

Received: 27.02.2008 Received in revision: 26.01.2011 Accepted: 14.02.2011 Published: 24.05.2011



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Landscape Online
25, 1-11. DOI:10.3097/LO.201125

Landscape metrics as a tool for evaluating scenarios for flood prevention and nature conservation

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Abstract

Within the framework of the project „Flood Prevention and Nature Conservation in the Weisseritz area“ („Hoch-Natur“), a method including landscape metrics was developed and applied to assess and to compare different land use scenarios with regard to flood prevention and nature conservation. For the analysis, two sub-catchments strongly differing in land use within the Weisseritz catchment (Eastern Erzgebirge, Saxony, Germany) were selected. The first step of the evaluation procedure was a biotope assessment using three assessment criteria (naturalness, substitutability, rareness / endangerment). However, the biotope assessment did not yield any information about spatial distribution or the structural composition of the landscape. Therefore, landscape metrics were applied to analyse the structural and biotope type diversity at the landscape scale. Different landscape metrics (Shannon/Weaver diversity index, mean patch size index, Interdispersion/Juxtaposition index) and a weighting system were used to compare the different land use scenarios and the current state. The analysed catchment areas differ substantially in terms of their current state and potential measures regarding flood prevention and nature conservation depending on the location and distribution of biotope types. It was demonstrated that this method can be used for small catchment areas regardless of their land use for assessing, analysing and comparing different land use scenarios for a specific area.

Keywords:

conservation assessment, landscape structure, biotope types, mountainous catchment, comparison of land use scenarios

Introduction

In response to the heavy floods in the Weisseritz catchment (Eastern Erzgebirge, Saxony, Germany) in August 2002, the German Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU) funded the project „Flood Prevention and Nature Conservation in the Weisseritz area“ („HochNatur“) which aimed to design measures integrating both flood prevention and nature conservation. Especially land use changes can have a substantial influence on flood prevention because of their high potential due to the large extent of area affected (Bronstert et al. 2001, Auerswald 2002) on the one hand and the significant role that society plays in actively changing land use on the other hand. According to Blöschl et al.

(2007), land use exerts dramatic impacts on flooding especially at smaller catchment scales. Most studies on the influence of land use changes have focused on runoff processes only (Bronstert et al. 2001, Auerswald 2002, Pöhler 2006) The aim of the HochNatur project was to incorporate nature conservation measures as well and to demonstrate that flood prevention and nature conservation interests can be compatible. Accordingly, land use changes such as the extensification of grasslands, transformation of arable fields into grasslands, ecological transformation of forests, reforestation and establishment of small landscape structures such as hedgerows were the focus of the project.

The aim of the conservation assessment was to develop and to apply an evaluation method in order to compare various land use scenarios. Therefore, two sub-catchments (Weissbach and Hoeckenbach) with contrasting land use and biotope patterns were used

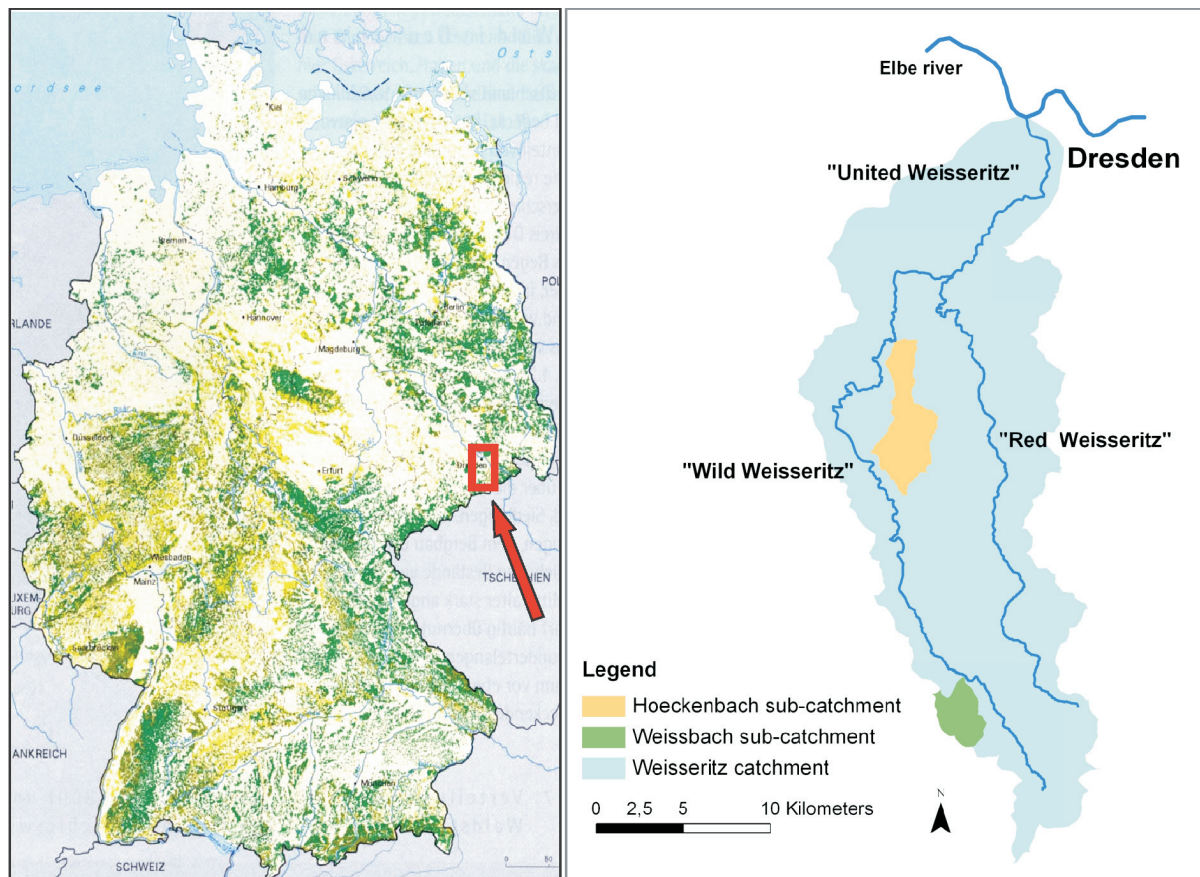


Figure 1: Location of the study area in Germany (left) and location of the sub-catchments (right)

as an example in order to assess the effect of various measures in view of differing starting conditions and landscape potentials. To test the conservation assessment on a different scale, the whole Weisseritz catchment was analysed to obtain information about the transferability of the developed method to larger catchments.

