V.3

INTEGRATION OF ECOLOGICAL ASPECTS IN FLOOD PROTECTION STRATEGIES: DEFINING AN ECOLOGICAL MINIMUM

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Abstract

Policy makers are confronted with the question how to combine sustainable flood protection and floodplain rehabilitation in the best possible way. Both topics deal with spatial planning aspects in a range of scales. This question was the starting point for the development of an evaluation method within the IRMA/SPONGE project INTERMEUSE, illustrated on the basis of assumed flood protection strategies in the Meuse river basin (the “sponge” strategy, the “retention” strategy, and the “floodplain lowering” strategy). The integration of flood protection and floodplain rehabilitation can be performed on two scale levels that are interrelated: on the regional level the focus is on (large parts of) an entire stream basin, on the local level specific site conditions are taken as starting point. Ecological aspects under study are spatial cohesion of habitats as identified by species population persistence modelling (regional, longitudinal level) and required habitat quality for carabid beetles and for meadow vegetation gradients as assessed by correspondence analysis (local, transversal level). The carabid beetles are taken as indicative for the ecological integrity of the river bed, the meadow vegetation for that of the floodplain.

Unifying concept in the evaluation of ecological integrity is the ecological minimum: the critical boundary or minimum level of habitat conditions for a potentially good ecological functioning. It is the least acceptable state for a river ecosystem that is still functional to some extent, compared to a natural river ecosystem. The results of this study show clearly that there is a good chance to combine floodplain rehabilitation aims with flood protection activities, both on a local and on an international scale. Although ecological effect assessment and ecological optimising (referring to a natural reference state) remain basic, additionally the assessment of the ecological minimum helps defining design strategies for integrated flood protection, especially in situations where river rehabilitation is an opportunity.

Introduction

The natural river landscapes in NW Europe have changed drastically over the last centuries due to human activities. Normalisation and regulation of the river ensured quick run off of water, ice and sediments and at the same time enhanced navigation. Dikes were raised to protect people and goods from flooding. The remaining floodplain areas are almost completely in use for agriculture and at some places gravel, sand or clay mining has been carried out (Van Dijk et al., 1995). The massive flooding events of 1993 and 1995 along the rivers Meuse and Rhine and of 2002 along the Elbe demonstrated that the presumed safety against flooding is to be reconsidered.

In the past dikes were raised after (potential) flood events; now it is clear that new strategies need to be developed as further raising of dikes is not a long term solution (Van der Kraats, 1994). The central theme of these new strategies is to give back the rivers some of the “room” they had lost in the past centuries (Pedroli & Postma, 1998). However, space is scarce and this is especially true along and around river systems. Apart from flood protection other river functions claim the scarce available space, like urbanisation, industry, recreation, agriculture and nature (Lorenz et al., 1997). Therefore, to realise the new strategies in flood risk management, so-called ‘win-win’ situations need to be achieved, i.e. measures that are beneficial for various river functions. Several functions, e.g. nature, could benefit from the changes in river management that will take place to maintain flood protection.

Natural features of river systems are the result of dynamic geomorphological processes (Wolfert et al., 2001). As a result of the above mentioned human activities the impact of these processes diminished and the natural river landscape deteriorated. With the decline of natural habitat diversity, the accompanying characteristic species vanished or were left in isolated scattered fragments of habitats. The last decades national and international programs have started aiming at the ecological rehabilitation of river systems. The guiding principle for this needs to be the (restoration of) natural river processes: in particular the hydro- and morphodynamics. Concomitant with the expected large scale changes in spatial design of floodplain areas along NW European river systems, resulting from flood protection measures, tuning of measures and aims for the ecological rehabilitation of river systems have become a prerequisite.

The translation of new flood protection strategies into daily practice incorporating ecological rehabilitation goals, calls for new concepts and accompanying tools which can help the stakeholders to explore future spatial designs for floodplain areas (Smits et al., 2000). Both flood protection and river rehabilitation are strongly served by an integrated approach on a river basin level, partly as space is scarce, partly as problems cannot always be solved at the particular site in question. For both flood protection and river rehabilitation it is not enough to have sufficient space, also a good spatial connectivity is important, even a necessity. For flood protection this coherence is even the guiding principle for future spatial arrangement. The same applies for conservation and restoration of natural assets.

This paper is one of the outcomes of the project INTERMEUSE under the IRMA/SPONGE umbrella, directed to the development and application of a methodology for the evaluation of spatial planning alternatives for river basins, with respect to the integration of flood protection and floodplain rehabilitation. Focussed is on the case of the river Meuse. For a complete description of the INTERMEUSE project is referred to Geilen et al. (2001).

Principles of river restoration

Integrating flood protection and river ecology

Integration of flood protection and floodplain rehabilitation focuses on the following process: in order to maintain safety against flooding a certain flood protection measure (or strategy) will be carried out, resulting in changes in the abiotic environment that in turn will influence biological succession and potential. To integrate the goals of both flood protection and floodplain rehabilitation, knowledge on this basic theme and understanding of the interrelations is of utmost importance.

