Hydrologic science and social problems

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The anomalous properties of water that affect its occurrence, movement and influence on the environment are introduced. The wide range of spatial and temporal scales involved in the study of water are describes. The increased interest in recent years concerning the links between hydrology and problems of the environment and of society is emphasised. The need for interdisciplinarity in research and a full participatory approach in planning is emphasised. Requirements for successful communication between disparate groups are summarised.

Introduction

Hydrology is defined in the McGraw-Hill Encyclopaedia of Science and Technology (Amorocho [1]) as:

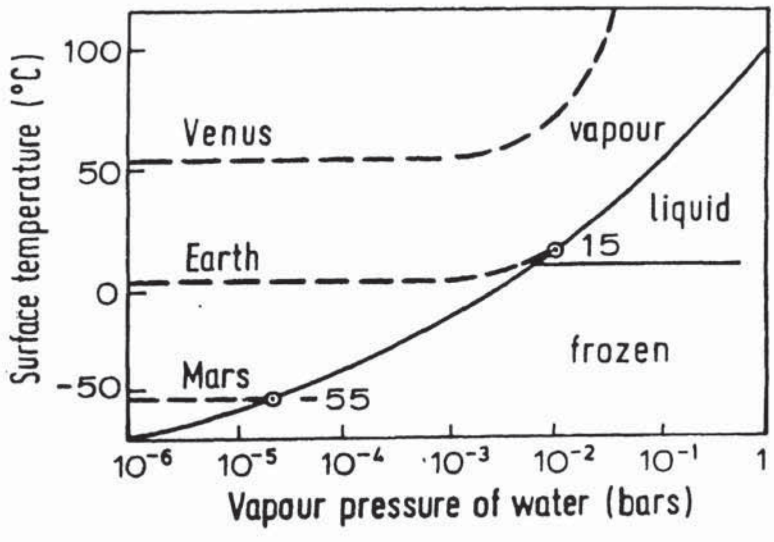
> «Hydrology is the science that treats of the waters of the earth;
> their occurrence, their chemical and physical properties;
> and their interaction with the environment,
> including their relation to living things.»

lt is the basic science that informs and influences good practice in the design and operation of water resource systems. In order to achieve the latter purpose, hydrology must interact not only with the other branches of geophysics and the other physical sciences but also with the biological sciences and the social sciences.

Water a Simple Substance?

The natural world as we know it has been shaped more by water rather than by any other single factor. A first question to be answered is whether this was inevitable or whether it arose from special circumstances. Figure 1 shows a simplified picture of the evolution of the surface temperatures and pressures of the Earth and its two closest planetary neighbours Mars and Venus (Goody and Walker [2]). It has been estimated that: (a) if the Earth were 5% further from the sun the surface would be frozen at all times as in the case of Mars; (b) if the Earth were 5% closer to the sun it would suffer a runaway greenhouse effect similar to that of Venus which has a surface temperature more than 500'C higher than that of the Earth (Rasool and de Bergh [3], Kondratyev and Hunt [4]). The variation in surface temperatures in the Earth's system around the mean value of about 15 ºC results in a vigorous hydrological cycle involving water in all three phases: ice, liquid water, water vapour.

FIGURE 1. Planetary temperatures



Water at atmospheric pressure is transferred from solid to liquid form around 0 ºC and from liquid to vapour form around 100 ºC. These values are anomalous if compared with the corresponding anhydrides formed by a combination of hydrogen with the other group VI elements of the periodic table (Dooge [5]). Physical chemists tell us that this discrepancy is due to the fact that water is a polar molecule i.e. electrically balanced but with a dipole moment. This gives rise to hydrogen bonding and as a result water behaves in a more complex fashion than its simple appearance would suggest. One consequence is the occurrence of liquid water on this planet and its influence on the life forms that are found there.

