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Towards an ecological assessment of watercourses

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Abstract. Due to a fast decline in the ecological quality of watercourses combined with the threat of human functions, policy makers started to legislate water quality objectives for watercourses and to set up water purification programs. The description of universal quality objectives is too limited as a frame of reference and a policy only based on water quality cannot guarantee the goals of river restoration as a whole. In most countries the need for a more integrated approach of water management is growing. Water quantity must be managed together with water quality, surface water with groundwater, and the water economy with town and country planning.

To restore and maintain the natural diversity of watercourses, together with the natural species richness, policy makers need a frame of reference based on the natural functioning of the ecosystem. The highest level of reference is called the 'ecological naturalness'. Based on the present and the potential ecological value and on the intensity of human uses, policy makers together with a group of scientists should decide on the ecological quality objectives of watercourses. The lowest quality level that must be reached in all watercourses can be described as the 'ecological basic quality'. Together with a frame of reference, there is a need for a refined ecological evaluation method for ecological quality as a whole, and especially to evaluate 'potential ecological values' in an objective way.

1. Introduction

Watercourses are often considered as the veins of the landscape. They collect the water of a whole catchment area. The running water is closely related to the groundwater. A watercourse is an open ecosystem. Water is the medium along which nutrients and organisms can move. Consequently, these ecosystems are very vulnerable to abuse. Interventions in infiltration zones (sometimes far away from the course) can strongly influence the natural qualitative and quantitative characteristics of the flow. Interventions upstream can influence the ecosystem far downstream. Large areas of the river basins fulfil many human functions including transport of goods, production of drinking water, recreation, discharge of effluents, etc. Watercourses with clean water and natural stream characteristics became very rare, especially in a densely populated area such as Flanders. It is absolutely imperative to preserve these for the future and protect them against possible interventions. Concurrently, an attempt should be made at restoring as much as possible of the lost natural values (Bervoets & Schneiders, 1989). For this purpose, the policymakers need a solid and concrete frame of reference, which defines the quality objectives for each watercourse.

2. Quality objectives

2.1. *Man-oriented quality objectives*

With the increasing pollution, concern for the quality of surface waters has grown, especially because the various functional uses are threatened. Through the last decades several measures have been taken to fight pollution. In most European countries the legislation concerning water quality standards is based on the European directives. The European Community Policy operates on a two-pronged approach, the first consists of contesting the discharge of dangerous substances into the aquatic environment, the other of defining certain quality standards according to the proposed use (Johnson & Corcelle, 1989). The following functional uses are distinguished:

- drinking water;
- bathing water;
- water for freshwater fish: Salmonids and Cyprinids;
- water for shellfish.

The Member States themselves have to specify the areas in which the quality objectives must be respected. Also in the United States of America (USA) water quality standards are elaborated covering intrastate and interstate waters (Karr, 1991).

In Belgium the directives are enlarged by the description of a minimum required quality level for surface waters ('basic' water quality standards) (Royal Decree of 4 November 1987). All the norms should be reached in all watercourses by 1995. In the Netherlands a global environmental quality for surface water is described which should be met in all watercourses by the year 2000 (Anon., 1989).

The current legislation in most European countries offers a concrete description with which the water quality of most watercourses has to comply within the next decades. This frame of reference is a very valuable instrument, but it is based too much on the human functional uses and not enough on the intrinsic value of the aquatic environment. For example, certain acid upstream rivers, some canals and some chalk rivers have to meet the same universal standards of freshwater for Cypriniformes, when by nature these watercourses contain different biocoenosis, making other demands on their environment. On the other hand, a number of very valuable spring streams with rare fish species only need to meet basic quality, while this standardization does not guarantee the preservation of such relict populations.

The description of universal water quality objectives is too limited to be used as a frame of reference and the functions of the surface waters do not sufficiently consider their current or potential ecological value.

