Chapter 5

WATER DEVELOPMENT AND MANAGEMENT POLICY

5.1 WATER MANAGEMENT ACTIVITIES AND ORGANIZATIONS

Water management is a complex of activities, designed to meet the demands of economic development and aiming at an optimum development and utilization of water resources, depending on their quality and availability in space and time, and at the creation of an optimum living environment, through the conservation of water resources, their protection against exhaustion and deterioration, and through the protection of human society against the harmful effects of water.

The rational management of water resources utilization has as its aim, in common with development generally, an enhancement of the conditions for human life and must, therefore, be recognized as an integral part of social and economic development.

In periods of predominantly single-purpose water utilization, in areas with abundant water resources, low population density, scattered small-scale irrigation networks and a low degree of industrialization, social and individual water requirements can be satisfied by the activities of water users or different local organizations. To achieve a higher production and a better water utilization, various specialized organizations are formed with the aim of ensuring water supply, and/or disposal, irrigation development, power generation, inland navigation, protection against floods etc.

In the next development stage, river boards and other authorities are formed in order to achieve a greater efficiency in the management of water development to coordinate the multipurpose water utilization and protect the society against the harmful effects of water.

The supreme regulatory action concerning water, in order to meet the demands arising out of human activities and the necessary protection of the environment, is a government right and obligation. The delegation of authority from the centre varies from country to country and, in the case of federalized and developing countries, even within the same country, depending on the given social and political framework, the legal regime of water management, the availability of water in relation to its use, and other regional diversities.

Legal and institutional factors play an important role in the organization of the responsibilities for water resources management. The institutional framework is aimed at satisfying the different interests of all water users, and also at facilitating the correct implementation of all water-related policies and programmes. Decision-making is invariably closely linked with the relevant political, economic and social processes which are the result of the interaction of a number of bodies (Tab. 5.1).

TABLE 5.1

Sector			Water management	Sector		
LAW - MAKING	constitution civil law public works law labour law taxation law	water law water uses law flood control law pollution control law	WATER MANAGEMENT water law enforcement registry of water rights cadaster of water rights rights of way for water uses	POLICY-MAKING & PLANNING	national water policy international waters policy water management strategy	national objectives and goals international policy sectoral development policy
INTERIOR	municipal development	urban & rural water supply waste water treatment and disposal water pollution control	water pricing legal tools reimbursement of costs water administration	TRANSPORT	waterway development and maintenance hydrographical services water pollution control	inland navigation timber flotation railway, highway and air transport development
INDUSTRY & MINING	water supply and use waste water disposal	water supply for industry water pollution control	rights of way for water uses granting of water rights water disputes decisions	ENERGETICS	hydropower generation water for thermal & nuclear power generation water pollution control	thermal and nuclear power development distribution networks
AGRICULTURE	agricultural development irrigation drainage fisheries river training watershed management	water supply for irrigation livestock, processing and fish breeding water pollution control	approval of water development projects project design project construction project operation technical assistance	FORESTRY	water supply for timber industry forest irrigation water pollution control	forest management watershed management erosion control training of brooks and creeks
ENVIRONMENT PROTECTION	natural resources zoning landscape protection	flood control erosion control siltation control pollution control	hydrological services hydrogeological services data monitoring & processing hydraulic and hydrologic research	RECREATION	water supply for recreation waste water treatment and disposal	recreation services national parks administration tourism promotion sport promotion

Interrelationship between water management and other sectors.

Four basic groups can be distinguished among water management activities:

(a) legal administration,

(b) development activities,

(c) economic activities (Tab. 5.2),

(d) other management activities (incl. services - Tab. 5.3).

Depending on the individual characteristics of a given country, the institutional framework for water resources management includes the agencies with political and regulatory functions, working e.g. under regional authorities, and legislative bodies, working under a centralized water or other national authority. In order to restrict possible conflicts and provide a view which unifies nation-wide interests, the supreme coordination is usually entrusted to a special national authority, to one of the ministries responsible for the various water development aspects such as the Ministry of Water and Energy / Agriculture / Forestry / Public Works or to a multi-sectoral commission or special institute. To avoid any ambiguity, the exercising responsibility has to be separated from the administering and controlling/monitoring responsibility.

The diversity of institutional integration in water management depends on the separate consideration of such specific problems as municipal and industrial water supply and waste water disposal, groundwater development, irrigation and drainage, forest management, hydropower generation, inland navigation etc., and may be reflected by the existence of various organizations for some of these purposes.

Nevertheless, all matters relating to water should be regarded as forming part of an integral whole based on the unity of the relevant catchments. The structure of river boards corresponds to this territorial principle, whereas the institutional structure of water supply and waste water disposal organizations often depends on the particular in-house political arrangements.

In order to achieve the economic and social goals of a country in consideration of its environmental limitations, existing surface and groundwater resources have to be assessed, their quality, natural functions and present uses for all purposes identified, the future demands in the medium and long-term estimated, and both the medium and long-term plans formulated on the basis of an optimization process.

Water resources planning as an integral part of water development and management is a continuous process, whose implementation basically requires:

(a) a fixed strategy of water resources development and environmental protection,

(b) a flexible tactics of water requirements and withdrawals management,

(c) an operational control and checking of water quality and occurrence, water withdrawals, effluents and their quality, in-stream water uses and of measures of environmental protection.

5.2 PARADOXES OF WATER RESOURCES DEVELOPMENT

The course of water requirements and water withdrawals is generally deterministic, whereas the course of water availability is deterministic only within the limits of the realistic forecast of groundwater and surface water availability, which greatly depends on weather (rain) forecasts. It is, therefore, basically stochastic in the long term. The occurrence of water requirements and surface availability is usually contradictory: this leads to the first paradox which has to be dealt with in water resources development:

IN THE PERIOD OF HIGH WATER REQUIREMENTS A SUBSTANTIALLY LOWER WATER QUANTITY EXISTS IN NATURAL UNREGULATED RESOURCES THAN IN PERIODS OF LOW WATER REQUIREMENTS.

A gradual increase in total water requirements frequently results in a situation where, during water utilization, a point is reached when water requirements cannot be satisfied by an increase in water withdrawals from groundwater or unregulated discharges only. The water availability has to be regulated by artificial water accumulation.

Daily and weekly fluctuations can easily be balanced by small reservoirs or water tanks. Seasonal fluctuations in water requirements manifest a comparatively high dispersion of minimum and maximum values, which call for an overutilization of available water resources and claim a substantial increase in the parameters of relevant development projects.

As the number of reservoirs increases, gradually less and less feasible localities or less feasible arrangements for supplementing the required supply availability have to be used, including distant water resources, deep groundwater strata, and, in the last stage of development, even resources with low quality and unconventional water resources.

This is the reason for the rise in the average investment, operational and maintenance costs for water resources withdrawal, conveyance, purification and distribution. In addition, effluents depreciate the quality of available water resources and waste water treatment becomes necessary, thus further increasing relevant costs. This leads to the second paradox which has to be dealt with in water resources development:

THE AVERAGE INVESTMENT AND OPERATIONAL COSTS PER CUBIC METER OF WATER SUPPLIED GROWS EXPONENTIALLY, EVEN THOUGH THE SPECIFIC COST OF WATER SUPPLY FOR INDIVIDUAL WATER DEVELOPMENT PROJECTS DECREASES DOWN TO A CERTAIN LEVEL WITH THE INCREASING QUANTITY OF WATER SUPPLIED.

Problems associated with a lack of water or inadequate water quality are solved by the construction and subsequent operation of water projects. Water development projects which have in good time been implemented create a temporaty surplus of water that cannot be fully utilized immediately after their completion. This leads to the third paradox which has to be dealt with in water resources development:

THE TEMPORARY SURPLUS OF WATER OFFERING AN INTERLUDE FOR WATER OVERUTILIZATION WITHOUT ANY IMPORTANT NEGATIVE ECONOMIC EFFECTS, FORMS PRECONDITIONS FOR A SUBSEQUENT WATER SCARCITY.

Any period of temporary surplus of water ends by achieving an equilibrium between water resources and over-excessive water requirements. Any further lack of water is again solved by constructing a new project (Fig. 5.1). This cycle is to be repeated, extending the water resources development to more distant areas, until a stage of a utilization of economically feasible water resources is achieved. This leads to the fourth paradox that has to be dealt with in water resources development:

ALL AVAILABLE WATER RESOURCES ARE USED BEFORE EFFICIENT WATER-SAVING TECHNIQUES ARE APPLIED.

