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# Water Ecotope Classification for integrated water management in the Netherlands

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## Abstract

The Water Ecotope Classification (WEC) has been developed as a tool for integrated water management in the Netherlands. The classification is based on abiotic processes, such as morphodynamics, hydrodynamics and land use, that determine the appearance of the water systems. Abiotic conditional factors were selected to represent these processes in the classification, due to their stability, measurability and manageability. For lakes, canals, rivers, transitional waters and coastal waters, system-specific classifications have been made, each resulting in 20-80 spatially defined, abiotic and biotic more or less homogeneous units. Each ecotope is described in terms of its position in the landscape, abiotic conditions and processes, ecological processes and dominant biotic groups. Ecotopes are mapped every eight years in the large water bodies on a scale of 1:10,000. Ecotopes are used in national policy analysis and regional studies to portray alternative spatial configurations, and they serve as input for hydrological and ecological models to analyse effects on water levels and habitat suitability. The success of ecotopes is due to the fact that they provide a common language for different disciplines, since the concept is used both by hydrologists and ecologists as well as by scientists and decision makers.

## Keywords

Ecotope, landscape ecological unit, classification, conditional factor, spatial planning

## Introduction

Space is scarce in the Netherlands, and human activities have changed the natural landscapes over the past centuries and will continue to do so in the future. These developments demand a sound spatial planning policy and the accurate scheduling of measures and particular functions. This is especially true for a small and intensively used country like the Netherlands, including its water systems. It has been recognised that raising the dikes will not guarantee an acceptable safety level in the near future, due to increasing river discharges and the rise in the sea level as a result of climatic change. Instead, our water systems need more space. Due to increasing urbanisation, more space is claimed for recreation and drinking water collection, while some space will continue to be necessary for shipping, agriculture, and fisheries. Apart from these functions, the ecological rehabilitation of the water systems is one of the policy goals. However, these various functions are not always easy to combine.

In order to balance all interests correctly, proper communication is required between the parties and disciplines involved in the spatial planning process. This communication includes the supply of information and tools that all relevant parties can use. To supply this information in an unambiguous way, so that it is understandable to everyone, the Water Ecotope Classification (WEC) has been developed. The concept of ecotopes originates from landscape ecology and was first introduced by Tansley [1]. Since then, most classifications have focused on terrestrial ecosystems. One of the first spatial typologies for wetlands was based on vegetation [2]. The WEC covers the most important spatial ecological units for the large Dutch water systems. The consequences of changes, whether due to natural processes or the intervention of water managers, can be displayed by means of ecotopes and ecotope maps may serve as input for spatial models and policymaking. This paper reviews the classification principles and the applicability of the WEC for water management.

## Ecotope definition

In the WEC, an ecotope is defined as ‘a physically limited ecological unit, whose composition and development are determined by abiotic, biotic and anthropogenic aspects together’ [3]. Ecotopes are more or less homogeneous units on the scale of the landscape, identifiable by their similarities and differences in geomorphological and hydrological characteristics, and characterised by a vegetation structure linked to the above-mentioned abiotic conditions in combination with land use (Figure 1). The definition of ecotopes is closely related to the definitions of eco-series and habitats [4]. However, ecotopes differ from ecological typologies which are predominantly derived from biological data-sets [5, 6].