In Belgium, the General Water Treatment Program for the Flemish Region (AWP) discussed the quality objectives for the first time in general terms during the eighties: ' . . . the ultimate goal of the water treatment policy is the restoration of the watercourses to their original natural state'. This policy should be aimed at pushing back the extent of the causes of pollution to the level at which the self-cleaning capacity of the watercourses is completely restored. In the USA a general description of river restoration is formulated within the amendments of the Water Pollution Control Act (WPCA): ' . . . restore and maintain the physical, chemical and biological integrity of the Nation's waters' (Karr, 1991).

A policy which is only based on water quality cannot guarantee these goals of river restoration as a whole. Different countries started to realize that integrated water management must form the platform of their water management, underlining the coherence between quantity and quality management, between surface water and groundwater management, between water management and town and country planning. They set up a committee assembling all the authorities responsible for a certain river basin together with a staff of scientists to work out a program for the next few years.

In the United Kingdom the Water Authorities have adopted a policy of integrated water management. They are responsible for pollution control, purification, and production of drinking water, flood control, sewerage, the fishery, and water recreation. Recently the Water Authorities are in a centralized National River Authority with ten regional groups. The integration will be further strengthened in the future due to the elaboration of 'Catchment plans' which include town and country planning in the program (Gardiner, 1989).

In the Netherlands the governmental objectives concerning the water economy is summarized in the 'Nota Waterhuishouding', revised every five years. The note is connected to an indicative program (Indicatief meerjarenprogramma) with a coherent and integrated water management. Together with security and habitability ' . . . the development and maintenance of healthy water economy systems which guarantee sustainable development' is the central objective of the note (Anon., 1989).

In France, a local river contract (contract de rivière) is set up for each of the catchment areas. All the instances responsible for a certain area or a functional use together work out a five year program covering water purification, water engineering, agricultural activities, recreation, and nature conservation. These practical programs must lead to an integrated management for the catchment area. The Flemish government followed this idea recently by elaborating ten river basin committees. The main objective is to develop healthy water economy systems which guarantee sustainable development. This objective is comparable with the program of the Netherlands and is derived from the Brundtland report (Anon., 1987). The government stresses an integrated water management on a broad basis. Water quality should be combined not only with water quantity management but also with environmental and nature policy and with town and country planning (Anon., 1991). The first results of this broad cooperation is still awaited. Also, in the objectives of the Water Quality Acts of the USA, the emphasis from technology-based controls with simple chemical water quality standards changed to a protection of specific waterbodies (Karr, 1991).

2.2. *Ecological quality objectives*

If the ultimate goal is '. . . to restore the watercourse to the original state' or '. . . to restore and maintain the physical, chemical and biological integrity of waters' as mentioned before, the policymakers need a frame of reference describing the natural diversity of watercourses combined with their ecological requirements. The frame of reference is the natural functioning of the ecosystem. The highest reference level is called the 'ecological naturalness'.

Ecological naturalness of watercourses is reached when the biocoenosis occurring there by nature and belonging to the physical-geographical situation can survive permanently.

This frame of reference includes, apart from the physico-chemical characteristics of the surface waters, a description of the structural features, flow rate, width, depth, substrate, sediment transportation, riverbank vegetation, and the biocoenosis occurring in it. It must describe as many aspects as possible of the ecosystem and as concretely as possible. The fact that the 'physical-geographical situation' was included in the definition, implies that it is not enough to refer to spontaneous settlement, continuation and expansion of species in a suitable environment. Also, the features from the physical environment should be determined mainly by natural processes. Ecological naturalness can be found, for example, in a meandering watercourse with waterlevel fluctuations which depend upon the net precipitation and the (unaffected) water storage capacity of its river basin, and with a quality determined by the sediments and the position in the river basin (Gielis, 1987). Situations in which ecological naturalness is reached or can be reached are so rare that such streams, stream valleys or ecosystems should be protected as a whole against all kinds of human interventions.

