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Global-Change-Induced Disturbances of Water-Related Phenomena - The European Perspective

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IIASA Collaborative Paper
June 1989

GLOBAL-CHANGE-INDUCED DISTURBANCES OF WATER-RELATED PHENOMENA – THE EUROPEAN PERSPECTIVE

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June 1989
CP-89-1

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PREFACE

This report was prepared by Professor Malin Falkenmark for the IIASA study, Future Environments for Europe: Some Implications of Alternative Development Paths, which was sponsored by the Ministry of Housing, Physical Planning, and the Environment, Leidschendam, the Netherlands, and the Ministry of the Environment, Prospective Group, Paris, France. This report attempts to provide - against the background of the not impossible climate changes ahead - a comprehensive presentation of water related phenomena from the perspective of their relation to societal activities, both those dependent upon water, and those generating impacts on freshwater in aquifers and rivers.

The need for such a report was felt during the interdisciplinary, intersectoral and interprofessional discussions that took place between those involved with the IIASA study. Because of the multiple functions of water in society and the great complexity of water phenomena, the research being carried out within the study tended to result in considerable communication problems between individuals with vastly different perceptions of water-related phenomena.

The report is provided as a Swedish contribution to the study. A broad understanding among policy makers of the interaction between the water-soil-vegetation system on the one hand, and societal activities on the other, is a necessary condition for achieving well-informed decisions with due account of known realities of natural laws. Such an understanding constitutes a basic condition to avoid any unnecessary future surprises, which can be predicted from facts already known of natural science at the time of the decision.

William M Stigliani
Case Study Leader

ABSTRACT

Impact of global change on human society will first be felt through disturbances of water-related phenomena. Traditionally, land use discussions only seldom reflect water phenomena. Present methods may therefore be poor tools in addressing the impact of global change. This report takes an alternative approach to land use by addressing a number of water-related phenomena from the perspective of their relation to land use and land-use-related societal activities. Such activities include both those dependent upon water supply or water-related land attributes, and those generating impacts on local water balance or on freshwater in aquifers and rivers.

A series of matrices are presented to clarify propagation of change, based on the continuity and interdependence of water cycle related phenomena. Global change impacts in Europe are tentatively described in a 70 year scenario composed of two phases: first water quality changes, later hydrological shifts with major consequences both for water availability and other water-related impacts on societal activities.

Sustainable development is described as a question of a sustainable interaction between human society and the water cycle including all the ecosystems fed by that cycle. Man is seen as a factor in landscape hydrology, due to the intervention introduced as a part of land use activities. Water management and protection is basically seen as a question of balancing dependencies on water against threats to that water.

The report ends with a discussion of water-related decisions, both those concerning projects involving visible water, and those where water is involved in a more or less hidden way. The section includes the main conclusions from a policy workshop on the societal impacts of a changing hydroclimate where the Po river basin was used as the case to which policy makers were invited to react.

The paper closes with an open question: is the traditional "dry: approach taken to land use really effective? How will that approach allow attention to land-use-generated impacts on water phenomena? Will the present way of seeing water as a conditional factor only in relation to plant growth be helpful enough, when addressing impacts of global change in regions where water scarcity and soil water deficiency will expand and influence land use?

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INTRODUCTION

In spite of the general role of water as the blood and the lymph of the biosphere, past studies on land use have tended to treat water-related phenomena only indirectly. The same holds for many studies on environmental problems in general. Land use and land use changes have been discussed without explicit reference to water-related conditions. In plant production, water tends to be seen as a conditional factor only. In urban areas, supply and after-use return of water are seen mainly as technical issues. When land use leads to quality deterioration in aquifers and rivers, this is talked of as an "environmental impact", seeing water as a victim, not a generator, as theory would suggest.

The fact that water is being circulated in a coherent global system, which is going to be severely perturbated in response to the changing temperature of the atmosphere, may indeed be a very strong reason to address water-related land use attributes more directly. Important changes may in fact be overlooked if land use changes are approached without taking a more explicit water perspective.

The approach taken in this paper addresses land use and possible changes due to the greenhouse effect as seen from the perspective of water flows within ecosystems of all scales. Starting point is the fact that life is based on myriads of water flows and that human life is therefore constrained by the various phenomena of the water cycle. More specifically the paper addresses the water-dependency in land use, basically with Europe in mind. The present understanding of the terrestrial part of the hydrological cycle also suggests that land use is heavily impacting on water phenomena (Falkenmark 1985). Consequently, sustainable development is a question of striking a balance between land use impacts and its water dependency.

The paper also proposes a matrix system to clarify in a simple way, to the policy maker, the complex phenomena involved when disturbances of the geosphere are translated into changes in environmental indicators of societal interest. It finally illustrates how policy workshops may be an interesting way to communicate predicted changes to decision makers.

THE WATERING OF THE BIOSPHERE

Life is based on myriads of water flows

Man lives in the natural environment, which provides him with food to eat, fodder for his cattle, timber for his houses, fuel for heating, water to drink and secure hygiene, and with other natural resources to benefit from (Falkenmark et al 1987). Water is continuously circulated through the biosphere where life is based on water flows through every plant, every tree, every animal, every human body. Numerous species live in water. The chemical flow history of the water passing a certain locality controls its contents of dissolved nutrients and other materials, crucial for the local ecosystem. Disturbances of water chemistry and/or water flows therefore tend to produce endless higher-order effects on flora, fauna and human health.

At the same time, water is circulated in the global system between the ocean, the atmosphere and the continents. The global cycle has three main phases (Falkenmark 1987) (Figure 1):

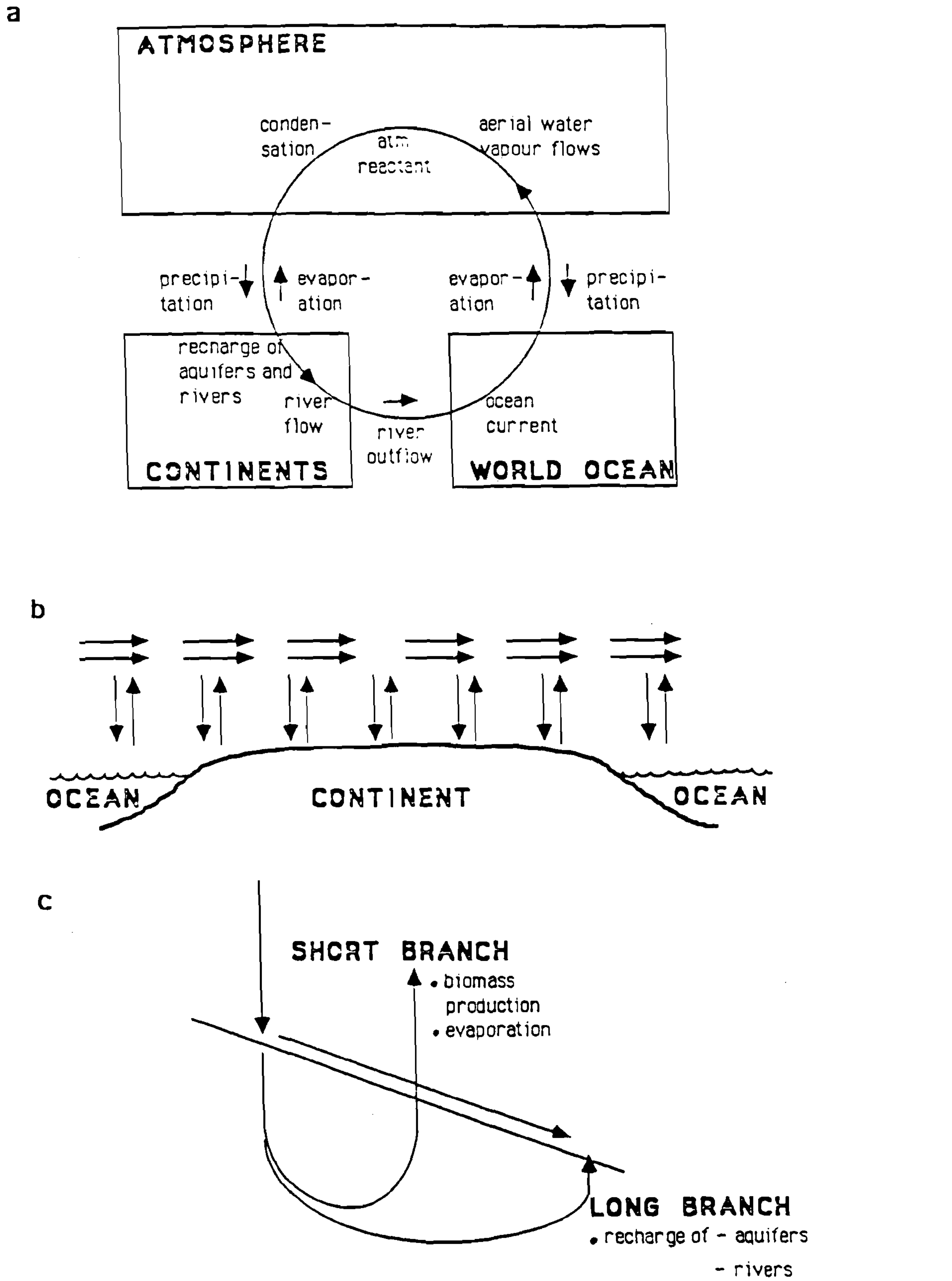


Fig. 1. The global water circulation system (a) brings water to the continents (b), wetting them and feeding their ecosystems (c). The surplus not returning to the atmosphere in the short branch of the water cycle recharges terrestrial water systems in aquifers and rivers (the long branch).

a) It distributes water vapour with the winds from the sea atmosphere in over the continents and back to the sea. This wind-driven aerial water vapour flux system constantly exchanges water with the underlying surfaces, giving off precipitation and receiving evapotranspiration in return.

b) The precipitation wettens the continents and drives the plant production in the terrestrial ecosystems.

c) The remaining flow goes to recharge terrestrial water systems in aquifers and rivers, finally returning the water to the sea.

The latter two functions are closely interrelated and involve the branching of the incoming precipitation into two subflows: the short, vertical branch, returning water to the atmosphere as part of the plant production process, and the long, horisontal branch, recharging terrestrial freshwater systems in aquifers and water courses.

Land surface partitions incoming water between two main branches

Basic conditions for life are therefore defined by the water cycle, the main system in the geosphere which distributes water, wettens the soils and recharges the terrestrial water systems. Basically energy and hydroclimate characteristics determine the main ecosystems developing in different regions. Water operates the energy-driven plant production which is sustained by a continuous water flow - in through the roots and out through the stomata in the foliage (short branch of water cycle). Plant growth stops when there is no accessible water present in the root zone. The water cycle also provides the water accessible to man in the terrestrial water systems, i e the long branch of water cycle (aquifers and rivers).

