Development of a rule-based fuzzy set classification model to determine process-based Chemical Hydrological Response Units (CHRUs) within the ArcView GIS ®

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Keywords: *Modeling & Assessment of nutrients dynamics; Fuzzy-Set classification; Response Units; GIS.*

EXTENDED ABSTRACT

Regarding nutrients impacts on river systems there is a great need to detect significant non point source areas being responsible for producing high amounts of impacts within a watershed. Moreover to cope questions of scales a multiscale analysis is imperative for understanding the dominant structure, function and dynamics. Thereby it is necessary to gain an insight of catchment processes on water and nutrients fluxes on these highly important areas. In response to this fundamental issue of great concern in hydrological and hydrochemical research is how to engage areas having a strong similarity in their process behavior. Because of spatial heterogeneity consequently the importance of this knowledge is especially valid when dealing in large-scaled catchments.

Hence in hydrological science the GIS-based approach of Hydrological Response Units (HRU) and Chemical Hydrological Response Units (CHRUs) is well established considering catchments heterogeneity (Leavesley & Stannard 1990; Flügel 1995, Kern & Stednick 1993, Bende 1997). Being part of distributed hydrologic or solute models pre-processing GIS-routines these units are delineated according to the spatial information, such as topography, soils and landuse. Overlay analysis and reclassification operations are applied in terms of spatial reasoning: unique spatial patterns are formed and related to dominant hydrologic and/or hydrochemical processes.

By taking lateral flow mechanism (‘runoff-runon’) into account the occurrence of dominant processes is strongly influenced by the interaction of these spatial catchment patterns. Therefore hydrologic and solute dynamics are consequently more complex (Fink 2004). With respect to this paper suggests an alternative view on such spatial categories. Thereby these units have to be defined according to the knowledge of unique process dynamics and relate them to spatial patterns (Bende-Michl 2004).

This is even more challenging due to the fact that uncertainty plays a role in classification of those process attributes. In this case several types of uncertainty appeared including kind of affiliations of processes. Considering their gradual process boundaries they can be classified by using fuzzy sets (Petry *et al.* 2004).

With the perspective of this a rule-based fuzzy set classification model was implemented within the ArcView GIS ® to assess homogeneous areas according to their variable turnover- and translocation dynamics in case of nitrogen and to observe their spatial relations. These units determine how hydrologic and hydrochemical processes reason about areas having impacts on river systems by conserving all process information for a specific unit.

The approach was developed for the 216 km² Bröl catchment, located in the middle mountain range area in Germany. It was successfully applied by

(i) Modeling significant nitrogen turnover and translocation process composing lateral flow dynamics by using the hydrochemical model WASMOD on the spatial distribution approach of ‘Smallest Common Geometries’ (SCGs),

(ii) setting up a fuzzy set classification model within the GIS ArcView®

(iii) Comparing and analyzing fuzzy classification CHRU results to spatial catchment properties.

The most benefit is using the tool for assessment studies like monitoring and detecting significant spatial and temporal variable non point sources by conserving the complex of underlain hydrologic and hydrochemical process information. It is also designed for application in other regions, where there is a great need to observe effects of management changes on river systems.

1. INTRODUCTION: RESPONSE UNITS AND UNCERTAINTY

Spatial heterogeneity is ubiquitous in nature across all scales and its formation and interactions with hydrological processes is one of the central issues in hydrologic studies. For hydrologic and solute modeling the use of 'response units', is well introduced to capture the complexity of natural spatial heterogeneity within a catchment. In general response units are geographical entities that are characterized by one or several attributes and by different instants of time (*t*) and by a spatial extend (*x*, *y* and *z* coordinate). The latter is described as the region of geographical space where the attribute or property exists (Fonte & Lodwick 2004).

In hydrologic science discussions on the delineation procedures of 'response units' recommended that, used as a zonal oriented approach, these attributes should have a certain understanding of dominant controls on hydrologic or hydrochemical processes within a particular area. Generally expressed the delineation of response units could be explained as follows. First of all is the determination of the range of *z* values (hydrologic and solute base attributes (A_b) such as measured or simulated values on a *Z scale* like evapotranspiration, denitrification rates) that fits to a derived attribute (A_d).

This is then declared by $Z_A = [\underline{z}, \overline{z}]$.