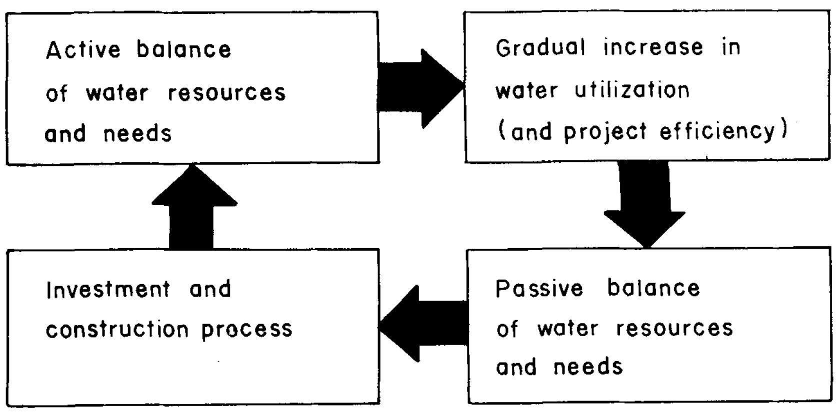

Fig. 5.1. Schematic interpretation of the cycle of water resources development and water use rationalization.

A society should form pre-conditions for its sound development by adapting its water requirements to water availabilities. But this rule functions under extreme situations only: When water availabilities are sharply restricted, water is used for indispensable uses only. The increased availabilities cause water to be used for less and less necessary uses. Under the situation of a long-term water surplus, growing water withdrawals differ more and more from the indispensable water requirements. This fact, accompanied by an exponential increase in specific investment and operational costs caused by utilizing less and less feasible project sites for growing total water withdrawals, leads to the fifth paradox that has to be dealt with in water resources development:

GRADUALLY INCREASING DEVELOPMENT COSTS GRADUALLY SAFEGUARD LESS AND LESS IMPORTANT WATER REQUIREMENTS.

5.3 STRATEGY OF WATER RESOURCES DEVELOPMENT

By formulating the desired water resources development objectives, it is possible to establish a strategy for the rational conservation and step-by-step development of those resources: i.e. to establish procedures for increasing the availability and subsequent utilization and disposal of water resources. A common objective is for example the conservation of the natural functions of water resources within the framework of the natural environment, especially of the quality and optimum allocation of these water resources among present and potential water users, i.e. their optimum multi-purpose utilization within the framework of the existing and expected social and economic structure (Fig. 5.2).

Long-term planning, a basic tool for helping to achieve these objectives, consists of the following steps:

(a) identification of available surface and groundwater resources, evaluation of their quality and uses in relevant categories of water utilization, which requires an information system or its establishment;

(b) evaluation of water demands in the medium term (five years) and of water needs in the long term, to match the physical and socio-economic conditions, national and regional development plans; treating inter-regional and international problems in the context of national interests;

(c) compilation of balances of water resources and needs, detecting critical areas, present and future problems;

(d) formulation of alternative scenarios and strategies, appropriate for solving particular national, regional and local problems;

(e) optimization and evaluation of these scenarios and strategies, with respect to their advantages and disadvantages, environmental and socio-economic after-effects, other implications and unavoidable repercussions, benefits and losses, and, last but not least, the investment, operation and associated costs required for the full completion and successful operation of the project or complex implementation of required arrangements in the framework of the present and future socio-economic structure;

(f) selection of the optimum scenario and strategy, i.e. the most appropriate for solving particular regional and local problems, capable of being pursued on a phased and flexible basis, taking into account environmental and socio-economic limitations incl. the lack of skilled human resources and the inertia of local customs, obsolete social structure, traditional labour methods, jeopardizing especially the successful introduction of modern agricultural practices, and the implementation and operation of modern irrigation systems;

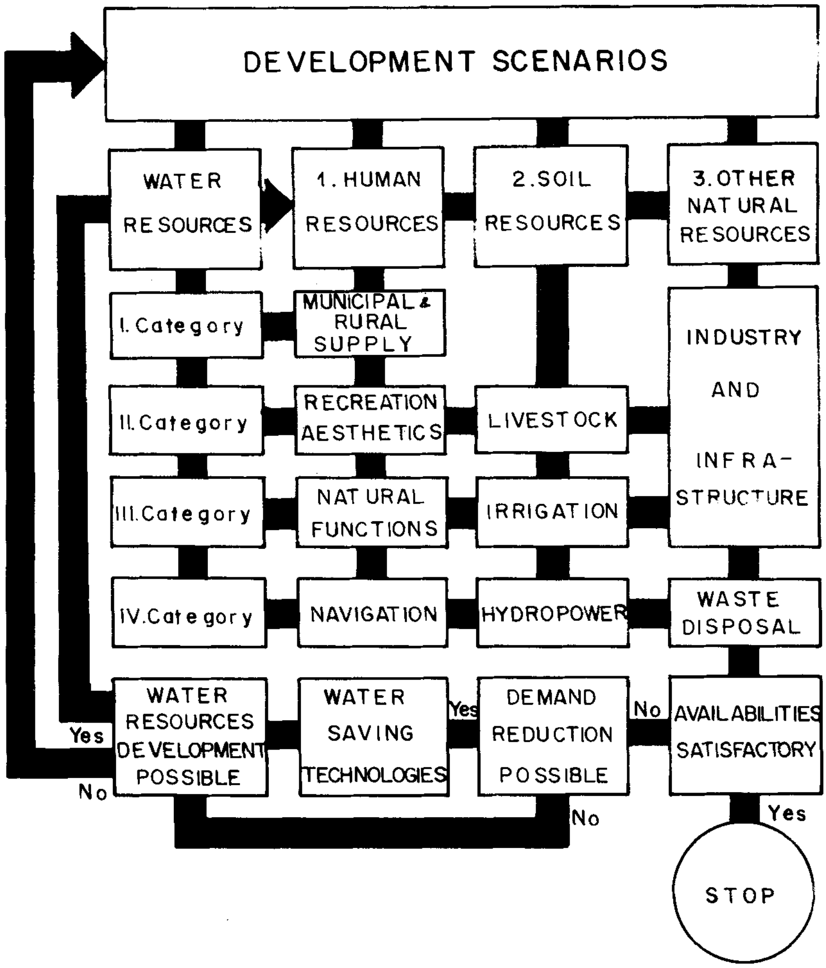

Fig. 5.2. Block diagram for allocation of water resources in line with development of the soil resources and industry. Any rational development tends to the ultimate stage of a sustained utilization of the natural potential by using the minimum matter and energy, which should be checked in relevant time horizons.

(g) approval and acceptance of the preferred scenarios and strategy by all central and regional authorities, involving the existence of an appropriate legal and institutional framework and two-way co-ordination among all levels of responsible authorities during the planning process;

(h) budgeting the gradual implementation within the framework of medium-term plans, whose aim is to integrate planned programmes of different sectors, define in financial terms the annual national, regional and local objectives, and to allocate funds for achieving those medium-term objectives;

(i) monitoring the performance of the plan, modifying it, if required by changed circumstances, needs and priorities.

Significant goals in medium-term plan implementation include the harmonization of:

(a) the development of the natural environment, balancing the needs of the utilization of natural resources and the necessity of environmental protection in order to decrease the negative impact of water utilization on the hydrological cycle, which reduces the volume of water available and leads to a deterioration in its quality,

(b) the water needs of present and potential water users with a view to the required water quality and quantity and to the optimum economic conditions.

To achieve the above goals, the following three principles have to be respected:

First principle of water development strategy:

KEEPING THE DEVELOPMENT OF WATER RESOURCES IN LINE WITH THE OVERALL SOCIO-ECONOMIC DEVELOPMENT BY RESPECTING THE DIVERSITY OF THE OCCURRENCE OF WATER RESOURCES UNDER NATURAL CONDITIONS.

