Integrated water resources management: the requirements of the European Union, the problem of environmental impact assessment, and implementation of the sustainable development principle

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Abstract This paper deals with the European Council Directive establishing a framework for action in the field of water policy. The core principles of sustainable development and integrated river basin management are discussed. Both require for their implementation, evaluation of the impact of measures (e.g. water projects). A technique for the evaluation of the ecological impact of hydraulic structures on ecosystems affected by such projects is described. The principle of "ecological risk" assessment is presented, for which it is necessary to evaluate the present ecological state of the ecosystem affected by the intended project and the degree of damage caused by the intended measure or project. For the other relevant new planning principle, i.e. sustainable development, an example is given of how this principle can be implemented in the design of a water supply system.

Key words ecological damage; ecological risk analysis; European Council Directive; integrated river basin management; multi-objective decision making; possibility theory; sustainable development; water supply systems

INTRODUCTION

Until recently the criteria used in the design and operation of water management schemes were: technical efficiency (engineering); performance reliability (social); and economic benefits (economy). After the World Commission on Environment and Development, UN (WCED, 1987) report appeared, new principles became more and more relevant, the two most important of which are the principle of sustainable development and the principle of integrated river basin management. While the former was advocated mainly by the United Nations the latter is strongly supported by the European Union (EU), which produced a Council Directive meaning that within the next few years all EU member states have to adopt new legislation postulating the introduction of the integrated river basin management principle.

EUROPEAN COUNCIL DIRECTIVE

The ambitious requirements of the Council Directive (European Union, 1997) cannot be satisfied at present due to a lack of tools for planning water management schemes following the two principles mentioned earlier. Here, only a few of the most important
items of the EU directive can be mentioned briefly in the form of a summary of the content of important articles.

**Article 4** Member states shall draw up and make operational within a comprehensive River Basin Management Plan the programmes of measures envisaged necessary to prevent deterioration of ecological quality and pollution of surface waters and to restore polluted surface water in order to achieve Good Water Status in all surface waters by 2010. Analogous requirements hold for groundwater. For “Severely Affected Water Bodies”, less stringent environmental objectives may be established under certain conditions.

**Article 12** By 2010 member states shall ensure full cost recovery for all costs of services provided for water uses over all economic sectors. This includes calculation of environmental and resource costs and benefits of water use. A scientific challenge lies here in the fact that methods for calculation of such costs are not available and need to be developed. Furthermore, implementation of this proposal may in practice cause significant conflicts.

**Article 13** Member states shall establish a Programme of Measures for each river basin to achieve the environmental objectives of Article 4.

**Article 16** For each river a River Basin Management Plan has to be produced, covering the whole river basin district (by the year 2010).

Implementation of the two new principles (sustainable development and integrated river basin management) requires comprehensive interdisciplinary analyses, evaluation of present and future conditions, and a management plan containing many measures to meet the requirements of Article 4. The solutions of this complex planning problem have to be found in the area of potential conflict between ecology, socio-economics and technical measures. A group of scientists formed by the author’s institute together with institutes of economy and ecology from other German universities and an important river basin management authority, has designed a scheme for a potential approach to solve this problem (Fig. 1). From Fig. 1 it can be seen that an important task is the development of a multi-dimensional evaluation system (Box 4 in Fig. 1) and a multi-dimensional spatial decision support system (Box 9 in Fig. 1). Due to the many gaps in knowledge required for implementation of the EU directive, it is doubtful whether the ambitious timeframe can be met.

**REQUIREMENT “EVALUATION OF MEASURES”**

As mentioned earlier, the decision on which measures to take in order to implement the principles of sustainable development or integrated river basin management depends strongly on the evaluation of the impact of such measures in various fields (ecology, economics, etc.). Theoretically sound instruments for an objective evaluation of the present and the future ecological state of a system require close cooperation between ecologists, engineers, and economists. Here only one example can be given, which shows a technique allowing the evaluation of the impact of a measure or a project on the affected ecosystems.
Modified ecological risk principle for environmental impact assessment, EIA

The technique developed by Giers et al. (1998) is explained along with an example of the evaluation of the ecological risk generated by the potential construction of a large dam on a river in Germany. Here only the environmental factor, called "water/stream" in conventional environmental impact assessments (EIA), will be considered. The other relevant environmental factors (e.g. soil, plants, animals) have also to be evaluated, but are beyond the scope of this paper.

