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THE ROLE OF WATER IN LANDSCAPE ECOLOGY AND IN CROP PRODUCTION

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Abstract

Water is an element of integration and interaction. Through its continuing cycles and renewal water maintains a finely tuned harmony between local diversity and macroscale coherence within natural evolution. Even a tentative review of the role of water in landscape ecology and in crop production clearly reveals that the holistic and dynamic character of nature's structure and functioning sharply contrasts and conflicts with the fragmented and static nature of the market induced industrial strategies and technologies. The causes and consequences of these gradually intensifying and accelerating conflicts are first outlined in a conceptual and historical framework then illustrated by indicative examples taken from recent studies on water related planning and policies in Hungary. A move towards reducing and preventing such conflicts seems to require, among many other things, the compilation of broadly conceived analytical studies on major water related prerequisites and consequences of various future scenarios. This can lead to a coherent set of matrices between the valued components of the region's water resources and the human activities affecting water balance and water quality. Problem-based and process-oriented internal and external integration of hydrological sciences — towards which significant contributions have been already made during the last few years — seems to be the key element in the elaboration of such comprehensive informational basis on the role of water in nature and in society.

Keywords: water resources, landscape ecology, crop production.

1. Introduction

Theory and practice of the scientific-technical-industrial revolution considered and still considers water as a free gift of nature. Accordingly, hydrology as the basic science of terrestrial waters remained largely outside the interest and the magic power of the market-induced and institutionalized research. The concept of water as an abundantly and cheaply available resource is becoming obsolete, however, during the last decades as one of the many new facts of the rapid environmental degradation accompanying industrialization all over the world. In response, a new vision of hydrology is dawning in the writings and initiatives of Dooge, Dyck, Eagleson, Falkenmark, Klemes, Nash, Shuttleworth and many others. This vision aims at a holistic and quantitative understanding of the many-branched roles of water in nature and in society.

The objective of this paper is to underline the importance and urgency of this holistic approach in hydrology and other water related sciences by the presentation of a few road-searching thoughts and tentative findings which emerged primarily from the elaboration of the latest 'master plan' of water management of Hungary (OVK 1984) and the subsequent policy studies (ORLÓCI et al, 1985).

2. The Role of Water in Nature and in Society

The ecosphere born from the interaction of the Geosphere and the Biosphere is the result of a roundly four billion years planetary evolution. It is characterized by a flexible and resilient coexistence and harmony of *local diversities and large scale coherences* developed and maintained through an extremely complex and finely tuned set of self-regulatory mechanism within which the global water cycle plays a central role. The other large entity of the present day Earth system, the man-created Technosphere has reached its global significance through the industrial revolutions of the past three centuries. These revolutionary changes have been accomplished with the assumptions that:

(i) The system forming principles and the driving forces of the Technosphere can be selected quite freely and independently from those guiding the evolution of the Ecosphere;

(ii) Increasing material wealth of a small minority of mankind will automatically lead in longer terms to improved living conditions and social stability for humanity as a whole.

The fact that these assumptions have lost their validity, and that there is a pressing need for redirecting the modern technologies and the underlying economic principles towards an environmentally and socially sustainable future has been recognized and substantialted by now also in terms of theory and practice of the economic sciences (see e. g. DALY – COBB, 1989). These recognitions raise the question: What are the principal differences between the Ecosphere and the present day Technosphere in terms of their impact on planetary evolution and the living conditions of man? An overview and a comparison of the major features of landscape ecology and industrialized crop production might provide some clues to answering this question and to specifying some water related implications.

3. Landscape Ecology and Crop Production

Crop production — lying at the heart of agriculture, food supply and population growth — can be looked upon in two ways: As the greatest success story of mankind removing the ecological barrier of population size and holding the promise of Paradise for all. It can also be seen, however, as the largest human intervention into nature's functioning lying at the heart of the present environmental crisis and hiding the danger of a catastrophic falldown of our civilization. Both visions are valid and might become our common future pending on motivations, attitudes and decisions of individuals and governments during the years and decades to come.

In terms of *managerial sciences* crop production systems can be thought of as consisting of *four interdependent components* and tied to the encompassing socio-economic system by a number of *external factors*. The function of the system is to produce food and fiber by combining land, water, labor, fertilizer and other *resources* in specific ways defined by the adopted *technologies* and by following the specific rules and procedures formulated and enforced through the *institutional* framework. Part of the resources are taken from the *environment,* which also receives the effluents. Within the context of the modern world economy these crop production systems are driven by the effective demand for food and fiber as mediated through the market mechanism and governmental policies.

When looking to this scheme from the viewpoint of the *natural sciences* it becomes clear that the terms 'Environment' and 'Resources' hide essentially another system which comprises the factors and processes of *plant physiology* and *landscape ecology* based on the interactions among climate, soil and vegetation as mediated by the infiltrating and exfiltrating water fluxes of the root zone (boxes 1.a, 1.b and 1.c of *Fig. 1*). This local unit of landscape ecology with practically uniform conditions of climate, soil and vegetation becomes also organic constituent of its broader regional and global environment through the fluxes of energy, water and biogeochemical materials cycling within the fluvial systems and the atmosphere (boxes 2 and 3).

How Do Two Systems Relate to Each Other?