Landscape metrics can be used as indicators for describing, characterising and quantifying the pattern, composition and configuration of biotope and landscape structures on various spatial and temporal scales (Lausch & Thulke 2001, Lausch 2001, Nagendra et al 2004, Walz 2004, 2008) and, therefore, they can also be used for the evaluation and comparison of land use scenarios as Li et al. 2005 and Zhang & Wang 2006 proved. To the best of our knowledge, landscape metrics have not been used to assess land use scenarios which have been derived to combine nature conservation aspects with flood prevention measures.

2 Methods

2.1 Investigation area and data

The Weisseritz catchment in the Eastern Erzgebirge in the southeast of Germany (Fig. 1) stretches from about 800 m above sea level (m a.s.l.) in the mountain ranges down to 200 m a.s.l. in the northern low-

land. It includes the three partial catchments „Rote Weisseritz“, „Wilde Weisseritz“ in the upper ranges and „Vereinigte Weisseritz“ in the lowland. The two sub-catchments selected are the Weissbach (WB, 630 to 800 m a.s.l.) and Hoeckenbach (HB, 350 to 500 m a.s.l.).

On the basis of aerial photographs and topographical maps, a detailed high resolution and spatially extensive biotope mapping (scale of recording 1:2500) of the two sub-catchment areas Hoeckenbach and Weissbach was performed. A specifically developed mapping key was used along the lines of the biotope key of Saxony (LfUG 1998, also LfUG 2004) and the forest biotope key of Saxony (LAF 1996) to integrate special features such as hedgerows, stone ridges and small wetlands and to represent the special conditions of the small sub-catchments. As a result, digital biotope maps were created using the software ArcView and Arc GIS.

The Weissbach sub-catchment is characterised, apart from forests (24% of the total area), by grassland (42% of the area), which is mainly extensively used (33% of the area) (Fig 1). In contrast, the Hoeckenbach sub-catchment is dominated by arable fields (69% of the area) and grasslands and forests cover only 6 and 13% respectively (Fig 2).

The distribution of biotope types (Fig.3) in the sub-catchments differ widely because of different biogeographic conditions. The Hoeckenbach sub-catch-

Table 1: High priority goals from the perspective of nature conservation and flood prevention as the basis for deriving and assessing land use scenarios in the HochNatur project

Nature conservation	Flood prevention
<ul style="list-style-type: none"> • Conservation/increase of habitat connections and landscape connectivity • Conservation/development of habitat types with high conservation value • Conservation/development of landscape appearance characteristic for the nature area • Conservation/increase of species and habitat diversity 	<ul style="list-style-type: none"> • Quenching of peak flood discharges • Reduction of fast runoff components (surface runoff and fast interflow) • Increase of water storage capacity of the landscape • Increase of water retention in the floodplain • Reduction of soil erosion