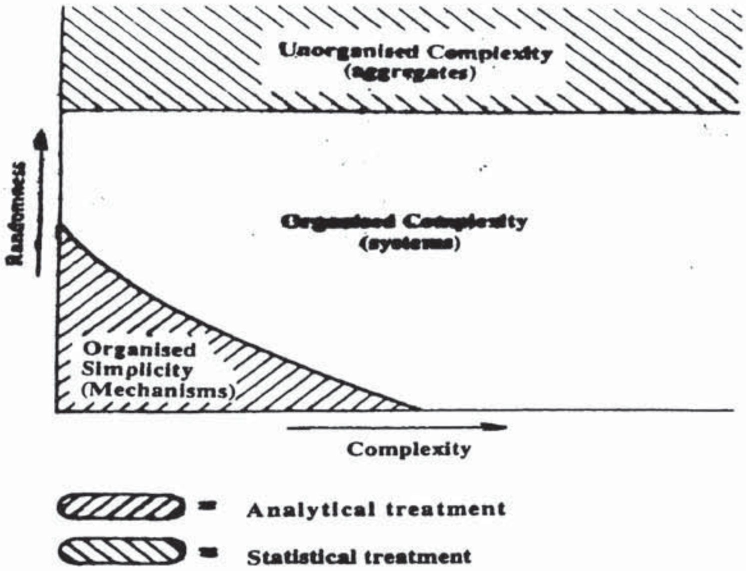
There are other anomalous properties of water that affect both geophysical processes and human society. The surface tension of water is anomalously high and this results in a greater retention of water around contact points in unsaturated soil thus promoting longer vegetational survival during droughts than would occur if the surface tension of water were more in line with that of other group VI anhydrides. The latent heat, the thermal conductivity, and the specific heat of water are all anomalously high and all these act as climate modifiers which reduce the variations of climate with latitude and hence extend the proportion of habitable territory. Additionally water is an almost universal solvent and thus is the main natural carrier both of the nutrients necessary for life and the toxic elements that are harmful to it.

Classical physics has applied (a) deterministic methods to the analysis of highly organised mechanisms that are relatively simple and have a small degree of randomness and (b) stochastic methods to the analysis of aggregates that may be quite complex but are relatively unorganised. The systems studied in hydrology are intermediate between these two types as indicated on Figure 2 (Weinberg [6]). In part, this may reflect the nature of liquid water with its short term (10^{-13} seconds) clustering and re-clustering of molecules as intermediate between the deterministic structure of ice crystals and the highly random fluctuation of particles of water vapour.

Scales in Water Science

Fluid mechanics and hydrology in dealing with the movement of water operate on scales much higher than the molecular and ignore most of the molecular properties of water. Batchelor [7] has characterised the continuum scale at which molecular fluctuations can be ignored as being of the order of 10^{-5} metre or five orders of magnitude higher than the molecular scale of 10^{-10} metre. At this continuum scale we can ignore the non- isotropic nature of the water molecule and derive the 2-parameter Navier- Stokes equation for laminar flow of a compressible

FIGURE 2. Mechanisms systems and aggregates

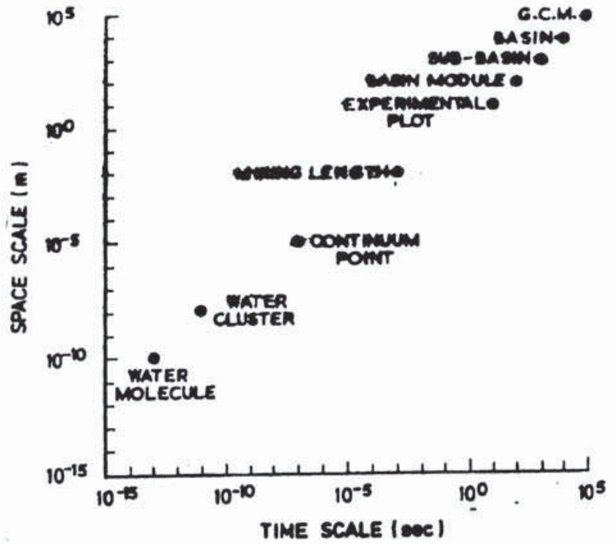


fluid by postulating that water is completely isotropic (Dooge [5]). For turbulent flow there is a further aggregation which in simplistic terms can be characterised by the Prandtl mixing length which may be of the order of 10^{-2} metre for typical turbulent flows of liquid water.

