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Decision support for integrated wetland management☆

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Abstract

Wetlands perform functions that support the generation of ecologically, socially and economically important values. European legislation has increasingly recognised the importance of preserving wetland ecosystems. The Water Framework Directive (WFD) embodies many of the existing directives that have implications for wetlands. The EU funded EVALUWET project (European valuation and assessment tool supporting wetland ecosystem legislation) aims to develop and implement an operational wetland evaluation decision support system to support European policy objectives. A multidisciplinary approach is adopted combining expertise from natural and social scientists.

The region of Noord-Hollands Midden is selected as the Dutch case study within EVALUWET. This region north of Amsterdam is a typical Dutch landscape with drained peat meadows in polders below sea level. Important stakeholders are: agricultural organisations, recreation, nature conservation organisations, and provincial/regional authorities. Water levels are controlled in the area. Changes in water regimes are proposed (National Policies, WFD) which will have an impact on the performance of functions such as agriculture, nature and residential and recreation opportunities. In this case study, three alternatives will be compared: (1) modern peat pasture (current), (2) historical peat pasture and (3) dynamic mire.

Impacts of these alternatives on a number of criteria relevant to EU policy are assessed. Spatial evaluation techniques in combination with multicriteria methods are used to support evaluation. This provides a better insight into the consequences of alternative water regimes on the performance of the wetland functions and is used to support stakeholders participating in the decision process. The system is based on the following software components: impact assessment is performed by a rule-based knowledge base implemented in NetWeaver. Spatial evaluation and map presentation are handled in ArcView and ArcMap. Multicriteria analysis is performed using the software package DEFINITE.

Keywords: Wetland management; Impact assessment; GIS; Multicriteria analysis

1. Introduction

Wetland ecosystems, or "wetlands", currently receive much attention in environmental science and policy. The widely supported Ramsar definition is a good starting point for the delineation of wetland ecosystems: "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six metres" (http://www.ramsar.org). Interest in wetlands has two origins: first, wetlands provide many important goods and services to human societies, ranging from flood control and nutrient removal to fish products and recreational opportunities. Second, wetlands are sensitive ecosystems that are subject to stress from human activities. European legislation has increasingly recognised the importance of preserving wetland ecosystems. The Water Framework Directive (WFD)

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embodies many of the existing directives that have implications for wetlands (European Union, 2000).

EVALUWET (European valuation and assessment tools supporting wetland ecosystem legislation) is a research project supported by the European Commission under the Fifth Framework programme. It is a collaborative project involving 10 partner organisations in seven countries. Its aim is to improve the management of wetlands within Europe by facilitating their integration into river basin management as defined in the Water Framework Directive (WFD). Within the project a wetland evaluation decision support system is developed to support European policy objectives. A multidisciplinary approach is adopted combining expertise from natural and social scientists. The system is applied in nine European catchments.

The region of Noord-Hollands Midden is selected as the Dutch case study within EVALUWET. This region north of Amsterdam is a typical Dutch landscape with drained peat meadows in polders below sea level. Important stakeholders are: agricultural organisations, recreation, nature conservation organisations, and provincial/regional authorities. Water levels are controlled in the area. Changes in water regimes are proposed (National Policies, WFD) which will have an impact on the performance of functions such as agriculture, nature, residential and recreation opportunities. In this case, study alternatives are compared. Impacts of these alternatives on the various functions are assessed. Spatial evaluation techniques in combination with multicriteria methods are used to support comparison of alternatives. This will provide a better insight into the consequences of alternative water regimes on the performance of the wetland functions and will be used to support all stakeholders participating in the decision process.

The current system is based on four separate software components. Impact assessment is performed by a rule-based knowledge, which uses the NetWeaver logic engine for processing (Reynolds et al., 2003). Spatial evaluation and map presentation are handled in ArcView and ArcMap. Multicriteria analysis is performed using the software package DEFINITE (Janssen et al., 2002). At present these components are operated as separate programmes and linked by input–output routines. In the final stage of the projects all components will be integrated in the EMDSS environment (Reynolds et al., 2003). A detailed description of the software components can be found in Goosen et al. (2003).

This article is structured as follows: the management problem is introduced in Section 2. Section 3 describes the procedure used to assess performance of wetland functions. Map representation of the problem is introduced in Section 4 and performance maps are shown in Section 5. Finally, Section 6 shows how the information produced can be used in decision support for wetland management. Conclusions are presented in Section 7.

2. Management of a Dutch wetland

The region of Noord-Hollands Midden is an area of about 400 km^2 situated north of Amsterdam (Fig. 1). Large areas of this region are fen-meadows that consist of wet pasture lands with drained peat soils alternated by natural and artificial lakes, ditches, reed swamps and quaking fens. Many characteristic bird and plant species are present and ecosystem values are high in both a national and an international context. The current fen-meadows have originated from the drainage of a large peat system dating back from 1800 B.C. To keep the land suitable for agricultural use, the peat area has been drained deeper in recent decades. This drainage has resulted in a subsidence of the soil and as a result the polders with fen-meadows are now 1–2 m below sea level. In between the fen-meadows, deep polders with a clay soil are found. These deep polders used to be large lakes, which have been reclaimed in the 17th century for agricultural use. Presently, these polders are 2–6 m below sea level (Best and Bakker, 1993).

As in other parts of the country, water tables in Noord-Hollands Midden are controlled to facilitate agriculture, building of housing, infrastructure and other land-uses and to avoid damage and inconveniences caused by water. However, problems with water surpluses as well as water deficiencies have had large economical consequences in the area recently. Based on predictions from climate change scenarios, the problems in the area are expected to increase in the future (Commissie Waterbeheer 21ste eeuw, 2000).

The Wormer- and Jisperveld is selected as a representative fen-meadow area for the region (Fig. 2). The area of about 2500 ha consists of small lots of drained peat land within a network of ditches and shallow lakes. The area is mainly in agricultural use (low-intensity) and internationally important as a habitat for meadow birds. The outer belts of the area and land parcels connected to houses are private property and are in (more intensified) agricultural use. The fen-meadows of Wormer- and Jisperveld, with respect to their hydrology, can be considered as representative for the region. The same can be said for the major policy issues in the Wormer- and Jisperveld, although the emphasis may differ slightly in other parts of the region. Keeping in mind these small differences, the results from this initial study can be regarded representative for the whole region and used in decision-making problems in other fen-meadow areas. Policy makers are faced with complex decisions about future land-use in these fen-meadow areas. A process of discussion and negotiation with stakeholders and institutions in the area has already started. Different stakeholders, such as agricultural organisations, recreational organisations, nature conservation organisations and provincial/regional authorities, each have their own ideas about the future land-use. Three alternatives are