Second is to detect the membership function if the value of the base attribute (A_b) fits into a region (r_i) or not (F ‿. 1). In affirmative case that is designated by $z(r_i)$ and the classification results will be outlined as '*A*'**.** Therefore it has to be proofed whether $z(ri) \in [\underline{z}, \overline{z}]$ or not. The latter of course does not belong to '*A*'.

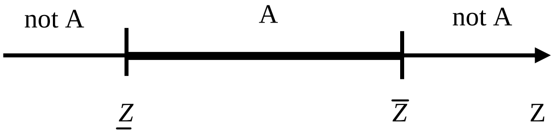

Figure 1. Z values for the attribute '*A*' (after Fonte & Lodwick 2004)

Results of this classification are typically Boolean, i.e. results pertaining to a derived attribute or not. Hereby the varying principles of delineation are based on

(i) Dominant landscape elements and their arrangements which include a complex system analysis (Flügel 1995). First of all the GIS-overlay based HRU concept suggests to derive units through overlaying geology, soil and topography information, because all layers are interacting according to weathering-, erosion-, and accumulation mechanism (geo-pedo-topo sequences). Adding landuse information they are located on a specific geo-pedo-topo sequence providing different contributions on the hydrologic processes. In terms of solute modelling landuse information have to be more differentiated, because of management operations (Bende 1997). Generally it is criticised that the spatial relation between adjacent areas is overlooked due to runon-runoff processes.

Secondly there exists knowledge of rule-based concepts based on the observation and validation in well-instrumented small catchments and transferring the results on the model scale (Müller 1998, Waldenmeyer 2003). Thereby rules are derived according to the observed and predicted catchments response on precipitation input and its variable effects on existing hydrologic processes. Coupling topographic, soils and landuse information they address questions, e.g. when does hortonian overland flow exists on urban areas, slopes etc.. Hereby they differ in areas with potential dominant hydrologic processes and in real dominant hydrologic processes by taken several precipitation conditions into account. Transferring the approach to other catchments is questionable because of changing hydrologic conditions and reactions.

In contrast to this the deterministic GIS approach of delineation of 'Smallest Common Geometries' (SCGs) renounces reclassification operations of landscape information and is considered as equipotential surface areas. For modeling purposes it is suggested to simple overlay topographic, soils, geology and landuse information. Hereby the scale of spatial representation is due to the resolution of the modeling input data. Hence delineation procedure is based on

(ii) The assessment of spatially distributed hydrologic or solute-modeling results based on these SCGs to reduce the number of areas towards catchments significant process units. Approaches comprise geostatical concepts like cluster analysis based on hydrologic modelling results (Diekkrüger, 1999). Hereby yearly estimated evapotranspiration rates as well as simulations results of overland flow and surface flow were combined to clusters for representing a unique catchment response. Difficulties occur by defining the clusters boundary conditions and properties. Additional the lacking hydrologic processes such, as groundwater flow within the classification algorithm has to be annotated. Furthermore classes of clusters remain to be static and discrete over time and areas they are applied to.

In contrast to this it has to be pointed out that in general the hydrologic and solute processes are dynamic and continuous over time and space with two or three spatial dimensions. The use of GIS is therefore naturally given a static representation of these dynamic attributes. The idea to address this problem is to transform these spatial base data or attributes from discrete to a continuous representation scale of hydrologic and solute attributes (Burrough, 1996; Cheng & Molenaar, 1999; Peuquet, 2002).

The delineation procedure of entities like response units then implies on the aggregation of contiguous (derived) areas to which the classification constitutes the same attributes. Consequently it focuses on the uncertainties in classification on the spatial extend of response units. Uncertainty arises when the derived attribute is not easily determined by the values of $\underline{z}$ and $\overline{z}$ (Figure 1) because of gradual transition of the attribute *'A'* and *'not A'*. Leading back on theory of Zadeh (1965) this transformation process may be presented by fuzzy sets. The idea originates from application studies where fuzzy set approaches had been developed e.g. for (i) suitability analysis (Wolf, 1994), (ii) classification of thermotops (Schmidt, 1996) and (iii) deriving of continuous geomorphology features (Wood, 1998). Additional studies include (iv) terrain entities (Shi et. al, 2004) and (v) multiscale analysis of landscape morphometry (Fischer et. al, 2004).