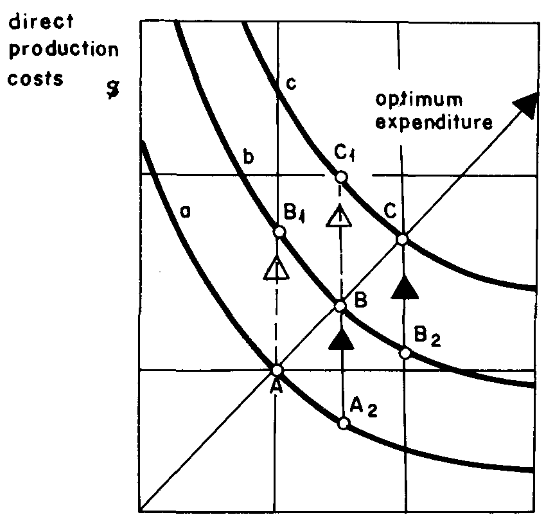

Fig. 5.3. Graphic representation of the relation of the total direct production cost and the expenditure on infrastructural investment and operation according to Czuka (1975). Excess infrastructural capacity (path A A_2 B B_2 C) enables lower production costs.

Economic development requires a proportional development in the fields of both productive and infrastructural projects. Expenditures in the sphere of the infrastructure decrease the cost of direct production activity. Production costs increase with decreasing infrastructural costs until a minimum infrastructural value is attained which is indispensable for obtaining any output from the direct production activity.

The national objective is to increase production at the minimum total cost, i.e. including the expenditures both in direct production activity and in the infrastructure. The curve expressing the relation between direct production costs, investment and operation costs in the sphere of infrastructure, also including investment and operation costs for water development projects, is hyperbolic. It moves gradually away from the zero point in time, due to more developed and financially more and more demanding investments.

The way to technically more developed production may be twofold:

(a) with deficient infrastructural capacity, requiring higher direct production costs,

(b) with excess infrastructural capacity, permitting direct production costs to be maintained at a low level.

The development scenario with excess infrastructural capacity (A A_2 B B_2 C) - (Fig. 5.3) enables lower production costs, thus forming more favourable productions, attracting productive investments and dynamically increasing living standards.

The development scenario with deficient infrastructural capacity, which appears in countries with slowly developing economies (path A B_1 B C_1 C), leads to higher production costs, which are then difficult to reduce in the period of a sufficient infrastructure. It is therefore advantageous to develop water investments belonging partly, in some economic models, to the production sphere, five to ten years before the full development of the production sphere.

Second principle of water development strategy:

RESPECTING THE LIMITS OF THE NATURAL ENVIRONMENT IN THE STAGE OF ITS FULL, RATIONAL AND LASTING UTILIZATION FOR THE SAKE OF HUMAN SOCIETY.

The basic objective of water development as an integral part of social and economic development can be defined simply either as

- the maximization of the living standard for the population or in its second extreme, under completely different local or environmental conditions,
- the safeguarding of the survival of the population.

The second objective may appear as decisive, not only under the speficic conditions of underdeveloped populated countries or areas with extreme climatological conditions, but also in the conditions of some developed areas whose development has already exceeded the environmental limits, i.e. the potential of renewable natural resources. As mentioned before feedbacks exist, causing a deterioration in the environmental quality as a result of any over-utilization.

The resources potential of a certain area can be defined as its ability to satisfy permanently the needs of society, arising from its socio-economic development. In can be expressed by a multitude of physical, chemical, biological and aesthetic values and be simply represented by the number of inhabitants whose nourishment and economic development it is possible to permanently sustain by agricultural or other production. Overproduction in excess of this resources potential is therefore possible, but relevant feedback causes a temporal or permanent deterioration in the environmental quality.

Water potential, which forms an integral part of this resources potential, can be defined by the

- annual discharge of the surface water and by the table and quantity of the groundwater,
- annual rainfall and the discharge coefficients,
- minimum discharges and the flow duration curve
- water quality relevant to quantity records or to the depth below the surface.

Over-utilization of the water potential causes first the decline in the water quality, and the second decline of the environment.

During the development of water resources local resources available nearby are used first. The utilization of these local water resources is, in the next development stage, often replaced by mass water supply from substantial resources of generally lower quality. The inter-connection of these mass water supply networks gradually creates regional water supply systems. The possibilities of further extensive development are exhausted by long-distance water conveyance and by the creation of an inter-regional system.

Respecting the limits of the natural environment means a rational approach from the stage of a non-systematic utilization of water resources, depending on their availability and economic feasibility, to the ultimate development stage of the full, rational and lasting utilization of water resources without any important long-term impact on the natural equilibrium.

Third principle of water development strategy:

MAXIMIZATION OF THE REQUIRED OR POSITIVE EFFECTS OF THE PROJECT AND MINIMIZING ITS SIZE AND NEGATIVE IMPACT.

This principle is derived not only from the need of economic feasibility, but also from the previous principle of respecting the environmental limits. By decreasing the size of the project, its negative impact may also be reduced and reserves left for the diverse future needs of the society.

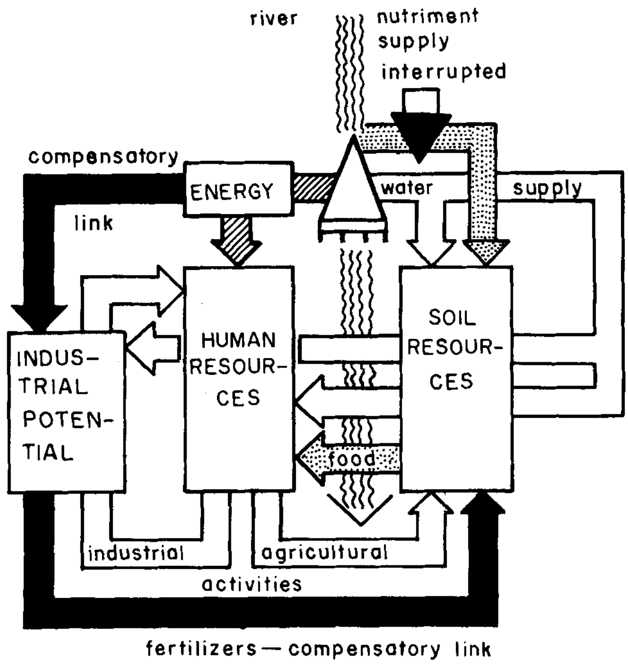

Fig. 5.4. An indispensable precondition for the efficiency of any water development measures is the maintenance of the uninterrupted structures of the system: interrupted structures have to be replaced by new ones, e.g. fertilizing effect of floods after completed flood control measures has to be compensated by artificial fertilizers, which is energy- and labour-intensive.

5.4 TACTICS OF WATER MANAGEMENT

Water requirements and water withdrawals usually exceed, or tend to exceed, the rational water requirements. In addition to this, effluents and excessive water consumption impair water quality, restricting its further utilization. The need to search for means of managing a water economy usually arises as a result of an actual or expected deterioration in water resources caused by the pollution of the area in question or of a whole country. An adequate utilization of water resources and a proper control of the use of water are impossible without an adequate utilization of all available means, which are basically:

(a)	legal	l
(b)	institutional (and organizational)	i
(c)	technical	t
(d)	economic	e
(e)	personal and moral	p

The legal, institutional, organizational, technical, economic and personal arrangements and criteria which are required to provide effective tools for the rational and integrated development, use and conservation of water resources at the national level are not very different from those required at the local level. Water withdrawals W, water consumption C and water pollution N are a function of the indispensable water requirements R_i and of the above variables:

$$W, C, N = f_{1-3} \ (1, i, t, e, p, R_i) \qquad (m^3.s^{-1}, BOD_5.m^{-3}) \quad (5.1)$$

From a social point of view, it is indispensable to safeguard first of all the relevant personal water requirements of any individuum as a basic precondition of his living standard. This basic quantity is to be offered to the individuum in the optimum quality and at a rate which does not substantially restrict his living standard. Water requirements and uses in industry, agriculture, energetics and transport are to be safeguarded under different economic conditions, because these bodies directly benefit from water utilization.

On the other hand, it is indispensable to use all the above tools for the protection of human society before unuseful wastage, misuse and depreciation of water resources and before overexcessive water withdrawals, demands and arrangements threaten or have a negative impact on the environment, thereby restricting the future development or negatively influencing the living standard or life-style of the society concerned.

A dominant economic characteristic of water utilities is the large investment in fixed capital, characterized by the capital-turnover ratio, i.e. gross annual revenues divided by total investment, ranging from 0.15 - 0.25 comparing with 0.3 to 0.5 for other utilities and 2.0 for manufacturing industries.

