Centre for Geo-Information

Research Report GIRS-2006-20

Fuzziness in spatial planning data

An exploration into uncertainty

Arie J. Duindam

26 April 2006

WAGENINGEN UNIVERSITY

WAGENINGEN UR

Fuzziness in spatial planning data

An exploration into uncertainty

Arie J. Duindam

Registration number 70 08 16 202 060

Supervisors:

Dr. ir. S. de Bruin
Dr. ir. G.B.M. Heuvelink

A research submitted in partial fulfilment of the degree of Master of Science at Wageningen University and Research Centre, The Netherlands.

26 April 2006
Wageningen, The Netherlands

Research code number: GRS-8040X
Research Report: GIRS-2006-20
Wageningen University and Research Centre
Laboratory of Geo-Information Science and Remote Sensing

IV

‘Kijk, daar loopt de evenaar!’ En werkelijk, daar liep een dikke, rode streep dwars over het zand.
‘Dit is tenminste een houvast,’ zei Pa Pinkelman.
(uit: Godfried Bomans, De Avonturen van Pa Pinkelman)

Foreword

One morning in December 2003 I woke up in my IT career, looked in the mirror, and decided I wasn't doing the right job. This feeling persisted for weeks, and I felt very tired. To investigate these feelings, I went to a career coach, and found out in two visits what was wrong: I wasn't doing anything geographical! Two visits later I had quit my job, and after one other visit I enrolled for the MSc Geo-information Science (MGI) course at the Wageningen University. In September 2005 I started as a fulltime student, after a working career of more than eight years. To my surprise, my family fully supported this step, although our budget was drastically cut. But life felt like a game again, and symbolically we even sold the electrical water cooker in favour of a kettle on the stove.

The most interesting thing was that I almost physically felt that one cannot foresee the future. I quit my job to start an MSc course, and suddenly I discovered a wine yard in Wageningen. Suddenly I was lecturing in Tashkent together with Jan-Hein Loedeman. Suddenly I was doing a guest lecture on data management. Suddenly I was involved in the SDI course together with Arnold Bregt. Suddenly I became contributing editor of a professional magazine. And suddenly I got a job at Grontmij, thanks to John Stuiver, one of my teachers. All these things were totally unforeseen the moment I decided to go back to university.

This thesis report is the end of a process that started before the mirror, and in this period I have learned a lot about geo-information. But I also learned that choosing a different direction in life can be a very inspiring and rewarding thing.

At this place I would like to take the opportunity to thank the MGI staff for all the given opportunities. Furthermore I would like to thank my thesis supervisors Sytze de Bruin and Gerard Heuvelink for their motivating support during the lengthy process of this thesis work. I also would like to thank my parents for their eternal trust. My father died almost two years ago, but he knew I was going to do this and, as always, he trusted my decision. Finally I would like to thank Julia for supporting my career turn. At the time of decision it was a big step with an unknown outcome, and sometimes it is difficult to live with uncertainty. There has never been a single complaint about this, so Julia, thank you again for your support.

Abstract

Spatial planning in the Netherlands is quickly transforming from a paper to a digital process. A reason for this is the improved comparability of spatial plans. However, in order to disclose the full advantages of a digital spatial planning process, it is necessary to address the issues of uncertainty in the planning data, because the lack of this information within the digital planning objects is currently restricting this comparability. Many planning areas do not have a sharply defined boundary, and also the relation between other objects from other plans is often uncertain. To deal with these uncertainties, the fuzzy set theory is applied to the spatial planning data.

In the geometric domain, fuzzy sets are used to describe planning objects that do not have sharply defined boundaries. Overlay operations with fuzzy planning objects are implemented as fuzzy intersections or t-norms. An analysis of these intersections demonstrates that the fuzzy boundaries provide a more objective and quantitative judgement about the overlay areas.

In the thematic domain, a fuzzy consistency relationship is defined to cope with the heterogeneous nature of the planning object types. A methodology is presented to assess the planning consistency in a region. This framework is based the application of available t-norms to the consistency relationships, and an example demonstrates the value of the fuzzy consistency relationships.

To investigate to what extents the results of this work would be judged a better alternative to the current practice of dealing with uncertainty, a questionnaire was distributed to professionals directly involved in the spatial planning process in The Netherlands. The results of this questionnaire demonstrate that the uncertainty aspects in spatial planning are a recognized issue, and that the use of fuzzy sets is regarded as a better alternative compared to the current practice. The implementation of fuzzy boundaries and fuzzy relationships in a legal framework is considered a potential issue. However, the conclusion is drawn that the fuzzy set theory is a useful framework for dealing with the type of uncertainty found in spatial planning data.

Index

List of figures

List of tables

Glossary

AOI - Area of Interest; the case area for this research.

AVL - Archaeological values. A classification of the area in higher / lower archaeological values. This set of objects serves as a source of inspiration for spatial and landscape development, as well as a testing element with spatial compromises.

COA - City overflow areas. These are multifunctional areas around the city borders. In these areas a varying spatial structure is present as well as a varying extensive or intensive use of the area. City overflow areas may consist of parks, forest, nature areas, agricultural areas, open air recreational areas and mansions.

DURP - Digitale Uitwisseling in Ruimtelijke Processen (Digital Exchange in Spatial Processes), a stimulation and implementation programme by VROM and its relevant partners to have local, provincial and national parties generate spatial plans in a digital, exchangeable and comparable way.

EHS - Ecological Main Structure. The EHS contains objects with the most important nature values, with the goal to protect and develop these values.

GeO3 – A research project to handle uncertain plan objects with the goals to facilitate monitoring and spatial analyses of spatial policy.

IRA - Intensive recreation areas. In these areas space is offered for the development of either small-scale or large-scale recreative facilities.

IZL - Integral Zoning Layer; this is the most important data layer in the reconstruction plan; this layer holds the classification for the main destination of the rural areas in the AOI.

PAA - Acidification protection areas A; these are the areas that are very sensitive for acidification. The polygons to define these areas have been constructed via a custom GIS process, and this process has yielded a map with many small areas within the AOI. By law a buffer of 250m around all areas is drawn, and this buffered zones layer is used. Except for some special cases, no new agricultural activities are allowed within these buffered areas, because of the very low capacity for acid emissions, especially ammonia.

PAB - Acidification protection areas B; these are areas similar to the PAA (*see* PAA), but somewhat less sensitive to acid emissions.

PLA - Project location areas. Areas where a sustainable project location is present. Housing of new individual companies at the same location is possible.

POM function – Planning Object Membership function; a specific membership function suitable for spatial planning data constructed in this research.

RLG – Revitalisering Landelijk Gebied 2005, the project to revitalise the rural area of the province of Noord-Brabant.

RNLE - Regional Nature and Landscape Units. The core of the RNLE are the existing forest and nature conservation areas. Around these areas small nature and agricultural areas are added as buffers, with a primary focus on hydrological and landscape

consistency. The main goal of an RNLE is the protection and development of hydrological, natural, landscape and culture historical values.
VROM – Dutch Ministry of Housing, Spatial Planning and the Environment (ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer).

1 Introduction

1.1 Context and background

Because of scarcity of space, urban and regional planning is a complex and dynamic process in the Netherlands as well as in many other places. Several parties make plans from different spatial perspectives and scales (local, regional and national). These plans need to be integrated to enable spatial analyses, examining and monitoring of policy. Dutch legislation requires that as from 2007 all spatial plans must be digital, exchangeable and comparable. The project DURP (VROM 2005-1) has already produced many digital plans. However, uncertainty issues in these plans have not yet been addressed, which imposes serious comparability limitations (GeO3-project 2005).

To overcome these limitations, the project GeO3, "Omgaan met onzekere planobjecten bij monitoring en analyse van ruimtelijk beleid" (Dealing with uncertain planning objects to facilitate monitoring and analyses of spatial policy) has been initiated (GeO3-project 2005). The goal of this research project is to study the various properties of uncertainty in planning objects, to formalize these and integrate them in existing information models. The main goal of this project is to overcome the comparability limitations and to resolve comparability issues in digital spatial planning. The result will be more transparent spatial planning process.

This research has contributed to the GeO3 project, and supported some of its project goals, by choosing a subject in the field of the aforementioned uncertainty issues.

1.2 Problem definition

The general problem that has been addressed in this research is dealing with uncertainty in spatial planning data. It is necessary to take a closer look at the term *uncertainty*, because this term has many meanings, even within the context of spatial data (Cross *et al.* 2000). In the scientific literature, uncertainty mixes with terms like inaccuracy, imprecision, incompleteness, imperfection, vagueness, imperfection, error, indeterminacy and even data quality (Duckham *et al.* 2001, Mowrer *et al.* 2000). To decide which concepts are relevant for spatial planning data, a general investigation of all data in the Geo3 case, the RLG Reconstructieplannen deel B (Noord-Brabant 2004), was made during the preparation of the here reported work. In this investigation, general uncertainty aspects of spatial data were evaluated for the *geometric domain*, where position or location is concerned, and the *thematic domain*, where the properties of the objects are concerned (Cheng *et al*. 1999).

This inventory demonstrated that the concept of *fuzziness* matches well with the type of uncertainties found in many planning objects. The concept of fuzzy sets was introduced by Zadeh (1965), as a means to deal with classes that do not have sharply defined boundaries. Fuzzy sets are characterised by membership functions that assign grades of membership in the real interval [0, 1] to elements. The membership grade expresses the degree to which an element is similar to the concept represented by a fuzzy set (De Bruin 2000). Because of the apparent relevance to the case data, this research has focussed solely on fuzziness in spatial planning data.

In order to disclose the full advantages of a digital spatial planning process, it is necessary to address the issues of uncertainty in the planning data. What are the possibilities for creating a more meaningful description of uncertainty in digital spatial planning objects? What are the possibilities for developing methodologies for monitoring and evaluation of spatial plans under uncertainty? To what extent and in what way can spatial plans be compared in a quantitative way, to indicate areas of similarity (Hagen 2003) or conflict?

1.3 Research objective and research questions

The general objective of this research is to generate applicable knowledge and methodologies about dealing with fuzziness in spatial planning data. To establish this main objective, the following research questions are formulated:

A. **How are fuzzy boundaries of planning objects best described?**
   This question summarizes the goal of the work in the geometric domain. Specific effort will be put in reasoning on membership functions (Robinson 2003).
B. **How is thematic fuzziness of planning objects best described?**
   This question summarizes the goal of the work in the thematic domain. An exploration of the formal description of the fuzzy relationships between planning objects is carried out.
C. **How can a fuzzy spatial plan be compared to other spatial plans?**
   This question formulates an important goal of the research: to use the answers to questions A and B to enable comparison of different plans (Cheng *et al.* 2001). This comparison will be at least a quantitative assessment of the consistency of plans amongst each other.
D. **What are the potentials and drawbacks of accounting for fuzziness in spatial planning data?**
   This question addresses a discussion about the applied methodologies, in order to find out what the main advantages and drawbacks are and which opportunities and conceptual obstacles are encountered.

Chapter 2 introduces relevant elements of the fuzzy set theory. Elements from Burrough and Frank (1996), Cheng (2001), Duckham (2002), Schneider (2003, 1998), Worboys (1998) and Wang (1996) are used in this research. In chapter 3 the case data is described. These chapters are an introduction to the rest of the work. Chapter 4 reports the work done in the geometric domain. In the geometric domain, *location* of the planning objects can be captured by means of a fuzzy boundary (Burrough and Frank 1996, Burrough and McDonnell 1998). Chapter 5 reports the work done in the thematic domain. In the thematic domain, the *meaning* of the planning objects can be captured by relating the objects to other planning objects using a set of fuzzy relationships (Cross 2003, Robinson 2003). Chapter 6 reports about a questionnaire that was distributed to obtain feedback about the work that was done in the previous chapters. In chapter 7 the work is discussed and conclusions are drawn.

2 Fuzzy set theory

The concept of fuzziness was introduced by Zadeh (1965), as an extension to boolean logic. Boolean logic is a formal means of reasoning where something is either true or false, something either belongs to a given set or it does not belong to the set. Burrough and McDonnell (1998) introduces the topic by stating that formal thought processes in Western logic have traditionally emphasized on this paradigm, and that there is not much experience with formal overlapping concepts; that the rules of logic used in computer query languages are all based on exact ideas of truth or falsehood, but that in environmental data this is not always the case.

A general example mentioned by Zadeh is the case of a number such as 10 in relationship to the "class" of all numbers which are much greater than 1, concluding that such a "class" does not constitute sets in the usual mathematical sense. In natural language there is much more freedom to deal with this concept than in logic, and people are much more used to it. It is easy to refer to tall people, because it is not necessary to define the boundaries of this set. In a formal *logical* environment this idea is more difficult: if all tall people in a group have to be identified, suddenly the meaning of tall has to be defined. Some are definitely tall, some definitely not, but the boundary of the class of tall people is not clearly defined. This unclear boundary condition is the basis of fuzzy set theory.

2.1 Membership

The concept of a fuzzy set is used to describe phenomena with non-sharp boundaries. A fuzzy set is a class with a continuum of grades of membership (Zadeh 1965), where the idea of *membership* is the key concept. In a conventional set or hereafter called a crisp set, only a binary membership (true or false) is allowed. In such a crisp set (A), all class boundaries are sharp, and the membership μ of an element x in the crisp set A is either 0 or 1. For elements on a numerical scale with a single membership interval, this is defined as follows:

$$\mu_A^{crisp}(x) = 1 \quad for\ b_1 \leq x \leq b_2$$
$$\mu_A^{crisp}(x) = 0 \quad for\ x < b_1\ or\ x > b_2$$

with b_1 and b_2 the exact boundaries of the set.

In a fuzzy set, membership of a certain set is specified with a real number in the interval [0...1]. A membership 0 means that the element concerned is not part of the set; a membership 1 means that the element is fully part of the set. Any membership in the open interval <0...1> implies a *partial membership* of the set. The degree of membership μ is specified with a membership function f_A for all elements x in A, as follows:

$$\mu_A^{fuzzy}(x) = f_A(x) \quad for\ all\ x \in A$$

Reverting back to the example with the set of numbers much greater than 1, Zadeh gives the following precise, although subjective membership example:

$f_A(0) = 0$
$f_A(1) = 0$
$f_A(5) = 0.01$
$f_A(10) = 0.2$
$f_A(100) = 0.95$
$f_A(500) = 1$

In the above example, the membership function f_A is given for some x values. In more general terms, a membership function is the relationship between all elements x and the membership of A. Figure 2-1 shows an example of a crisp, boolean membership function, whereas Figure 2-2 shows an example of a general fuzzy membership function.

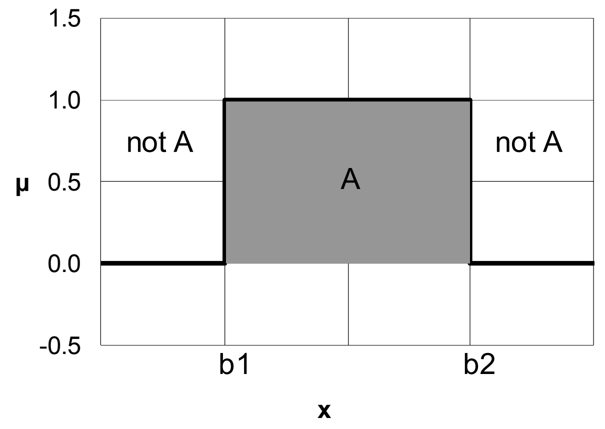


Figure 2-1 – Example of a crisp membership function: this function defines a boolean membership value for each x in A; μ = 1 for b1 ≤ x ≤ b2 and μ = 0 otherwise

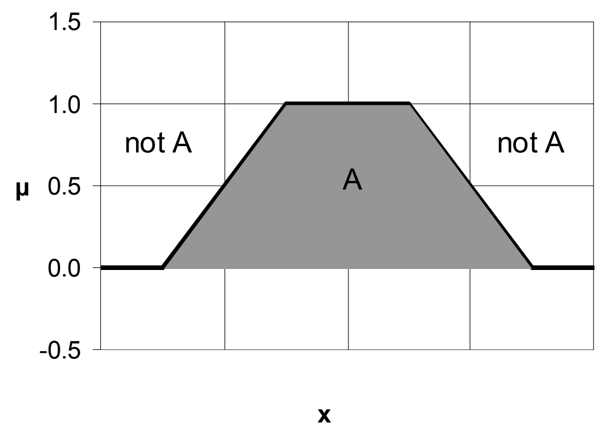


Figure 2-2 - Example of a fuzzy membership function: this function defines a continuous membership value [0..1] for each x in A

2.2 Logical operations

Boolean logic makes use of operators like AND, OR and NOT. Fuzzy equivalents of these operators are available. The standard fuzzy set operations (Klir and Yuan 1995) are shown in Table 2-1.