In hydrology further aggregation is required, as shown on figure 3, from the 1 metre scale of an experimental plot or a soil-vegetation-atmosphere model (SVAT) to the 10^3 metre scale of a sub-basin model or the 10^5 metre scale of a global climate model. Scientific hydrology tackles the many problems of synthesising concepts, theories and data at these higher scales (Dooge [8]).

The question naturally arises as to whether there is a fundamental theorem of hydrology that is valid over the whole range of spatial and temporal scales shown on the logarithmic plot of figure 3 in the same sense as such concepts as the fundamental theorem of algebra, the fundamental theorem of chemical valency, the fundamental theorem of natural selection etc. In hydrology the equation of continuity meets the criteria that it (a) can be written in appropriate form at all scales, (b) is necessary for meaningful analysis at all scales, and (c) can be transformed from one scale to another without the necessity of upscaling parameters for aggregation of individual terms or of distribution assumptions for disaggregation. Hydrologic theory combines the equation of continuity with other theorems appropriate to the scale of interest.

FIGURE 3. Scales in water science

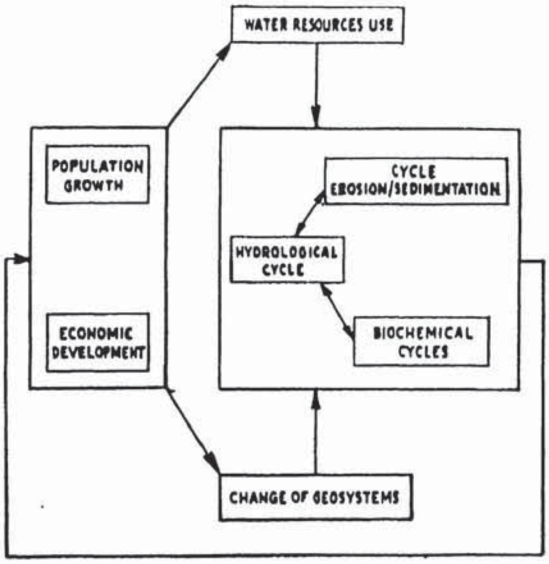


Hydrology and the Environment

For more than a century hydrologists have broadened their field of interest from the study of water per se to include the movement of sediment under the influence of flowing water (Walling and Webb [9]). In recent decades this has been further extended to include the occurrence and movement of water-borne biota. Already there have been surprises in the area of aquatic geochemistry and water-related ecology and there are surely more to come. In the authoritative report by the U.S. Committee on Opportunities in the Hydrological Sciences, chaired by Professor Pete Eagleson, three of the five priority categories related to the environment rather than the physical occurrence and movement of water (NRC [10]). These were (a) the chemical and biological components of the hydrologic cycle; (b) land surface-atmosphere interactions; and (c) hydrologic effects of human activity. The other two were (d) co-ordinated global- scale observations of water storages and fluxes and (e) the scaling of dynamic behaviour.

The hydrologic cycle and the associated cycles of sediment transport and of biogeochemical transport are themselves linked to a number of socio-economic systems as indicated in figure 4 (Golubev [11]). Population growth and economic development produce an increase in the use of water resources and a change in the global geosystem both of

FIGURE 4. Water-related Cycles



which affect the hydrologic cycle, the sediment cycle and the biogeochemical cycles. These interactions have been increasingly studied in recent years. Thus a recent International Conference on Hydrology in a Changing Environment, organised by the British Hydrological Society (Wheater and Kirby [12]), covered such themes as: (1) global hydrological processes, (2) ecological and hydrological interactions, (3) groundwater at risk, (4) hydrology of environmental hazards, (5) catchment management and resource assessment in dry areas, and (6) hydrology of large cities.