A negative relationship exists between water price and the water quantity demanded. An increase in price is associated with a reduction in the quantity demanded. Pricing policy, by affecting water requirements, is the effective tool which can, in relation to other tools, satisfy the varied goals of water management.

Domestic, industrial, agricultural and infrastructural water requirements are responsive to price changes. Concerning domestic water requirements, the change from flat rates to metered rates may result in a permanent decrease of some 30 to 40% in water use. A decrease exceeding 60% was recorded as a result of warm water supply metering and paying separately for each flat, being a result of altering basic uses, e.g. using stoppers, dishpans etc. instead of constant flow, repairing leaks in the domestic plumbing system etc.

When the ratio of water management costs to the total social property is relatively small, water development and management expenses can be fully covered either from private or from common funds. There is a great diversity in the degree of institutional integration in water management, but the growing costs of water development and management result in increasing state and international coordination and financial intervention, and in a general tendency to ensure that the users who directly benefit from such control cover the cost.

TABLE 5.2

Product	Unit	Definition	Symbol
1. Surface (raw, irrigation) water	m^3	Water withdrawn from a stream. (delivered to the user)	M_1
2. Groundwater	m^3	Water withdrawn from an aquifer.	M_2
3. Drinking water	m^3	Water corresponding to drinking water quality standards, delivered to the water user.	M_3
4. Process water	m^3	Treated water delivered to the water user for industrial use.	M_4
5. Waste water	m^3	Waste water taken away by the sewerage system to the stream or waste water treatment plant.	M_5
6. Treated waste water	m^3	Waste water treated in the waste water treatment plant.	M_6
7. Sludge	t	Utilisable waste from waste water treatment and purification plants incl. recovered material.	M_7
8. Hydropower	kWh	Energy (average continuous, peak, breakdown) generated by concentration of head and by storage, if required.	M_8

Classification of water management products.

This tendency results in the formation of river boards and water supply/ disposal authorities as economic organizations safeguarding the required products, productive and unproductive services (Tab. 5.2, 5.3). Hence, the task of economic management tools is as follows:

(a) they partially or fully finance the main activities of water management organizations, which regulate water development activities,

(b) they regulate water withdrawals, water consumption and the quantity and quality of effluent,

(c) they regulate industrial and agricultural development, municipal and rural development, water power generation, inland navigation, water recreation, thus also influencing the living standard of the population, which is also directly affected by their impact on the domestic water requirements.

The determination of charges for water withdrawals, water consumption, in-stream water use, water pollution, effluent disposal, as well as variations and exemptions in these charges and rates, and using water for any of the mentioned purposes without charges, influences the social efficiency of water utilization. But the degree of such influence depends on local, and especially economic conditions. These charges and rates influence the water requirements of the population in connection with the living standard and style, i.e. the net income, standard of dwelling and social customs.

The influence of water rates on agricultural water requirements mainly depends on the cost-benefit ratio, on expenses for other arrangements needed for an increase in agricultural yield, on the market and credit possibilities, and on the inertia of traditional irrigation and other agricultural practices.

TABLE 5.3

Water management services	Unit	Definition	Symbol
Productive service:			
1. Flood control	km^2	Water resources management aimed at protection against floods and erosion.	N_1
2. Soil protection	km^2	Drainage and soil protection.	N_2
3. Navigation	tkm	Improvement of waterways, operation of locks and flow control.	N_3
4. Aquatic life management	$m^3.s^{-1}$	Water delivery and water resources management to increase especially fish production.	N_4
5. Pollution control	$m^3.s^{-1}$	Management of water resources to restrict water pollution.	N_5
6. Other productive services	$m^3.s^{-1}$	Management of water resources to enable production in other production sectors, e.g. water delivery for pump storage plants etc.	N_6
Unproductive services:			
7. Recreation and water sports	capita per season	Management of water courses to enable or improve recreation.	N_7
8. Hydrometeorological services		Collection and processing of hydrometeorological data.	N_8
9. Other unproductive services			

Categorization of water management services.

The impact of water rates on industrial water demands depends on the ratio of the water supply and effluent disposal cost to the total cost of production, on their influence on the development of the relevant industrial plant, on the water-saving technology available, on the inertia of traditional production practices, and, last but not least, on their influence on the net income of the relevant managers.

Practical water pricing systems generally represent combinations of the following water pricing possibilities:

(a) Free of charge, i.e. price of water included in general taxes,

(b) Specific water tax,

(c) Water rates

- per unit of water ($ per $1.s^{-1}$)
- per unit of product ($ per 1000 pc, per kWh)
- per unit of services (tkm)
- lump sum, without relation to the quantity of water supplied.

Rates can take the following forms

(a) uniform rates, dependent on the quantity supplied in the relevant categories of water users,

(b) rates with increase for increased quantities (supporting water saving)

(c) rates with reductions for increased quantities (supporting the development in the relevant category of water users)

(d) seasonal (depending on the balances of water resources and requirements and supporting water saving in the period of its deficiency).

Water rate per unit can be

(a) uniform for all water users,

(b) differentiated (dependent on the state social and development policy: basic quantity free of charge, lower prices for preferred water users, e.g. for agriculture, higher for high-income producers etc.)

(c) dependent on water quality (surface water, groundwater, treated water etc., class Ia, Ib, II, III, IV),

(d) dependent on the quality of the product (in energetics for kWh basic, peak, breakdown etc.)

(e) dependent on water consumption (in industry and energetics).

In the case of water rates per unit of water consumption, these can be

(a) uniform,

(b) categorised on the basis of the consumption ratio,

(c) with an increase for increased water consumption and a decrease for decreased consumption),

(d) seasonal (increased during unfavourable balance of water resources and needs).

Rates per unit of effluent can be

(a) uniform,

(b) with linear or exponential progressive increase for increased pollution,

(c) categorized according to the category of polluter (agriculture, industry, municipality),

(d) categorized on the basis of the water quantity and quality in the recipient, class Ia, Ib, II, III, IV,

(e) categorized on the basis of the effluent quantity and quality.

Legal tools can achieve similar stimulating functions to those of economic tools namely through:

(a) official duties (for utilization permissions, discharge permits, rulings etc.) P_1

(b) sanction rates, assessments P_2

(c) fines (e.g. for utilization of water in violation of valid regulations) P_3

(d) recompenses etc. P_4

Expenses connected with water development and management include

(a) management and control costs O_1

(b) operational costs for water withdrawal, distribution, purification, waste water disposal etc. O_2

(c) maintenance and reproduction costs of water development projects (depreciation costs etc.) O_3

(d) investment costs O_4

The balance of relevant benefits and expenses can be expressed by a simple equation

$$S + \sum_{k=1}^{4} O_k = \sum_{k=1}^{8} M_k + \sum_{k=1}^{6} N_k + \sum_{k=1}^{4} P_k + \sum_{k=1}^{n} G_k \qquad (5.5)$$

S - surplus required (if necessary)

G_k - grants from other sectors and bodies

O_k - expenses

N_k - accumulated charges for products connected with the water use

N_k - accumulated charges for services connected with the water use

P_k - duties, fines, recompenses etc. (if incorporated in economic tools).

The economic basis for water resources development and management has to be established by including or excluding the above mentioned components in the equation. Hence, this inclusion or exclusion and the level of the relevant charges not only decide on the creation of financial reserves, on a timely acquisition of the necessary means for operation, maintenance, investment, administrative and other costs, but also on the utilization of water resources in a socially desirable manner, on the coordination of the development rate, and, last but not least, on the development of living standards.

Bearing this in mind, water rates should be determined on the basis of the following factors:

(a) reimbursement of expenses for:

- operation,
- reproduction and modernization,
- administration,
- investment for further development,

TABLE 5.4

Factor	Basic aims in water supply	Basic aims in waste water disposal
	Reimbursement or partial reimbursement of expenses for:	
1. Financial balance	a) management and control b) operation and maintenance of water supply networks and facilities c) their modernization d) new water supply projects	a) management and control b) operation and maintenance of sewerage systems c) their modernization d) new waste water disposal projects
2. Factors of time	a) seasonal limitations of availability b) seasonal and daily limitation of requirements c) long term limitation of water needs due to limited resources	a) restriction of environmental pollution b) seasonal and daily control of waste water disposal c) limitation of lasting pollution due to resources potential
3. Factors of consumption and concentration	a) limitation of actual water consumption b) limitation of water consumption in the long term	a) limitation of concentration of toxic and other substances in waste waters b) restriction of change in ecosystems
4. Factors of quality	decrease in water requirements in the production sphere	a) decrease in water pollution b) material recovery
5. Policy	Effect of water and waste water disposal pricing on general economic development and on the living standard of population, especially on low-income groups. Effect of penalties and subsidies on water use from environmentally, regionally and socially desirable viewpoint.	