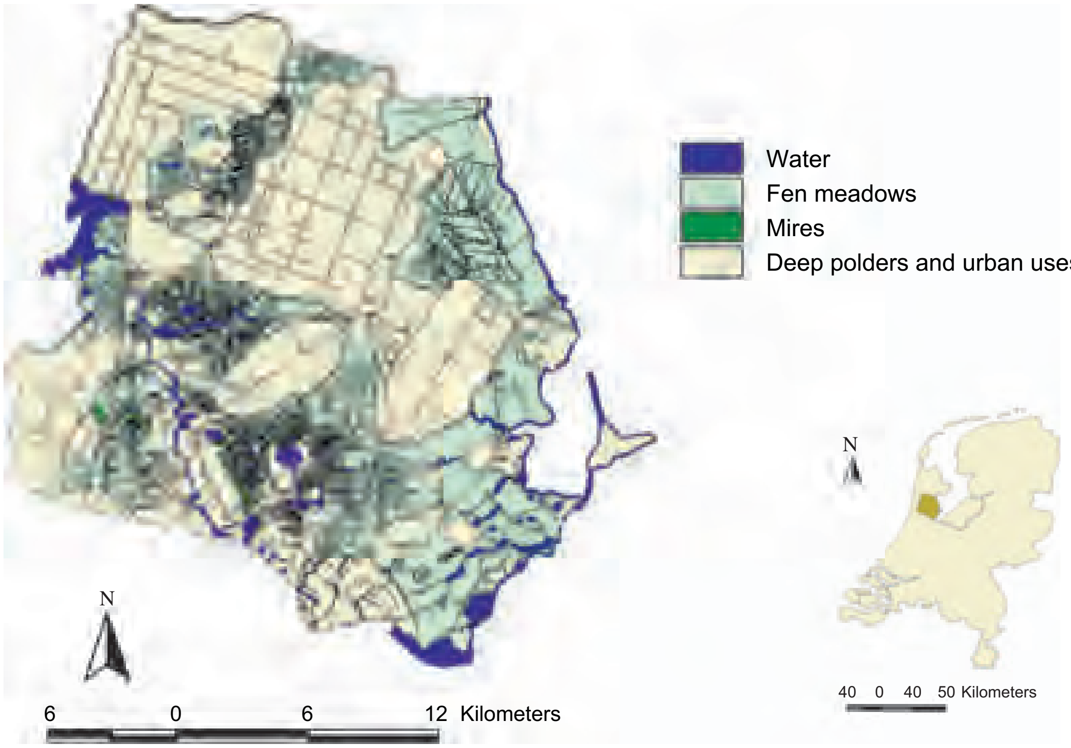

Fig. 1. Noord-Hollands Midden.

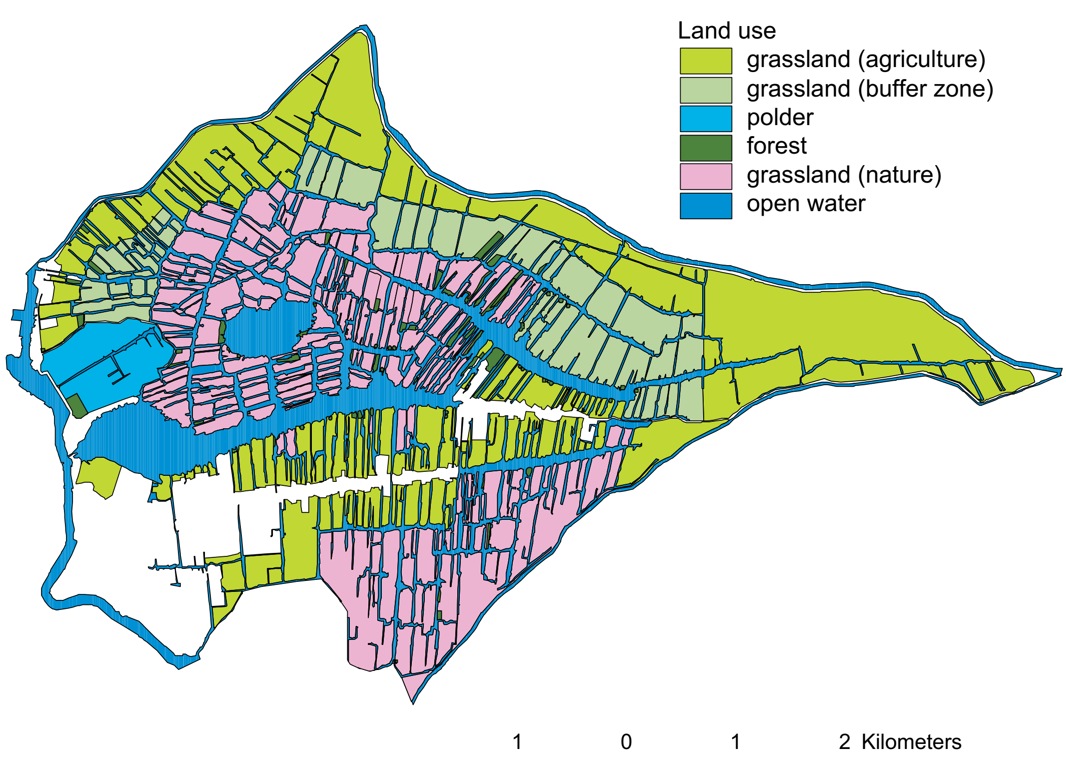

Fig. 2. Wormer- and Jisperveld.

identified for the Wormer- and Jisperveld (IWACO, 2000):

- Modern fen-meadow: this is the current situation with "counter-natural" water management. Water levels are higher in summer (40 cm below ground level) than in winter (70 cm below ground level). The area can be used for (extensive) agricultural practices and is suitable for meadow birds. However, because of the relatively low water levels year round, the peat will oxidise and the soil will subside.
- Historical fen-meadow: a more historical situation with management aimed at a more natural water level fluctuation: the groundwater level varies between 40 cm below soil surface in summer and 20 cm below soil surface in winter. Agriculture is still possible, however, less intensive than in the modern peat pasture scenario. The area is still suitable for meadow birds. Soil subsidence will still occur, but less rapidly than in the modern fen-meadow scenario.
- Dynamic mire: water levels will fluctuate between 40 cm above soil surface in winter and more or less at the soil surface in summer. The area is not suitable for agriculture any more and as a result the meadow birds will largely disappear. The area will consist of reed beds, carrs, quaking fens and open water. Nature values belonging to these habitats will develop. The area will be suitable for storage of water in periods of heavy precipitation.

3. Assessment of wetland functions

In successive projects funded by the EU, an interdisciplinary consortium of universities and research institutes has collaborated with the objective to produce a system for the Functional Analysis of European Wetland Ecosystems (FAEWE) (Maltby et al., 1994, 1996). These activities have resulted in a procedure for the assessment of a comprehensive set of hydrological, biogeochemical and ecological wetland functions. These Functional Assessment Procedures (FAPs) are implemented in a rule based knowledge system (NetWeaver). Each wetland function is a result of interactions between the ecosystem structure (the geomorphology, hydrology and soils) and one or more wetland processes (changes or reactions which occur naturally within wetland ecosystems). To assess the wetland functions, first, spatial units are defined that are homogeneous with respect to hydrology and geomorphology. Next, the performances of all processes contributing to the function are estimated for each homogeneous unit. These results are combined to obtain an assessment of the function. The performance of functions can be different in different units of the wetland. To obtain a functional assessment for the whole wetland, the results from all spatial units are combined. This results in the following four steps: (1) definition of the spatial units, (2) assessment of the relevant processes, (3) assessment of the functions and (4) up-scaling the outcome of the functional assessment to the wetland level.

3.1. Step 1. Definition of the spatial units

As a first step the wetland is subdivided into units, which are homogeneous with respect to functioning. These HydroGeoMorphic Units (HGMUs) are delineated in the procedures on the basis of soil characteristics and hydrological and geomorphological landscape features. A short field trip (a field visit of about a day) is required to define the HGMUs based on geomorphic, hydrological and ecological indicators and the dominant vegetation type. This is complemented by a desk-study to add information about climate, land use, management, protection status and water/groundwater characteristics (see also Maltby et al., 1998).

