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FREE OPINION

Water resources management at the turn of the millennium: *towards a new scientific paradigm*

La gestion de l'eau à l'aube du 3e millénaire : vers un paradigme scientifique nouveau

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SUMMARY

The aim of this article is to analyze the new approach to water resources management adopted by the scientific community at the turn of the millennium. After reviewing the basic concept of this approach, a scientific methodology is proposed, in order to express the general and mostly descriptive new concept in analytical and quantitative terms, so that it may be applied in practical cases.

For several decades now the general concept of this new approach has been developing along the lines of sustainable development. This means that social and environmental considerations have been added to the traditional objectives of technical performance and economic effectiveness. The question now being raised is how the complex concept of sustainability, which until now has been expressed in general and descriptive terms only, may be formulated in the analytical and quantitative terms of a scientific methodology.

On the methodological level, the fact that several criteria and objectives within a coherent framework of hypotheses and reasoning are taken into account may suggest a move towards a new scientific paradigm. The general framework of the paradigm proposed in this paper is that of multidimensional quantitative risk analysis.

Traditionally, the general objective of water management has been the satisfaction of demand for various uses, such as agriculture, drinking water or industry, using available water resources in technically reliable and economically efficient ways. This approach has led to structural and mostly technocratic solutions being suggested and implemented in several countries. However in many cases, building dams, modifying riverbeds and diverting rivers has had serious negative repercussions on the environment and on social conditions. Moreover, waste in the use of this precious resource and

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rampant pollution in all areas of water use have raised doubts about this form of management. The concept of a sustainable management of water resources was first mentioned in Stockholm in 1972, during the United Nations World Conference and then at the Rio summit in 1992 with Agenda 21.

The new philosophy is based on the integrated management of water at the watershed basin level. Emphasis is placed on environmental protection, the active participation of local communities, the management of demand, institutional aspects and the role of continuous and lifelong education of all water users.

On the methodological level, integrated water management remains an open question and several different approaches are seeking to define a coherent paradigm. One possible paradigm is proposed in this article and may be called the "4E paradigm": Epistemic, Economic, Environmental, Equitable. It is based on risk analysis, with a multidimensional character: Scientific, Economic, Environmental and Social. This paradigm uses either the theory of probability, or fuzzy logic, or both, in order to assess and integrate technico-economic and socio-environmental risks in a perspective of sustainable management of water resources.

Key words: *water resources, sustainable management, risk analysis.*

1 – INTRODUCTION: A CHANGING WORLD

As a scientific and professional activity, water resources management has inevitably been influenced by the socio-economic changes affecting society at the turn of the new millennium. History shows us that changes concerning production patterns and lifestyles are continuous, only the rate of change varies, with periods of slower evolution followed by periods of rapid and profound change. The world is currently going through a period of rapid change, with economic globalization, the development of information access and remote communication and the exponential progress of science and technology. After the agricultural and the industrial revolutions, there is no doubt that at the start of the 3rd millennium, we are undergoing a 3rd revolution, the information revolution.

The management of water as a natural resource could not fail to have been influenced by these socio-economic changes. Indeed, the former purely scientific and technical approach to the management of this precious resource has been modified to such a degree that it may be said that a new paradigm has started to emerge. This paradigm is related to our new view of the world, to the new values established and to the priorities granted to these values.

Before explaining this new view, it should be stated that water management is a horizontal discipline, where various approaches are possible:

– *scientific*: water and earth sciences, such as hydrology and hydrogeology, environmental sciences, such as ecology, as well as basic sciences like physics, chemistry and biology, study the properties and behavior of water as a natural resource as well as its applications in various fields of human activity.

– *technical*: hydrological engineering, hydraulics and other disciplines of mechanical engineering deal with water in a technological context.

– *economic*: water in terms of being an economic resource, the price of water and the pricing of water services may be used as instruments for the regulation and rational use of water.

– legal: national legislations, directives and standards, as well as international treaties regulate water uses and quality at national and international levels.

– social: social sciences stress socio-political attitudes, human behavior and public perceptions regarding the use of water in a social context.