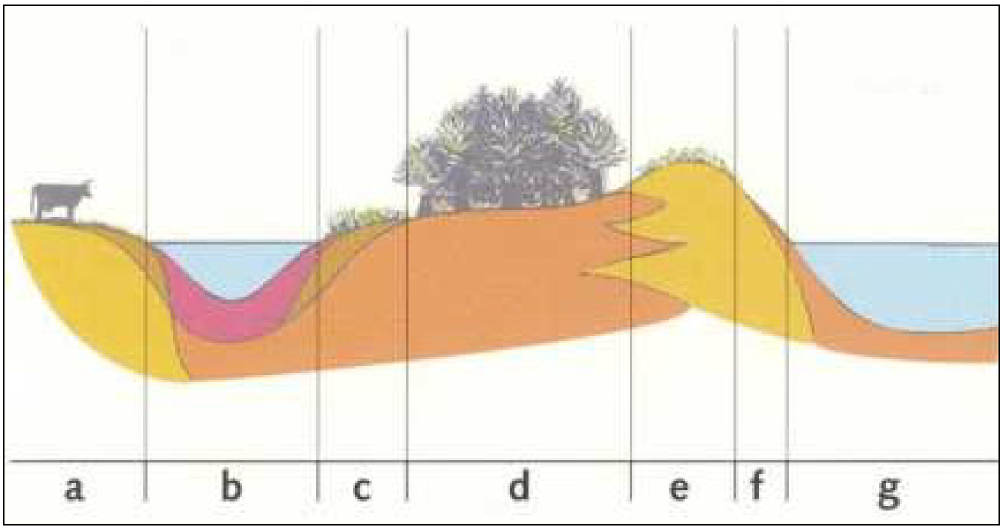


**Figure 1: Examples of ecotopes in a cross-section of a river. a = Floodplain production meadow, b = Connected floodplain channel, c = Herbaceous swamp, d = Floodplain softwood forest, e = Natural levee pasture, f = Sand bar, g = Deep riverbed. Details of the ecotopes are presented in Table 2.**

The following criteria (in random order) identify the field of application and have therefore been conditional for determining ecotopes in the WEC [3]:

- Ecotopes should be relatively easy to map, and the complete set of ecotopes should give an overall picture of the water systems.
- The total number of ecotopes should be limited to make classification and mapping feasible.
- The effects of policy making, landscape design and management should be registered in terms of changes in nature, surface area and/or location of ecotopes.
- Ecotopes should be meaningful to research, landscape design, and (water) management and should appeal to non-scientists and be recognisable in the spheres of politics, social affairs and management.
- Based on the above criteria, ecotopes should be spatially applicable at a scale varying from 1:10,000 to 1:25,000.
- Ecotopes should reflect current conditions, but should also be applicable for historical and future representations.

## Classification method

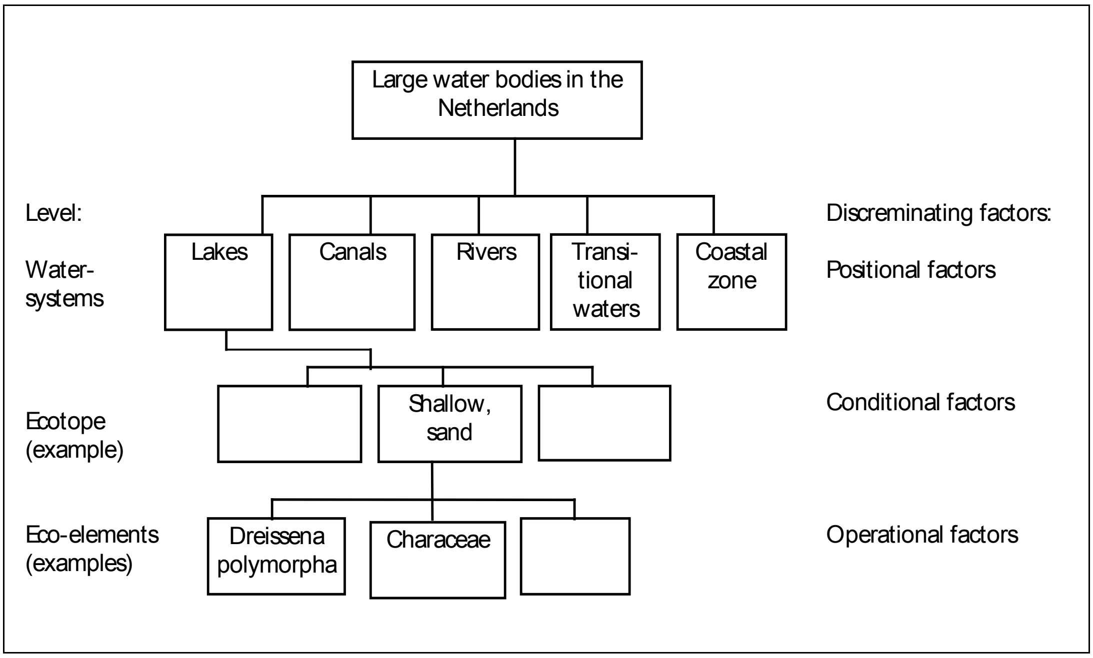


**Figure 2: Positional, conditional and operational factors, determining water systems, ecotopes and eco-elements respectively.**