As stated, the central theme in modern flood management concepts is to give back the rivers some of the "room" they had lost in the past centuries. In the Netherlands this concept has lead to a new policy directive "Room for the River" (Anonymous, 1997). The new strategies for flood protection concentrate on the following principles:

- Retaining water to slow down run-off to the main streambed and thus lowering the peak discharge. In practice this strategy applies mostly to upstream reaches and tributaries and may consist of land-use changes or re-meandering of streams;

- Retention of peak discharges. In practice this strategy applies mostly to the upstream parts of the main river bed and can be performed inside the winter bed or outside in specially designed "retention basins";
- Increasing discharge capacity to ensure quick run-off of water. In practice this can be performed for example by floodplain lowering or river bed widening.

The ecological effects of flood protection measures related to one of the above principles have been assessed, using a scenario approach. Based on the above principles three distinct flood protection strategies were stated: 'Sponge', 'Retention' and 'Winter bed' (i.e. floodplain lowering). Due to its characteristics each strategy will result in specific ecological potentials differing in scale and type, thus creating different chances to integrate flood protection and river rehabilitation goals.

Longitudinal and transversal aspects

In most lowland rivers, flood protection will dominate the process of decision making in river management. Integration of flood protection and river rehabilitation will focus on optimising the future situation on the basis of river rehabilitation demands. Because ecological integrity and biodiversity patterns are scale-sensitive (Wiens, 1989; Ward et al., 2002), regional comparisons cannot be applied to local scales. Thus, integration should focus on mutual aspects at different scale levels. Within the project INTERMEUSE this is elaborated for two scale levels.
On the scale of river basins longitudinal aspects form the basis for the integration of flood protection and floodplain rehabilitation goals. For flood risk management scale and configuration of measures determine the impact and sustainability of flood protection strategies. The same is true for river ecosystem quality at this scale level as is elaborated in the river continuum concept (Vannote et al., 1980), one of the theoretical concepts for river rehabilitation. In this project, ecological network analysis of habitat configurations is used to assess the impact of the flood protection strategies on the development of viable populations of species as indication of the river ecosystem integrity.
On the scale of floodplains we assume that completeness of transversal gradients form the basis for integration. As river ecosystem quality at this scale level is large-

ly determined by the impact of dynamic abiotic processes, the presence of gradients is an important prerequisite. This constitutes the basis of the flood pulse concept (Junk et al., 1989), another important theoretical concept for river rehabilitation. There is a direct linkage with flood protection through the design and dimensions of physical planning measures.
The transversal aspects focus on species assemblages in relation to local conditions, as indication for ecological quality. In this project, carabid beetles were chosen as indicator group for the river bank, and floodplain meadow vegetations for the floodplain. From the ordination of data and the correlation with groupings of environmental variables, predictor variables of river conditions for the biota can be quantified (Petts & Bradley, 1997). The tolerance of species (groups) to habitat conditions allows the quantification of boundary conditions based on species or communities at risk (Hansen et al., 1999).

The ecological minimum as a design parameter

Traditionally the assessment of river ecosystem quality has been based solely on the measurement of physical, chemical and some biological characteristics. These measurements are not very useful for large-scale management of catchments or for assessing whether river ecosystems should be protected or not (Fairweather, 1999; Norris & Thoms, 1999). New approaches try to combine as many ecosystem indicators as possible, based on relationships between environmental variables and biota in the river system (Petts et al. 1995; Petts & Bradley 1997). In many publications the number and size of patches of streambed and riparian communities and the presence of suitable habitat for threatened species are proposed as criterion in the evaluation of rehabilitation and protection needs (Van Kalken & Havno, 1992; Reijnen et al., 1995; Lamouroux et al., 1998; Hansen et al., 1999; Palmer et al., 2000; Vis et al., 2001). The principle element for the integration of flood protection and floodplain rehabilitation as it is elaborated in this project, is the identification and quantification of key elements, to incorporate floodplain rehabilitation aspects in spatial planning and integrated effect assessment. Starting point is the identification and quantification of the so-called "ecological minimum", the critical boundary or minimum level of habitat conditions for a potentially good ecological functioning.

According to the new EU Water Framework Directive, all rivers should obtain at least a "good ecological status" (European Union, 2000). In defining ecosystem health, the "good ecological status" needs to be quantifiable, based on knowledge of species and community responses to natural processes and human pressures (Karr, 1999). Comparison of current conditions to desired post-restoration conditions determines the relative "health" of the system, with the possibility to define minimum values falling within the desired range of values of a good health (Kershner, 1997; Norris & Thoms, 1999). The ecological minimum as used in the INTERMEUSE project is a critical level of habitat availability corresponding with the lowest acceptable level of ecosystem functioning (Karr, 1999). This is elaborated for the longitudinal and transversal aspects mentioned above, on the basis of the results of the ecological effect assessment for the proposed flood protection strategies.