Categorization of the basic factors of water and waste water disposal pricing policy.

(b) passivity of the balance of water resources and needs,

(c) limitation of water consumption,

(d) restriction of water resources pollution,

(e) overall development goals.

The influence of economic tools on water withdrawals W, water consumption C and water pollution N ($BOD_5.m^{-3}$) can be expressed by a simplified equation 5.1 in this way

$$W\ ,\ C\ ,\ N\ =\ f_{1-3}(M_k)\ .\ R \qquad (m^3.s^{-1},\ BOD_5.m^{-3}) \quad (5.6)$$

An increase in water rates results in a decrease in water withdrawals, in a decrease in effluent quantity and in a decrease in water consumption.

$$^1M_{1-4} > {}^2M_{1-4} \longrightarrow W_1 < W_2 \longrightarrow C_1 < C_2 \qquad \text{(see Tab. 5.2)} \qquad (5.7)$$

An exponential increase in rates for water pollution results in a drastic decrease in water pollution

$$^1M_{5-6} \gg {}^2M_{5-6} \longrightarrow N_1 \ll N_2 \qquad \text{(see Tab. 5.2)} \qquad (5.8)$$

The attributes of efficiency are associated with competitive prices. Therefore, the rates should be varied with the required changes in demand, consumption, water pollution and cost conditions. Water consumption can be influenced, i.e. decreased, by the introduction of special rates or by associating water rates with the value of the water consumption ratio

$$^1M_c > {}^2M_c > 0 \qquad C_1 < C_2 < C_3 \qquad (5.9)$$

Applying the forces of supply and demand, water withdrawals W can be expressed, according to Hanke and Davis (1971), as a reversed and exponential function of price

$$W = \frac{K}{M^e} \qquad (5.10)$$

M - unit rate

e - price elasticity of water withdrawals

K - constant, expressing the combined effect of other tools

K = f (l,i,t,e,p), and can be simply derived from indispensable water requirements R_i

$$K = k_i\ .\ R_i \qquad \text{(see paragraph 3.2)} \qquad (5.11)$$

If price is to be changed from ${}^1M$ to ${}^2M$, the expected water withdrawal W_2 can be estimated by taking the log transform

$$\text{Log } W_1 = \text{Log } K - e \log {}^1M$$
$$\text{Log } W_2 = \text{Log } K - e \log {}^2M \qquad (5.12)$$

as well as by subtracting and rearranging to find the water withdrawal W_2 from the known values of the other variables:

$$\text{Log } W_2 = e \cdot (\log {}^1M - \log {}^2M) + \log W_1$$

In the water resources utilization sector of the economy prices are generally not determined by objective factors of supply and demand, but set by the pricing policies of utility managers. They remain constant from the season of peak availability to the season of peak demand. Available resources are used inefficiently and inequities are imposed on the utility's consumers.

The season of peak water demands frequently occurs in the period of low water availability. Water withdrawals in the season of peak water demand or in the period of low water availability are economically different from those in other periods: This water is high-cost water, because additional capacity must be provided if requirements exceed the original capacity. By not varying water rates to reflect these cost differences, investments are larger than economically justified.

The elasticity of water requirements and their sensitivity to changes in water rates vary according to the different categories of water users. But in any case the seasonal regulation of water rates decreases the difference between the maximum and minimum values of total withdrawals

$$W_{max} - W_{min} > W^+_{max} - W^+_{min} \qquad (5.14)$$

provided that W^+ and W correspond to seasonal and constant prices respectively which reimburse the same total amount.

The application of seasonal water rates for a hypothetical utility can be illustrated by two curves:

m_{min} - curve representing off-peak water requirements (for the period of an effective balance of water resources and needs)

m_{max} - curve representing peak water requirements (for the period of a passive balance of water resources and needs) (Fig. 5.5).

The constant average cost pricing line is horizontal and implies that capacity stands at some constant ratio to peak water requirements. The average variable costs are assumed to be constant and equal to marginal costs. The in-

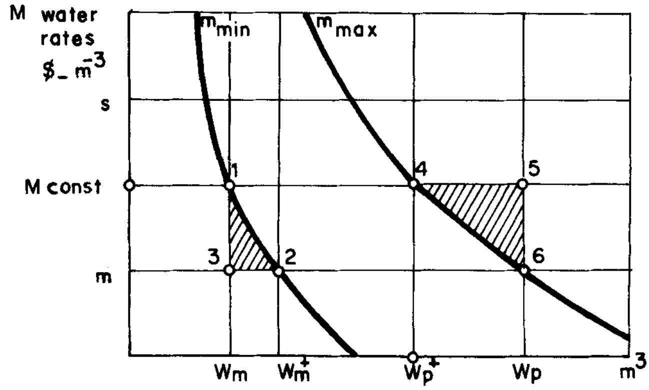

Fig. 5.5. The effect of an increase in water prices in the season of increased water requirements and drop in water availability and its off-seasonal decrease, safeguarding the same profit but increased efficiency in water use according to Hanke and Davis (1971).

cremental costs of expansion are depicted by a proxy, average variable costs plus recorded capacity costs distributed over six months.

Constant average prices result in inefficiencies during the period of peak water requirements, demanding the needlessly excessive capacity W_p. The use of water in the period of excess availability is needlessly limited, leading to withdrawals W_m.

Seasonal prices produce higher off-peak requirements W_m^+ and lower water requirements W_p^+ during the period of lack of water. Water use in the off-peak season should be allowed until the relevant incremental costs are equated to incremental value. By allowing this expansion in off-peak use there would be an efficiency gain, represented by the triangle 123 (Fig. 5.5). In the case of maximum withdrawals during constant prices W_p, the loss generated by the needlessly excessive capacity pricing rule is postulated for future years, significant reductions in water requirements can be expected, resulting in investment savings.

To relieve the problem of peak requirements occurring in the period of low water availability and safeguard a dynamic water development

(a) the water rates should refer to the actual cost structure and actual cost of resources used or saved by consumer decisions,

(b) the water rates should reflect operating costs with no, or only a partial contribution to capacity costs, if the capacity of the available resources is not adequately utilized (i.e. in the period of a highly active balance of water resources and needs),

(c) the period of an equilibrium of water resources and needs, or if requirements exceed capacity at the relevant price, the price should reflect both operation and capacity costs and should be adjusted upward to restrain water withdrawals to the capacity level, and seasonal rates should be determined to restrict the fluctuation of water withdrawals during peak and off-peak periods of demand.

A similar policy should be accepted to decrease water pollution by industry.

5.5 NON-CONVENTIONAL TECHNIQUES OF WATER USAGE

The programme in keeping with the final phase of water development, when all surface and groundwater resources are fully utilized in the conventional way, includes

- the general extension of water-saving technologies, including non-conventional water utilization and
- using non-conventional water resources or non-conventional techniques of water supply, i.e.

(a) long-distance water conveyance and long-distance transportation of water,

(b) conjunctive utilization of surface and groundwater resources,

(c) groundwater mining and artificial recharge,

(d) watershed management aimed at modifying the quantity and timing of water production,

(e) changes of total runoff, namely changes of evaporation or evapotranspiration rate, changes of snow and ice melting,

(f) weather modification,

(g) desalination, renovation of waste water, treatment of other low-quality water.