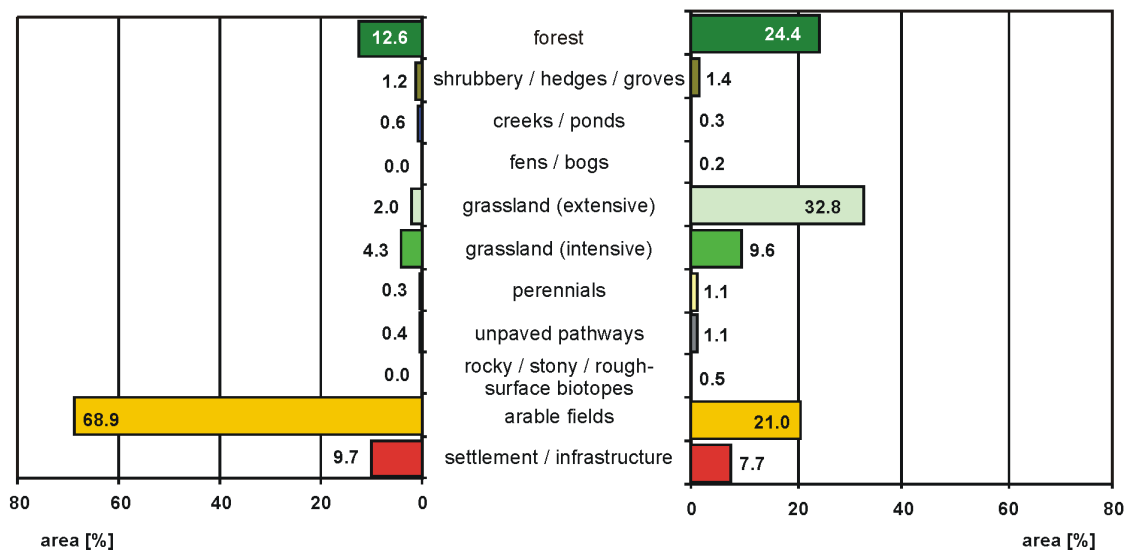


Figure 2: Present land use and biotope distribution of the sub-catchments

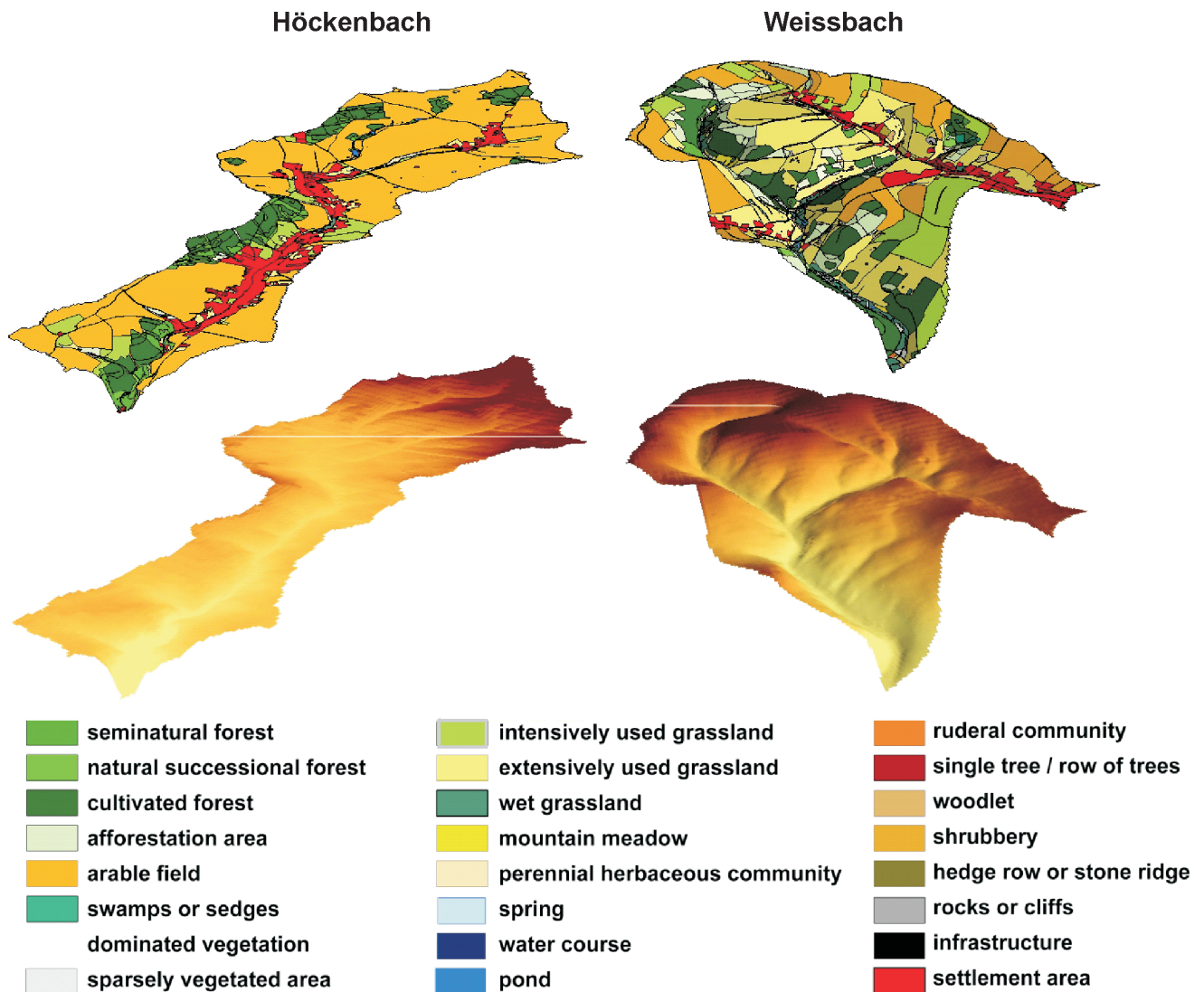


Figure 3: Distribution of biotope types (upper part) and elevation classes (lower part) in the two sub-catchments (Hoeckenbach scale approx. 1 : 120.000 and Weissbach approx. scale 1 : 70.000)

Table 2: Compilation of the land use scenarios analysed and the area percentages affected by land use changes in comparison to the present state in the sub-catchments Hoeckenbach (HB) and Weissbach (WB). n. a. = scenario not analysed

Scenario	Abbreviation	HB	WB
present land use	pres	-	-
complete reafforestation with potential natural vegetation	pnv	89.7	90.8
arable field into grassland	a-g	69.0	16.3
ecological transformation of forests	trans	12.6	24.3
partial reafforestation	aff	25.9	24.9
establishment of hedges	h	<0.1	<0.1
extensification of grasslands	gext	n. a.	9.8
trees along river banks	trees	n. a.	<0.1
hedges practical for land owners	h-prac	<0.1	<0.1
nature conservation approach	nat	83.7	53.8
flood prevention approach	flood	82.2	51.8
combination of nature conservation and flood prevention measures	comb	82.9	51.3

ment is mostly flat except for the escarpment into the valley of the Weisseritz whereas the Weissbach sub-catchment is hilly with steep slopes (Fig. 3). Because biotope mapping could not be conducted for the entire Weisseritz catchment, the CIR data (Colour infrared aerial photographs scale of recording 1:10 000) was used.

2.2 Scenario Development

Based on the results of the biotope mapping different land use, various scenarios were developed from the perspective of both flood prevention and nature conservation (Tab. 1). These scenarios considered land use changes such as the extensification of grasslands, transformation of arable fields into grasslands, ecological transformation of forests, partial and complete reafforestation with the potential natural vegetation (Schmidt et al. 2002) and conservation tillage, watercourse rehabilitation and the establishment of small landscape structures such as hedgerows, groves and trees along river banks (Tab.2).

For identifying synergetic effects between nature conservation and flood prevention measures, extre-

me scenarios from the conservation point of view and the flood prevention side were developed and united in a combined scenario. This scenario of a „combination of nature conservation and flood prevention measures“ attempted to consider both aims as much as possible on the basis of various guidelines (Richert et al. 2007). The scenario of an „extensification of grasslands“ was not defined for the sub-catchment Hoeckenbach due to the small percentage of grasslands in this area. The same holds true for the scenario of „trees along river banks“ because the Hoeckenbach flows mainly through settlement areas where the establishment of trees is not possible (Fig. 3).