Table 2-1 – Basic logical operations in boolean form and standard fuzzy equivalent			
Logical operation		**Boolean logic**	**Fuzzy logic**
Intersection	A AND B	$A \cap B$	min[A , B]
Union	A OR B	$A \cup B$	max[A , B]
Complement	NOT A	~A	1 - A

Functions to calculate a fuzzy intersection are called t-norms (Anthony and Sherwood 1982). Functions to calculate fuzzy unions are called t-conorms. Not all functions are suitable for t-norm or t-conorm calculation. For instance, the result of a fuzzy logical operation must always be in the domain [0...1]. This means that the plus (+) operation for a fuzzy union cannot be used. A number of axioms have been defined for a function to qualify as a t-norm or t-conorm, which is discussed in detail in Klir and Yuan 1995. In this research, the fuzzy intersection or t-norm is used. Some common t-norms (Klir and Yuan 1995) are shown in Table 2-2. Although not used in this research, for the sake of completeness, some common t-conorms are displayed in Table 2-3 (Klir and Yuan 1995).

Table 2-2 – Commonly used t-norms to calculate fuzzy intersections	
Standard intersection	min[A , B]
Algebraic product	$A \cdot B$
Bounded difference	max[0 , A + B – 1]
Drastic intersection	A when B = 1 B when A = 1 0 otherwise

Table 2-3 – Commonly used t-conorms to calculate fuzzy unions	
Standard union	max[A , B]
Algebraic sum	$A + B - A \cdot B$
Bounded sum	min[1 , A + B]
Drastic union	A when B = 0 B when A = 0 1 otherwise

2.3 Misconceptions about fuzzy sets

The term fuzzy is somewhat unfortunate, because it is associated with not knowing, vague, undefined, and therefore unscientific. This is however not what a fuzzy set is about. A fuzzy set is a descriptor for classes that have no sharp boundaries for some reason (Burrough and McDonnell, 1998).

Another incorrect association is to interpret the concept of a membership value as a probability: to think that if the membership $\mu_A(x) = 0.9$, then the chance that x belongs to A is 90%. The difference between both concepts is demonstrated clearly by using the example of the class T of tall people mentioned earlier in the text. If a person x has a membership $\mu(x) = 0.9$ of class T, it means that x is “quite tall”. If x has a probability $p(x)=0.9$ to be member of T, there is a probability of 90% that x is tall, but also a probability of 10% that x is not tall at all; x could even be the shortest person in the set of people. Probability is a concept of randomness, fuzzy is a concept of gradual class boundaries.

2.4 Fuzzy sets in the geographic domain

In the geographic domain, fuzzy sets are common phenomena, but they are not always recognized as such. Some examples of fuzzy areas, with underlined the descriptors with fuzzy characteristics:

- a clay-rich area
- a suitable area for growing wheat
- a polluted area
- a species’ living area

There is an interesting similarity between a *set* in the logical domain and an *area* in the geographic domain, which is the basis for the visualisations of fuzzy bounded objects in this research. In mathematics, an illustration of a set or the relationship between sets is made using a Venn diagram. Figure 2-3 shows the Venn diagram of a crisp set, Figure 2-4 shows the Venn diagram of a similar fuzzy bounded set.

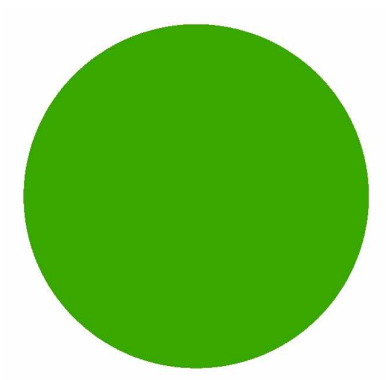


Figure 2-3 – Venn diagram of a crisp set; this set is visualised with a sharp boundary

Figure 2-4 – Venn diagram of a fuzzy set; this set is visualised with a gradual boundary

For planning objects a similar visualisation is chosen. A geometrically crisp object has a sharp boundary. A fuzzy boundary is displayed with a gradual colour. An example is given in Figure 2-5, where the definition of a built-up area is given with a crisp boundary versus a fuzzy boundary.

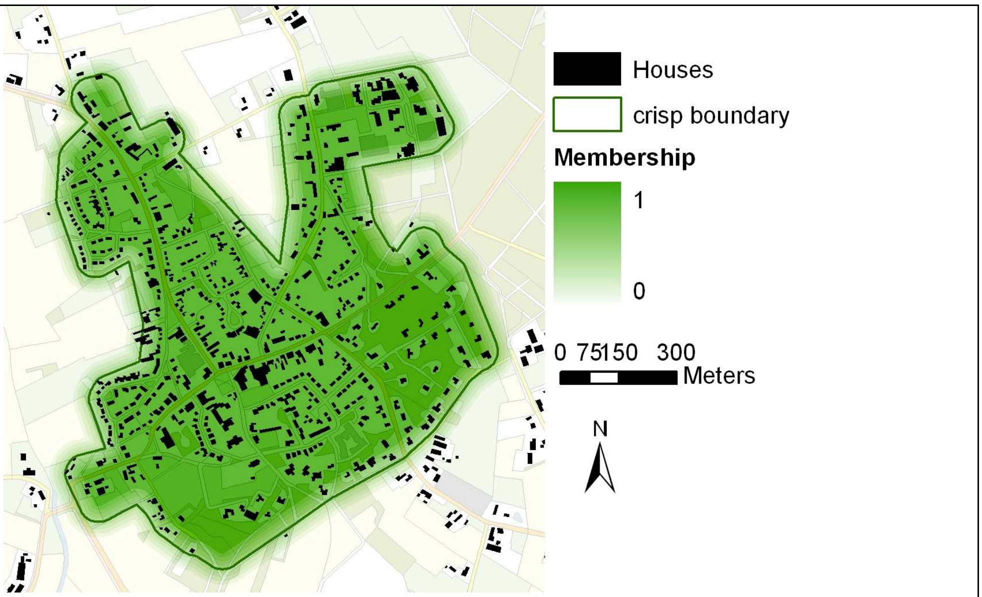


Figure 2-5 – A defined built-up area as an example planning object in the context of a topographic map, displayed with a crisp boundary as well as a fuzzy boundary

2.5 Rough sets

A rough set (Pawlak 1982) divides the object space into three regions:

- inside the object;
- inside the object boundary (no membership specified);
- outside the object.

Rough sets are an alternative to fuzzy sets for the description of spatial planning objects. However, the use of rough sets is disregarded in this work, because of the context of the data: when a planning object O is constructed, it expresses the desirability of activity A within O. Either activity A is not desirable within O, or it is indeed desirable within O. For example, within a search area for new forestation, it is desirable to have new forests. Within a silent area, it is not desirable to construct new industry. Inside the boundary area of O, the debate about the desirability of A becomes more important if A extends further into this boundary area, positive as well as negative. This indicates that in spatial planning data in most cases there will be a varying membership value inside the boundary area, which can not be specified with rough sets. With the use of a rough set, it would be indifferent if a new industry area would intrude a nature conservation boundary area 1cm or 100m. Often this does not reflect the intention of the data; hence the use of rough sets is rejected.

3 Noord-Brabant case

The GeO3 practical working group has chosen the Noord-Brabant reconstruction plans as study object. A description of these plans is given in Noord-Brabant (2004):

> "Problems in the intensive livestock industry led to the reconstruction. However, the reconstruction is now focused on an integral plan to tackle all rural problems: economic, social and ecological. Many people are involved in this process. Farmers and citizens, politicians and public servants, entrepreneurs and representatives of many organizations. In the region of Noord-Brabant, seven reconstruction committees (Baronie, Meierij, Beerze Reuzel, Boven-Dommel, De Peel, Peel en Maas, Maas en Meierij) and two region committees in the region of West-Brabant (Wijde Biesbosch and Brabantse Delta) have collaborated in a joint plan for the land use in the countryside. The reconstruction and region plans that have now been designed will lead to a considerable reorganization and improvement of the Brabant countryside. The plans focus on the whole province up until 2016 and deal with the following subjects:
>
> - Development opportunities for agriculture (12,240 hectares primary agriculture, 2,860 hectares secondary agriculture);
> - Decoration (12,300 hectares) and acquisition (11,500) of the Ecologische Hoofdstructuur (EHS, main structure of ecological zones in the Netherlands) (12,300 hectares);
> - Restoration of wet natural areas (27,000 hectares);
> - 670 kilometres of creek reparation;
> - Extensification dairy farming (5,100 hectares);
> - Regions for vulnerable species (3,900 hectares);
> - Management of nature and landscape (8,960 hectares).
>
> The direct reason leading to the reconstruction was the swine fever in 1997. Many pig farmers terminated their activities, sometimes out of necessity, sometimes as a result of government regulations. Companies that remained are often in the wrong location and should be relocated. The 2002 Reconstruction Act aims to improve the different functions of the rural area. Not only nature and landscape values should be secured and improved, but the reconstruction should also encourage economic development and focus on new possibilities for the intensive livestock industry. The Provincial Executive wishes to reinforce the social-economic vitality of the countryside. Quality of life, innovation of agriculture and new economic activities are stimulated."

Figure 3-1 shows an overview of the reconstruction areas.

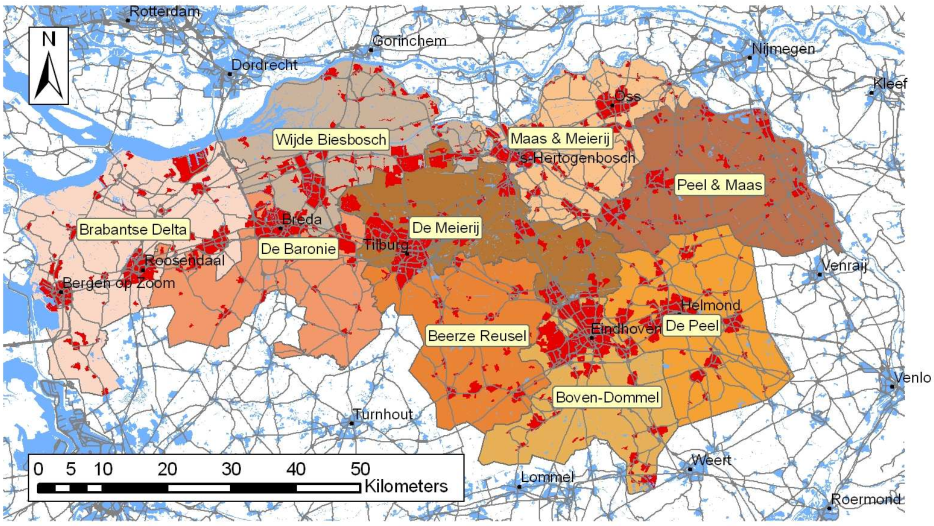


Figure 3-1 – Overview of the Noord-Brabant reconstruction areas

The reconstruction plans have been used in this research as case data, for the following reasons:

- These spatial plans are current, and represent a realistic case of the spatial planning situation in The Netherlands;
- There are many planning object types involved in this case;
- There are many object types with relevant, non-trivial fuzzy characteristics in this case;
- this case is also used by GeO3, which links the current work to this project;
- All data including complete meta-information are available in a digital atlas (Noord-Brabant 2005).

For the study area, a region of three adjacent reconstruction areas has been selected as the study area (hereafter called Area of Interest AOI). The area of the AOI is about 1555 km^2, and its location is chosen as presented in Figure 3-2.

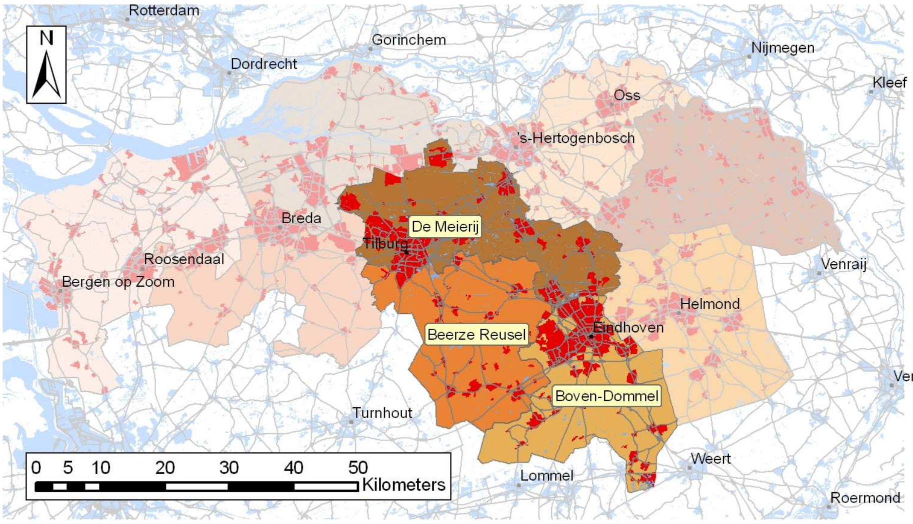


Figure 3-2 – Overview of the AOI in relationship to the reconstruction areas. The AOI is the aggregated area Meierij, Beerze Reusel and Boven-Dommel.

In the digital atlas of the reconstruction plans, more than 200 map layers are available. A relatively small subset of layers is used in this research. The selection was made on criteria like relevance, coverage and the existence of significant fuzziness characteristics in data layers, because not all planning objects have fuzzy characteristics. In this selection process, the data layers displayed in Table 3-1 were selected, roughly in descending order of importance in the reconstruction plans.

Table 3-1 – Reconstruction case data sets used in this research

Abbr.	Description	# classes	# objects	coverage of the AOI
IZL	Integral Zoning Layer; this is the most important data layer in the reconstruction plan; this layer holds the classification for the main destination of the rural areas in the AOI.	8	413	100%
PAA	Acidification protection areas A; these are the areas that are very sensitive for acidification. The polygons to define these areas have been constructed via a custom GIS process, and this process has yielded a map with many small areas within the AOI. By law a buffer of 250m around all areas is drawn, and this buffered zones layer is used. Except for some special cases, no new agricultural activities are allowed within these buffered areas, because of the very low capacity for acid emissions, especially ammonia.	2	67	39%
PAB	Acidification protection areas B; these are areas similar to the PAA, but somewhat less sensitive to acid emissions.	2	180	30%
EHS	Ecological Main Structure. The EHS contains objects with the most important nature values, with the goal to protect and	8	18829	35%

	develop these values.			
RNLE	Regional Nature and Landscape Units. The core of the RNLE are the existing forest and nature conservation areas. Around these areas small nature and agricultural areas are added as buffers, with a primary focus on hydrological and landscape consistency. The main goal of an RNLE is the protection and development of hydrological, natural, landscape and culture historical values.	2	5	38%
AVL	Archaeological values. A classification of the area in higher / lower archaeological values. This set of objects serves as a source of inspiration for spatial and landscape development, as well as a testing element with spatial compromises.	3	428	89%
PLA	Project location areas. Areas where a sustainable project location is present. Housing of new individual companies at the same location is possible.	2	11	1%
COA	City overflow areas. These are multifunctional areas around the city borders. In these areas a varying spatial structure is present as well as a varying extensive or intensive use of the area. City overflow areas may consist of parks, forest, nature areas, agricultural areas, open air recreational areas and mansions.	2	26	4%
IRA	Intensive recreation areas. In these areas space is offered for the development of either small-scale or large-scale recreative facilities.	2	28	3%

More detailed information on the case data including the classes for each layer and an overview map are given in Appendix 1 – Case data.

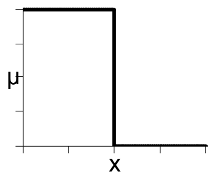
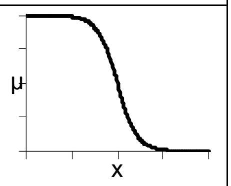
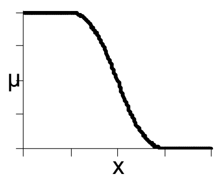
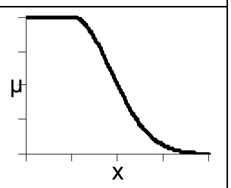
4 Fuzzy planning objects in the geometric domain

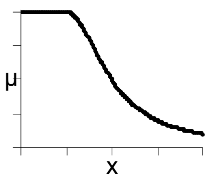
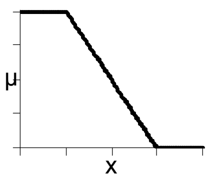
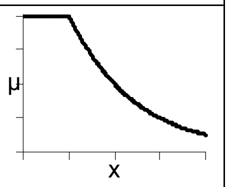
4.1 Methods

Robinson (2003) provides an overview of fuzzy membership functions used in GIS related analyses. He considers open form membership functions and closed form membership functions. In an open form membership function, only a transition from no membership (μ=0) to full membership (μ=1) or vice versa is defined. In a closed form membership function, both transitions are defined within the function, so there is a single closed range with non-zero memberships.