The WEC has been worked out for the various types of large water systems in the Netherlands (Figure 2). The water systems are identified on the basis of positional factors related to large-scale processes. The water systems correspond with the categories in the EC Water Frame-work Directive [7], although canals have been added as a separate group. Each ecotope classification is based on conditional factors derived from the abiotic processes that determine the appearance of the water systems. The dominant processes are morphodynamics (mechanical forces exercised by water and sediment), hydrodynamics (physiological and chemical effects of water) and land use (effects of human intervention – that is, conscious landscaping and management). These processes determine operational factors such as moisture regime, nutrient availability and acidity. Operational factors directly affect the flora and fauna. However, conditional factors are more stable than operational factors and are related to natural processes that may be controlled by means of landscaping and management [4, 8]. Moreover, there is usually sufficient information available about these factors (measurements or model output) to portray ecotopes on a scale that meets the above-mentioned criteria. The conditional factors differ for the water systems (Table 1). The different classes for each conditional factor are linked to relevant ecological features in order to categorise different ecological units, e.g. the possible presence of a thermocline at a certain water depth in lakes or a sequence of flooding related to vegetation in river floodplains.

| Water system / Conditional factors | Lakes | Canals | Rivers | Transitional waters | Coastal zone |
|---|---|---|---|---|---|
| Morphodynamics | | | | | |
| - flow regime | - | anthropogenic (sluice control) | natural (river discharge) | natural (tidal movement, river discharge) | natural (tidal movement) |
| - wave regime | wind | navigation | navigation | navigation/ wind | wind / tidal regime |
| Hydrodynamics | | | | | |
| - water depth | + | + | + | + | + |
| - flooding (duration / frequency) | - | - | + | + | + |
| -(ground)water table | + | + | - | - | - |
| Land use | + | + | + | + | - |

**Table 1. Conditional factors for the elaboration of the Water Ecotope Classification for the different water systems**

Morphodynamics. Conditional factors derived from morphodynamics are flow and wave regime, which are generally joined together and worked out into three or four classes. High dynamics refer to a situation with little permanent settlement of species, dominance of species with a short life cycle and a high relocation of substrate, which is mostly sandy. Ecotopes characterised by high dynamics are mainly found in rivers and transitional and coastal waters. Intermediate dynamics usually result in the highest biomass and biodiversity of species. Sediments are in motion, but not too much; substrate may be diverse. Low dynamics are characterised by silt substrate dominated by worms in aquatic sediments and they allow development to climax stages of vegetated areas. Soil characteristics are mostly the result of morphodynamics. When the substrate cannot be explained through processes – as with man-made canals or when artificial hard materials are applied for safety reasons – soil type or substrate is sometimes used as an additional conditional factor for characterising ecotopes.

Hydrodynamics. Conditional factors have been reformulated in according with the steering process in the different water systems. In rivers and transitional waters, this involves the duration of flooding or drought, and in stagnant waters (ground) water depth is used to indicate (permanent) wet, soggy or more terrestrial conditions. The related biological groups range from plankton, benthic macroinvertebrates and fish in deep wet areas, aquatic macrophytes in the more shallow zones, a helophyte zonation in intermediate areas, to more terrestrial vegetation in the drier parts of the water system.

Land use. The absence of specific management, management from an environmental perspective, and management dictated by a production function or protection against flooding are used as conditional factors. The absence of specific management is not the same as ‘natural’, because external conditions generally prohibit the natural state of an ecotope in the Netherlands. Water level management or the introduction of mowing or grazing to create more diverse vegetation or to maintain a specific succession stage may exemplify management from an environmental perspective. If production or another non-ecological function is a dominant target for a specific area, land use dynamics are characterised as multi-functional.