From the point of view of landscape ecology and the global biosphere there is nothing unusual or exceptional in that living creatures are modifying their environment by taking food from it and disposing wastes into it. In fact, such fundamental features of our planetary system as the availability of free oxygen in the atmosphere, or the near constant salinity level in

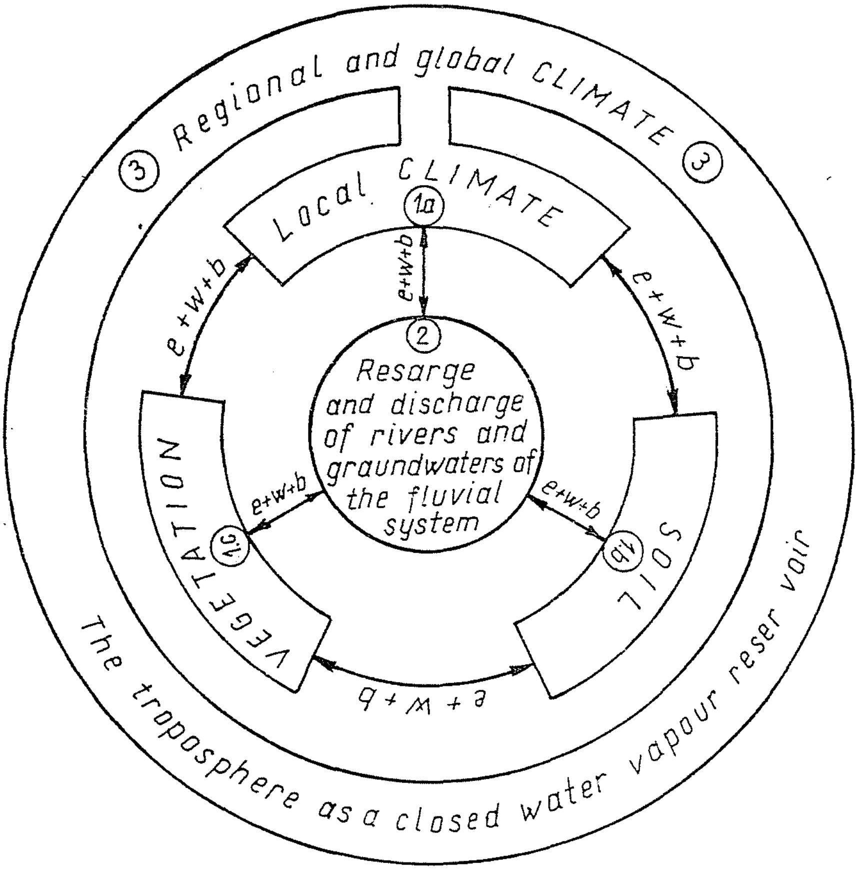

Fig. 1. Internal and external flow of energy e, water w and biogeochemical elements b within and among the landscape ecological units

the world ocean are direct consequences and achievements of the living organisms. The evolutionary trends and present patterns of planetary life seem to suggest that when the various creatures and species follow their own interests in their daily life, under a broader perspective they also contribute to the preservation and evolution of the biosphere as a whole. The unusual and exceptional about Homo Sapiens is only that we have developed exceptionally powerful tools and organizations for intervening into nature's functioning but we have not yet found our special place and role in the planetary co-operative enterprise.

From the point of view of crop production there is also nothing unusual or exceptional in that selected elements of the biosphere are used up as free gifts of nature and wastes are given over for decomposition and reprocessing. These would have little or no externalities and feedbacks among the various economic units and social groups if these inputs and outputs were following the patterns and constraints of natural evolution.

The origin of conflicts between crop production systems and landscape ecology (and essentially all other sources of the present day environmental crisis) lies in the sharply contrasting nature of the *specific technological solutions and organizational principles.*

This state of affairs leaves room for hope that these environmental conflicts can be resolved if mankind learns more about the specific organizational principles and technological solutions of natural evolution (as it is now beginning through the Global Change programme and other initiatives) and is willing and able to learn from history and to apply the newly acquired knowledge through radical changes in education programmes and governmental policies.

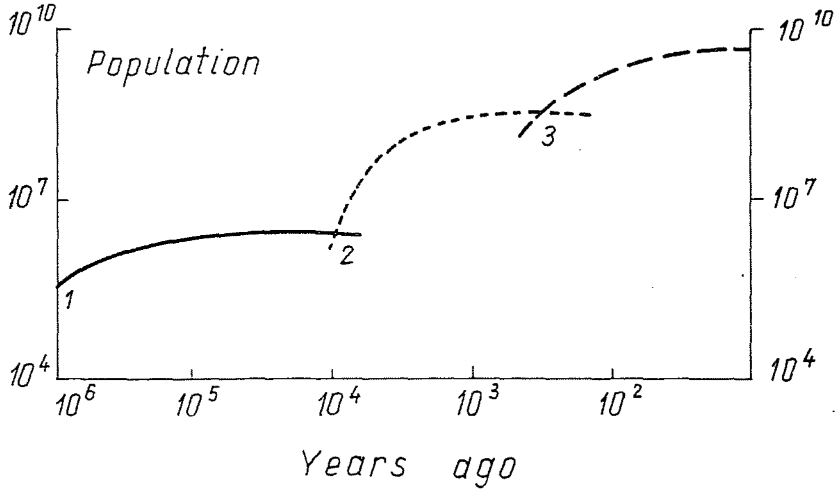

Fig. 2. Estimated increase of human population during the last million years (Deevey) 1960 as in CLARK – MUNN (1986)

The invention of crop production and its widespread introduction some ten thousand years ago was a central event in the human occupation of this planet. It made possible a hundredfold multiplication of the population number within a relatively very short span of time (point '2' in *Fig. 2.*) and it marks a significant and rapid increase in the scale of *social organization* (first from tribe groups into settled village communities followed rather soon by city states and the first empires of the fluvial civilization). There are two other revolutionary turning points in the population curve. Point '1' about a million years ago indicates the estimated beginning of widespread tool making. This also required new forms of co-operation among members of the family group, e. g. for successful tool-using in hunting and other activities.