Characteristic water balances tend to develop in different hydrological regions. Based on a conceptualization of water flows to and from a catchment area developed by Lvovich, data typical for the main ecohydrological regions in European USSR are visualized in figure 2 (Chernogaeva 1971). What mainly differs between the regions is the amount of water recharging the terrestrial water systems: the groundwater recharge forming base-flow in the rivers, and the flood-forming more surficial flow through the landscape. Whereas around 300 mm or even more reaches the rivers in the tundra and taiga zones, only 40 mm is left to form runoff in the steppe region. Whereas the groundwater recharge amounts to around 100 mm in the taiga zone, only 10 % of that amount percolates to feed the aquifers in the steppe zone.

Figure 3 shows the relative amount of the incoming precipitation that forms runoff and its relation to the evaporated portion of the water entering the soil (soil wetting) in different European landscapes. In very wet mountain regions (a), the evaporation is limited and most of the precipitation is available to form runoff. In the undulating landscapes of Central Europe and the wet plains (c), about half of the precipitation goes to feed the terrestrial water systems, whereas 60 - 80 % of the water entering the soil returns to the atmosphere. On the arid plains, finally, practically all the water entering the soil is consumed in evaporation and transpiration, and only around 10 % of the precipitation is available to feed the terrestrial water systems.

Changes in flow regime due to land use change

The land surface forms the "station", where the incoming precipitation is being partitioned between tne short vertical branch involving food, fodder, fuelwood and timber production, and the long branch involving production of terrestrial water (Falkenmark 1986a, Figure 4). Principally, therefore, all vegetation changes of any size are necessarily reflected not only in altered water yields but also altered seasonality in water courses. Sucn changes have their greater relevance in areas on the hydrological margin between different climates.

Due to the continuous character of the water cycle, manipulations with soil and vegetation - the branching zone in the cycle - is propagated along the cascade of water cycle phenomena and reflected in flow changes, quality changes and all their various "domino effects" on both water phenomena and on water-dependent biological phenomena of flora, fauna and human health.

The type of vegetative cover has great influence on the response of catchments to precipitation (Kovacs 1988). Due to large response differences between forests and cultivated land, any change due to forest management (deforestation, thinning, reforestation etc) may influence the partitioning between the vertical and horizontal water flows. The impact of the development of forest on evapotranspiration is examplified from a Hungarian forest planted in the early 1950's (Figure 5).

A dramatic example of the impact of deforestation under semi-arid climate is the increase in groundwater recharge in SW Australia, generated by the European settlers, and resulting in a slow rising of saline groundwater towards the land surface (Heathcote & Mabbutt 1988). In the end, a saline flow will appear in local water courses, and cause problems to the water supply in the area.

Chemical composition generated in the root zone

In the landscape, water is on a continuous move. According to the present understanding within temperate-zone hydrology, the rainwater enters the soil on the hilltops and along the slopes, and reappears in local hollows where wetlands are formed, and along the foothills and valley bottoms, feeding the water courses (Figure 6a). Thus, the landscape is divided in recharge areas, where incoming water moves downwards, and discharge or seepage areas, where the underground water returns to the ground surface. This water-related structure of the humid landscape is of fundamental importance for the ecosystems, characterizing the area. One reason is that the water has quite different chemical characteristics in the recharge and the discharge areas. In the former, the content of dissolved solids is low, in the latter high, as a result of the chemical interaction with the geological surrounding all along the water pathways through the underground landscape.

The moving water and its biogeochemical environment tend to form a multicomponent system, which is quite complex. What happens is principally the following (Falkenmark & Allard, 1989, Figure 6b). The vivid interaction in the root zone between infiltrating water, carbon dioxide produced by the roots, and humates produced by decomposing organic matter, is one main component of these interactions. The other component is the output from the mineral matrix, through which the water is passing, of weathering products.

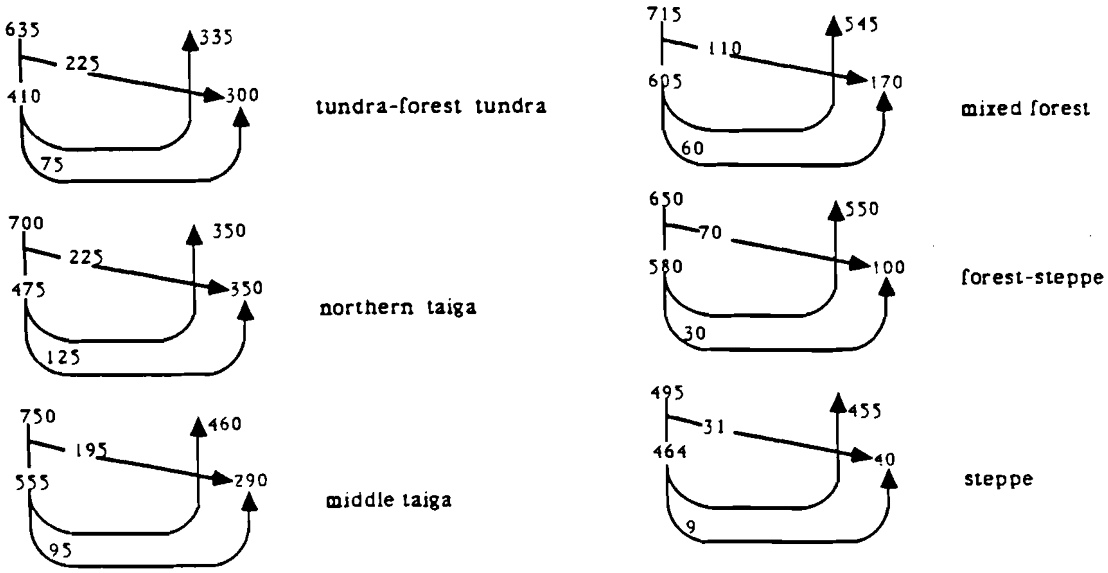


Figure 2. Comparison of zonal regularities in the water partitioning between main ecohydrological zones in the European part of USSR. Numbers indicate water flows in mm per year. Data from Chernogaeva (1971).

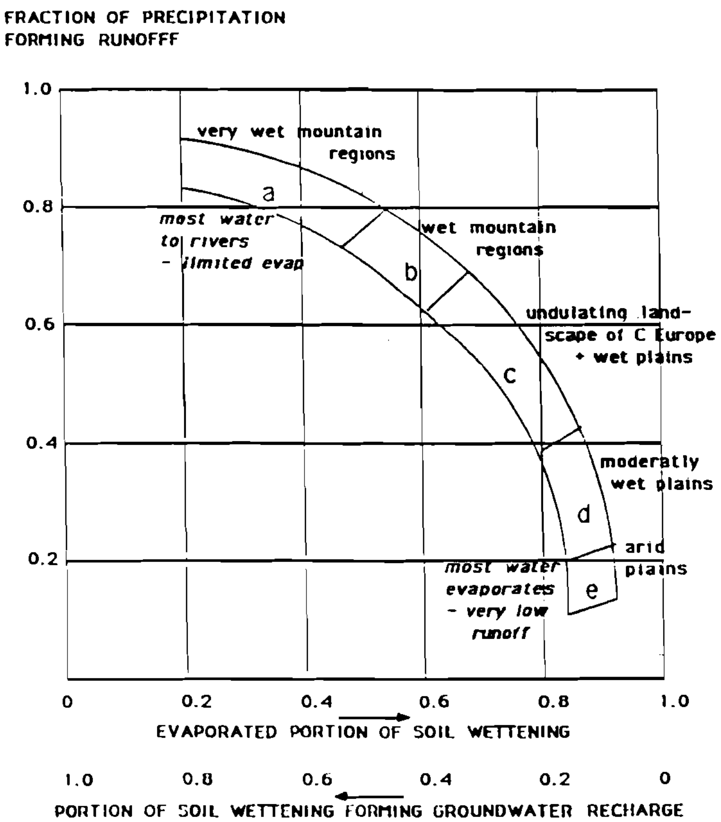


Figure 3. Water balance characteristics in different subregions of the European continent. Diagram shows the regional shifts in water partitioning between vertical return flow to the atmosphere and recharge of terrestrial water systems. Data from Chernogaeva (1971).

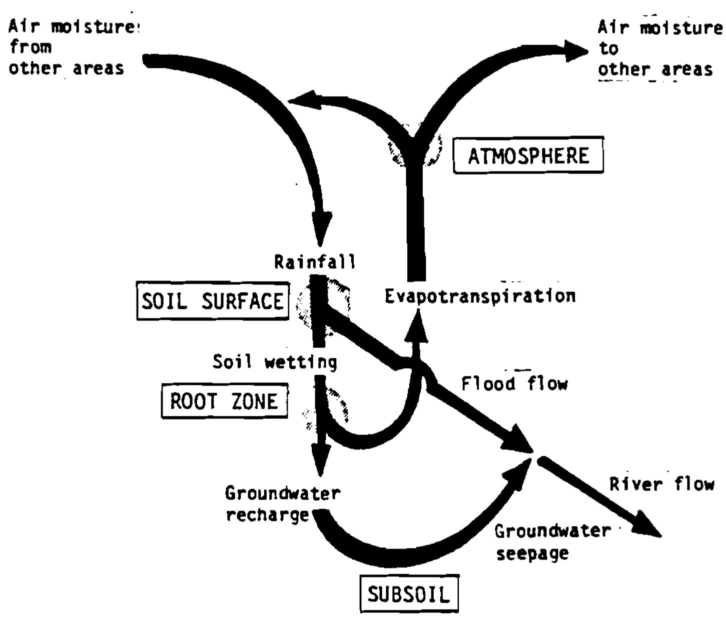


Figure 4. Continuity relations in the terrestrial part of the water cycle. From Falkenmark 1986a.
Main land-use generated perturbations of the water cycle hit three main partitioning joints:

SOIL SURFACE: . partitioning: infiltration of precipitation vs. flood flow;
. perturbations caused by deforestation, land mismanagement, crusta formation, sealing structures

ROOT ZONE: . partitioning: "water losses" via short branch vs. "water yield" via long branch;
. perturbations caused by vegetation changes

ATMOSPHERE: . partitioning: recirculated part of transpired water via convectional rainfall vs. part evacuated by local winds;
. perturbations caused by changes in atmospheric conditions.