The role of water in food production and health promotion remains critical and the task of meeting requirements is an immense one (Young et al. [13]) . The expert trained in the developed world is often hampered by his training in tackling the health problems of developing communities. Thus, in the case of water-related diseases, the textbooks and lectures reflect the problems of an urban municipality in a temperate climate and are of limited application to the problems of a rural community in a tropical developing country. The very classification of diseases based on categorisation by causative agent (virus, bacterium, protozoa etc.) is a hindrance to finding an appropriate solution. A key step towards success in dealing with the sanitary problems of developing countries was the reclassification of water-related discases based on the role of water in the manner of infection (Bradley [14]). The latter scheme identified four basic categories: (1) water-borne infections (e.g. typhoid, cholera) which could be reduced by improved quality of water; (2) water- washed infections (e.g. trachoma, dysentery) which could be reduced by a greater quantity of water; (3) water-based infections due to skin penetration (e.g. schistosomiasis) or ingestion (e.g. guinea worm) which could be checked by protection of the user or the source respectively; and (4) water-related insect vectors that bite near water (e.g. sleeping sickness) or breed in water (e.g. yellow fever) that could be controlled by piping from the source to the site of use.

Ecology and Hydroprojects

The neglect of ecological considerations in water resources planning in the past led to a number of environmental problems. These were well summarised by Kenneth Boulding in his Ballad of Ecological Awareness composed to summarise a discussion of the ecological effect of large dams which took place during a Conference on the Application of General Systems Theory to Social Systems. The first verse deals with the erosion problem:

> «The cost of building dams is always underestimated-
> There's erosion of the delta that the river has created,
> There's fertile soil below the dam that's likely to be looted,
> And the tangled mat of forest that has got to be uprooted.»

The second turns to the social problem of community displacement:

> «There's the breaking up of cultures with old haunts and habits lost,
> There's the education program that just doesn't come across,
> And the wasted fruits of progress that are seldom much enjoyed
> By expelled subsistence farmers who are urban unemployed.»

The next two verses touch on a variety of problems relating to ecology, water loss, erosion, sedimentation, groundwater rise:

> «There's disappointing yield of fish, beyond the first explosion;
> There's silting up, and drawing down and watershed erosion.
> Above the dam the water's lost by sheer evaporation;
> Below, the river scours, and suffers dangerous alteration.
> For engineers, however good, are likely to be guilty
> Of quietly forgetting that a river can be silty,

While the irrigation people too are frequently forgetting
That water poured upon the land is likely to be wetting.»

After dealing with these, Boulding turns to health, food and further ecological aspects:

«Then the water in the lake, and what the lake releases,
Is crawling with infected snails and water-borne diseases.
There's a hideous locust breeding ground when water level's low.
And a million ecologic facts we really do not know.»

He turns finally to a critique of benefit/cost analysis:

«There are benefits, of course, which may be countable, but which
Have a tendency to fall into the pockets of the rich.
While the costs are apt to fall upon the shoulders of the poor.
So cost-benefit analysis is nearly always sure,
To justify the building of a solid concrete fact,
While the Ecologic Truth is left behind in the Abstract.»

While there is an increased awareness and an improvement in design practice since these lines were written 26 years ago, the range of factors involved remains largely the same.

Water Management and the Social System

The Dublin Conference which provided the input on water problems to the Rio Conference on Environment and Development based its main recommendations on four guiding principles aimed at reversing the current trends towards over-consumption, pollution, and rising threats from droughts and floods (Young et al. [13]). The first of these principles emphasised that:

«Fresh water is a finite and vulnerable resource,
essential to sustain life, development and the environment.»

and stressed that:

«Effective management of water resources
demands a holistic approach,
linking social and economic development
with protection of natural ecosystems.»

To transform this guiding principle into effective action requires a considerable effort of communication between people from a number of disciplines.