Acceptable values for $\underline{z}$ and $\overline{z}$ to the correspondent attribute therefore can occur in several versions. Figure 2 shows three variants of $Z_A = \lfloor \underline{Z}_{Aj}, \overline{Z}_{Aj} \rfloor$ with j = 1…3, relating to attribute *'A'*. Here the gradual transition is displayed through the gradual transcription of memberships with different ranges of boundaries.

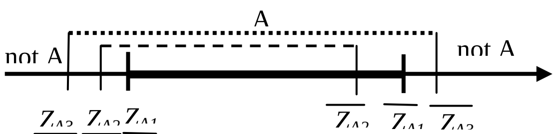

Figure 2. Ambiguous scale of membership of Z to the attribute *'A'* or *'not A'* (after Fonte & Lodwick 2004)

In this study definition of CHRUs is in general termed as a geographical entity (*E*), which is declared by a membership functions $\mu_E(ri) \in [0,1]$ of a region (*ri*) of dominant hydrologic and nitrogen process dynamics and their connectives. Membership functions comprise dimensionless values between 0 and 1 whereby 1 assigns fully membership for a given attribute. The boundary beyond the value of 0 illustrates no membership. Values between 0 and 1 is used to compute gradual, increasing memberships (Zadeh 1965). Hereby different functional forms of membership functions occur like trapezium, triangular or normal distribution forms. The letter is used in this application. Thereby the construction of the membership functions $\mu_{CHRU}(ri)$ is declared for each CHRU, their connectives and their semantic representation.

2. STUDY AREA

The approach was developed for the 216 km² scale catchment of the River Bröl. It is located on the northern bound of the middle mountain range of the Rhenisch Slate-mountains, Germany, about 50 km east of the city of Bonn. The river Bröl drains into the Sieg, which is a tributary of the main River Rhine. The climate is oceanic with annual mean temperature of 8°C. Annual precipitation is ranging from 950 mm to 1100 mm. Evapotranspiration adds up to about 50% of the annual precipitation and the runoff is clearly dominated by the interflow dynamics appearing as lateral flow along the hill slopes. The catchment is underlain by impermeable devonian shale. Native soil-series developed with brown soils and soils lessivé on the hill slope (partially eroded) as well as on the upper peneplain. Gleysols are located on plains and fluvisols within the valley floors. They are all consisting to over 90 % of homogeneous material such as silty loam. Given the natural conditions the predominant landuse besides settlements and forests are pastures and meadows. Agricultural land (corn, winter grain) accounts for fodder purposes only.

3. MODEL DESCRIPTION AND RESULTS

The process based model WASMOD (*wa*ter and *s*ubstance *mo*del, Reiche 1994) was selected to calculate in nutrients flow dynamic the 216 km² Bröl River catchment. Time period for calibration and validation took place during the period of water year 1992-1995 on a daily time scale.

The heat mass transfer in the soil is following the numerical solution of the general heat flux equation according to the thermal conductivity and heat capacity. Soil water movement and fluxes follows the potential concept by the solution of Richards's equation. Three pools of organic matter based on specific decay rates are used to describe the heterotrophic and autotrophic activity of microbial biomass and their sequential reduction of organic matter and inorganic contents as NO_2,

NO_3^- and N_2O during C oxidation. Mineralisation-immobilisation turnover as well as nitrification-denitrification processes were modelled according to first order kinetics. Nitrogen uptake by plants is simulated by a crop specific plant uptake function following the Michaelis-Menten type.

The model is fully distributed and process routines are related to the spatially resolution of 'smallest common geometries' (SCGs). For modelling application the Bröl river catchment was subdived into 8207 SCGs. These units were coupled for each of the SCGs within the ArcView GIS ® and analysed through the ArcView extension 'Spatial data modeller' (SDM) for fuzzy-classification.

Modeling results

Model analyse is shown by **Error! Reference source not found.** and Table 1 presenting a high goodness-of-fit, between observed and simulated hydrologic as well as nitrogen dynamics on a daily time scale.