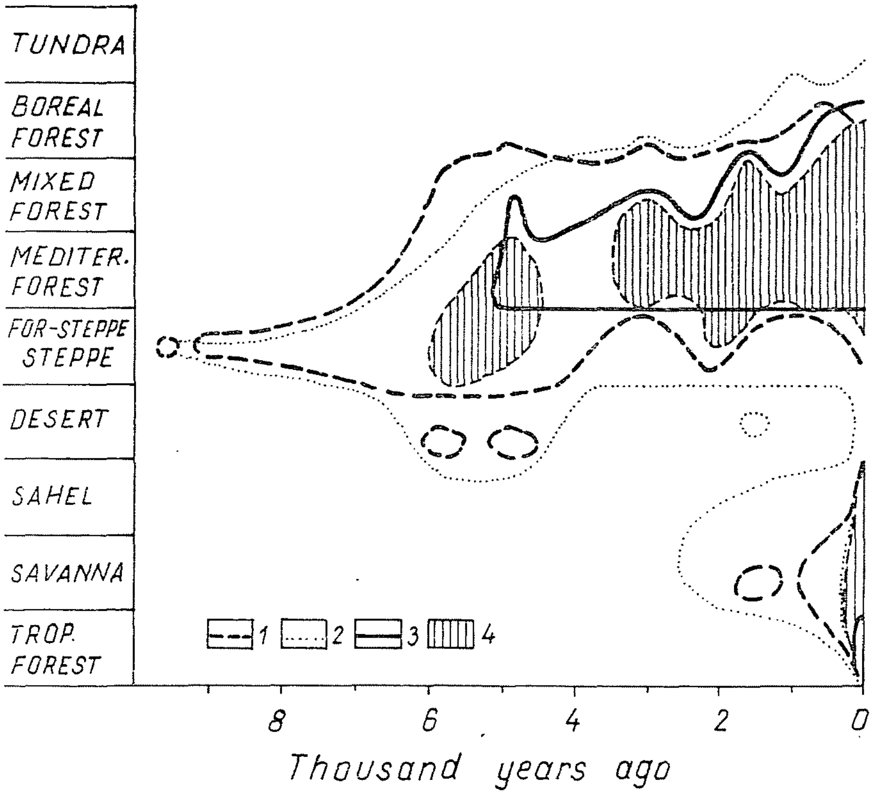

Fig. 3. History of human occupation in the Eurasian-African transect (STARKEL, 1987 and 1990). Signs: 1. cultivation combined with periodic destruction of natural ecosystems, 2. grazing, 3. extensive deforestation, 4. intensive cultivation

In this way the slow and difficult process of improving tools and cooperation was set into motion as the necessary preparation for the second revolution. Point '3' is the beginning of industrialization about 300 years ago which channeled human ingenuity towards increasing extremely fast and efficiently technological skills and social organizations of crop production — and gave also rise to the serious social, environmental and political disruptions and concerns of our days. *Fig. 3* gives a close-up view of the transition from point '2' to point '3' for the Eurasian-African transect structured according to the major vegetational zones. It is important to note that history offers ample examples for both, the successful harmonization of crop production with landscape ecology, and an almost total and irreversible deterioration of soil resources and natural ecosystems caused mostly by *complete deforestation* followed by intensive cultivation. Total deforestation can increase the rate of *soil erosion* by a factor of 100 or even 1000 (from 1–20 t per sq. km in the forests to 1000–2000 t in cultivated areas) as documented e. g. by depositions of the Neolithic agriculture in Europe, the late Bronze age and Roman agriculture in Southern Europe and in Britain, as well as by the very recent 1 to 1,5 m thick flood loam deposition in South Wisconsin caused by the deforestations of the last 120–150 years (STARKEL, 1990, p. 146). A slower and more subtle form of deforestation-caused soil degradation has been experienced in the flatlands of Hungary. Due to basin-type hydrogeological structure large parts of this region have an *upwards directed* pressure gradient and *groundwater supply*. The original deep rooted forests 'pumped' this slow flow into the atmosphere without its migrating salt content reaching the soils and the surface. After deforestations (which were accelerated during the wars of the 16. and 17. centuries) the salt content of the upwards moving groundwater reaches the surface and degrades the formerly good quality soils by salinization with increasingly serious consequences (*Fig. 4*).

4. Informational Infrastructures for Integrated Water Management

In a historical perspective it is the second time that water is becoming a critical factor of human evolution, the first being the age of fluvial civilizations within which water was a limiting constraint in the form of irrigated agriculture and inland transportation. These ancient constraints were eliminated during the subsequent ages by technological innovations revolutionizing the realms of economic and social development. Today water is becoming a critical factor of human evolution through its integrating roles within and among the technosphere, the biosphere and the geosphere. The constraints and hazards stemming from these roles can now be overcome through improved societal and political water awareness only.