3.2. Step 2. Assessment of the relevant processes

In each HGMU, the performance of the wetland functions is assessed on the basis of the underlying hydrological, biogeochemical and ecological processes. For example, the wetland function 'export of nitrogen' is based on four biogeochemical processes: (1) denitrification, (2) ammonia volatilisation, (3) nitrogen export through vegetation management, and (4) export of nitrogen via wind and water erosion. For each HGMU and for each process, the user answers questions on the controlling variables of the process. For the process denitrification, these variables are: (1) nutrient input, (2) occurrence of nitrate-rich water flows, (3) soil carbon, (4) soil oxygen, (5) soil pH and (6) soil temperature. This information is available from the desk-study and field survey. The combined answers of the questions result in a qualitative statement that indicates the performance of the process. If the answers to the questions all refer to good or (almost) optimal conditions for the performance of a process, the outcome of the assessment will result in the statement that the process is definitely being performed. Other answer combinations result either in the assessment outcome that the process is partially being performed or to the outcome that the process is not being performed.

Some processes have been thoroughly investigated quantitatively in the field and have been well documented in the literature. For these processes, the assessment outcome 'the process is definitely being performed' can be refined with a quantitative estimate (presented in ranges) about the degree of performance of the process under the specified circumstances. For denitrification, for instance, there are three categories of ranges indicating the performance of the process under different circumstances:

1. High: ($10 < x < 300$ kgN per ha per year);
2. Medium: ($10 < x < 80$ kgN per ha per year);
3. Low: ($5 < x < 15$ kgN per ha per year).

3.3. Step 3. Assessment of the functions

The results of the assessments of processes are combined into a quantitative assessment of the function. Combining the outcomes of the processes to a quantitative assessment of a function is performed in three steps. First, an average performance rate is determined for all processes contributing to the performance of the function. For instance, to obtain an assessment of the performance of the function 'nutrient export', the average performance of the contributing processes (denitrification, ammonia volatilisation, nitrogen export through vegetation management and nitrogen export via wind and water erosion) should be determined. For quantified processes, average performance rates are calculated on the basis of the minimum and maximum performance indicated in the ranges. For denitrification these average performance rates are: 155 (high), 45 (medium) and 10 (low) kgN per ha per year. For the non-quantified processes and the processes with an assessment outcome 'the process is partially being performed', no ranges with quantitative information are available. As the dimensions for all processes contributing to one function are similar, the performances of such processes can be estimated, relative to performances of the quantified processes. In the procedures, these estimates have been made by experts in wetland science. For instance, no quantitative information is available for the process ammonia volatilisation, but experts estimated the export rate of this process to fit within category medium of the denitrification process, resulting in an average export rate for this process of 45 kgN per ha per year. Other processes contributing to other functions are scaled to values of quantified processes within that particular function. For each function, a table, in which the average performance rates for all contributing processes (including different categories) are calculated, is provided in the procedures. The user can look up the average performance rates belonging to the outcomes of his process assessments. The second step is to add up these average performance rates found in the table to obtain the final outcome of the performance of the function. The quantitative value obtained in this step provides the user insight in the order of magnitude and therefore the importance of the function. In the third step, performance of the function is compared with the theoretically best outcome for this function, i.e. all contributing processes are performing optimally, and with the theoretically worst outcome, i.e. none of the contributing processes are being performed. This comparison helps the user to interpret the outcome for function performance and is used to standardize the performance scores on a 0–1 scale.

3.4. Step 4. Up-scaling the outcome of the functional assessment to the wetland level

Steps 2 and 3 are performed in each HGMU separately. The results are combined to obtain a final outcome of the performance of functions in the whole wetland. A weighted summation of the results of all HGMUs is performed using size of the HGMUs as weights. Users (not necessarily trained in wetland science) can complete the assessment, from HGMU delineation to the final outcome in about three days, including the one-day field survey.

The original HGMU delineation method described in the FAPs is based largely on 'natural' circumstances only. As the Dutch fen-meadows have undergone (and still undergo) strong anthropogenic influences, the characteristics of the landscape have changed drastically. Since management is such an important factor in Dutch wetlands the HGMU delineation method is extended to include management in the Dutch case-study. Based on soil characteristics, hydrology, geomorphology and management, the Wormer- and Jisperveld can be divided into eight different HGMUs: (1) fen-meadows in agricultural use, (2) fen-meadows under nature management, (3) multi-functional fen-meadows (mixed agricultural and nature management), (4) forestland, (5) reed beds, (6) quaking fens, (7) open water, including lakes and ditches and (8) reclaimed lake (deep polder). The areas of the different HGMUs relative to each other will change in the scenarios other than the current modern fen-meadow scenario and some HGMU types may disappear. For instance, in the dynamic mire scenario, the area of reed beds is expected to increase enormously compared to the reed bed area in the current situation. On the other hand, the fen-meadows in agricultural use will disappear in the dynamic mire scenario, as the very wet conditions are unfavourable for agriculture. For each of these HGMUs the wetland functions will be assessed for all three scenarios.

4. Map presentation

The spatial decision support system was developed in ArcView 3.3. It combines a HGMU map with the integrated evaluation of wetland functions (the Functional Assessment Procedures). The goal of the decision support tool is to provide insight into the spatial distribution of impacts predicted for the management alternatives. An important step in creating the spatial decision support system is the construction of a map of HGMUs.

The HGMU map for the area was created on the basis of a standard land use map (1:25,000) (Fig. 3). The polygons of the land use map were 'cut' from the land use map and reclassified. Each map unit was removed from the initial map and moved to a separate file and classified according to the HGMU method. Soil maps and hydrological maps were used to assign the correct HGMUs to the polygons from the land use map. The local manager provided information on the different management regimes and a map showing the management regimes was digitised manually.

4.1. Mapping small units

Small areas such as reed banks and small quaking fens are difficult to map. These HGMUs occur around the edges of parcels (polygons). The land use map on which the HGMU map is based is not sufficiently detailed to show these HGMUs. In fact it would require very detailed mapping (1:1000) which is very time consuming. Although small, the reed lands and quaking fens are important features in the landscape and for the wetland evaluation it is essential to incorporate them. To solve this the reed lands and quaking fens were expressed as a fixed percentage of a polygon. The advantage of this is that even very small HGMUs can be included in the calculations. The disadvantage is that the areas are not visible on a map. In other words, the small units can be included in the calculations but they cannot be made spatially explicit. This can of course not be done when the *location* of a HGMU is important for the performance of the wetland. This is the case, for example, for forests. Predator birds are present in forested areas and as a result only few breeding meadow birds are present in the vicinity of forested polygons. This is a typical spatial effect, and in order to express these effects the forested areas need to be expressed as separate polygons. The forested areas were digitised in ArcView 3.3 from a hand-made map obtained from the local manager. Fig. 4 shows a close-up from the HGMU map indicating the approach.

The percentages of reed land and quaking fens can be changed for each polygon individually. The areas of the different HGMUs relative to each other will change. For instance, in the dynamic mire alternative reed beds will be more abundant than in the current situation and fen-meadows in agricultural use will mainly disappear due to the incompatibility with high water levels.

