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Conceptual classification model for Sustainable Flood Retention Basins

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Abstract

The aim of this paper is to recommend a rapid conceptual classification model for Sustainable Flood Retention Basins (SFRB) used to control runoff in a temperate climate. An SFRB is an aesthetically pleasing retention basin predominantly used for flood protection adhering to sustainable drainage and best management practices. The classification model was developed on the basis of a database of 141 SFRB using the River Rhine catchment in Baden (part of Baden-Württemberg, Germany) as a case study. It is based on an agglomerative cluster analysis and is intended to be used by engineers and scientists to adequately classify the following different types of SFRB: Hydraulic Flood Retention Basin, Traditional Flood Retention Basin, Sustainable Flood Retention Wetland, Aesthetic Flood Retention Wetland, Integrated Flood Retention Wetland and Natural Flood Retention Wetland. The selection of classification variables was supported by a principal component analysis. The identification of SFRB in the data set was based on a Ward cluster analysis of 34 weighted classification variables. Scoring tables were defined to enable the assignment of the six SFRB definitions to retention basins in the data set. The efficiency of these tables was based on a scoring system which gave the conceptual model for the example case study sites an overall efficiency of approximately 60% (as opposed to 17% by chance). This conceptual classification model should be utilized to improve communication by providing definitions for SFRB types. The classification definitions are likely to be applicable for other regions with both temperate oceanic and temperate continental climates.

Keywords: Environmental management; Flood retention basin; Rural runoff; Classification system; Flood protection; River Rhine; Germany; Baden; Cluster analysis; Principal component analysis

1. Introduction

1.1. Flooding risk and landscape planning

A statistically significant increase in precipitation has been observed in many regions of Northern Europe, particularly during the winter and spring seasons, inevitably resulting in an increased risk of flooding (Bardossy and Caspary, 1990). Future changes in moderate river peak flow are likely to depend on the variability of extreme rainfall in combination with land use management. These problems need to be addressed by civil and environmental engineers, urban and landscape planners, hydrologists and geomorphologists. To address these issues, the European Union funded projects such as IRMA-SPONGE aimed to assess the impact of flood risk reduction measures, as well as changes to land use and the climate, on the international River Rhine catchment planning process (Hooijer et al., 2004).

In light of this discussion, German flood retention basins ('*Hochwasserrückhaltebecken*' in German) have recently received increasingly more attention by politicians, planners and developers on the local and regional scale (Scholz, 2007). This has been confirmed by personal discussions with politicians and civil servants in Freiburg (Breisgau). The current design of German flood retention basins is based on outdated statistical rainfall events (ATV-DVWK, 2001), which are now called into question because of the reality of climate change.

1.2. Current general classification of floodplains and retention basins

Bastian et al. (2006) reviewed and assessed landscape classification systems, and pointed out their corresponding

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importance in terms of landscape diagnosis to assess different landscape functions. However, there are currently no effective classification schemes for floodplains and retention basins that could be of direct use for engineers and planners.

There are various useful scientific attempts that are of potential relevance for a new engineering classification system. For example, Schnitzler et al. (1992) indicated that floodplains could be classified according to plant species. Vegetation, soil and geomorphologic data can also be used to classify floodplains according to their degree of succession. The corresponding classes or groups may be used as a basis for rehabilitation strategies (Schoor, 1994). Carbiener et al. (1995) proposed a hierarchical classification of the following factors responsible for the distribution of vegetation (in order of decreasing importance): water mineralization, trophic status (particularly phosphate and ammonia), rheology, sedimentology and morphology. Furthermore, Haase (2003) examined indicators such as flood-loam expansion, groundwater table, relief and land use to characterize floodplain functionality in urban areas.

The ecological effects of water retention in the River Rhine Valley have been reviewed by Scholz (2007). This paper summarizes a relevant literature review assisting future retention basin classification.

1.3. Relevance of the Sustainable Flood Retention Basin (SFRB) classification methodology for stakeholders

The concept of SFRB is novel and based on the definitions and characterizations proposed by the authors. For the purpose of this paper, the authors define an SFRB as an "aesthetically pleasing retention basin predominantly used for flood protection adhering to sustainable drainage and best management practices". The word "sustainable" describes more than an 'attempt' and is linked to the well-known phrase sustainable drainage system, which describes a series of sustainable techniques and sustainable products such as combinations of, for example, swales, ponds, wetlands and/or infiltration structures predominantly within an urban context. However, an SFRB is not a traditional sustainable drainage system (Scholz, 2006).

The SFRB may or may not contain water, and its 'aesthetically pleasing' property refers to its ability to integrate well and non-intrusively with the surroundings from a landscape architecture or landscape management perspective. In the context of flood retention basins, the adjective 'sustainable' refers to the philosophy of 'sustainability', that seeks to provide the best outcomes in terms of design and operation of SFRB for the human and natural environments both now and into the indefinite future.

