service water.

The temperature of water in the supply network of warm water systems generally depends on the energy input and often reaches 150°C. Temperatures not exceeding 100°C are admissible in networks whose output does not exceed 1.7 GJ per hour. Warm water for industrial purposes is seldom supplied by the municipal supply system.

The water quality requirements follow

- the decrease in corrosion
- the decrease in clogging.

Corrosion is supported by free CO_2, low pH factor (< 8), iron Fe and copper Cu content, and by a higher oxygen content (> 0,02 mg $O_2 . l^{-1}$). Clogging is caused mainly by $CaCO_3$, $MgCO_3$, H_2SiO_3, sediments, organic colloids and oil.

The quantity of water in power generating systems is formed by feed water to fill the system and supplementary water to cover water losses, caused especially by leakage and evaporation:

$$V_o = R_f + R_s - \int_0^t \Delta dt \qquad (m^3) \qquad (2.86)$$

V_o - volume of water in the recycling system (m^3)

R_f - feed water (for the first filling up) (m^3)

R_s - supplementary water (m^3)

Δ - water losses $(m^3.s^{-1})$

t - time (s)

After the first filling of the system $V_o = R_f$ and, therefore,

$$R_s = \int_0^t \Delta dt \qquad (m^3) \qquad (2.87)$$

Total water requirements, corresponding to the water withdrawal, are

$$W = R_f + R_s \qquad (m^3) \qquad (2.88)$$

The quality requirements of the feed and supplementary water should also safeguard its thermostability, limiting the content of suspended matter, oil and chemically aggressive components to almost nil. Such water should be clear and without any colour. The total content of ions is limited to 10-14 $mmol.l^{-1}$, ions of calcium Ca^{2+} and total carbon dioxide CO_2 to less than 3.6 - 7.0 $mmol.l^{-1}$. Lower values correspond to the density of the energy output above 23 $kW.m^{-2}$ (Tab. 2.28).

The content of gases and organic matter in condensed steam depends on the nominal pressure and on the thermal scheme of the system - it exceeds the water content. The feed water of these systems is a mixture of the returned condensed steam and the supplementary water.

Methods of treating the condensed steam include filtration, demineralization and deoxygenation. Steam treatment in heating plants and power plants often includes the softening and removal of organic matter and oil. Steam systems have to be protected from the aggressivity of water by maintaining the protective alkalinity, which can be achieved by dosing solid or volatile deoxigenation or other agents. This protection can also be achieved under a neutral regimen by the removal of corrosive gases, salts and other aggressive particles, i.e. by the treatment of the condensed steam and by the demineralization of the supplementary water.

TABLE 2.28

Water quality indicator	Unit	Evaporators	Steam exchangers	Boilers with nominal pressure 0.15 MPa: <23 kW.m^{-2}	Boilers with nominal pressure 0.15 MPa: >23 kW.m^{-2}	Discharged boilers: <6.5 MPa	Discharged boilers: >6.5 MPa	Drum boilers: 6.5 MPa	Drum boilers: 9.6 MPa	Drum boilers: 13.9 MPa	Drum boilers: 17.8 MPa
$Ca^{2+} + Mg^{2+}$	μmol.l^{-1}	15	15	50	15	1.5	0.25	2.5	1.5	1	0.5
C_2	μg.l^{-1}	50	50	500	100	20	10	20	10	10	10
CO_2	mg.l^{-1}					1	0.5	5	1	0.5	0.5
Fe	μg.l^{-1}					20	20	30	20	20	20
Cu	μg.l^{-1}					5	5	10	5	5	5
Oxidizability COD_{Mn}	mg O_2.l^{-1}						1	5	3	2	2
Suspended matter	g.l^{-1}						50	-	50	50	50
Specific electrical conductivity	10^3 μS cm^{-1}	9+	9+	13+	10+	0.5	0.3				
SiO_2	μg.l^{-1}					20	20	6+	2.5+	0.6+	0.3+
p-apparent alkalinity	mmol.l^{-1}							0.05-1.5		< 0.05	
Surplus of P_2O_5	mg.l^{-1}							2-10	1-3	0.5-2	0.3-1
Oil	mg.l^{-1}	3	3	3	3						

Water quality indicators for feed and boiler water (+) depend on the type and output of the thermal economic system.

Heated water and steam form a medium which enables the transformation of chemical and nuclear energy into electrical energy in thermal and nuclear power plants. According to Minasian et al. (1977), the water requirements reach

	At present	in 2000	
- in a thermal power plant	0.127	0.104	m^3.kWh^{-1}
- in heat and power plants	0.101	0.050	m^3.kWh^{-1}
- in nuclear power plants	0.200	0.125	m^3.kWh^{-1}

The ratio of water consumption in this case reaches 0.01 to 0.02. Davis and Wood (1974) estimate water consumption during power generation at 10 km^3 yearly. The water demand for this purpose in developed countries is gradually reaching the water demand for irrigation. But the use of water for power generation purposes is not as consumptive.

2.5.4 Water Losses in Industry and Flow Chart of Water Use

Because of the prevailing percentage of water used for cooling purposes, the prevailing losses of water in industry are formed by

	Percentage of the volume of water used
(a) evaporation	1.5 %
(b) escape and spreading	0.2–0.8 %
(c) leakage and leaching	1 - 2 %
(d) mud discharge	up to 6 %.

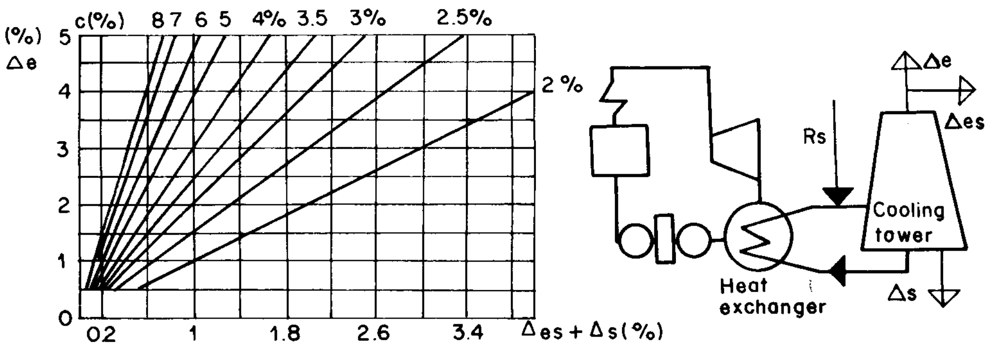


Fig. 2.16. Interrelations of evaporation, spreading and wind action losses and of the concentration of salts in a water cooling system: e - evaporation, es - spreading and escape, s - sludge, c - concentration of salts.

The prevailing losses are those caused by evaporation. They depend not only on the type of the system and its equipment, but also on the method of its operation. Minimum losses can be achieved in closed recycling systems by uninterrupted operation. Losses through evaporation and corrosion cause the concentration of salts which may exceed the relevant maximum permissible values in the recycling system (Fig. 2.16). This concentration is defined by the following concentration ratio (for a cooling or similar system)

$$c = \frac{\sum_{i=1}^{3} \Delta_i}{\sum_{i=1}^{2} \Delta_i} \qquad (2.89)$$

Δ_1 - losses through escape (Δ_a) (m^3)

Δ_2 - losses through spreading (Δ_{es}) (m^3)

Δ_3 - evaporation losses (Δ_e) (m^3)

Losses through water escape may arise in open systems only when the air flow takes away droplets and carries them outside the cooling system. The value of this loss depends on the air flow rate, i.e. on the gradient of temperatures and the type of system.

Losses through spreading arise as a result of the influence of wind, i.e. again in open systems only. The value of this loss depends on the construction of the spray cooler and on the velocity of the wind. Its value is not constant and, therefore, cannot be replaced by an estimated average.

Unproductive leakage may not only arise in cooling systems, but also in lagoons, oxidation ponds etc., i.e. after processing. They do not necessarily increase the relevant water requirement. Their values reach a maximum after the first filling up of the reservoir and then gradually decrease due to clogging.

Losses during water purification or waste water treatment are caused by using water as a medium for collecting waste material and sludge. They occur periodically or permanently, depending on:

N – the volume of removed waste material (m^3)

w – the moisture content of the waste material (%)

t – the time period of their accumulation (s)

$$F_m = \frac{N \cdot w}{t \cdot 100} \quad (m^3.s^{-1}) \qquad (2.90)$$

Water consumption and mud discharge water in a recycling system has to be replaced by supplementary water R_s

$$R_s = C + F_m = \sum_{i=1}^{3} U_i + \sum_{i=1}^{n} \Delta_i + F_m \quad (m^3.s^{-1}) \qquad (2.91)$$

F_m – mud discharge water, replaced for improving water quality ($m^3.s^{-1}$)

U_{1-3} – consumptive use by a product, by-product and by means of wastes ($m^3.s^{-1}$)

The function of industrial water supply and disposal systems using water in contact or without any contact with the product can be analyzed by means of modelling. The model using water without any contact with the product includes e.g. a spray cooler, treatment plants for the recycled and feed water and for mud discharge.

Inputs of such a model include (Fig. 2.17)

- feed (supplementary) water, characterized by

R_o – discharge ($m^3.s^{-1}$)

c_o – concentration of dissolved solids ($mg.l^{-1}$)

T_o – water temperature (^oC)

- liquid and solid particles entering the system from the air characterized in the same way, Q_a, c_a, T_a
- thermal energy: J_o, J_a, J_m. (J)

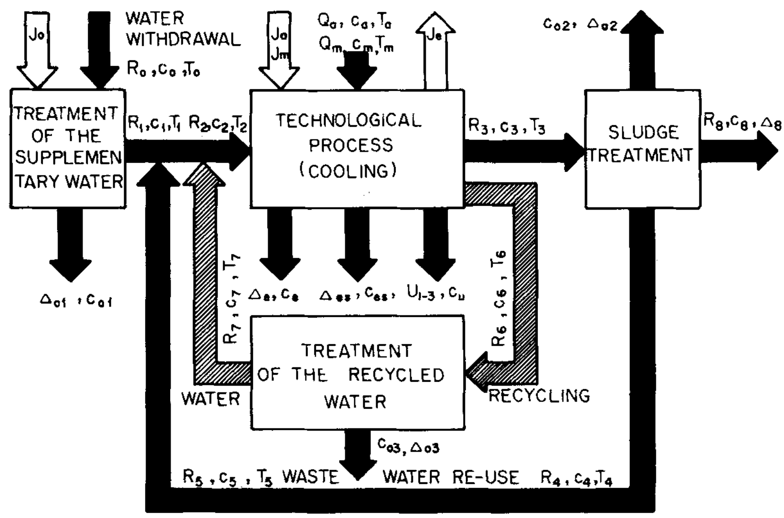


Fig. 2.17. Simple model of water usage in industry with one water recycling and one water re-use circuit, illustrating the balance of water quantities, of the diluted and suspended matter and of the energy input and output.

Inputs in a system using water in contact with the product include, in addition to this,

- liquid and solid particles entering the system from the raw material and semi-finished product (Q_m, c_m, T_m)

Outputs of a model of industrial water supply and disposal system without any contact with the product include:

- waste water, characterized by

R_8 - discharge ($m^3.s^{-1}$)

c_8 - concentration of dissolved solids ($mg.l^{-1}$)

T_8 - water temperature (^oC)

- mud discharge (from the treatment of the recycled water, sludge treatment etc.)
- water losses through evaporation Δ_e, escape and spreading Δ_{es}
- losses of energy (e.g. by evaporation J_e)

Outputs in a system using water in contact with the product include, in addition to this,

- consumptive use U_1 , U_2 , U_3.

Using such a model, the balance

(a) of the water quantities (water delivery, recycling and disposal),

(b) of the diluted and suspended matter

(c) of energy input and output

can be analyzed in different parts of the system.

(a) The volume or discharge of the supplementary water can be determined on the basis of the balance

$$R_1 = \sum_{i=1}^{8} \Delta i + \sum_{k=1}^{3} U_k + R_8 - Q_a - Q_m \qquad (m^3.s^{-1}) \qquad (2.92)$$

Apart from the supplementary water R_1 the recycled water R_7 and re-used water R_5 also enter the subsystem, thus

$$R_2 = R_1 + R_5 + R_7 \qquad (m^3.s^{-1}) \qquad (2.93)$$

$$R_2 = \Delta_{es} + \Delta_e + \sum_{k=1}^{3} U_k + R_3 + R_6 - Q_m - Q_a \qquad (m^3.s^{-1})$$

The outfall from the industrial water system is the waste water

$$R_8 = R_3 - R_5 - \Delta_{02} \qquad (m^3.s^{-1}) \qquad (2.94)$$

and mud discharge

$$N = \Delta_{01}.c_{01} + \Delta_{02}.c_{02} + \Delta_{03}.c_{03} \qquad (2.95)$$

(b) The chemical balance can be analyzed by equations of the following type:

$$R_2.c_2 = R_3.c_3 + R_6.c_6 + \sum_{k=1}^{3} U_k.c_k + \sum_{i=1}^{n} \Delta_i \; c_i + Q_m c_m + Q_a c_a \qquad (2.96)$$

The water quality in the system changes as a result of the input of energy and matter. In the case of a cooling system ($U_{1,2,3} = 0$), the rate of disintegration, caused by different chemical and biochemical processes resulting in changes in water quality, depends on the discharge to volume ratio in the cooling plant. This can be expressed by a differential equation

$$\frac{dc_i}{dt} = \frac{R_3.c_{3i}}{V} \qquad (2.97)$$

c_i - concentration of the water quality indicator i ($mg.l^{-1}$)

V - volume of water in the system

The rate of concentration changes in the component i depends on the original maximum concentration $c_{i(0)}$ at the moment t_o

$$c_{i(t)} = c_{i(0)} \cdot e^{-\frac{R_3}{V}(t-t_o)} \qquad (2.98)$$

The trouble-free operation of an industrial water supply, and re-cycling and disposal, system requires a stable water quality, which should be maintained by

- a sophisticated water recycling and re-use system
- appropriate delivery of the supplementary water
- maintenance of water quality by an appropriate dosage of relevant chemical substances.