The integrating roles of water have a twofold societal implication: within the individual managerial activities the high level of interrelatedness requires readiness for co-operation and compromises in order to reach mutual advantages, as well as to avoid unnecessary confrontations; in the domain of national and regional policies the holistic nature of the hydrological cycles urges the legal and economic recognition of water as a fundamental survival factor, as well as the establishment of an informational

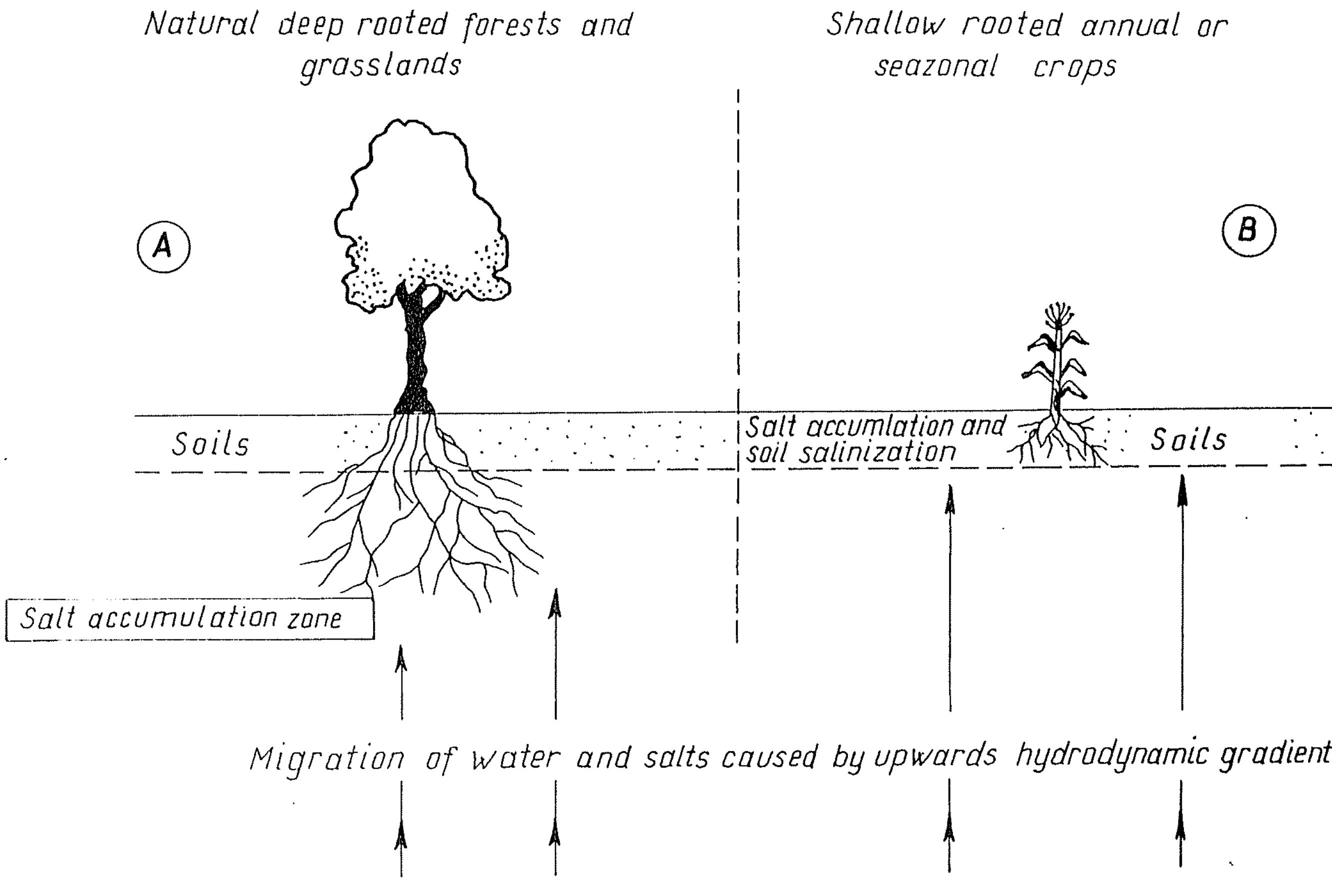

Fig. 4. Salt migration driven by upwards hydrodynamic gradient does not reach the soils in case of deep rooted natural vegetation (*Fig. A*), but it reaches the soil and causes salinization in case of shallow rooted crops (*Fig. B*)

infrastructure as the basis for expressing and validating the broad public interest within water-related planning and decision-making.

The last decades are frequently labelled as the beginning of the age of information and knowledge. In terms of data handling and modelling capabilities all technological and computational barriers seem to be overcome in constructing electronic information systems of any scale and complexity. The real bottlenecks of the implementation of societal water awareness seem to derive from the fragmented nature of our water-related concepts and information. The specific form and content of a holistic knowledge on water is, of course, site and time specific.

The following questions might give, however, a tentative and general indication of a holistic approach (ORLÓCI et al, 1985, pp. 28–29):

- What are the socially significant roles /the valued components of the country's hydrological processes? How can these components be analytically described and quantitatively assessed?
- What are the natural factors and human activities within and outside the country area that have a significant impact on those valued hydrological components?
- What is the role of water in the utilization of land and other natural resources?
- What is the extent of human interventions in the country's water balance and water quality processes, and what are the critical levels of eventual future interventions?
- What are the major social and economic demands for water and water-related services, and what are the major alternatives for satisfying, or for influencing these demands?
- What are the major possibilities and modalities for the protection and development of the country's water resources?

The answers to these and other similar questions require (*Fig. 5*):

(i) a set of basic studies on water-related implications of major policy factors as a point of departure;

(ii) analytical planning and impact assessment exploring future scenarios with alternative options of human responses and their environmental consequences, and

(iii) series of carefully designed publications disseminating findings and messages of these studies in easily accessible form and language for the various groups of addressees.

Within the basic studies water-related implications of present and expectable future technologies deserve particular attention. These preparatory studies should also include a systematic performance analysis of existing water systems and services.