The link between more natural types of SFRB and German flood retention basins is that the latter is likely to transform into the former over decades of neglect, lack of maintenance and overgrowth. Alternatively, it is possible to build a flood retention basin which can be classified as an SFRB straight away, if the design and management strategies are holistic (taking sustainable drainage, social issues, habitat ecology, landscape aesthetics and other issues into account) from the very beginning.

The rapid classification methodology is relevant for stakeholders and decision-makers such as local authorities, politicians, community interest groups and non-governmental organizations, and it will greatly assist them with subsequent urban and landscape planning. The classification itself is required to aid communication between the various bodies, in order to avoid misunderstandings and legal disputes which result from current practice as there are, as of yet, no widely-accepted definitions for different types of retention basins. This is true not only for Germany, but also on an international scale. Methods to assess decision-making processes relevant for flood management have been discussed elsewhere (Akter and Simonovic, 2005).

The current legal status of the German flood retention basins and their catchments, in terms of planning law, is not clear. For example, the question may arise if a town is allowed to upgrade an existing German flood retention basin, which has become an SFRB or nature reserve, or if it is required to build a new German flood retention basin (such a structure is labor-intensive and costs millions in any currency). This clearly shows that there are large financial matters involved in solving planning disputes. A classification scheme for retention basins in general, and their different subgroups (of which SFRB may be considered to be one), is therefore timely and urgently required to support communication between stakeholders.

1.4. Aim and key objectives

The aim of this research paper is to define SFRB and, in particular, to characterize subclasses (i.e. types) for these SFRB in temperate climates such as Baden, Germany (Fig. 1) with the help of a rapid conceptual classification model. The key objectives are as follows:

- to provide stakeholders from very different backgrounds with a 'common language' to aid communication by avoiding misunderstandings with respect to planning and legal matters concerning the status of SFRB;
- to determine and characterize all relevant and particularly the key independent classification variables using a principal component analysis (PCA);
- to assess the uncertainty associated with the numerical value of each classification variable;
- to determine weightings for all classification variables based on a correlation analysis and estimation certainties, supported by the PCA analysis;
- to develop the conceptual classification methodology with the support of a large and detailed example case study data set; and
- to illustrate and discuss examples of the most relevant SFRB types for civil and environmental engineers and landscape planners.

2. Methods

2.1. Overview of the methodology

A mathematically sound methodology has been developed to justify the very concept of classifying SFRB in a case study