The distribution and localisation of the land use areas considered for change in terms of flood prevention were selected by using an expert system (WBS-FLAB) which identified areas with fast runoff components (Merta et al. 2008). For land use changes from the nature conservation perspective, areas with an already high nature conservation value were preserved and other less valuable areas where attempts were made to develop and to enhance them. However, areas with fast run-off components do not always correspond to areas which are to be modified from the viewpoint of nature prevention primarily. Therefore, in the combined scenario for nature conservation and

flood prevention measures, land use changes were deliberately discussed and defined.

Because of the smaller data resolution for the whole Weisseritz catchment, different scenarios had to be developed. Therefore, the results from the sub-catchments and the entire Weisseritz catchment cannot be directly compared. But the aim was to test the assessment procedure on a larger scale and to acquire information about the transferability of the method to differently scaled catchments. Scenarios for the Weisseritz catchment consider land use changes such as complete reforestation with potential natural vegetation (pnv), extensification of grasslands and reforestation of selected areas with spruce (gext+aff), ecological forest transformation and arable fields to grassland above 500 m a.s.l (trans+a-g).

Apart from the present state, 11 scenarios were analysed for the Weissbach sub-catchment, 9 for the

Hoeckenbach sub-catchment. Due to specific land use settings, not all developed scenarios from the Weissbach catchment were applicable for the Hoeckenbach catchment (Tab 2). For the whole Weisseritz catchment, 3 different scenarios were analysed.

2.3 Biotope assessment

The aim of the developed method was the comparison of different scenarios developed from the flood prevention and the nature conservation point of view with the present state within the sub-catchments as well as the whole Weisseritz catchment. It should analyse the increase or decrease in the conservation value of the scenarios not only regarding a conservation assessment at the patch level but also considering the spatial distribution of the biotopes and their diversity within the different scenarios. In the end, a comparison with the reduction of fast runoff components should be possible to evaluate the scenarios

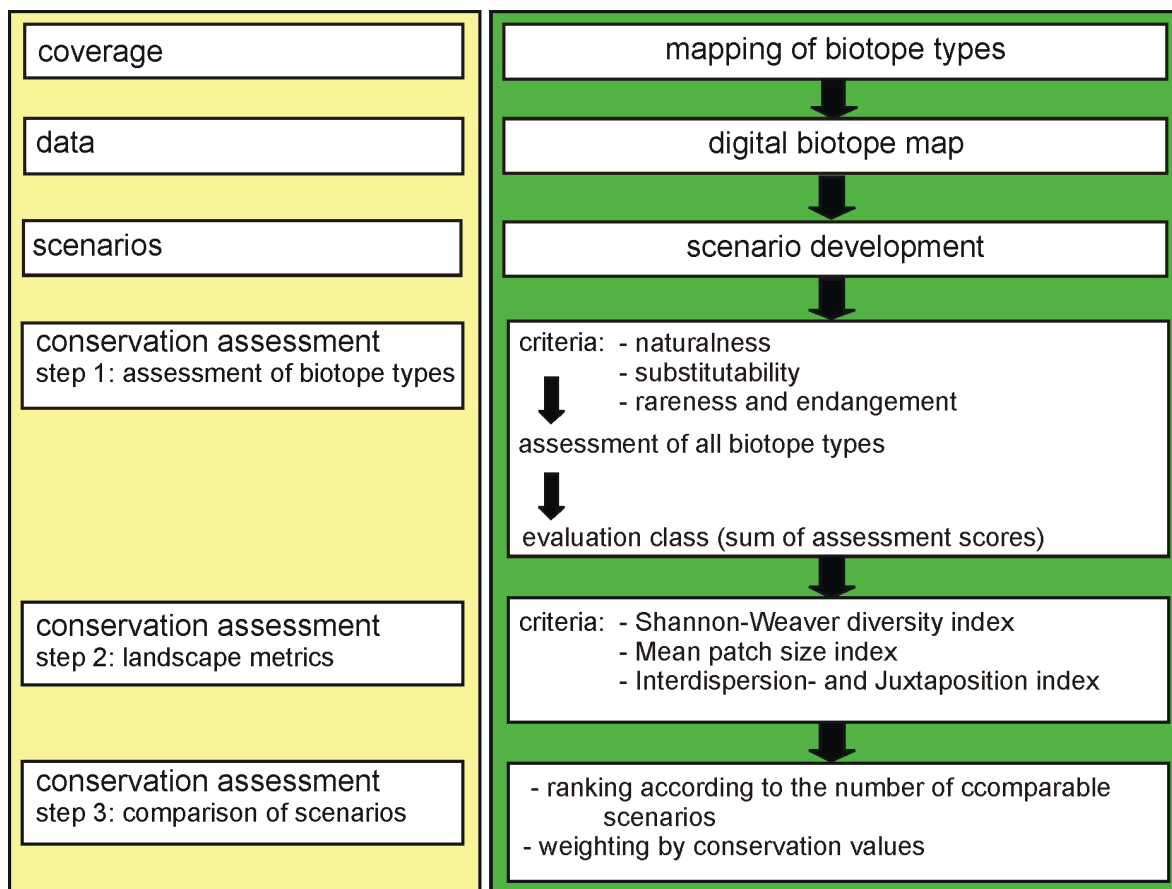


Figure 4: Main steps of the conservation assessment

regarding their flood prevention and nature conservation potential. The intention behind the assessment of the whole Weisseritz catchment was to test the transferability of the method to larger scales. The assessment was done in three main steps (Fig. 4). In the first step, the various biotope types were assessed using three evaluation criteria; namely, naturalness, substitutability and rareness / endangerment according to Bastian & Schreiber (1999) as well as Knospe (2001), Börning & Wiegleb (1999), LFUG (1999), LFU (1997) and Usher & Erz (1994). For these criteria, the assessment was done using a five score evaluation scale. The sum of these scores led to the assignment of the evaluation class of the con-

2.4 Landscape metrics analysis

Landscape metrics are a good method for monitoring landscape elements, classes and the total landscape depending on the scale and the necessary spatio-temporal resolution (Lausch & Thulke 2001, DiBari, J. 2007, Peng et al. 2010).