The dose of the chemical substance to maintain its required concentration (to protect the water supply and recycling system or to maintain the quality required for processing) is, therefore,

$$c_t = \frac{R_1 \cdot c_1}{R_3} + \left[\frac{c_{i(0)} - R_1 \cdot c_1}{R_3}\right] \cdot e^{-\frac{R_3}{V}(t-t_o)} \qquad (g) \qquad (2.99)$$

The influence of water losses on water quality differs: evaporation losses change the concentration of most water quality indicators, while seepage, escape and spreading do not. To maintain the required water quality, the necessary input of the supplementary water is to be derived from evaporation losses Δ_e and the differences in the input and output concentration

$$R_1 = \Delta_e \cdot \frac{c_3}{c_3 - c_2} \qquad (m^3.s^{-1}) \qquad (2.100)$$

When the water treatment plant of both the supplementary and the recycled water are able to maintain a constant water quality, the changes in concentration depend mainly on the evaporation rate and on the matter input from the water re-use circuit. The quality of water that can be recycled depends on the permissible concentration of the suspended matter and on the efficiency of filtration in the treatment plant of the recycled water. High efficiency of filtration helps to increase the ratio of the recycled water

$$\frac{R_6}{R_3 + \Delta_{es}} = \frac{f}{1-f} \qquad (2.101)$$

f - efficiency of filtration

(c) The water temperature in different parts of the system and the temperature of the waste water can be determined from different equations of the energetic balance, e.g.

$$J_8 = J_o - J_e - \sum_{i=1}^{n} \Delta J_i + J_a + J_m \qquad (J.s^{-1}) \qquad (2.102)$$

Water recycling and re-use require higher funds to be allocated by the user for the investment, enabling him to make savings in operation costs. The application of these technologies results in a reduction of water withdrawals with a subsequent improvement of water balances and of the water quality in surface and groundwater resources.

2.5.5 Waste Waters and Waste-free Technologies

Waste water which is discharged into streams constitutes an ever-increasing proportion of water supply. With regard to the self-purification and water treatment process, the relevant waste particles can be considered as

(a) biologically degradable,

(b) biologically undegradable.

In effect, the contamination caused by industrial waters can be categorized as

(a) chemical - diluted and suspended chemicals,

(b) biological - bacteria, viruses and other pathogenic organisms,

(c) thermal.

Industrial waste waters are generally mixed. The contamination is mostly toxic; but the harmfulness of the wastes depends not only on their toxicity, but also on their ability to slow down or to stop the processes of self-purification in rivers, or of biological water treatment in relevant plants.

TABLE 2.29

Waste water groups		Origin	Suitability for re-use and re-cycling
Cooling	F_c	cooling systems	good, occasionally without specific treatment
Mining and hydraulic transport	F_m	lagoons, settling tanks	good, simple treatment technologies
Processing incl. rinsing	F_p	quality depends on raw material and technology applied	generally demanding treatment technologies; food, paper and pulp industry waste waters suitable for irrigation; possibilities for material recovery
Sewage	F_g		not suitable for industrial re-use, suitable for irrigation
Other waste waters	F_b	feed water, precipitation	not suitable, accidental occurrence, requires accumulation

Classification of industrial waste waters with regard to possibilities of their re-use and re-cycling. See Fig. 2.15.

The possibilities of waste water re-use or recycling depend on the quality of the waste waters concerned, i.e. on their origin and on the type of the industrial process (Tab. 2.29). The outfall of the system is treated waste water:

$$F_o = \sum_{i=1}^{5} F_i - \sum_{i=1}^{e} \Delta_i \qquad (m^3.s^{-1}) \qquad (2.103)$$

This quantity, or part of it can be re-used, thus decreasing the quantity of waste waters discharged into water resources (Fig. 2.15):

$$F'_o = F_o - R_w - \sum_{i=f}^{m} \Delta_i \qquad (m^3.s^{-1}) \qquad (2.104)$$

Data on the chemical and biological composition of waste waters can be derived by an analysis of the relevant technological processes on the basis of the material balance. The degree of pollution of industrial waste waters can be compared with domestic sewage by means of population equivalent values. The population equivalent value of industrial pollution corresponds to the number of inhabitants producing pollution whose biological oxygen demand BOD_5 has the same value as waste waters from the relevant industrial production processes. This population equivalent value E can be related to the daily production or to the production unit:

$$E = \frac{BOD_5(g.m^3) \ . \ Q(m^3)}{54 \ g \ BOD_5} \text{ (per unit of production, per day)} \qquad (2.105)$$

The sewerage system normally discharges different kinds of sewage water, or discharges different types of sewage waters separately. Nevertheless it is necessary to prevent the penetration of aggressive substances into the sewerage system, or to prevent the penetration of waters containing

(a) matter which destroys sewerage structures or damages the materials of the sewerage system,

(b) matter which causes breakdowns in the waste water treatment processes.

(c) matter which is infectious, contaiminated, poisonous, narcotic or radioactive to such a degree that it threatens the health of the staff in the treatment plant or of the population, or forms these substances in admixture with waste waters from other processes,

(d) explosive or combustible substances, or compounds which form such substances with water or air or other substances which can penetrate into the system,

(e) substances with an extremely offensive odour or which cause such an odour in admixture with waste waters from other production processes.

These waters are also not suitable for re-use or recycling. The penetration of waste waters into water resources leads to a deterioration in their quality, as well as in the quality of the other compounds of the biosphere.

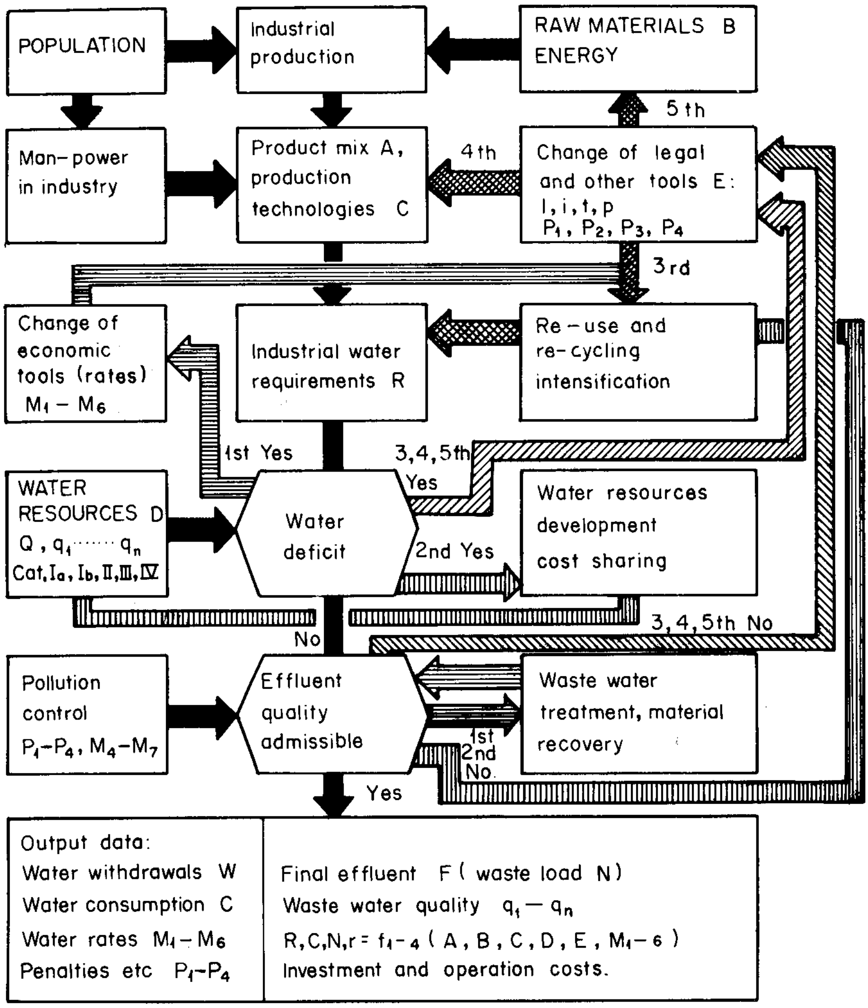


Fig. 2.18. Block diagram for the determination of water requirements and management of water deliveries as well as waste water disposal in industry in accordance with the hierarchy of goals and the basic limitations.

In order to reduce the negative impact on future development, the utilization of water in industry should be rationalized, especially by means of the following water-saving measures (Fig. 2.18):

(a) reducing water wastage,

(b) limiting the duration of water utilization during technological processes to the absolute minimum,

(c) selecting processes which entail minimum water consumption and minimum water pollution,

(d) applying internal recycling and waste water re-use,

(e) decreasing the requirements on water quality to the technologically permissible limit and by using available resources of low quality,

(f) using industrial waste waters in other branches of the national economy, especially in agriculture.

A decrease in the volume of wastes in industrial production can be achieved by

- a change of technological processes,
- a change of product mix, enabling the utilization of waste material as raw material for other products,
- a reduction in the weight of products
- water recycling and waste water re-use,
- using selected waste material as fertilizers in agriculture.

Liquid, solid and gazeous wastes are often suitable

- as raw material for other production processes,
- for material recovery,
- for soil regeneration,
- for power generation.

These problems are interdisciplinary, having an impact not only on water management, but also on the biogeochemical cycles and the exhaustion of the natural resources. To moderate this problem, the production processes should be gradually, as far as possible, incorporated into natural biogeochemical cycles.

Production processes which are aimed at the maximum utilization of all raw materials on the one hand and at the re-use of material products after their utilization on the other hand gradually lead to waste-free technologies. Their introduction requires the variety of products and the system of their utilization to be changed, in order to enable their return into the production cycle or their unexceptional coalescence with the environment. This goal can partly be achieved by the higher service life of products, if their repair is economically feasible. The issue of energy consumption is also interconnected with these problems, because power generation likewise leads to the over-utilization of available natural resources and to environmental pollution (Fig. 2.19).

The necessary reorganization of production can be achieved by grouping relevant production processes into integrated schemes. In such a way it is possible to apply continuous technologies, which may be financially less feasible, but restrict the negative impact on the environment. But there are limits to production concentration. A high concentration, even in the case of a low production of wastes per product, causes such a high concentration of waste material and waste waters that this cannot be locally and economically disposed of without harmful effects on the environment.

The step-by-step introduction of waste-free technologies requires a systema-

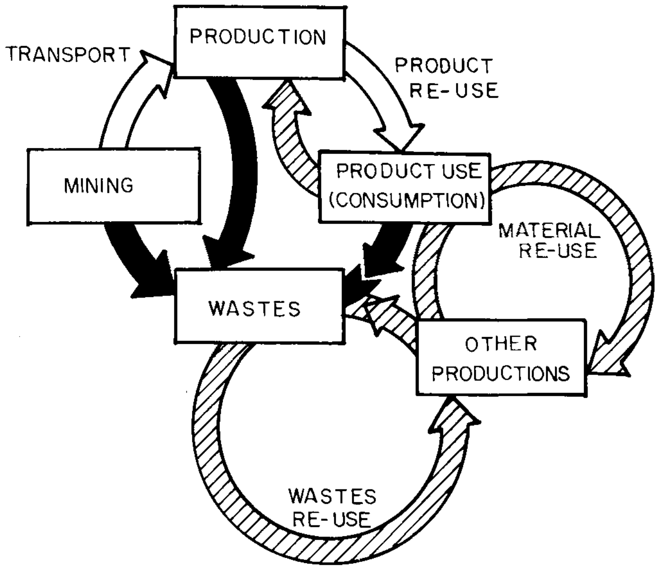


Fig. 2.19. Schematic representation of the conventional natural resources-demanding production and consumption process which leads to accumulation of wastes (black arrows) and to an excessive environmental pollution. Unconventional waste-free technologies (hatched arrows) decrease the environmental pollution and the natural resources exhaustion.

tic approach, which must consider all the scientific, technical, economic, structural and social aspects of human development: industrial production, transport and power generation, covering the sphere of all users: in short, the everyday life of all inhabitants. The transition to this prospective technology is an integrated and gradual process aimed at closing the circle between the sphere of production and the sphere of users.

2.6 WATER IN AGRICULTURAL SYSTEMS

Agricultural production is a result of the function of agricultural systems and has to be managed within their framework. An agricultural system can be defined as a set of interconnected soil and microbiological, plant, mechanical and human elements whose interaction produces organic matter for the nourishment of man on the basis of the supply of solar, mechanical and human energy and matter including water, fertilizers and agrochemicals (Fig. 2.20). This system can also be expressed as the intersection of plant ecosystems, the microbiological system of soil and the livestock breeding as well as agrochemical producing system

$$AS = PE \cap MS \cap IA \qquad (2.106)$$

AS - agricultural system

PE - plant ecosystems (t)
MS - microbiological system of soil (t)
LA - livestock breeding and agrochemical producing system (t)

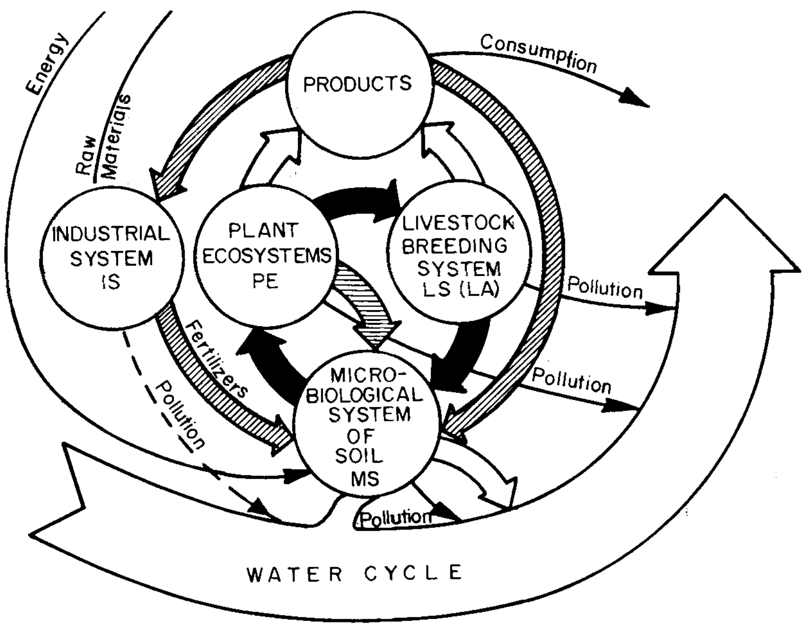


Fig. 2.20. Agricultural system, its environment and basic interrelationships of its subsystems (microbiological soil system, plant ecosystem, livestock breeding system). Basic inputs (energy and labour, sediments and fall-out, fertilizers and pesticides) and outputs (plant and animal products, eroded and leached material).