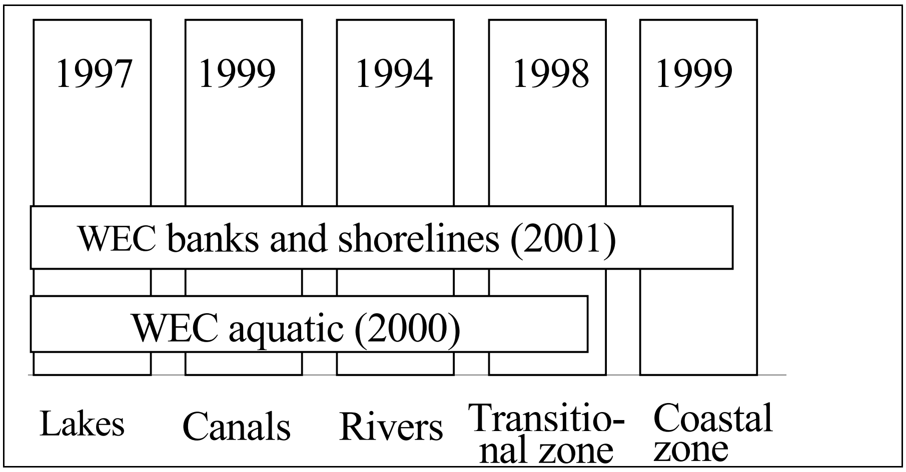


**Figure 3: Ecotope classifications have been set up for lakes, large canals, rivers, transitional and coastal waters and furthermore for the permanent aquatic areas and banks and shorelines; numbers refer to years of publication.**

As stated earlier, conditional factors that reflect the determining processes have been applied to each of the large Dutch water systems: lakes, canals, rivers, transitional waters and coastal waters. Consequently, different but interrelated ecotope classifications have been developed for each type of water system and have been updated where necessary. Recently, classifications were updated for the aquatic parts and for the banks and shorelines (Figure 3). Each classification consists of about 20-80 ecotopes that are hierarchically arranged in a number of layers, starting with the dominant classification factor. Table 2 illustrates a number of ecotopes in rivers and their relationship with conditional factors. Each ecotope is described in terms of its position in the landscape, abiotic conditions and processes, dominant biotic groups and ecological processes. Two examples of ecotopes are:

- Natural levee river dune: develops in higher parts of the river banks in the case of high wind dynamics and specific management; sandy substrate, rich in minerals; flora characterised by a high species richness, including rare species, and an important area for specific amphibians
- Very deep stagnant water: stratifying water; primary production-dominated by phytoplankton, often dominated by cyanobacteria in summer; macro-invertebrates occur in low biodiversity and density (chironomids, tubificids, bivalves); pikeperch (*Stizostedion lucioperca*) and piscivorous water birds are top predators.

| Code | Ecotope (Conditional factors) | Morphodynamics<br>a very large dynamics<br>b large dynamics<br>c moderate dynamics<br>d small dynamics | Hydrodynamics<br>0 deep water (>1.5 m)<br>1 permanently flooded<br>2 shoreface<br>3 >100 d/y flooded<br>4 20-100 d/y flooded<br>5 <20 d/y flooded<br>6 never flooded | Land use<br>1 completely natural<br>2 natural<br>3 semi-natural<br>4 cultural |
|---|---|---|---|---|
| Zd | Deep riverbed | a, b | 0 | 1, 2, 4 |
| Zs-2 | Sand bar | b | 2 | 1, 2, 3 |
| Og-1 | Natural levee pasture | b | 5 | 1, 2, 3 |
| Ub-3 | Floodplain softwood forest | c | 3 | 1, 2, 3 |
| Mr-1 | Herbaceous swamp | c, d | 3, 4 | 1, 2, 3 |
| Ws-1 | Connected floodplain channel | c | 1, 2 | 1, 2, 3 |
| Ug-3 | Floodplain production meadow | c, d | 3, 4 | 2, 3 |

**Table 2. Group of ecotopes from the river ecotope classification and their relation with conditional factors. The ecotopes are illustrated in Figure 1.**

### Visualisation

As part of the national monitoring program for large freshwater bodies [9], surveys of ecotopes have been carried out that have resulted in area-covering ecotope maps [10]. The mapping is based on true colour aerial photographs on a scale of 1:10,000. By taking these photos with an overlap of 60%, it is possible to interpret them two by two, three-dimensionally, using a mirror stereoscope (Figure 4). In that way, differences in height of the surface and vegetation structures can easily be seen. Based on these vegetation structures, relief and other visible differences in land use such as built-up areas or agricultural land, operators can draw borders between different mapping units.