The description of ecological naturalness corresponds well with the definition of 'Biological Integrity', a widely quoted definition in the USA: Biological Integrity is the ability to support and maintain 'a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region' (Karr 1991). The term 'ecological' naturalness emphasizes more the importance of the natural environmental conditions and not solely of the biotic components.

When restoring a polluted watercourse and thus obtaining an unpolluted state, the ecological naturalness will rarely by obtained. This highest level of reference can no longer be reached because of the intensity of the various functional uses of man in and around the stream. Only a certain level of 'biological naturalness' can be obtained.

Biological naturalness is the spontaneous settlement or success of autochthonous organisms, irrespective of the naturalness of the environment.

Biological naturalness, in contrast to the ecological naturalness, is not a real target. It does not constitute a frame of reference. Each level between dead water and ecological naturalness allows for spontaneous settlement and succession of autochthonous organisms. One can strive for the highest possible level of biological naturalness, i.e. a level coming closest to the (original) ecological naturalness. River regulation and pollution of surface waters lower the level of biological naturalness, so that most watercourses are getting farther and farther away from the level of ecological naturalness (Fig. 1).

One can roughly say that an increase in human interventions involves a decrease in habitat diversity, which causes alterations in biocoenosis (Bruylants *et al.*, 1989; Lewis & Williams, 1984) and a sharp decline of the biological potentials of the stream ecosystem. The uniformity of the profile will lead to a uniform rate of flow, a uniform sediment, and the absence of shelters. This decrease in abiotic variation involves a decrease in diversity of species. In natural circumstances this variation is brought about by the meandering capacity of the watercourse combined with a pool-riffle pattern and with the presence of natural shelters (cavities in the bank). This also guarantees a diversity in rate of flow and substrate. Pools are deeper, contain a finer sediment, and the water flows sluggishly compared to the riffles. In a watercourse where these natural circumstances are no longer present, one can raise the level of biological naturalness with a policy of conservation. Habitat adaptations in a straightened stream (Lewis & Williams, 1984; Logemann & Schoorl, 1988) can enhance the structural diversity, at the same time increasing the biological potentials resulting in distinct increases in numbers of species and biomass. A higher level of biological naturalness is reached, approximating more the ecological naturalness.

To come to integrated water management the frame of reference should be extrapolated to the groundwater system. The highest level of reference is again the 'ecological naturalness'.

Ecological naturalness of a groundwater system is reached in a catchment area where 'the amount of precipitation infiltrating to deep