5.5.1 Long-Distance Water Conveyance and Long-Distance Transportation of Water

The problem of the long-distance conveyance and transportation of water is basically economic. During the conventional water supply the costs for water withdrawals and treatment prevail:

$$M_w + M_t \ll M_c \cdot L$$

M_w - specific cost for withdrawal of 1 m^3 of water ($ per m^3)

M_t - specific cost for treatment of 1 m^3 of water ($ per m^3)

M_c - specific conveyance cost for transport of 1 m^3 of water ($\$.m^{-4}$)

The total specific cost M_o is, therefore,

$$M_o = M_w + M_t + M_c \cdot L \qquad (\$ \text{ per } m^3) \qquad (5.16)$$

and $M_o = (r_{tc} + 1) \cdot M_c \cdot L$ (5.17)

$$r_{tc} = \frac{M_w + M_t}{M_c \cdot L}$$

L - conveyance distance (length of the headrace or pipeline) (m)

r_{tc} - ratio of water supply and transport costs

Water losses during water conveyance depend first on the construction of the conveyance structures and second on their length. Leaving the losses which occur during water withdrawal and treatment aside, the water quantity supplied can be simply expressed on the basis of the quantity withdrawn as

$$D = (1 - c_w \cdot L) \cdot W \qquad (5.18)$$

D - water delivery - quantity of water supplied $(m^3 . s^{-1})$

W - water withdrawal $(m^3 . s^{-1})$

c_w - coefficient of specific water conveyance losses (m^{-1})

The total expenses of water supply can be similarly derived as

$$D \cdot M_o = W \cdot (M_w + M_t) + D \cdot M_c \cdot L$$

$$(1 - c_w \cdot L) \cdot M_o = M_w + M_t + (1 - c_w \cdot L) \cdot M_c \cdot L$$

$$(1 - c_w \cdot L) \cdot (M_o - M_c \cdot L) = M_w + M_t$$

This equation can be simplified to

$$M_o = M_c \cdot L \cdot \left[1 + \frac{r_{tc}}{1 - c_w . L} \right] \qquad (\$ \text{ per } m^3) \qquad (5.19)$$

Comparing two water conveyance projects of the same capacity (M_{c1} M_{c2} , c_{w1} c_{w2}), a limiting distance exists which has the same total conveyance cost in both cases:

$$(1 - c_{w1} \cdot L_m) \cdot W_1 = (1 - c_{w2} \cdot L_m) \cdot W_2 \qquad \text{(see eq. 5.18)}$$

$$W_1 \cdot M_{c1} = W_2 \cdot M_{c2}$$

$$L_m = \frac{M_{c1} - M_{c2}}{c_{w2} \cdot M_{c1} - c_{w1} \cdot M_{c2}} \qquad (m) \qquad (5.20)$$

L_m - marginal transport distance, requiring the same costs in both alternatives, i.e. one alternative is more feasible for longer conveyance distances and the other (with higher conveyance losses) for shorter ones.

The above equation is valid only for comparing projects which have the same costs for water withdrawal and treatment. It goes without saying that this limiting transport distance depends on the discharges diverted, their quality and purpose of their utilization.

The same equation can be applied for the option of transporting water from surplus areas to water-short areas by using cistern wagons, tankers or towing mammoth containers or blocks of icebergs. The realistic distance from the source to the receiver has to be in the order of below 2500 km, and the maximum size of the container approaches some 1.5 million m^3.

5.5.2 Conjunctive Use of Surface and Groundwater Resources

The volume in groundwater resources exceeds by more than a thousand times the volume of fresh water in all water courses. Half of this amount is available at a depth below 1000 m, but its quality is not sufficiently known and the rate of its natural replenishment is extremely low (see Tab. 1.1).

The over-excessive extraction of water from groundwater resources has the same character as mining minerals and causes similar environmental effects: settlement of the Earth's surface, ecological damages, diminution of discharges in rivers and streams, difficulties with both surface and groundwater quality etc.

Pumping from deep aquifers is energy-demanding. Owing to the high fluctuation of water tables, which is due to changing lifts, pumps often work under conditions of low pumping efficiency. The temperature of water from deep aquifers is often higher and depends not only on the depth but also on the geological age of the strata, - younger geological formations contain water of higher temperature.

Nevertheless, aquifers can be successfully used in conjuction with surface water resources, especially in the period of peak demands and in dry periods. Thick, interstitial aquifers in natural dry conditions, or only filled up with water to a minor extent, can be used as underground reservoirs to store large quantities of water of acceptable quality for the period of peak requirements.

Artificial infiltration can increase the quantity of water in groundwater resources by the help of infiltration basins, channels and artificial channels, infiltration galleries and wells, working in the period of excess water in surface resources. An overpumping of these groundwater resources in the period of drought may contribute considerably to balance water availability and needs even in the period of peak demand (see paragraph 5.5.3).

The conjunctive use of surface and groundwater resources means a coordinated utilization of available water discharges as well as reservoirs and compensation for a lack of water in two or more successive dry years by groundwater for seasonal, annual and carry-over storage.

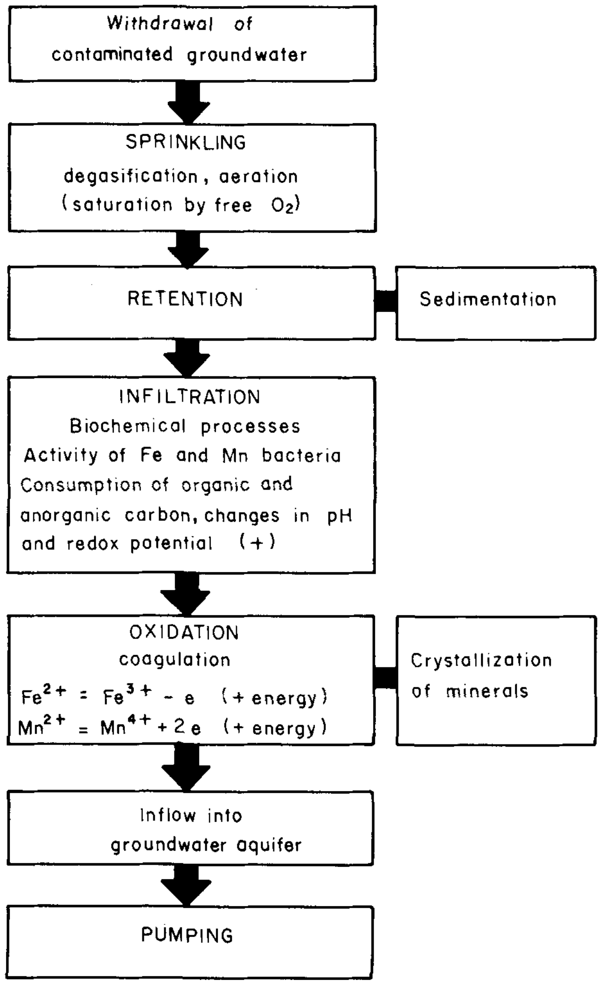

Fig. 5.6. Flow chart diagram representing the basic processes of the utilization of geological strata to change water quality, explored by Hatva and Reijonen (1972).

The drop of the groundwater table provokes a more efficient natural recharge, also from non-utilized strata which do not normally contribute to the groundwater reserve of the aquifer in question. The volume of water extracted from groundwater resources in a dry year may, under favourable geomorphological and topographical conditions, even exceed the average annual recharge, provided the surface reservoirs safeguard the recharge during wet years.

The conjunctive use of surface and groundwater resources also forms conditions for water storage in locations where construction of a surface reservoir is not feasible, offering possibilities for economizing on the size of reservoirs and their use for carry-over storage. It restricts the space requirements for water development projects, thus enabling better utilization of the land surface.

In this way the availability for operational runoff regulation is utilized in an integrated and environmentally feasible manner, restricting the evaporation losses and also improving the water quality: artificial recharge offers favourable conditions for water treatment (Fig. 5.6).

Among the other advantages of the conjunctive use of surface and groundwater resources, the construction in stages should be mentioned: this enables the step-by-step connection of the new resources to the existing system of mass water supply for population, industry and agriculture. The conjunctive use of surface and groundwater resources economizes on the construction of the distribution and drainage network for irrigation: the groundwater table can be regulated by means of relevant recharge and supply wells, and the lining of distribution canals can be restricted, because the percolation losses recharge the groundwater reserve. A more flexible irrigation regime facilitates their operation, making it possible to pump outside the period of peak energy demand.

The main obstacles to a desirable development of the conjunctive use of surface and groundwater resources include:

(a) gaps in the investigation of deep aquifers,

(b) technical problems of waterlogging and clogging during infiltration,

(c) higher operational costs due to higher consumption of energy during extraction of groundwater from deep aquifers,

(d) institutional gaps and diversity in investigation of surface water and groundwater (see paragraph 3.1),

(e) the lack of common understanding between the relevant surface and groundwater specialists as well as tradition.