Regional integrity: networks of viable populations

Method

On a regional scale, spatial planning alternatives can be assessed on potentials for ecological integrity by means of a habitat network analysis (Pedroli et al., 2002). The ecological rehabilitation goals and therefore the analysis focus on the spatial configuration of habitats. A number of habitats within reach of each other can form an ecological network, thus enabling species to form viable populations. This concept is based on the theory of metapopulations (Levins, 1970; Hanski & Gilpin, 1997; Verboom et al., 2001).
For the evaluation within the project INTERMEUSE the model LARCH (Landscape Analysis and Rules for the Configuration of Habitat; Foppen & Reijnen, 1998; Chardon et al. 2000; Groot Bruinderink et al., 2003) was adapted and used for the ecological impact assessment of the proposed flood protection strategies in the Meuse catchment. LARCH is designed as an expert system, used for scenario analysis and policy evaluation. The model requires a habitat map and ecological standards or rules (e.g. on dispersal distance, population density etc.). Of each proposed flood protection strategy a resulting habitat map was predicted based on landscape ecological units. LARCH standards are based on literature, empirical studies and simulations with a dynamic population model.

The results of the habitat network analysis indicate potentials for the development of viable populations of species on the basis of the spatial habitat configuration analysed. Key elements in this approach are:

- characteristics of a species: e.g. habitat preference, home range, dispersal capacity;
- the amount, shape and area of habitat patches in a landscape;
- connectivity of the landscape, which defines how easily species can move to other habitat patches. For example, roads can seriously hamper the connectivity between closely orientated habitat patches.

With the developed method the network function of a flood protection strategy can be tested on the basis of a set of so-called ecological profiles. Each ecological profile represents a range of species with similar habitat requirements (defined in terms of ecotopes) and dispersal capacity, that can occur in a landscape. The ecological profile "Corncrake" (Crex crex) for example, stands for species that find their habitat in large patches of herbaceous grassland and have a dispersal capacity on a(n inter)national scale level. For this study, a set of 8 ecological profiles was selected (Table 5.7). For these species the current habitat configuration in the Meuse catchment area and the situations resulting from the defined flood protection strategies were analysed on the potential sustainability of viable populations. Since the assessment is based on potentials for a habitat network of a species, actual species distribution or abundance data are not required.

Table 5.7 Summary of results of the ecological network analysis for the three defined flood protection strategies (Retention, Sponge, Winterbed), compared to the present situation. o: no change; -: decrease; --: strong decrease; +: increase; ++: increase almost everywhere; (+): localised increase.

Ecotope	Ecological profile	Retention	Sponge	Winterbed
Grassland and rough growth	Large marsh grasshopper	(+)	o	++
	Whinchat	o	o	++
	Corncrake	(+)	o	++
Marshland	Bittern	+	o	o
	Bluethroat	(+)	o	++
	Large marsh grasshopper	(+)	o	++
Forest	Medium sized forest bird	(+)	o	o
	Otter	(+)	+	+
Side channels, open water	Otter	(+)	+	+

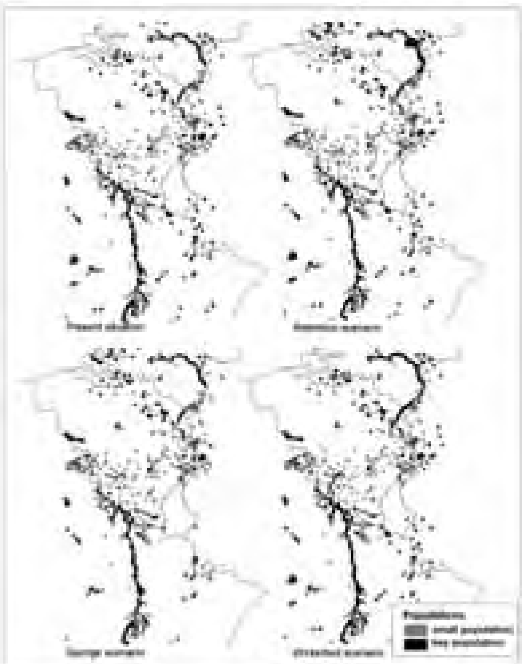

Figure 5.21 Example of results of population viability analyses for the present situation and the three defined flood protection strategies for the ecological profile "Large Marshgrasshopper" (Stetophyma grossum; Van der Sluis et al., 2001). Mvp: minimum viable population; core: key population; small: local population, too small to be a key population.