The process of the accumulation and transformation of solar, mechanical and human energy and matter takes place especially on the active surface of soil minerals, in their microbiological communities, in the roots, stems, leaves and fruits of plants and in the digestive organs of livestock. Plant ecosystems transform solar energy, water and nutriments into organic matter. This plant matter, decomposed especially by the digestive organs of polygastric livestock, is transformed into more complicated proteins, sacharides and animal fat.

Waste matter which has not been incorporated into the resulting animal matter contains mainly carbon and nitrogen. It returns into the soil in the form of manure, dung-water etc. and is subsequently transformed into polymolecular matter, or humus, by the microbiological communities in soil.

This process regenerates the bioenergetic potential of the soil, which depends on the extent of the active surfaces and the structure of the soil components and may be characterized as

$$E = \frac{\sum Y}{\sum N} \qquad (2.107)$$

$\sum Y$ - dry weight of yield (t)
$\sum N$ - weight of main nutrients (nitrogen N, phosphorus P, potassium K) (t)

The stability of the agricultural system and the permanent course of the agricultural production process depend on the equilibrium of the relevant soil, plant and animal subsystems and on the equilibrium of the agricultural system and its environment within the framework of the natural biogeochemical cycles: Basic input factors, i.e. energy, water and labour, must safeguard a permanent and sufficient supply of relevant matter from one subsystem to another. In the case of an insufficient or interrupted supply, the system becomes unstable and can enter an uncontrollable state.

Two of the existing feedbacks in an agricultural system are particularly important and regenerate the bioenergetic potential E

$$PE \longrightarrow MS \qquad (2.108)$$

$$LA \longrightarrow MS \longrightarrow PE \longrightarrow LA \qquad (2.109)$$

The agricultural production gradually takes away, for the sake of human society, a certain amount of matter in the form of plant and animal products, thus destroying the natural balance. Where this production is very intense, the missing matter is not sufficiently replaced by the biogeochemical cycles. It has, therefore, to be replaced artificially, by means of fertilizers and irrigation.

A positive biogeochemical development of the territory sets in whenever the functions of the agricultural system gradually bring more and more matter into the biogeochemical cycles. This process, which results in an extension of the biological productivity of the territory, can be achieved

(a) extensively - by the extension of agricultural land,

(b) intensively - by the intensification of the agricultural and agro-industrial processes, i.e. by an increased input of energy and matter, especially water, fertilizers and forage.

Agricultural water requirements are frequently satisfied by a combination of on-site and external supplies. The regulating function of water has to be achieved by an external water supply for

(a) regulating the soil moisture by means of irrigation and drainage,

(b) livestock and poultry breeding,

(c) fish and water poultry breeding,

(d) processing, boiling, cooling, heating, waste disposal,
(e) public uses in agricultural settlements.

2.6.1 Agricultural Production and Agricultural Yield

The subsystem of the lithosphere and atmosphere where plant production takes place includes

(a) 2 - 4m deep and, exceptionally, deeper soil layer with the root system and microbiological communities,

(b) 2 - 6m high and, exceptionally, higher layer of the atmosphere containing the upper part of the plants.

Present-day agricultural production is becoming a more and more complicated process with industrial character, which has, inter alia for economic reasons, to take maximum advantage of natural factors and must not be allowed to adversely affect the environment. The agricultural yield in a given area is a function of eight factors

$$Y = f(S, W, C, F, M, H, Q) \qquad (t.ha^{-1}) \qquad (2.110)$$

Y - yield
S - soil type, its texture and structure, its water holding capacity (relatively stable)
W - weather, supply of energy and water (variable, controllable only in hothouses)
C - quality and suitability of plants and their seeds (controllable in advance)
F - quality and suitability of fertilizers (controllable in advance)
M - machinery and its proper utilization (operatively controllable)
H - human labour (operatively controllable)
Q - water supply and its appropriate timing, water quality and appropriate irrigation practices.

Weather and soil, stable within the framework of crop rotation cycles, are key factors in this equation. The other factors, especially these controllable in advance, have to be adapted to their characteristics. Operatively controllable factors have to be managed with particular regard to the weather, which is a variable and uncontrollable factor.

The exploitation of soil and water demand closely depends on both these key factors. Fertile soils generally have higher water requirements per hectare of land, permitting higher specific yields to be achieved (t per hectare). Their specific water demand per unit of product (m^3 per t) is, therefore, absolutely lower. These soils permit the achievement of higher yields with a lower dose of fertilizers (Fig. 2.21). Under the conditions of a warmer climate, evapotranspiration is more intensive due to the higher input of solar energy. Resulting yields are higher as far as relevant higher water requirements are satisfied.

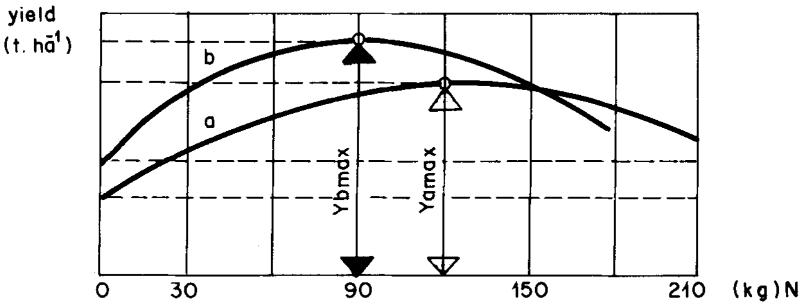


Fig. 2.21. Interrelations of yield, soil quality and the quantity of fertilizers according to Bulíček (1976): higher yields are achieved by lower fertilizing rates under better soil conditions (a - medium quality soil, b - high quality soil). An increase in fertilizing rates above the optimum value increases water resources contamination, thus reducing both the yield and economic efficiency.

The water requirements R_a of plants are primarily controlled by the prevailing weather and also depend on the soil conditions when water supply is unlimited. Transpiration is proportional to radiation and can be quantitatively assessed from the relevant weather elements. The water requirements R_a consist

- of the transpiration T of the physiologically active plant and
- of the evaporation E from the adjoining soil surface

$$R_a = T + E = k_e \cdot T \qquad (m^3.ha^{-1}) \qquad (2.111)$$

k_e - soil quality coefficient, also depending on agricultural practices, overshadowing, the presence of weeds, generally $k_e = 1.2 - 1.5$.

The growth of plants in terms of net assimilation or dry-matter increment, also depends on the energy input, but does not commence until radiation reaches a certain minimum intensity. It reaches a maximum rate at moderate radiation intensities, increasing only a little at high intensities.

Yet yield does not only depend on a sufficient and adequate supply of energy and water, but also on a sufficient supply of air to the root zone. This fact is expressed by the interplay of the factors S - soil quality and Q - water supply - of the yield equation (Eq. 2.110). Under efficient agricultural practices the amount of water supplied corresponds to the actual evapotranspiration; losses are negligible. Water consumption is almost equal to water requirements. Irrigation is an inherently consumptive use, largely reducing the possibilities for the multiple utilization of water.

Maximum yields can be achieved under soil moisture conditions of the field capacity FC. When the value of humidity is higher, the aeration is insufficient. In heavy soils, the aeration is already insufficient in the conditions of the field capacity, thus decreasing yields considerably. The size of the pores is too small to enable the necessary degree of aeration. Light soils are far more tolerant to an increase in soil humidity above the limits of the field capacity. The size of the pores enables a sufficient supply of both water and air (Fig. 2.22).

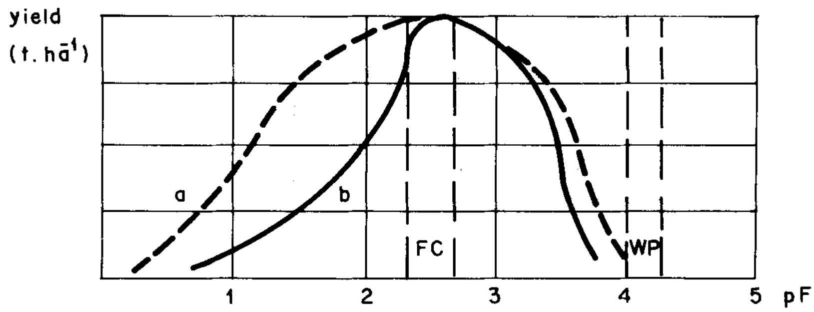


Fig. 2.22. Interrelations of yield, soil humidity (expressed as the suction pressure pF), and soil type according to Kutílek (1963): (a) sandy soils form better conditions for achieving higher yields at lower soil humidity due to the better aeration, i.e. the same yield is achieved with lower water requirements. - (b) heavy clayey soils.

The maintenance of the moisture capacity between the limits of the field capacity under the variable conditions of weather especially of uneven precipitation and evaporation, has to be achieved not only by irrigation, but also by drainage. Yields depend on the maintenance of adequate soil moisture levels during the various stages of plant growth.

The water requirements of plants depend

(a) on the interplay of the transpiration rate and the supply of water from the root zone, i.e. on the resistance of the plant body to the penetration of water from the soil to the atmosphere,

(b) on the accessibility of the soil profile to water, depending on the development of the root system,

(c) on the evapotranspiration rate, depending on weather conditions.

The water requirements of plants R_a and their consumptive use U_a are a combined function

$$R_a = U_a = f\,(S\,,\,C\,,\,A\,,\,W) \qquad (m^3.s^{-1}) \qquad (2.112)$$

S - soil type, its texture and structure, its water-holding capacity
C - plant type: morphology of leaves, stem, root zones etc.
A - agricultural and irrigation practices (see Eq. 2.110 - M, H, Q)
W - weather conditions (solar radiation, temperature, wind etc.).

The actual water requirements of plants depend on weather: on the variable energy input or output from the atmosphere, water and soil, i.e. mainly on the intensity of the sunlight, but also on the irrigation water temperature, air humidity and wind velocity. Their characteristic course shows a maximum during the summer months in all the climatic zones of the northern hemisphere. As transpiration after sowing is almost nil, water requirements cover evaporation from the soil surface in order to maintain sufficient soil moisture. In the next period transpiration increases, reaching a maximum shortly before the period of maximum growth (Fig. 2.23).

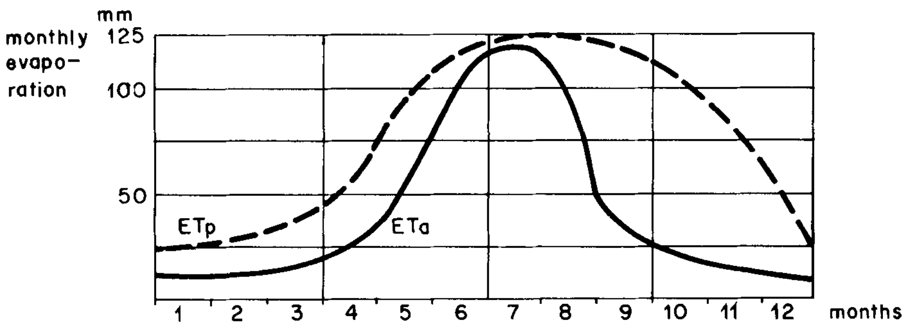


Fig. 2.23. Representation of the evapotranspiration of an annual plant. The actual evapotranspiration ET_a approaches the value of the potential evapotranspiration ET_p in the period of maturing: FC - field capacity, WP - wilting point.

Water is the regulating factor of energetic processes during the transformation of the organic matter in agricultural systems. These energetic processes are controlled by thermodynamic laws. The expected yield of the dry matter can be derived from the characteristics of the change of the internal energy y

$$y = \left(\frac{T_n}{T} - \frac{h_n}{h} \right) . Y_{max} \qquad (2.113)$$

T_n - temperature total in the relevant period (^oC)

T - temperature total during the year of the maximum yield (^{o})

h_n - precipitation in the relevant period (mm)

h - precipitation total during the year of the maximum yield (mm)

Y_{max} - long-term maximum yield of the dry matter ($t.ha^{-1}$ / year)

The course of the change of the internal energy is characteristic for the periods of growth and the plants in question. Thermodynamic curves limit the critical periods in which the lack of water considerably decreases the yields.

Different plants require different amounts of soil moisture in different periods of growth and seasons of the year. They show a preference for a particular soil texture, structure and other physical conditions. Some plants thrive on well-drained soil, coarse-textured and with a poor water-holding capacity. Others show better development in more finely textured soil, with a higher degree of moisture.