Below in Table 4-1 a summarized overview of membership functions as recognised by Robinson (2003) is given, together with their general left-shoulder open form membership function, a decreasing membership from μ=1 to μ=0.

Table 4-1 – Overview of membership functions used in GIS-related problems (Robinson 2003)

Type	**Robinson 2003 reference**	**Left-shoulder open form function μ(x) (with δ a function parameter)**	**Example**
Crisp	▪ Crisp closed form	$\mu = \begin{cases} 1 & \text{for x} < \beta \\ 0 & \text{for x} > \beta \end{cases}$	
Sigmoidal	▪ Left shoulder sigmoidal open form ▪ Right shoulder sigmoidal open form	$\mu = \begin{cases} 1 & \text{for x} < \alpha \\ \dfrac{1}{1+e^{\delta(x-\beta)}} & \text{for } \alpha < \text{x} < \gamma \\ 0 & \text{for x} > \gamma \end{cases}$	
S-Shaped	▪ S^- left shoulder open form ▪ S^+ right shoulder open form	$\mu = \begin{cases} 1 & for\ x < \alpha \\ 1-2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right)^2 & for\ \alpha < x < \beta \\ 2\left(\dfrac{x-\gamma}{\gamma-\alpha}\right)^2 & for\ \beta < x < \gamma \\ 0 & for\ x > \gamma \end{cases}$	
Gaussian	▪ Gaussian closed form	$\mu = \begin{cases} 1 & \text{for x} < \alpha \\ e^{-\left(\frac{x-\alpha}{\delta}\right)^2} & \text{for } \alpha < \text{x} < \gamma \\ 0 & \text{for x} > \gamma \end{cases}$	

Bell	▪ As in Burrough and McDonnell 1998 ▪ As in Graniero and Robinson 2003	$\mu = \begin{cases} 1 & \text{for } x < \alpha \\ \dfrac{1}{1+\left(\dfrac{x-\alpha}{\delta}\right)^2} & \text{for } \alpha < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$	
Linear	▪ Left Trapezoidal open form ▪ Right Trapezoidal open form ▪ Linear open form ▪ Triangular closed form ▪ Trapezoidal closed form	$\mu = \begin{cases} 1 & \text{for } x < \alpha \\ \dfrac{x-\alpha}{\gamma-\alpha} & \text{for } \alpha < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$	
Exponen-tial	▪ Negative exponential open form	$\mu = \begin{cases} 1 & \text{for } x < \alpha \\ e^{-\delta(x-\alpha)} & \text{for } \alpha < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$	

In the formulae above, and in the remainder of this section, the meaning of the parameters α, β, γ and δ is as follows, displayed in Figure 4-1.

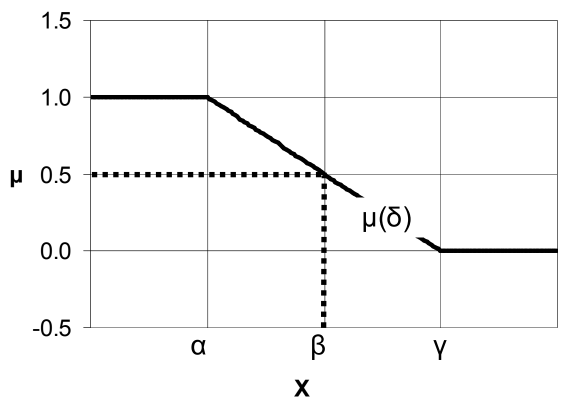


Figure 4-1 – Overview of the meaning of the membership function parameters α, β and γ

Choosing a membership function

The absence of a theory for choosing and parameterizing membership functions is often regarded as a weakness of the application of fuzzy set theory. Concerning the research case data this is no different, because in none of the cases a direct relationship can be given to the meaning of the boundary and a *true* membership function. Therefore, appropriate membership functions must be derived by expert judgement within the context of the spatial planning problem.

In the process of formulating criteria for membership functions for the object-based planning data, a choice is made to choose or construct a membership function that decreases from $\mu=1$ to $\mu=0$ within a *finite range*, because the spatial planning process is driven by an object-based approach, and the planning objects need boundaries. If a choice would be made for a membership function that extends indefinitely like the exponential types, this would conceptually be far off the current planning data and planning process, including all case data. Therefore, these function types are rejected for practical reasons.

Another wish is the possible to fix the location where $\mu=0.5$, because this marks an important crossover point, and in most cases the current position of the object boundary represents exactly this membership. The polygons are explained in the metadata to be an "indicative location", which is explained as the centre of a boundary region.

Characteristics of available membership functions

The overview of available membership functions used in a geographic context (Table 4-1), shows that there are membership functions that degrade slower than the linear membership function in the interval $\mu \in [1, 0.5]$, and membership functions that degrade faster than linear in this interval. At this point it must be noticed that the sigmoidal, Gaussian, bell and exponential functions are parameterized by δ, which means their shape can be modified according to this parameter.

Membership function criteria

A membership function for the planning data must be constructed, and such a function will define the membership based on perpendicular distance to the current object boundary location. In order to select or construct a membership function, criteria of this membership function for the planning data are listed. These criteria are as follows:

- the function should be parametrical so that an operator can change its shape based on expert judgement;
- the function should always return the value $\mu=1$ at $x=\alpha$, and return $\mu=0$ at $x=0$, to have control over the boundary width, and to preserve the familiar idea of an object boundary;
- the function parameter should specify the location x where $\mu=0.5$, because most boundaries will be derived from a $\mu=0.5$ polygon.

To determine whether the above mentioned membership functions satisfies all criteria, a detailed assessment of these function is made in Appendix 2 – Membership function characteristics. The results of the assessment are displayed in Table 4-2. This means that the ideal membership function for planning data in general is not available. For this reason a membership function for planning data is constructed below.

Table 4-2 – Assessment of available membership functions according to criteria for planning data				
membership function	function uses a δ parameter	function returns $\mu_\delta(x=\alpha) = 1$	function returns $\mu_\delta(x=\gamma) = 0$	$x_{\mu=0.5}$ is not a function of δ
Sigmoidal	X			X
S-shaped		X	X	n.a.
Gaussian	X	X		
Bell	X	X		
Linear		X	X	n.a.
Exponential	X	X		

Constructing the membership function

To construct a membership function that implements all three criteria defined above, a parameterized form of the s-shaped function is taken as a starting point:

$$\mu(x) = \begin{cases} 1 & \text{for } x < \alpha \\ 1 - C\left(\dfrac{x-\alpha}{\gamma-\alpha}\right)^{\delta} & \text{for } \alpha < x < \beta \\ C\left(\dfrac{\gamma - x}{\gamma-\alpha}\right)^{\delta} & \text{for } \beta < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$$

In this form, β is always in the exact middle of α and γ. This is not according to the criteria, and it may be useful to specify an inner boundary half (μ>0.5) that is narrower than the outer boundary half (μ<0.5) or vice versa. To accommodate this, the general form is rewritten to:

$$\mu(x) = \begin{cases} 1 & \text{for } x < \alpha \\ 1 - C\left(\dfrac{x-\alpha}{\beta-\alpha}\right)^{\delta} & \text{for } \alpha < x < \beta \\ C\left(\dfrac{\gamma - x}{\gamma-\beta}\right)^{\delta} & \text{for } \beta < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$$

From this general form and the criterion that there must be control over the position of μ=0.5 at x=β (not a function of δ), the value of C is derived as follows

$$\mu(\beta) = 0.5 \Rightarrow 1 - C\left(\frac{\beta-\alpha}{\gamma-\alpha}\right)^{\delta} = 0.5 \Leftrightarrow 1 - C\left(\frac{1}{2}\right)^{\delta} = 0.5 \Leftrightarrow \left(\frac{1}{2}\right)^{\delta} C = \frac{1}{2} \Leftrightarrow$$

$$C = \frac{1}{2}\cdot\left(\frac{1}{2}\right)^{-\delta} \Leftrightarrow C = 2^{\delta-1}$$

With this result and the substitution $\delta=2^{\rho}$ with $\rho \in R$, the general form is reformulated to:

$$\mu(x) = \begin{cases} 1 & \text{for } x < \alpha \\ 1 - \frac{1}{2}\left(\frac{x-\alpha}{\beta-\alpha}\right)^{2^{\rho}} & \text{for } \alpha < x < \beta \\ \frac{1}{2}\left(\frac{\gamma-x}{\gamma-\beta}\right)^{2^{\rho}} & \text{for } \beta < x < \gamma \\ 0 & \text{for } x > \gamma \end{cases}$$

This specific membership function is called the POM (Planning Object Membership) function hereafter. The POM function satisfies all criteria, and examples for various parameters are given below in Figure 4-2 to Figure 4-7.

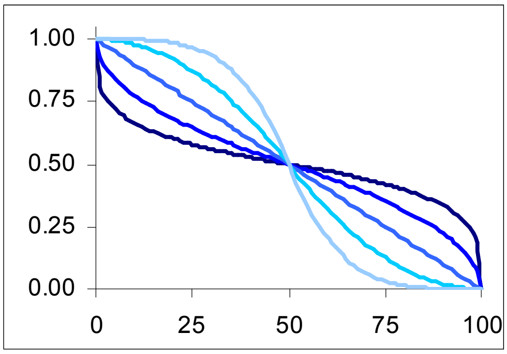


Figure 4-2 – Basic POM functions for ρ = (-2, -1, 0, 1, 2) with (α, β, γ) = (0, 50, 100)

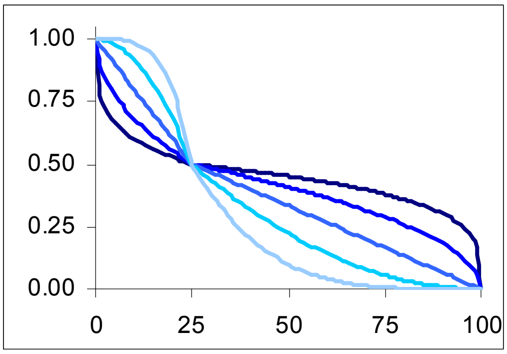


Figure 4-3 – Alternative POM functions for ρ = (-2, -1, 0, 1, 2) with (α, β, γ) = (0, 25, 100)

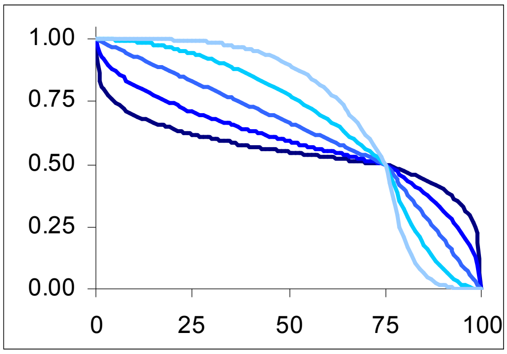


Figure 4-4 – Alternative POM functions for ρ = (-2, -1, 0, 1, 2) with (α, β, γ) = (0, 75, 100)

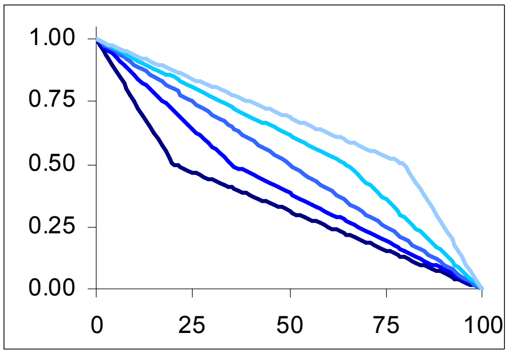


Figure 4-5 – Alternative POM functions for β = (20, 35, 50, 65, 80) with (α, γ) = (0, 100) and ρ = 0

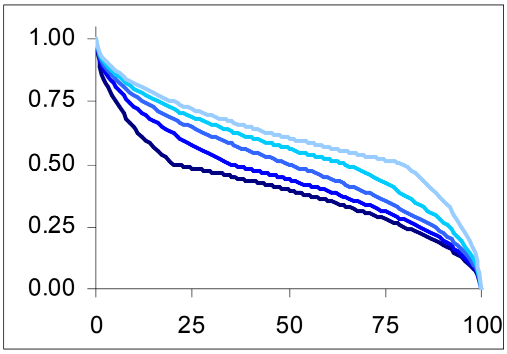


Figure 4-6 – Alternative POM functions for β = (20, 35, 50, 65, 80) with (α, γ) = (0, 100) and ρ = -1

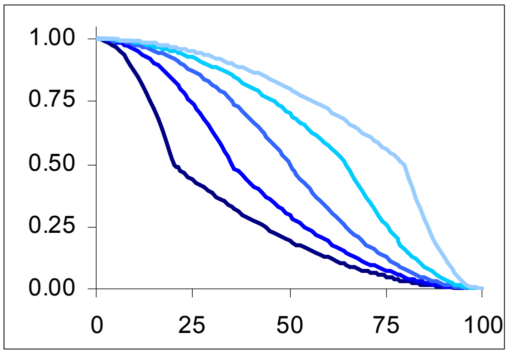


Figure 4-7 – Alternative POM functions for β = (20, 35, 50, 65, 80) with (α, γ) = (0, 100) and ρ = 1

Apart from being fixed at x=α, x=β and x=γ, the POM function has the following characteristics:

- for ρ = 0 the function is linear;
- for ρ → ∞ the function becomes crisp;
- for ρ → -∞ the function becomes 0.5, which means the membership does not discriminate on x.

The POM function is used to fuzzify the currently crisp boundaries. For each object type, a decision on ρ is made. This means that decisions are made on a general level, i.e. linear, more pronounced than linear or less pronounced than linear. With a known μ=0.5 transition point and a defined boundary area, this is a reasonable starting point.

The parameterised POM function has been implemented in a conversion process in ArcGIS. This conversion process, displayed in Appendix 3 – Crisp to fuzzy process flow, takes as input parameters the values α, β, γ and ρ, and converts a layer with crisp objects to a layer with fuzzy bounded objects according to the parameters set.

4.2 Results

In this section the potentials of objects with fuzzy boundaries in intersection operations are explored. For this exploration, three data layers were used:

- IZL
- APA
- APB

The APA and APB layers were combined to a single layer of objects AB.
An intersection of IZL and AB is analysed. The goals of such an intersection could be the evaluation of the reconstruction plan (at a provincial level) against the emission law (at a national level), and the potential of using fuzzy boundaries is assessed in the light of this goal: what information is extracted from the intersection operation?

Intersection of crisp objects

To allow a comparison with the current practice, an intersection is made with crisp planning objects. The primary agricultural development areas from the IZL are intersected with the AB layers, areas sensitive to nitrates, where new agriculture is not allowed. Both datasets exclude each other, which mean that the intersection should be empty. The result of the intersection within the AOI however is that there is an overlap in 43 areas, 276 ha in total, which is 5.6% of the total IZL area. An example of one of the intersection areas is given below in Figure 4-8.

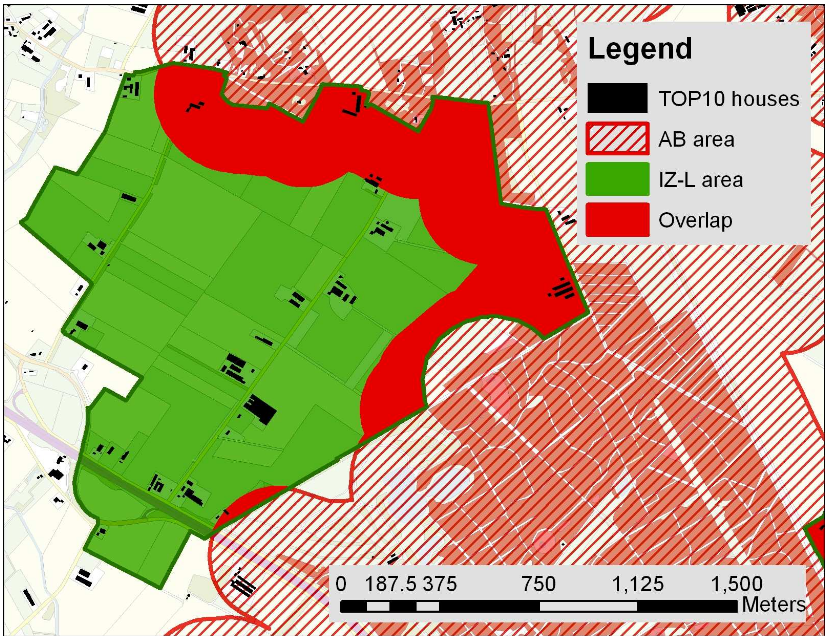


Figure 4-8 – Intersection of crisp AB exclusion areas with a crisp IZL agricultural development area (IZ-L)

In this example, one of the new planned agricultural development areas is shown in green. The province has planned this area around the exclusion area (in this case, a B-area), but did not take into account the required buffer distance of 250m, and therefore four overlap areas are detected. The central question now is: what information is possibly derived from this intersection operation? First of all, some summary statistics for the sizes of all areas in the AOI are given (Table 4-3).