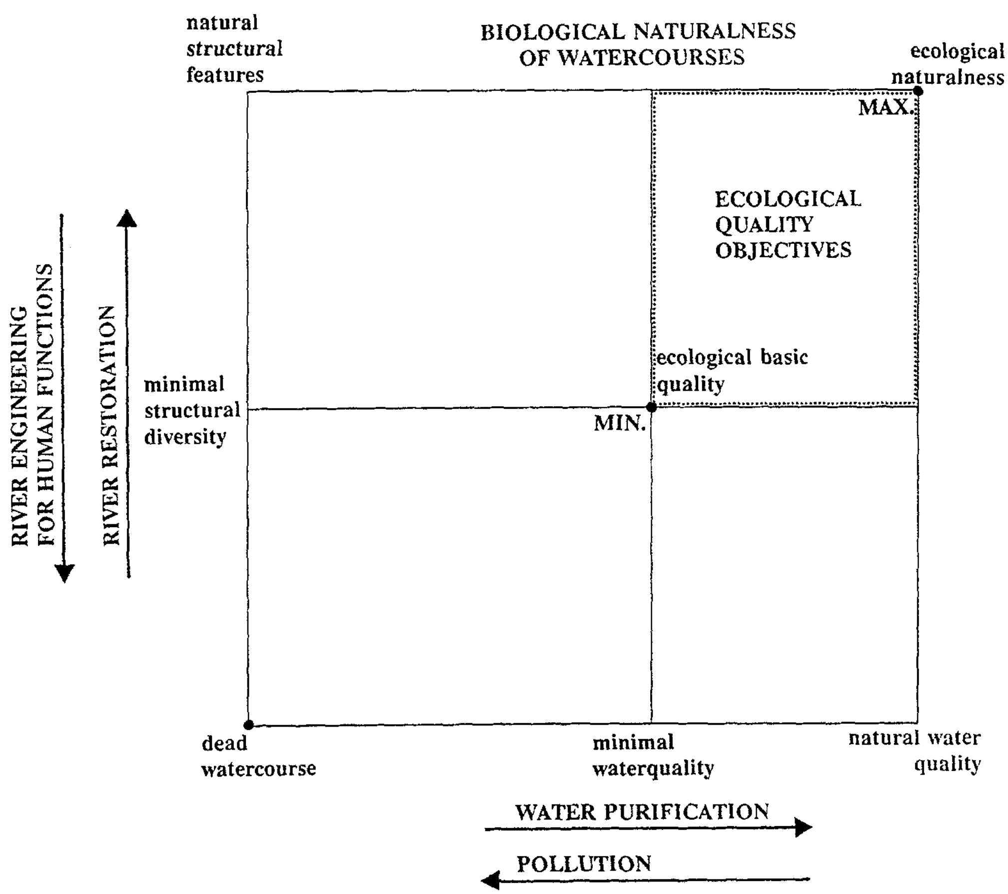

Fig. 1. Schematic representation of different levels of 'biological naturalness' in a watercourse.

and shallow groundwater layers and flowing to a natural discharge area, is determined by the amount of net precipitation and by the natural infiltration and water storage capacities of the soil' (Verhaert *et al., 1990*).

The natural biotic communities in infiltration areas depend largely upon a downward water and nutrient movement, and in a discharge area upon an upward water and nutrient movement. Sites where the ecological naturalness of groundwater systems is reached became very rare due to intensive human uses, lowering the penetrability for precipitation and enlarging the fast runoff. Protection and restoration of these areas should be stressed in the water management program.

When preserving and developing the natural potentials, one should consider the socially desirable functional uses (Ter Brink & Hosper, 1989). Depending on the selection of the social functional uses a certain level of biological naturalness can still be strived for. This level is usually reached by a combination of water treatment, conservation, and river restoration.

Many watercourses are intensively used for industrial purposes, as means of transport of goods, for discharge of wastewater from urban environments, whether treated or not, etc. They will never reach a high level of biological naturalness. Floodgate systems, bank fortification, artificial substrate, the flow of effluents, etc. will always remain. For these watercourses it is important for the policymakers to present, apart from a description of ecological naturalness, a description of the ecological basic quality, in which the minimum attainable standards of quality are set (Fig. 1).

Ecological basic quality is the quality in which, on the one hand, organisms that demand little of their environment survive permanently and in which, on the other hand, the migration of rare species is not hindered (Schneiders *et al.*, 1990).

These quality objectives are an extension of the minimal water quality objectives as formulated by Belgium and the Netherlands. The first part of the definition implies that, apart from the physico-chemical characteristics of the water, a minimal physical structure also is needed for organisms to be able to complete their life cycle. Table 1 presents a number of fish species that are not so demanding of their environment, respectively in the upper, middle, and lower courses. These fish species should always be able to survive if the ecological basic quality is attained. The second part of the definition implies that there are no

Table 1. Survey of the vulnerable and less vulnerable fish species which can be found in the different sections of the river basin. The less vulnerable must have the possibility to survive permanently in watercourses reaching the basic ecological quality.