The root system of plant species is adapted to accept

- the rain from the surface (shallow, dense, vast root system)
- the soil water
- the groundwater (deep-rooted species, phreatophytes)

The arrangement and the density of the root system varies from species to species. A relationship between root systems and the water regime can be traced: species which prosper in rainfall may have a comparatively poor and shallow system, while species in an area where the rainfall does not penetrate to a greater depth have a vast surface system. Other species develop two to three root systems, which are supplied from rainfall, groundwater and the soil moisture. The root depth of one single species depends on the structure and depth of the soil profile and is influenced by the moisture conditions and groundwater table, which are interconnected with the climate.

In deep well-drained soils in humid countries plants are able to accept water from a depth ranging from 0.3 to 1.8 m, depending on the particular species and local conditions. The root depth of semi-arid to arid areas exceeds the root depth in humid areas by up to two times. Seeds and seedlings are able to accept water from their proximity only. With the development of the plant, the roots penetrate into deeper layers and spread horizontally.

A decrease in the groundwater table has an important effect on the yield in the case of light and medium soils. Under conditions of heavy soils, this influence is not so substantial (Fig. 2.24). But heavy soils do not allow a sufficient water supply in dry seasons - yields are then considerably affected by weather conditions. Light soils, requiring high water tables, because of their low capillary rise, do not allow the necessary development of the root system. A decrease in the water table under conditions of a shallow root system restricts yields because of the lack of water, while an increase has the same impact because of the lack of air.

Yields cannot be expected when the upper soil layer, whose depth is 0.1 m in the case of light and 0.4 m in the case of heavy soils, is completely wetted - because of the lack of air in the root zone. It is rare for an uninterrupted supply of soil moisture from groundwater to occur. But when the capillary rise and the suction pressure ensure an adequate supply of groundwater even in dry periods, not limiting a sufficient supply of air, the groundwater table is in the optimum position for the species of plant in question to achieve the maximum yields. To achieve higher yields under these conditions, the fluctuation of the groundwater table must be restricted (Fig. 2.24).

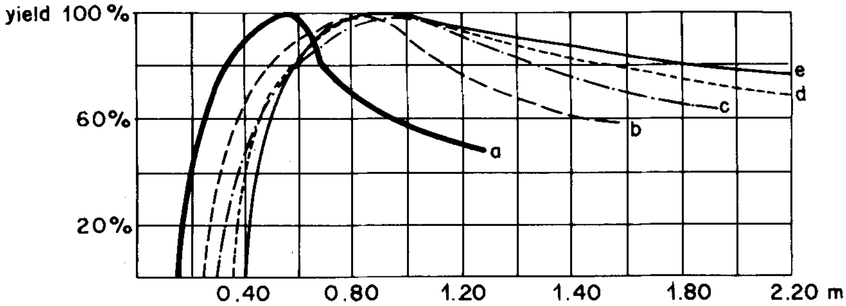


Fig. 2.24. Interrelationship of yield, soil quality and depth of groundwater table according to Benetín (1963): a - sand, b - sandy loam, c - loamy clay, d - clayey loam, e - clay. A fall in the groundwater table has a greater effect on yield from soils with lower capillarity.

At the same location, characterized by the soil quality, the weather conditions, the suitability of plants and the quality of seeds the relationship between the water supply and the yield can be expressed under simplified conditions, not taking into account agricultural practices including the suitability, quality and quantity of fertilizers, as follows:

$$Y = f(D) \qquad (t.ha^{-1}) \qquad (2.114)$$

Y - yield

D - water delivery (natural and artificial) and its timing $(m^3.ha^{-1})$

The course of this function (Fig. 2.25) proves that maximum yields can only be achieved with an optimum water supply. A decrease below or an increase above this optimum value cuts yields. Lowering the water supply below the mentioned optimum value can increase the cost-benefit ratio, i.e. the financial or the economic yield. Taking into account economic reasons, it is necessary to mention that a long term oversupply of abundant water not only causes economic losses, but also the gradual degradation of the soil layer.

Under these simplified conditions, for the purpose of water balances compilation only, total water requirements can be derived directly from the yield

$$R_a = m_e \cdot Y \qquad (m^3.ha^{-1}) \qquad (2.115)$$

m_e - coefficient of water requirements $(m^3.t^{-1})$(Tab. 2.29)

Y - total yield $(t.ha^{-1})$

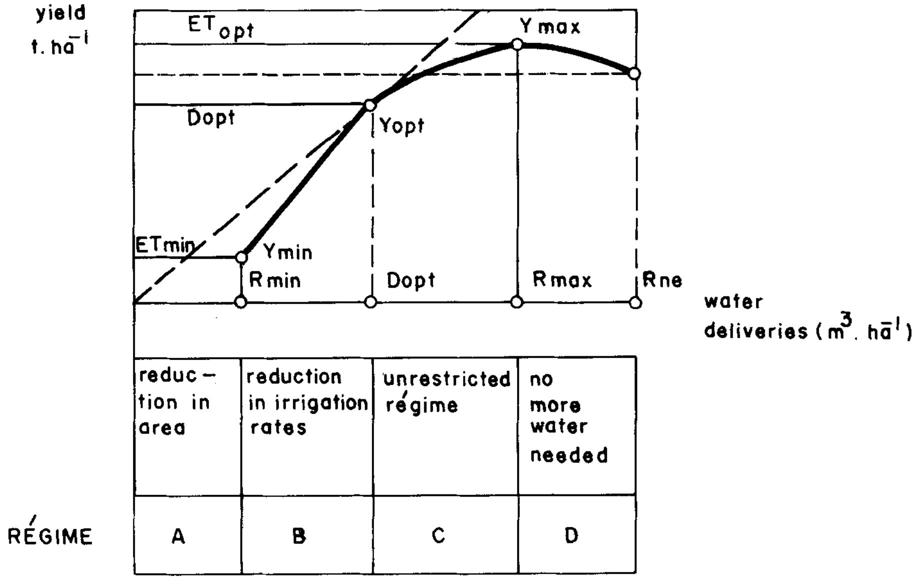


Fig. 2.25. Interrelationship of the yield and the adequacy of the water delivery. The decrease in water delivery below minimum water requirements results in no yield. Regime: A - reduction of the area irrigated, B - reduction in irrigation rates, C - unrestricted regime, D - no more water needed. Symbols: Y_{max} - maximum yield, Y_{min} - minimum yield, ET_{opt} - optimum evapotranspiration, D_{opt} - optimum water delivery, R_{min} - minimum (unavoidable) water requirements.

The coefficient of water requirements depends on climatic factors. The equation was adapted for practical application and coefficients derived e.g. Cherkasow (1950) (Tab. 2.30)

$$R_a = 0.1 \cdot m_e \cdot k_t \cdot y_e \cdot Y \qquad (m^3.ha^{-1}) \qquad (2.116)$$

k_t - coefficient of transpiration $(l.kg^{-1})$

y_e - coefficient of yield

Under the same climatic conditions the transpiration/assimilation ratio of different species varies considerably. Some species are more efficient producers of dry matter than others, with the same expenditure of water. This difference depends on the given morphological characteristics, e.g. on the leaf, stem and root arrangement.

As was shown above, the rate of the physiological processes, i.e. the transpiration/assimilation/production processes depends mainly on the supply of energy and moisture, and on the wind speed. But it also depends on the duration

TABLE 2.30

Products	Coefficients k_t $(l.kg^{-1})$	y_e	$m_e(m^3.kg^{-1})$	Yield $Y(t.ha^{-1})$
Cereals:				
wheat	271-639	2.14	0.8-1.1	3 - 6
rye	431-634	2.25	0.8-1.1	3 - 6
barley	404-664	1.77	0.8-1.1	3 - 6
oats	432-876	1.35	0.8-1.1	3 - 6
corns	239-495	1.28	0.7	5 - 8
Root crops:				
sugar beet	304-377	0.35	0.8-0.9	50-90
potatoes	285-575	0.25	0.8-1.0	40-80
Vegetables:				
Cucumbers	713	0.08	1.2-1.3	30-70
Tomatoes	500-650	0.10	1.0-1.2	30-60
Cabbage	250-600	0.15	0.7-1.0	40-90

Table of transpiration coefficients k_t, yield coefficients y_e, water requirement coefficients m_e according to Cherkasow (1950) and relevant yield depending in addition on soil quality, fertilizing and adequate solar radiation.

of the daylight. The course of water requirements can, therefore, be derived from astronomic and meteorological factors. The Hargraeves (1955) formula is based on an optimum simplification of internal plant and external environmental factors:

$$R_{opt} = 45.7 \cdot k \cdot d \cdot T \cdot (0.38 - 0.0038\ h) \quad (mm) \qquad (2.117)$$

k - monthly consumptive-use coefficient

d - monthly daytime coefficient dependent upon latitude

T - mean monthly temperature in ^{o}C

h - mean monthly relative humidity at noon in per cent (Tab. 2.31).

To achieve optimum crop yields

(a) in climatic conditions, where the relevant plants can be cultivated without artificial watering, irrigation supplements the natural water supply,

(b) in adverse climatic conditions, where plants cannot be cultivated without an artificial water supply, irrigation safeguards the undisturbed growth of plants. Under such conditions, irrigation rates should be adequate to achieve at least minimum yields. If the water quality available is not sufficient to cover these minimum requirements, it is vital to reduce the extent of the area irrigated.

TABLE 2.31

Consumptive use coefficients										
Crop/Month	3	4	5	6	7	8	9	10	11	Seasonal
Pasture	0.11	0.25	0.29	0.33	0.31	0.32	0.32	0.22	0.14	0.25
Alfalfa	0.41	0.70	0.64	0.67	0.74	0.67	0.64	0.40	0.41	0.41
Corn				0.12	0.38	0.42	0.26	0.10		0.26
Rice		0.32	1.34	1.42	1.40	1.44	0.51			1.07
Potatoes early	0.55	0.72	0.73	0.62						0.66
Onions early	0.28	0.45	0.30	0.31	0.28					0.32
Carrots	0.16	0.18	0.19	0.52	0.64	0.28				0.33
Peas	0.28	0.36	0.49	0.31						0.36
Beans				0.15	0.28	0.66	0.51			0.40
Tomatoes				0.32	0.41	0.71	0.67	0.81		0.58
Sugar beets	0.19	0.27	0.55	0.87	0.69	0.36	0.15	0.10	0.03	0.36
Water melons				0.15	0.18	0.25	0.51			0.27
Prunes	0.17	0.34	0.34	0.50	0.48	0.32	0.42	0.48	0.24	0.37
Peaches	0.22	0.45	0.43	0.46	0.51	0.51	0.38	0.60	0.41	0.44

Monthly daytime coefficients												
N latitude	1	2	3	4	5	6	7	8	9	10	11	12
5^{o}	1.01	0.91	1.02	0.99	1.03	1.00	1.03	1.03	0.98	1.02	0.98	1.00
25^{o}	0.91	0.86	1.01	1.03	1.12	1.11	1.13	1.09	1.00	0.97	0.89	0.89
50^{o}	0.72	0.76	0.99	1.11	1.28	1.32	1.32	1.20	1.01	0.89	0.73	0.68

Consumptive use coefficients at Davis, California and monthly daytime coefficients in the Hargreaves (1955) equation for the determination of the potential evapotranspiration.

The actual water requirements depend on the field conditions, which change with the weather conditions. A plant requires different quantities of soil moisture, depending on the species and the soil, during its different stages of growth. Maximum transpiration rates appear in a developing crop before assimilation has reached its peak. The actual problems of how to supplement these requirements by irrigation and of how to overcome adverse climatic, soil and water conditions should be worked out on the basis of daily measurements in the course of the irrigation season.

Basic decisions include

- amount of water required to moisten the desired depth of soil (not smaller and not greater)
- appropriate method and timing of irrigation (also to reduce evaporation and percolation losses)
- the coordination of other agricultural treatment processes with the irrigation method and the timing of rations.

2.6.2 Efficiency of Irrigation Water Use

The efficiency of irrigation water utilization is presently the key problem of water management, because

(a) irrigation water forms the main element in water requirements on a global scale. The extent of both the irrigated land and the irrigation intensity is increasing because of the increasing demand for food, caused partly by the world population boom and partly by improving living standards;

(b) irrigation is an inherently consumptive use which considerably reduces the possibility of further re-use or recycling;

(c) irrigation networks and their supply systems have a substantial and lasting impact on the natural environment.

The economy of irrigation is characterized by the ratio of the water withdrawal and the market unit, i.e.

$$i_1 = \frac{W_i}{Y - Y_o} \qquad (m^3.t^{-1}) \qquad (2.118)$$

Y - yield under conditions of irrigation $(t.ha^{-1})$

Y_o - yield under the same conditions, but without irrigation

W_i - water withdrawal for irrigation purposes $(m^3.ha^{-1}$ per year)

From the point of view of the population's nourishment this economy can be expressed by the ratio of the water withdrawal and the nutritive value of the product

$$i_2 = \frac{W_i}{I \,.\, (Y - Y_o)} \qquad (m^3.J^{-1}) \qquad (2.119)$$

I - nutritive value of 1 t of the produced plant $(J.t^{-1})$

The benefits of all investments in irrigation projects depend on proper water use in the field in conjunction with other agricultural inputs and cultural practices.

The planning and design of water development projects in agriculture should therefore be based on a water-use concept and should reflect the planned development of agriculture resulting from the need for a further intensification and diversification of production, and the resulting changes in agricultural practices.

Human society can determine only two out of the four input variables of the equation 2.112 namely: C - plants (seeds) and A - agricultural and irrigation practices. However, the mutual relationship of these variables is complex and can be solved reliably enough on the basis of system analysis alone. This complex relationship is often not reflected by current practice. The structure of agricultural systems and crop patterns is often still the result of

- the traditional food pattern,
- the given economic interests,
- the traditional agricultural practices,
- the local degree of relevant know-how etc.

The equation of water balance and the optimum use of the soil moisture available in the absence of irrigation, or the optimum use of natural discharges available without storage are seldom included among the relevant decision criteria in agriculture and irrigation development projects. The results of such a routine approach are excessive irrigation requirements without sufficient cause and exaggerated claims on water withdrawal and storage.