5. Impact assessment of three management alternatives

The EVALUWET project intends to assist in the strategic, sustainable management of wetlands. Local decision makers are faced with the dilemma of bringing the oxidisation of peat layers to a halt, at the same time dealing with agriculture and the conservation of landscape and natural values. In Section 2 three management alternatives are presented which play a role in the decision-making process. In this section, a number of criteria relevant to EU policy issues have been selected and the impacts of three management

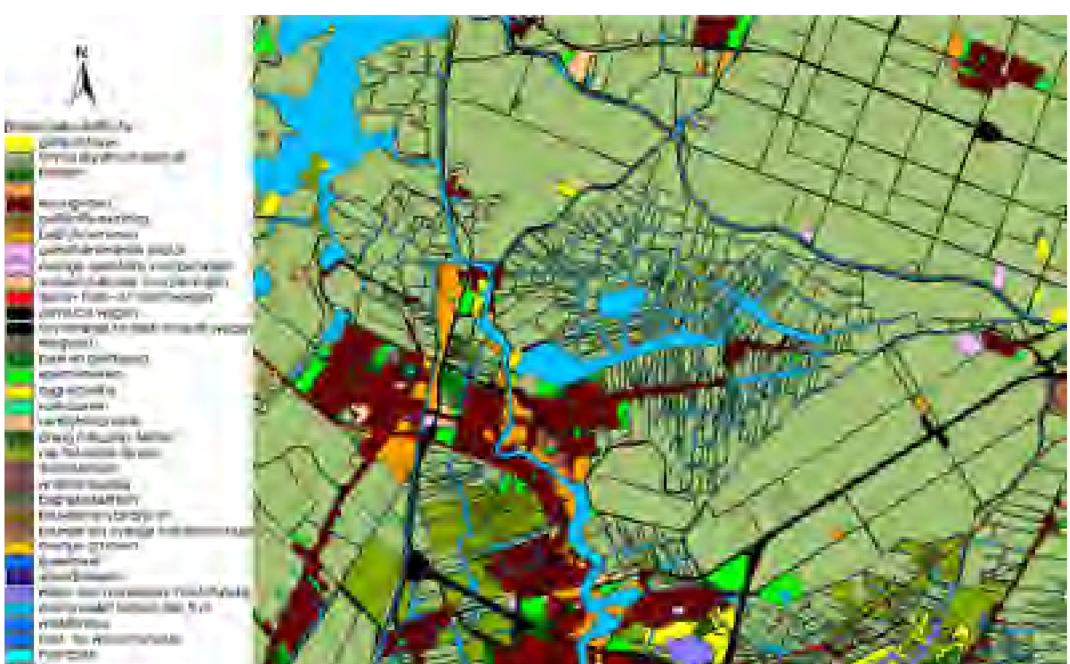

Fig. 3. Land use map of the study.

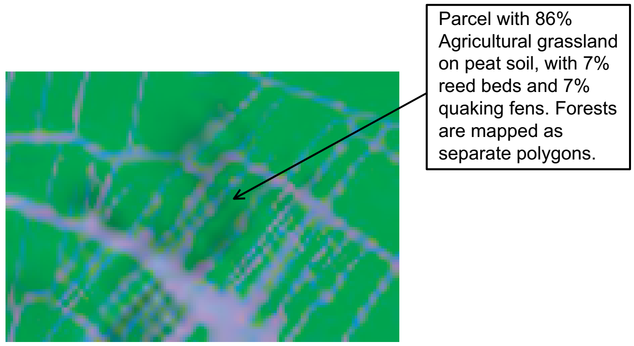

Fig. 4. Close-up from the HGMU map.

alternatives on these criteria are presented. Policy objectives and criteria are listed below (Table 1).

As shown in Section 4, EVALUWET is based on the HGMU delineation method. Each alternative consists of a set of HGMUs with a specific management. Therefore, the performance of wetland functions is expressed for individual HGMUs under specific management. For instance, the 'modern' fen-meadow alternative consists mainly of grassland under agricultural, mixed or natural management. In the 'dynamic mire' alternative, the area of grassland is smaller and taken over by forested areas, reed lands and quaking fens. These HGMUs perform different functions and the overall water management is different in both alternatives. The performances of the HGMUs on the functions specified above are estimated using the Functional Assessment Procedures.

However, for a number of functions the FAPs were not able to reveal the differences between management alternatives, while it is generally known that these differences do exist. For instance, application of the FAPs for the 'ecosystem maintenance' function, did not show any differences between the alternatives. Each of the alternatives performed well on ecosystem maintenance and no differences between alternatives were found. However, species composition does change in the alternatives and is valued differently by the stakeholders. In fact, the potential change in species composition is a very important issue in discussions on future management of fen-meadows in The Netherlands. The 'Handbook Nature Target Types' (Bal et al., 2002) contains lists of the potential occurrence of rare species in so-called nature target types in The Netherlands. The HGMUs used in this study were translated to nature target types and lists of the potential occurrence of species were derived. The lists were used to indicate changes in the potential species diversity in the three management alternatives. Also for the water retention function, the FAPs were not able to show differences between alternatives. A water balance study (i.e. all inflows and outflows of water) in the area was used to estimate the changes in water retention of the three alternatives (IWACO, 2000). These data in combination with expert judgement were used to determine the capability of retaining water in the three alternatives. The greenhouse gas storage function could also not be estimated in sufficient detail. In the FAPs emission of greenhouse gasses is mentioned briefly in several sections, however, no questionnaire is available to assess the impact of these emissions. Estimations of the different net greenhouse gas storage capacities of the HGMUs were derived from literature (Burgerhart, 2001; van den Born et al., 2002). For socio-economic functions, performance of HGMUs were based on interviews with key stakeholders in the study area and expert judgement.

Figs. 5–9 illustrate the performance of the three management alternatives on the selected evaluation criteria. These figures show that the dynamic alternative is best for water quality, water quantity and climate change, with the historic alternative in second position. The historic and modern alternatives are best for biodiversity. The historic alternative also performs best on the socio-economic criteria followed by the modern alternative and dynamic mire as the worst alternative. A decision on which management alternative to choose will depend on the weights added to the individual criteria. Section 6 will deal with weighting

Table 1
Objectives, functions and evaluation criteria

Policy objectives	Wetland functions	Evaluation criteria
Water quality (Water Framework Directive)	Nutrient retention and export	Water purification (nitrogen)
		Water purification (phosphorus)
Water quantity (Water Framework Directive)	(Flood)water retention	Water retention
		Peak storage
		Flood storage
Climate change (Kyoto Protocol)	Net greenhouse gas storage	Carbon retention
		Greenhouse gas emissions
Biodiversity	Ecosystem maintenance	Flora diversity
		Fauna diversity
Socio-economic	Generation of products and services	Cultural heritage
		Agriculture
		Recreation

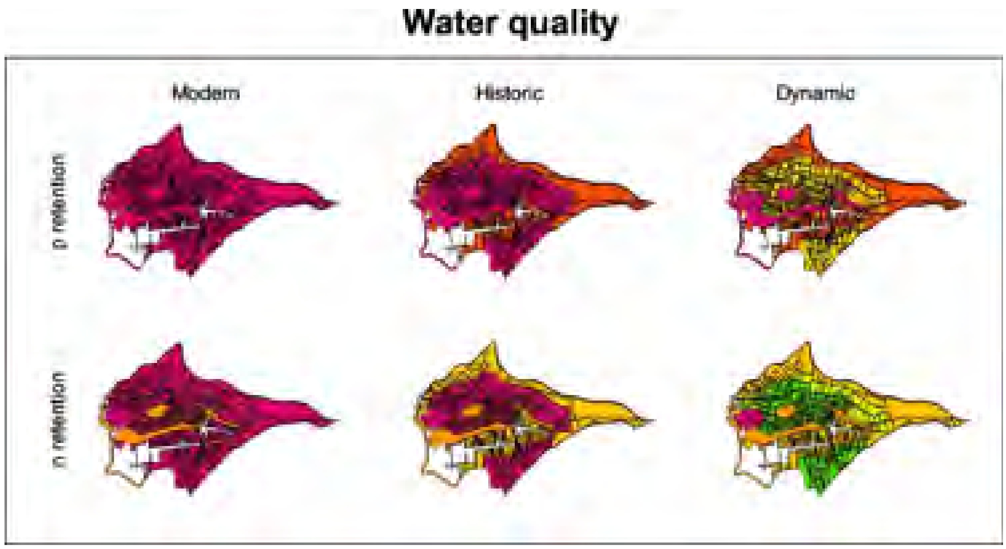

Fig. 5. Performance of three management alternatives for water quality.

and processing the data. Although differences between alternatives are much bigger than within alternatives a distinct difference between the north and centre part of the area can be observed. Note for example the low values for water quality in the central area for the historic alternative and the high value for biodiversity in the central area for the modern alternative. Agriculture is better for all alternatives in the northern section due to better access.