The principle of ecological risk as developed by biologists does not deal with the risk as used by engineers and specified by probability theory. The ecological risk specifies the impact of measures (e.g. structures) on ecosystems in the form of ordinal value ranging from \( -V \) (worst possible case) up to \( O \) (no change) and possibly up to \( +V \) (optimum possible improvement). Evaluation of the ecological risk has to go through three steps: (a) evaluation of the ecological situation of the area under consideration for conditions of the present state; (b) evaluation of the degree of ecological damage caused by the measure (e.g. a dam construction); and (c) superposition of the evaluation of the present state and the degree of damage in order to generate the
“ecological risk.” Evaluations have to be carried out for all area elements affected by the project, which usually requires the application of a geographic information system (GIS).

The evaluation of the environmental factor “water/stream” is based on four main parameters: water physics, morphology, discharge, and water chemistry. Each of these main parameters is aggregated from several single parameters (e.g., pH value, conductivity, and $O_2$-content for the parameter “water physics”; morphology of water, bank, and land for parameter “morphology”; hydrological regime, mean values etc. for “discharge”; and metals, organic loading, nutrients, waste water indicators for “water chemistry”). A set of rules has to be established that defines categories for each of the four main parameters ranging from “natural” to “extremely damaged” in order to specify the present state. Initially it is necessary to specify the ecological quality of each river reach and for each main parameter. Figure 2(a) shows the results of a rule-based aggregation of the main parameters for the ecological evaluation of the present state of the river system under consideration: the Neger River, a tributary to the Ruhr River in Germany. The four diagrams on the left hand side show the evaluation of the four main parameters, while the diagram on the right shows the aggregation result, specifying the evaluation of the environmental factor “water/stream” for the present state in the form of ordinal values ranging from I (very bad ecological condition) to V (optimum ecological conditions). The specification of these values is achieved by aggregation of the values obtained for the four main factors to form one parameter based on a matrix of highly specific rules.

**Evaluation of degree of damage due to a dam construction**

For the four main parameters mentioned above, the second step in the procedure of ecological risk evaluation consists of the specification of the “degree of damage” caused by a measure or project. A team of experts has to identify “values” for various degrees of damage caused by a structure (Fig. 2(b)). In the aggregation process for the specification of the degree of damage for the whole river system, again a set of rules is applied that allows the estimation of the degree of damage as shown in the right hand diagram of Fig. 3 (ranging from $-V$ (worst) to $+V$ (best case)).

**Estimation of ecological risk caused by a structure**

On the basis of the evaluation of the present state and the evaluation of the expected degree of damage of the river system, the ecological risk is then determined, again following a set of rules specified by experts. Figure 3(a) shows the evaluation of the present state (Fig. 2(a)), Fig. 3(b) shows the degree of damage (Fig. 2(b)), and Fig. 3(b) represents the ecological risk, again specified for the various river reaches and computed by a set of rules based on the evaluation of present state and degree of damage. This ecological risk results from a reservoir built in the headwaters of the river system (Fig. 3). From this diagram it can be seen that the ecological risk is rather high in the headwaters of the river system, which is caused by the construction of the dam and its impact on the total ecosystem.
Integrated water resources management

(a) Present state

- **water physics**
- **water chemistry**
- **discharge**
- **morphology**
- **environmental factor “water/stream”**

evaluation of water physics, chemistry and discharge:

- natural
- slightly affected
- strongly affected

evaluation of morphology:

- natural
- almost natural
- slightly damaged
- moderately damaged
- clearly damaged
- strongly damaged
- extremely damaged

aggregated evaluation:

- V
- IV
- III
- II
- I

(b) Degree of damage caused by a dam project

- **water physics**
- **water chemistry**
- **discharge**
- **morphology**
- **environmental factor “water/stream”**

modification intensity of main parameters:

- strongly damaged
- moderately damaged
- slightly damaged
- unchanged

- slightly improved
- moderately improved
- strongly improved

degree of damage:

- V
- IV
- III
- II
- I

Fig. 2 Aggregation of main parameters for the ecological evaluation, Neger River system, Germany (environmental factor “water/stream”).
This result is valid only for the environmental factor “water/stream”. The same procedure has to be repeated for all the other environmental factors (e.g. soil, plants, animals) and then an evaluation for the total ecological risk can be carried out, again following certain rules. As far as the ecological risk for the factor “water/stream” is concerned, it can be seen that the dam in the headwaters is highly negative in its ecological impact. An alternative, a dam further down the river would cause much less significant ecological risk due to the lower values of the present state conditions there and a lower degree of damage. Thus the technique described here is not only valuable for determining the ecological risk of a structure, but it is also extremely helpful for comparing the ecological risks of various project alternatives. Thus it becomes possible to select (among various potential project alternatives) the one that causes least ecological risk.