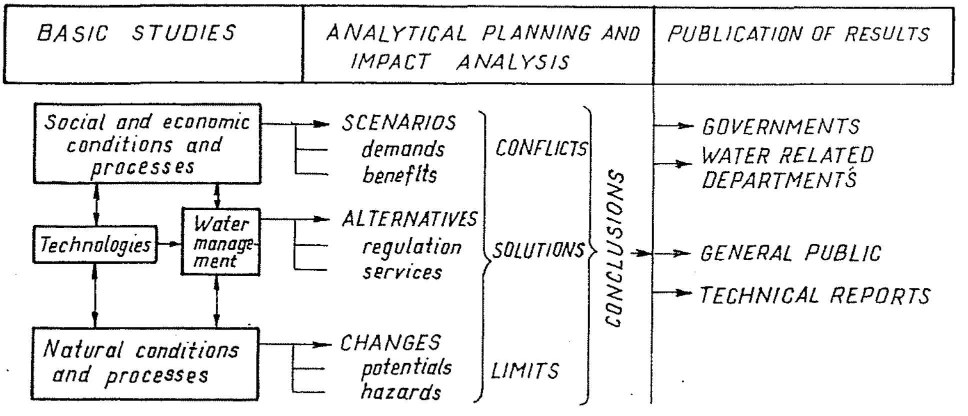

Fig. 5. Formulation of water-related informational infrastructures (ORLÓCI et al, 1985, p. 30)

The interrelationship between the valued components of water resources (*VC* in *Fig. 6*) and the various kinds of water-related human activities *HA* is the central issue of analytical planning and impact assessment. The determination of this interrelationship requires two groups of intermediating factors *IF:* those directly carrying and influencing the valued components IF_1 and those directly affected by human activities IF_2. The required VC/HA relationship is thus reached by defining first the HA/IF_2; IF_1/IF_2 and the VC/IF_1 relations. The conceptual groundwork for analyzing such a set of matrices was laid down by C. S. HOLLING in 1978 within the context of adaptive environmental assessment and management. This approach was recently revived in a more elaborate form within the Biosphere programme of IIASA (CLARK – MUNN, 1986) and was also interpreted in water-related terms (FALKENMARK, 1989).

5. Towards Integration in Hydrological Sciences

During the earlier periods of industrialization, water-related activities were qualified in most countries and languages by concepts and words corresponding more or less to the English term 'hydraulic engineering'. In these periods water was abundant in quantity, clean in quality and cheap to provide. Water supply for domestic, industrial and agricultural purposes and other water related activities usually achieved a high level of technological perfection and social recognition. Economic concepts and managerial skills were needed and applied in terms of efficiency in using capital, manpower,

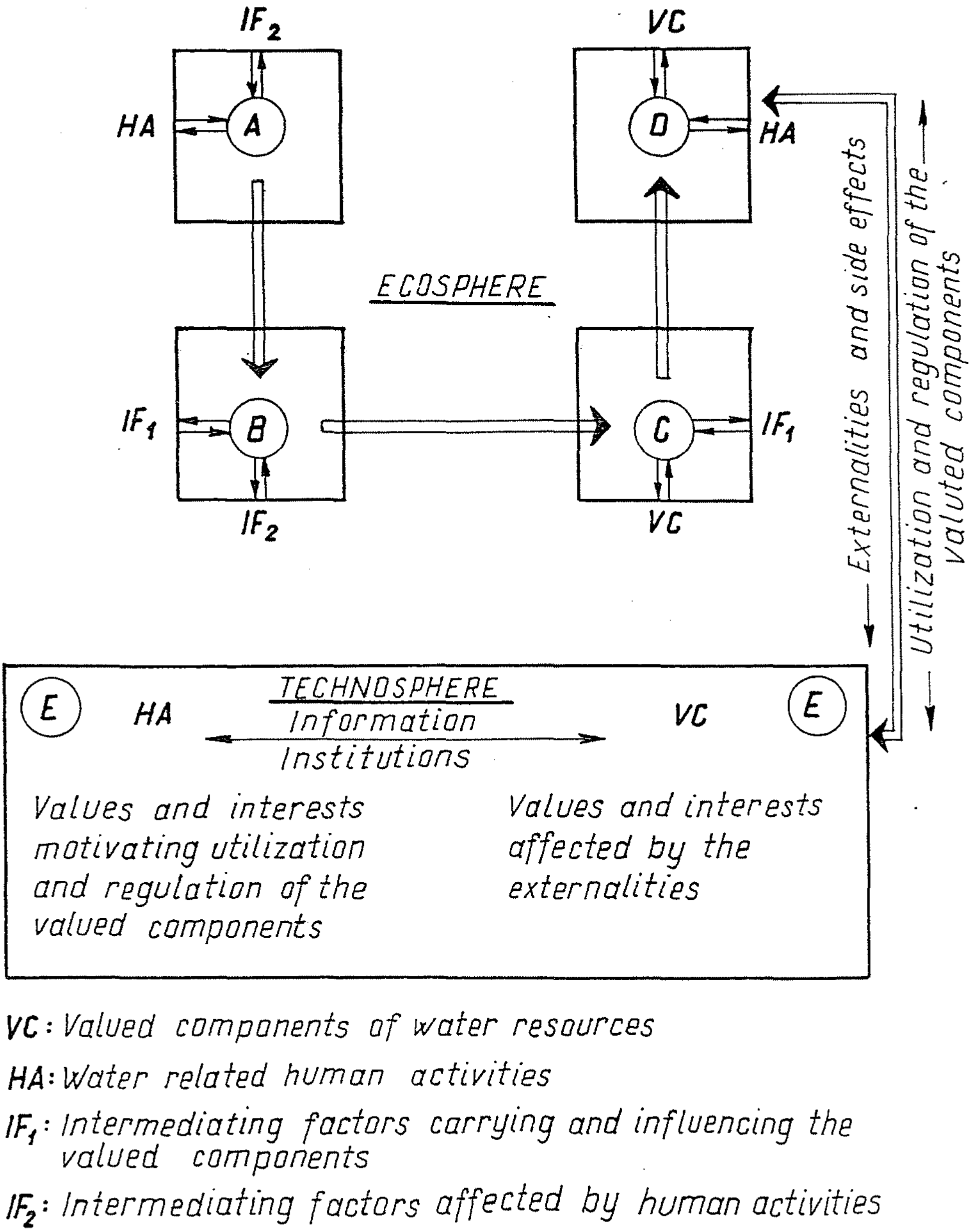

Fig. 6. Conceptual scheme of water related informational infrastructures for integrated management of the Ecosphere-Technosphere interactions

energy and other inputs, but not in terms of using, developing and protecting water as a natural resource. This was the period of water as a free gift of nature.