With the EVALUWET tool spatial relationships can also be studied. An example of such a spatial relationship is the occurrence of predator birds in forested habitats. The predator birds feed on nests of breeding meadow bird species. It was indicated by the manager of the nature reserve that within a range of approximately 150 m from forested areas, there is more predation on breeding meadow birds. Fig. 10 indicates areas where there is a high potential impact of predation on birds'

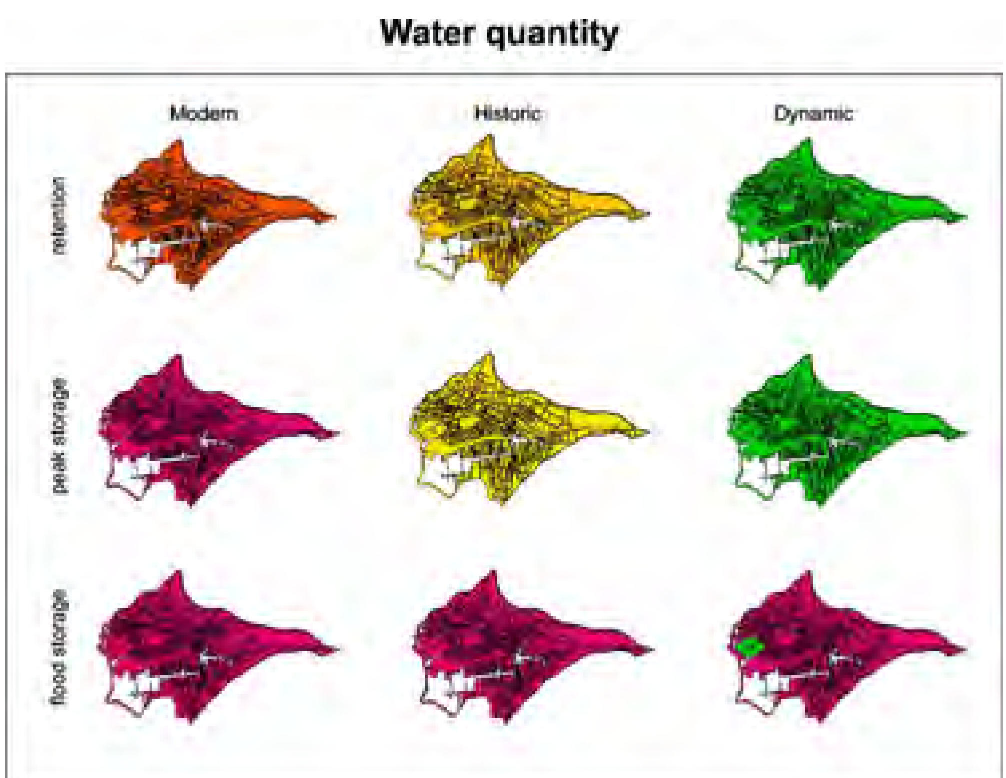

Fig. 6. Performance of three management alternatives for water quantity.

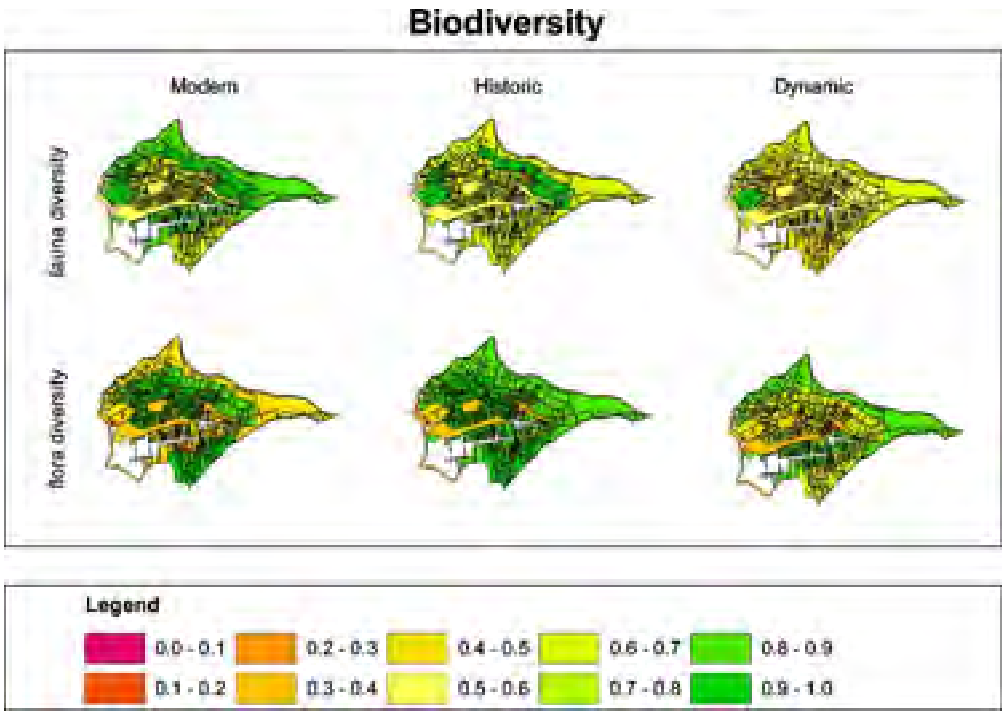

Fig. 7. Performance of three management alternatives for biodiversity.

nests by predator birds. Note that the predator birds are most abundant in the areas where management is aimed at protection of meadow birds. Moving the forested habitats towards the northern and eastern borders of the area will most likely improve diversity and density of meadow birds.