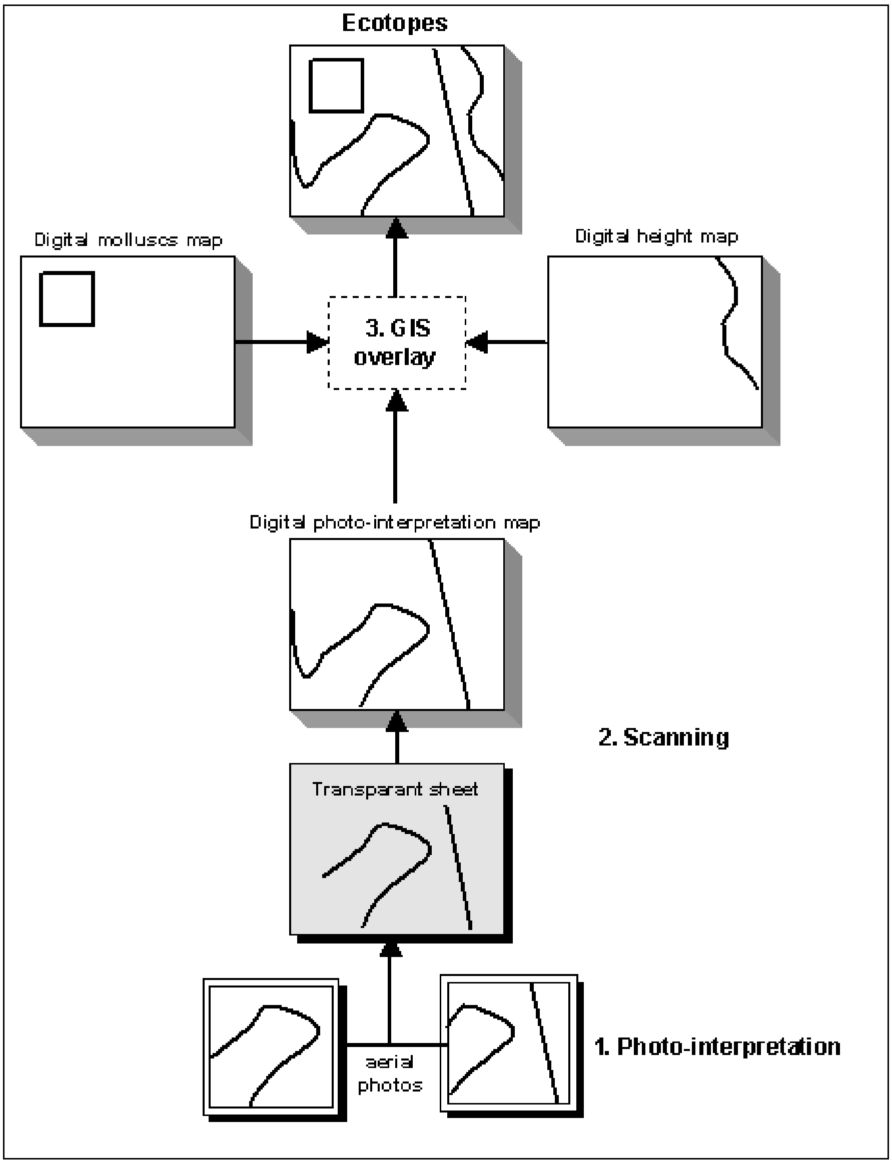


**Figure 4: Illustration of the mapping procedure (see text for explanation)**

Conditional factors such as water depth and flooding duration cannot be distinguished using just aerial photos. Therefore, supplementary data are used, such as river inundation maps and relief maps (digital terrain maps). The information in these supplementary maps is combined with ground truth data and the information from the photos in a Geographical Information System by means of an overlay operation. Results of the ecotope mapping may be at observed at www.ecotopenkaarten.nl. Surveys of ecotopes will be repeated every eight years to trace changes in the spatial arrangement in the large water systems.