Besides the basic discipline of hydrology, effective holistic water management needs a number of other inputs - the understanding of environmental dynamics provided by ecologists, the expertise in relation to infrastructure provided by engineers, the appreciation of market forces provided by economists, and the sensitivity to social and political factors provided by social scientists. In the case of economics, scientists and engineers should not be unduly influenced by the misunderstanding of the appropriate role of market forces that is evident in much of public discourse and media reporting. The Business Council for Sustainable Development, which was the input to the Rio Conference from the perspective of global business, clearly distinguished between the social objectives of the community and the role of the market as an implementing mechanism. In its Report published under the significant title of «Changing Course» (Schmidheiny [15]), it stated:

> «The market does not tell us where to go,
> but it provides the most efficient means of getting there.»

and stressed the importance of establishing goals and strategies by political systems rather than relying solely on economic instruments:

> «Therefore, society - through its political systems -
> will have to make value judgements, set long-term objectives,
> implement measures such as charges and taxes step by step,
> and make midcourse corrections based on experience and changing evidence.»

This important distinction is often ignored resulting in short-term advantage for some but long-term burdens for the community as a whole.

Interdisciplinarity in Practice

Talk about interdisciplinarity in theory is relatively easy; successful interdisciplinary co-operation in practice is decidely difficult. Gilbert White has distinguished between four types of interdisciplinarity as follows. First, the synthesis of separate disciplines by a single individual which is typified by the Renaissance Man but is highly unusual nowadays and virtually impossible in most cases. Secondly, specialists combining together on tasks with common elements or interfaces under some umbrella, which often takes the form of a single large research budget or an external research grant. Thirdly, federated teams of scientists from different disciplines who prepare their separate research plans and then confer together so as to harmonise them and if necessary modify them to form a single programme. Fourthly, integrated interdisciplinary research which is planned as a single programme from an early stage and managed as such. The last approach is by far the most fruitful in terms of scientific advancement, technological innovation and successful project management.

The involvement of disparate groups on a basis of parity has been found to be the key to success in the planning and design of water resource projects. Table A, which is based on an original table by Goodland [16], illustrates the changes in the planning of major hydroprojects over recent decades in the involvement firstly of non-engineering experts and later of some of the «stakeholders». It shows the successive involvement, firstly as post-hoc evaluators and then as members of

TABLE A INTEGRATION OF SPECIALIST INPUTS. COOPERATION ON HYDROPROJECTS

Period	Design Team	Post-design evaluation
Pre - 1950	Engineers	Economic
1950 - 1970	Engineers + Economists	
Late 1970s	Engineers + Economists	Environment
Late 1980s	Engineers + Economists + Environmentalists	
Early 1990s	Engineers + Economists + Environmentalists + People affected	NGO's
Late 1990s	Engineers + Economists + Environmentalists + People affected + NGOs	

Goodland (1993).

the design team, of groups such as economists, environmentalists, affected communities, and non-governmental organisations. Such an approach is in accordance with another one of the four guiding principles of the Dublin Conference on Water and the Environment which states (Young et al. [13]):

> «Water development and management should be
> based on a participatory approach
> involving users, planners and policy-makers at all levels.
> The participatory approach involves raising awareness of the
> importance of water among policy-makers and the general public.
> It means that decisions are taken at the lowest appropriate level,
> with full public consultation and involvement of users
> in the planning and implementation of water projects.»

This principle puts an onus on those trained in a particular discipline to look outward towards co-operation not only with scientists in other disciplines but with many social groups concerned with the topic under discussion.

Communication and co-operation between persons and groups from diverse backgrounds and with differing interests is far from easy. Whether at a social gathering or at a planning session, the basic elements for meaningful communication are the same. They may be characterised as follows: (1) a common language known moderately well by all participants; (2) a well-defined common focus of real interest to all parties; (3) a willingness and an ability to talk clearly and to the point; and (4) an ability and a willingness to listen patiently. All four are important. The special jargon of each individual group facilitates communication within the group but makes communication with other groups more difficult. Experience from attempts at interdisciplinary research in science indicates the vital need for sharp focussing on a well- defined specific problem. The ability to speak clearly is important not only for communication to others but also for the organisation of one's own thinking. As for patient listening, this must involve a genuine effort to understand and not consist merely of a passive interval of recuperation between bouts of expounding one's personal viewpoint.

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