HY	r [-]	r^2 [-]	log r^2 [-]	R_{eff} [-]	log R_{eff} [-]	Δ Vol. [%]	Δ Vol. [mm/a]	Φ Real [-]	Φ Sim. [-]
1992	0,96	0,92	0,80	0,88	0,71	4,48	0,84	0,45	0,43
1993	0,83	0,68	0,79	0,65	0,73	7,04	1,52	0,48	0,51
1994	0,92	0,85	0,85	0,85	0,83	-0,57	-0,13	0,48	0,48
1995	0,87	0,72	0,73	0,46	0,73	-3,34	-0,94	0,56	0,51
Average	0,90	0,79	0,79	0,71	0,75	0,02	0,06	0,49	0,49

Table 1. Goodness-of-fit for discharge during simulation period for Bröl catchment (HY 1992 – 1995)

A comparison between the daily-simulated nitrogen contents and the 2 weeks interval nitrogen samples for 2 gauges in the Bröl catchment show a relative good fit for the observation period (Table 2). In general the modeling of nitrogen dynamics is dealing with more uncertainties due to the limitations of input data, e.g. like field based fertilizer application. Furthermore uncertainty follows the portioning of the organic pools of soils, biomass, and added organic substances and their reaction kinetics by subdividing the pools into the metabolic rates such as 'slow/stable' and 'fast/active'. Hence it is suggested to add more organic and nitrogen pools characterized by different decomposition rates. As referred to Figure 3 best modeling results on a daily time step is observed during washout periods of highly mobile nitrates (April-July and October-November). During winter period a strong undersimulation of the predicted nitrogen concentrations is shown due to the fact that solute transport is not calculated by surface runoff. In contrast to this during the summer period the nitrogen concentration level is much more higher in the simulated values. It is interestingly that a better correlation result were achieved by the upper located gauging station (Bröleck), which indicates strong river internal nitrogen turnover rates. In summary modeling results show best

HY	r [-] Bröl	r [-] Bröleck	Median Sim. [mg/l]	Median Obs. Bröl [mg/l]	Median Obs. Bröleck [mg/l]	Max Sim. [mg/l]	Max Obs. Bröl [mg/l]	Max Obs. Bröleck [mg/l]	Min Sim. [mg/l]	Min Obs. Bröl [mg/l]	Min Obs. Bröleck [mg/l]
1992	0,65	0,71	22,3	20,6	23,1	43,7	32,2	53,6	12,3	15,4	14,4
1993	0,56	0,67	17,6	19,6	20,4	29,2	25,4	33,1	11,4	15,1	12,7
1994	0,43	0,49	18,8	17,5	19,1	41,0	26,9	28,6	6,7	15,1	15,7
1995	0,32	0,60	17,8	17,2	18,6	33,6	22,8	28,8	8,6	13,8	14,0
Average	0,49	0,62	19,1	18,7	19,9	36,9	26,8	36,0	9,8	14,9	14,2

Table 2. Comparison of observed and predicted nitrogen concentrations of the Bröl catchment

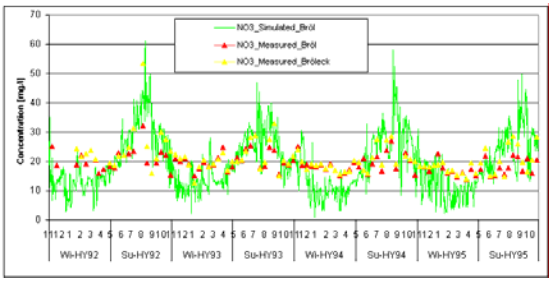

Figure 3. Two weeks observed nitrogen samples of 2 gauges and simulated nitrogen values at the outlet

achievements when focusing on the yearly time scale. Consequently they are proofed for being reasonable as input data for the fuzzy set CHRU classification at that time scale.

4. FUZZY SET-CLASSIFICATION OF CHRUs

The GIS based CHRU classification scheme includes the following steps (Figure 3). First of all the CHRU classification structure is determined by significant input variables which originate from modeled values of hydrologic and solute processes, i.e. attributes for each of the 8207 modeling entities (SCGs). These attributes were transferred into functional groups depending on its purposive property (Figure 5). After fuzzification according to their process conditions specific fuzzy operators were used to connect the input variables (Figure 5). These results have been defuzzificated by using semantic expressions of participating attributes defining CHRUs (Figure 6).