Results

The results of the habitat network analysis with the model LARCH are summarised in Table 5.6. For a complete presentation of the results is referred to Van der Sluis et al. (2001). An example of the output of the habitat network analysis performed is presented in Figure 5.21. Consequences of the spatial configuration of habitat resulting from the three flood protection strategies are shown for the potential population of the Large Marshgrasshopper.
Improvement of the network function of a landscape can be obtained by enlarging existing habitat patches or the creation of new habitat patches. Depending on type, size and shape these new patches can function as key area, stepping stone or corridor. The main objective with respect to a cohesive, viable ecological network should be prevention of further fragmentation and creation of natural areas as great in size as possible. For the Large Marshgrasshopper this would mean that a floodplain lowering strategy to maintain flood protection would result in far the most attractive spatial arrangement (Figure 5.21).
The ecological minimum was described as a critical level of habitat availability corresponding with the lowest acceptable level of ecosystem functioning (Karr, 1999). Translated to the habitat network analysis performed, the ecological minimum indicates the minimal habitat integrity for the development of sustainable populations. This can be linked to the spatial cohesion in ecological network analysis, by the potentials and boundary conditions for key populations, as minimum condition for population persistence of specific target species (Verboom et al., 2001). In the LARCH-methodology a key population is a relatively large, local population in a network, which is persistent under the condition of one immigrant per generation. In Table 5.7 indications are listed for key area size (to support a key population) and total area needed for an ecological network supporting viable populations of species. These indications are based on autecological knowledge of large numbers of species, concerning habitat demands, area needs and dispersal capacity in search of new habitats to colonise (Vos et al. 2001).

Table 5.7 Indications for the area ratio needed for sustainable networks, with and without a key area, according to Vos et al. (2001).

Species group	Key area	Sustainable network with a key area	Sustainable network without a key area
Large birds	1	4	6
Medium birds	1	3	5
Small birds and mammals	1	1.5	2
Reptiles	1	2.5	2.5
Amphibians and butterflies*	-	-	20 habitat spots

*For amphibians and butterflies not the size of the habitats but the number of habitat patches seems to be the determining factor with respect to habitat configuration.

Ecological integrity of river banks: carabid beetles

Method

As stated carabid beetles were chosen as indicator group to assess the ecological integrity of river banks. River banks are characterised by dynamic habitats and as such direct links to flooding characteristics exist (i.e. morphodynamics, water level fluctuation and flood frequencies). Based on cluster analysis of field survey data, correlations between species communities and environmental features were made. Combined with habitat requirements of indicator species a predictive model was designed, with which future situations resulting from e.g. flood protection measures can be assessed on their potentials for the integration of river bed rehabilitation goals (Jochems & Van Looy, 2001).
For the analysis of the carabid beetle communities data were collected on carabid fauna, vegetation and abiotic river bank characteristics in three pilot stretches (20km stretch each) in the three participating countries (i.e. near Mouzay (F), within Common Meuse and the Sand Meuse). In this river basin sampling 4,881 carabid beetles were counted. In a more intensive local level analysis some 80 plots were sampled in the Common Meuse stretch for two consecutive years, resulting in the catch of some 16,000 carabid beetles.
The environmental variables in the analysis were selected to have maximum ecological relevance, while being possibly influenced by flood protection measures

(Table 5.8). To identify the explanatory values of these environmental variables, a correspondence analysis (CCA) was used for the regional and local scale analysis. Based on this clustering and correspondence analysis between species communities and environmental features habitat templates are defined. These templates can be assigned to three zones within the river bank that represent the transversal gradient of river dynamics, based on the templates characteristics.

Table 5.8 River variables of channel morphology, hydrology and river bank habitats used in the cluster analysis.

Variable	Description	Measurement
River kilometre	Distance from river source (km)	regional / local
Width/depth–ratio	Dividing river width by mean river depth	regional / local
Base flow index	Dividing lowest flow by mean flow	regional
Coefficient of Variation	Dividing discharge variation by mean discharge	regional
Peak frequency (of summer discharge peaks)	Number of relevant summer peaks per summer season	regional
Peak Velocity	Hourly or daily maximum flow increment	local
Rising Speed	Velocity of water level rise	local
Habitat diversity	Number of riverbank types per station	regional / local
Texture	D50-value of substrate (mm)	regional / local
Vegetation cover	Percentage of soil covered by plants (%)	regional / local

As final step in the analysis a multiple logistic regression was executed for the explanatory river management variables. From this a response and optimum range of the variables for the ecological integrity of river banks was derived. Linkage of the defined templates to these river management related parameters resulted in a response model that can be used for the prediction of potentials for carabid beetle community development resulting from river management activities.

Based on the habitat templates and the transversal gradient they represent in the river bank, the formulated general definition of the ecological minimum is translated to a minimum available habitat within each gradient zone to allow sustainable populations of one of the communities. So, a minimum of 3 communities, divided over the 3 zones of the defined gradient, is necessary to achieve basic ecological integrity of the river bank for this species group.