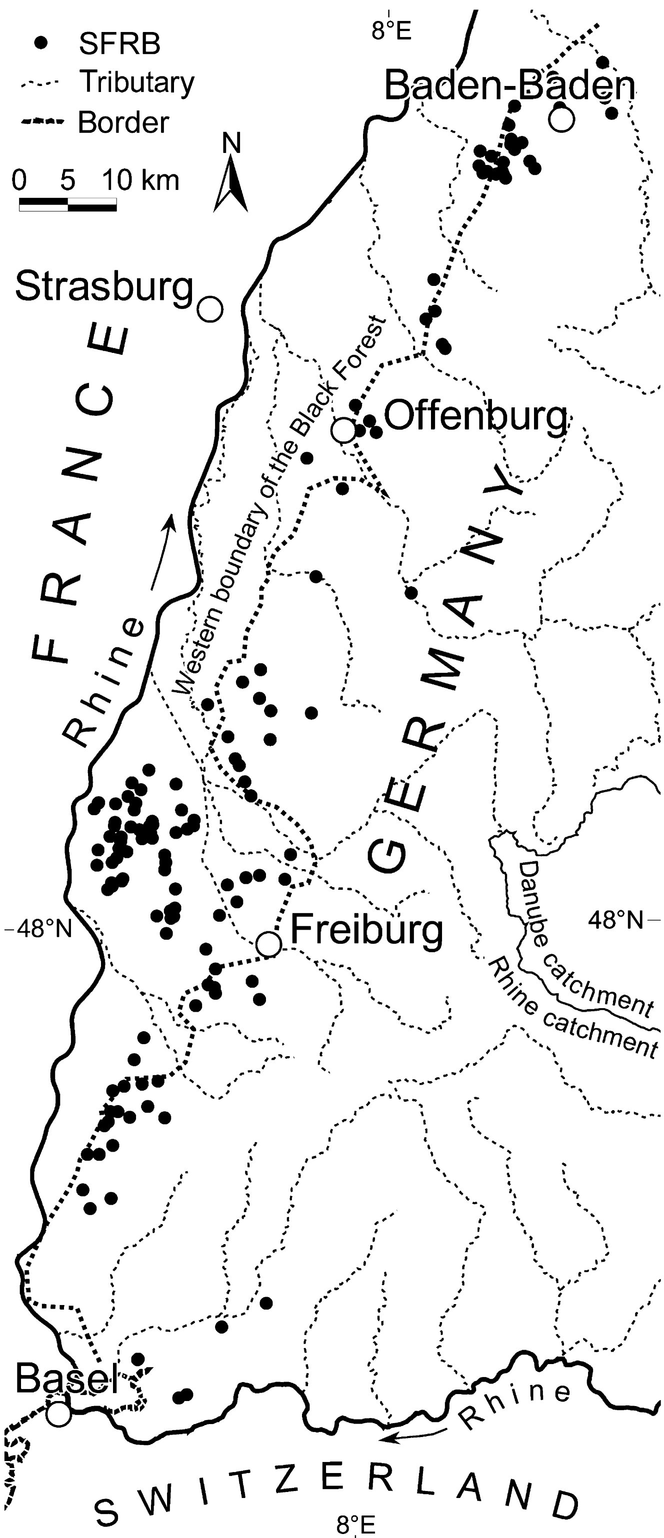

Fig. 1. Map showing the entire study area in the European context and particularly the 141 identified SFRB in Baden (Germany). The weakly dotted line running roughly through Offenburg and Freiburg represents the western boundary of the Black Forest.

area with a high density of flood retention basins allowing the research team to visit a large number of sites within one season. Firstly, six SFRB subclasses are defined based on expert judgment provided by engineers, scientists and environmentalists working at The University of Edinburgh (including authors) and the Albert Ludwigs University of Freiburg (including collaborators named in the acknowledgement section). Furthermore, it is necessary to create a set of measurable physical parameters in order to relate a real flood retention basin, which has been deemed to comply with the authors' definition of an SFRB, to its predetermined conceptual classification. These parameters, of which there are 34 in total, have been named 'classification variables' and are intended to be a reasonable compromise between the accuracy and rapidity required in their assessment. It is also necessary to devise a weighting system to account and possibly compensate for the uncertainty of measured values and for the relative importance of the classification variables.

The methodology also makes use of two powerful statistical techniques, notably cluster and principal component analyses. The cluster analysis involves the forceful grouping of the results of the classification surveys of all 141 SFRB into six distinct clusters. Then, using a system of scores for the measured values of all classification variables per SFRB and scoring templates for each predefined SFRB subclass, it is possible to identify which cluster relates best to which SFRB definition. It is also possible to create a classification methodology for future SFRB based on these scoring templates.

2.2. Identification of classification variables and the definition of SFRB types

Based on discussions with regional landscape managers, the authors estimate that there are in excess of 3000 areas within the River Rhine catchment of the state of Baden-Württemberg (south-west of Germany), which could be classified as retention basins using the widest possible definition in agreement with German guidelines (ATV-DVWK, 2001).

The authors' own definitions and characteristics for six subclasses of SFRB as a function of their predominant purpose based on expert judgment, feedback from collaborators including landscape planners, data collected during desk studies and field visits have been listed (Table 1). Furthermore, the characteristics of each SFRB type are also based on the interpretation of findings obtained from the statistical evaluation (see below). The six subclasses are the following: Hydraulic Flood Retention Basin (type 1), Traditional Flood Retention Basin (type 2), Sustainable Flood Retention Wetland (type 3), Aesthetic Flood Retention Wetland (type 4), Integrated Flood Retention Wetland (type 5) and Natural Flood Retention Wetland (type 6). The numerical order of these definitions is deliberate and important, as an SFRB of any one type exhibits natural tendencies towards both the preceding and successive types (i.e. type 2 tends to both types 1 and 3). The above definitions of SFRB subclasses are independent of all statistical analyses and were formulated based on expert judgment (see above) and logical empirical observations (e.g. too few types would result in a too coarse classification system and too many classes would make classification too time-consuming and impractical) before the latter were carried out.