Fussification and Fuzzy-Operations

The next step includes the fuzzification procedure and the selection of fuzzy set operations to provides connectives of the input variables. Fuzzyfication was constructed by simply replacing either half (left or right) of the model values with a constant linear function (Figure 4). The segmentation of exact simulations values of each input variable into fuzzy memberships is based on a regional assessment of each participating hydrologic and solute process, for instance: a plant

N consumption of greater than 140 kg/N/year is assumed to be 'very high' within the catchment

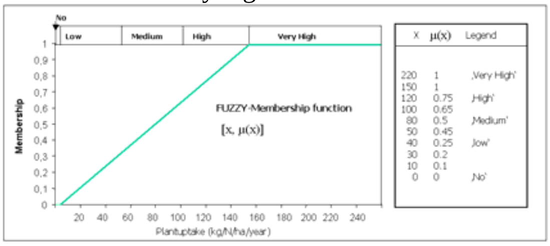

Figure 4. Graphical and tabular fuzzy membership ($\mu(x)$) grades for values of input variable (x)

comparing to 45–90 kg/N/year which is considered as 'medium'. In the enhancement of the Boolean logic, fuzzy operations have been developed to process two or more fuzzificated input variables. For CHRU classification one of the suitable fuzzy operations is fuzzy 'OR' to address the problem of determine 'process dominance' within the functional groups (Figure 5). Hereby fuzzy 'OR' is defined as

$$\mu_C(x) = \max\{\mu_A(X), \mu_B(X)\} \; x \in X$$

where x are membership functions of the input variable X of layer 'A' and 'B'. Consequently the output of this operation is a derivation of fuzzy memberships ($\mu_C(x)$). Note that processes are portioned into nitrogen and water parts.

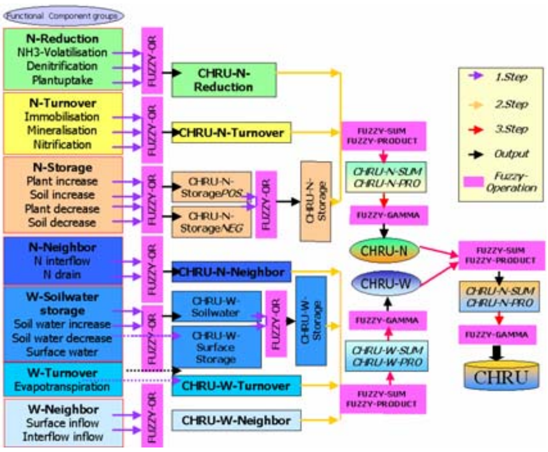

Figure 5. Fuzzy operations steps for CHRU classification

To union these areas of functional dominances the use of fuzzy SUM and fuzzy PRODUCT operations is suggested. They are defined as

$$\mu_C(x) = 1 - \prod_{i-1}^{n}(1-\mu_i) \quad \text{(Fuzzy algebra SUM)}$$

$$\mu_C(x) = \prod^{n}{}_{i-1\mu i} \quad \text{(Fuzzy algebra PRODUCT)}$$

where $\mu_C(x)$ is the result of derivation of fuzzy memberships by several input fuzzy sets. To derive the uniqueness of distinct output memberships by these operations the $\mu_C(x)$-output has to weighted according to the fuzzy GAMMA operation which is defined as

$$\mu_{CHRU}(x) = (\text{FuzzyAlgebraSUM})^{\gamma} * (\text{Fuzzy AlgebraPRODUCT})^{1-\gamma}$$

with γ as scaling parameter [0,1]. The scaling parameter of 0,9 was used. After being processed the CHRU output grid (Figure 5) was defuzzificated by defining rules which is aggregated for cumulative result (fuzzy envelope).

Defuzzification, CHRU rule base and fuzzy envelope

Defuzzification is done by semantic representation of the operational CHRU output for each of the 8207 modelling units. Therefore *'if-then'* rules within the ArcView GIS ® have to be identified which imply distinguishing attributes for characterising CHRUs. These rules are designed by querying Boolean constraints whether a prompted process property is existent (to be dominant) or not. The results of this query are stored as 'true' and 'false' variables within the CHRU attribute table. Therefore it is clearly suggested to union the memberships of the CHRU criteria. Thence the simplest but least useful defuzzification method is to choose the set with the highest membership grade of the CHRU output grid (Figure 6).