Results

In the regional scale correspondence analysis (CCA) the main explanatory variables were width/depth-ratio of the riverbed and peak discharge frequency (summer season). Minor explanatory value is in habitat diversity and substrate texture. On the local level, further correlations were detected for the variables peak velocity (with the first axis 82%), and to a lesser extent rising speed of the water level (for the fourth axis 81%). Width/depth – ratio of the riverbed showed a high correlation with the habitat templates related to higher altitudes in th river bank gradient (i.e. higher vegetated bar and higher open gravel bar), which are inversely correlated with rising speed of the water level. These explanatory variables were used in the multiple regression, to build a response model for the carabid communities. Especially for width/depth-ratio of the riverbed, peak velocity, peak discharge frequency and habitat diversity, optimal ranges and responses to impacts in the system, caused by the proposed flood protection strategies, were defined, resulting in a useful evaluation tool.
The regional analysis showed that the stated ecological minimum habitat integrity was achieved in 50% of the sites monitored. The sites attaining the ecological minimum had an average species richness of 23 carabid beetles species, compared to an average of 14 for the sites with lower habitat diversity and an overall mean of 18 for the total sampling. The total cumulative species richness over the habitat diversity classes is presented in Figure 5.22. The position of the ecological minimum (as minimum habitat diversity measure) is high on the flattening curve.

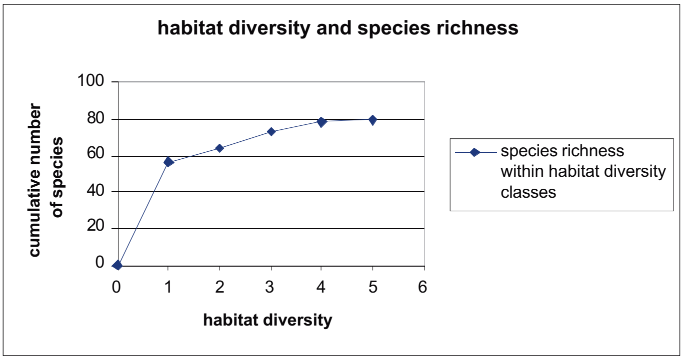

Figure 5.22 The species richness in carabid beetles over the sampling plots, cumulative over the habitat diversity range

The natural baseline (maximum habitat integrity) is achieved when all characteristic communities have sufficient habitat for the development of sustainable populations. Based on this the ecological goal was determined by interpretation of the landscape ecological unit mapping and the carabid beetle sampling results (Table 5.9). To reach the ecological minimum in one of the proposed flood protection strategies, at least three habitats should have an area corresponding to the ecological goal defined. This evaluation method is demonstrated for the WINTERBED-strategy in the different pilot stretches (Table 5.9 and Figure 5.23), based on hydraulic modelling results.

Table 5.9 Goals for rehabilitation of river bed habitats based on carabid beetle communities, with actual performance for the pilot stretches indicated as percentage of the formulated goal.

		Mouzay		Common Meuse		Sand Meuse	
Habitat	**Landscape ecological unit**	**goal**	**present**	**goal**	**present**	**goal**	**present**
Pioneer gravel bar	gravel bar	20ha	100%	100ha	10%	10ha	20%
High open bar	sandy bank	10ha	100%	150ha	10%	30ha	10%
Pioneer sand bar	sand bar	5ha	20%	25ha	5%	20ha	0%
High vegetated bar	wet border	5ha	10%	70ha	20%	15ha	30%
Wooded bar	softwood fringe	5ha	10%	50ha	5%	50ha	10%
Cut off bank	steep bank groin	2ha	80%	3ha	40%	2ha	50%
Steep bank	steep bank	1ha	100%	10ha	100%	10ha	100%
Overbank levee bar	sand bar dune	5ha	5%	20ha	15%	150 ha	10%
Flood channel	flood channel	20ha	20%	120ha	10%	400 ha	20%

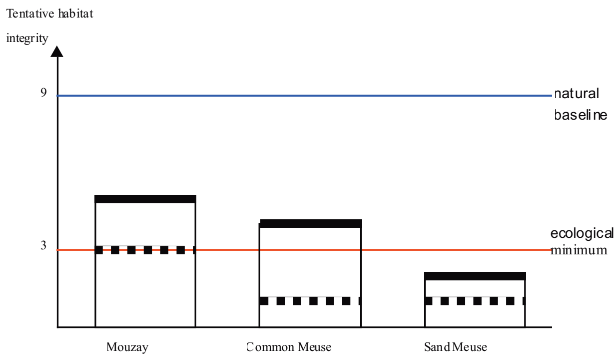

Figure 5.23 Tentative habitat integrity in the present situation (dashed line) and the WINTERBED flood protection strategy (solid line), for carabid beetle communities.

For the implementation of these ecological goals some guidelines can be stated. Principle elements in river bank habitat integrity are the river dynamics and its gradient over the river bank. A good measure for improvement of river dynamics proves to be the width/depth ratio of a river stretch. Within INTERMEUSE for each pilot stretch the variation in these parameters was assessed. The results are listed in Table 5.10 and form additional information for the ecological rehabilitation of the river bed and the integration with flood protection activities.

Table 5.10 Guidelines for river class types for the planning predictor variable width/depth ratio of the river bed (W/d-ratio).