6. Decision support for wetland management

Impact assessment as described in the previous section provides a map for each evaluation criterion for each alternative. This resulted in a total of 36 maps (12 criteria × 3 alternatives) to be used for comparison

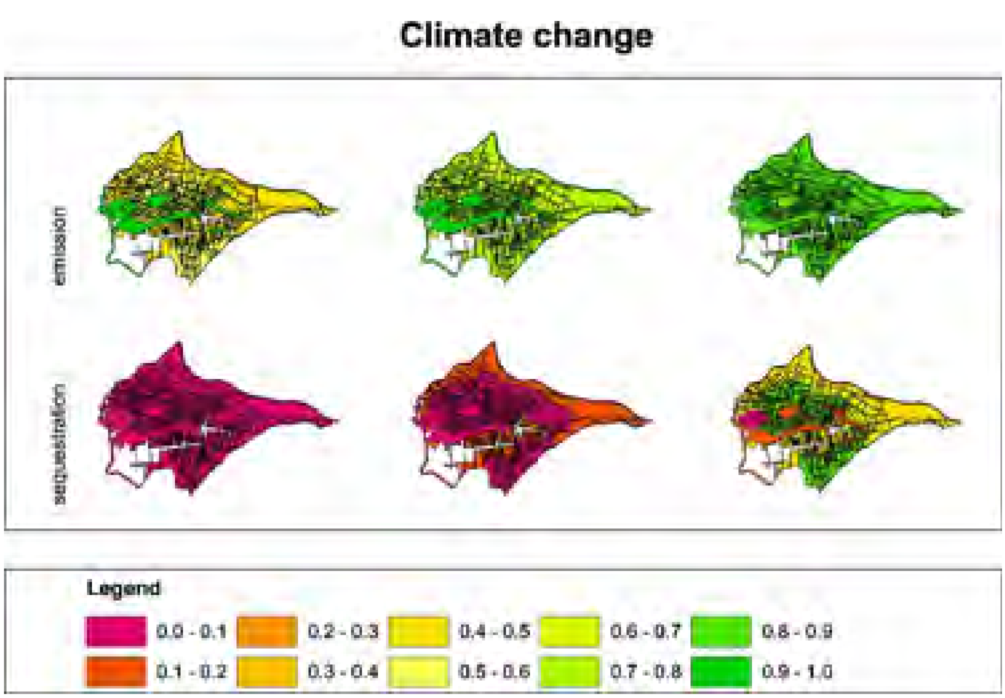

Fig. 8. Performance of three management alternatives for climate change.

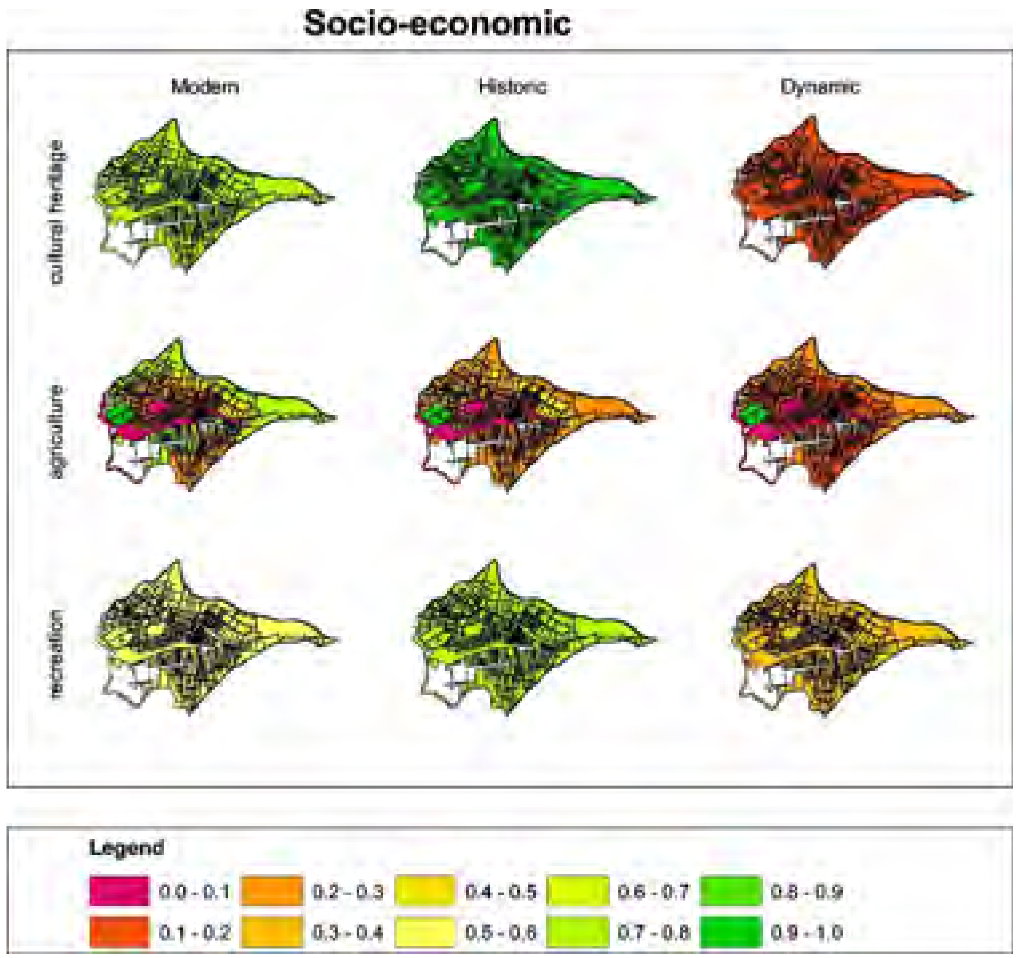

Fig. 9. Performance of three management alternatives for socio-economic criteria.

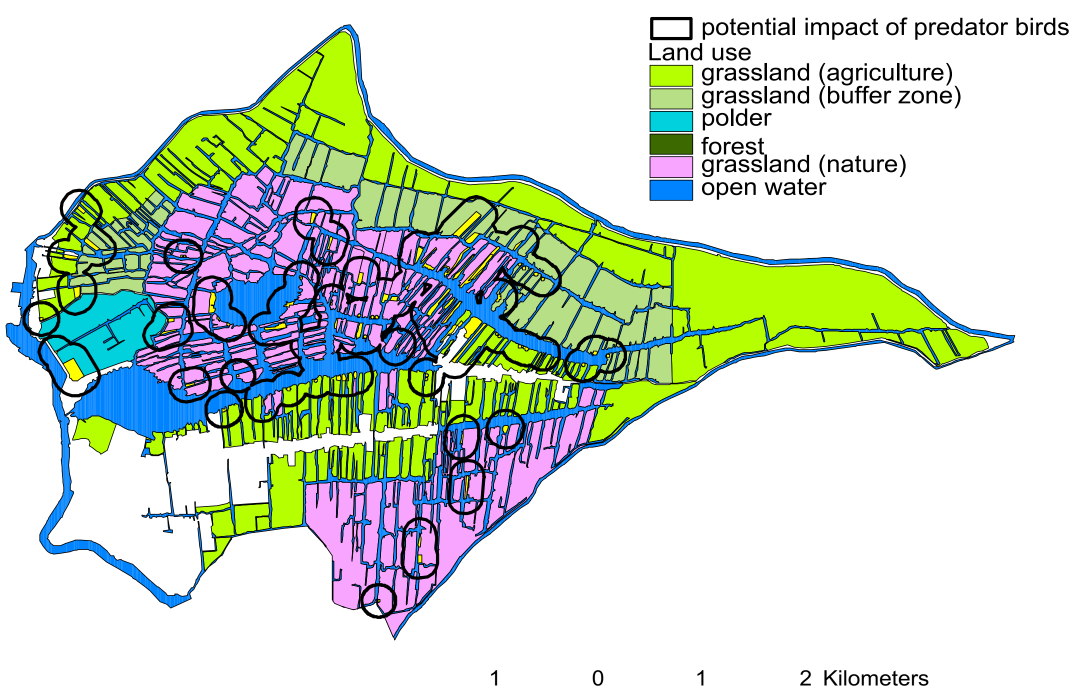

Fig. 10. Predator birds and their range of impact. The circles indicate areas with high potential impact of predation.