A change in the relevant engineering approach is needed, including an optimization of cropping patterns and a harmonization of the resulting total water requirements with the course of natural water supply: soil moisture, precipitation, discharges and groundwater resources available during the vegetation season. This harmonization of irrigation requirements with availability of water without storage may also require changes in the traditional food pattern: e.g. in arid countries with heavy rainfall and high river discharges at the beginning of the vegetation season, the introduction of precocious potatoes instead of rice cultivation can help to ensure the food supply without extensive water storage, which results in high evaporation losses (Fig. 2.26).

Arrangements for increasing the efficiency of water utilization during agricultural production include

- the creation of an optimum structure of agricultural systems, i.e. the optimum ratio of the producers and consumers of carbonic matter,
- the optimization of the crop pattern, preferring plants and seeds with lower water requirements corresponding to the pattern of water occurrence, thus ensuring an optimum utilization of the soil moisture, rain water and natural surface water discharges,
- the appropriate preparation of the land, including efficient measures to increase infiltration and transform overland flow into subsurface runoff,

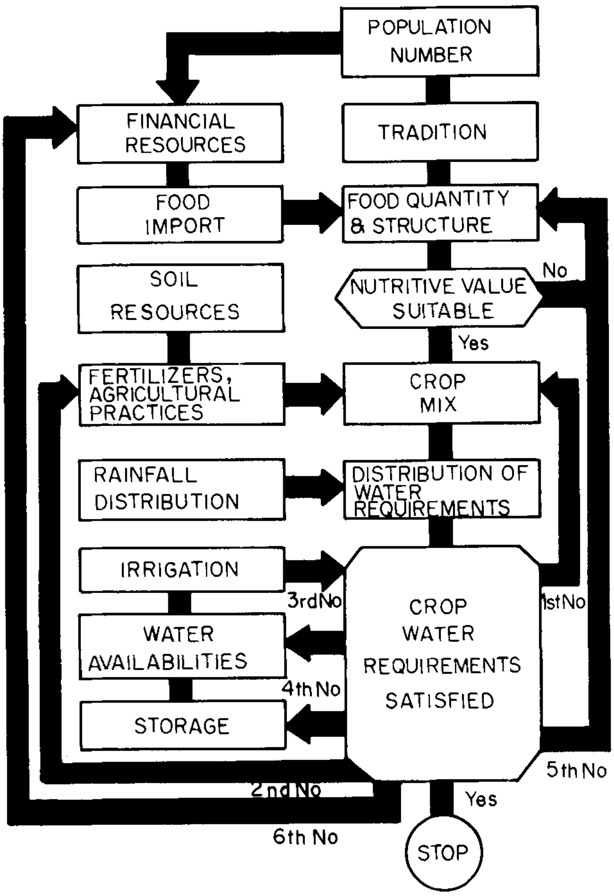


Fig. 2.26. Block diagram depicting the hierarchy of necessary basic measures for safeguarding of food for population.

- the construction of small reservoirs, diversion dams etc. in order to decrease the slope of the terrain and slow down the surface runoff.
- the utilization of appropriate water-saving irrigation methods, corresponding to the species of the crops cultivated and the relevant cultivation practices,
- the reduction of water losses during conveyance by adapting the design of conveyance structures to local conditions e.g. lined canals in pervious soils, closed culverts in arid climate and by appropriate maintenance and by economical operation,
- the management of agricultural systems on the basis of daily agrohydrometeorological data, i.e. by watering only in periods of a substantial decrease in soil moisture below the optimum value, without any overirrigation,
- the drainage and re-use of excess irrigation water,

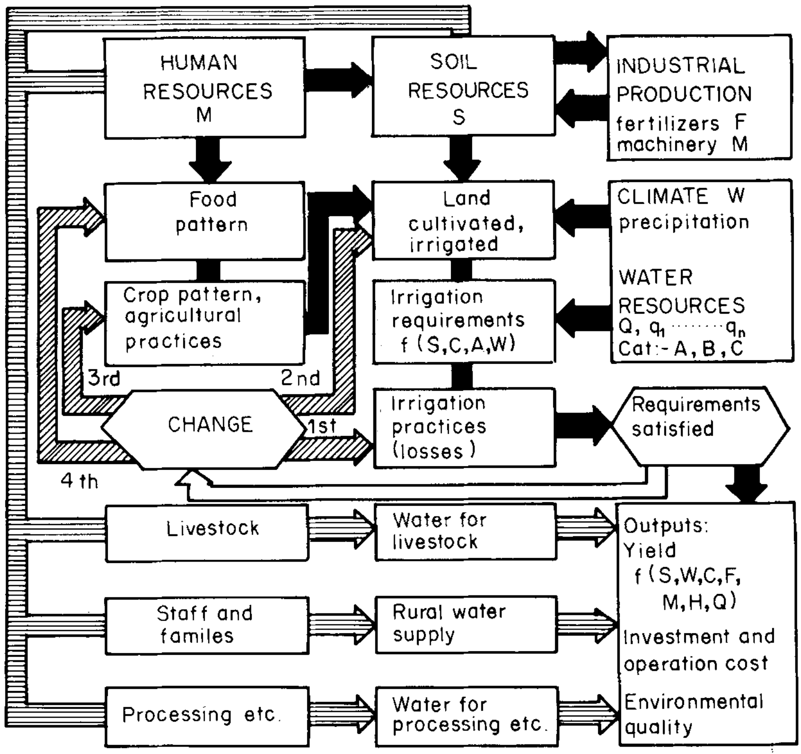


Fig. 2.27. Block diagram of water delivery management in agriculture to safeguard the environmental equilibrium of the agricultural system.

- the reduction of evaporation losses, e.g. by protecting the soil surface by means of wind-breaks, irrigation at night etc.,
- the re-use of municipal, industrial and agricultural waters for the purpose of irrigation,
- the observation of optimum agricultural practices during fertilizer and pesticide application.

There are essentially three ways of ensuring the adequate nourishment of the population:

(a) self-sufficiency across the entire range and assortment of necessary agricultural products,

(b) over-production and export of selected agricultural goods, thus forming financial resources to supplement the lacking varieties by means of import,

(c) exporting industrial goods or raw materials with the same goal.

The over-intensification of agriculture, namely the over-application of fertilizers and chemical substances in plant pest control as well as insufficient protection measures resulting in soil wash,the wastes from farm machinery and repair shops and highly concentrated livestock production results in surface and groundwater pollution and threatens the quality of products and of the environment.

The scientific coordination of the crop pattern with both the agropedological and the hydrometeorological conditions results in an increase in yields without a substantial increase in water requirements for irrigation, as well as in an increase in the total nutritive value per hectare cultivated. It helps to maintain the equilibrium of the biogeochemical cycles in the agricultural system, whose lasting function is possible only under the conditions of the stability of energy and matter input and output, and under the conditions of an equilibrium of the system and its environment (Fig. 2.27).

2.6.3 Water for Irrigation and its Quality

The supplementation of soil moisture to satisfy crop water requirements is the main, but not the single purpose of irrigation. By means of irrigation bioelements and other matter which improves plant production or soil conditions can either be naturally or artificially supplied, favourable microclimatic conditions to support plant growth maintained, and matter including pests which jeopardizes the soil structure and texture or the health of plants removed. From this point of view, irrigation can be categorized as follows

(a) proper irrigation (supplementary watering),
(b) fertilizing and remedial (plant health promoting) irrigation,
(c) protective irrigation,
(d) soil leaching irrigation.

The quality of the water used for irrigation depends on the required purpose, on the soil properties and on the irrigation operation. The basic requirements affecting the quality of water used for irrigation can be summarized as follows:

(a) it should favourably influence plant growth and the quality of the products grown,

(b) it should not cause breakdowns during the irrigation operation,

(c) it must not cause sanitary complaints, either during its operation or during the processing and consumption of the relevant agricultural products,

(d) it should not endanger the quality of the surface water and the groundwater,

(e) it must not deteriorate the structure, porosity and other agrochemical properties of the soil profile.

The quality of the water used for irrigation has to be categorized on the basis of its relevant physical, chemical, biological and bacteriological properties (Tab. 2.32). An important property of water, deciding on its suitability for irrigation, is the salinity, frequently expressed as the sodium percentage, the amount of sodium Na present in respect of the cationic concentration. But generally more important is the sodium- adsorption ratio SAR, which expresses

TABLE 2.32

Indicators			A good	B conditioned	C marginally admissible
			Categories		
Oxygen content ($mg.l^{-1}$) at 10^oC			>11		50%
at 20^oC			>9		saturation
Dissolved matter ($mg.l^{-1}$)			<800	800-1200	>1200
Chlorides ($mg.l^{-1}$)			<300	300- 400	> 400
Sulphates ($mg.l^{-1}$)			<250	250- 300	> 300
Toxic matter				traces Cl	CO_2, Cl H_2S, F ($1mg.l^{-1}$)
Radioactivity	Ra^{220}	(Curie)			3.10^{-12}
	Sr^{88}	(Curie)			3.10^{-11}
Odour			slight	mediocre	offensive
Temperature in spring		^oC	10-15		
in summer		^oC	15-20	15-35	>35
Sediment size (mm)			0.005-0.1	0.001-0.005 1)	0.1 2)
Water pollution class			Ia,Ib,II	III	IV

Degree	Salinity	Electrical conductivity ($mmhos.cm^{-1}$)	Alkali hazard S1 Low	S2 Medium	S3 High	S4 Extreme
C1	Low	0 - 0.25	<9	9 - 17	17-24	>24
C2	Medium	0.25 - 0.75	<7	7 - 14	14-20	>20
C3	High	0.75 - 2.25	<5	5 - 11	11-16	>16
C4	Extreme	2.25 - 6.0	<3	3 - 8	8-12	>12

Categories of water quality for irrigation purposes and of its suitability according to the alkali and salinity hazard (derived from the graphical representation of the US Salinity Laboratory in Riverside).
1) fine sediments have a positive impact on the fertility of highly pervious soils, but decrease the quality of heavy soils, restricting the perviousness and aeration
2) cause sedimentation in the canal and pipeline network.

the relative activity of sodium ions in exchange reactions with soil, in which calcium Ca and magnesium Mg in the soil are replaced by the sodium in the water. The SAR is calculated from the ionic concentrations in millimoles of relevant bioelements according to the following formula:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{4}}} \qquad (2.120)$$

The second basic property of irrigation water is the alkali hazard, measured as electrical conductivity, which refers to the conductance of one centimeter cube of water on a side measured at 25 ^{o}C. Depending on these two criteria, which possess dividing points for low, medium, high and very high values, irrigation water can be characterized by sixteen combinations of salinity, i.e. sodium adsorption ratio and alkali hazard (Tab. 2.32). Water with a low alkali hazard and low salinity can be used for irrigating almost all crops with any type of soil. Water with high salinity or a high alkali hazard is not suitable for irrigation under normal conditions.

TABLE 2.33

Species	Salt tolerance high	medium	low
Fruit trees	dates	grapes, citrus fruit	pears, apricots, peaches, plums, apples
Field crops, vegetables	sugarbeet, beetroot, savoy, rape	barley, rye, oats, rice, flax, tomatoes, asparagus, melons, lettuce, carrots, spinach, capsicum, garlic, gourds, sunflowers, wheat, corn	peas, celery, cabbage, potatoes
Fodder crops		clover	alfalfa

Salt tolerance of crops, i.e. their ability to survive under conditions of increasing salinity.

When irrigation with water which has medium or high salinity, salt-tolerant crops should be cultivated (Tab. 2.33). Measures to counteract against the salination of the soil profile include especially good drainage and leaching. When irrigating with water whose utilization for this purpose is conditional, due to the sanitary hazard (Tab. 2.36) special measures are required.

In addition, protecting zones without irrigation by such water should be established around dwelling areas and communication lines for pedestrians.

2.6.4 Irrigation as Supplementary Watering

Soil moisture can be controlled by means of an irrigation and/or drainage system. An irrigation system consists of five subsystems: storage, transmission, distribution, soil moisture and, exceptionally, also underground aquifers.

Irrigation basically safeguards the supplementation of the water which escapes from the vegetative system, especially by evapotranspiration, thus contributing to its undisturbed development. Its feasibility depends on soil and land conditions (Tab. 2.34). The total water supply required for one irrigation season is the sum of uses and losses, derived from seasonal consumptive use and leaching requirements, less the amount of rainfall and groundwater input in the vegetation period which contributes to the moisture of the soil layer in question and less the utilizable moisture-holding capacity of soil at the beginning of this period.

TABLE 2.34

Class		Simplified characteristics
I	Good irrigable land	No erosion or gravel problem, adequate permeability, good soil structure and texture
II	Moderately	Slight erosion, gravel problem, low permeability, slightly undulated, slight salinity etc.
III	Marginally irrigable	Moderate gravel, slope, erosion, deep soil, wetness problem etc.
IV	Irrigable special conditions	Steep slope, shallow soil, gravel, undulated surface etc.
V	Undetermined suitability for irrigation	Salinity, etc.
VI	Non-irrigable land	Rocky land, marsh, flooding problem etc.