5.5.3 Groundwater Mining and Artificial Recharge

Under special economic and environmental conditions groundwater can be extracted as an exhaustible recource of fixed supply on a mining-yield basis. Mining yield is a total volume of non-renewable water in an aquifer, analogous to a mineral deposit (see paragraph 3.2). Five types of overdraft have to be recognized according to Snyder (1955):

(a) Development overdraft, a necessary first stage in groundwater development in that withdrawals cause a lowering of the water table in areas of natural recharge and discharge. This permits full utilization of the interaction between the components of the hydrologic cycle.

(b,c) Seasonal (annual) or cyclical (periodic) overdraft, both characterized by a zero net change in water levels over a specified interval of time. Seasonal overdraft occurs when water levels at the beginning of the pumping season remain the same from year to year, but are in a continual state of decline during pumping seasons. Cyclical overdraft exists when water levels decline over two or more seasons, but eventually return to their original level. These types of overdraft are relatively unimportant and depend a great deal on the seasonal or annual demand for water.

(d) Long-run overdraft is perennial pumping in excess of natural replenishment, which may lead, ultimately, to depletion.

(e) Critical overdraft occurs when pumping leads to some undesirable physical result, restoration from which is technologically or economically impossible.

If environmental restrictions (see paragraph 5.5.2) are not taken into account then long-run overdraft is profitable as long as annual net revenue from water mining exceeds the capitalized annual loss in value of recharge. Assuming that natural replenishment is constant and independent of the stage of storage development, Domenico and others (1968) determined the optimal-mining yield as

$$V_{my} = \frac{M_w}{M_p . S} - \frac{G_r}{r} \qquad (m^3) \qquad (5.21)$$

M_w - net unit value of water at the beginning of pumping ($\$.m^{-3}$)

M_p - marginal cost of pumping ($\$.m^{-4}$)

r - rate of interest

G_r - natural recharge (m^3)

$S = \frac{dh}{dV}$ - water level decline per unit of storage withdrawal ($m.m^{-3}$)

As a marginal cost of pumping becomes high, or the interest rate becomes small, the mineable volume is low, which indicates that a sustained yeild policy is desirable. Equilibrium storage is achieved when the rate of extraction is equal to natural (or natural and artificial) replenishment. The optimal water use policy then specifies use rates below natural recharge when storage is below its equilirbium value, the tendency being to move toward equilibrium storage.

Artificial recharge of groundwater may be defined as the planned activity of man to augment the natural infiltration of precipitation, surface and other water into underground formations with the objective to

(a) reduce overdraft and replenish depleted aquifer,

(b) store water for periods of lack of surface water or for periods of substantial drop in water quality of other resources.

(c) transport water to the locality of use,

(d) maintain the requested groundwater level (equilibrium storage),

(e) prevent intrusion of low quality water,

(f) improve the water quality by infiltration, and, under special circumstances,

(g) dispose unwanted water, industrial and mining wastes as well as toxic substances.

Methods of artificial recharge may be classified according to Huisman and Olsthoorn (1982) in two groups:

(a) indirect methods (induced recharge) in which increased replenishment is obtained by locating the means for groundwater abstraction as close as practicable to areas of natural discharge or effluents.

(b) direct methods, in which water from surface sources is conveyed to suitable aquifers where it is made to percolate into a body of groundwater.

Direct methods of artificial recharge are to be practised mainly when:

(a) sealing of a river bed seriously reduces the capacity of natural infiltration,

(b) the river bed is not in direct contact with the suitable aquifer,

(c) the supply area is far away from a suitable location of induced recharge,

(d) the surface water requires treatment or storage, which can be avoided by aquifer recharge.

The choice of the appropriate method of direct artificial recharge is governed mainly by topographic, geologic and economic conditions:

(a) when the aquifer extends to the ground surface, shallow ponds formed by a network of dikes and levees, further ditches and furrows, adapted to irregular terrain, modified dry stream beds or relatively flat land may be flooded to increase the area over which infiltration occurs and extend its duration,

(b) when the aquifer is situated at moderate depth, it can be replenished through shafts, pits and basins, e.g. through abandoned gravel pits,

(c) when confined and unconfined aquifers are situated at some depth below the ground surface and are topped by a semi-pervious or impervious layer, they can be replenished through wells and galleries.

5.5.4 Watershed Management

Watershed management is the planned use of land to conserve natural resources and produce renewable ones by an appropriate form of land and resources use and non-use, by modifications to the vegetative canopy and other measures to change surface runoff into groundwater runoff.

Vegetation extracts water from the soil and transpires it into atmosphere, thus reducing the total runoff. Land management practices designed to affect the volume and timing of the surface and groundwater runoff involve modifications to the vegetative canopy.

Timber harvesting methods which reduce evapotranspiration rates and increase snowmelt include block and strip cutting as well as thinning. Heavy vegetation, phreatophytes, with a deep and extensive root system, also extracts water from deeper strata which are normally affected by evapotranspiration. Clear-cut watersheds yield an increase of 20%, even recharging 450 mm in humid areas. A reduction in phreatophytes results in a 5 - 15% increase: the replacement of old forests by young ones increases water yields, as does the conversion of pine forests into hardwood forests too, due to the greater interception losses and the longer period of intensive transpiration of evergreens.

The conversion of brush or chaparral into grass, and forests into forbs and shrubs generally increases the flow from the watershed. But the water yield may drop below the original value, when e.g. the grassland is lush from sufficient water supply and efficient fertilization.

Water yields which are obtained by vegetation conversion and/or removal and fall back to the original, pre-treatment levels with regrowth or as the natural cover becomes re-established. The yield increment corresponds to the difference in water requirements off the original and converted vegetative canopy. The change affects the natural ecosystems, with a possibly negative impact on wildlife and habitat. Management activities may involve problems with erosion, peak flows and water quality. Water yield increases are economically feasible if combined with other forest management objectives, especially timber production.

Runoff phenomena are the integrated result of overall watershed behaviour. The lack of understanding of the causal mechanisms limits the degree to which data obtained from pilot studies can be extrapolated for complex watersheds in order to forecast integrated hydrological responses on watersheds under different geomorphological and climatological conditions.

The type of vegetation can to a certain degree also affect the amount of water transpired. But evapotranspiration depends more on the climate: its rate is extremely high wherever heavy and dense vegetation, energy and moisture input occur together.

The suppression of evaporation is, therefore, of key importance in tropical areas, especially in arid and semi-arid areas. Measures to decrease the evaporation include in particular:

(a) surface-area reduction (removal of phreatophytes, groundwater storage, reservoirs with minimum ratio of area to storage, narrowing and straightening of channels etc.)

(b) reduction in moisture gradient (e.g. by limitation of air circulation by windbreaks)

(c) reduction in energy input (e.g. by protecting the surface by mechanical covers - roofs, floating rafts, screens or granulated material reflecting solar energy)

(d) evaporative suppressants (layers of porous material, dust mulch, quickly drying cultivated surface soil layer, pebble and paper mulch, chemical alteration of the soil surface e.g. by polyelectrolytes, thin impervious layers which form resistance in the evaporation process).

One of the basic tools available for the suppression of both evapotranspiration and evaporation are films of monomolecular thickness, e.g. the longer carbochain alcohol mixtures, straight-chain fatty alkanols incl. hexadecanol, octadeconal, ethylene oxide, dosoconol, ethylated ethers etc. All these chemicals have to be non-toxic, having no detrimental effects on man, fish, fowl and wildlife. They must form a thin continuous impervious layer, penetrable by raindrops and closing again after being broken, pervious to oxygen and carbon dioxide.

It is generally cheaper to use powdered monolayers for this purpose than liquid forms such as hot solutions and emulsions. The effects of monolayers on food chains in open lakes have been found to be negligible, with some beneficial interference with insect occurrence. The physical and chemical changes in water quality, such as a slight increase in water temperature and dissolved oxygen, have been found to be minor and not adverse. Any increase in bacteriological populations can be easily controlled by addition of normal bactericides.

The degree of the reduction in evaporation and evapotranspiration varies with the thickness of the applied film and with the kind of surface or plant. It also depends on the deterioration effect of winds, which occurs on free water surfaces after winds with a speed in excess of 8 km per hour. According to Haeussner (1972) reduction rates of 8 - 14% are reported for reservoir surfaces, and higher rates for smaller reservoirs. Reduction rates of up to 40% and 20% are reported for bare soils and citrus trees respectively. Due to the degradation, the maximum effect on reservoir surfaces within the first day decreases to a value of some 15% of the initial one within about ten days.