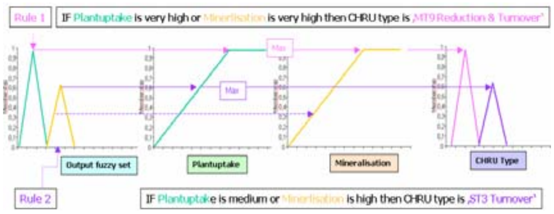

Figure 6. Decomposition of CHRU fuzzy output by using semantic expressions

Note that the example of Figure 6 is explained by two membership functions whereas for the CHRU rule base definitions each of the CHRU input variable is used. For fuzzy envelope 29 rules are detected to query the unified CHRU output layer (**Error! Reference source not found.**). Thereby three different levels of CHRU interpretations are excluded.

(i) Definition and description to the main type class: 'single type' ('ST' = one functional fuzzy group is dominant), or 'mixed type' ('MT' = two or more functional fuzzy groups are equal dominant) and 'zero type' ('ZT'= one or more functional fuzzy groups have no attributes).

(ii) Number and description of hydrologic and solute process dominance according to the contents of the functional fuzzy groups.

(iii) Dominance of occuring hydrologic and nitrogen processes for each CHRU type.

5. RESULTS

Analysing the CHRUs output layer comprises the view on the spatial distribution of these entities. The overall catchment reaction shown by Table 3 . It contains to each of 40% of mixed (mainly driven by reduction and turnover) and zero CHRU types (mostly driven by types with no neighbours and no turnover & neighbours). The latter however occurs due to the fact that no turnover and neighbour functions are modelled on urban areas. Single types CHRUs cover additional 20%.

Within the 'ST'-CHRU group about 15% of the catchments area belong to the dominant reaction of 'turnover' and here refer to the process (net)'mineralisation'. Relating these areas to spatial patterns they are mostly detected on forested and low fertilized winter grain locations and typically found on shallow sinks and on colluviums. Therefore it can be concluded that input of plant residues coupled by persistent soil moisture conditions is more important in the Bröl river comparing to the other abiotic factors influencing the mineralisaion- immobilisation turnover such as C/N proportion, pH and temperature conditions.

With the view on the catchment reduction capability the denitrification processes is the mainly driving factor. Areas on shallow plateaus, knolls and eroded soil areas cover them characterised by a temporary impounded water table providing saturation. Is supported by sustained precipitation input and high temperatures during the summer periods. Furthermore denitrification is depending on the availability of organic substance as electronic donator for reducing agent. Within the Bröl watershed plant residues give this. Thereby denitrification areas are related to all types of landuses where residues occur. Further analyses comprise the examination of individual responses on pedo-topo-sequences and of areas of interests such high impact areas. From that 'point view' it has to be stated out that the amount of Nitrogen impacts on the river system depends on the relation of availability of nitrogen and the Ability to reduce it from the system. Mineralisation and nitrification is influenced by soil moisture and therefore depending on evapotranspiration and soil storage change. Moreover decomposition rate is referred to organic nitrogen impact from adjacent areas and N storage in soil percolates. This is again influenced by climatic dynamics whereas dry conditions tend for N accumulation and wet conditions tend to mobilise N. N reduction is mainly driven by plant uptake and denitrification. It is related to climatic conditions and to specific landuse patterns. Plant uptake of N showed a strong dependence on soil moisture. Especially dry conditions inhibited plant