Simplified FAO classification of land according to its suitability for irrigation.

$$R_a = \sum_{i=1}^{n} \frac{1}{e_f} \cdot (E_{ei} + R_{li} - \alpha_i P_v - W_{wi} - W_{gi}) A_i \quad (m^3 \text{ per year}) \quad (2.121)$$

R_a - total annual irrigation demand

E_{ei} - seasonal consumptive use of the pland i in the vegetation period ($m^3.ha^{-1}$ per year)

R_{li} - leaching requirements, approximately 0 to 50% of E_{ei} (see paragraph 2.6.7) ($m^3.ha^{-1}$ per year)

P_v - decisive total rainfall in the vegetation period (for planning and design purposes the rainfall of the vegetation period in a medium dry year should be used) ($m^3.ha^{-1}$ per year)

α_i - coefficient of the rainfall efficiency (depends on the soil quality: 0.5 for heavy soils, 0.6 for sandy soils, 0.7 for clay soils, 0.75 for loamy soils)

W_{wi} - utilizable moisture-holding capacity of soil at the beginning of the vegetation period, formed in the winter period ($m^3.ha^{-1}$)

W_{gi} - the groundwater input in the vegetative season, depending on the capillarity of soils and the groundwater depth ($m^3.ha^{-1}$)

e_f - coefficient of field efficiency, depending mainly on the irrigation method (Tab. 2.35)

A_i - area of crop i (ha)

It goes without saying that the value of the total withdrawal is

$$W_o = R_a + \sum_{i=1}^{n} \Delta_{c_i} = \frac{1}{e_d} \cdot R_a \qquad (m^3) \qquad (2.122)$$

A - area (ha)

Δ_{c_i} - delivery losses (see paragraph 2.6.8) (m^3)

e_d - coefficient of water delivery

TABLE 2.35

Methods of irrigating	Definition	Coefficient of field efficiency e_f
Basin (level-border) irrigation	Flooding of level plots surrounded by small dikes. Water layer 0.15-0.3 m is held until complete infiltration.	0.4 - 0.6
Border irrigation	Water delivery at the high end of long strips, e.g. from ditches running along contours, drainage at their low end, depth of the overland flow 0.03-0.07 m.	0.6 - 0.7
Furrow irrigation	Controlled flooding from furrows or corrugations running between crop rows.	0.7 - 0.8
Subsurface irrigation	Creation of artificial groundwater table, e.g. by delivery of water by means of underground pipes.	(a) 0.6 - 0.8
Sprinkler irrigation	Artificial rainfall from overhead sprinklers supplied e.g. from pipes.	0.7 - 0.87
Drip (trickle) irrigation	Nozzles discharge the water from pipes in drips along the length of the plant row.	0.85-0.92

Categorization of irrigation and irrigation field efficiencies: (a) coefficient depends on the hydraulic conductivity of soils and on the surface runoff caused.

The total rainfall with an 80% frequency of occurrence in the vegetation period may be considered as decisive, depending on local climatic conditions and yield. The efficiency of the rainfall utilization depends on evapotranspiration and outflow, i.e. on climatological, geomorphological, soil and vegetation factors.

The crop irrigation depth which has to be penetrated by watering, and thus the crop water requirements too, depends on the depth of the root system (Paragraph 2.6.1).

The utilizable moisture-holding capacity W_{wi} of soil at the beginning of the vegetation period also depends on the root depth and on the capillary rise of the soil structure. Its value can be derived according to Holý (1976) from the formula

$$W_{wi} = 25 \cdot n_c \cdot h_i \qquad (m^3.ha^{-1}) \qquad (2.123)$$

n_c - average value of the capillary porosity (%)

h_i - effective depth of the root system (m)

This value fluctuates between 150 $m^3.ha^{-1}$ in light sandy soils and 350 $m^3.ha^{-1}$ in clay soils for cereals, root-crops and fodder crops with the exception of corn and beetroot, whose moisture holding capacity is some 30% higher. Higher values can be also expected for alfalfa and in orchards, when they fluctuate between 200 and 250 $m^3.ha^{-1}$.

The groundwater input in the vegetative season W_{gi} depends mainly on the groundwater table depth and on the soil structure. According to Kostjakov (1951), the value of the groundwater input to the seasonal consumptive use of plants does not exceed an average of 5% when the groundwater table depth exceeds 2.5 m, reaching 25% for deep root systems and smaller groundwater table depths. Under normal conditions, the capillary rise does not exceed 3 m, i.e. the groundwater cannot supplement the water requirements of current plants when deeper than 3 m below the land surface.

The economy of plant production and the efficiency of irrigation water application are closely interconnected. The actual irrigation rates are to be determined and irrigation operation managed on the basis of the measured actual evapotranspiration. The water rates must not overload either the plant or the soil, which results in a degradation of both, and they should not harmfully affect the underground biosphere.

Useless losses through unused outflow, deep percolation and excessive unproductive evaporation should also be avoided. Irrigation rates can further be derived from the actual soil moisture, capillary rise and the necessary depth of water. The capillary porosity practically corresponds to the full field capacity FC. The irrigation rate also depends on the method of irrigation and on the conditions of operation, which have a basic impact on losses, i.e. on the coefficient of irrigation efficiency

$$R_r = \frac{100}{e_f} \cdot (FC - W_a) \cdot h_r \qquad (m^3.ha^{-1}) \qquad (2.124)$$

R_r - irrigation rate

FC - field capacity (%)

W_a - actual soil moisture (%)

h_r - effective depth of the root system (m)

e_f - coefficient of irrigation efficiency

2.6.5 Fertilizing and Remedial Irrigation

Fertilizing irrigation serves to supplement important nutriments. For the purpose of fertilizing irrigation the following solutions are used:

(a) solutions of fertilizers,

(b) flood waters,

(c) municipal, industrial and agricultural waste waters and sludges,

(d) dung and dung-water.

The annual irrigation requirements and the irrigation rates depend and are to be determined on the basis of the prevailing purpose of the irrigation which can be either supplementary watering or fertilization or waste water disposal. When irrigation is expected to be the prevailing purpose of the irrigation by waste waters, the water requirements are expressed by the following function

$$R_f = f\,(S\ ;\ C\ ;\ A\ ;\ W\ ,\ N\ ,\ M\ ,\ t) \qquad (m^3.ha^{-1} \text{ per year}) \quad (2.125)$$

For an explanation of factors S, C, A, W see equation 2.112

N - nutriment requirements $(t.ha^{-1})$

M - suitability of waste waters, i.e. quality and exploitability of nutriment contents

t - period from the beginning of the vegetation period.

When waste water disposal is expected to be the prevailing purpose of irrigation, the seasonal irrigation requirements R_f are to be determined with a view to the annual production of waste waters

$$R_f = R_a - \frac{1}{e_{fo}} \cdot R_{ao} \qquad (m^3 \text{ per year}) \qquad (2.126)$$

R_a - annual irrigation requirements (m^3 per year)

e_{fo} – off-season coefficient of farm losses

R_{ao} – average useful irrigation rate off-season (m^3 per year)

When fertilization is expected to be the prevailing purpose of irrigation, the annual irrigation demand is to be derived on the basis of the requirements of the main nutriment

$$R_f = \frac{N_m}{n_o \cdot C_o} \qquad (m^3.ha^{-1} \text{ per year}) \qquad (2.127)$$

N_m – average requirements of the relevant nutriment, nitrogen N, phosphorus P or potassium K, derived from the cropping pattern (t.ha^{-1})

n_o – average coefficient of the exploitability of the nutriments from waste waters

C_o – average concentration of the nutriment in waste waters (t.m^{-3})

Before being used for irrigation, sewage effluent should be

(a) treated mechanically or at least strained by fine racks, or

(b) treated biologically, if necessary, and

(c) accumulated in the medium term or in the short term for balancing the inflow of the waste water and the required irrigation rates.

$$f = \frac{N_o - N_a}{N_a} + \frac{P_o - P_a}{P_a} + \frac{K_o - K_a}{K_a} \qquad (2.128)$$

f – indicator of the fertilizing efficiency

N_o, P_o, K_o – content of the main nutriments: nitrogen N, phosphorus and potassium K in 1000 m^3 of the sewage effluent (kg)

N_a, P_a, K_a – average demand of nitrogen N, phosphorus P and potassium K for 1 hectare of cultivated land, derived from the cropping pattern and the required yield.

The positive impact of these basic nutriments can be increased by the presence of other compounds and elements, namely trace elements, by the presence of organic matter, matter forming humus or matter supporting the growth of plants. But they can also, through the presence of toxic matter, considerably limit such an impact.

The sanitary efficiency of these forms of irrigation, characterizing the effect of the filtration through the soil layer on the quality of the return flow, can be expressed by the indicator of the sanitary hazard

TABLE 2.36

Crops:	Indispensable measures
For direct consumption:	
a. eaten raw:	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<100 bacteria coli per ml)
	c. protecting period of 21 days without irrigation before harvest
	d. sprinkler irrigation prohibited
b. not eaten raw	a. and b. as above
	c. protecting period of 14 days without irrigation before harvest
Fodder crops:	
a. grazing	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<1000 bacteria coli per ml)
	c. grazing allowed after drainage and evaporation of irrigation water
	d. grazing of milk cows prohibited
b. consumed dry	a. as above
	b. no grazing allowed (fences)
Parks and sports fields:	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<1000 bacteria coli per ml)
	c. pipeline is used for the primary and secondary network
	d. access of public is prohibited during watering with the exception of subirrigation
Lumber, industrial crops incl. flax and hemp:	Mechanical and biological treatment

Indispensable measures for irrigation with waste waters.

$$s_h = 1 - \frac{Q_s \cdot q_s + Q_g \cdot q_g}{R_f \cdot q_f} \qquad (2.129)$$

Q_s - volume of the surface outflow from irrigation (m^3)

Q_g - volume of groundwater outflow from irrigation (m^3)

R_f - volume of water applied (m^3)

q_s - quality indicator of surface outflow (eg. BOD_5)

q_g - quality indicator of groundwater outflow

q_f - quality indicator of irrigation water applied

When applying the solutions of mineral fertilizers, concentrations of 0.1 to 0.5 % and sprinkler or drip irrigation methods should be used. Sprinkler irrigation can also be applied to spread solutions of pesticides, stimulators and agrochemicals which protect against pest and plant diseases, i.e. as irrigation which improves plant health.

If the layers of soil above the groundwater level are uninjured and strong enough, it is possible to eliminate all dangerous forms of bacteria before penetration into surface and groundwater resources, but not to eliminate some chemical substances which might represent acute or potential health hazards.

Water which is hazardous from a sanitary point of view cannot be used on land whose soil depth is not deep enough to guarantee the necessary biological filtration needed to safeguard the groundwater from contamination. Irrigation with such waters must be prohibited for this reason e.g. in the flood plain of water courses whose water is used for the supply of the population.

The application of not only toxic or infectious matter, but also high concentrations or overdoses of generally harmless chemicals, might represent acute or potential health and environmental hazards, jeopardizing

(a) the health of the service personnel,
(b) the air and water quality,
(c) the soil quality,
(d) the quality of agricultural products.

They also have a negative impact on the irrigation operation and act aggressively on structures and technological equipment. When looking for the origin of current mass diseases, it is necessary to take the factors of the environment into account, as well as the long-term consumption of products treated by this feasible, but unnatural method, which has not yet been sufficiently investigated, especially from the point of view of its long-term impact.

2.6.6 Protective Irrigation

Protective irrigation is used to safeguard the optimum conditions for the undisturbed development of plants. It includes climatizing and purifying irrigation.

The temperature and humidity in plant systems can be controlled by climatizing irrigation in order to achieve favourable conditions for further development: Anti-frost irrigation protects the plant system against the impact of freezing temperatures. This type of irrigation is applied exclusively by means of sprinklers, delivering heat energy to the air, the soil and the plants.

The impact of this irrigation is based on the physical properties of water, especially on its high heat capacity, the high value of the latent heat of solidification and its low heat conductivity. The temperature of the water applied generally fluctuates between 5 and 12^{o}C. When it drops to 0^{o}C , the ice may cover the leafs and blossoms, thus forming an insulating layer and supplying them with its latent heat of solidification. By sprinkling, the humidity of the air increases, thus decreasing the air albedo and slowing down the cooling of the plant system.

The efficiency of this anti-frost irrigation depends not only on the intensity of the water application and its temperature, but also on the wind velocity, the relative humidity of the air, and on the plant species and its stage of growth. Anti-frost irrigation has proved sufficient down to - 6^{o}C. Irrigation rates for this purpose range between 1 and 3 mm per hour, depending on the above conditions.

According to Achtnich (1957), the water requirements for anti-frost irrigation can be determined as follows:

$$R_{af} = \frac{11.15 \cdot h_p \cdot v_w \cdot (T - 2)}{K \cdot (80 + T_w)} \quad \text{(mm per hour)} \qquad (2.130)$$

h_p - height of the plant (m)

v_w - wind velocity (m.s^{-1})

T - temperature of the surface air layer (^{o}C)

T_w - water temperature (^{o}C)

K - coefficient corresponding to the area of irrigated leaves and stems

2.6.7 Soil Leaching Irrigation

The goal of leaching irrigation is the protection of the soil quality, i.e. its chemical composition, texture and structure. The basin method is generally used for leaching, aiming at the removal of excessive salts from the soil surface and root zone, especially of carbonates, chlorides, sulphates and nitrates, which may gradually result in a decrease in yields as well as in soil degradation.