For this analysis, the Shannon / Weaver diversity index, the mean patch size index as well as the Interdispersion / Juxtaposition index were selected. As there is no fixed rule in the choice of indices to apply, the selection is

Table 3: Definition of the evaluation classes of the conservation assessment and requirements for measures

Σ points	evaluation class	definition and need for action
3-4	1	lowest conservation value upgrade and transform into a better ecological state, reduction of intensive use
5-7	2	low conservation value preserve, upgrade and transform into more natural ecosystems
8-10	3	medium conservation value preserve and prevent deterioration, strive for the development into biotope types with higher conservation value
11-13	4	high conservation value preserve, prevent deterioration at all costs, only partly substitutable, very valuable biotope types
14-15	5	highest conservation value preserve at all costs, not substitutable, save these very valuable biotope types

servation assessment (Tab. 3) for every biotope type.

This initial assessment of biotope types did not yield any information about their spatial distribution and the structural composition of the landscape. Accordingly, the second step was an assessment at the landscape scale using landscape metrics to analyse the spatial distribution of the biotope types and their diversity within the catchments.

linked to the specific requirement of the investigation:

The Shannon / Weaver index (SHDI) was analysed using the program Vlate (Vector-based Landscape Analysis Tools Extension for ArcGIS). The SHDI is a popular measure of diversity in community ecology (McGarigal & Holmes 2000) and was applied to landscapes in the present study. It describes the variability of the landscape related to the biotope types and their area proportions. The Shannon/Weaver index is 0 when the landscape contains only one biotope type (i.e. no diversity). It increases as the number of different biotope types increases and/or the proportional distribution of area among patch types becomes more equitable (Mc-

Garigal & Holmes 2000). This index is particularly sensitive to rare events; in this case, the occurrence of small sized biotope types (Farina 2000). Only biotope types with an evaluation class better than 2 (Tab. 3) were used for the calculation meaning that only areas with at least a medium conservation value were considered. Areas of lower conservation value (settlements, infrastructure, arable fields, intensively used grasslands, ruderal communities) were not included in the calculation of this index because the aim of the analysis was not an increased diversity of non-natural biotope types.

The Mean Patch Size (MPS) analysis was also done using Vlate. The value is lower as the landscape becomes more and more diverse and small structured, which means plenty of small biotope patches with different land use adjoining each other. In the case of a high MPS, only a few large biotopes are found in the investigation area. This analysis was carried out for biotope types with an evaluation class higher than 2. Since the aim, from the conservation point of view, was the creation of a diverse and highly structured landscape, therefore, the scenario with the lowest MPS received the highest number of points.

The Interdispersion- and Juxtaposition-index (IJI) (McGarigal & Marks 2000) relates the heterogeneity of the biotope types to the maximum possible heterogeneity of the biotope type mosaic at a given number of types and patches. This index is close to 0 when adjacent biotope types are unevenly distributed and approaches 100 when all biotope types are equally distributed (Farina 2000). For this calculation, a grid based spatial pattern analysis program FRAGSTATS (McGarigal & Holmes 2000) was used which also analyses border contacts between the biotopes within the landscape. Consequently, all biotope types had to be investigated, regardless of their conservation value. The cell size chosen for the grid analysis of the sub-catchments was 1 m and for the whole Weisseritz catchment 5 m.

The different scenarios as well as the present state were ranked relative to every calculated index and scores were assigned according to the ranks to enable

a comparison between them all. The scenario with the highest score got the highest rank and, accordingly, the highest number of points depending on the number of compared scenarios. The final step was the weighting of the results of the landscape metrics analysis (points) through multiplication with the percentage of area with high conservation value (evaluation classes 3 to 5, Tab 3.). To enable a comparison of the results for the Weissbach and the Hoeckenbach sub-catchment as well as the whole Weisseritz catchment, the weighted points were standardised as to the number of compared scenarios.

3 Results

3.1 Results of the biotope assessment

The percentage of biotope types with the highest conservation value (evaluation class 5, Tab. 1) was very low in both sub-catchments (Weissbach 0.1%, Hoeckenbach < 0.1%) (Fig. 5). The biotope types with the highest conservation value are, for instance, natural mountain creeks and springs. A high to medium conservation value (evaluation classes 4 and 3, Tab. 3) covers 51% of the Weissbach sub-catchment area but only 16% of the Hoeckenbach sub-catchment area. Biotope types in these classes include forests and groves, mountain meadows and wetlands.

In the Hoeckenbach sub-catchment, biotopes with low and lowest conservation values (evaluation classes 2 and 1, Tab.1) dominate. Intensively used arable fields are the most dominant biotope type in these classes.

3.2 Results of the landscape metrics analysis

For the Weissbach sub-catchment, the final number of points after weighting and standardising was highest for the scenarios WB nat and WB comb, which also performed well in regard to the landscape metrics (SHDI, MPS, IJI) and the percentage of area of

high conservation value (Table 4). The present state and all scenarios for the Hoeckenbach sub-catchment achieved a lower number of scores compared to the Weissbach sub-catchment as a result of a higher percentage of biotopes with a high conservation value (evaluation class 3 to 5, Tab. 1) in the latter sub-catchment.

In both sub-catchments, the nature conservation approach (dark green) gets the highest number of scores (Fig. 7). The flood prevention scenarios (dark blue) scores evidently lower but, when compared with the present state, still show an improvement for both catchments. The combined scenarios (azure) fall in-between. For the scenarios „nature conservation approach“ and „flood prevention approach,“ land use changes were developed nearly exclusively with respect to the relevant objectives (see position of scenarios in figure 8). The present state of the Hoeckenbach sub-catchment got the least number of points (26.2 points) closely followed by the PNV (27.0 points) and hedge scenario (30.2 points). Scenarios with minor land use changes, for example the establishment of hedges and trees along river banks, show only minor improvement compared with the present state.