The term 'water resources management' and the equivalents in other languages first emerged some 40–50 years ago, when the finite nature of water began to manifest itself through rising costs of water supply and the necessity for water quality treatment owing to increasing demand and pollution.

The transition from hydraulic engineering to water resources management was rather fast and universal at the formal level (in changing names of institutions and curricula, establishing water-related co-ordinating committees, introducing legislative measures for pollution control, etc.). The results were and still are, however, slow in coming and mixed in nature.

Achievements in harmonizing water-related activities and increasing efficiency have been mostly of a technological nature. Improvements in water quality have proven to be local and transitory, and are frequently overcompensated soon by further degradations in other places or in other forms. New fields of environmental and social disciplines have been added to water-related university curricula and research programmes, mostly as separate supplements with little or no real impact on and integration with the earlier engineering core.

Initiatives to face and analyze water-related root problems of the technology (environment) society interface have been and still are rare exceptions, rather than the rule. In serious water-related crises and conflicts the co-ordinating committees are frequently unable to cope with the situation. Local regional or national governments have had to assume direct leadership with the inevitable result of decisions based mostly on political compromise and conventional wisdom — instead of relevant and reliable scientific knowledge. As a residual indicator of the continuing and growing water problems, public and governmental recognition and trust in hydraulic engineering and water resources institutions have diminished recently in many industrialized countries — although the real causes of the experienced anomalies were mostly external rather than internal to these institutions. It has also become increasingly evident that the level and orientation of water awareness within a given society cannot be significantly better (or worse) than that of the general environmental awareness, and both can become easily distracted from the issues of real social and economic significance.

Decisive challenges and promising avenues towards rectifying such distracted and distorted public and political perceptions could probably come from the recognition that in response to the radical changes within the motivating economic demands and social expectations *fundamental changes*