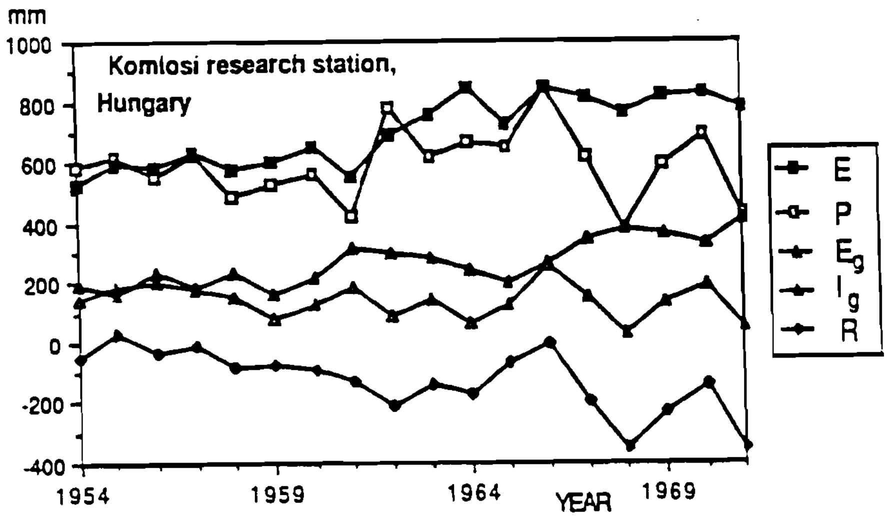


Figure 5. Forest management may have considerable impacts on the local water balance as illustrated for a growing forest in Hungary, planted in the early 1950's. Figure shows a 200 mm increase of annual evapotranspiration, out of which 150 mm emerges from increase of the root-zone-fed evapotranspiration and the remaining 50 mm consequently from interception increase. From Kovacs et.al. (1989).

Legend:

E = evapotranspiration
P = precipitation
E_g = upward evaporation flux from groundwater
I_g = downward flux groundwater
R = net groundwater recharge

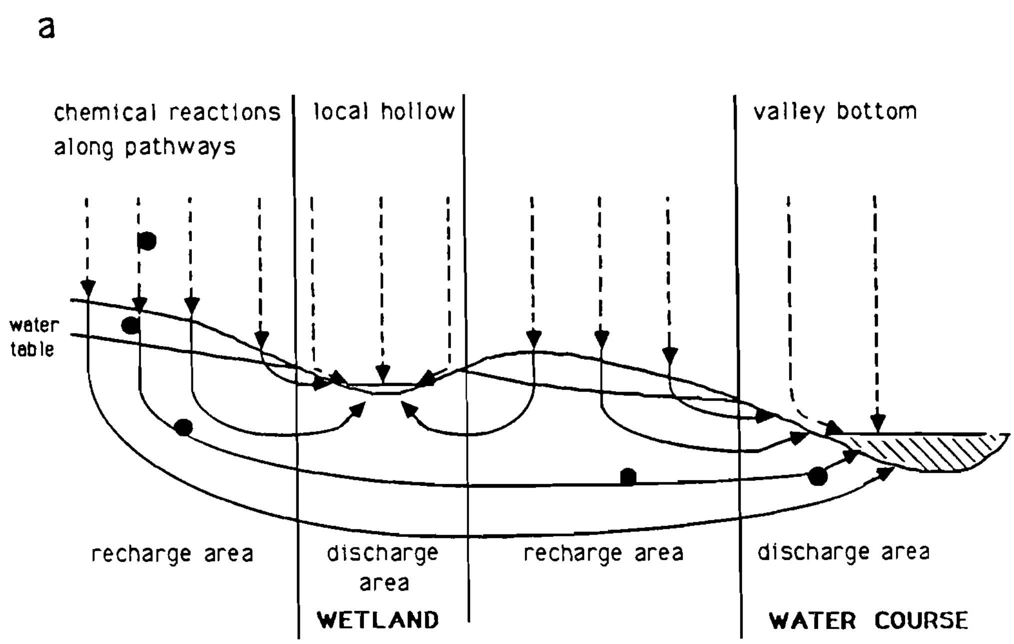


Fig. 6a. Water flow through a landscape under humid conditions. All along its pathways, the mobile water reacts chemically with its local environment.

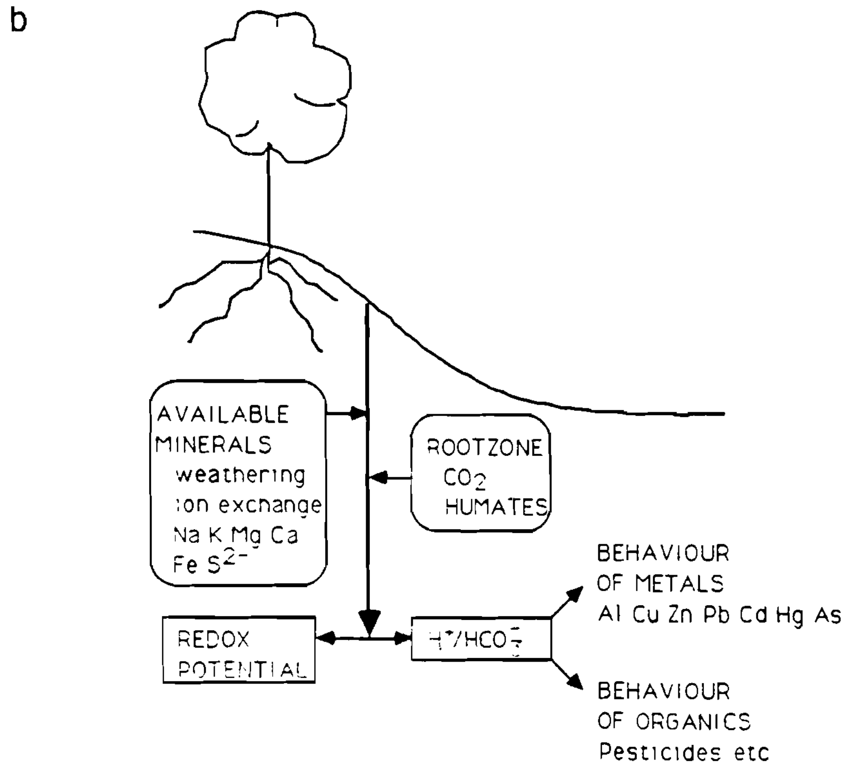


Fig. 6b. A simplified sketch of the water quality genesis, taking place in the soil. Main groups of reactions of the complex multicomponent system are indicated, as well as crucial chemical components, influencing the mobility of metals and organics.

This output is produced by the slow weathering of silicate minerals, on the one hand, and fast ion exchange reactions in clay minerals on the other. The interactions in these different subsystems control the acidity/alkalinity of the water as well as its redox potential (willingness to act as oxidizing or reducing substance). These two fundamental chemical characteristics of the water, moving through the ground, control in their turn both the mobility and the behaviour of metals and the behaviour of organics, like pesticides.

Interregional differences in groundwater recharge

Before we leave the water-flushed landscape in which man lives and acts, we have to be aware of regional differences in terms of the way in which groundwater is being recharged (Falkenmark & Chapman 1989). In the humid zone, groundwater recharge takes place all over the landscape except for the valleys and local hollows (Figure 6a). In arid regions, the phenomenon looks quite different: regional recharge takes place only in higher and more humid parts of the terrain, wheras the main recharge takes place along the river bottoms during flash floods. In both regions, a second form of groundwater is formed along flooded rivers, where recharge may take place in the inundated areas.

FUNDAMENTAL LINKAGES BETWEEN CATCHMENT LAND USE AND WATER

Water's multiple functions

Water is an extremely complex part of the natural environment with many parallel roles and functions. This complexity adds communication problems, as different professional groups tend to perceive water differently. Four main functions are particularly fundamental:

. water for plant production: the solar-driven biomass production is operated by water. This is the main water perspective of terrestrial ecologists and land use experts

. water for supply purposes to support households, societies, industry, and agricultural irrigation. This is the general perspective taken by engineers serving society with water schemes and projects

. water as a landscape element, providing the aquatic environment for fish and other biota. This is the main perspective held by environmental experts and aquatic ecologists.

. water as a chemically active, mobile substance on continuous move through the surface and subsurface landscape. This is a perspective which was frequently foregotten in the past, and has tended to create endless "surprises", manifested as water quality disturbances.

Water has also other fundamental functions. Water is often seen as a nuisance - there may be too much water, calling for measures such as drainage and flood mitigation. Water is wellknown also as a disease transmitter but, at the same time, a fundamental agent for breaking disease transmission routes. This is the main perspective behind the UN-sponsored International Drinking Water and Sanitation Decade. Finally, water is an extremely active erosive medium, causing massive land degradation damages all around the world.

Land and water interactions

In their life-supporting roles, water and land evidently interact closely: water makes land fertile, water is a main land attribute in controling possible land use. Land use therefore depends on water, both directly (water supply = access to water) and indirectly (water-related attributes McHaig 1971). All these interactions imply that the interventions with land and water, that man is forced to make, are reflected not only in the intended benefits but also in negative feedbacks on the environment itself, providing the natural constraints to human activities (Figure 7). We have in other words in front of us an intricate system, full of interactions of which one has to be aware in order to take well informed decisions.

Likewise, the frequent handling of polluting substances on the ground surface involve interventions with water quality, having in mind that water is an excellent solvent, chemically active and always on the move according to the laws controling the water cycle. Once caught by the moving water, pollutants therefore tend to move along with the water, unless chemical tranformations along the water pathways influence their mobility.

Water carries pollutants through unvisible and visible landscapes

Figure 8 illustrates the consequences of water cycle integrity in terms of polluting land use activities and their translation into water pollution. In the local scale (Figure 8a), water-soluble compounds used in agriculture (fertilizers, pesticides), industrial refuse, dry waste deposits etc in recharge areas may be caught by the water and produce groundwater pollution, which will not be detected until the polluted water passes a local well. Similarly, refuse in the discharge area may be leached by passing water, and transferred to the river. Pollution effects may show up further downstream where the river water is being used for some vulnerable purpose, like irrigation of gardens or greenhouses.

In view of the annual production of waste incl chemical waste with a high hazard potential, the present practice of transferring dry waste to landfills in the landscape is extremely unfavourable as leachates from such waste deposits are caught by passing water and transferred to local groundwater aquifers. As shown by Kerndorff et al (1988), this may lead to enormous problems for drinking water supply in regions heavily dependent on groundwater for such supply. Figure 10 from that study gives an idea of the extent of the problem. It shows the 15 organic contaminants most frequently found in groundwater downstream of 92 sites in FRG and 358 sites in USA.

In view of the slow subsurface movement of groundwater through a catchment, pollutants from contaminating land use activities, taking place in recharge areas, where water moves downwards in the terrain, may move with considerable transit times before reappearing in the water courses. Pollutants from activities in discharge areas may however be rapidly transferred to local water courses, as they are being washed out by groundwater seepage and excess precipitation. It is indeed possible that most land-use-originating river pollution experienced until now is mainly effects of discharge-area deposits. Pollutants leached from recharge-area deposits from the 1950's and 60's may to a large extent still be on the move in catchment aquifers.