The quantity and timing of water production from glaciers, ice and snow can be achieved by a change in the albedo. A thin layer (1 mm) of light ashes, coal dust, foundry sand etc. can be used for this purpose, resulting in a reduction in the albedo from 0.6 to 0.1 and an increased rate of melting, depending on the solar energy input. Under favourable conditions the yield from glaciers can be doubled. According to Meir (1964) the mentioned change in the albedo results in an increment of 2.4 m^3 of water from 1 m^2 of glacier surface.

The disadvantages of this practice of runoff augmentation include the following negative environmental effects

(a) temporary deterioration in the scenary, which is otherwise attractive from the recreational point of view,

(b) water pollution by fine suspended matter, which is nevertheless not important from the water use point of view.

Depending on the balance of the hydrologic cycle, water which has been artificially withdrawn in this way can be recharged naturally. If not, the following practices for decreasing the rate of the melting process and the artificial recharge of water in glaciers have proven feasible:

(a) insulatory cover of the glacier surface, e.g. sawdust,
(b) snow breaks,
(c) weather modification, i.e. cloud seeding in winter.

5.5.5 Weather Modification

Water from the atmosphere can be extracted by various techniques of vapour condensation. These practices concern both the lower and upper layers of the atmosphere.

The moisture of the low atmosphere layers can be artificially condensed, the natural interception and fog drip increased and an accumulation of the resulting flow achieved by various technical measures and cultivation practices, such as by tree or other wood plantations in locations with favourable conditions for vapour condensation, by vegetative measures on and arrangement of the land surface, the installation of impervious sheets, the installation of constructions with plastic fibres, acting as water condensers and collectors, by applying various chemicals and by electrical means. The feasibility of such measures and arrangements depends on local conditions. Satisfactory quantities of water can be gained especially in areas with a high air humidity, being frequently in clouds, or where ground fogs are frequent - in mountains, maritime and submountain areas.

Artificial precipitation, augmenting natural rainfall within meteorological limits at a given place and time, requires a comprehensive understanding of the physics of rainfall occurrence. The problem of weather modification consists especially in:

(a) determining the need of this treatment and its justification,

(b) recognizing a suitable opportunity,

(c) method of delivering the required treatment,

(d) method of evaluating the result of this treatment,

(e) unpredictable impact on long-term changes of climate,

(f) compensating for economic benefits and losses in the areas affected, and for possible adverse impacts on the environment.

Rainfall and snowfall can be influenced by changes in the heat balance in the atmosphere. Its equilibrium can be affected e.g. by cool water pumped from deep sea layers.

A feasible technology for gaining more water from showers over agricultural areas in summer and increasing snowfall or rainfall in mountains is offered by cloud seeding. This technology consists in dispersing condensation nuclei - silver diiodide AgJ_2, ammonium nitrate NH_4NO_3, compounds of urea and their combinations, other hygroscopic materials, e.g. finely divided common salt NaCl, by burning propane and acetone solutions of silver diiodide or by the electric disintegration of the various compounds whose product this silver diiodide is.

Cloud seeding is practised from aircraft or directly from the ground surface, using upward air currents. The air mass movement cannot be determined with the required accuracy, unless limited by a land surface, e.g. by a mountain barrier.

But uncertainty still remains, in the case of both cold and warm cloud seeding, because the rainfall mechanism is extremely complicated (Fig. 1.8); it depends on air conditions including wind profiles, updraft velocity, on a good supply of supercooled liquid droplets and low concentrations of freezing nuclei, on the course of the coalescence growth process etc.

Summer cumulus producing moderate showers and shallow winter clouds, formed by the mountain-produced lifting of moist air, offer suitable seeding opportunities. The seeding of heavy summer rain clouds and deep winter clouds can even decrease precipitation in comparison with the normal rate.

Current techniques have little value in areas with very low rainfall occurrence and during dry periods in areas of medium precipitation. The best results are still achieved in regions where, and during seasons when natural rainfall is most likely.

The evaluation of the results of cloud seeding is based on probabilistic methods. Due to the great variations of precipitation over time and space, methods which compare the target area and control area data are more reliable but not sufficiently free of uncertainty.

The economic effects and losses caused by cloud seeding bring about serious problems of compensation or reimbursement. This treatment may not only cause excessive floods or hail events, but also avalanches in mountainous areas. It negatively affects other areas as well, where a substantial decrease in rainfall may occur. Cloud seeding which results in increased precipitation over continental areas with a precipitation deficiency and reduces precipitation over seas is the only case where this discrepancy does not appear.

The efficiency of cloud seeding, ranging from 8 - 15 percent of the expected values for annual rainfall (the limit of a possible increase by improved application being estimated at some 30%), may under favourable conditions be of crucial importance for saving the harvest in critical dry periods.

5.5.6 Desalination and Treatment of Low-Quality Waters

Water desalination and the treatment of low-quality waters may prove to be practicable solutions to the problem of water shortage in certain restricted areas. Salinity control measures which reduce the salinity of surface water discharges include:

(a) point source control, insulation of a localized area or removal of a source which contributes an extremely salt load to the system (insulation of salt plugs, diversion or desalination of salty springs, mine drainage, decreasing the table of salty groundwater, beneficial consumptive use of the salty water within the catchment, utilizing saline return flow from irrigation etc.),

(b) diffuse source control, i.e. control of salt concentration and disposal spread over large areas (collection and consumptive use, evaporation, desalting, measures of watershed management etc.),

(c) reduction of evaporation and evapotranspiration (especially in regions of groundwater recharge, improving irrigation efficiencies, by watershed management measures incl. phreatophyte removal etc.),

(d) desalination of the discharge.

Most natural waters are not sufficiently suitable for desalination, but pretreatment can sufficiently modify their quality for subsequent

- distillation processes,
- membrane processes, i.e. electrodialysis and reverse osmosis,
- chemical processes, especially by ion exchange,
- crystalization, especially freezing processes.

These techniques can be applied for the desalination of sea water, surface and groundwater as well as for the desalination of geothermal water resources. Desalting processes are still economically feasible only under special circumstances, being used almost exclusively for drinking or feed water supply. The basic problems involved in desalination are

(a) high energy input requirements,

(b) disposal of residual salts.

Similar problems are also encountered in techniques for treating low quality waters e.g. heavily polluted waste water for re-use, which are essentially concerned with the removal of nitrogenous compounds, phosphorus, heavy metals, other dissolved inorganic compounds, as well as with the inactivation of pathogens.

5.6 CONCLUSIONS

At present, at the dawn of a combined population and technological boom, it is indispensable not only to declare, but also to safeguard in a rational and planned manner the right of mankind and of each individual to live in sufficiency and beauty. It is, therefore, essential to accept population growth and the associated development of heterogeneous demands as the basic criterion for making decisions concerning the allocation of water and other natural resources.

The utilization of water and other natural resources is a precondition of economic growth. The dramatic pace of current economic development, however, is based on an over-utilization of these resources. While some natural resources (such as air, water and soil) are renewable, they may - and increasingly do - become gradually deteriorated as a result of the secondary effects of their development. An over-utilization and excessive deterioration of natural resources, results in additional and inordinate restrictions on future development. It is, therefore, absolutely necessary to manage the given development process within the framework of the biosphere, taking into account the numerous functional relationships as well as environmental constraints, and to make optimum use of all water and finite natural resources.

The recognition of this new responsibility for integrated development/biosphere management is a crucial first step to achieving sustainable economic growth. To move towards this policy, it is possible to choose optimum scenarios by means of modelling and optimization.

The very serious environmental constraints which could arise through the interaction of agricultural, industrial, urban and rural development on the one hand and the biosphere on the other hand may require such measures as:

- the revision of raw/waste material use/re-use and water/waste water utilization in industry,
- the revision of land use patterns and forestry/agricultural/irrigation practices etc.

A new and complex interdisciplinary theory has to be developed for the approach described above, penetrating into every activity of mankind. The present monograph attempts to formulate at least part of this theory, the theory of water development and management, from this point of view and so form the basis for a deeper understanding between civil engineers, economists, natural scientists and other specialists involved in the gradual change in current practices towards a rational and balanced utilization of the biospheric system in this particular field.