**Practical applications in the Netherlands**

The WEC is not an aim in itself, but rather a tool that may be useful for integrated water management, particularly in relation to spatial planning. As landscape ecological units, ecotopes not only provide an area-covering insight into the physical variety within water systems, but also an insight into the operation of system-related processes. This information is important for all stages of the policy cycle: policymaking, landscaping and evaluation.

Policymaking. In the Dutch national water policy analysis, ecotopes were used to portray several alternative future landscape scenarios. For example, the effect of climate chance has been expressed in ecotopes [11]. The alternative spatial configurations of ecotopes may be transformed to habitats and subsequently assessed using selected key species to formulate the main outlines for future policies [12, 13]. Regional water boards use ecotopes to translate national policy into operational management goals. In addition, ecotopes may also be used for the bottom-up participation of public awareness in planning [14]. There are several Decision Support Systems integrating socio-economic, physical and ecological disciplines that need spatial data, such as ecotopes, for calibration and running [15, 16, 17].

Landscaping. Ecotopes serve as a tool in environmental impact assessments. In the landscaping plan of the Rijnwaardense flood plains, the Netherlands, planned ecotopes were projected on aerial photos in order to properly visualise the future situation. Within the framework of the Environmental Impact Report for Haringvliet, the Netherlands, it was illustrated where changes in the configuration of ecotopes would take place in this former estuary when tidal movement and salt concentration increased due to the reopening of the sluices. At present, the natural hydrological and ecological processes are blocked by these sluices, which have turned the estuary into a freshwater system. Not only the spatial arrangement but also species may be taken as a starting point. The habitat requirements of species can be translated to and expressed in ecotopes. In doing this, species requirements can be used in spatial planning and landscape ecological effect assessment [18, 19]. The 'Rhine-Econet' project consisted of an estimation of the viability of species populations based on different spatial configurations of ecotopes, varying from a few large nature reserves to many smaller ones connected by means of corridors [20, 21].

Policy evaluation. Ecotopes are used as a visualisation tool, as illustrated by the ecotope maps resulting from the Dutch national monitoring program. In this way, changes in the landscape can be traced and evaluated. Moreover, in addition to current biological monitoring, information about species and communities can now also be provided in a spatial context. For the main branch of the river Rhine, the effect of rehabilitation is determined using ecotope maps before and after the measures [22]. Ecotopes are also used to provide hydraulic models with a profile of the roughness of the landscape. Next, they are used to evaluate the interaction between landscaping and water levels in flood plains on a regional scale. In the project Landscape Planning of the River Rhine, the Netherlands, a comparison was made between two scenarios (with ecotope distributions concentrating on either nature or safety) – using models to calculate the effect on water levels – to weigh up the various interests, such as safety, navigation, mineral extraction and nature [23].

Previous examples illustrated the use of ecotopes as a visualisation tool, as a tool to extrapolate point data, and in combination with hydraulic and ecological mathematical models and decision support systems. For all applications, the classification presented in the WEC is the starting point. Depending on the aim and scale, clustering or further detailing of ecotopes may be considered. In practice, the units most frequently used are 1 ha or larger.

## General discussion

Abiotic conditional factors are the key to characterising ecotopes in the Water Ecotope Classification. This is because these factors represent processes that are both measurable and manageable. It is questionable whether the concept of abiotic conditional factors is applicable to areas other than (semi) aquatic environments and brackish habitats, because their dynamics and changeable nature is a prerequisite. In less dynamic environments, probably only operational factors are sufficiently distinctive. Because of the use of abiotic factors, one may argue that physiotopes should be used instead of ecotopes. The concept of the physiotope is used for the unit homogeneous with respect to the abiotic conditions important for biotic aspects. This also applies to ecotopes in the WEC, but the abiotic conditional factors have also been chosen because of their relevance to biotic aspects. Moreover, ecological processes distinguish classes of determinants. Defining spatial units is more important than naming them in an exact and uniform way [24].