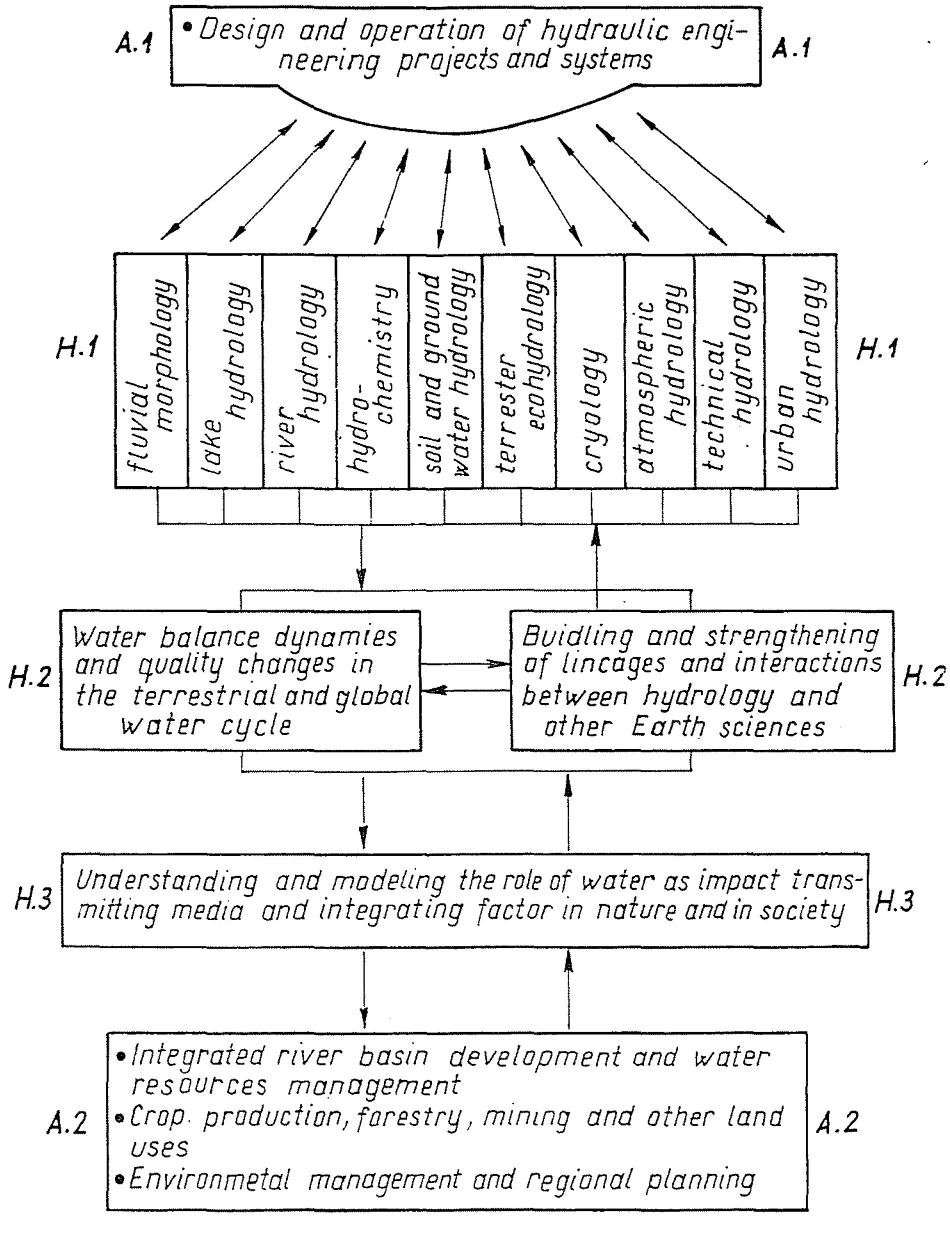

Fig. 7. Interactions and phase transitions in the evolution of hydrological sciences *H* and the motivating applications *A*. Subdivision in *H. 1* according to FALKENMARK (1989)

are first to be accomplished in hydrological sciences before the required shifts towards integrated management of water, land, forests and other environmental resources can succeed (Fig. 7).

Under conditions when motivating demands emerge primarily and almost exclusively through design and operation of hydraulic engineering structures and systems hydrology remains a loose collection of subdisciplines each dealing with specific compartments or aspects of terrestrial waters following narrowly defined practical questions and objectives (with some eventual byproducts towards improved understanding of local hydrological processes pending on eventual personal ingenuity or curiosity). The integration of these more or less fragmented sub-disciplines into a coherent knowledge of the terrestrial and global water cycle seems to require a paradigmical change in scope and objective of all the sub-disciplines. This change is probably to be guided by three major levels of broadening theoretical and practical competence. First, the sub-disciplines have to undergo an internal transformation towards the common objective of understanding and modeling local, regional and global processes of *water balance dynamics and water quality transformations;* Second, based on this coherent knowledge hydrology is in a position to initiate or accept opportunities for systematically *building, broadening and strengthening linkages and joint explorations with other Earth sciences;* Third, supported by such internal and external coherence hydrology becomes capable to fulfil its central role in achieving a proper harmonization of the economic, ecological and societal (cultural) dimensions of human evolution. Crucial in this third stage seems to be an understanding of the processes and resolving the conflicts that arise in relation to the role of water as impact transmitting media and integrating factor in the coexistence and interaction of local diversities and macroscale coherences. This three phased broadening of scientific competence is paralleled in practical capabilities first in *integrated river basin development* and water resources management; second in *policies and planning for crop production, forestry and other land uses;* and third by providing a key component for comprehensive *environmental management and regional planning* at various scales and complexities.

It should be emphasized that the above outlined internal and external integration of hydrology in no way undermines its relevance and efficiency in supporting hydraulic engineering activities. On the contrary, it shall enhance such applications in several important ways. First of all, improved understanding and modeling of water balance and water quality dynamics offers more reliable and more widely applicable methods for the design and operation of engineering projects. In addition, its integration with landscape ecology, crop production sciences and other aspects of land management enables hydrology to significantly broaden the scope and im-

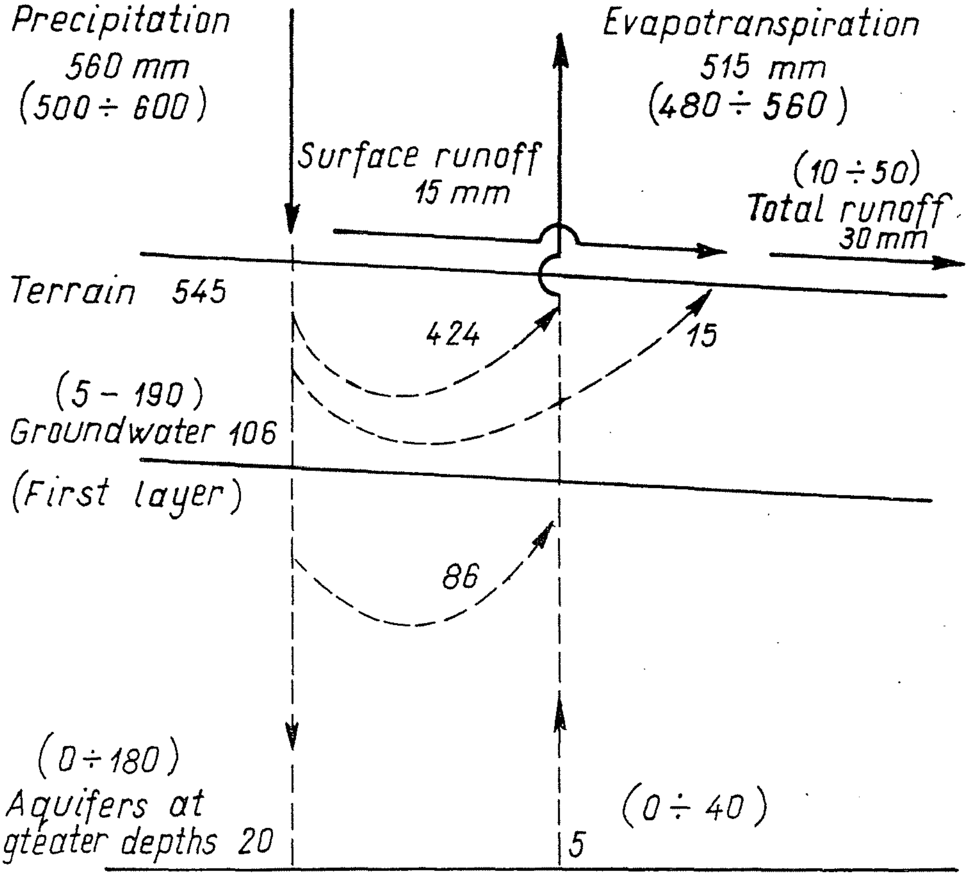

Fig. 8. Annual averages characterizing the partition of the precipitation water within the Great Plain of Hungary (Data from OVK 1984) Figures in bracket indicate minimum and maximum of 57 subregions as defined by P. Major