Table 1
Definition of the Sustainable Flood Retention Basin (SFRB) types

Type	Name	Definition of SFRB type	Characteristics
1	Hydraulic Flood Retention Basin (HFRB)	Managed traditional SFRB that is hydraulically optimized (or even automated) and captures sediment	Very high rainfall and seasonal impact; high site elevation; normal floodplain elevation; very highly engineered or even automated with high outlet flexibility; fully managed and tidy in appearance; very high flood water volume; very deep flooding depth; potentially high basin gradient; very large flood surface area; very long wetted perimeter and dam; very problematic animal passage; high algal cover in spring and summer if permanently flooded; usually very dry; inorganic sediment; very high pollution; very low vegetation cover; very little groundwater infiltration; very large (forested) catchment
2	Traditional Flood Retention Basin (TFRB)	Aesthetically pleasing retention basin used for flood protection adhering to sustainable drainage and best management practices	Very high rainfall and high seasonal impact; high site elevation; managed, highly engineered or even automated with high outlet flexibility; quite high flood water volume and deep flooding depth; potentially high basin gradient; large flood surface area and long wetted perimeter; high and long dam; problematic animal passage; algal cover in summer; mostly dry; inorganic sediment; very low vegetation cover; not excessively polluted; little groundwater infiltration; large and partly forested and cultivated catchment
3	Sustainable Flood Retention Wetland (SFRW)	Aesthetically pleasing retention and treatment wetland used for passive flood protection adhering to sustainable drainage and best management practices	High rainfall and clearly recognizable seasonal impact; relatively low engineered; some outlet flexibility; acceptable animal passage; medium flood water volume and quite shallow flooding depth; normally high and long dam; average wetted perimeter and flood surface area; usually highly polluted if wet; partly wet; mainly inorganic sediment; substantial vegetation cover; average (highly urbanized) catchment size
4	Aesthetic Flood Treatment Wetland (AFTW)	Treatment wetland for the retention and treatment of contaminated runoff, which is aesthetically pleasing and integrated into the landscape and has some social and recreational benefits	Fairly low rainfall; highly engineered; high flood water volume and shallow flooding depth; acceptable animal passage; flat and short dam; short wetted perimeter; easy animal passage; large flood surface area; usually highly polluted and quite wet; substantial vegetation cover; catchment with no dominant usage; no strong geometrical variables; appearance similar to constructed treatment wetland
5	Integrated Flood Retention Wetland (IFRW)	Integrated flood retention wetland for passive treatment of runoff, flood retention and enhancement of recreational benefits	Natural; flat and short dam; low flood water volume and very shallow flooding depth; small flood water surface area and short wetted perimeter; easy animal passage; usually highly polluted with high organic sediment; usually substantially wet; very high vegetation cover; small catchment; appearance similar to constructed treatment wetland
6	Natural Flood Retention Wetland (NFRW)	Passive natural flood retention wetland that became a site of specific scientific interest requiring protection from adverse human impacts	Very natural and most likely a site of specific scientific interest; flat and short dam and virtually no outlet flexibility; very low flood water volume and very shallow flooding depth; very small flood surface area and short wetted perimeter; very easy animal passage; usually very wet; usually deep natural organic sediment layers (originating predominantly from within basin vegetation for mature SFRB); little pollution; very high vegetation cover; very small catchment with dominant pasture cover; high groundwater infiltration; possibly neglected for decades

The most important classification variables (Table 2) for various types of SFRB in Baden (Fig. 1; 48°N and 8°E) were identified and grouped. These were determined on the basis of literature reviews, various recent site visits in Germany, UK, Ireland and Denmark, and group discussions among British, German, French, Irish and US engineers, scientists, and landscape and urban planners.

The user should be able to estimate most variables during a desk study, which should take approx. 20 min, and during a site visit of approx. 40 min. A certainty percentage point (i.e. low = 1–40%; medium = 41–60%; high = 61–100%) was attributed to each variable during the desk and field studies to reflect the likelihood of selecting a correct value.

Table 2
Prioritization example for classification variables used for a detailed data set of 141 Sustainable Flood Retention Basins in South Baden (Germany)

ID	Variable	PP[a]	Correlation[b]	Certainty[c]	Mean	SD[d]
18	*Mean Annual Rainfall* (mm)	545	6.9	79	741	95.3
21	*Seasonal Influence* (%)	515	6.2	83	74	5.8
2	*Dam Height* (m)	517	6.3	82	4.29	2.870
33	*Forest and Natural Catchment Proportion* (%)	454	6.3	72	27	25.6
6	*Floodplain Elevation* (m)	445	5.7	78	0.56	1.124
8	*Wetness* (%)	411	5.2	79	17	25.3
32	*Pasture Catchment Proportion* (%)	406	5.8	70	43	30.0
7	*Basin and Channel Connectivity* (m)	402	4.1	98	0.9	4.20
15	*Wetted Perimeter* (m)	384	6.5	59	339.5	398.75
4	*Outlet Arrangement and Operation* (%)	380	5.2	73	22	23.2
22	*Site Elevation* (m)	369	4.1	90	231.5	65.87
5	*Aquatic and Land Animal Passage* (%)	362	4.7	77	29.5	22.47
29	*Catchment Size* (km^2)	360	6.2	58	5.6	10.70
3	*Dam Length* (m)	344	4.3	80	240.8	460.49
23	*Vegetation Density* (%)	332	4.2	79	50	27
17	*Flood Water Surface Area* (m^2)	330	5.5	60	13 994.6	37 519.22
25	*Relative Total Pollution* (%)	310	4.7	66	48	21.4
30	*Urban Catchment Proportion* (%)	312	4.0	78	11	16.5
16	*Maximum Flood Water Volume* (m^3)	306	3.6	85	67 094	263 003.2
1	*Engineered* (%)	289	3.9	74	51	19.1
28	*Flotsam Cover* (%)	277	3.8	73	28.6	27.61
20	*Impermeable Soil Proportion* (%)	276	6.0	46	20	22.2
31	*Arable Catchment Proportion* (%)	270	3.7	73	16	22.2
26	*Mean Sediment Depth* (cm)	264	4.0	66	3.7	6.36
24	*Algal Cover in Summer* (%)	267	3.0	89	3.2	11.02
9	*Flow in Channel* (%)	251	2.7	93	96	15.0
34	*Groundwater Infiltration* (%)	240	3.0	80	2.3	5.81
11	*Typical Wetness Duration* ($d\,a^{-1}$)	244	4.2	58	38.7	92.62
13	*Mean Bed Gradient* (%)	221	3.2	69	2.7	3.26
19	*Drainage* ($cm\,d^{-1}$)	216	4.7	46	11.9	11.97
27	*Organic Sediment Proportion* (%)	208	3.1	67	42.6	18.79
12	*Flood Frequency* (a^{-1})	176	3.6	49	6.0	5.47
10	*Mean Flooding Depth* (m)	159	2.6	61	1.8	3.05
14	*Mean Basin Flood Velocity* ($cm\,s^{-1}$)	154	3.5	44	36	41.3