	Upper course	Middle course	Lower course
Less vulnerable fish species:			
Three-spined stickleback *(Gasterosteus aculeatus)*	+++	+++	+++
Nine-spined stickleback *(Pungitius pungitius)*	+	++	++
Stone loach *(Noemacheilus barbatulus)*	+++	+++	+
Gudgeon *(Gobio gobio)*	+	++	+++
Perch *(Perca fluviatilis)*	*	++	++
Roach *(Rutilus rutilus)*	*	++	++
Rudd *(Scardinius erythrophtalmus)*	*	++	+++
Pike *(Esox lucius)*	*	++	++
Common bream *(Abramis brama)*		+	+++
White bream *(Blicca bjoerkna)*		+	+++
Tench *(Tinca tinca)*		+	+++
Bleak *(Alburnus alburnus)*		+	++
Common carp *(Cyprinus carpio)*		+	+
Vulnerable fish species:			
Dace *(Leuciscus leuciscus)*	+	++	+
Brown trout *(Salmo trutta fario)*$^{\$}$	++	+	+
Grayling *(Thymallus thymallus)*$^{\$}$	+++	+	+
Bullhead *(Cottus gobio)*	+++	++	+
Brook lamprey *(Lampetra planeri)*	++	++	+
Spined loach *(Cobitis taenia)*	++	++	+
Chub *(Leuciscus cephalus)*	+	+	+
Barbel *(Barbus barbus)*	+	+	+
Lampern *(Lampetra fluviatilis)*		+	++
Bitterling *(Rhodeus sericeus)*		+	++
Weatherfish *(Misgurnus fossilis)*			++

+ Rare, ++ frequent, +++ highly represented.
* Presence or absence is dependent on depth.
$^{\$}$ Only with a stream gradient > 3%.

barriers, such as dams, divers, pipes through which the stream is routed, etc., which prevent migration of rare fish species.

2.3. *Evaluation of ecological quality of watercourses*

To determine the current ecological value of a watercourse, a global evaluation method is needed. The current evaluation methods are mostly limited to the determination of the water quality. Two large types of quality analysis can be distinguished:

- physico-chemical analysis of the water and the sediment,
- biological water quality assessment.

Both are complementary.

The physico-chemical analyses determine the kind of pollution at a specific moment. Short periods of high pollution are often not detected. The variables that should be analyzed are described in a standard reference list of the European Community.

To study the response of the aquatic community to pollution, different groups of organisms can be used: macroinvertebrates, fish populations, macrophytic vegetations, micro-organisms, plankton, etc. They often give supplementary information of the water ecotope.

For the biological water quality assessment a preference for using macroinvertebrates has emerged for the following reasons (Metcalfe, 1989):

- macroinvertebrates are differentially sensitive to pollutants of various types and react to them quickly;
- they are easy to collect and their identification is not so difficult as for micro-organisms and plankton.

Macroinvertebrates are relatively sedentary and they are representative for the local conditions. When applying small adaptations for specific local circumstances, this method can be used in a very broad range of watercourses. Even in very small upstream lowland rivers, in canals or in very broad river systems. The adult stage in the life cycle of some macroinvertebrates takes place out of the water on specific habitats. The species richness could be partly dependent on the surrounding land use. A lot of European countries worked out a biological index for water quality assessment in running waters (Metcalfe, 1989):

- Belgium uses the Belgian Biotic Index. This method is widely used in Belgian river systems. At this moment a program is running, using this method in all the river basins of Flanders, up to the very upstream reaches (Bervoets & Schneiders, 1989). The method is even incorporated in the standard list of 'basic water quality'.
- France uses the 'Indice Biologique Global'.
- The United Kingdom uses the modified Biological Monitoring Working Party score (BMWP-score).

All these indices are extrapolations of the 'Trent Biotic Index'. The USA worked out the Invertebrate Community Index (ICI), based on the framework of the fish IBI (Karr, 1991).

Fish communities belong to the typical inhabitants of the river. They can also be used as indicators of ecological quality of rivers. Most species migrate a lot through the river corridor and reflect the ecological quality over a longer distance. The evaluation methods are mostly based on the presence or absence of rare species and healthy populations. An index often used in the USA is 'the index of Biological Integrity' of fish communities based on species richness and composition, trophic composition, fish abundance and composition (Karr, 1991).