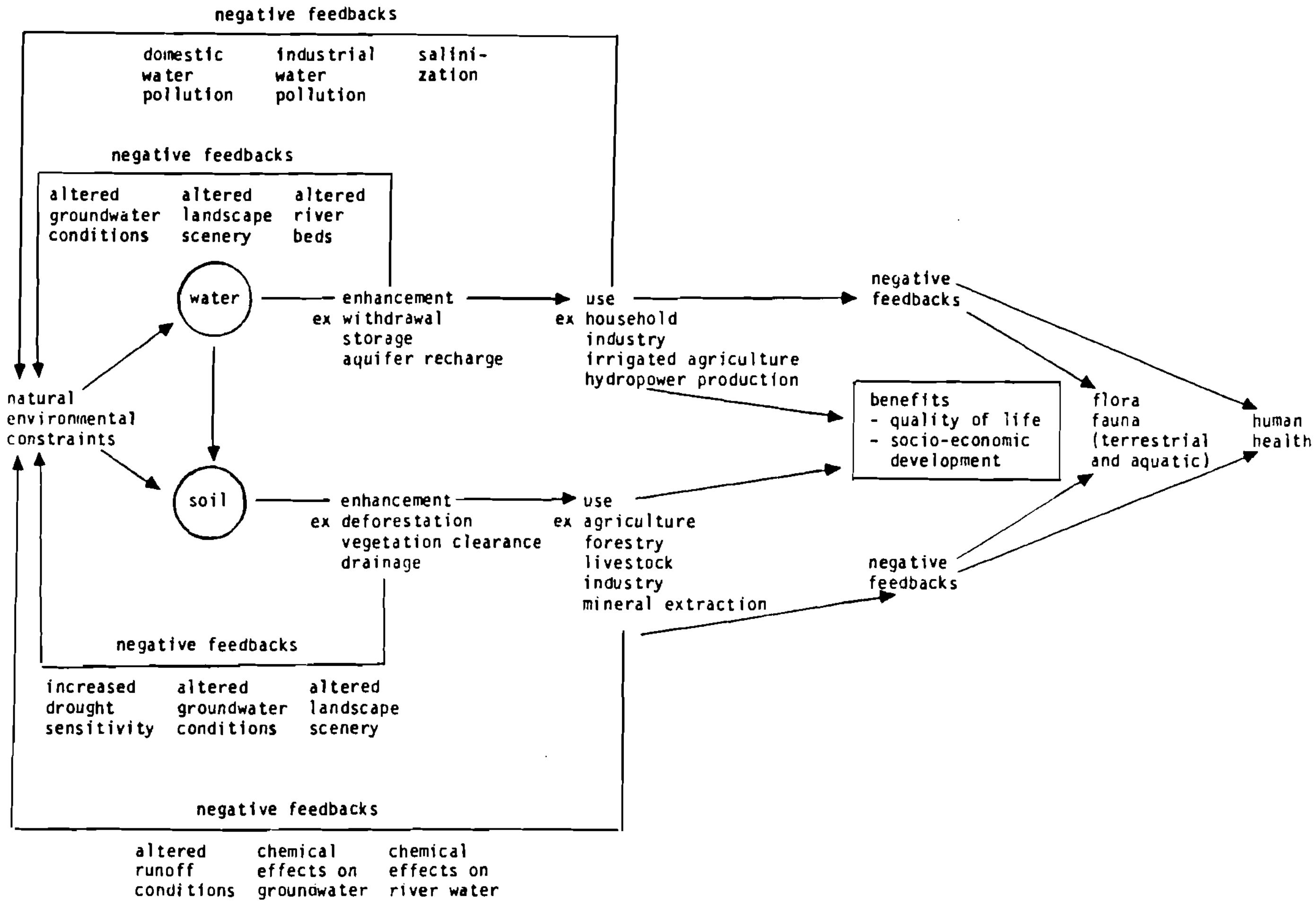
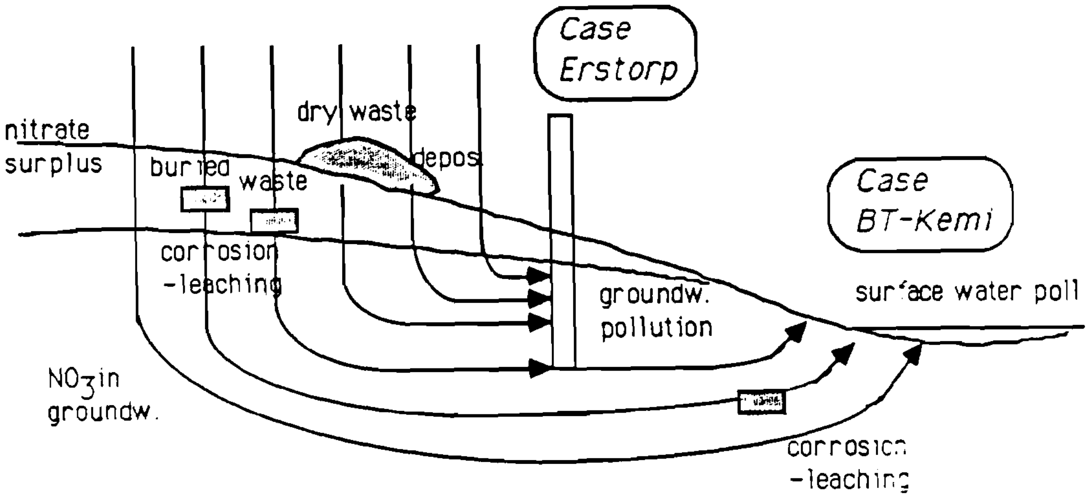


Figure 7. The natural environment provides man with water, soil, food, energy, wood and minerals. In order to benefit from these resources, various natural constraints have to be overcome by enhancement measures, increasing availability, and productivity and reducing obstacles. When such measures interfere with complex natural systems, negative feedbacks are produced, accompanying the intended positive effects of the measures.

a Mesoscale perspective



b Macroscale perspective

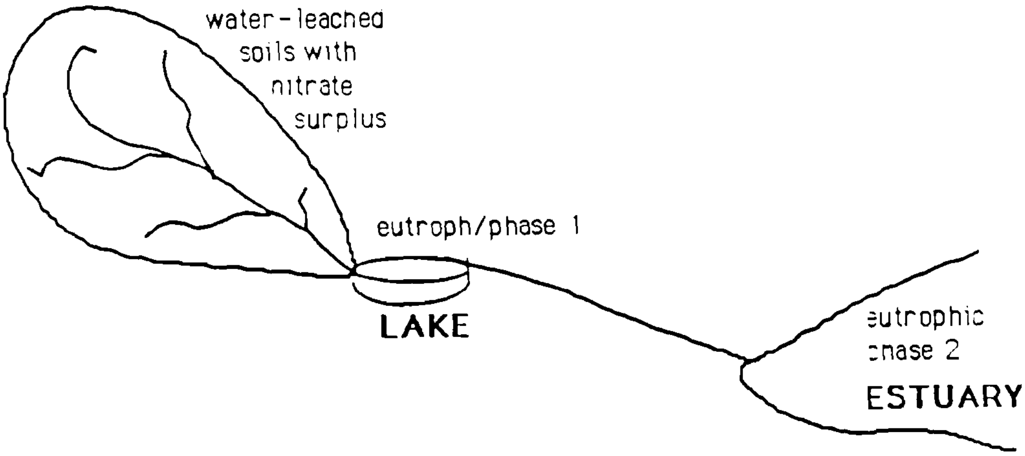


Fig. 8. Consequences of water cycle integrity in terms of consequences of polluting land based activities.

fig. a = mesoscale perspective, indicating different types of pollution. Case Erstorp refers to a Swedish case where buried industrial refuse in a recharge area polluted a village water supply; case BT Kemi a case where industrial refuse had been tacitly buried in a discharge area close to river Braan

fig. b = macroscale perspective, indicating upstream-downstream progression of water pollution.

On the regional scale (Figure 8b), pollutants emerging from land use activities in upstream parts of the river basin, are successively being transferred first to lakes along the river, and finally to the estuary region and coastal waters. This is what is presently being observed in the North Sea region, where nutrients emerging from land use have generated massive algae growth including toxic algae, reflected in large scale fish kill and other damage to sea biota. This evidently constitutes a late stage of pollution due to catchment land use. It is furthermore unnecessary, as it might have been avoided if the polluting activities had been stopped on land. Not until the integrity of the water cycle and the inexorable character of these processes is understood by the general public and the politicians can we envisage wiser land use policies.

Two opposite water quality perspectives

Bringing together the quality-producing phenomena with the water mobility along the slopes in the terrain, we are in a position to tie together water quality with land use. Two main opposite perspectives are of interest (Figure 9):

. to where does the water, which is infiltrating in a certain locality go? In other words, where should we be expecting any land-use-generated pollution to show up?

. where did the water, appearing in a certain river section, originally infiltrate? In other words, where should we look for land-use generated pollution?

In a European landscape, three main groundwater systems may be distinguished: the shallow groundwater with short pathways and rapid transit times; the intermediate groundwater with somewhat longer pathways and transit times; and the deep, regional groundwater with long pathways and transit times (Eriksson 1984).

The water appearing in a certain river section is composed of different water fractions, each one with its own chemical history: the net rainfall over the water surfaces; the net rainfall over the discharge areas close to the water courses, rapidly transferred to the river (responsible for the "acid shocks" with the meltwater in the spring); and three different groundwater fractions: downslope, hillslope and hilltop groundwater. The river water is a mixture of these different fractions, appearing in different proportions during different seasons (Birtles 1978). During the flood season, the main components are the two first ones; during the dry season when the groundwater table is low, the two last ones dominate. This is a main explanation of the large fluctuations typical for surface water quality - so frustrating to people engaged in environmental monitoring.

LIFE QUALITY AND ENVIRONMENTAL MANIPULATION

Balancing water-dependence against generated impacts in an integrated management

Even if man lives his life on land, many of his activities are, as earlier indicated, water-dependent. Moreover, he is more of less forced to interact with virgin ecosystems and to manipulate the natural landscape in order to get the food and energy needed (Falkenmark, da Cunha and David 1987).