If we examine the recent developments and trends of the above disciplines in the field of water resources use and management, we can identify three main characteristics, which clearly result from the influence of the current revolution in information technology:

1. Contrary to the opinion generally prevailing a few decades ago, it is now widely admitted that science and technology alone cannot solve the complex problems of water resources management.
2. Several experts and international organisations have vigorously and persuasively demonstrated the importance of environmental consequences and social repercussions of water management projects.
3. New information technology (IT) and remote communication techniques have revolutionized working methods and modified the means used in planning and management studies of water resources. For example, the use of Geographic Information Systems (GIS) in conjunction with sophisticated mathematical models, the handling of digitized databases now available on the Internet and the networking of information have radically changed our scientific and technical approaches.

Due to these changes water resources management is now considered to be a complicated technico-social process involving several disciplines, and several different approaches need to be taken into account simultaneously. This new integrated approach has led to the criteria and methodologies used being modified to such an extent that one may claim that a new scientific paradigm, in the sense given to the word by KUHN (1962), needs to be specified.

In order to justify this claim, one must first recall what the traditional framework of water resources management was like. The consequences of traditional planning and management patterns have shown that environmental protection and social repercussions must be considered to be equally important as technical reliability and economic performance. The current worldwide water crisis on the practical, methodological and institutional levels is a clear illustration of the risks being run and of the need for a profound change in our scientific and technical approaches.

This was the research theme of the specific project SP-E entitled “the European Paradigm of Integrated Management of Water Resources,” developed under the co-ordination of the author of this article, within the framework of the first phase of Etnet - Environment/water. Etnet, known since 2000 as Etnet21, is a network of more than 100 European universities and other institutions dealing with water resources management (ETNET, 1998). Most of the arguments as well as the basis of the analysis developed in this article have benefited from the experience and views of the colleagues who took part in the SP-E/Etnet project.

2 – THE TECHNICO-ECONOMIC APPROACH: A TRADITIONAL MANAGEMENT MODEL

The traditional approach of water resources management emphasizes one main goal: meeting human needs both in terms of water quality and quantity. This anthropocentric view is based on the implicit assumption that resources are unlimited, and that whatever helps satisfy human needs does not need to take environmental consequences into consideration.

According to this line of reasoning, the supply of drinking water in agglomerations and irrigation water for agriculture and industry is based on the available quantities of water. Figure 1 shows how in the case of drinking water, this management model emphasizes an increase in water supply.

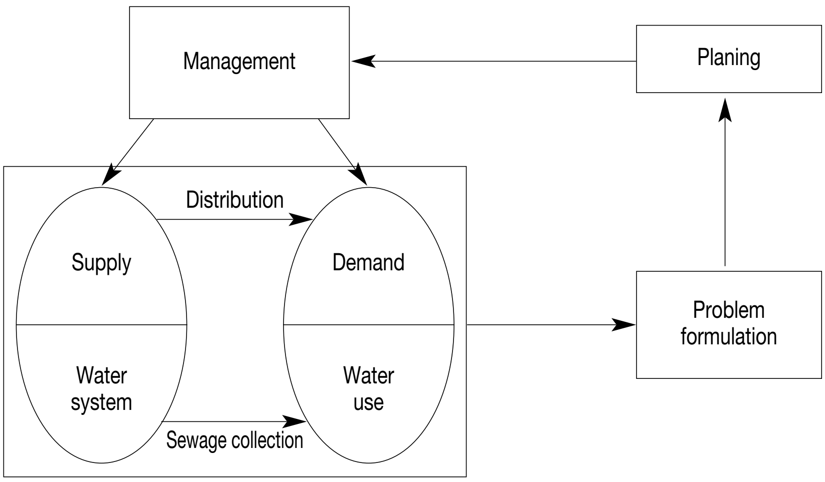

Figure 1 Water resources management in urban areas.

If nearby water supplies are inadequate, the additional drilling of wells, the building of long aqueducts to bring water from far away, or the diversion of nearby rivers is recommended. This type of planning has meant that for example in Athens, where there is an increase in urban population, drinking water is now brought from several hundred kilometers away.

In the case of flood protection, the traditional approach relies either on retaining the whole volume of the extreme rise in the water level away from the area to be protected, or on quickly redirecting the water as far away as possible. These technocratic solutions either meant building large dams with capacious reservoirs able to contain the flood volumes, or modifying riverbeds by widening their sections, straightening their reaches and increasing their flows by using concrete, chosen because of its low cost.

The consequences of this management pattern have been witnessed in several countries throughout the world and brought to light by several specialists and international organizations. Generally speaking, experts agree that the world is currently facing a “water crisis”. This is not simply a quantitative crisis, even though several countries are reaching the limits of their resources, but also a qualitative crisis caused by pollution, all aspects having institutional and social repercussions.