prove the efficiency of water management through a shift from 'runoff and riverflow management' towards ' precipitation management'. Such a shift in concept and practice is particularly important for Hungary and other alluvial flatlands of the temperate and semi-arid zone. Under such conditions precipitation is rather unequally partitioned between infiltration and runoff, and groundwater flow is a locally diversified component of the partition cycle (*Fig. 8*). Integration with landscape ecology also opens new perspectives in the assessment of human impacts on water balance and runoff formation. As indicated by data of *Fig. 9a,* relatively slight but opposite changes in potential and actual evapotranspiration (by about 8 to

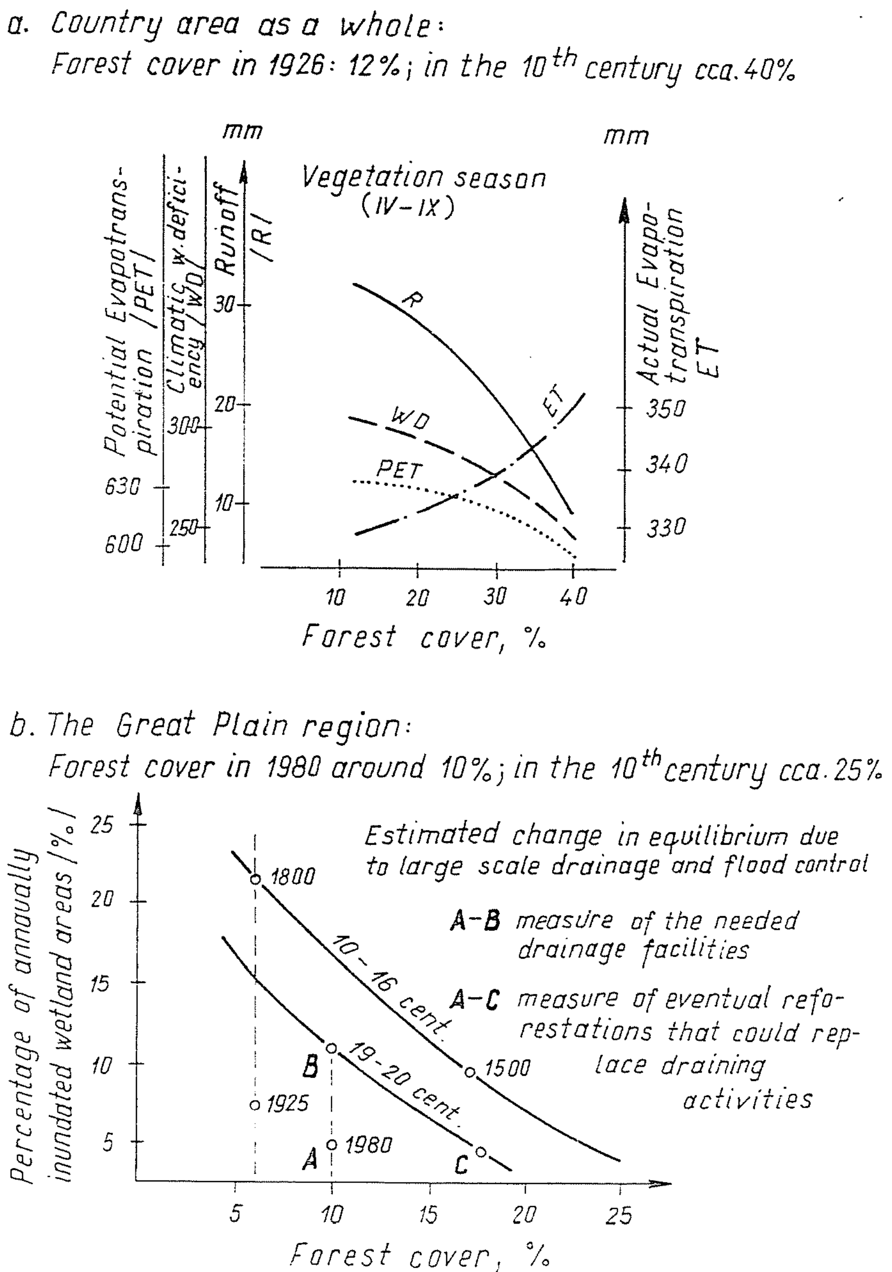

Fig. 9. Tentative (chronologically based but causatively not proved) relationships describing the effect of deforestations on water balance regime of Hungary (ORLÓCI, 1991. Based on consultant report of E. Antal and Cs. Pachner for OVK, 1984)

10 per cent) caused in Hungary by a decrease in forest covered lands from about 40% in the 10^{th} century to about 12% in 1926, gave rise to a substantial change in local climate (as measured by climatic water deficiency) and led to a drastic increase in seasonal runoff (from about 10 mm to 25–30 mm). Water-balance dynamics of the land surface and the unsaturated zone is particularly sensitive to deforestation (and other land use changes) within the Great Plain region. This is reflected by historical changes in the percentages of wetland regions, as well as by the capacity of drainage systems needed for maintaining intensive crop production (*Fig. 9b*).

Acknowledgment

Great part of the seed ideas of this paper emerged from consultations and discussions with *István Orlóci*, the intellectual leader of the planning and policy studies referred to in the Introduction.

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