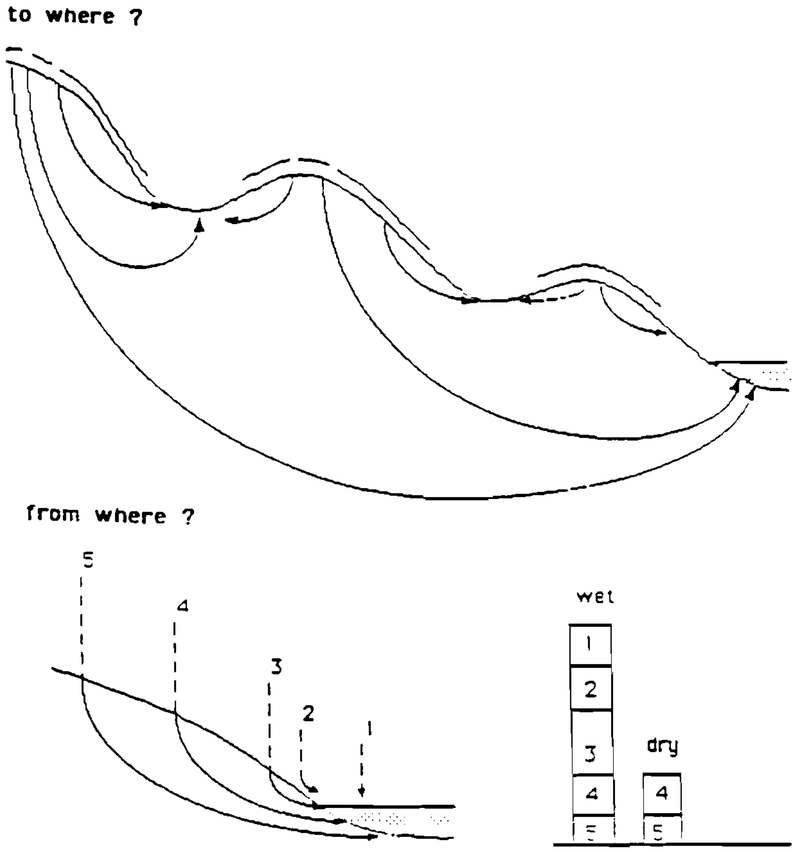


Fig. 9. Two opposite aspects of interest: to where does the water go and from where does the water come?

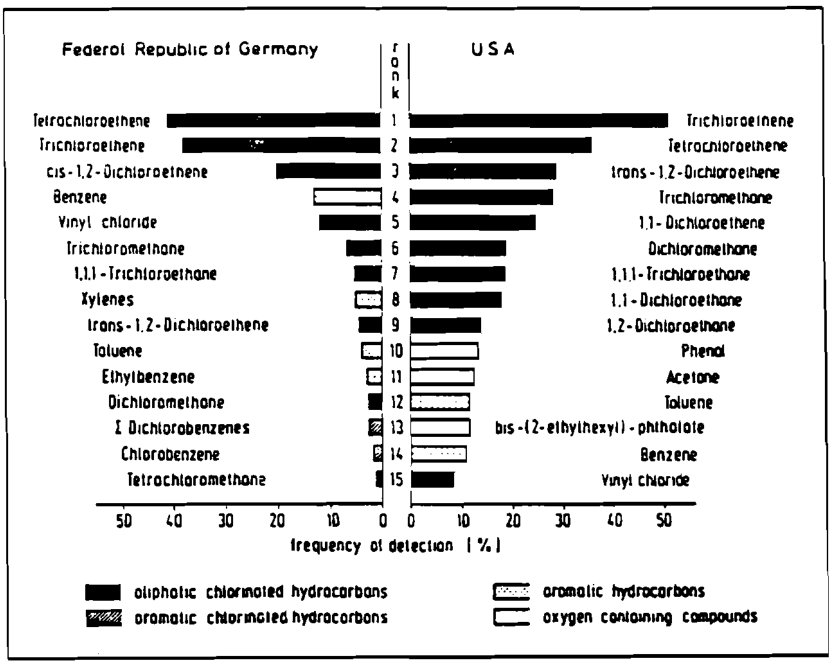


Figure 10. The most frequently detected organic contaminants in groundwater aquifers downstream of waste sites in FRG and USA. Data base composed of 92 sites in FRG and 356 sites in USA. From Plumb Jr. & Pitchford (1985). Kerndorff et.al. (1988).

Life evidently "forces" man to manipulate the natural environment in a multitude of ways: by manipulating ground surface and vegetation (ex. deforestation for slash and burn agriculture), by manipulations aiming at making water more easily accessible where needed (wells, tube wells, pipelines, canals etc), by intervention with the flow regime to make water accessible when needed (reservoirs, flow control devices etc), by intervention with water quality when benefitting from water mobility for carrying away waste, by introduction of chemical substances to improve agricultural production (fertilizers, pesticides), or as a by-product of other activities such as burning of fossil fuels and other exhaust gases from industry.

All these interventions make man water-impacting, as the interventions produce unavoidable feedbacks to water-related phenomena. For this reason, sustainable development must be a question of balancing the interventions needed against the unavoidable impacts produced. A typical example is the feared disturbance of rainfall over the Amazon basin (Salati & Vose 1984). A fundamental problem in the past has been that man has shown serious lack of basic competence in this regard (Brinkmann 1986).

Three manipulation categories

Basically, so-called environmental effects are induced by three main categories of manipulations with/perturbations of the natural environment:
a) introduction of chemical substances into the biosphere
b) manipulation of the soil/vegetation system
c) utilization of natural resources, renewable such as water and hydropower, and non-renewable such as minerals.

Based on this structurization, table 1 clarifies basic phenomena disturbed, and higher-order effects on flora, fauna and human health generated in complicated cascade systems. To a certain degree, such higher-order effects are unavoidable consequences of the "life-supporting" functions of water, mainly reflecting its tremendous versatility as a chemical substance.

MATRICES TO CLARIFY PROPAGATION OF CHANGE

Matrices as a tool in communication

Man, in his efforts to control the natural environment, needs a satisfactory understanding of the complex interactions between policy actions that he may contemplate and their possible impacts on the natural environment. He must have at least a basic understanding of the main linkages in order to design effective societal responses to practical concerns regarding undesired phenomena in the natural environment.

The way in which disturbances are propagated through the water cycle can easily be clarified to the decision-maker by the use of matrices. Following an exemple in IIASA (Clark 1985), where effects on interesting environmental indicators of perturbations of atmospheric chemistry where visualized, a similar series of matrices has been developed for land/water-related disturbances. The aim is to demonstrate how a disturbance somewhere in the system is propagated onwards by the water cycle, and is translated into changes of different environmental components.

Clark's framework is a further development of an environmental assessment matrix by Crutzen & Graedel (1986) as part of their contribution to the

Table 1. Categories of environmental manipulations, some phenomena disturbed and higher order effects

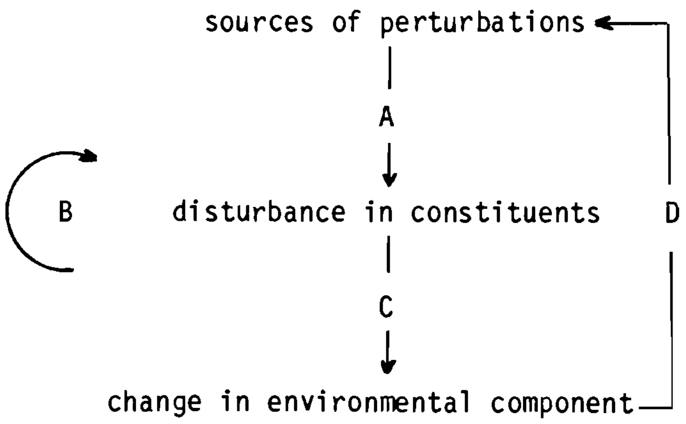
<table>
<tr><th>Disturbing activity</th><th>Disturbed phenomena</th><th>Higher order effects</th><th>Mitigation strategy</th></tr>
<tr><td>(1)
introduction of chemical substances</td><td>water's chemical composition</td><td>flora, fauna
human health</td><td>avoid</td></tr>
<tr><td>(2)
intervention with soil and vegetation</td><td>. water's partitioning (short-long branches)
. soil permeability</td><td rowspan="2">a) "domino"-effects on water-related phenomena
b) higher order effects on
. flora
. fauna
. human health</td><td rowspan="2">balance benefit against damage</td></tr>
<tr><td>(3)
utilization of natural resources ex water hydro-power</td><td>. water pathways
. river profile</td></tr>
</table>

IIASA program on "Ecologically sustainable development of the biosphere". Their matrix aimed at focussing on the atmospheric environment and the ways in which chemical processes influence its nature, composition and response to disturbance.

Conceptual base

The overall framework was developed around a set of basic concepts:
- valued environmental components, i e properties most worthy of attention or protection in a given assessment context, reflecting the judgement of broader political and social communities as well as those of scientific experts
- sources causing changes in those environmental components, in other words potential activities and fluctuations (perturbations) leading to environmental disturbances
- mutual interactions between environmental constituents themselves, in other words such interactions by which one environmental constituent might have impact on another
- a final overall framework tying together the overall implications of sources of environmental disturbances with the resulting changes in the selected environmental components.

In a basic table A (see the sketch below), potential sources of environmental perturbations (e g coal combustion) were related to the environmental constituents disturbed (ex. CO_2, O_3). In the next table B, the mutual interactions between the various constituents were linked to each other (i.e. a change in halocarbons has an impact on O_3). In a third table C, disturbances in the selected constituents were linked to the changes produced in the selected environmental components (ex. impact of a change in O_3 on thermal radiation budget and photochemical oxidant formation). The final overall matrix D, linked the changes in environmental components back to the potential sources of perturbations, producing those changes.



Land/water-related disturbances

Evidently the soil provides a key zone in the terrestrial phase of the water cycle. Indeed, the processes in the upper soil determine not only the amount of water remaining for groundwater recharge but also its quality, the pathways followed by the water through the catchment to the river and the river quality. At the same time, the soil productivity is directly dependent on the soil moisture conditions. There is therefore today an increasing awareness of the wide environmental importance of this soil/water mutual interplay and consequently of the need to treat water and soil in an integrated way. This means that an environmental matrix on water should include also soil and land use phenomena.

Summarizing, the conceptual base is the following:

disturbance →	change in fundamental process →	change in environmental component →	flora fauna human health and life quality
source	mechanism	primary effect	higher-order effects

In addition, the water cycle continuity implies that a change in a primary hydrological process is propagated through a sequence of water cycle steps, producing changes also in secondary hydrological processes.

Environmental processes and disturbing activities

The criteria followed in selecting the processes and environmental components to be reflected in a joint matrix for land/water disturbances were the following. Most interesting water-related environmental components are those related to land fertility and land-use attributes on the one hand, and water use and aquatic ecosystems on the other. This means that the processes of interest for the matrices are of three kinds:

- soil: wetting and nutrient supply
- groundwater: recharge and quality
- river flow: formation and quality.

The relevant activities to be included are therefore a wide array of disturbances, i.e. those influencing processes such as precipitation, water attraction capacity of the atmosphere, infiltration into the ground, percolation down the soil profile, underground pathways of water, water quality genesis processes etc.