Problems caused by faulty management of water resources are partly linked to a sectorial policy and the lack of co-ordination between responsible organizations on a national and international level (GANOULIS et al., 2000). These problems are acute in certain regions: for example the destruction of the Aral Sea caused by the overexploitation of the region’s water resources, the disappearance of wetlands in Europe and the USA, ground erosion in the Mediterranean area and the pollution of large rivers in Siberia.

3 – TOWARDS A SUSTAINABLE MANAGEMENT OF WATER RESOURCES

The water crisis and environmental problems have led to a drastic change in attitudes towards water resources management.

The term “sustainable management” first replaced that of “eco-development” at the 1972 United Nations Conference in Stockholm and was then taken up and analyzed at the Rio summit in June 1992. The concept of sustainable management was mentioned in the Rio Declaration, unanimously adopted by 178 countries, and then detailed in Action Plan 21, now known as Agenda 21. In principle 3 of this Declaration, it is stated that sustainable management “must be implemented so as to meet in an equitable manner the needs related to development and to the environment of the present and future generations”.

This statement is more of a wish than a definition, as it does not specify the means, the approach or the actions needed to achieve this objective. In the field of water resources, several organizations and associations have tried to define the criteria and the methodology to be used in order to achieve sustainable management (ASCE, 1998; ETNET, 1998; UNESCO, 1999). In a recent article published in *Water International,* D.P. Loucks reviews the debates and the various opinions concerning the sustainable management of water resources (LOUCKS, 2000).

This article shows that although a common definition of sustainability is starting to emerge, no simple and clear model has yet been defined and adopted by the scientific community. Such a model would concern the methodology to be used and the criteria to be taken into account, in order to achieve sustainable water resources management.

It should perhaps be emphasized that what matters is the analysis of alternative technological solutions, where the whole spectrum of possible solutions should be studied. These solutions may lie between two extremes. Some of them rely on so-called advanced techniques using new technologies, while others are simple, traditional and often low productivity solutions. The impact of these solutions should be assessed in four areas:

1. Scientific and technical reliability

2. Economic effectiveness

3. Environmental impact

4. Social equity.

A sustainable solution should provide gains in all four of these areas, with priorities being established according to local needs. In game terminology, this would be known as a solution with *a game of positive sums*. As shown in *figure 2*, the sustainable solution should in fact minimize risks in four dimensions:

1) Scientific/Technical, 2) Economic, 3) Environmental 4) Social.

The scientific paradigm called 4E (EEEE: Epistemic, Economic, Environmental, Equitable) is based on multidimensional risk analysis and allows the integration of these four criteria towards sustainable management.

4 – MULTICRITERIA RISK ANALYSIS

The main idea of this paradigm is that every technical or organizational alternative in water resources management involves a possibility of failure. The consequences of these failures may appear at several levels: technical, economic, environmental and social. How serious these failures may be will depend on each case. In extreme cases, the consequences are catastrophic, for example on the technical level when a dam bursts or, on the economic level when there is a bank crash when finance is being sought for a large hydraulic project.

In the field of water resources management, possible failures, their frequency and their consequences can be calculated, as for example, the hydrologic risk of an urban rainwater network overflowing as a result of a period of rainfall greater than that provided for by a project. The evaluation of failure frequency is the main object of the discipline known as *risk analysis*. The quantification and management of risk on several dimensions (technical, economic, environmental and social) can be used as a general framework to evaluate the degree of sustainability of an alternative management strategy (*figure 2*).

The theory of probability or fuzzy logic (DUBOIS and PRADE, 1980) can be used as evaluation tools in technical, economic, environmental and social risk analysis. This methodology has been used to study water quality in the environment (GANOULIS, 1994).