A global water quality assessment method for macrophytes in and along the watercourses is not available. The method of De Lange en Van Zon (De Lange & De Ruiter, 1977) is worked out for standing waters and is not usable in river systems (Verhaert, 1980). Nevertheless, an extended knowledge is available, describing the relations between individual plant species and a broad set of abiotic components as physico-chemical water characteristics, stream velocity, width, depth, sediment, etc. (De Lyon & Roelofs, 1986; Haslam, 1978, 1987; Holmes, 1983; Van Katwijk & Roelofs, 1988). Based on this knowledge macrophytes can be ranked in a tolerance range for water pollution (Haslam, 1987; Schneiders & Wils, 1991). Most of the common macrophytes are less sensitive to organic pollution and to the lack of oxygen than macroinvertebrates or fish populations. In heavily (organic) polluted river basins often without fish and with a very low diversity of macroinvertebrates it is still possible to distinguish different levels of pollution using the macrophytes (Schneiders & Wils, 1991). Within this heavily polluted waters there is still a gradient from species-rich vegetations over a dominance of macrophytes indicating pollution (e.g. *Potamogeton pectinatus*) to a dominance of green algae and sewage fungi. In very dirty (and often very turbid) waters a complete absence of waterplants is possible. A disadvantage of using macrophytes is their sensitivity to shading. The evaluation method can for example not be used in a woody environment.

Evaluation methods based on macroinvertebrates, fish populations, or macrophytes are often complementary. Together they give a better picture of river conditions than either does separately (Haslam, 1987).

An ecological evaluation of the river corridor must go further than a water quality assessment. Some indices already give a more global ecological evaluation (e.g. the fish-IBI), but most of the evaluation methods need further adaptations to define the level of naturalness of the ecosystem as a whole. In Germany a group of scientists worked out a detailed ecological evaluation method resulting in a broad description of the river ecosystem (Ant *et al.*, 1985). In the Netherlands, the University of Wageningen works out a global ecological evaluation method based on macroinvertebrates (Peeters & Gardeniers, 1992). Nevertheless, even when a refined biological method is developed, bad water quality will always reflect a low ecological value, whatever the potential value of the river system may be. Together with the 'present' ecological value, it is interesting to evaluate also the 'potential' ecological value. A meandering watercourse with natural water quantity characteristics but heavily polluted water should be protected and should get priority in the water purification program. Certainly in a densely populated area as Flanders, having large areas of polluted river basins, it is important for the policy makers to make a distinction between high and low potentional values of river basins. From the viewpoint of nature conservation the level of potential ecological values forms a good base to indicate priority levels for water purification or river restoration for certain tributaries.

The evaluation method of the potential ecological value must be based on the abiotic parameters of the ecosystem. With reference to the river corridor itself the potential value is largely defined by the meandering capacity, combined with the development of a pool and riffle pattern and with the presence of natural shelters (cavities in the backs). These characteristics can easily be evaluated on the field (Table 2). Also the presence or absence of barriers for fish migration must be checked. The meandering capacity can be analysed over the whole length of the river by using aerial photographs and topographical maps. It is an easy method useful to compare large river basins in a short time (Bervoets & Schneiders, 1989). In Fig. 2 an example is worked out to compare the structural diversity of two river basins. Both are heavily polluted. It is clear that river basin A still has a better structural diversity and consequently a higher potential value than B. From the viewpoint of nature conservation river basin A deserves priority for water purification. Figure 3 represents a practical application of the theoretical Fig 1, showing different levels of biological naturalness correlated with different levels of priority for

Table 2. Structural evaluation of watercourse.