Such disturbances and their effects on fundamental processes are indicated in table 2 a. The "domino-effect" phenomenon is demonstrated for the disturbed processes in table 2 b, showing for each primarily disturbed water cycle process, the processes which will also be disturbed due to the continuity of the water cycle. The coupling between processes disturbed and generated changes in environmental components, considered to be of general societal interest, is demonstrated in table 2 c (minor effects disregarded).

Final land-water disturbance matrix

Table 2 d shows the final matrix, tying together perturbations/ disturbances tied to human activities with the environmental components of

Table 2. Series of matrices linking perturbations of environmental systems, primarily effected phenomena, and secondarily effected phenomena with resulting changes in various environmental properties. Explanation, see text.

A

PERTURBATIONS

PRIMARILY AFFECTED PHENOMENA	atmosphere air temp	air qual	terrestrial imperm surface	soil struct improvem	vegetation	fertilizer	chemicals, dry waste	groundw withdr	aquatic river water withdr	waste water	river works
sea evaporation	0										
precipitable water											
available solutes		0									
infiltration			0	0							
soil nutrients					0	0					
water storage capacity				0							
humus					0						
ion exhange, soil chem processes							0				
land evapotranspiration					0						
groundwater percolation											
available subsurf solutes							0				
basin pathways			0								
water avail for runoff								0			
available river solutes										0	
river heat exchange	0										
erosion					0						
river flow pattern									0		0

B

PRIMARILY AFFECTED PHENOMENA

SECONDARILY AFFECTED PHENOMENA	sea evap	prec water	avail solutes inprec	in-filtr	nutr	soil water storage capac	humus	ion exch, chem proc.	land evapo transp	per-col	avail solutes	basin path-ways	water avail for runoff	river heat excn	ero-sion	avail solutes	rive flow pat
sea evaporation	0																
precipitable water																	
available solutes																	
infiltration		0															
nutrients																	
soil water storage cap																	
humus																	
ion exhange, soil chem processes																	
land evapotranspiration				0		0											
percolation				0					0								
available solutes			0		0			0									
basin pathways																	
water avail for runoff		0							0	0							
river heat exchange																	
erosion																	
available solutes			0								0						
river flow pattern													0				

AFFECTED PHENOMENA — C

CHANGED ENVIRONMENTAL PROPERTY	sea evap	prec water	avail atm solutes	in-filtr	nutr	soil-water storage capac	humus	ion exch, chem proc	land evapo transp	per-col	avail subsurf solutes	basin path-ways	water avail for runoff	river heat exch	ero-sion	avail river solutes	river flow patter
precipitation	0	0															
soil fertility			0	0	0	0	0	0									
groundwater recharge				*					0	0							
groundwater quality			*					0			0						
river flow									0				0				
river extremes										0		0					
river quality			0													0	
water levels									0				0				0
sedim yield															0	0	
water temperature														0			
estuary quality			0								0					0	

0 = primarily

* = higher order/acc to B

PERTURBATIONS — D

CHANGED ENVIRONMENTAL PROBERTY	atmosphere: air temp	atmosphere: air qual	terrestrial: imperm surface	terrestrial: soil struct improvem	terrestrial: vege-tation	terrestrial: ferti-lizer	terrestrial: chemicals, dry waste	terrestrial: groundw withdr	aquatic: river water withdr	aquatic: waste water	aquatic: river works
precipitation	0										
soil fertility	*	0	0	0	0	0	0				
groundwater recharge	*		*	0	0						
groundwater quality		*				*	0				
river flow	*		*	*	*			0			
river extremes			*	*	*						
river quality		*				*	*			0	
water levels	*		*	*	*			0	0		0
sedim yield					0						
water temperature	0										
estuary quality		*				*	*			*	

societal interest, and changes generated as a consequence of the domino-effects set in motion by the original perturbations. Circles indicate the primarily changed phenomenona, whereas asterisks denote "domino effects".

This final table gives two fundamental pieces of information. Read along a vertical column, it shows the array of environmental properties which are being disturbed by human interventions with the atmospere, the terrestrial system, or the aquatic system. In the column "vegetation", for example, we recognize all the different impacts caused by deforestation. Read in this way, the table shows that the effects on environmental components are much more complex for interventions with the atmospheric and terrestrial systems than for those with the aquatic system. The table however gives information only of the variety of properties disturbed, not on the size or importance of the effects. It is well known that very large efforts have been put into structures, reducing the direct waste water input into aquatic systems due to the deleterious higher-order effects already witnessed on aquatic ecosystems.

When reading the table in the horizontal direction we get an idea of the conglomerate of disturbances that may produce changes in individual environmental properties. What is demonstrated is basically the futility of the efforts to try to prove scientifically what sort of perturbations has caused a certain change in for example river flow or soil fertility. Table 2 d in other words demonstrates today's environmental "syndrom" (Clark 1988) reflecting the fact that man is exerting an endless number of interactions with the atmosphere, the terrestrial and the aquatic systems. Many interactions tend to generate effects on the same environmental property. The present way to work backwards from environmental effects is not neccessarily the best way to address environmental change.

GLOBAL CHANGE IMPACTS IN EUROPE - A TENTATIVE SCENARIO

Climate change to be felt first through water-related phenomena

The large-scale climatic change predicted to follow as a consequence of the present accumulation of greenhouse gases in the atmosphere will "hit" mankind first through the water cycle and the multitude of phenomena closely related to the water cycle and its processes.

What will primarily change with a changed energy balance of the atmosphere is the aerial water vapour flux pattern. As seen from a terrestrial perspective both the wettening of the land surface and the water attraction capacity of the atmosphere (potential evaporation) will change. These two phenomena will drive changes in the terrestrial ecosystems and consequential changes in the feeding of the terrestrial water systems (aquifers and rivers), i e the amount of water going onwards in the long branch of the water cycle.

All these large scale system changes will produce a multitude of impacts on the human environment, which may be characterized as changes in environmental components. Basically, two groups of higher order consequences will be produced: 1) of the changes in plant production, leading to changes in ecosystems and land use; 2) of the changes in the terrestrial water systems, which will in their turn produce a multitude of changes of water-related phenomena and systems (incl water quality changes).

Probable water problems in response to environmental change

During the coming seventy years, Europe will be overtaken by a creeping change in hydroclimate, altering on the one hand soil productivity and ecosystems, and on the other both flow and water levels in terrestrial water systems (groundwater aquifers and rivers). All these changes in the general watering of European land will have massive, almost endless consequences on all sorts of water-related activities from those depending on water availability in the root zone (agriculture, forestry) to those influenced by river and groundwater conditions (water supply, floods, inundated cellars, urban drainage, navigation, subsidence, collapsing permafrost structures, health of coastal seas etc).

The first decades will however be dominated by deteriorating water quality in many aquifers, rivers and coastal seas, and a multitude of secondary effects on quality-dependent sectors of society on the one hand, and on flora and fauna on the other.

Even if the changing climate basically will imply a rising long-term average temperature, the result over Europe may be influenced by atmospheric blocking phenomena, and many years may indeed be cooler than earlier over large parts of Europe. In the early decades of the 21 century the sea level around Europe may start to rise, causing increasing problems due to inundations of low-lying areas and sea resorts. By the 2020's the increase of extreme events may start to create greater and greater problems, in particular devastating summer droughts with vaste crop failures and frequent floods and inundations.

Some of the shifts encountered during the coming seventy years will be quite rapid, such as changes in groundwater level in response to changes in the precipitation pattern. Also rivers will respond instantly to changing amounts of water flows in the landscape. Other responses will tend to be slower, such as adaption of agriculture, flora and fauna to the modified conditions. A number of changes will remain latent, such as the shifts to be expected in forestry, delayed due to the long life-cycles of trees, and in natural water quality, delayed by the slow reactions and movement of water through soils and rocks.

Seventy years of increasing disturbances

The almost endless consequences may in fact clog the decision-making system. There may develop a tremendous pressure from the general public for engineering counter measures and for economical support to reduce the consequences and damages. The climatic fluctuations incl the effects of the blockings, and the different opinions of scientists on what is really happening, may confuse the reactions. Some parts of Europe may be more vulnerable than others, due to differences both in the extent of the hydrological changes taking place, and in the resources available by which they could be met.

Climatologists may report that we are witnessing a transient phase in the climate and that climate averages are on the move. This makes all planning and management extremely difficult. The general public may get frustrated when the authorities will not be able to protect them better in meeting the endless problems hitting them, and the damages on their houses, gardens, roads etc.

Water quality changes during phase 1

By the turn of the century, i e before the real problems with the changing hydroclimate will probably start to materialize, other sorts of water problems will dominate. Evidently urban water pipe systems, both those carrying drinking water, those evacuating sewage and those draining urban storm runoff will continue to deteriorate at an accelerating pace. The consequences will include moisture damages on other service lines using the same street trenches. Increasing leakages on distribution networks will cause pressure problems, and high buildings may get problems in getting their water supplies. Already by 1987 a number of Swedish municipalities reported losses of the same order of magnitude per capita as the total amounts recommended for water supply systems.

Another problem getting much attention during this phase will be the groundwater pollution which will successively manifest itself in rural wells. Sources will be leaking pipes, leached landfills and industrial waste deposits, and agricultural chemicals. Some of the problems will be accelerated by acid rain, and the leaching of metal-rich mine deposits. Also, land ownership rules and legislative and administrative weaknesses will make it difficult to control all ground-based polluting activities (Lönegren 1987). The general public may remain quite uninformed in this area for a considerable time, as environmental education in the schools tends to focus on higher-order effects on flora and fauna rather than the slow and latent processes leading to such effects.

Already in the 1980's, the nitrate level in groundwater has reached levels of health hazards over large parts of Denmark (Miljöstyrelsen 1985), and the problem will rapidly expand over the agricultural areas of Europe. In the acidified regions of Scandinavia, groundwater started to get acidified already in the 1980's, forcing rural households to neutralize their consumption water from private wells. Interestingly enough, this phenomenon was first noted by the greenish shade acquired by blondines, due to the presence of copper ions in the water solution by which they shaded their hair.

Hydrological shifts during phase 2 and their ecological consequences

What may happen during the second phase of the next seventy years is a long-term shift in the temperature and precipitation pattern over Europe. The resulting changes in land runoff drained by the rivers are impossible to predict due to uncertainties on the water consumption of plants in a CO_2-rich atmosphere. In some countries in the North a not impossible future may imply that the runoff may double, whereas in some countries in the South runoff may decrease by 50-80%.