Table 4-3 – Summary statistics for the intersection of the crisp AB areas with a crisp IZL agricultural development area

Count	43
Minimum	2 m^2
Maximum	368661 m^2
Sum	2759562 m^2
Mean	64176 m^2
Median	18705 m^2
Standard Deviation	93541 m^2
Kurtosis	2.7
Skewness	1.8

These summary statistics give a general quantitative impression of the intersection areas and therefore the planning inconsistency. However, there is no information about the geometric characteristics. The largest area might be the biggest issue, but it could also be a very long overlapping, irrelevant boundary area. Of course geometric aspect of the intersection areas could be assessed with a visual inspection of all intersection areas, either on screen or on paper using a printed map, like the example above. But this is not a result of the intersection operation, but a manual, qualitative judgement. Below an investigation is made when the AB areas are described by means of a fuzzy boundary, to see which extra information becomes available in that case.

Intersection of a crisp object with a fuzzy object

To explore the information potential of an intersection of a fuzzy object with a crisp object, the 250m buffer zones around the AB acidification protection areas are replaced by a fuzzy boundary. This replacement in itself is a nice example of the use of fuzzy boundaries in spatial planning, considering the meaning of the buffers: the buffer zones indicate areas that are *too close to the acidification protection areas* to permit new intensive agricultural activities, which is translated to a fuzzy boundary of 250m. This means that the closer the new IZL agriculture development areas are to the AB protection areas, the worse it is. The opposite also holds: the further away from the protection areas the better, but at distances greater than 250m there are no further differences. With this in mind, a fuzzy boundary is constructed using a POM function with (α, β, γ, ρ) = (0, 125, 250, 0). This yields the following result, displayed in Figure 4-9.

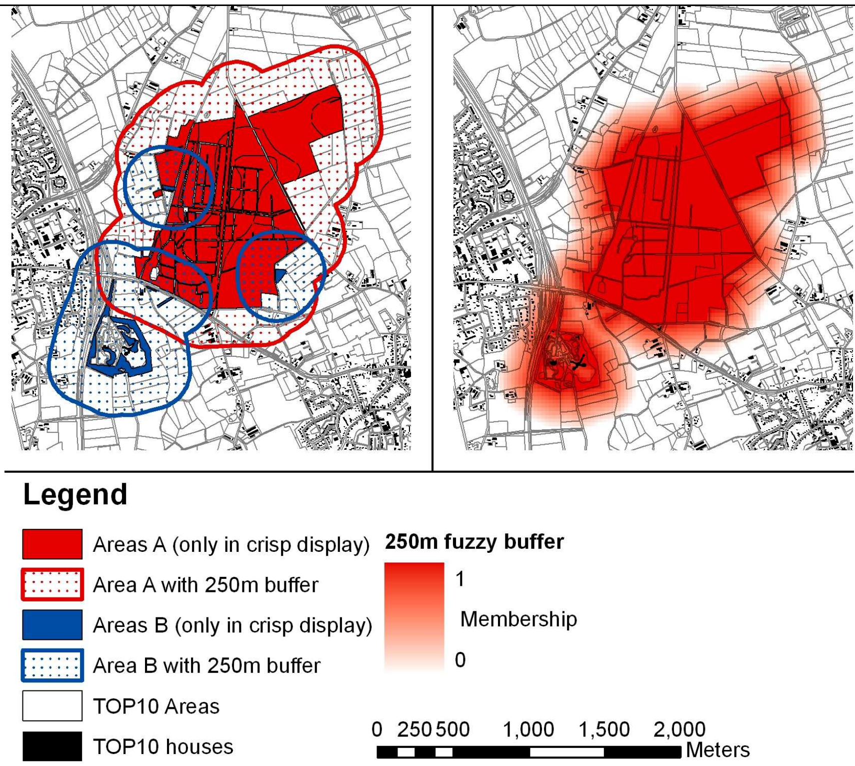


Figure 4-9 – AB areas with a crisp 250m buffer compared to constructed AB areas with a fuzzy boundary replacing this buffer

The next step in the explorative process is to intersect the fuzzy areas with the IZL areas, to see which information is derived from such an operation. The intersection itself is easy, and is visualised below in Figure 4-10 for the same area as the example in Figure 4-8.

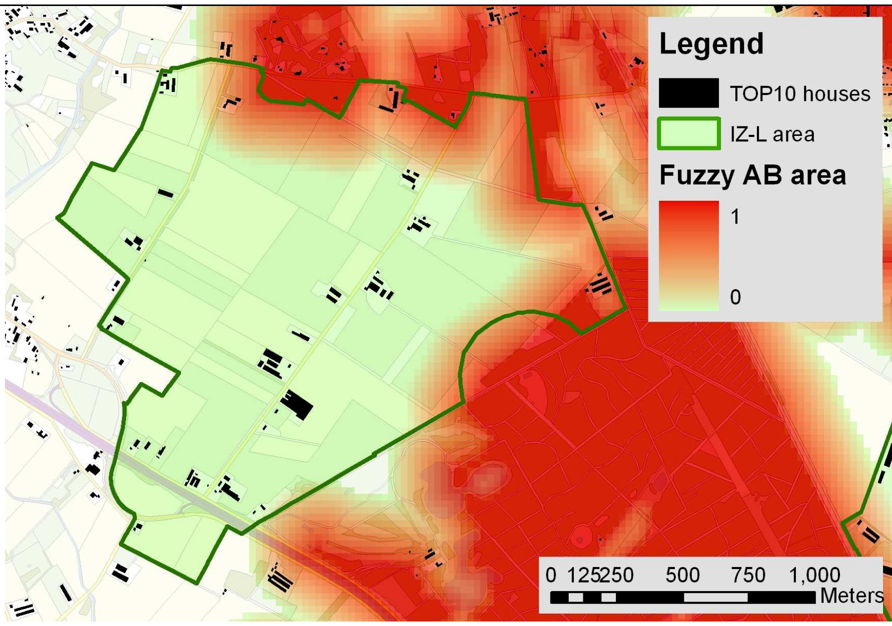


Figure 4-10 - Intersection of constructed fuzzy AB exclusion areas with a crisp IZL agricultural development area (IZ-L)

The fuzzy AB boundary has a different visualisation than the crisp buffer of Figure 4-8. In this figure and subsequent figures, a colour gradient is used to display membership values, which is an intuitive way of displaying the meaning of the object. The red colour (μ=1) matches the general colour of the A and B areas, so intuitively the idea of an object-based approach is reserved. The green colour (μ=0) matches the colour of the IZL agricultural development area in a way that the exclusion zones fade away into this area. Any other colour for the outer boundary edge would result in a sharp-looking boundary, which might be confusing for a less-experienced spectator of the map. However, this representation is not necessary for the analysis of the result.

If these intersection results are analysed, the same summary statistics as in the situation with an intersection between two crisply defined object types (similar to Table 4-3, but not repeated here) could be generated. This again would tell us things about the distribution of the size of intersection areas. But with the membership values available in the intersection area, there is also the possibility to express the intersection statistics in terms of membership, as follows in Figure 4-11.

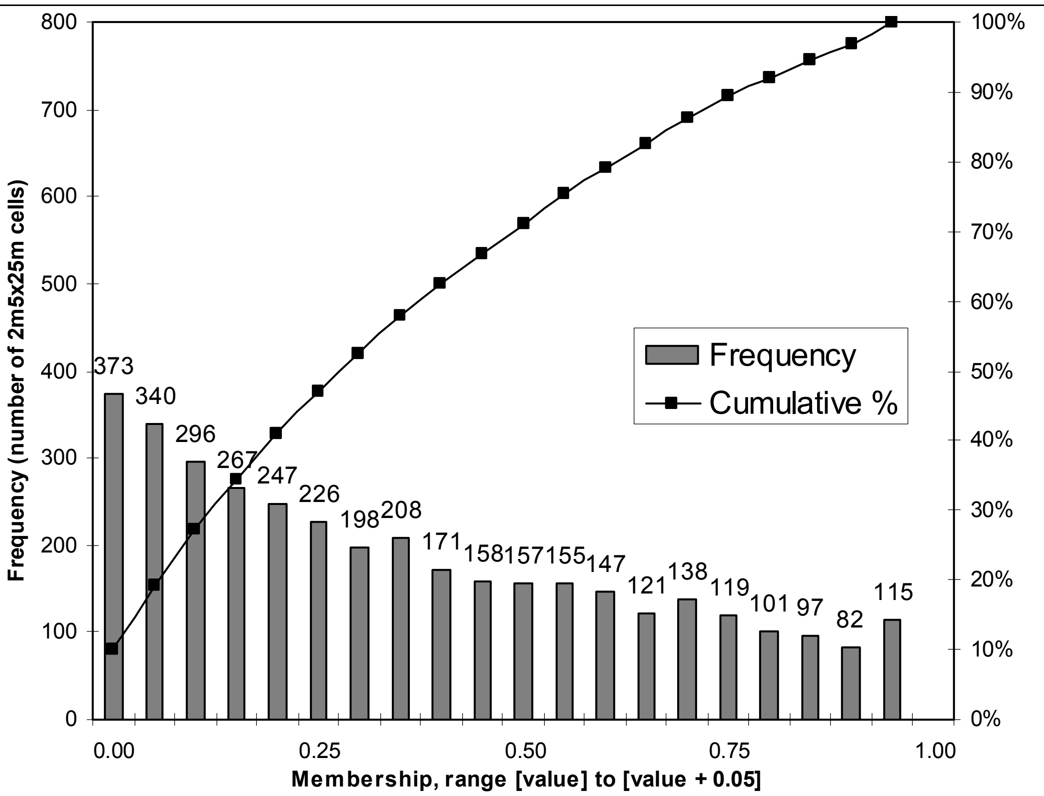


Figure 4-11 – Membership distribution of the intersection area of the constructed fuzzy AB exclusion areas with crisp IZL agricultural development areas

This distribution reveals interesting aspects about the geometric distribution of the intersection area. For instance it shows immediately that almost all overlapping cells have a membership smaller than 1, which indicates that the intersection takes place *within* the boundary area. Furthermore, it shows that in about 2/3 of the overlapping cells, the membership is smaller than 0.5, which means, given the membership function of the boundary, that the intersection takes place in the outer half of the boundary area.

Intersection of fuzzy objects

To investigate the potential of intersections with fuzzy objects, the crisp IZL area boundaries were also converted to fuzzy. This makes sense, given the statement about the intended scale of 1:125000. The meaning of these objects could be: “Please consider this boundary to be indicative; if some planning activity is taking place within this boundary, please apply the regulations given in the metadata”, and these regulations could well be based on membership values.

In this example the IZL areas are defined with a fuzzy boundary $(\alpha, \beta, \gamma, \rho) = (-75, 0, 75, -1)$. In this example $\rho = -1$, which means a more pronounced boundary area is constructed than a linear membership function with $\rho = 0$ would provide.

Figure 4-13 visualises this intersection in a 2-dimensional subtractive colour map, using Magenta-Yellow (MY) values. The IZL membership $\mu_{IZL} \in [0..1]$ is displayed linearly with a yellow [0..1] intensity, the combined PAA and PAB membership $\mu_{PA} \in [0..1]$ is displayed linearly with a magenta [0..1] intensity, as follows:

$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 0 \\ \mu_{PA} \\ \mu_{IZL} \end{pmatrix}$$

This visualisation is converted to a Red-Green-Blue (RGB) composite as follows:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} 0 \\ \mu_{PA} \\ \mu_{IZL} \end{pmatrix} = \begin{pmatrix} 1 \\ 1-\mu_{PA} \\ 1-\mu_{IZL} \end{pmatrix}$$

with the main processing flow displayed in Figure 4-12.

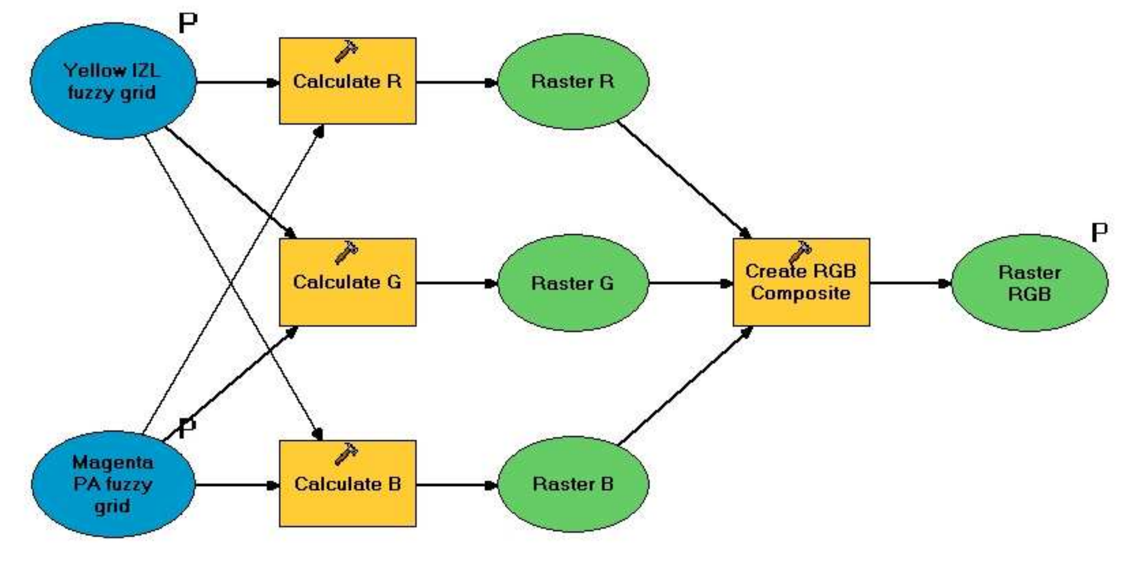


Figure 4-12 – Visualisation processing flow to calculate RGB values from a subtractive intersection of a fuzzy Yellow object with a fuzzy Magenta object

This generates the result displayed in Figure 4-13.

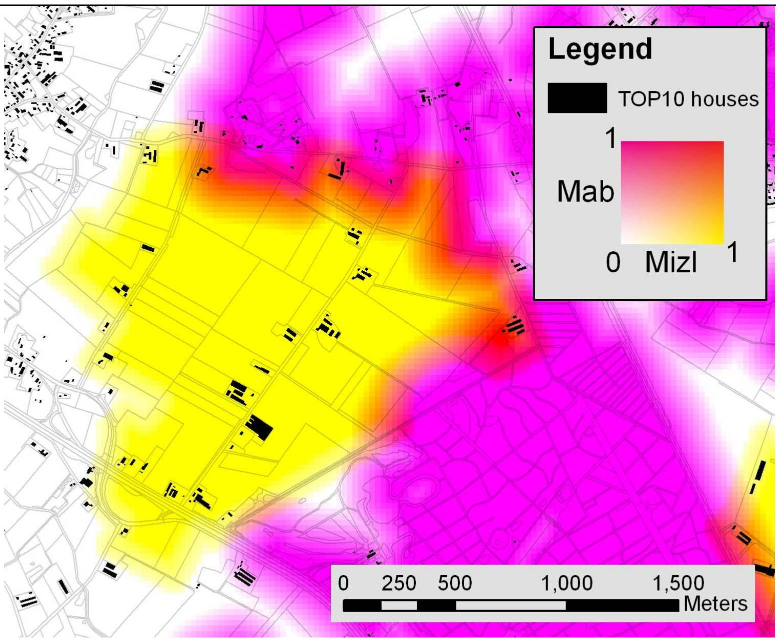


Figure 4-13 - Intersection of constructed fuzzy AB exclusion areas with a fuzzy IZL agricultural development area using a 2-dimensional legend

In this situation the same summary statistics could again be given as the crisp-crisp and crisp-fuzzy intersections above, but in this case an intersection of two membership values in the mutual boundary area is available. The intersection operation of these fuzzy objects is a logical intersection. Extra information from this intersection is derived using a t-norm. In this exploration the algebraic product is applied, which leads to the following distribution in Figure 4-14.