Leaching increases the original crop water requirements at

$$R_{al} = R_a \frac{c_w}{c_a - c_w} \quad (\text{m}^3.\text{ha}^{-1} \text{ per year}) \qquad (2.131)$$

R_a - irrigation requirements without leaching

c_w - concentration of salts in the irrigation water $(g.l^{-1})$

c_a - permissible limiting concentration of salts in soil water $(g.l^{-1})$

The water requirements for a decrease in the salinity of soils consist of the volume needed for the solution and washing away of salts R_1, the volume needed to supplement the soil moisture R_2 at the value of the field capacity FC, and the losses

$$R_{a1} = R_1 + R_2 + \Delta_1 + \Delta_2 - P - W_s \quad (m^3.ha^{-1}) \qquad (2.132)$$

R_1 - volume needed for the solution and washing away of salts $(m^3.ha^{-1})$

R_2 - volume needed for the supplementation of the soil moisture at the field capacity FC $(m^3.ha^{-1})$

Δ_1 - losses caused by inactive penetration through the soil profile $(m^3.ha^{-1})$

Δ_2 - losses caused by evaporation $(m^3.ha^{-1})$

P - precipitation during the period of leaching $(m^3.ha^{-1})$

W_s - surplus moisture which remains in soil after completed leaching $(m^3.ha^{-1})$

Losses caused by inactive penetration through the soil profile and evaporation losses depend on the regime of leaching. The volume needed for the solution and washing away of salts can be derived according to Legostajev (1965) as follows:

$$R_1 = 100 \cdot h_s \cdot \gamma_s \cdot \frac{s_o - s_a}{s_1} \quad (m^3) \qquad (2.133)$$

s_o - original content of salts in soil (% of weight)

s_a - admissible content of salts in the soil profile (% of weight)

s_1 - amount of salts which can be removed by 1 m^3 of water (% of weight)

γ_s - unit mass of soil $(kg.m^{-3})$

h_s - depth of the soil profile in question (m)

The quantity of salts which can be dissolved and washed away by 1 m^3 of water depends on the water quality, the chemical composition of the salts, the soil structure and texture, the temperature and the groundwater level.

The quantity of water needed for the supplementation of the soil moisture at the field capacity should only be delivered in well drained soils, i.e. when the water remaining in the soil layer does not reach the field capacity. In this case

$$R_2 = 100 \cdot h_s \cdot \gamma_s \cdot (FC - W_o) \qquad (m^3) \qquad (2.134)$$

FC - field capacity (% of weight)

W_o - soil moisture before leaching (% of weight)

The effect of leaching depends on the efficient drainage of the leaching water by means of a permeable subsoil layer or a drainage network. After leaching the water polluted by leached salts returns to the groundwater or surface resources. The loss which decreases the capacity of the water resources is caused by evaporation and deep percolation.

The irrigating schedule of leaching generally consists of several irrigation rates in the off-season period. It is useful to apply the leaching rate in the period of drought, and especially, during the drop in the groundwater table, in order to preclude an oversaturation of the soil layer and possible washing up of the salts. A high groundwater table and insufficient drainage increases the evaporation losses and carries the salt up to the soil surface.

An excessive drop in the groundwater table may considerably increase the losses caused by inactive penetration through the soil profile. Leaching by groundwater decreases the groundwater table, thus deplenishing the groundwater resources. Leaching by surface water can result in a recharging of the groundwater resources. But in both cases the quality of the groundwater is negatively affected, especially when the ratio of leaching requirements to the volume of groundwater resources is high.

2.6.8 Irrigation Losses

It is possible to distinguish the following water losses during irrigation operation (Fig. 2.28):

1. Delivery losses (losses of water diverted for irrigation before applying to irrigated land):
   - (a) canal and reservoir seepage losses
   - (b) leakage of gates, unused spills and other escape losses,
   - (c) evaporation losses,
   - (d) unused water in the irrigation network,
2. Farm losses (losses of water applied to irrigated land):
   - (a) supplementation of the soil moisture, not used by plants,
   - (b) surface and groundwater outflow of the unused water,

(c) deep percolation into subsoil layers,

(d) inefficient evaporation from the soil surface and evaporation in the atmosphere during sprinkler irrigation,

(e) evapotranspiration of weed plants,

3. Off-farm losses, i.e. by irrigation of areas where irrigation is not planned or where it is not feasible.

Farm and delivery losses in irrigation networks which have been overaltered and are badly maintained as well as not properly operated frequently exceed the consumption of plants. The losses can also be caused by water wastage, i.e. by wrong operation or by using improper irrigation methods and techniques. They can be significantly limited by technical and operational measures including proper maintenance, controlled operation on the basis of flexible operating schedules, by the modernization and automatization of the operation and by the management of irrigation rates on the basis of the continuously measured agro-hydrometeorological data and weather forecast.

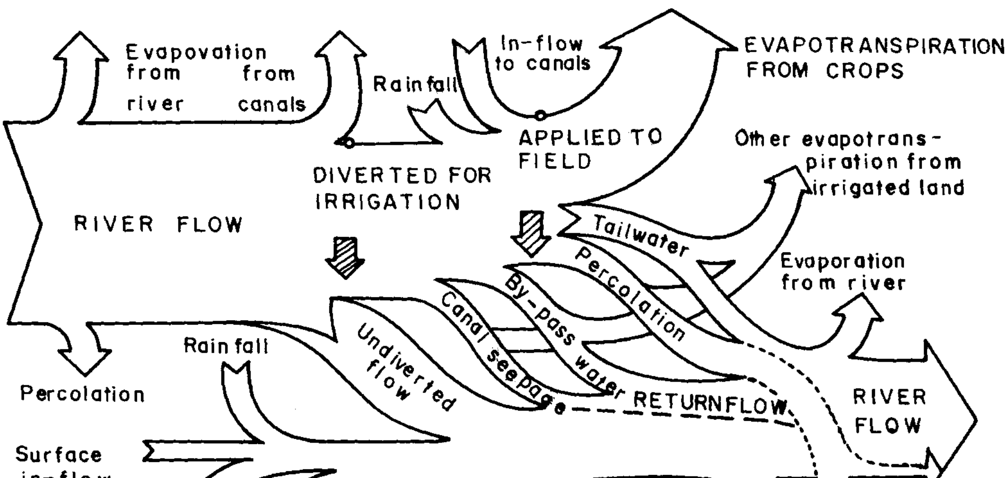


Fig. 2.28. Model of the irrigation return-flow system according to Law and Denit (1972), completed.

The coefficient of water delivery i.e. of the e_d efficiency of the irrigation network, is expressed by the ratio of the amount of water delivered to the farm field to the water withdrawal

$$e_d = \frac{R_a}{W_o} = \frac{W_o - \sum_{i=1}^{m} \Delta_{d_i}}{W_o} \qquad (2.135)$$

e_n - coefficient of water delivery

R_a - amount of water delivered to the farm field (m^3)

W_o - water withdrawal (m^3)

Δ_d - delivery losses (losses in the delivery network) (m^3)

The coefficient of the field efficiency e_f is expressed by the ratio of the amount of water actually consumed by the irrigated plant to the amount of water delivered to the farm field

$$e_f = \frac{R_c}{R_a} = \frac{R_a - \sum_{j=1}^{m} \Delta_{f_i}}{R_a} \qquad (2.136)$$

e_f - coefficient of water actually consumed by the irrigated plants

Δ_f - farm losses (m^3)

It goes without saying that the amount of water actually consumed should correspond to the irrigation requirements of the plants

$$R_a - \sum_{j=1}^{m} \Delta_{f_i} = \sum_{i=1}^{n} (E_{ei} + R_{1i} - \alpha_i P_v - W_{wi} - W_{gi} \quad (m^3.ha^{-1} \text{ per year}) \qquad (2.137)$$

The total losses of irrigation water can be derived from the coefficient of the total efficiency, i.e. from the ratio of water withdrawals to the actual consumption of plants, corresponding to the product of the coefficients of water delivery and field efficiency

$$e_t = \frac{R_c}{W_o} = e_d \cdot e_f \qquad (2.138)$$

2.6.8.1 Delivery Losses

An irrigation distribution system consists of open or covered canals, culverts, pipelines, ditches and corrugations; water can be transported in tanks, cisterns or by combinations of all these possibilities. Delivery losses depend mainly on the type and length of the distribution system, on its equipment, operation and maintenance.

The value of losses and the possibility of an economic operation of the irrigation network depend on its design, which is interconnected with the irrigation method and on its state.

Modern irrigation methods such as sprinkler or trickle irrigation, which have small farm losses, are often supplied from pipeline networks.

The precision of pipelines, the dimensional accuracy of their fittings result in very low seepage and leakage losses in this type of delivery network. Seepage losses in concrete pipes are very low and metal, asbestoscement and plastic pipes are almost without seepage.

With regard to the evaporation losses of pipes, they are almost nil under pressure operation and are also extremely low during free surface flow, due to the high humidity inside. Higher losses may occur through the leakage of untight pipes under pressure or during the operation of incorrectly erected portable pipes.

TABLE 2.37

Method	Probable drop (%)
Spontaneous clogging	40 - 50
Compacting	50 - 60
Sprinkling with chemicals	50 - 75
Floating with clay or loam	40 - 75
Clay layer	70 - 85
Concrete, asphalt membranes	80 - 95

The impact of different methods of decreasing seepage losses in unlined channels.

The amount of water which remains in the pipeline network is also very small compared with that in the open channel network. Generally, losses in the pipelines of an irrigation network are relatively lower than those of the municipal water supply system. They should not exceed 3 - 5 % for small-scale networks consisting of pipes with small diameters and not more than 8 - 10 % for large-scale networks and for portable ones.

Water losses in open channels are comparatively higher: they consist mainly of seepage, leakage and other escape losses, which are relatively bigger due to the perviousness of the construction material, low dimensional accuracy, higher roughness and bigger cross sections.

Seepage losses in open channels depend

(a) on the length of the wetted perimeter and the water depth,

(b) on the hydraulic gradient and the roughness of the canal, which determines the flow velocity,

(c) on the bank and bottom lining, i.e. on its perviousness, (Tab. 2.37).

(d) on the water quality, especially on the content of suspended matter, its grain size distribution, which in combination with the flow velocity decides on the sedimentation rate and on the clogging of the pores,

(e) on the soil properties of the bottom and banks, i.e. on their saturation and hydraulic conductivity,

(f) on the difference in the water level altitude and the groundwater table altitude,

(g) on the duration of the operation and its schedule.

The formula for seepage losses according to Davies and Wilson (1965) includes basic parameters only. The results of computations according to other formulas, including more entry data influencing seepage, do not produce more reliable results. The problem is the coincidence of the relevant entry data with the real data of the particular case. More precise values of seepage can be determined by analytical methods only or by electrical analogy, which is more reliable for the selection of alternatives and the design of the irrigation network and for the relevant economic analysis.

Reliable data on seepage in an existing network can be gained by measuring only. Delivery losses per 1 km from unprotected earth canals per 1 km exceed 10 % of the discharge provided the operation is permanent and the discharges are relatively low (below 0.1 $m^3.s^{-1}$). In the case of higher discharges, interrupted operation and pervious ground, these losses range between 10 and 20% of the discharge at 1 km length, dropping to half this value in the case of permanent operation. These values can be used for a first orientation only: the problem of water savings by means of a change in the operating schedule from continuous to iterrupted operation and vice versa is complex and depends on local conditions, and not only on the duration of the operation.

Delivery losses in open channels can be decreased by increasing the velocity of flow, by minimizing the canal cross sections, by optimizing its shape, and lining the banks and bottom of these canals. By lessening the roughness of the bottom and of the banks, it is possible to reduce seepage not only because the increased velocity of flow, but also due to the generally lower perviousness of the fine materials used for this purpose. All these measures should be analyzed taking into account the interrelated problems of canal operation, e.g. with a view to the resulting waterlogging, erosion and sediment transport problems.

Evaporation losses of open channels in humid areas are relatively low. But in semi-arid and arid areas the impact of evaporation is relatively high. These losses can be reduced by operation at night, which is feasible only for relatively small networks that can be operated for a just a few hours per day.

To reduce delivery losses by this interruption of the operation during high evaporation rates, seepage losses resulting from new filling must not exceed evaporation losses during the period that was excluded from operation. Interrupted operation reduces the total delivery losses, providing that the seepage losses are relatively low. A substantial decrease in evaporation losses can be achieved by covering the canal, by constructing closed culverts, or by overshadowing its water table with a protecting canopy, as well as by minimizing the water table width by forming a semi-circular or semi-eliptic or rectangular cross section with a longer vertical axis.

Water losses through evapotranspiration, caused by the bank canopy, are negligible in humid areas only. In semi-arid and arid countries, these losses may play an important role. Nevertheless, the protecting canopy makes it possible to increase the slope of the banks and overshadow the water table, thus limiting the evaporation from open water surfaces. This positive impact of the canopy may prove prevailing, also having a favourable influence on the microclimate.

Evaporation, seepage, leakage as well as waste water and other losses should be considered as losses in the balance of water resources and needs, if not recovered in streams or under the ground. These losses may produce problems of oversaturation, waterlogging and salinity, thus decreasing not only the yields but also the soil fertility and causing environmental problems as well as sanitary hazards.

2.6.8.2 Farm Losses

The selection of the irrigation method depends on cultivation practices, which are closely interconnected with the crop pattern and plant species. Modern methods of irrigation are characterized by substantially lower farm losses, but also by lower delivery losses, because modern irrigation practices require modern methods of water conveyance.

These methods also require higher investments and operation costs; furthermore, they are energy-consuming, as well as frequently being labour-demanding, thus requiring skilled workers. The change from traditional irrigation to modern irrigation often requires a basic change in cultivation practices, replacing primitive labour by skilled installation and operation. Local forces may not always be available to overcome the gap in manpower needs.

Farm losses depend not only on the irrigation method, but also on the technical level of its operation its control and regular checking, as well as on the reliability of the manpower or of the automatic equipment.

At the beginning of the application of the irrigation rate water losses caused by supplementation of the soil moisture can occur, which cannot be recovered by the suction pressure of the plants. These losses can be substantial, especially in dry heavy soils. Another farm loss is the percolation into subsoil layers which have no capillary interconnection with the soil profile. This percolation loss, which recharges the groundwater resources, can only be determined by local metering.

Losses through overland flow occur during overirrigation, namely after the accumulation of the surplus water on the soil surface, unless the subsequent runoff can be utilized for the effective irrigation of the adjacent land. The accumulation of water on the land surface, which is also caused by water-logging, increases the evaporation losses.

The value of evaporation losses depends on the area of the water accumulated on the land surface. During basin, graded-border or contour-ditch irrigation, the whole irrigated area is flooded and unproductive evaporation occurs from the entire irrigated strip. During furrow or corrugation irrigation, the flooded surface is remarkably restricted, resulting in a substantial decrease in evaporation losses. This depends on the density and width of the furrows, and on the soil structure.