The Scandinavian mountains will produce considerably larger amounts of flow than in the 1980's. Areas that were earlier rather dry in S Sweden, Poland, DDR and E USSR may also produce considerably more runoff. In contrast, Italy, France and SE Europe may produce less runoff. Summer droughts may expand up into Central Europe, suffering major reductions in the amount of water available in the soil during summer months. This may evidently create great problems for agriculture, especially in areas where irrigation is not easy to implement, due to water scarcity during the summer season. As a contrast, Fennoscandian wetlands and bogs may expand. In the South, the dry forests may spread over N Italy, large parts of France, over SE England and the Central lowlands.

Considerable seasonality changes may be generated by the much warmer winters in the North, radically altering the flow rythm of the rivers and the water exchange pattern of the many lakes. The snow winters may vanish in Southern Fennoscandia and the former pattern of low flow in winter months and high meltwater flows in summer be replaced by high winter flows, early snow melt and low summer flows. This will create problems not only with high pollution due to lack of dilution flow in summer, but also with groundwater tables in inhabited places close to the rivers.

The disappearance of the ice covers on N European rivers may also cause a number of problems, as much of the local traffic is now based on availability of winter roads across the rivers and lakes. This will create a demand for new bridges across many of the rivers.

The rising sea level will be causing major problems in all the major coastal lowlands on the Atlantic and Mediterranean coasts. The areas suffering include nature reserves, major wine districts like the Bordeaux area, and others. N Europe where the land uplift following the last glaciation has not yet ceased will be fortunate in partly avoiding this problem. Already in the early 21 century, the Netherlands will have to start the giant task to heighten their dams, protecting the vast and productive lowlands against the rising sea. The successively increasing pumping head of the polders will contribute to a considerable rise of the energy needs.

Water availability problems in S Europe

The changing runoff in Europe will alter also the general water supply conditions in the different countries (Brouwer & Falkenmark 1989, Figure 11). Reported to be the most water stressed in the 1970's - in terms of number of individuals to be supplied from each flow unit of water available to the country from the global water cycle - are Belgium, DDR and Poland (Forkaziewitz & Margat 1980, Falkenmark 1986). Both DDR and Poland may be favoured by the increased wetness in N Europe, whereas Belgium may be less influenced in this regard.

A number of countries in S Europe, characterized by good relative water availability in the 1970's, may develop increasing problems in response to the drier hydroclimate of the coming decades. Especially Spain, Italy and Greece may be suffering accelerated water scarcity: from around 300 p/flow unit in the 1970's (similar to many Mid-European countries at that time), they may arrive close to 700 p/unit. This is a level characterized by a definite water stress comparable to the one in the Lower Colorado basin in SW USA in the 1970's. Considerable water scarcity problems may therefore meet these countries, and in fact make it increasingly difficult to meet increasing summer droughts with large-scale irrigation.

Every sector of society exposed

The versatility of water will make every sector of society exposed when water-related conditions start to change. Table 3 summarizes these implications, listing the main problems to be expected, together with the engineering measures needed to mitigate the problems. The table lists the multitude of societal sectors that will be concerned. The water-related disturbances have been classified in two main groups: disturbances of

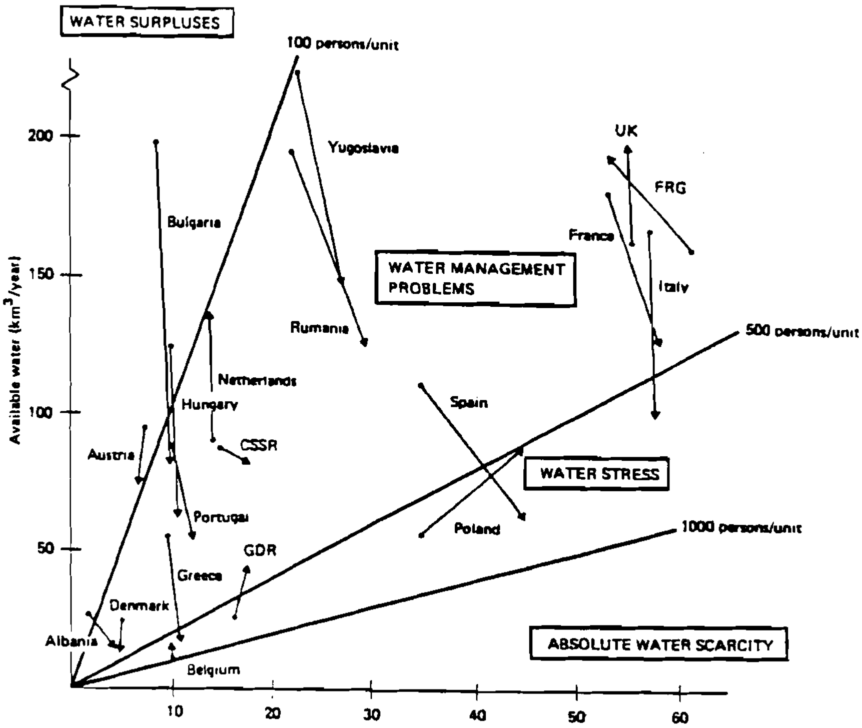


Figure 11. Relation between population changes and changes in water availability due to not impossible hydrological shifts for different European countries. Water availability calculations based on global climate simulations for a $2xCO_2$ atmosphere by UK Meteorological Office. Crossing lines indicate water competition levels in p/flow unit. From Brouwer & Falkenmark (1989).

Table 3. Implications of water-related disturbances. + indicates wetter conditions, - indicates drier conditions

		Land				River and Lakes		
Societal activities concerned		soil moisture	ground water	surface water	flow	carrier of effluents	water bodies	water depth.
		. agriculture . forest prod. . buildings . roads	. rural water supply . local irrigation	. urban activities	. water supply . hydropower . irrigation	. sanitation . industrial waste water disposal	. fishing . recreation	. navigation
Problems	+	. reduced fertility	. water logging . building damages	. urban storm runoff probl. . erosion	. failing flow control . flood problem		. erosion sedi-mentation . increasing currents . flushing of lake phosph.	. floodings, inundation
encountered	-	. drought . crop failures	. drying wells . incr. pumping costs . foundation problems . subsidence		. water defi-ciencies . reduced hydropower production	. reduced dilution . aeration problems . unsafe for bathing	. changing fishpopul. . reduced water removal	. collapsing navigation system . reduced traffic
Engineering measures to mitigate	+	. drainage	. drainage	. urban drainage	. flow control		. river training	. increased levee height . reservoirs
	-	. irrigation	. deeper wells		. water transfer schemes	. flow control . waste treatment . aeration	. dredging	. flow control . barrages . sluices . dredging

terrestrial water (i e soil moisture and groundwater), and of water in aquatic systems (i e rivers and lakes). The table also distinguishes different functional uses of water: flow-related uses, use of water systems as carrier of effluents, use of water bodies as such, and activities related to water depth.

The most serious problems to meet in response to the changing hydroclimate will be crop failures, exploding drainage costs to meet groundwater and sea level rise, hydropower failures including possible dam collapses in the North and some closed-down plants due to river depletion in the South. A number of water supply schemes may also collapse for various reasons: early in the century due to leaking pipes, pollution from rising groundwater and collapsing sewage systems, polluted source areas and later due to advancing water scarcity in the South. The rising river flows in N and C Europe may cause inundations and levee problems. Indeed, the need for increased water storage may tend to reverse the attitudes of the general public to storage reservoirs, as compared to the time when they were used mainly for hydropower regulation.

Many of the European lakes will be changing limnologically: temperature stratification will change in lakes that used to be ice-covered in winter time. They will be circulating all through the winter (i e turn monomictic in stead of earlier dimictic). During the present climate, they circulate only short periods in autumn and spring. Pollutants will therefore be more effectively mixed into the whole water mass. The increased throughflow may reduce response time of river systems to pollution, but also increase the flushing of phosporus which is at present buried in the sediments. These changes may cause the biological characteristics of the lakes to alter, leading to changes in the fish population.

The considerable water balance changes in N Europe may create also some definite changes in the characteristics of the Baltic Sea (Falkenmark 1986b). The net input of freshwater will increase due to the wetter climate, although to some extent compensated by the larger evaporation from the sea surface. At the same time the inflow from the North Sea may increase considerably in response to the rising sea level. The water exchange may therefore speed up considerably, the salinity may increase and the ecological characteristics change accordingly.

SUSTAINABLE INTERACTION BETWEEN SOCIETY AND THE WATER CYCLE

Sustainability criteria and threats to sustainability

Recalling the crucial role of water in the geophysiological system of the global biosphere, and the fact that water is globally circulated in the water cycle with which man continuously interacts by land use and by societal activities, sustainable development must be a question of a sustainable interaction between human society and the water cycle, including all the ecosystems fed by that cycle.

A basic criterion for sustainable development, according to WCED (1987), is the satisfaction of present needs without compromising future needs. This criterion, translated into the water domain, would mean that a number of water-related needs are to be met not only today but also tomorrow:

- soil permeability and water retention capacity has to be secured in order to allow both rainfall to infiltrate and adequate water supply to biomass production on a large enough scale for self-sufficiency

. drinkable water has to be available
. there has to be enough water to allow general hygiene
. fish in rivers and lakes has to be edible.

Today, a number of water-related factors and phenomena, however, tend to threaten sustainability. Food production may be threatened as regional productivity may be decreasing due to soil erosion or other forms of fertility deterioration, such as accumulation of toxics or imbalance of necessary soil productivity components (air, water, nutrients, humus, biota, cf. Hyams 1976). Under arid conditions, it may not be possible to increase productivity enough to support local populations, due to lack of water. Water sources may be getting polluted; this means that water will not be drinkable and/or not usable for irrigation purposes without treatment. Water bodies in the landscape may be getting polluted: this means that the fish will not be edible, and that aquatic systems will be deteriorating.

Three types of water involved

Evidently, both water quantity and quality may pose limitations, rendering development unsustainable. Both types of limitations may relate to three different types of water, all equally important for human life: soil water in the root zone, groundwater in aquifers, and surface water in river systems. Local scarcity may be generated by two phenomena: too large a population in relation to the available amount of renewable water supply, and a man-generated destruction of the permeability and/or the water retention capacity of the soil. Table 4 shows to what extent these different water parameters act as determinants of basic components of sustainable development, and in what way they may be threatened.

Three threatening types of land-use-related activity

Basically, three different types of human activities may threaten sustainability. First, interaction with the soil/vegetation system may have deleterious effects on the soil permeability in certain soils, leading to the formation of physical or chemical crustas when the vegetation is removed (i.e. for fuelwood harvesting, slash and burn agriculture, or industrial forestry). Vegetation removal will interfere with the local water balance, with particularly severe impacts in vulnerable environments in the tropics.

Second, the handling or deposition of polluting substances, accessible to overland or subsurface water on its way to groundwater aquifers and rivers may threaten sustainability. This group of activities includes a broad spectrum of measures: landfills of dry waste, leaking pipes, corroding oil containers, surplus fertilizers, pesticides, etc.