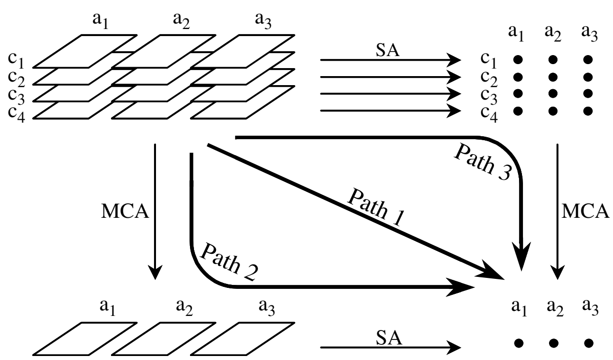

Fig. 11. Three approaches to evaluate the relative performance of alternatives on the basis of spatial information (van Herwijnen and Janssen, 1998, 2001).

of the alternatives. Fig. 11 shows three possible paths to use the available information for this task.

Path 1 is by far the most common approach: the decision maker is offered all maps and it is left to the decision maker to process the information in most cases without additional support. If the information presented is complex this approach can easily lead to the wrong conclusion (Uran, 2002). Path 2 first reduces the number of maps to be compared using a multicriteria approach (MCA). This is followed by spatial aggregation (SA). Path 3 starts with spatial aggregation followed by multicriteria analysis. In many cases only the first step of paths 2 and 3 are performed. Following path 2, evaluation maps can be generated that represent the overall performance of the alternatives. With small adaptations most multicriteria methods can be used to aggregate the evaluation maps into an overall evaluation map (Beinat and Janssen, 1996; Eastman et al., 1998). In this study, weighted summation is used to perform the aggregation. For each polygon the evaluation scores are standardized between the worst possible score (0) and the best possible score (1), the standardized scores are multiplied by their weights and aggregated. In this example criteria within each objective received the same weight. Fig. 12 shows the performance of the alternatives on the five policy objectives: water quality, water quantity, biodiversity, climate change, and socio-economic. This figure also shows the overall performance of the alternatives. To calculate the overall performance, all five objectives were given the same weight.

From Fig. 12 it is clear that the dynamic alternative is the best for water quality and quantity and climate change. The historic alternative is best for biodiversity and the socio-economic objective. The modern alternative is last on water quality, water quantity and climate change. However, the modern alternative is slightly better than the dynamic alternative for biodiversity and the socio-economic objective. The overall comparison shows the dynamic alternative as the best followed by the historic alternative and the modern alternative in the last position. Much of the spatial pattern is lost in the last two aggregation steps. It is therefore important to always present both the aggregated maps for overview and the original maps for explanation.

Path 3 starts with spatial aggregation. Methods for spatial aggregation in path 3 can be derived from a large variety of spatial analysis methods described in the literature (Burrough and McDonell, 1998; van Herwijnen, 1999). In this case study scores are weighted by area size, aggregated and standardized using total area size. This generates the evaluation table presented in Table 2. An evaluation score of 0 results if all areas have the worst possible score. Examples are the scores for peak and flood storage of the modern alternative. An evaluation score of 1 is reached if all areas have the maximum possible score. Scores of 1 are found for water retention and peak storage of the dynamic alternative only.

Weighted summation was used to rank the alternatives (Janssen, 1992; Janssen et al., 2001). The overall performance of the alternatives is presented in Fig. 13. This figure shows that if equal weight is given to the five objectives, "dynamic mire" is the preferred alternative. The difference in total score with the historic and modern alternatives is substantial. Fig. 13 also shows that the dynamic alternative scores are best on water quality, water quantity and climate. The high score on these three objectives compensates for the slightly lower score on biodiversity and the much lower score on socio-economic.

The weights necessary to aggregate criteria within one objective can be set using expert judgement. However, trade-offs between objectives are usually politically motivated. In this example, criteria within each objective received the same weight. Fig. 14 shows what happens if priority is given to the various objectives. In each row priority is given to one objective: in the first row a weight of 0.5 is given to water quality, the second row to water quality etc. This figure is useful to demonstrate the relation between political priority and preferred choice. In this example the dynamic alternative ranks first if priority is given to water quality, water quantity, climate and biodiversity. However, this alternative ranks last if priority is given to socio-economic. The modern alternative ranks last for all weights. Fig. 14 shows that the ranking of the alternatives is not sensitive to changes of the weights between the four environmental objectives. In all four cases the dynamic alternative clearly ranks first.

Although the last figure is relatively complicated it should be kept in mind that it is a summary of 36 maps made for the purpose of linking political priorities to ranking of the alternatives. In practice the best way to provide information will always be a mixture of the various ways of presenting. The aggregated information provides overview but it should always be possible to dive back into the detail.

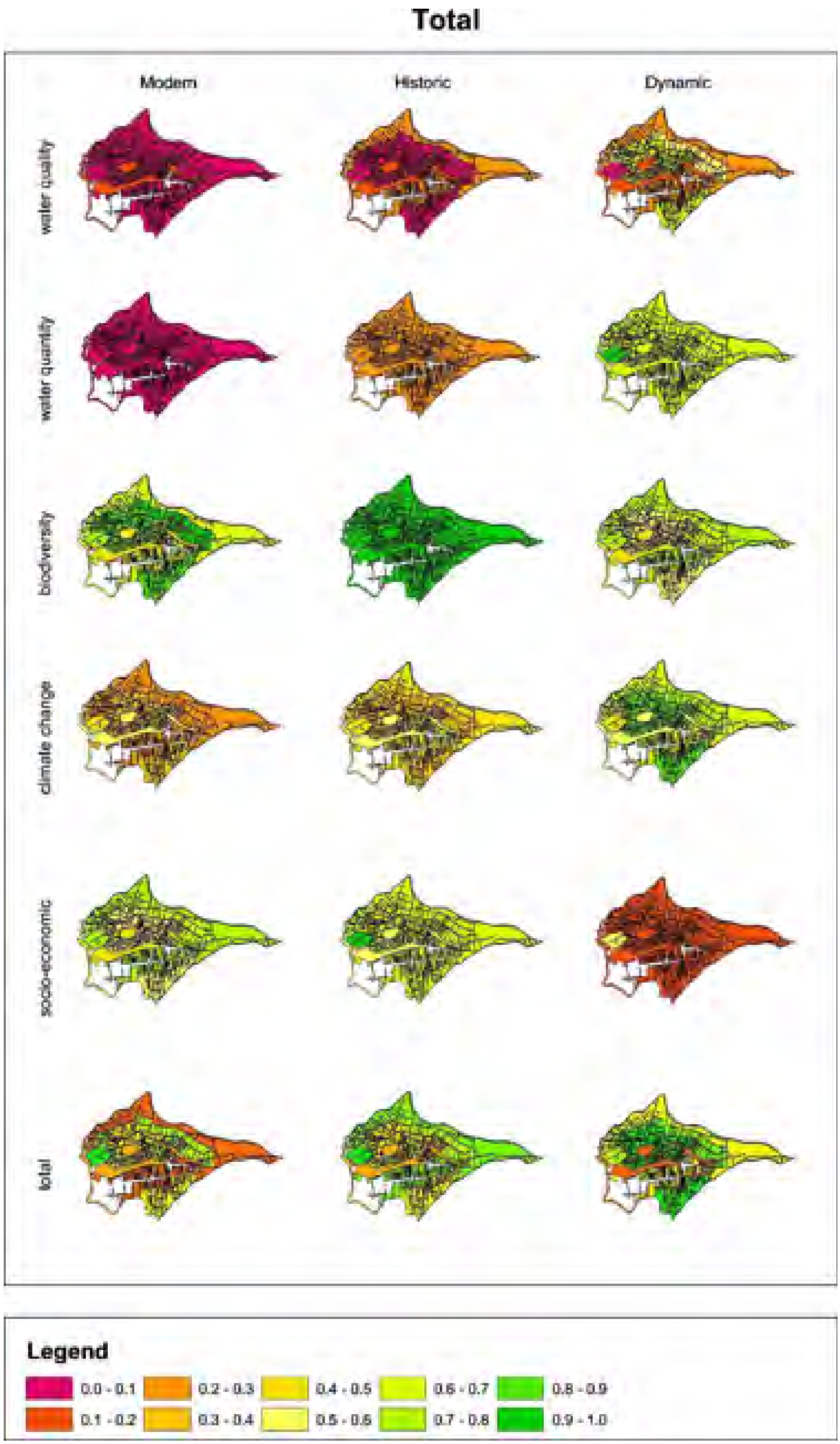

Fig. 12. Performance of three management alternatives on five policy objectives and overall performance of alternatives.