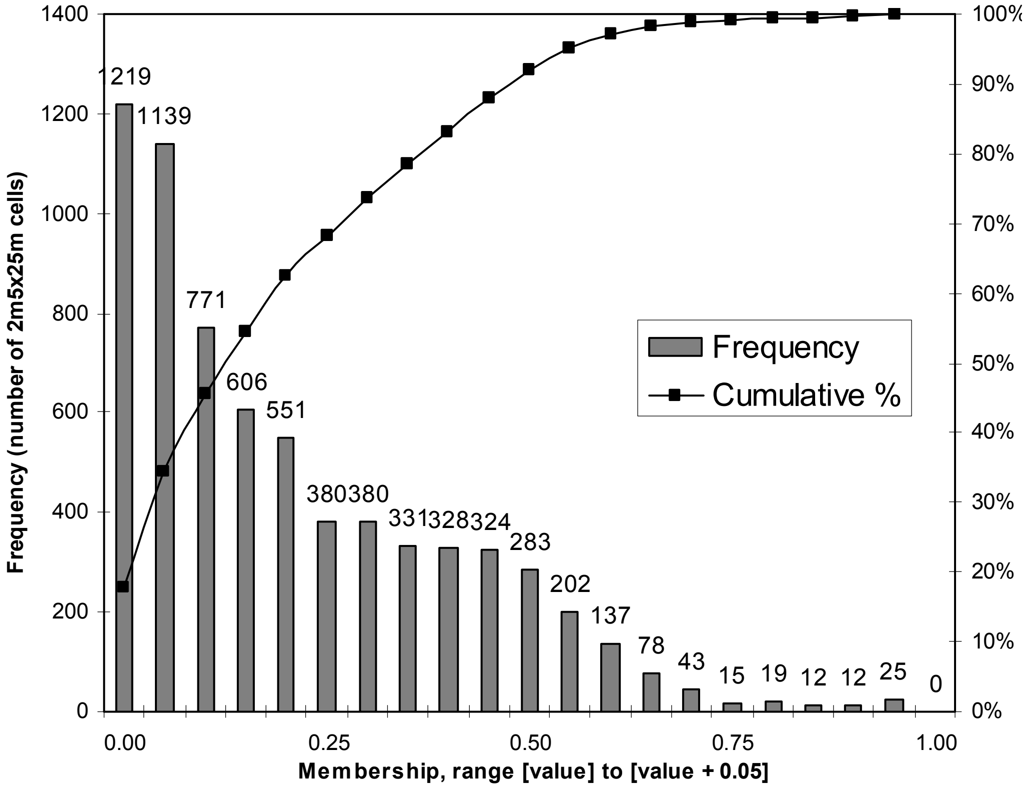


Figure 4-14 – Membership distribution of the intersection area of the constructed fuzzy AB exclusion areas with fuzzy IZL agricultural development areas after an algebraic product t-norm has been applied to the mutual boundary areas

The result of this t-norm has been used in a classification of the intersection area. An example classification result is displayed in Figure 4-15. In this example class boundaries are chosen as the squares of 0.9, 0.8, 0.7 and 0.6, to normalize for the multiplication operation on the membership values by using the algebraic product. Classification choices in a real assessment situation will be based on expert judgements.

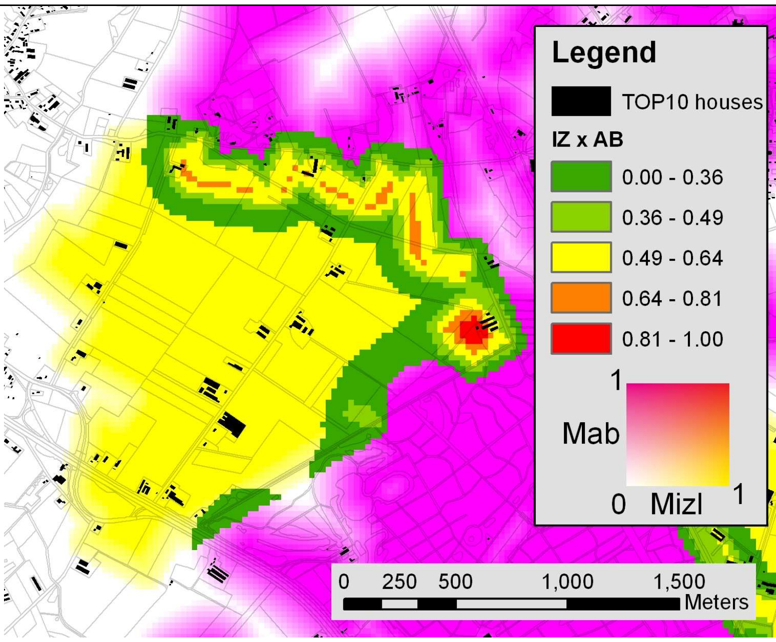


Figure 4-15 – Classification of the intersection t-norm in the mutual boundary area

5 Fuzzy planning objects in the thematic domain

In this section fuzziness in the thematic domain of spatial planning data is investigated. The thematic domain is the attribute space of the objects. In the thematic domain the issue is not to describe location of planning objects, but to describe properties of planning objects, specifically in relationship to properties of other planning objects. In relationship to fuzzy sets, it means determining to what extent the objects are of the same kind (Burrough and McDonnell 1998).

5.1 Methods

To determine if two planning objects are of the same kind is simple if similarity is defined as the equality of all object attributes. However, the case data demonstrates that many different planning layers have many different object types in a very heterogeneous way, and there are hardly any formal object attributes available. The planning objects are described in planning reports, with a low level of standardisation. This implies that a comparison of planning data is a comparison of very dissimilar objects. It also implies that for a meaningful digital comparison some of the informal object descriptions in the planning reports must be captured in the object attributes. To enable comparison of the heterogeneous planning objects, a comparison methodology was created in this research. An important goal of the comparison is to assess the *consistency* of spatial plans. This goal has been the foundation of the comparison methodology in the thematic domain.

The central idea in this section is to define a planning object as an area that expresses a level of appropriateness for all other planning object types available. This appropriateness is thus expressed in terms of all other planning object types using the concept of a fuzzy relationship. This fuzzy relationship specifies mutual *consistency* of compared planning object types. Consistency is a specialisation of membership. A consistency relationship between object A and B is a fuzzy membership $\mu_{AB} \in [0...1]$ to express the appropriateness of A at the same location as B and vice versa. For further explanation, two examples are given below.

- **Example 1 -** The comparison between an extensivation area from the IZL and a nature development area in the EHS. It is clear that these objects are thematically different: the first object represents an area which is taken out of intensive agricultural production, the second object represent an area where new nature is to be developed. However, there is no objection to stop intensive agriculture in a nature development area, and there is no objection to develop new nature in an area where intensive agriculture is not allowed. This means that the objects have a consistency relationship $R = 1$.

- **Example 2 –** The comparison between a COA city overflow area and the EHS nature development area of example 1. A COA area is a multifunctional area with a varying spatial structure with varying extensive and intensive recreational use. It is not entirely wrong to designate such an area in a nature conservation area, nor is it entirely wrong to plan a nature development area in a city overflow area. However, it is far from ideal because both object definitions will restrict each other; hence the objects have a fuzzy consistency relationship R in the open interval <0...1>.

In the examples above the consistency relationship R between A and B is defined as a single value, which is an expression of the total appropriateness of a planning constellation between planning objects. This means that the relationship satisfies commutativity rule R(A, B) = R(B, A). This choice is made in correspondence with a t-norm, where commutativity is one of the basic axioms (Klir and Yuan, 1995). This choice enables intersections of multiple fuzzy relationships as t-norms.

Data selection

In this section the potentials of comparing heterogeneous planning objects via fuzzy relationships are explored. In the case data there are many object types. In the current work, a trade-off was made between complexity and realism. The most complex would be to compare all case data, about 100 data layers with potentially fuzzy consistency relationships between all object types. The simplest case would be to compare two layers with at least one fuzzy consistency relationship between object types. In this research nine layers were compared to avoid complexity that would blur the concepts, yet avoiding triviality that would also blur the concepts. These layers are as follows:

- IZL
- EHS
- RNLE
- PAA
- PAB
- AVL
- PLA
- COA
- IRA

A spatial intersection was made of all these layers. This resulted in a total of 44021 polygons with 1109 unique class combinations.

One of the research questions is to find out how to compare different spatial planning data sets, and to check for consistency amongst these planning objects. In this case, the intersection has, as expected, lead to a large number of areas. A maybe less expected result is the large number of unique class combinations. Checking all combinations for consistency is best done in a digital environment, specifically a GIS environment. In this environment, matrices with all possible fuzzy relationships between all available object types were produced. These matrices and the results of the analyses are presented below.

5.2 Results

Crisp assessment

In a crisp environment, the assessment strategy could be as follows:

- identify which object types are conflicting;
- for each area, determine the number of conflicting object combinations;
- if there are more than zero conflicting combinations, conclude that the area is inconsistently planned.

In this case, the conflicting object types are given as crisp consistency relationships, chosen as follows in the matrix in Table 5-1.

Table 5-1 – Crisp consistency relationships matrix of all planning object types from the selected layers

		IZL								EHS								RNLE		PAA		PAB		AVL			PLA		COA		IRA	
		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	0	1	0	1	0	1	2	0	1	0	1	0	1
EHS	0	1	1	1	1	1	1	1	1																							
	1	1	1	1	0	0	0	0	0																							
	2	1	1	1	0	0	0	0	0																							
	3	1	1	1	0	0	0	0	0																							
	4	1	1	1	0	0	0	0	0																							
	5	1	1	1	0	0	0	0	1																							
	6	1	1	1	0	0	0	0	0				EHS																			
	7	1	1	1	0	0	0	0	0	0	1	2	3	4	5	6	7															
RNLE	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	RNLE														
	1	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	1	0	1													
PAA	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	PAA												
	1	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1											
PAB	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	PAB										
	1	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1									
AVL	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1									
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		AVL							
	2	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	2						
PLA	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	PLA					
	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	1				
COA	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	COA			
	1	1	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1		
IRA	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		

This consistency analysis was performed on the case data, and Figure 5-1 and Figure 5-2 show the results.

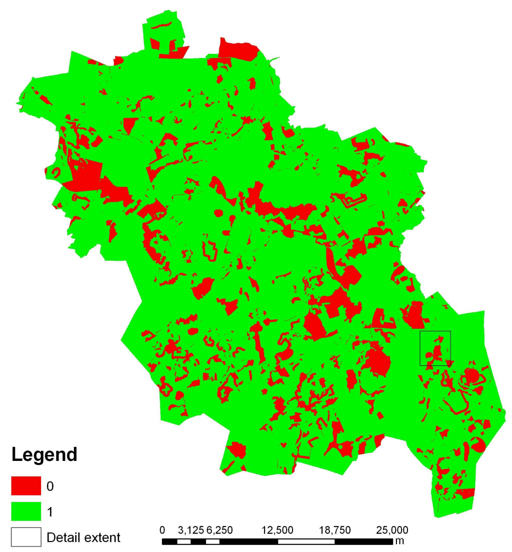


Figure 5-1 – Thematic consistency assessment derived from a crisp methodology

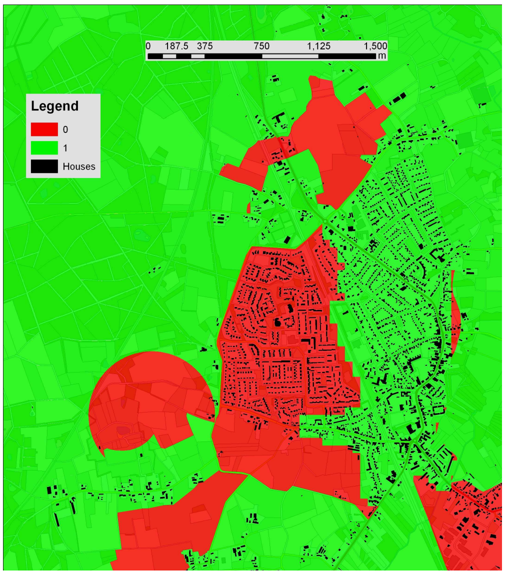


Figure 5-2 – Detail of the thematic consistency assessment derived from a crisp methodology

This result shows a binary classification: areas with no consistency problems (value 1), and areas that suffer from some inconsistency amongst the nine layers (value 0). What is missing in this result is the qualitative information regarding the degree of inconsistencies. In reality, some problem areas will be worse than others.

Fuzzy assessment

To explore the potential of fuzzy consistency relationships, these have been defined in the relationships matrix between all object classes, as shown in Table 5-2.

Table 5-2 – Fuzzy consistency relationships matrix of all planning object types from the selected layers

		IZL								EHS								RNLE		PAA		PAB		AVL			PLA		COA		IRA	
		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	0	1	0	1	0	1	2	0	1	0	1	0	1
EHS	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0																							
	1	1.0	1.0	1.0	0.3	0.1	0.2	0.1	0.2																							
	2	1.0	1.0	1.0	0.3	0.1	0.2	0.2	0.4																							
	3	1.0	1.0	1.0	0.3	0.1	0.2	0.2	0.4																							
	4	1.0	1.0	1.0	0.3	0.1	0.2	0.0	0.0																							
	5	1.0	1.0	1.0	0.3	0.1	0.2	0.3	0.6																							
	6	1.0	1.0	1.0	0.3	0.1	0.2	0.1	0.2																							
	7	1.0	1.0	1.0	0.3	0.1	0.2	0.2	0.4																							
RNLE	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0															
	1	1.0	1.0	1.0	0.3	0.2	0.2	1.0	0.5	1.0	1.0	0.8	0.8	1.0	0.8	0.8	1.0															
PAA	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0													
	1	1.0	1.0	1.0	0.2	0.1	0.2	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0													
PAB	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0											
	1	1.0	1.0	1.0	0.4	0.2	0.3	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0											
AVL	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0									
	1	1.0	1.0	1.0	0.9	0.9	0.9	0.7	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0									
	2	1.0	1.0	1.0	0.8	0.8	0.8	0.4	0.8	1.0	1.0	0.6	0.6	1.0	1.0	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0									
PLA	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0						
	1	1.0	0.4	0.6	0.8	0.8	0.6	1.0	1.0	1.0	0.2	0.2	0.2	0.0	0.4	0.2	0.2	1.0	0.2	1.0	0.8	1.0	0.9	1.0	0.8	0.6						
COA	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0				
	1	1.0	0.2	0.4	0.4	0.4	0.4	1.0	1.0	1.0	0.5	0.5	0.8	0.2	0.5	0.5	0.5	1.0	0.6	1.0	0.8	1.0	0.9	1.0	0.9	0.8	1.0	1.0				
IRA	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
	1	1.0	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	0.7	0.7	0.8	0.4	0.7	0.7	0.7	1.0	0.8	1.0	0.8	1.0	0.9	1.0	0.9	0.8	1.0	1.0	1.0	1.0		

The table figures show that there are many crisp relationships ($\mu = 1$). But a number of object type pairs now have a fuzzy relationship, with $\mu \in$ <0, 1>. In these cases, the objects partially exclude each other in terms of appropriateness.

Once the relationships had been established, the t-norms were calculated for k layers with fuzzy relationships R. For reasons of comparison, t-norms were calculated for both main intersection types:

- Standard intersection $I_k = \min(R(i, j))$ for all $i = 0..k$, $j = 0..k$, $i \neq j$
- Algebraic product $P_k = R(i, j) \cdot R(i, j)$ for all $i = 0..k$, $j = 0..k$, $i \neq j$

This yields the following results, displayed in Figure 5-3 to Figure 5-6.