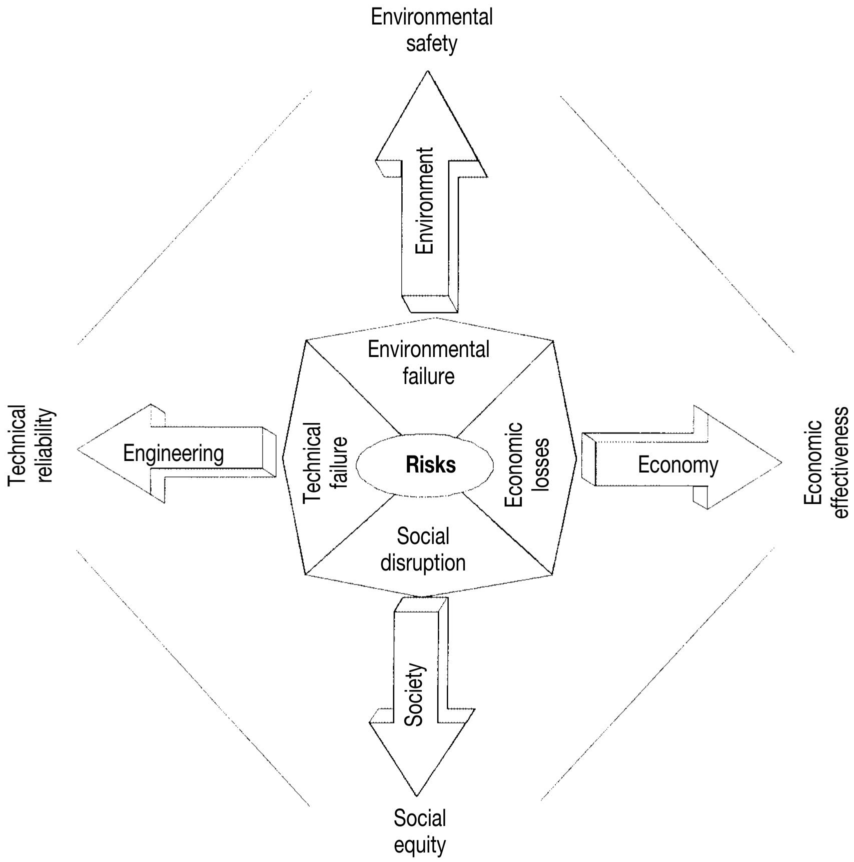

Figure 2 Risks and objectives for sustainable water resources management.

Briefly the main stages of the methodology are:

1. Establish a conceptual definition of a set of *alternative management strategies.*
2. Estimate the *matrix of technical, economic, environmental and social risks* corresponding to each alternative strategy.
3. Using an algorithm of average taking, calculate the *index* of technical and environmental *composed risk* (*technico-environmental risk*) and the index of social and economic *composed risk* (*socio-economic risk*).
4. Rank the alternative management techniques in a two-dimensional space along the criteria of the composed risks previously defined (stage 3) and of the distance to the ideal point (0 risk) for each strategy.

This methodology is linked to multicriteria decision analysis (GOICOECHEA *et al*., 1982; VINCKE, 1989; BOGARDI and NACHTNEBEL, 1994). It may be seen from *figure 3* how alternative strategies 1, 2 and 3 are represented in the two-dimensional space of composed risks by the co-ordinates corresponding to the technico-environmental and socio-economic risk indexes. These strategies are

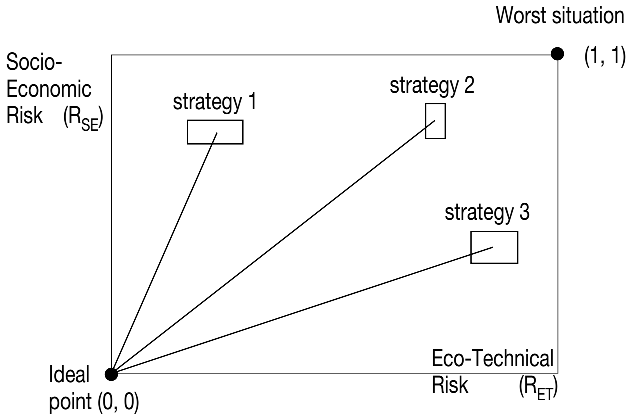

Figure 3 Distance-based ranking of alternative strategies.

ranked 1-3-2 according to their distance to the ideal point (zero risk, ideal sustainable solution).

5 – CONCLUSIONS

Phenomena related to water resources are characterized by a high degree of uncertainty, particularly because of their variability in time and space. Risk analysis is an appropriate methodology in order to assess the reliability of a resource management solution.

Among alternative solutions, the sustainable one should have a positive game sum on the four reliability indexes: technical, economic, environmental and social. The 4E paradigm, briefly described in this article, allows an assessment of the most sustainable solution using multidimensional risk analysis.

Moreover, the risk involved must be considered in relation to time, as a sustainable solution must, by definition, be one that maintains its characteristics in the near and more distant future.

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