[a] Priority points = correlation (column 4) × certainty (column 5).
[b] Sum of all absolute correlation coefficients for one particular variable with all other variables.
[c] Certainty of a correct value expressed in %.
[d] Standard deviation.

Certainty estimations depend very much on the expertise and bias of the user.

2.3. Rationale for the selection of weightings

The classification variables have been summarized in Table 2. Standardized values are not shown because of their high number (4794 in total), but means and standard deviations for all variables characterize the example data set well.

Table 2 outlines an unbiased attempt to score and prioritize the classification variables. The scores are calculated both on the basis of a correlation analysis of all 34 variables with each other using the Pearson's correlation formula (Minitab, 2003) and on the certainties of the measurements and/or estimates obtained by the researchers in the field. The priority scores associated with the weightings should be seen as guidelines only and are by no means fixed.

The priority scores were obtained as a function of a correlation matrix, which was simply a diagonal 34 by 34 matrix containing the correlation coefficients of each variable with all other variables. One triangular half of the matrix was set to zero to avoid duplication (the matrix is symmetrical), as were the entries for the correlations of each variable with itself, which obviously constituted unity. Consequently, the corresponding row and column were summed for each variable (column 4, Table 2), and this value was multiplied by its corresponding certainty (mean percentage between 1 and 100; column 5, Table 2) to give the priority point (column 3, Table 2). These scores were subsequently standardized (i.e. divided by the maximum score) to obtain dimensionless weightings between 0 and 1. The application of the weights merely involved their multiplication with each of the numerical entries for the corresponding variables. This result was then also standardized for the benefit of the subsequent cluster analysis. Alternatively, a more advanced weighting system could have been made up on the basis of the PCA results (e.g. Fig. 2).

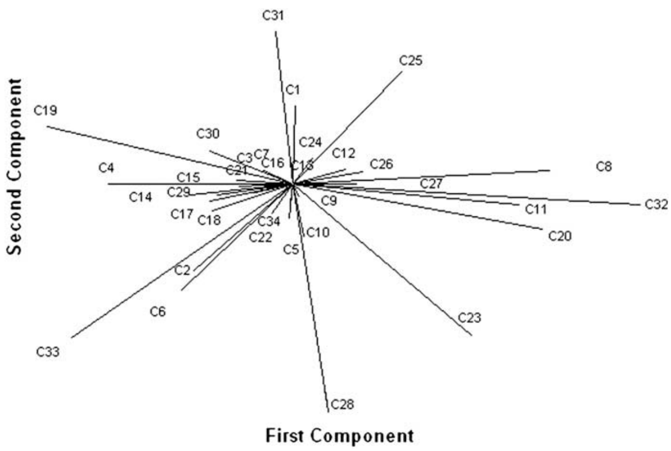

Fig. 2. Loading plot of the principal component analysis identifying the most important classification variables and their similarities with each other.

2.4. Assignment of SFRB types with the help of cluster analyses

The statistical software package Minitab 14 (Minitab, 2003) was used to perform cluster analyses on the standardized example data set. The clustering technique used was an agglomerative method (otherwise known as a 'bottom up approach'). The results are displayed on a dendrogram which allows an unambiguous appreciation of the cluster properties of the data (Fig. 3).

Aside the distance criterion in clustering, the analysis was carried out twice using different cluster linkage criteria (where more than two entries need to be compared). The first analysis involved 'average linkage' and was used exclusively to identify the top outliers in the data (see below). The second analysis used 'Ward's linkage', which effectively forced the data into a predefined number of clusters thus eliminating outliers (Kaufman and Rousseeuw, 1990). In this case, the objective was to obtain as many clusters, as there are SFRB subclasses

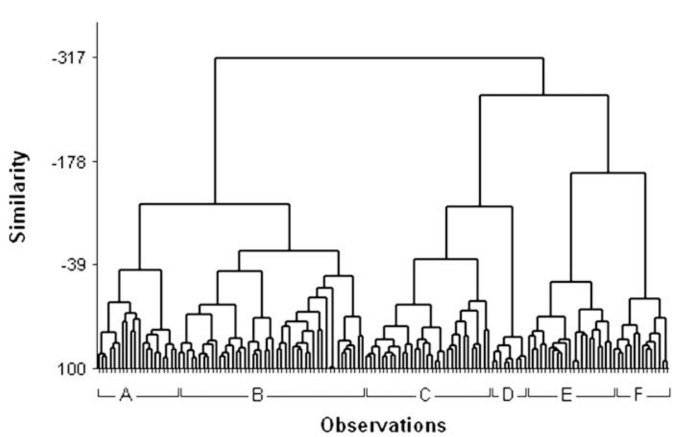

Fig. 3. Dendrogram of the data set of 141 retention basins (observations on *x*-axis) with Ward linkage and Euclidian distance used to identify the six Sustainable Flood Retention Basin types.