**REQUIREMENT “SUSTAINABLE DEVELOPMENT”**

The principle of sustainable development (WCED, 1987; UNCED, 1993) requires that we have to make decisions today such that our grand-grandchildren could agree to them, if they could participate in the decision process. Since we do not know future developments, we have to make long-term forecasts of such potential development. The uncertainty is taken care of by the fact that we do not make only one forecast, but rather an ensemble forecast for each relevant parameter. The information generated in this way has to be aggregated in order to serve as decision support.
A planning tool for the design of a regional water supply system (Hornbogen & Schultz, 1998) is discussed next. The two main design parameters for a water supply system are: (a) future water supply; and (b) future water demand. In conventional designs usually only a long-term forecast for the parameter water demand is made, normally just by extrapolating the historical trend. This procedure now seems inadequate, since it is known that there are many driving forces influencing both main design parameters. Such driving forces include on the water supply side: economic restrictions, ecological restrictions, sources of non-point and point pollution, land use changes, climate change, etc. On the water demand side such driving forces are population growth, industrial development, quality of life, substitution of drinking water, saving of water, climate change, etc.

For each of these driving forces a long-term ensemble forecast has to be made as a basis for decisions. As can be seen in Fig. 4, the range of possible outcomes of those forecasts is subdivided into ranges of high, medium and low possibility of occurrence. It would be preferable to have probability distribution functions in order to allow computations with well-known stochastic techniques. Unfortunately it is, however, impossible to allocate to the outcomes for the ensemble forecasts probabilities of occurrence. As a substitute the “possibilities” were chosen. Analogous to probability theory there is possibility theory, which belongs in the field of fuzzy set theory (Dubois & Prade, 1988). Possibility theory provides specific computational rules that allow aggregation and other manipulations of possibility functions. The specification of the possibility levels (high, medium, low) is, of course, subjective and has to be done by expert groups.

![Water Supply:](image)

![Water Demand:](image)

Fig. 4 Scenarios of the effect of relevant driving forces on the long-term development of the two main design parameters "water supply" and "water demand", showing different levels of possibility of occurrence.

A project area in northwest Germany was chosen, in which a water supply company is active. Here significant changes in the near and more distant future can be expected. Based on data provided from the project area, the relevant driving forces for water supply and water demand were specified and a large number of ensemble forecasts for a period of 40 years was generated (Figs 5 and 6). Figure 5 shows for
Various driving forces of the main design parameter (water supply) the possibility range and its specification (high, medium, low). At the bottom of the figure the aggregated possibility function, derived after application of the methods of possibility theory, is shown. The same procedure was applied to produce the possibility functions for the relevant driving forces of the second design parameter, water demand (Fig. 6). The selection of a specific project out of various design alternatives can now be based on the information presented in Figs 5 and 6. The decision problem can be made more transparent if the diagrams at the bottom of Figs 5 and 6 are aggregated into a two-dimensional possibility distribution function.

The technique described allows consideration of measures which could be taken against unfavourable developments (e.g. saving water, protection and rehabilitation of catchment areas, improvement of water treatment technology, substitution of drinking water, the use of efficient facilities (e.g. low flush toilets, low flow shower heads,
efficient washing and dish washing machines, drip irrigation). If such measures are considered, they lead to the generation of different (more favourable) possibility functions. These functions provide information on the efficiency of various potential measures which could be taken, thus leading to the decision in favour of implementation of the most efficient (highest effects, lowest costs) measures. The technique described is very general and can also be used for decisions on other water projects besides water supply systems, perhaps in a slightly modified form.

CONCLUSIONS

The European Directive requirements are very progressive, but hampered by the fact that they cannot yet be met due to the lack of adequate planning tools, which are still to be developed. The development of scientific techniques for the evaluation of the environmental impact of water projects is still in progress. An example of a new development in this field, i.e. the comparison of the ecological risks due to various alternatives of a potential water reservoir project has been presented. Also, there are not many techniques and tools available for the implementation of the sustainable development principle in water management planning. Here too, new methods are still under development. As an example, a technique for planning a water supply system was presented applying the principle of sustainable development. In order to solve the dilemma which is caused by the situation that modern requirements in planning and operation of water management systems have been formulated and exist already (at least partially) in the form of relevant legislation, and the failure of existing planning tools to meet these requirements, has to be recognized as an urgent issue in modern water management.

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REFERENCES