Size/ character class	Meuse stretch	Sinuosity	Bank full discharge (m^3/s)	Ecological minimum W/d-ratio	Natural baseline W/d ratio
Upper middle course	Lorraine Meuse	>1.5	100-150 (<500)	10	30-50
Upper straight course	Ardennes Meuse	<1.5	250-500 (>100)	10	20-30
Lower middle course	Common Meuse	>1.2	1500 (>500)	20	50-100
Lower course	Sand Meuse	<1.2	1600 (>500)	18	>100

Ecological integrity of floodplains: meadow vegetations

Method

For the winter bed, meadow-vegetation communities are used as indicator group, in the same way as carabid beetles have been used for the river bank. Differences in plant species composition and zonation in floodplains can be largely explained by two major environmental factors: hydrological regime (mainly flood duration) and agricultural practices (Grévilliot et al., 1999; Grévilliot & Muller, 2002).
Based on cluster analysis data correlations between species communities and environmental features were made. For the regional analysis vegetation monitoring results from 80 rélevés from France, 60 rélevés from Belgium and 20 rélevés from the Dutch part of the Meuse were combined. The effects of interactions between hydrology and agricultural practices on vegetation spatial distribution were investigated by using a model based on CCA (Canonical Correspondence Analysis). The

CCA identifies the most important variables in predicting the probability of occurrence of the different units of vegetation. In a final step again logistic multiple regression was used in combination with GIS (Geographical Information System) to develop a predictive model that can be used for the prediction of potentials for meadow vegetation community development resulting from river management activities.
The local analysis of the impact of the proposed flood protection strategies was performed on the same pilot stretches as used for the carabid beetle analysis. The developed vegetation response model was adjusted in the Mouzay pilot stretch, as this is the most natural stretch remaining in the Meuse basin. This model is applied in the other pilot stretches (Common Meuse and Sand Meuse) as well as for the proposed flood protection strategies. A complete description of these activities within the project INTERMEUSE is presented in Krebs (2001).
As stated, the main aspects with regard to the diversity of floodplain meadow communities are the hydrological gradient (mainly flooding duration) and agricultural practices. So the ecological minimum, as minimum acceptable state of floodplain integrity that allows development and persistence of sustainable meadow communities, is based on these two aspects. The elaboration of this ecological minimum is performed for the unregulated French pilot stretch. Cluster analysis for this pilot stretch resulted in 13 distinguished vegetation groups, that in turn were clustered in four classes of meadow communities. These classes correspond to the whole hydrological gradient in the floodplain. Analogue to the carabid beetle communities, the ecological minimum was defined as a minimum of 1 vegetation group per community class (= gradient zone). Thus, a total of 4 vegetation groups representing the whole hydrological gradient should be the lowest acceptable level of ecosystem integrity based on this species group. The natural baseline is achieved if all vegetation groups are present in the floodplains. Based on the natural French pilot stretch, the ecological minimum was quantified by defining a minimum area for each community necessary to allow its persistence (Table 5.11). The connectivity with the fluvial system is an important factor for the preservation of the two wettest communities (mesohygrophilous and hygrophilous). So, spatial fragmentation in small patches of these two habitats severely hampers sustainable communities.

Table 5.11 Quantification of the ecological minimum for the different meadow vegetation communities to allow preservation. Indications are derived from the near-natural pilot stretch Mouzay (F).

Meadow vegetation communities	% of area
Hygrophilic communities	2.5
Mesohygrophilic communities	10
Mesophilic communities	5
Mesoxerophilic communities	2.5

Results

Correlation and regression analyses between the identified vegetation clusters and the determining environmental factors resulted in probability assessments for the vegetation communities. With this, for each vegetation type a vegetation response map was calculated, showing the probability of occurrence of each type. These probability maps were combined to produce a new vegetation map, based on the vegetation type with the highest probability of occurrence. In Table 5.11 the results of this exercise are listed for the Mouzy pilot stretch. With this approach potentials for meadow vegetation developments can be assessed for any given (future) situation. But, to what extent these potentials can be achieved is not only depending on the new hydrological conditions. The soil seed bank may prove to be a very important factor in this respect.

Analysis showed that, compared to the rather natural French pilot stretch, the other pilot stretches not always achieved the above formulated ecological minimum in the present situation. Both the Common Meuse and the Sand Meuse attained only 50 % of this minimum: only two communities out of four are sustainable in the present day situation. The ecological goal for the pilot stretches was set by translating the situation of the French phytosociological results to the other stretches, assuming a considerably less intensive agricultural management practice (Table 5.12).

Table 5.12 Goals for rehabilitation of meadow vegetations, with actual performance for the pilot stretches indicated as percentage of the formulated goal.