The third group of activities are related to water withdrawal and after-use return to natural water systems, for purposes such as water supply or irrigation. The withdrawal of groundwater above the rate of natural or artificial recharge will lead to overexploitation, with a sinking groundwater table, and in susceptible environments also a sinking of the ground surface as consequences. The return of surplus water after use is another threatening activity, either as polluted waste water, or as surplus water from irrigation, carrying the excess salts left by the evaporated

Table 4. Water-related determinants of and threats to sustainable development

TYPE OF WATER	DETERMINANT OF	THREATENED BY
soil water	. crop production . forest production . fuelwood supply	. crusta formation, ex by - overgrazing - overuse - deforestation
Terrestrial systems:		
. Flow	. water supply . hydropower . irrigation potential, i.e. dry region crop production	. vegetation changes, e.g. upsetting partitioning of rainwater
. Quality	. water supply . irrigation potential . aquatic ecosystems . fish production, i.e. food supply	
- rivers		. waste water . return flow from irrigation
- ground water		. leaching, ex - waste deposition - fertilizers - pesticides . leaking pipes . vegetation changes (in arid regions)

water fraction. Finally, when drainage is not provided to evacuate the surplus, water logging and salinization cause a threat to soil productivity.

Limitations posed by the environment

The concept of sustainable development is in some way related also to limitations, imposed by the environment on society's ability to meet human needs both today and tomorrow. One type of environmental limitation has its origin in the amount of renewable water supply made available from the global water cycle. This amount is a function simply of a country's geographical position in relation to the global pattern of aerial water vapour flux, the precipitation-forming processes active over that country, and the hydrographic pattern bringing exogenous water from upstream areas. The amount may change in response to climate change.

Such water-related constraints tend to limit the degrees of freedom available for development. They may even limit the population, which it is possible to sustain with both food and water (Falkenmark 1987). Experience has shown us that even a western semi-arid society is not able to manage above a certain "water barrier" of about 2,000 p/flow unit (1 million cubic metres of water per annum), reached already in the mid-1970's in Israel.

Another type of environmental limitation is related to a country's potential vulnerability to the consequential effects of human interventions on soil permeability, and on terrestrial and aquatic ecosystems. In principle, only such interventions are acceptable that do not jeopardize crucial determinants of either soil productivity (soil permeability, water holding capacity of the root zone), or local water accessibility (groundwater level, dry season flow in local rivers).

WATER AND SOCIETAL DECISION MAKING

Although not generally realized by policy makers, a vaste multitude of societal decisions are in fact water-related. Water-related decisions may concern water projects on the one hand, and other issues where water is involved as a more or less hidden factor on the other: land use, agriculture, forestry, traffic, energy, city planning, environmental protection, navigation etc. Decisions may also be related to various types of water cycle interventions, direct or indirect, and related to either water flows and pathways, or to water quality. Table 5 gives a number of indications of decision-issues according to these categories.

Decision-makers are expected to base their decisions on the existing understanding of an environmental phenomenon. It follows from the previous sections that this is not an easy task even when limited to the perspective of water and water-related phenomena of societal relevance. Different factors contribute to the difficulties, in particular the incompatibility between the integrated environmental system in which man lives, and the fractionalized administrative system by which that system is being managed. The communication problems due to perceptional differences between the different professional groups involved add to the decision-making difficulties. As pointed out by Professor Jim Dooge, famous hydrologist, it should be recognized that decisions are generally based not on facts but on perceptions of facts.

Overriding criteria for wise water-related decisions

What should a policy look like that pays adequate attention to water complexity, and water's role in generating higher-order effects of perturbations and disturbances of the natural landscape? As seen from a water perspective, the policy has evidently to allow a balancing of water-related dependencies and water-related threats/impacts.

As already indicated, land uses may be both water depending (water supply, water-related land use attributes) and water impacting (polluting activities, surplus fertilizers, impact on water yield and seasonality due to interventions with the short/long branch partitioning). Also water use may be both water depending and water impacting. By such dependencies and impactings different land uses may disturb each other. So will different water uses. For similar reasons land uses may intervene with water uses.

A useful perception in the preparation for societal decisions is to take an integrated perspective by seing man as a factor in the hydrology of the landscape (Figure 12). Water management and protection would then mean that decisions have to balance dependencies against threats in the landscape context.

Unfortunately, numerous barriers will tend to complicate such decisions We have already been referring both to the problem of diffuse and unprecise concepts, such as "environmental impact", and to the inconsistency in water perceptions of different groups of actors. Even among the water experts themselves, different professions may have quite different main perceptions. Besides such communication barriers, there are a multitude of barriers in the form of inconsistencies in existing legislation (legislation is often based on outdated perceptions) or in the intricacies following from the end-use oriented, sectorized adminstrative complexity, which is typical of the modern society. These various barriers were recently addressed at an IHP Seminar on Water Awareness in Societal Planning and Decision-Making, held in June 1988 at Skokloster Castle in Sweden.

Changing hydroclimate in the Po river basin - some conclusions from a policy workshop

The general reactions among decision-makers to a creeping change in the hydroclimate, and the consequential changes in water-related phenomena were exploited during one of the sessions of the IIASA Policy Workshop in Baden in June 1988 with the Po river basin as the test case. The audience was asked to respond to a sequence of seven consecutively presented scenarios, representing different moments of time from 2002 to 2038 AD.

The problems and responses emerging during the discussions were the following:

- reforestation to reduce floods, complemented by fire control
- changed agricultural pattern
- recycling industry, reduced municipal water demands
- reduced tourist industry on the coast
- development of advanced water conservation methods
- possibility to import water or, alternatively, export people
- problem of increased storage capacity in relation to both geological difficulties to find sites and public opposition

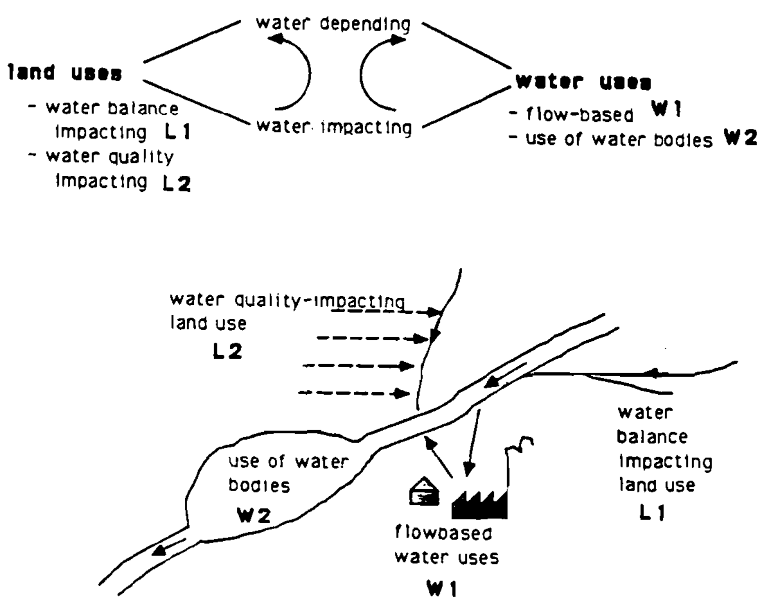


Figure 12. Water management and protection decisions have to balance dependiencies against threats, seeing man as a hydrological factor in the landscape context.

Table 5a. Water-related decisions

Issue category	Subject of decision	Involvement of water
visible water	water projects	water cycle interventions (see table 5b)
water = hidden factor	water-depending land use	. water supply dependence . access to water fronts . access to waste-water disposal . water-related attributes (ex. soil wetness, water logging . water-related hazards
	water-impacting land use	. water-cycle interventions (ex. floods, erosion) (se table 5b)

Table 5b. Decisions related to water-cycle interventions

Type of intervention	direct	indirect
water flows and pathways	- water mains - pipes - canals - industs. water supply - hydropower - agric. drainage - reservoirs	- land preparation - urbanization - agric. management - forest management - mining
water quality	- waste water outlet - waste water treatm. - industrial waste water	- agric. chemicals - dry waste deposit - ind. waste - mine tailings

The general feeling was that the measures most likely to be implemented as time proceeds were pollution abatement, water demand control, forest management, and the establishment of a river basin authority. The latter was considered important to avoid conflicts between authorities in charge of different aspects of water resources. Water prices might be significantly increased and good quality water become a manufactured good.

It was also concluded that catastrophies would probably be "helpful" in changing attitudes and making complete policy changes possible. Such events may also be active in triggering new developments, for example a restructuring of agriculture after a number of consecutive drought years. Problems would however emerge due to conditions of land ownership. One might also meet strong public disapproval by being forced to go against the presently favoured idea of self-reliant communities.

The itinerary of extreme events would probably be crucial for the solutions to be chosen. The usefulness and role of technology in meeting the expected water-related problems should not be underestimated. One fundamental measure, once that the possibility of a major change in hydroclimate is being generally accepted, would be to evaluate the present land and water policies against possible futures.

CONCLUSION

The land use changes to be foreseen in the next half century or so will have two different origins. One origin is the potential changes in land use due to degradation of soil fertility and water quality, which has already gone quite far, and is reflected in a number of higher-order effects on flora (forest dieback), fauna (birds, fishes, marine biota) and human health. Whereas some of the effects have already manifested themselves, others remain hidden along subsurface pathways of polluted groundwater. The second origin of change is the climatically induced changes.

Two different facts suggest that water-related changes will influence land use changes. Land use is not only water dependent - directly for water supply and indirectly through water-related attributes. It has also a strong impacting influence on water itself, both due to negative feedbacks from manipulations hitting the water partitioning, and from water-carried pollutants on the move in slow-response subsurface systems.

As a conclusion, land use and water are closely interrelated, and will have to be studied in a more integrated way in the future. "Development can hardly be sustained when the natural resources of soil, water and vegetation, the basic economic capital of a country, are depleted" (Rajiv Gandhi). To address the land use changes of a region, expected to develop in response to a climatic change, without also assessing the result from a sustainability perspective would therefore be unwise.

An open question to address is finally whether the traditional "dry" approach taken to land use is really effective. Even if the involvement of water in biomass production can be greatly simplified by the traditional factor approach, valid under humid conditions, this is not necessarily true under more marginal conditions, like those likely to develop in Southern Europe under a new, more arid climate. In certain ecotone regions, it is fundamental, for human life conditions and for the landscape in general, how much of the incoming precipitation that is really left for recharge of the terrestrial water systems in aquifers and rivers, and how much is being consumed through biomass production, returning water to the atmosphere. In such regions, a formal "competition" may indeed develop between water consumed in the production of food, fiber and timber, on the one hand, and the production of water available for the support of land use and human societies, on the other.

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