The flooding of the entire strip can also occur during sprinkler irrigation, by exceeding the appropriate irrigation rate. The efficiency of sprinkler irrigation depends on the harmony of the irrigation rate with the suction pressure of soil, which decreases the evaporation.

Losses during sprinkler irrigation are also caused by the irrigation of unproductive land and by evaporation in the atmosphere. The value of evaporation losses in the atmosphere depends on the temperature and air humidity, on the wind velocity, on the size of the water drops and the duration of the penetration through the atmosphere. Evaporation losses during wind of velocity 4 $m.s^{-1}$ exceed these recorded during calm periods by four times and more. When the wind velocity does not exceed 1 to 1.5 $m.s^{-1}$, the total field losses through sprinkler irrigation are lower than those during traditional irrigation methods, even in arid areas.

The size of the water drops and the duration of their penetration through the atmosphere depend on the operation pressure of the sprinkler, on the shape and diameter of the nozzles, i.e. on the type of the sprinkler, as well as on the arrangement of the irrigation rate and on the sprinkling intensity, which should be harmonized with the given climatological conditions.

Operation should be controlled according to the meteorological conditions, i.e. the conditions of the local microclimate; e.g. air temperature at night are lower, the wind velocity is milder and relative humidity higher. These favourable conditions usually result in a 10 to 15% decrease in evaporation losses in comparison with sprinkling operation in the morning or afternoon. The relative evaporation losses decrease with the increase in the irrigation rate, due to the influence of the humid microclimate formed by this operation provided the actual infiltration rate is not exceeded.

Maximum irrigation efficiency is achieved by drip/trickle irrigation. This high efficiency follows from the limitation of the area irrigated to the immediate vicinity of the plant, controlled by its suction pressure. In this way not only are evaporation losses effectively restricted, but percolation into unproductive subsoil layers is also correspondingly reduced.

This irrigation method, also used to add fertilizers, is characterized by high investment and operation costs and therefore is feasible for fruit trees and shrubs and for selected types of vegetables, such as tomatoes, peas, lettuce, cucumbers, gourds, aubergines, water-melons, peppers etc.

The advantages of trickle irrigation include in particular:

(a) water savings, resulting in a 10 to 20% increase in yield and, under special conditions, even by a high 60% and higher increase without any rise in water requirements or water consumption,

(b) the possibility of also using low quality water for irrigation, i.e. brackish and even sea water, because in the course of the trickle irrigation the soil and plant accept the minimum physiologically indispensable water quantity, which consequently restricts the input of salts. Trickle irrigation with low quality water requires appropriate operation including regular leaching.

(c) the possibility of fertilizing irrigation, which can be dosed depending on the actual growing stage and nutriment requirements of the relevant plant species,

(d) larger size, higher quality and better colour of plants, restricted occurrence of pests, weeds and plant diseases,

(e) shortening of the vegetation period.

2.6.9 Water for Livestock and Processing

Livestock breeding is an important component in the balance of biogeochemical cycles. During livestock breeding and agricultural processing, water is used

(a) to water cattle (including pressure cooking, dilution of fodder mixtures etc.)

(b) as service water (for waste disposal, washing and cleaning)

(c) as process water

(d) as drinking water (for newly born calves and sucking-pigs, for personnel etc.)

With regard to the quality of water for livestock, the relevant requirements are relatively lower in comparison with the drinking water quality, especially in terms of the chemical and bacteriological indicators. But the reaction of different species of domestic animals varies and depends on their age. (Tab. 2.38, 2.39).

Horses require high water quality, while sheep can take relatively low quality. The quality requirements of newly born and sucking animals are relatively high, resulting in the use of drinking water to supply young calves and sucking pigs.

The health stage and yield of livestock and poultry depends on the quality and quantity of the water delivered. A 30% decrease in water supply in large-scale breeding results for example in a 40% decrease in milk yield and in a 30% decrease in pork yield.

TABLE 2.38

Indicator		Livestock	Man mass supply	Man individual
Oxidizing	$mg.O_2.l^{-1}$	5	3	3
Sulphates	$mg.l^{-1}$	< 450	< 25	< 50
Bacteria coli 0 per		10 ml	100 ml	10 ml
mezophyllic per ml		< 500	< 20	< 100
psychrophyllic per ml		< 2000	< 200	< 500
Temperature (minimum)	°C	6 10a), 14b)	8-12	8-12

Differences in water quality requirements of drinking water for man and livestock. a) for calves, b) for sucking-pigs. For newly born calves drinking water standards and minimum temperature 25°C.

TABLE 2.39

	Evaporation residium	Chlorides	Sulphates
Cows	< 2400 $mg.l^{-1}$	< 600 $mg.l^{-1}$	< 800 $mg.l^{-1}$
Calves	< 1800	< 400	< 600
Pigs	< 1200	< 400	< 600
Sucking-pigs	< 1000	< 350	< 500
Horses	< 1000	< 400	< 500
Foals	< 1000	< 350	< 500
Sheep	< 5000	< 2000	< 2400
Lamb	< 3000	< 1500	< 1700

Indicators, characterising the sensitivity of different livestock species to water quality requirements and the feasibility of livestock breeding under different water quality conditions.

The requirements of watering livestock and of service water necessarily depend on the breeding technology. Modern breeding technologies result in a 50 to 100% increase in water requirements compared with small-scale breeding, because higher sanitary standards are necessary to cope with the increased probability of diseases due to high degree of cattle accumulation. Furthermore, replacing human labour by mechanical processes results in an increase in service water requirements: removing litter results in a 20% increase in water requirements (Tab. 2.40).

The total daily water requirements of livestock production consist of watering and processing as well as service water for waste disposal, washing and cleaning:

$$R_b = \sum_{i=1}^{k} n_i \cdot r_i + R_p + \sum_{k=1}^{k} A_k \cdot r_k \qquad (m^3 \text{ per day}) \qquad (2.139)$$

R_b – total daily water requirements of a cattle breeding farm

r_i – specific requirements per head of cattle or poultry (m^3 per pc)

n_i – number of heads in category i (pc)

R_p – daily requirements of processing water, if not included in specific requirements per head (m^3 per day)

A_k – area of relevant operational space k (m^2)

r_k – specific water requirement per square meter (m^3 per m^2)

TABLE 2.40

Species	Water requirements per pc and day Average	Maximum	Excrements liquid (l per day)	solid (kg per day)
Livestock:				
under fattening	10-40[a)]	60	10	30
milk cows	15-60[a)]	140	20	35
calves	15	20	2	5
horses	40	60		
mares and stallions	60	80		
sheep	8	10		
lambs	4	6		
fattened hogs	1,5-15	25	8	9
Poultry and small animals:				
Hens	0,25[b)]-0,75[c)]	1,5[d)]		
Broilers	0,25[b)]	0,35		
Geese and ducks	1,2	1,5		
Guinea-hens and turkeys	0,8	0,9		
Rabbits	3	5		

Water requirements for livestock and poultry breeding
a) lower value piped water, higher one rinsing system,
b) drip and self-filling drinking bowls,
c) flow drinking bowls,
d) during long summer days

The actual requirements for watering depend on the season, temperature, duration of the daylight, on the real weight of the relevant species, and on the particular breeding practices (stable and walk, hen-roost or run, outdoor breeding, small-scale or large-scale, type of equipment etc.). A remarkable fluctuation in requirements depending on the duration of the daylight occurs especially on poultry farms.

The maximum daily and per hour requirements can be derived with the aid of simple equations

$$R_d = R_b \cdot k_d \qquad (m^3 \text{ per day}) \qquad (2.140)$$

$$R_h = \frac{1}{24} \cdot R_d \cdot k_h \qquad (m^3 \text{ per hour}) \qquad (2.141)$$

R_b - total daily water requirements

R_d - maximum daily water requirements

k_d - coefficient of daily fluctuation ($k_d = 1.6 - 2.4$)

R_h - maximum per hour requirements (m^3 per hour)

k_h - coefficient of per hour fluctuation ($k_h = 1.8 - 3.5$)

Process water in agriculture, as in industry, includes all water needed for

(a) processing (including milk production)

(b) hydraulic transport (of manure, potatoes, beets, cereals etc.)

(c) cooling (of milk and other products) and air conditioning,

(d) boiling and heating,

(e) sorting, washing, rinsing and cleaning (of potatoes, vegetables, fruits, cereals, meat etc.)

Water in agriculture is used either as matter entering the product, as matter which comes into direct contact with the intermediate or final product or as a cooling or heat carrying medium. Relevant water quality requirements can be, therefore, classified in the same manner as the industrial water use.

2.6.10 Water Pollution from Agricultural Production

There are three main groups of pollutors in agricultural production:

(a) pollution from plant production (mainly areal): washing away of the eroded soil particles, applied and stored fertilizers, wastage of plant products, drainage waters and waste waters from irrigation polluted by extraction of salts due to overirrigation etc.,

(b) pollution from livestock and poultry breeding (mainly local): wastes from small and large-scale cattle, sheep and poultry breeding, including areal pollution from cattle walks, hen runs and pastures, escape of dung water and waste water from stables, escape of silage etc.,

(c) pollution from agricultural processing (mainly local): waste water from processing, dairies, from washing of agricultural machines, escapes of oil and oil products, stored agrochemicals etc.

Agrochemicals can be categorized according to their solubility, toxicity, possibility of decomposition or accumulation in organic matter, and their migration properties, which influence the water quality (Tab. 2.41, 2.42).

TABLE 2.41

Category	Characteristic	Lethal dose for warm-blooded animals a) X_k	Coefficient of accumulation for warm-blooded animals K_k	of aquatic organisms K_n	Stability b) (days) in soil	in water
1	slightly dangerous	>1000	> 5	<50	<30	<5
2	dangerous	201-1000	4-5	51- 200	1-6 month	6-10
3	highly dangerous	51-1000	1-3	1000	0,5-2 years	11-30
4	extremely dangerous	<50	<1	>1000	> 2 years	>30

Classification of chemicals, especially pesticides, after their threatening of surface and groundwater according to the COMECON proposal for standard (1981).
a) mg per kg of weight, peroneal dosage
b) duration of degradation on harmless constituents

$K_k = \frac{LD_{50}\ chronica}{LD_{50}\ acuta}$ – coefficient of accumulation for warm-blooded animals

Average dose for warm-blooded animal, peroneal dosage, mg per kg of weight:
LD_{50} chronica – by repeated dosage
LD_{50} acuta – by single dosage

$K_n = \frac{C_g}{C_v}$ – coefficient of accumulation in aquatic organisms

C_g – concentration in aquatic organisms

C_v – concentration in water

The quantity of excrements from livestock and poultry breeding can be derived from the weight of the relevant animal species. The ratio of the daily production of excrements fluctuates between 3.6 and 10% of the given weight. Poultry is characterized by lower, pigs by higher values. The daily average production of liquid excrements rises almost three times, and the maximum daily production to 250%, when water delivery by cisterns is replaced by a waterworks.

The prevailing pollution of water resources by agricultural production depends on local conditions and so any of the mentioned three groups of pollution may predominate in a given locality. Under conditions of intensive plant production the areal mineral and synthetic pollution by fertilizers and pesticides generally predominates. The influence of this areal pollution may substantially exceed (up to several times) the total pollution of water resources caused by industrial and municipal pollution.

TABLE 2.42

Class	Characteristics	Application	Species of pesticides
0	Non-poisonous	without limitation	sulphur fungicides (except barium polysulfide), zincous oxide, iron sulphate
1	Slightly dangerous	Application limited in protection zones for drinking water resources	Zincous sulphate, zonepion acid, hexachlorbenzol, acid substituted by halogens, fungicides with copper content, engine oil
2	Dangerous (easily degradable, non-accumulative)	Application prohibited in protection zones for surface resources and restricted in protection zones for groundwater resources used for municipal and rural water supply	derivatives of phenoxiacid, carbamate, triazin, dithiophosphorousacid (except metidation), heterocyclic fungicides, amid acids, analides, trichlorfon, dichlorfos, fenytrion, fenthion, bromfos, 1,4-dichlorpropane, zincous phosphide, baryum polysulphide
3	Highly dangerous (poisonous, easily degradable, accumulative)	Application prohibited in protecting zones for surface resources, exceptional usage in protecting zones for groundwater resources used for public water supply	derivatives of bipyridin, morkaptan (except forat), other chlorinated hydrocarbons (except endosulphane), carbamin acid, derivatives of ureas, all combinated herbicides
4	Extremely dangerous	Strict prohibition of usage in protecting zones for water resources	nitroderivatives, derivatives of dinitrophenol, forats, endosulphane, poisonous grain, matter containing mercury Hg or arsenic As

Classification of chemicals used during plant production according to their suitability for application in public water supply protecting zones.

The production and physiological processes of plant production take place in a pervious soil environment. Precipitation and surface irrigation washes away soil particles and agrochemicals, especially under conditions of large-scale production, thus causing their leaching and extraction and the consequent contamination of surface and groundwater resources.

The inconsistency of fertilizer and pesticide application with protecting water resources occurs when these agrochemicals escape from the root zone of the plants. Plants accept selected chemical elements only, especially nitrogen N, potassium K , phosphorus P - partially also calcium Ca, magnesium Mg and microbioelements. They do not accept any elements which are present in the soil in surplus.

The aim of maximizing agricultural yields with a minimum of human labour (unfortunately coupled with a lack of technological discipline) leads to an overapplication of agrochemicals. The application rates of chemicals frequently exceed 1.5 to 2 times and more the output of relevant bioelements during plant production. The contamination of water resources by intensive plant production is a problem of balancing the nutriment input and output. The resulting surface and groundwater pollution indicates not only overapplication and improper application practices, but also an uneconomic way of production, i.e. the wastage of agrochemicals.