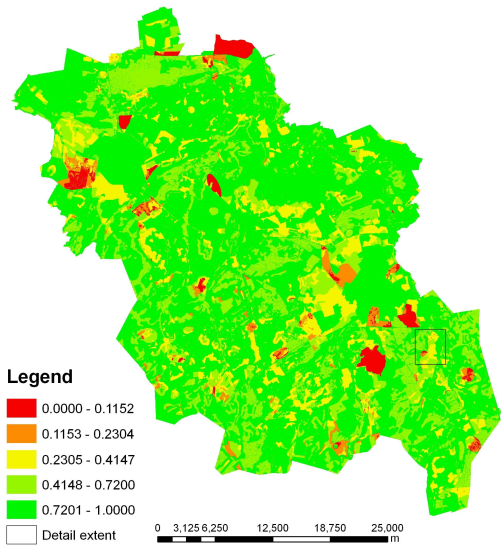


Figure 5-3 - Thematic consistency assessment derived from a fuzzy methodology using the algebraic product t-norm

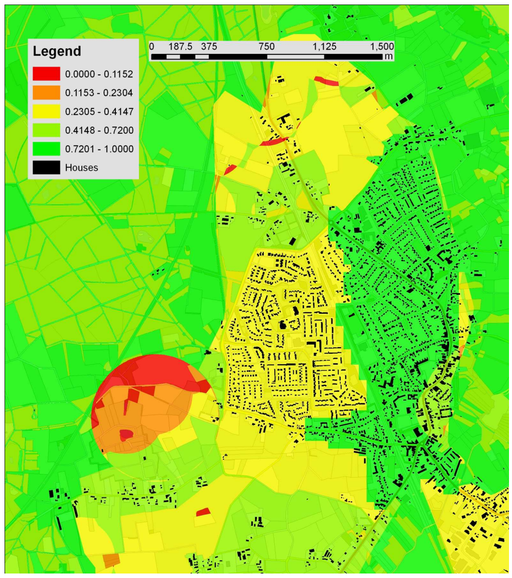


Figure 5-4 – Detail of Figure 5-3

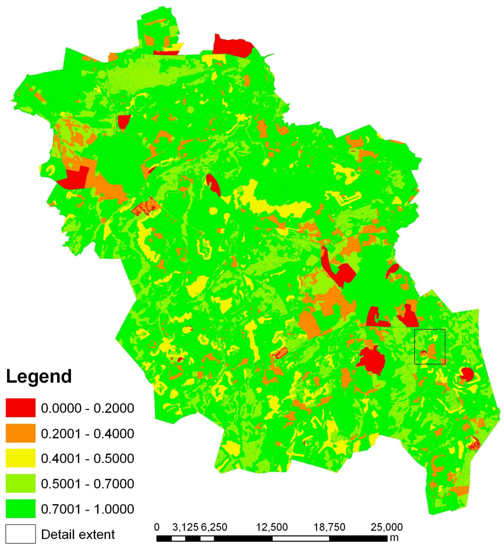


Figure 5-5 - Thematic consistency assessment derived from a fuzzy methodology using the standard intersection t-norm

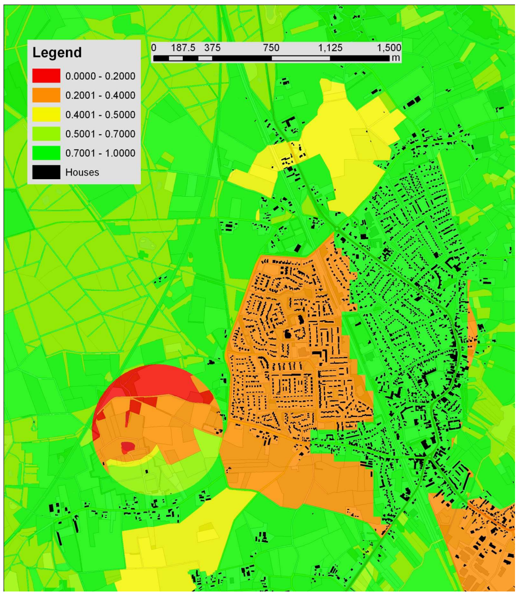


Figure 5-6 – Detail of Figure 5-5

In the above overviews it shows that with both intersection mechanisms roughly the same problematic areas are detected. Note that in both map legends the class boundaries are chosen differently. This is because as a classification result the method of natural breaks (Jenks and Caspall 1971) was used to determine the consistency classes in each case. This choice was made for best comparison of both ordinal classification results.

Both methods were compared, and some results are listed in Table 5-3.

Table 5-3 – Comparison of results from different intersection algorithms

Statistic	Standard intersection	Algebraic product
min	0.000	0.000
max	1.000	1.000
average	0.719	0.659
median	0.600	0.600
correlation	0.962	

These statistics show that the results are comparable. However, local differences do occur.

6 Questionnaire

6.1 Methods

In research question D, the potentials and drawbacks of accounting for fuzziness in spatial planning data are queried. In response to these issues, a questionnaire (see Appendix 4 – Questionnaire) was distributed during a GeO3 meeting on 25 January 2006. In this meeting, 17 responses were obtained from people directly involved in the spatial planning process in The Netherlands (see Appendix 5 – Background of questionnaire respondents). The main goal of the questionnaire was to find out to what extents the results of the current work so far would be judged a better alternative to the current practice of dealing with uncertainty. The questionnaire consisted of five sections:

- **Introduction section**. In this section the concept of fuzziness in spatial planning data was gently introduced to the respondent and four questions were asked about the recognition of the respondent to these phenomena in the spatial planning process.
- **Case 1**. In this case an ecological connection zone was presented in a crisp (A) versus a fuzzy (B) methodology, accompanied with some explanation. In this case the fuzziness in the geometric domain was presented. In four questions the respondent was asked to compare both methods regarding the level of realism, appropriateness for exchange of fuzziness information within the spatial planning process, appropriateness outside the process, and suitability to test different spatial plans for consistency.
- **Case 2**. In this case a number of emission sensitive areas were presented, again in a crisp (A) versus a fuzzy (B) way, again accompanied with some explanation. In this case some aspects of thematic fuzziness were presented. The respondent was asked the same questions as the previous case.
- **Case 3**. In the last case two conflicting but overlapping spatial planning object were presented, again in a crisp (A) versus a fuzzy (B) methodology, and again accompanied with some explanation. The respondent was presented with the same questions as the previous cases.
- **Final section**. In this section the changes for implementation in The Netherlands were assessed on an easy to difficult scale for the domains of concept, technical, juridical and political. Finally some general background information about the respondent was asked and there was some room for final remarks.

All questions in the introduction and the three cases were answered on a nominal scale with five classes. Significance levels between differences in response were calculated using the Wilcoxon Matched-Pairs Signed-Ranks Test, elaborated in Appendix 7 – Wilcoxon Matched-Pairs Signed-Ranks Test (Wilcoxon 1945).

6.2 Results

The response can be found in Appendix 6 – Questionnaire response. In the results below in Table 6-1, the nominal scale of the questions is presented with a number ranging from 1 to 5. Question 3 and 4 were compared to determine if the respondents did see any statistically significant difference between problems in an analogue environment versus a digital environment. The case questions 5 to 16 were compared to see if the respondents significantly discriminated the presented crisp and the proposed fuzzy methodologies. Question 17 is analysed to see if there are any significant expected difficulties between the four implementation domains.

Table 6-1 – Main results of the questionnaire

*Wilcoxon significance * <0.1, ** < 0.05, *** < 0.025, **** < 0.01*

#		Subject	Ordinal scale ranges	Mean		SD			Wilcoxon	
General questions										
1		Recognition of fuzziness	no recognition – recognition	4.2		1.0				
2		Current practical problems	never – often	3.6		1.3				
3		Problems with analogue exchange	no problem – large problem	3.2		1.1			0.08	*
4		Problems with digital exchange	no problem – large problem	3.8		1.1				
Case 1				**A**	**B**	**A**	**B**			
5		order of reality	abstract – realistic	2.2	3.4	1.3	1.3		0.07	*
6		suitable within planning process	unsuitable – suitable	2.9	3.8	1.3	1.2		0.05	**
7		suitable outside planning process	unsuitable – suitable	2.3	3.6	1.4	1.2		0.01	***
8		suitable for testing spatial plans	unsuitable – suitable	2.8	3.6	1.3	1.0		0.13	
Case 2										
9		order of reality	abstract – realistic	2.9	3.9	1.4	0.7		0.03	**
10		suitable within planning process	unsuitable – suitable	3.2	3.6	1.3	0.9		0.36	
11		suitable outside planning process	unsuitable – suitable	2.6	3.8	1.2	1.3		0.02	***
12		suitable for testing spatial plans	unsuitable – suitable	3.4	3.9	1.4	1.1		0.13	
Case 3										
13		order of reality	abstract – realistic	2.5	4.0	1.2	0.9		0.00	****
14		suitable within planning process	unsuitable – suitable	2.8	3.9	1.0	1.1		0.00	****
15		suitable outside planning process	unsuitable – suitable	2.6	4.1	1.2	1.2		0.00	****
16		suitable for testing spatial plans	unsuitable – suitable	3.1	4.1	1.1	1.1		0.01	****
Implementation difficulties										
17	a	conceptual	simple – problematic	2.6		1.3		a-b	0.17	
	b	technical	simple – problematic	2.0		1.1		a-c	0.00	****
	c	juridical	simple – problematic	4.5		0.7		a-d	0.02	**
	d	political	simple – problematic	3.7		1.0		b-c	0.00	****
								b-d	0.00	****
								c-d	0.00	****

7 Discussion and conclusions

Fuzziness in spatial planning data is something that people may not like to know about. It is much easier to look at and discuss clearly defined areas on a map. The paradigm of a map with crisp objects is strong, because a reason to map an area is indeed to structure the area into similar classes. Therefore, people are disturbed by inexact objects. An inexact boundary is experienced as a paradox.

In the spatial planning process, aspects of fuzziness are often kept away from the map, and these aspects are described in complementary reports. With a shift towards a digital spatial planning environment, it becomes apparent that a sketched area on a paper map has another denomination than a digitized polygon in a GIS, because the polygon allows for operations like zooming and intersecting with other objects. Now what can be concluded from the current work?

7.1 Geometric domain

In this research it has been investigated if it would be appropriate to use fuzzy sets to describe the type of inexact geometry found in spatial planning data. The answer is yes. It proved quite convenient to implement an “indicative area” as an object with a fuzzy boundary. Duckham considers visualisation of imperfect geographic data difficult (Duckham *et al*. 2001), but in this research it has been no problem. From the response of the questionnaire the chosen visualisation of gradual colour schemes proved quite intuitive: the respondents had no difficulties understanding the meaning of the fuzzy objects. It showed that intersection of fuzzy objects in the geometric domain is possible with existing techniques like the available t-norms, and that the result gives a more detailed classification of the intersection situation.

What proved more difficult in this domain is the exact choice of membership function. In this research existing membership functions have been combined to a new general form, the POM function that is easily understood and suitable for object-based planning data. However, expert decisions remain, and as the questionnaire demonstrated, especially political and juridical problems are expected when uncertainty is formalised. Currently, writing in a report that a polygon is indicative seems better accepted then specifying this in the object itself, because in the report one does not need to define the meaning of the word ‘indicative’. Nevertheless the framework of fuzzy boundaries is suitable for a more realistic modelling of planning data with an indicative nature, and the digital transfer of this information. Others who have done research in the field of fuzzy quantifiers for spatial data in general come to similar conclusions. The intersections also demonstrate the improved semantic aspects of using a fuzzy descriptor: the meaning of the buffer or boundary is expressed in the data itself rather then in the metadata.

With the results of this work it becomes possible to start formulating spatial policy based on membership-dependent rules. This means that more objective and quantitative judgements about intersecting areas can be made.

7.2 Thematic domain

The work in the thematic domain has led to a framework for comparing heterogeneous spatial planning data. Fuzzy similarity was already explored by Zadeh in the early 1970s, by presenting a unified conceptual framework for the study of fuzzy equivalence relationships. A concluding remark is made that it is a relative simple matter to extend some of the well-known results in the theory of relationships to fuzzy sets (Zadeh, 1971). However, not much research has been done in the combination of spatial data and fuzzy relationships, and most is done in the field of remote sensing. Hagen (2003) compared the similarity of two maps by means of fuzzy relationships [0...1], but this is more a fuzzy classification solution (Hagen, 2003). Ahlqvist (2004) states that most conceptual modelling in geographic information science to date has used a symbolic approach with little or no recognition of the semantic uncertainty often found in geographic concepts (Ahlqvist 2004). This means that there is not much reference in this field. However, the practical approach with fuzzy consistency relationships for assessing consistency in diverse and overlapping spatial planning data seems useful, while being consistent between different general t-norms. The result was an ordinal classification of the whole area with respect to the degree of planning consistency, in a more detailed and discriminating way than a crisp assessment would allow. This framework could be extended in the future by better classification mechanisms for the calculated fuzzy consistency relationship intersections. The applied methodology has lead to a better insight in spatial planning in the AOI, and more research in this direction would contribute to the understanding of the results.

The values of the fuzzy relationships must be assigned by expert judgement. This is also the case for the crisp situation where a choice must be made whether or not two object types are conflicting, but there the choice is a binary one, here it is a floating point number. Choosing the membership value and in this case the relationship value is an inherent issue that is often mentioned when using fuzzy sets. However, it must be remembered that the goal of this procedure is to perform an assessment of the spatial planning consistency, at least at the ordinal scale. This means to find areas with potentially larger consistency problems than other areas, so it is not only the relationship value that counts, but also the value relative to other relationship values.

7.3 Questionnaire

From the results of the questionnaire the following conclusions are drawn:

- Exchange of fuzziness information is a larger problem in a digital environment than in an analogue environment ($p = 0.08$);
- Incorporating fuzziness information *within* the planning objects is a more realistic approach than specifying this information in the meta-information ($p = 0.07$, $p = 0.03$, $p = 0.00$ for questions 5, 9 and 13 respectively);
- If presented with individual fuzzy objects (case 1 and 2), suitability for testing planning objects on consistency using these objects is regarded not significantly

better when fuzzy formation is incorporated within the planning object ($p > 0.10$ for questions 8 and 12). However, if the respondent is presented with the intersection result of two fuzzy objects (case 3), the suitability difference for testing on consistency is regarded highly significant ($p = 0.01$ for question 16);

- Presenting ordinal classified intersection results for planning objects (case 3) is more convincing to the respondents than showing individual fuzzy objects with respect to all aspects of the case-specific questions (p_{case3} is consistently smaller than p_{case1} and p_{case2}).;
- Expected implementation difficulties in the conceptual and technical domains are lower than expected difficulties in the juridical and political domain. Expected difficulties in the juridical domain are estimated the highest of the four domains, and significantly higher than in the political domain (p values for question 17).

These results demonstrate that the uncertainty aspects in spatial planning are a recognized issue, and that the use of fuzzy sets is regarded as a better alternative compared to the current practice. A restriction must be mentioned, which is the case of legal issues. The respondents consistently indicate that legal issues with this matter will become an issue. In the current practice, a crisp boundary might have a legal status: it is forbidden to do activity A within O, and the location O is part of the law. If the current legislation is taken as a starting point, no fuzziness exists. However, extending the legal framework to make choices based on membership or fuzzy relation could be beneficial. Today planning object boundaries with a legal status are crisp. This means that difficult black-and-white choices have been made concerning exact location of object boundaries. Choices that are not always very realistic, with outcomes that can be disputed. If these choices can be avoided by facilitating an uncertainty framework in the data, this is an advantage over the current practice.

7.4 Final remarks

Finally it becomes possible to answer the research questions:

A. How are fuzzy boundaries of planning objects best described?
Fuzzy boundaries of planning objects are well described by the set of POM functions. This allows for a more sensible definition of object boundaries than the current crisp descriptions. Intersections of objects with such boundaries produce a more realistic result.

B. How is thematic fuzziness of planning objects best described?
Thematic fuzziness of planning objects is well described in terms of other planning object, by means of a fuzzy consistency relationship between each class of objects.

C. How can a fuzzy spatial plan be compared to other spatial plans?
Comparing fuzzy spatial plans with other plans, including other fuzzy plans, is done using the generally available t-norms from the fuzzy set theory. For comparing objects in the geometric sense, the t-norm yields a spatially distributed ordinal field

of intersection values. For comparing objects in the thematic sense, the t-norms are used to intersect the consistency relationship combinations for every set of values, which yield an ordinal consistency classification of the area.

D. What are the potentials and drawbacks of accounting for fuzziness in spatial planning data?

Burrough (Burrough and Frank 1996) states that the concepts of a continuous membership function and overlapping sets permit a more realistic description of complex phenomena, and conclude that it is sensible to have a formal way to handle indeterminacy. Robinson (2003) ends his review paper about the perspective on the fundamentals of fuzzy sets in GIS with the expectation that fuzzy sets will play a major role in the development of GIS related applications (Robinson 2003). Until now, this has not been the case. In ArcGIS 9.1, the software that was used in this research, there is no support for any formal uncertainty model. However, it proved not too difficult to build a parameterized implementation of the POM functions to specify a fuzzy boundary. Nor was it very difficult to build the necessary lookup tables for the consistency relationships for the spatial consistency assessment. A possible drawback in these practices is the current legal framework. Currently there is no experience with spatial legislation using fuzzy boundaries or fuzzy relations. But a readily available GIS toolbox would increase the potential and initiate the normalization of fuzzy boundary descriptions in planning and other spatial data. This would lead to more natural and meaningful GIS objects, and disclose the full advantages of a digital spatial planning process.