	Mouzay		Common Meuse		Sand Meuse	
Vegetation type	Ecological goal	Present	Ecological goal	Present	Ecological goal	Present
Hygrophilic communities	100 ha	60 %	490 ha	12 %	495 ha	10 %
Mesohygrophilic communities	400 ha	73 %	1965 ha	4 %	1980 ha	1 %
Mesophilic communities	180 ha	100 %	880 ha	25 %	890 ha	26 %
Mesoxerophilic communities	100 ha	52 %	490 ha	100 %	495 ha	100 %
Crops	0 ha	100 %	0 ha	100 %	0 ha	100 %

In Table 5.13 the ecological minimum and natural baseline are linked to flood duration, one of the main predictors for meadow habitat integrity. This forms essential input for the planning process within integrated river management related to the winter bed.

Table 5.13 Relation between the defined ecological minimum, the natural baseline and the relevant flood duration classes as prerequisite for the desired meadow vegetation development.

	Mouzay		Common Meuse		Sand Meuse	
Flood duration	Ecological minimum	Natural baseline	Ecological minimum	Natural baseline	Ecological minimum	Natural baseline
0 = < 1 week	2 ha	10 ha	140 ha	700 ha	100 ha	500 ha
1 = 1-2 weeks	18 ha	90 ha	240 ha	1200 ha	360 ha	1800 ha
2 = 2-5 weeks	40 ha	180 ha	220 ha	1100 ha	100 ha	400 ha
3 = 5-8 weeks	75 ha	370 ha	140 ha	700 ha	125 ha	600 ha
4 = 8-12 weeks	20 ha	100 ha	200 ha	1000 ha	120 ha	600 ha
5 = 12-20 weeks	8 ha	35 ha	115 ha	500 ha	95 ha	400 ha
6 = > 20 weeks		30 ha		400 ha		600 ha

Remark : Class 6 includes river bed and side channels

Integration of flood protection and river rehabilitation

Integrated river management implies that the new flood protection practices should at the same time focus on prevention of further deterioration of natural features and preferably lead to rehabilitation of lost natural elements. Within the project Intermeuse this was analysed for two distinct scale levels: the whole river basin and for specific pilot stretches, by using the three defined flood protection strategies. For both scale levels results of the analysis show that flood protection measures can be beneficial for nature rehabilitation aspects as well. This is elaborated in conceptual approaches and practical guidelines that can be implemented in integrated river management and spatial planning. For this, the identification and quantification of the ecological minimum for the several aspects presented before (habitat network functioning, carabid beetles and meadow vegetation) is an important step. By definition it is meant as the lowest acceptable ecological state and as such it marks the lower boundary were integration of river rehabilitation goals and flood protection can be achieved, whereas the natural baseline forms the upper boundary.

Integration on a regional scale

The performed habitat network analyses on the regional level in this project show that for the development of viable populations of species depending on typically river-bound habitats, the WINTERBED-strategy has the most obvious positive effects, especially in the Upper Meuse and in the Lower Meuse. However, since there are little possibilities to change the small winter bed in the Ardennes Meuse, this stretch appears to be a natural bottleneck for the migration and dispersal of species. Regulation of the river will however enhance this situation. The aim should be the creation of small areas wherever possible in this stretch. These can function as stepping-stones within the habitat network.

In general it might be presumed that, on the basis of the concept of ecological networks, ecological rehabilitation of river ecosystems should focus on enlargement of habitat prior to optimising habitat connectivity. For many species, one substantial area is better than a number of tiny spots (amongst others due to the larger effect of interference with surroundings, disturbance etc.). Application of the formulated guidelines requires knowledge on the present situation and formulated ecological rehabilitation targets for a river ecosystem. These targets can be based on existing nature values that need to be preserved or enhanced, or on the degree to which natural processes are still operative or can be made operative in the process of rehabilitation. Most important processes are hydro- and morphodynamics, as these are the driving forces for habitat development and diversity. These processes embody the characteristics of a certain river(stretch). This emphasises the statement that the distinguished scale levels, each having their own value within the river management process, are strongly interrelated. The influence of dynamic river processes is the most distinct on the local scale level.

Integration on a local scale

Gradients play an important role in the degree in which dynamic river processes still can influence the river landscape. Meadow vegetation and carabid beetles appear to be valuable indicators for habitat integrity for respectively winter bed and river banks. As such, a direct link is available with the type and dimensions of possible flood protection measures and river management. However, as river bed and winter bed are separate parts within the hydrodynamical gradient, conclusions on the impact of certain flood protection measures can differ in the way that measures favouring riverbed conditions will have impact on the winterbed conditions (i.e. flood duration and frequency). The decision making following the evaluation remains a balancing process, that needs to be support with knowledge and practical tools and guidelines.

With respect to the river bank, analysis of the flood protection strategies used in INTERMEUSE leads to the following guidelines. SPONGE measures can best be situated adjacent to the actual river bed. Even in small upstream parts of tributaries modified bank structures can already improve the water retention capacity considerably. Implementation of SPONGE at these sites also has a positive effect on the development of natural bank forms and the desired habitat integrity. Secondly, SPONGE measures may have a positive effect downstream: peak velocities nowadays exceed the natural conditions. Yet, a too strong decrease in peak fluxes would have a negative effect on the morphological processes necessary for habitat integrity.