(data not shown), of which there are six. The resulting dendrogram (Fig. 3) shows a very favorable distribution of data points, with no single cluster holding too many or too few entries.

After the Ward cluster analysis had grouped the 141 data points' (one point corresponds to all 34 variable values per site) sites into six groups, the general statistics of each cluster were found. The objective was to determine which SFRB type corresponded best to which newfound cluster, and this was done on the basis of an intelligent scoring system.

Firstly, the mean value of each variable of each cluster (some data are shown in Fig. 3 and Table 3) was compared to the maximum mean value of all the six clusters combined. If the mean was at or above 90% of the maximum mean, the variable got a score of 10. If it was at or above 80%, it got a score of 9. Between 20 and 80%, the score was 4, below 20%, the score was 2, and below 10%, it was 1.

Secondly, a template of score characteristics was devised independently of the above for each SFRB type, on the basis of the definitions (Table 1) and on the expert knowledge of the research team (scores are not shown). For example, a Hydraulic Flood Retention Basin would have a value of 10 for the *Engineered*, *Rainfall* and geometric variables (amongst many others), 9 for the *Site Elevation*, 4 for variables such as *Sediment Depth* and *Slope*, and low values of 2 or 1 for *Aquatic and Land Animal Passage* and *Vegetation Density*. The actual scores were then compared with the template scores by dividing one against the other for each site, inversing values greater than unity, and summing each score.

2.5. Classification methodology for future SFRB

A preliminary classification template (Table 4) was created on the basis of the observed means and expected ranges of variables, and also on the basis of the relevance of each variable to any SFRB type (Table 1). The template follows a very similar logic to that of the weighting methodology, and the results are scored identically to the Ward cluster analyses.

The classification template (Table 4) is very straightforward to use. For example, if a site scores 55% for the *Engineered* variable, then it gets a score of 10 and if its dam is only 10 m long, it gets a score of 1 for the *Dam Length* variable, and so forth. Finally, each entry in this column of scores is then divided by its corresponding entry in each of the columns labeled types 1–6 (Table 4), all values greater than unity are inversed, and the scores are summed. The SFRB type that received the highest numerical score is likely to give the class of the site.

2.6. PCA theory and methodology

The application of the PCA with the help of Minitab (Minitab, 2003) helped to get a better overview of the underlying data structure. On the basis of the loading plot (Fig. 2), it may be possible, where several variables are grouped closely

Table 3
Scoring results for different SFRB types (based partly on Table 2 and Fig. 3)

Ward cluster	Type 1 (HFRB)	Type 2 (TFRB)	Type 3 (SFRW)	Type 4 (AFTW)	Type 5 (IFRW)	Type 6 (NFRW)
A	13.164	***14.589***	13.462	10.707	8.201	7.357
B	***14.360***	13.958	13.554	13.047	9.153	6.340
C	11.313	11.365	***15.110***	13.884	10.924	8.125
D	8.969	9.686	11.711	11.527	12.208	***10.305***
E	9.815	10.840	13.956	***15.058***	11.813	9.916
F	10.440	10.751	14.402	13.642	***12.659***	9.197
Conclusion	B	A	C	E	F	D
No. of entries	46	20	28	21	14	12

Note: the highest entries per SFRB type are highlighted in bold and italics.

together, to extract one single variable which may then replace the entire group. Besides the obvious time-saving advantages to this, the main point of the PCA is to remove redundant variables, hence reducing the risk of multicollinearity.

Nonetheless, during the data gathering stage all 34 variables were investigated. The cluster analysis and classification were performed twice: (a) using all 34 variables and (b) using only 28 variables.

3. Results

3.1. Cluster analyses

The ‘average linkage’ cluster analysis identified the 10 top outliers in the original full data set of 146 SFRB, on the basis of which five outliers were removed. These five removed sites included a water reservoir, an offline polder used for river flow

Table 4
Classification template based on 34 variables (identification (ID) codes described in Table 2) for future Sustainable Flood Retention Basin types (defined in Table 1)