The fuzzy set theory is a useful framework for dealing with the type of uncertainty that is found in spatial planning data. A broader appreciation for such a framework will depend on the acceptance of the concept of imperfection in our data and in our minds.

References

Ahlqvist, O. (2004). "A parameterized representation of uncertain conceptual spaces." Transactions in GIS 8(4): 493-514.

Anthony, J.M. and Sherwood, H. (1982). "Characterization of Fuzzy Subgroups." Fuzzy Sets and Systems 7(3): 297-305.

Burrough, P.A. and Frank, A.U. Eds. (1996). Geographic objects with indeterminate boundaries. GISDATA. London, Taylor & Francis.

Burrough, P.A. and McDonnell, R.A. (1998). Principles of Geographical Information Systems, Oxford University Press: 265-291.

Centrum voor Geo-Informatie (2005). LGN5. http://www.alterra.wur.nl/NL/cgi/LGN/. Visited 19 September 2005.

Cheng, T. and Molenaar, M. (1999). "Objects with fuzzy spatial extent." Photogrammetric Engineering and Remote Sensing 65(7): 797-801.

Cheng, T., Molenaar, M., et al. (2001). "Formalizing fuzzy objects from uncertain classification results." International Journal of Geographical Information Science 15(1): 27-42.

Couclelis, H. (2003). "The certainty of uncertainty: GIS and the limits of geographic knowledge." Transactions in GIS 7(2): 165-175.

Cross, V. and Firat, A. (2000). "Fuzzy objects for geographical information systems." Fuzzy Sets and Systems 113(1): 19-36.

Cross, V. V. (2003). "Defining fuzzy relationships in object models: Abstraction and interpretation." Fuzzy Sets and Systems 140(1): 5-27.

De Bruin, S. (2000). Geographic Information Modelling for Land Resource Survey. Wageningen University.

Duckham, M. (2002). "A user-oriented perspective of error-sensitive GIS development." Transactions in GIS 6(2): 179-193.

Duckham, M., Mason K., et al. (2001). "A formal approach to imperfection in geographic information." Computers, Environment and Urban Systems 25(1): 89-103.

GeO3-project (2005). Report: Handle uncertain plan objects to facilitate monitoring and spatial analyses of spatial policy.

Hagen, A. (2003). "Fuzzy set approach to assessing similarity of categorical maps." International Journal of Geographical Information Science 17(3): 235-249.

Jenks, G.F. and Caspall F.C. (1971). "Error on Choroplethic maps: Definition, Measurement, Reduction." Annals of the Association of American Geographers 61(2): 217-244.

Klir, G. J. and Yuan B. (1995), Fuzzy Sets and Fuzzy Logic: Theory and Applications, Prentice Hall PTR.

Molenaar, M. (1996). A Syntactic Approach for Handling the Semantics of Fuzzy Spatial Objects. Geographic Objects with Indeterminate Boundaries. P. A. Burrough and A. U. Frank. London, Taylor & Francis Ltd.: pp. 207-224.

Morris, A. (2003). "A framework for modeling uncertainty in spatial databases." Transactions in GIS 7(1): 83-101.

Mowrer, H.T. and Congalton R.G., Eds. (2000). Quantifying spatial uncertainty in natural resources: theory and applications for GIS and remote sensing, Sleeping Bear Press.

NCGI (2003). Van DURP naar DORP.
http://www.ncgi.nl/portalen/Van DURP naar DORP v1_02.pdf. Visited 19 September 2005.

Noord-Brabant, (2004). Project Revitalisering Landelijk Gebied.
http://rlg.brabant.nl/asp/. Visited 30 August 2005.

Noord-Brabant (2005). Digitale atlas revitalisering landelijk gebied (RLG).

Pawlak, Z.A. (1982). "Rough sets." International Journal of Parallel Programming (Historical Archive) 11(5): 341-356.

Reconstructiecommissie (2004). Reconstructieplan / Milieueffectrapport
De Baronie.

Robinson, V.B. (2003). "A perspective on the fundamentals of fuzzy sets and their use in geographic information systems." Transactions in GIS 7(1): 3-30.

Roy, A.J. (1999). "A Comparison of Rough Sets, Fuzzy Sets and
Non-monotonic Logic." Internal report of REVIGIS project, TR99-11.

Schneider, M. (1999). "Uncertainty management for spatial data in databases: Fuzzy spatial data types." LNCS: 330-351.

Schneider, M. (2003). "Design and implementation of finite resolution crisp and fuzzy spatial objects." Data and Knowledge Engineering 44(1): 81-108.

Usery, E.L. (1996). A Conceptual Framework and Fuzzy Set Implementation for Geographic Features. Geographic Objects with Indeterminate Boundaries. P. A. Burrough and A. U. Frank. London, Taylor & Francis Ltd.: pp. 71-85.

VROM (2005). Dossier DURP. http://www.vrom.nl/durp/. Visited 30 August 2005.

VROM (2005). 29 435, nr. 154, Nota Ruimte, Deel 3a: aangepast kabinetsstandpunt naar aanleiding van behandeling in de Tweede Kamer. http://www.vrom.nl/docs/ruimte/20050415_nota_ruimte_deel_3a.pdf. Visited 30 August 2005.

Wang, F. and Hall, G.B. (1996). "Fuzzy representation of geographical boundaries in GIS." International Journal of Geographical Information Systems 10(5): 573-590.

Wilcoxon, F. (1945). "Individual comparison by ranking methods. " Biometrics 1: 80-83.

Worboys, M. (1998). "Imprecision in finite resolution spatial data." GeoInformatica 2(3): 257-279.

Worboys, M. (1998). "Computation with imprecise geospatial data." Computers, Environment and Urban Systems 22(2): 85-106.

Zadeh, L. A. (1965). "Fuzzy sets." Information and Control 8(3): 338-353.

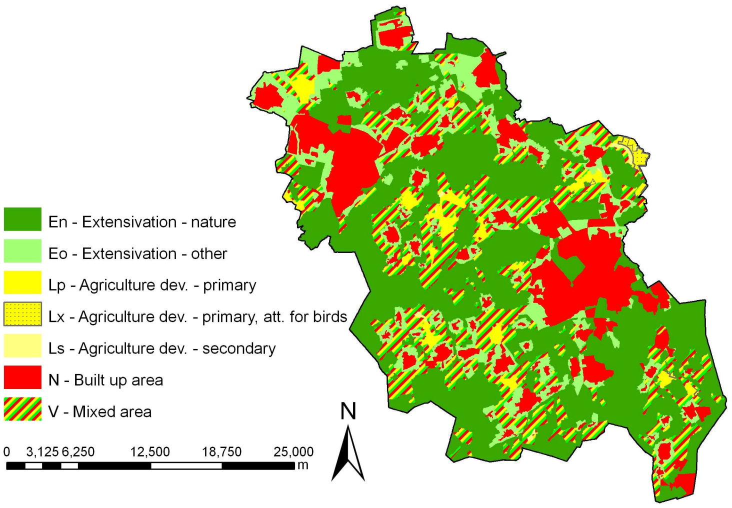
Zadeh, L. A. (1971). "Similarity Relations and Fuzzy Orderings" Information Sciences 3: 177-200.

Appendices

Appendix 1 – Case data

In this appendix all planning data used in the research is described by means of an overview map, the available classes, and the original General section of the metadata.

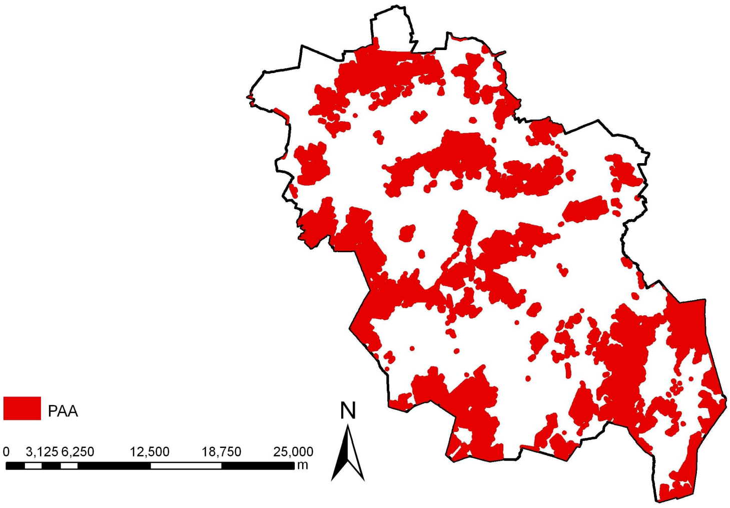
IZL - Integral Zoning Layer



Classification of the case data sets	
IZL	
0	Not in integral zoning plan
1	En - Extensivation - nature
2	Eo - Extensivation - other
3	Lp - Agriculture development - primary
4	Ls - Agriculture development - secondary
5	Lx - Agriculture development - primary, with attention for certain species
6	N - Built up area
7	V - Mixed area

beschrijving	De integrale zonering voor intensieve veehouderij is opgenomen op plankaart 2 in deel A en in kaart 19 in deel B van het reconstructieplan. Zie verder Extra informatie.
producent	Provincie Noord-Brabant
ruimtelijk schema	vlak
doel vervaardiging	Uitwerking van de reconstructiewet
beoogde toepassingsschaal	1:125.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

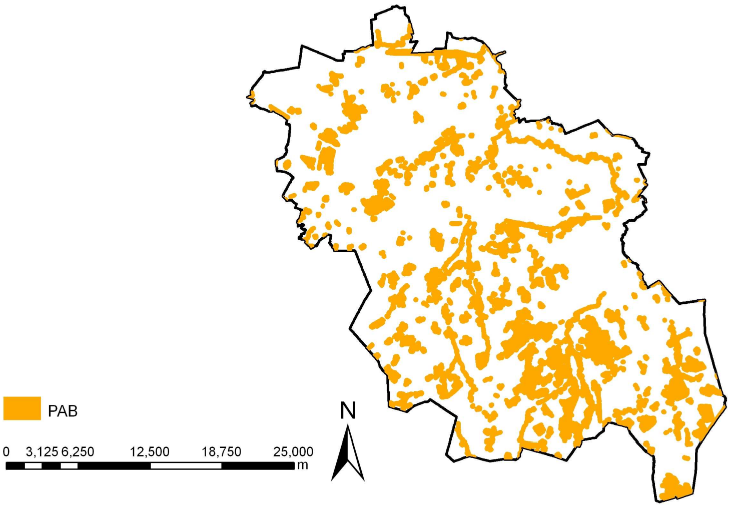
PAA - Acidification protection areas A



Classification	
0	No Area A
1	Area A

beschrijving	Werkkaart kwetsbare gebieden wet ammoniak en veehouderij (A- en B gebieden)
producent	Provincie Noord-Brabant en Arcadis
ruimtelijk schema	vlak
doel vervaardiging	Classificatie en zonering voor verzuring gevoelige gebieden
beoogde toepassingsschaal	1:25.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

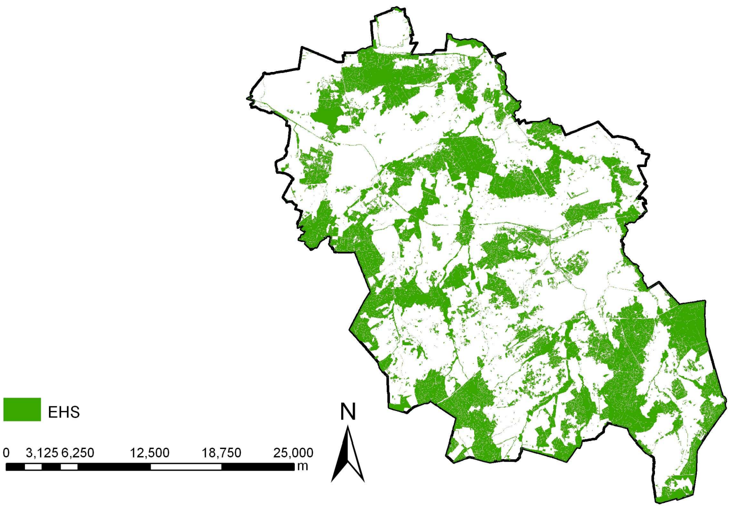
PAB - Acidification protection areas B



Classification	
0	No Area B
1	Area B

beschrijving	Werkkaart kwetsbare gebieden wet ammoniak en veehouderij (A- en B gebieden)
producent	Provincie Noord-Brabant en Arcadis
ruimtelijk schema	vlak
doel vervaardiging	Classificatie en zonering voor verzuring gevoelige gebieden
beoogde toepassingsschaal	1:25.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

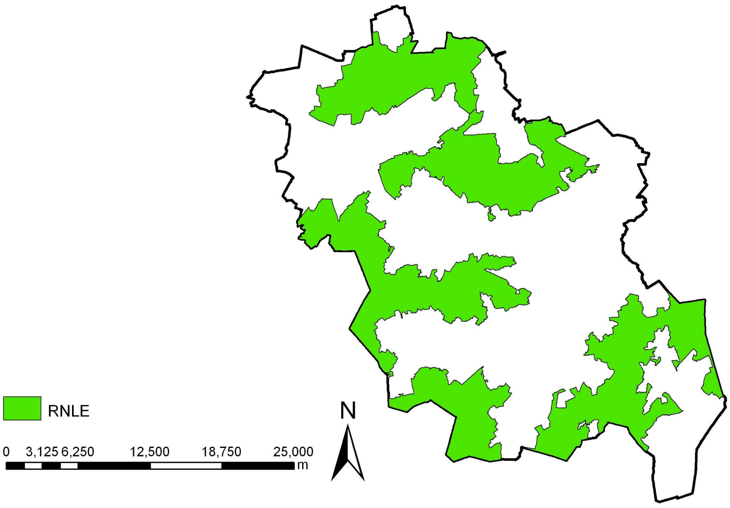
EHS - Ecological Main Structure



Classification	
0	Not in EHS
1	Existing forest or nature area
2	Nature development area
3	Planned forest or nature area
4	Reservation area
5	Managed area
6	Nature development area plus
7	Existing forest or nature area or managed area

beschrijving	De Ecologische Hoofdstructuur bevat gebieden waar de belangrijkste natuurwaarden aanwezig zijn met als doel deze te ontwikkelen en te beschermen. De gebieden die zijn begrensd in de Natuurgebiedsplannen en de Beheersgebieden uit het Beheers- en Landschapsgebiedsplan vormen samen de begrenzing van de Ecologische Hoofdstructuur.
producent	Provincie Noord-Brabant
ruimtelijk schema	vlak
doel vervaardiging	1) Vormt het kader voor de aankoop van nieuwe natuurgebieden (rijksbeleid). 2) Vormt het kader voor het subsidiestelsel Programma Beheer (rijksbeleid). 3) Vormt het kader van planologische bescherming: is de basis van de Groene Hoofdstructuur uit het Streekplan 2002.
beoogde toepassingsschaal	1:25.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

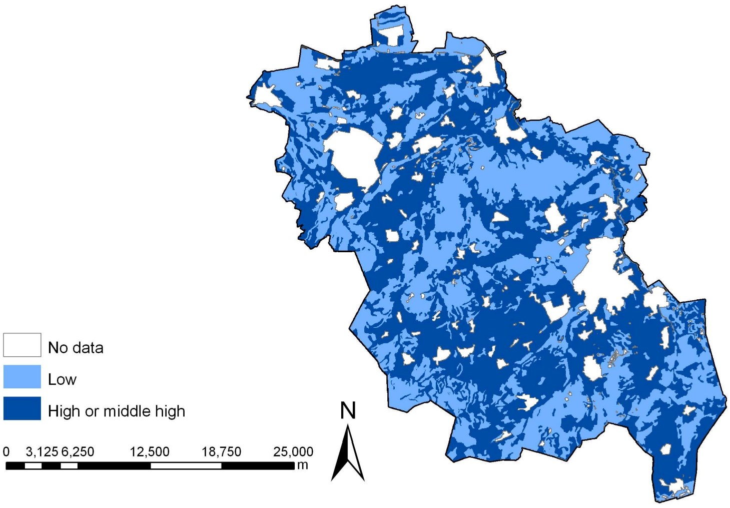
RNLE - Regional Nature and Landscape Units