Table 2
Evaluation table

	Modern	Historic	Dynamic
Water quality			
P retention	0.02	0.08	0.23
N retention	0.12	0.22	0.47
Water quantity			
Water retention	0.00	0.00	1.00
Peak storage	0.00	0.00	1.00
Flood storage	0.00	0.00	0.03
Climate			
Carbon sequestration	0.04	0.09	0.47
Greenhouse emissions	0.64	0.82	0.90
Biodiversity			
Fauna	0.23	0.66	0.55
Flora	0.58	0.71	0.61
Socio-economic			
Cultural heritage	0.80	1.00	0.20
Agriculture	0.43	0.15	0.03
Recreation	0.60	0.80	0.40

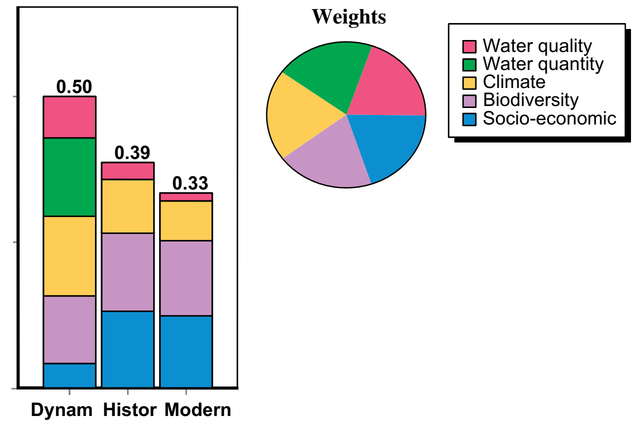

Fig. 13. Overall performance of the three management alternatives.

7. Conclusions

This paper demonstrates how the European Valuation and Assessment tooL sUpporting Wetland Ecosystem legislaTion (EVALUWET) can be used to compare management alternatives for a Dutch wetland area. Central to the tool is the system for the Functional Analysis of European Wetland Ecosystems (FAEWE). This system has produced a set of functional assessment procedures (FAPs) that can be used to assess the impacts of management alternatives on wetland functions. A geographical information system is used to translate the assessment scores to performance maps. Comparison of the alternatives is supported using a multicriteria approach. The approach is flexible, easy to use and uses a combination of quantitative and qualitative data combined with expert judgement. The tool is easy to implement. Necessary data can be obtained through a limited field survey complemented with interviews with experts. The GIS application is based on existing geographical data and standard GIS software. Therefore implementing the tool in other wetland areas will be relatively easy. The next step is the implementation of the tool in various other areas in the region. This will make it possible to combine management alternatives in

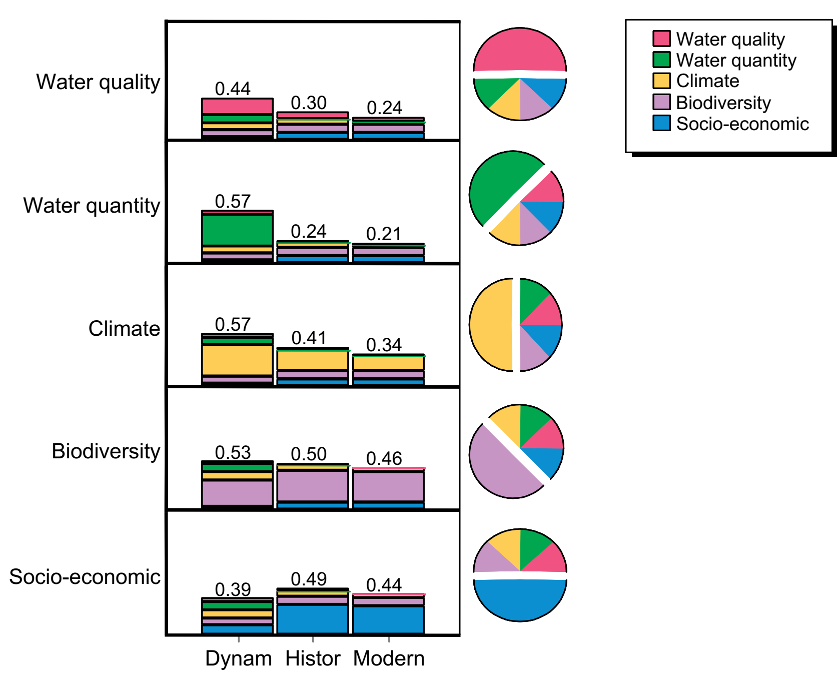

Fig. 14. Performance of alternatives according to policy priority.

the individual areas into an overall management alternative for the entire catchment. Feedback from stakeholders suggests that after completion the tool can play a role in the complex negotiations between all stakeholders involved in planning of Dutch wetlands.

The current system is based on four separate software components. Impact assessment is performed by a rule-based knowledge base, which uses the NetWeaver logic engine for processing (Reynolds et al., 2003). The user is asked to answer a series of questions, which results in an assessment for each function. A user interface has been made to enter these results into ArcView in combination with the socio-economic impacts. Spatial evaluation is handled in ArcView 3.3 using Avenue scripts to generate the performance scores. ArcMap generates the various map presentations. The software package DEFINITE performs the multicriteria analysis and the evaluation graphs (Janssen et al., 2001). Excel functions as an intermediary step to import the evaluation scores from ArcView into DEFINITE. At present these components operate as separate programmes. In the final stage of the project all components will be integrated in the EMDSS environment (Reynolds et al., 2003).

In the next phase of the research project, key stakeholders will be involved in the selection and weighting of criteria. The developed spatial decision support tool is flexible with regard to changing data, adding/removing/changing criteria. It is even flexible with regard to the spatial distribution of HGMUs, which means that users should in the future be able to change the distribution of HGMUs and create new alternatives or designs for the area. The tool will be tested and further developed in participatory approaches and interactive design sessions with (local) policy makers and stakeholders. Complex collaborative decision-making does not necessarily require large and complex models. Flexible and relatively simple spatial evaluation tools can in many cases capture sufficient detail and can support the collaborative planning process through negotiation and mediation support[1].

[1] The development and use of a detailed spatial explicit dynamic model for a particular area under concern might not be effective in decision-making (Brewer, 1986). Interesting examples of tools to support a collaborative planning process through mediation and negotiation support are developed at the division of Wildlife and Ecology in Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) (Cocks and Ive, 1996; Cocks et al., 1995). In their approach stakeholders provide allocation guidelines, which are essentially statements about which land uses should be allocated to various classes of mapping units. A GIS system facilitates the collaborative design of possible alternatives.

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