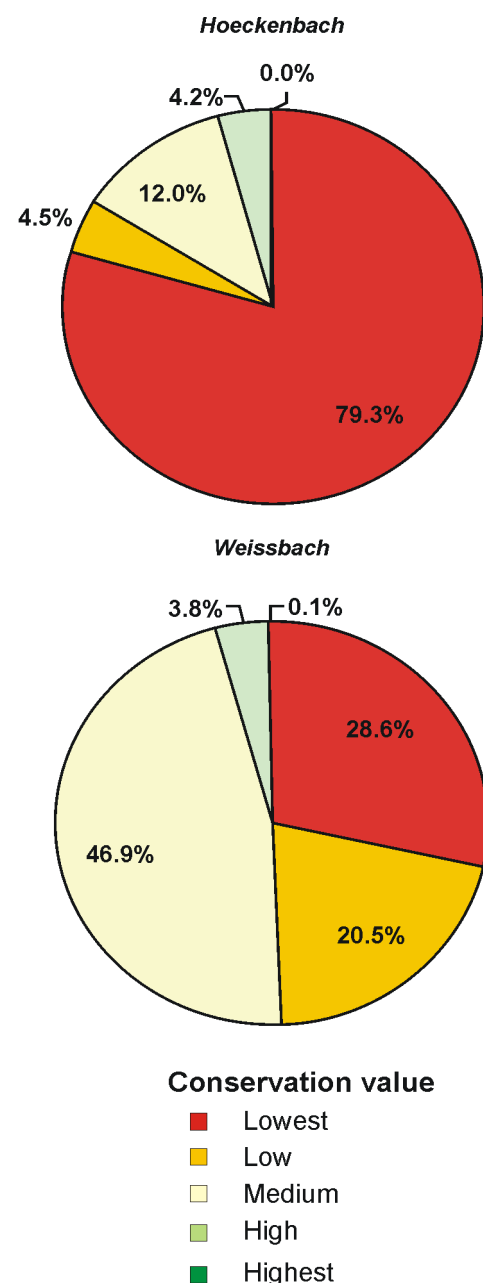
The PNV scenario for the Weissbach sub-catchment scores even lower than the present state because it leads to a loss in habitat diversity and heterogeneity of the already comparatively diverse catchment, especially the highly structured area of the Weissbach and its riversides. The complete reforestation of the sub-catchments leads to no more than a couple of large biotope patches.

The scenarios which expand the proportion of extensively used grassland for both sub-catchments cause a clear improvement in comparison to the present state. However, this can only be achieved if the grasslands do not exceed an area of 35 hectares. Forest transformation and partial reforestation (trans, aff) in the sub-catchments would lead to an enhancement of the nature conservation situation. In particular, the Shannon/Weaver diversity and the Mean Patch Size indexes for these scenarios obtain a very high number of points (Tab.4).

3.3 Results of Weisseritz catchment

For the entire Weisseritz catchment, all scenarios show an increase in scores compared to the present land use. The „gext+aff scenario“ achieve the highest score (125.9). This is especially surprising because the area modified (24 %) is smaller in comparison to other scenarios with lower scores, for example, the scenario of forest transformation (37 % of area modified and a score of 97.8) and the scenario of complete reaffo-

Figure 5: Present state assessment of the biotopes for the Hoeckenbach and the Weissbach sub-catchment