CHRU-Type-No.	CHRU characteristics	HY 1992 [%]	HY 1993 [%]	HY 1994 [%]	HY 1995 [%]
ST 1	Reduction	2,71	4,87	2,33	3,82
ST 2	Storage	4,12	3,71	4,48	3,16
ST 3	Turnover	13,77	16,17	14,26	17,82
ST 4	Neighbor	0,02	0,025	0,03	0,05
Σ Single Type (ST)		20,63	24,78	21,10	24,84
MT 5	Reduction&Turnover&Storage	1,91	1,07	4,47	1,38
MT 6	Reduction&Turnover&Neighbor	0,75	1,28	0,71	1,45
MT 7	Turnover&Storage&Neighbor	0,03	0,05	0,02	0,10
MT 8	Reduction&Neighbor&Storage	0,03	0,05	0,03	0,00
MT 9	Reduction&Turnover	33,42	33,33	36,47	34,17
MT 10	Reduction&Storage	1,51	2,69	0,59	1,17
MT 11	Turnover&Storage	0,21	0,08	0,12	0,21
MT 12	Turnover&Neighbor	0,06	0,13	0,15	0,27
MT 13	Storage&Neighbor	0,00	0,00	0,00	0,00
MT 14	Reduction&Neighbor	0,00	0,06	0,04	0,04
MT 15	Reduction&Storage&Turnover&Neighbor	0,32	0,25	0,43	0,51
Σ Mixed Type (MT)		38,25	39,00	43,04	39,30
ZT 16	no Reduction	0,00	0,00	0,00	0,00
ZT 17	no Storage	4,81	0,05	0,01	0,01
ZT 18	no Turnover	1,82	2,41	2,26	2,23
ZT 19	no Neighbor	13,42	8,16	8,17	8,14
ZT 20	no Reduction&Turnover&Storage	0,00	0,00	0,00	0,00
ZT 21	no Reduction&Turnover&Neighbor	0,00	0,07	0,01	0,02
ZT 22	no Neighbor&Turnover&Storage	2,00	0,00	0,00	0,01
ZT 23	no Reduction&Neighbor&Storage	0,02	0,00	0,00	0,00
ZT 24	no Reduction&Turnover	0,00	0,01	0,00	0,00
ZT 25	no Reduction&Storage	0,00	0,00	0,00	0,00
ZT 26	no Turnover&Storage	0,21	0,00	0,00	0,00
ZT 27	no Turnover&Neighbor	12,00	13,95	13,81	13,84
ZT 28	no Storage&Neighbor	6,82	11,53	11,54	11,54
ZT 29	no Reduction&Neighbor	0,00	0,01	0,02	0,02
Σ Zero Type (ZT)		41,13	36,19	35,87	35,86

Table 3. Percentage of the spatial distribution of CHRUs for HY 1992 – 1995

CHRU-Type No.	Dominance of process	HY 1992 [%]	HY 1993 [%]	HY 1994 [%]	HY 1995 [%]
ST 1 Reduction	Denitrification	2,42	3,53	1,44	3,31
	NH_3-Volatilisation	%	%	%	%
	Plantuptake	0,01	1,1	0,89	0,5
	Denitrification&Plantuptake	0,27	0,24	0,005	%
ST 2 Storgae	Plantstorage Increase	%	0,02	0,017	%
	Plantstorage Decrease	%	%	%	%
	Soilstorage Increase	3,95	3,28	4,14	1,9
	Soilstorage Decrease	0,16	0,41	0,32	1,26
ST 3 Turnover	Mineralisation	13,77	16,16	14,25	17,82
	Immobilisation	%	%	0,004	%
ST 4 Neighbor	N in Interflow	0,055	0,076	0,057	0,04
	N in drainage	0,082	0,017	0,014	0,01

Table 4. Main processes of CHRU type 'ST'

uptake by diffusion and mass fluxes and providing again a new source of N.

6. CONCLUSIONS

This paper discusses a rule-based method for deriving fuzzy representations of hydrologic and nitrogen processes and relates them to spatial patterns. The aim of this study was to develop an assessment tool, which provides profound information's on the detection of the catchments functionality. Moreover the system provides a new insight over the catchments response units to identify typical locations (cases) with homogeneous process resulting in similar reactions. Hereby it especially addresses the problem of uncertainty of process boundaries. In this research boundaries are represented for continuous scaling and were accurately distinguished in fuzzy sets. At this they are covering 'basin knowledge' on its process dimensions. Future studies will include the capabilities of neuronal networks (e.g. NEFCLASS, Nauck, U. 1999) to train ranges of the fuzzy sets of CHRUs. Therefore the approach could be valid for application to other catchments. Furthermore RCC8 theory (Randell et al. 1992, Guesgen 2004) will be incorporated to determine the connectivity, e.g. spatial relations between CHRUs.

7. ACKNOWLEDGMENTS

The author is pleased to thank Dr. E.-W. Reiche (†) for supporting in the solute model WASMOD. Financial support was done by the German Research Society (DFG) as well as of the 'Thuringian Hochschul- and Wissenschaftspro-gramm (HWP), Germany.

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