ID	10	9	4	2	1	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
1	>50	>45	≥25	≥20	<20	10	9	4	9	2	1
2	>8	>5.5	≥3.5	≥1.5	<1.5	10	10	4	4	2	1
3	>900	>700	≥100	≥60	<60	9	4	2	1	2	1
4	>85	>75	≥15	≥8	<8	10	9	4	2	2	1
5	>70	>60	≥20	≥10	<10	1	2	4	4	9	10
6	>2	>1.25	≥1	≥0.5	<0.5	4	4	2	2	1	1
7	>20	>15	≥5	≥1	<1	1	1	1	2	2	4
8	>45	>35	≥25	≥5	<5	1	2	4	4	9	4
9	>99	>95	≥90	≥80	<80	10	9	9	9	9	4
10	>4	>2	≥0.9	≥0.4	<0.4	10	9	4	4	1	1
11	>350	>200	≥20	≥5	<5	2	4	2	4	10	9
12	>12	>9	≥5	≥1	<1	10	10	9	4	4	2
13	>13	>8	≥4	≥2.5	<2.5	4	4	2	4	2	1
14	>150	>125	≥65	≥45	<45	9	9	4	4	2	1
15	>1100	>850	≥200	≥90	<90	10	9	4	2	4	4
16	>500	>100	≥50	≥1.5	<1.5	10	9	4	2	1	2
17	>1000	>600	≥20	≥4	<4	10	10	4	2	4	2
18	>1000	>900	≥800	≥750	<750	10	10	10	4	4	2
19	>10	>5	≥1	≥0.5	<0.5	2	4	4	4	9	9
20	>40	>25	≥5	≥2	<2	2	2	4	9	9	2
21	>80	>60	≥55	≥45	<45	10	9	9	4	4	2
22	>400	>350	≥280	≥150	<150	9	9	9	4	2	1
23	>80	>60	≥30	≥10	<10	1	1	4	4	9	10
24	>70	>50	≥10	≥3	<3	9	4	4	1	1	1
25	>60	>35	≥15	≥7	<7	9	4	4	9	9	1
26	>9	>6	≥2	≥0.5	<0.5	4	4	4	4	9	10
27	>80	>60	≥40	≥20	<20	1	1	2	4	9	10
28	>80	>70	≥30	≥10	<10	4	4	4	4	2	10
29	>30	>15	≥2	≥0.5	<0.5	10	9	4	4	2	1
30	>65	>45	≥15	≥4	<4	4	4	9	4	2	1
31	>50	>35	≥8	≥4	<4	4	4	9	4	4	1
32	>85	>75	≥30	≥10	<10	9	9	4	4	4	9
33	>60	>50	≥10	≥7	<7	10	9	4	4	2	2
34	>50	>40	≥10	≥5	<5	2	1	2	2	2	9

regulation, a below ground sewage tank and two fish ponds, all of which did not conform to the authors' definition of an SFRB. The remaining outliers were indeed proper SFRB. Consequently, these were kept in the data set. The results of the cluster analyses are shown in Table 3 and Fig. 3.

3.2. Reduction exercise for the classification variables

An attempt was made to reduce the total number of variables based on the results of the PCA. The loading plot (Fig. 2) allowed 15 definite independent variables, two approximate groups of dependent variables and four definite groups of dependent variables to be identified.

For the dependent variables, the PCA found an approximate but obvious relationship between the *Wetness* (8), *Wetness Duration* (11) and *Impermeable Soil* (20) variables. For the experimental cluster analysis (Fig. 3) with fewer variables, it was recommended to keep the *Wetness* variable only. A further approximate dependence was found between the *Mean Flooding Depth* (10), *Site Elevation* (22) and *Groundwater Infiltration* (34) variables. As this dependence was only approximate, it was recommended to keep all three.

Definite dependencies were found between the *Dam Height* (2) and *Floodplain Elevation* (6), the *Flood Frequency* (12), *Sediment Depth* (26) and *Organic Sediment* (27), the *Wetted Perimeter* (15), *Water Surface Area* (17), *Mean Annual Rainfall* (18) and *Catchment Size* (29), and finally the *Dam Length* (3), *Mean Basin Flood Velocity* (14), *Maximum Flood Water Volume* (16) and *Seasonal Influence* (21). The redundant variables, which could have been omitted in the future, had the results supported it, were *Wetness Duration* (11), *Impermeable Soil* (20), *Floodplain Elevation* (6), *Wetted Perimeter* (15), *Mean Basin Flood Velocity* (14) and *Seasonal Influence* (21), thus making the total number of variables 28. Furthermore, it was found that the SFRB classification on the basis of a Ward cluster analysis (Fig. 3) with 34 variables received a score of 86 out of 141 (61%), whilst that based on 28 variables received a score of 82.8 (58.7%).

4. Discussion

4.1. Groupings based on cluster analysis

Each cluster can be directly linked to an SFRB type, thus justifying their original choice, definition and number. The distribution of cluster entries in the corresponding SFRB types was both explainable and expected. The reason is that virtually all retention basins are initially built purely for flood protection (hydraulic) purposes. As a result, this purpose and hence this SFRB type still dominates the data base, even decades after construction or the last significant flood.

What has changed is that after years of absence of major local floods, total dryness, total wetness or neglect, the purposes of many sites have changed, and the types have 'shifted' from the original purely hydraulic function to something more sustainable, aesthetic or natural. Some sites have become so overgrown that they would not be able to handle the design flood any more and have instead become nature reserves, some even protected by law. The conceptual model provides clear definitions for the past and current (i.e. after aging) status of SFRB aiding therefore communication between different stakeholders.