The characteristics meandering, pool and riffle pattern and presence of natural shelters (cavities in the bank) are scored on a –2 to +2 scale:

–2 :	When the characteristic is absent and cannot be regenerated due to structural changes
–1 :	when the characteristic is absent
0 :	when the characteristic is poorly developed
+1 :	when the characteristic is well developed
+2 :	when the characteristic is natural

The overally score for the global evaluation of structure on each lacation is calculated by adding the scores of the three characteristics:

Score	Evaluation	Colour code
+5 → +6	natural	blue
+3 → +4	good	green
0 → +2	moderate	yellow
–3 → –1	poor	orange
–6 → –4	very poor	red

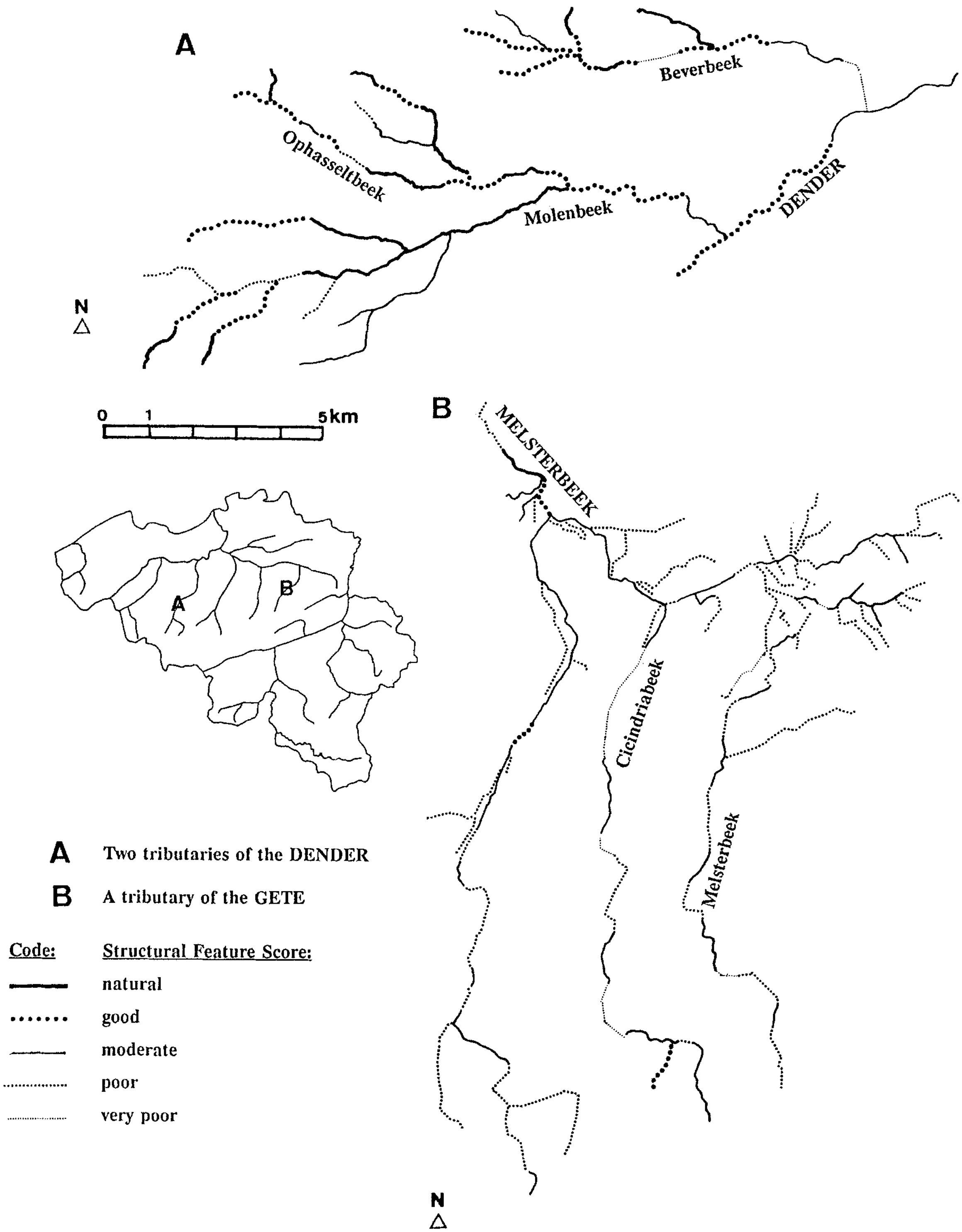

Fig. 2. Evaluation of the structural features in two polluted river basins in Flanders (Belgium).

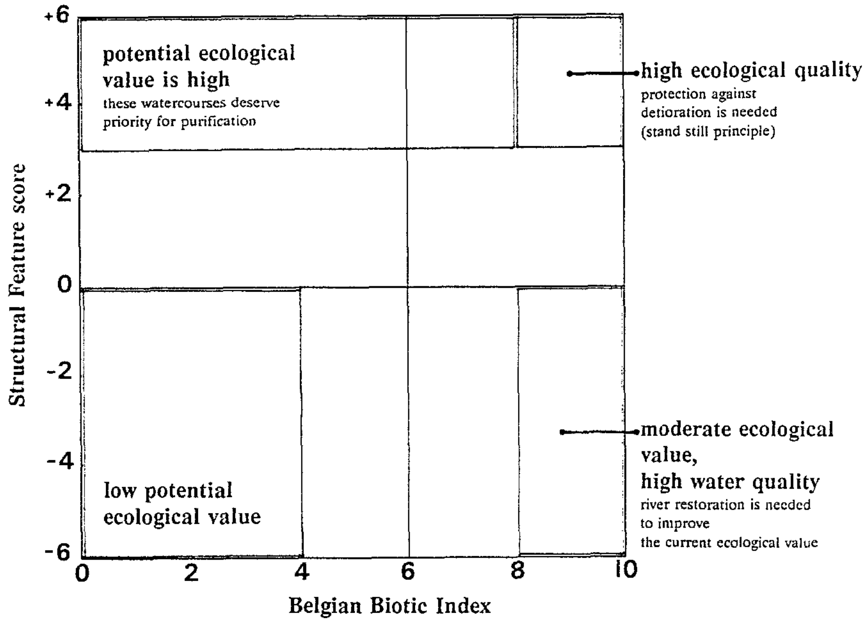

Fig. 3. Evaluation of 'biological naturalness' using the Belgian Biotic Index (BBI) and the Structural Feature Score (Table 2).

water purification and river restoration. In more detailed studies of river basins the method of evaluating the potential ecological value should be enlarged to other abiotic characteristics of the watercourse (substrate, stream velocity, etc.) and of the whole catchment area (ecological evaluation of the discharge areas along the river, the level of naturalness of the groundwater system, etc.). This methodology will be much more time consuming and often not workable to compare large riverbasins.

The general conclusion is that to fulfil the goals of integrated water management, policy makers need a frame of reference describing the natural diversity of watercourses together with their ecological requirements. To evaluate the ecological quality and to compare the quality of different catchment areas, the present ecological evaluation methods can and should be refined:

- abiotic evaluation methods to compare the present and the potential value of the watercourses should include more than water analysis and structural analysis of the watercourse;
- biological evaluation methods should go further than a water quality assessment. A practical method should be worked out to compare the ecological quality of different river basins as a whole.

There already exists an extensive ecological knowledge especially on the species level. Most of this knowledge is not translated in general evaluation methods applicable for the policy makers. The norms of the physco-chemical standard lists are often based on a poor scientific background as, for example, in ecotoxicological evaluation methods, where the validation of bioassays is often missing, leaving a gap between laboratory and field situations. It is time that scientists bridge these gaps between fundamental scientific information and the black box evaluation methods often used.

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