With respect to spatial scale, the WEC differs from most approaches based on habitats or a vegetation typology [5, 6, 25, 26]. The scale related to these concepts addresses the location where an organism or a specific group of organisms lives and is generally more detailed. The habitat concept is also more ecologically based and internationally accepted. The link between routine monitoring of flora [9] and the WEC is problematic due to the fact that relatively many species were found in small-scale elements, such as ditches, for example. To fill the gap between scales used for ecotopes and ecological requirements of species, WEC also distinguishes eco-elements (Figure 2), either as a relevant spatial unit on a smaller scale or as a specific biotic form within an aquatic ecotope. A vegetation type or mussel banks may serve as examples. The exact location of these areas requires information about operational factors, such as light extinction, but even then the appearance of these biotic forms seems to be somewhat stochastic. The eco-elements in terrestrial areas and the biotic forms in aquatic environments are not fully incorporated in mapping, as they do not meet all of the criteria for ecotopes. It is essential that ecotopes from the WEC should be measurable and controllable, and they should therefore be applied on a certain scale. This can be national or regional, but not for areas of a few square kilometres. Ecotope designation must have relevance for operational policymaking. Ecotopes without this relevance – because they are too small or insignificant – should be grouped together into more significant ecotopes.

With respect to temporal scale, it is important to note that the WEC includes different succession stages. These range from bare substrate, shallow water with macrophytes or terrestrial areas with grasses to marshes, herbaceous areas and floodplain forests. A temporal succession to climax stages or rejuvenation to previous stages is not explicitly taken into account. In relation to this, the actual quality of an ecotope is also important. The biotic community of an ecotope may be well developed or suffer, for example, from disturbance or toxic elements in the substrate. Both the succession and quality of ecotopes are subjects for further study.

A reliable data set of the above-mentioned conditional factors is a prerequisite for a precise identification of ecotopes. Experience has shown that uncertainty in the outcomes of hydraulic or ecological models using (information derived from) ecotopes as input is largely caused by imprecision in the ecotopes. Therefore, very detailed mapping should be avoided, so that the accuracy of maps (presentations) and outcome of models (calculation) are in the same order of reliability. For future situations (scenario studies), additional knowledge about the abiotic-biotic interactions is required in order to perform reliable ecotope predictions. With respect to this, a better understanding and quantification of morphodynamics is particularly required.

The WEC is not completely fixed. Definitions of ecotopes change according to prevailing insights and preferences. Moreover, technical aids for monitoring and data processing will improve. Finally, the international context will become more important for water management, especially the EC Water Framework Directive [7]. This Directive is rather complete with respect to the relevant ecological and physical parameters that are included. However, there is a gap between abiotic processes that result in spatial patterns and habitat requirements of (groups of) species. The causal relationships between abiotic processes and the possible occurrence of the various biotic elements still need to be filled up. Ecotopes may be very useful to fulfil this gap. The representation of the relevant ecological quality elements on a spatial basis would facilitate the descriptions of both actual and reference status of water bodies by mapping them, thus also allowing assessment of scale effects. Finally, with the inclusion of causal relationships between abiotic processes and biotic phenomena into spatially recognisable units it becomes a lot easier to formulate and visualise potentially successful restoration measurements.

## Conclusions

The Water Ecotope Classification has been devised as a useful tool for incorporating spatial information in planning and decision-making. Based on the results of a broad variety of applications, it is fair to say that ecotopes do fulfil this need. The success of the use of ecotopes in integrated water management is largely based on two properties of ecotopes: they provide a "common language" for the mutual understanding of disparate disciplines, and they can be used as input for the different (disciplinary) models and other tools. The processes represented by ecotopes appeal to both hydrologists and ecologists. When ecotopes are used in spatial planning and plan evaluation, then physical and ecological aspects of policies, landscaping variants and more detailed designs can be specified and assessed in a consistent and quantitative manner. At the same time, the experiences so far have indicated where optimisation is needed. Further developments may be guided by the requirements of the EC Water Framework Directive, which lacks a proper spatial intermediate between abiotic processes represented by physical parameters and habitat requirements of species.

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References (in Dutch) to the classifications mentioned in Figure 3 can be found on www.riza.nl/ecotopen.