4.2. Application of the conceptual SFRB classification methodology for Baden-Württemberg

A literature review on flood retention basins in the international context has been provided by Scholz (2007). On a more specific regional scale, the authors estimate that the total retention volume of the predominantly managed, large, engineered flood retention basins on record is likely to be over 95% of the total retention basin volume in the River Rhine catchment of Baden-Württemberg. The remaining retention basins are dominated by watercourses such as wet meadows, ditches and semi-natural ponds. Such basins are excluded from the proposed SFRB classification system because of their large number and very small size. Moreover, their locations are not officially noted.

The cluster analysis has shown that there are obviously large variations even among the key characteristics of SFRB, which are used predominantly for hydraulic purposes such as water retention and sedimentation, or which are located in the same area (e.g. The Kaiserstuhl in South Baden). The classification methodology can therefore be used to further subclassify SFRB.

For example, pictures (Figs. 4 and 5) for two SFRB classified as types 1 and 6 (Table 1) have been provided. The first example (Fig. 4) is a fully automated basin dominated by engineering structures including outlets for the base flow and normal flood flow, as well as a massive spillway. The second example (Fig. 5) is a Natural Flood Retention Wetland (NFRW). This is a passive natural flood retention wetland that became a site of specific scientific interest requiring protection from adverse human impacts. This NFRW is not

Fig. 4. Example of a Hydraulic Flood Retention Basin (type 1) in Kutzmühle (Neuenburg, Baden) on 8 May 2006.

Fig. 5. Example of a Natural Flood Retention Wetland (type 6) near Oberrotweil (The Kaiserstuhl, Baden) on 4 July 2006.

hydraulically optimized, but it is well integrated into the landscape and does bring ecological benefits.

4.3. Accuracy of the template and common standard of classification

It is important to stress that the concept of SFRB is novel. There is currently no official methodology to classify flood retention basins including SFRB. The conceptual model is holistic and multidisciplinary. A typical engineer or scientist with conventional academic and professional qualifications would not have the knowledge and experience to perform a classification accurately without Table 1 and/or Table 4. Moreover, he or she would 'lack confidence' without the guidance provided in this paper.

The user should apply some degree of common sense to determine whether the result of the classification model is plausible, as the current template has been found to be only approximately 60% accurate according to the scoring system based on the example data set. Nonetheless, this percentage score is relatively high considering that there are six possibilities and, by chance, the probability of choosing the correct one out of the six possible classes is 17%. However, the error of 40% refers only to the particular case study in Baden. The proposed conceptual model is therefore only a guidance tool for inexperienced stakeholders and does not replace expert knowledge (summarized in Table 1). An engineer or scientist experienced with SFRB is likely to make predictions with an error much less than 40%.

The template may be revised to suit different regions and should subsequently be applied by practitioners such as environmental consultants and landscape planners. The methodology is likely to be applicable to most parts of Europe and Northern America and other regions with both temperate oceanic and temperate continental climates. This is justified based on the large number of sites within the case study and variables assessed by the international team of experts. Landscape planners of the Institute for Landscape Management (Albert Ludwigs University of Freiburg) have tested the proposed conceptual model successfully during the development phase.

More tests on different data sets in other regions and countries involving more engineers, scientists and environmentalists need to be performed to increase the accuracy of the template. However, the template is based purely on mathematical and statistical considerations and is therefore not perfect. It does certainly not replace expert judgment. As a consequence, Table 1 can be interpreted as the 'common standard' to which engineers and scientists should be trained in the meantime. The content of Table 1 is based on empirical observations and the interpretation based on the findings obtained from the statistical evaluation (e.g. Table 4). Furthermore, it should be emphasized that the proposed methodology not just classifies flood retention basins but also provides a large database assisting in their future management (see above).

5. Conclusions

This paper has defined a Sustainable Flood Retention Basin (SFRB) as an aesthetically pleasing retention basin predominantly used for flood protection adhering to sustainable drainage and best management practices. The following new subtypes were defined: Hydraulic Flood Retention Basin (HFRB), Traditional Flood Retention Basin (TFRB), Sustainable Flood Retention Wetland (SFRW), Aesthetic Flood Treatment Wetland (AFTW), Integrated Flood Retention Wetland (IFRW) and Natural Flood Retention Wetland (NFRW).

The identification of SFRB in the data set adhering to these definitions was predominantly based on a Ward cluster analysis of 34 weighted qualitative and quantitative classification variables. The data set consisted of 141 flood retention basins, with 34 variables per basin, investigated in the region of Baden-Württemberg, Germany, between the months of April and July 2006. Scoring tables were defined to enable the assignment of the six SFRB definitions to retention basins in the data set, and also to future retention basins that need to be classified.

This proposed conceptual classification model may be utilized elsewhere by practitioners such as landscape planners, and the classification definitions are likely to be applicable for similar regions with both temperate oceanic and temperate continental climates.

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jenvman.2007.12.018.

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