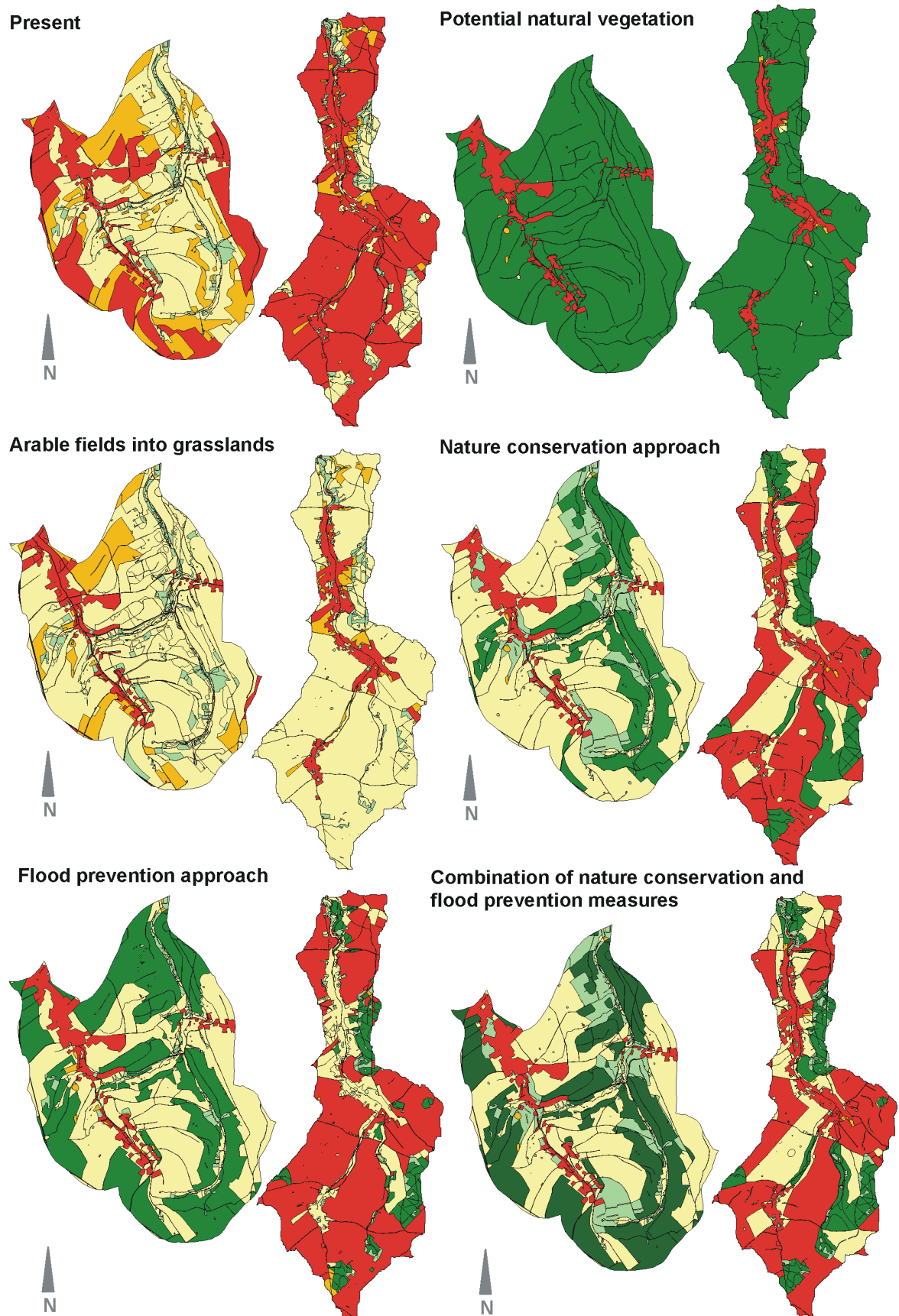


Figure 6: Results of the biotope assessment for the present state and selected scenarios for the sub-catchments Weissbach (left figure approx. scale 1 : 70.000) and Hoeckenbach (right figure approx. scale 1 : 120.000) (for legend see Figure 5)

restation with potential natural vegetation (84 % of area modified and a score of 105.6). The reason for the lower scores of these scenarios is the loss of biotope diversity in the forests through the creation of large and relatively homogeneous areas in the course of forest transformation and the complete reforestation with potential natural vegetation.

Overall, the results show that this method can be used for small to medium-sized catchment areas in order to assess, analyse and compare different land use scenarios for a specific area and research problem.

4 Discussion

The chosen landscape metrics (SHDI, MPS, IJI) proved to be sufficient enough for evaluating and comparing the developed scenarios and the present state and for obtaining results of different measures

for flood prevention and nature conservation on the landscape scale. They reflect the diversity and spatial distribution of the different biotope types at the landscape level and, therefore, can be used to compare different scenarios and the present state in consideration of nature conservation issues.

One problem with the chosen landscape metrics is that it is not always useful or desirable for achieving the lowest possible patch size, because specific and often endangered species, for example meadow breeding species, commonly depend on large habitats. This fact was not taken into account in the analysis because the scenario development did not result in very small individual biotope patches.

From the point of view of nature conservation, most suggested land use changes were promising, especially for the Hoeckenbach sub-catchment, in comparison to the present state (Fig. 8). In contrast, due to the high scores of the present state in the Weissbach sub-catchment, most of the scenari-

Table 4: Landscape metrics for the Weissbach sub-catchment

Weissbach scenarios	SHDI	MPS	IJI	area of high conservation value in %	final points
present land use (WB-pres)	1.49	6830.60	58.97	50.81	63.52
complete reforestation with potential natural vegetation (WB-pnv)	1.20	26043.89	50.87	91.02	30.34
arable fields into grasslands (WB-a-g)	1.95	9393.11	60.87	71.15	130.44
ecological forest transformation (WB-trans)	1.93	6409.06	54.88	59.53	104.18
partial reforestation (WB-aff)	2.00	8193.21	55.79	76.21	127.02
establishment of hedges (WB-h)	1.54	6361.88	59.26	51.05	102.09
nature conservation approach (WB nat)	2.35	8216.88	64.33	90.96	219.82
extensification of grasslands (WB-gext)	2.01	7897.93	61.91	60.58	146.40
trees along river banks (WB-trees)	1.49	6520.97	59.34	50.81	88.93
hedges practical for land owners (WB-hprac)	1.50	6630.59	59.03	50.95	80.67
flood prevention approach (WB-flood)	1.65	9867.55	44.60	90.71	68.04
combination of nature conservation and flood prevention measures (WB comb)	1.94	8402.71	60.43	90.96	159.18

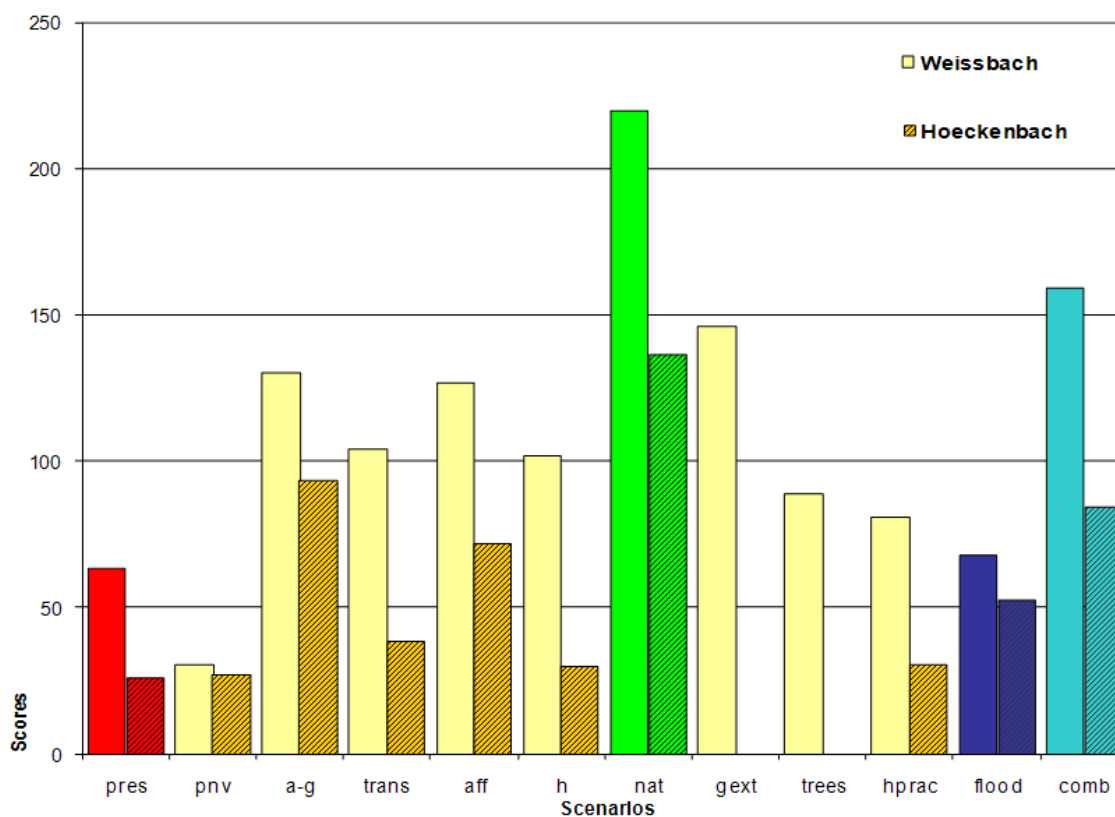


Figure 7: Landscape metrics comparison of the two sub-catchments (scores already standardised)