Depending on the type of RETENTION measures the same recommendations as made for SPONGE are valid: the inclusion of river banks in the measures can result in an increase of habitat integrity. The effects of peak discharge reduction should be focussed on the highest and lowest peaks. In these ranges the distortion of natural flow regime is the most pronounced. The peak frequency of the intermediate range of peak fluxes is responsible for the morphological processes and hence for the development of the characteristic river bank habitats. The location of retention measures should take into account valuable floodplain areas.

WINTERBED measures should be planned in an integrated way: the combination of bed widening, bank lowering and flood channel restoration, restores the dynamic gradient in the river bank zone and is therefore beneficial for the over-

all habitat integrity. The choice for only one of the measures (e.g. bank lowering) will have effect in only one of the river bank gradient zones and as such is only partly in line with the proposed interpretation of the ecological minimum.
For the habitat integrity of the winter bed the same guidelines as stated above are applicable to a large extent. However, based on the meadow vegetation analyses another general remark needs to be made. The integration of flood protection and river rehabilitation is a good approach in strongly regulated river stretches. As this is the case in large parts of NW-European rivers this integration can lead to multi-beneficial solutions in river management. However, in near-natural river stretches any change in abiotic conditions resulting from a flood protection measure can lead to serious negative impacts on existing natural values. This brings up the question of how to combine flood protection strategies and quality preservation of natural ecosystems? In the near-natural river stretches focus is on nature preservation and less on rehabilitation. Based on the analyses for the near-natural Mouzay pilot stretch, flood protection measures should be promoted preferably in the more degraded areas as rehabilitation of lost values after implementation may never result in the natural baseline which is available now.

Conclusions

- Integration of flood protection goals and river rehabilitation goals can well be established. In regulated river systems flood protection measures can have a positive effect on achieving river rehabilitation goals. In natural river stretches combinations may be less favourable as nature preservation may be a major goal. Flood protection strategies SPONGE and RETENTION in such areas will lead to significant changes in local hydro-dynamics, which could entail important habitat and biodiversity impoverishment. Therefore, thorough studies related to the impact of management measures on habitat and biodiversity have to be carried out before implementing such strategies in natural river stretches.

- Flood protection strategy SPONGE and RETENTION should be implemented as much as possible in the upstream reaches of a river basin, as to reduce the flood peak discharges. WINTERBED-measures, that increase dis charge capacity, are the most effective on a local basis.

- On a regional level river rehabilitation should focus on enlargement of habitats and the creation of cohesive networks of habitats. On a local level the focus should be on the habitat diversity linked to gradients in the river system.

- Development of viable populations of species depending on typical river-bound habitats is served the best with the WINTERBED-strategy, in our case especially in the Upper Meuse and in the Lower Meuse. The SPONGE-strategy especially improves the situation for wetland species. The RETENTION-strategy might improve the situation for marshland species with large home range (e.g. Bittern). Considerable areas of habitat are developed under this flood protection strategy.

- Based on the habitat network analysis, the Ardennes Meuse seems to be a natural bottleneck, due the physical characteristics of this river stretch. However, river regulation will have enhanced this situation. With the creation of stepping stones this situation can strongly be improved.

- The correspondence analysis and response analysis lead to the identification of three important variables with respect to prediction of river bank habitat integrity: peak velocity, peak frequency (summer season) and width/depth-ratio of the river bed. These variables can be linked to the flood protection strategies defined in this study: the SPONGE-strategy has the strongest influence on the lowering of peak velocity; the RETENTION-strategy reduces peak frequency, and the WINTERBED-strategy influences width/depth-ratios. Responses to these variables can be predicted for flood protection measures, the resulting impact on habitat integrity can be described with the multiple logistic regression results.

- In the current situation the Dutch meadow vegetations are poorly developed and intensively used by agriculture. Restoration of the hydro logical gradient would result in an increase in moist and wet meadows. This implies a change in land use and consequently an increase of meadow biodiversity. However, the restoration of meadow vegetations in such heavily regulated river stretches might be hampered by the lack of an effective soil seed bank. This was not studied in the project INTERMEUSE.

- Win-win situations for flood protection and floodplain rehabilitation are theoretically possible. In practice the involved costs may pose the major problem for actual implementation. The concept of the ecological minimum, however, presents an instrument to quantify externalities related to flood protection measures.

- The identification and quantification of the ecological minimum is an important new guideline that may prove to be very useful in the practical integration of flood protection and river rehabilitation goals. Together with the natural baseline it defines the range where integration is possible. It should be clear however, that the ecological minimum is not meant as the general ecological goal to be achieved in integrated river management. This might only be the case in heavily modified river stretches, where due to human pressures the opportunities for river ecosystem rehabilitation are limited.

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