os analysed did not yield significant improvements in this area. For both sub-catchments, most of the scenarios resulted in higher scores compared to the present state and only the „complete reforestation with potential natural vegetation“ scenario attained lower scores in both sub-catchments due to the loss of habitat diversity in comparison to the present state. The ecological transformation of forests did not yield marked improvements due to the low percentage of forest area. The scenarios „arable field into grassland,“ „combination of nature conservation and flood prevention approach“ and „nature conservation measures“ all resulted in high scores for both sub-catchments, especially as a consequence of increased naturalness and improved landscape structure and composition (cf. SHDI and IJI in Table 4).

The integrative assessment of scenarios of land use changes, aimed at both flood prevention and nature conservation in a mountainous area, has shown that the implementation of the suggested measures in

the individual sub-catchments can result in dramatic improvements for both objectives (Fig. 8).

The potential for flood prevention was estimated by the GIS-based expert system WBS-FLAB (area of equal runoff components) and the Runoff-Precipitation model WaSiM-ETH (Merta et al. 2007, 2008). Even scenarios with measures directed exclusively at nature conservation yielded improvements in flood prevention. For example, these measures result in a reduction in the extent of areas with fast surface and sub-surface flow and a reduction of flood peaks in rivers (Merta et al. 2007, 2008). Similarly, land use management designed with respect to flood prevention had positive effects on nature conservation. The greatest effects were associated with land use changes over vast areas. However, individual measures such as the establishment of hedgerows may be positive both from the nature conservation and flood prevention perspective. They affect especially the local habitat, for example, by reducing soil erosion.

Importantly, measures aimed at flood prevention interact in a synergetic manner with nature conservation (habitat and species diversity, connectivity), landscape conservation and aesthetics (tourism and recreation potential) as well as soil protection (erosion stability). Moreover, these measures contribute to a balanced regional hydrological budget, which can mitigate negative consequences of summers with low precipitation levels.

Given this background, the use of landscape metrics for this purpose is new and proved to be successful. Past studies on hydrological processes have used landscape spatial features for modelling (e. g. surface water flow in catchments) (Gergel 2005). In contrast, for the present approach spatial data have been integrated into a rule-based expert system in order to predict various run-off components. On the other hand, investigations addressing conservation issues have focused on landscape metrics as an assessment tool on their own without taking into consideration traditional evaluation criteria at the site scale (e. g. Bär & Löffler 2007, Schindler et al. 2008). Here, spatially explicit information is recommended for scaling nature conservation assessment results from the patch to the landscape level.

5 Conclusion

The method presented here is a good basis for evaluating and comparing different land use scenarios in regard to their nature conservation value. The effect of land use changes depends heavily on the specific conditions of the landscape such as the presence of habitat and landscape elements with high relevance for nature conservation or vegetation structure (density, height, root depth etc.) with relevance to flood prevention (see Merta et al. 2007, 2008). Therefore, the results from the individual scenarios developed for the two sub-catchments cannot be transferred to other catchments. However, the methods developed for the assessment can be transferred to other regions as well as differently scaled catchment areas, provided that necessary data (e.g. land use types and distribution) are available.

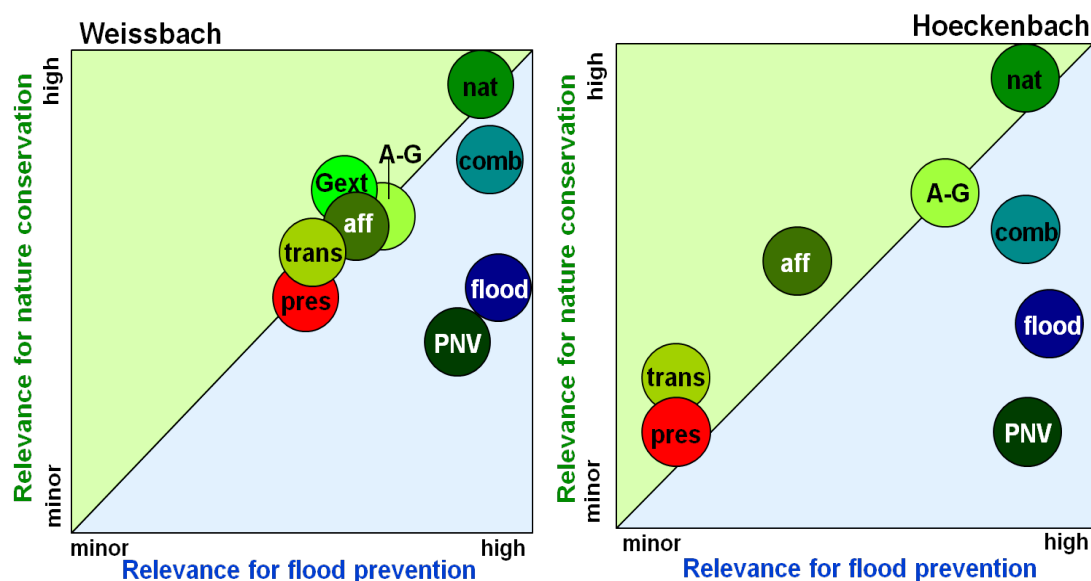


Figure 8: Combined assessment of land use scenarios with respect to flood prevention and nature conservation for the sub-catchments (for abbreviations of scenarios refer to Table 1).

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