Classification	
0	Not RNLE area
1	RNLE area

beschrijving	De RNLE's zijn een uitwerking van landelijk beleid. De kern van een RNLE wordt gevormd door bestaande bos- en natuurgebieden, de zogenaamde 'begeleid natuurlijke eenheden'. Rondom deze eenheden zijn kleine natuur- en landbouwgebieden als buffer opgenomen. Hierbij is met name gelet op de hydrologische en landschappelijke samenhang. De hoofddoelstelling van een RNLE is de bescherming en ontwikkeling van hydrologische, natuur-, landschap- en cultuurhistorische waarden.
producent	Onbekend
ruimtelijk schema	vlakken
doel vervaardiging	Onbekend
beoogde toepassingsschaal	Onbekend
copyright	Onbekend
gebruiksbeperkingen	Onbekend

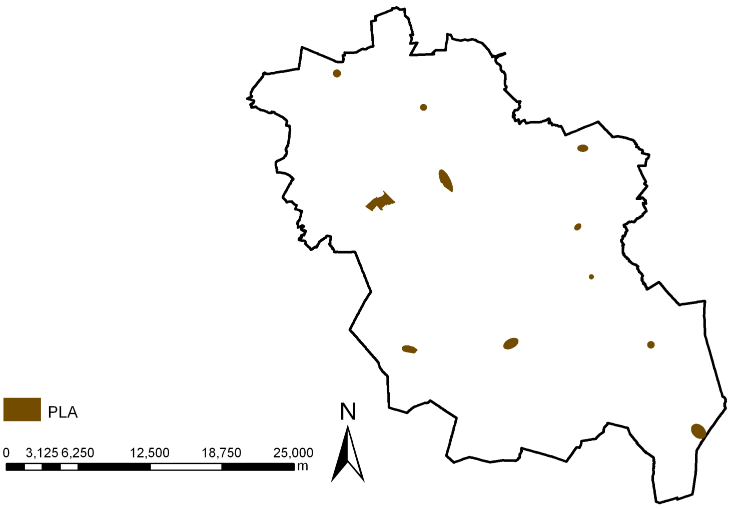
AVL - Archeological values



Classification	
0	Unknown
1	Low
2	High or middle high

beschrijving	Inventarisatie van indicatieve archeologische waarden uitgevoerd door de Rijksdienst voor het Oudheidkundig Bodemonderzoek (ROB)
producent	Rijksdienst voor het Oudheidkundig Bodemonderzoek (ROB)
ruimtelijk schema	vlakken
doel vervaardiging	Cultuurhistorische waardenkaart.
beoogde toepassingsschaal	1:50.000
copyright	Rijksdienst voor het Oudheidkundig Bodemonderzoek
gebruiksbeperkingen	Bestand is alleen voor intern gebruik en kan alleen uitgeleverd worden in het kader van provinciale projecten en nadat een getekende gebruikersovereenkomst is ontvangen.

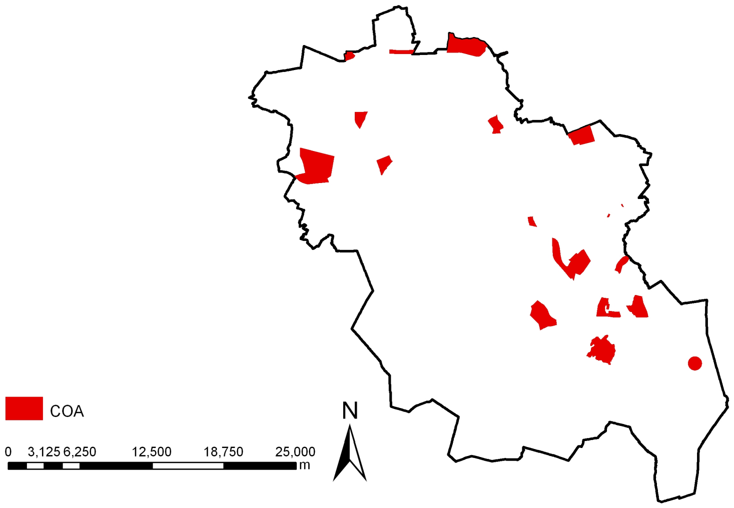
PLA - Project location areas



Classification	
0	No project location
1	Project location

beschrijving	Van het onderwerp recreatie is in het kader van revitalisering landelijk gebied een ontwikkelkaart gemaakt. Het resultaat daarvan staat deels op plankaart 2 van het reconstructie en gebiedsplan en op kaart 20 van deel B van de reconstructieplannen.
producent	Provincie Noord-Brabant
ruimtelijk schema	punten, lijnen en vlakken
doel vervaardiging	Het doel van deze informatie is het weergeven van de doelstellingen in het reconstructieplan.
beoogde toepassingsschaal	1:50.000 - 1:125.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

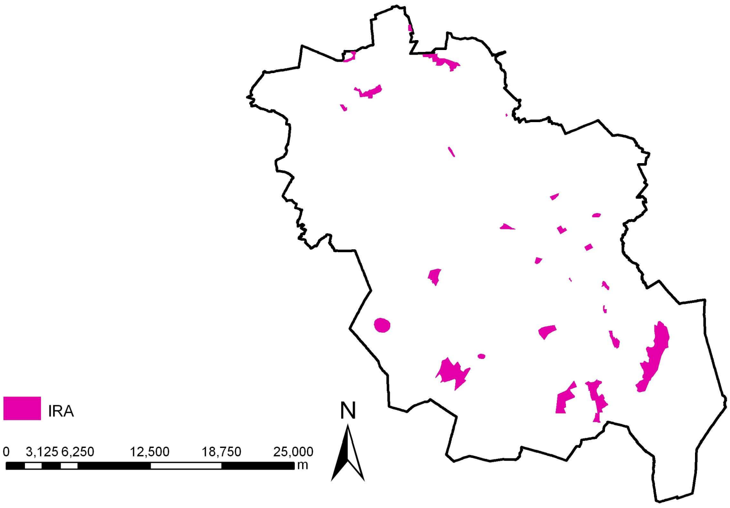
COA - City overflow areas



Classification	
0	No city overflow area
1	City overflow area

beschrijving	Dit zijn multifunctionele gebruiksgebieden in de stadsrandzones van de grotere kernen. In deze gebieden is sprake van en gevarieerde ruimtelijke structuur en eveneens gevarieerd extensief en intensief recreatief gebruik van de ruimte. Stedelijke uitloopgebieden kunnen bestaan uit parken, bos- en natuurgebieden, landbouwgebieden, gebieden met struinnatuur, openluchtrecreatiegebieden en landgoederen. De gebieden zijn niet op perceelsniveau begrensd. De ligging is afgestemd met de uitwerkingsplannen van het streekplan.
producent	Provincie Noord-Brabant
ruimtelijk schema	punten, lijnen en vlakken
doel vervaardiging	Het doel van deze informatie is het weergeven van de doelstellingen in het reconstructieplan.
beoogde toepassingsschaal	1:50.000 - 1:125.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

IRA - Intensive recreation areas



Classification	
0	No intensive recreation area
1	Intensive recreation area

beschrijving	gebied waar ruimte wordt geboden voor de nieuwvestiging van kleinschalige of verdere ontwikkeling van groot- of kleinschalige intensieve toeristisch-recreatieve bedrijven en voorzieningen, indien de randvoorwaarden uit het 'Afsprakenkader recreatie streekplan' dit toelaten.
producent	Provincie Noord-Brabant
ruimtelijk schematype	punten, lijnen en vlakken
doel vervaardiging	Het doel van deze informatie is het weergeven van de doelstellingen in het reconstructieplan.
beoogde toepassingsschaal	1:50.000 - 1:125.000
copyright	Provincie Noord-Brabant
gebruiksbeperkingen	Geen gebruiksbeperkingen, dit bestand kan onbeperkt uitgeleverd worden (copyright ligt bij de provincie)

Appendix 2 – Membership function characteristics

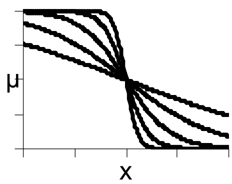
Sigmoidal function

In case of the sigmoidal function a δ function can be computed based on the desired value of μ at $\alpha=\gamma$, because the sigmoidal function never reaches 0 at a bounded interval. In case a value of $\mu=0.01$ is chosen, the following δ_0-function is derived:

$$x=\gamma \Rightarrow \frac{1}{1+e^{\delta(\gamma-\beta)}}=0.01 \Leftrightarrow \frac{1}{1+e^{\delta(\gamma-\frac{\gamma-\alpha}{2})}}=0.01 \Leftrightarrow 1+e^{\delta(\gamma-\frac{\gamma-\alpha}{2})}=100 \Leftrightarrow$$

$$1+e^{\delta\frac{\gamma-\alpha}{2}}=100 \Leftrightarrow \delta(\frac{\gamma-\alpha}{2})=\ln(99) \Leftrightarrow \delta=\delta_0=2\frac{\ln(99)}{\gamma-\alpha}$$

If this value as δ_0 is taken as a central function parameter, different membership functions around δ_0 can be calculated which is just an example of the change in function shape:



Sigmoidal functions for $\delta=0.25\delta_0$, $\delta=0.5\delta_0$, $\delta=\delta_0$, $\delta=2\delta_0$ and $\delta=4\delta_0$

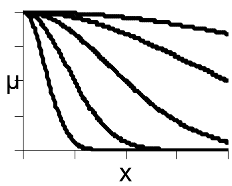
Gaussian function

For the Gaussian function, a similar δ_0 function can be computed, and this time this value is based on the assumption that if $x=\beta$, then $\mu=0.5$, which means the $\mu=0.5$ point is exactly halfway between $x=\alpha$ and $x=\gamma$. The following δ_0-function is obtained:

$$x=\beta \Rightarrow e^{-\left(\frac{\beta-\alpha}{\delta}\right)^2}=0.5 \Leftrightarrow -\left(\frac{\beta-\alpha}{\delta}\right)^2=\ln(0.5) \Leftrightarrow \left(\frac{\beta-\alpha}{\delta}\right)^2=\ln(2) \Leftrightarrow \delta=\frac{\beta-\alpha}{\sqrt{\ln(2)}} \Leftrightarrow$$

$$\delta=\frac{\gamma-\alpha}{2\sqrt{\ln(2)}} \Leftrightarrow \delta=\delta_0=\frac{\gamma-\alpha}{\sqrt{\ln(16)}}$$

with the following results:



Gaussian functions for $\delta=0.25\delta_0$, $\delta=0.5\delta_0$, $\delta=\delta_0$, $\delta=2\delta_0$ and $\delta=4\delta_0$

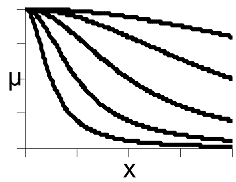
Bell function

With the bell function, things are again a bit different. The function is always 1 at x=α, and never reaches 0 at a bounded interval. If the same assumption as with the Gaussian function, $\mu_{x=\beta}=0.5$, the following δ_0-function is derived:

$$x=\beta \Rightarrow \frac{1}{1+\left(\frac{\beta-\alpha}{\delta}\right)^2}=0.5 \Leftrightarrow \left(\frac{\beta-\alpha}{\delta}\right)^2=1 \Leftrightarrow \left(\frac{\gamma-\alpha}{2\delta}\right)^2=1 \Leftrightarrow$$

$$\delta=\frac{\gamma-\alpha}{2} \vee \delta=\frac{\alpha-\gamma}{2} \Rightarrow \delta_0=\frac{\gamma-\alpha}{2}$$

with the following result:



Bell functions for $\delta=0.25\delta_0$, $\delta=0.5\delta_0$, $\delta=\delta_0$, $\delta=2\delta_0$ and $\delta=4\delta_0$

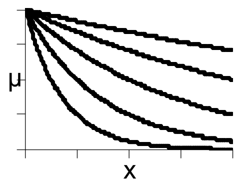
Exponential function

With the exponential function it is the same as with the bell function: it starts at 1 at x=α irrespective of the choice of δ, and never reaches 0 at a bounded interval. With the same assumption as with the Gaussian and bell function, $\mu_{x=\beta}=0.5$, following δ_0-function is derived:

$$x=\beta \Rightarrow e^{-\delta(\beta-\alpha)}=0.5 \Leftrightarrow -\delta(\beta-\alpha)=\ln(0.5) \Leftrightarrow \frac{\delta(\gamma-\alpha)}{2}=\ln(2) \Leftrightarrow$$

$$\delta=\delta_0=\frac{\ln(4)}{\gamma-\alpha}$$

which results in the following examples:

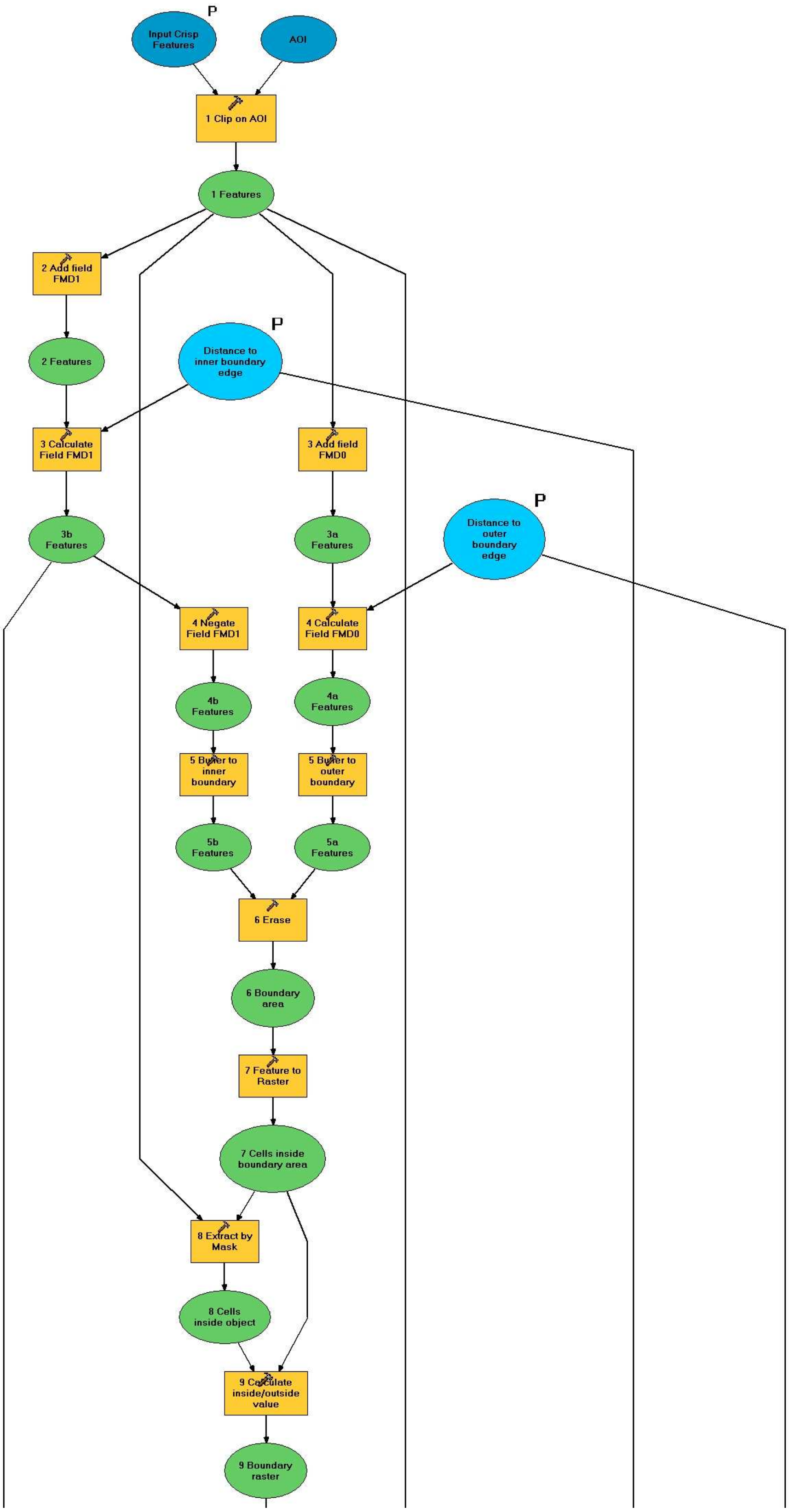


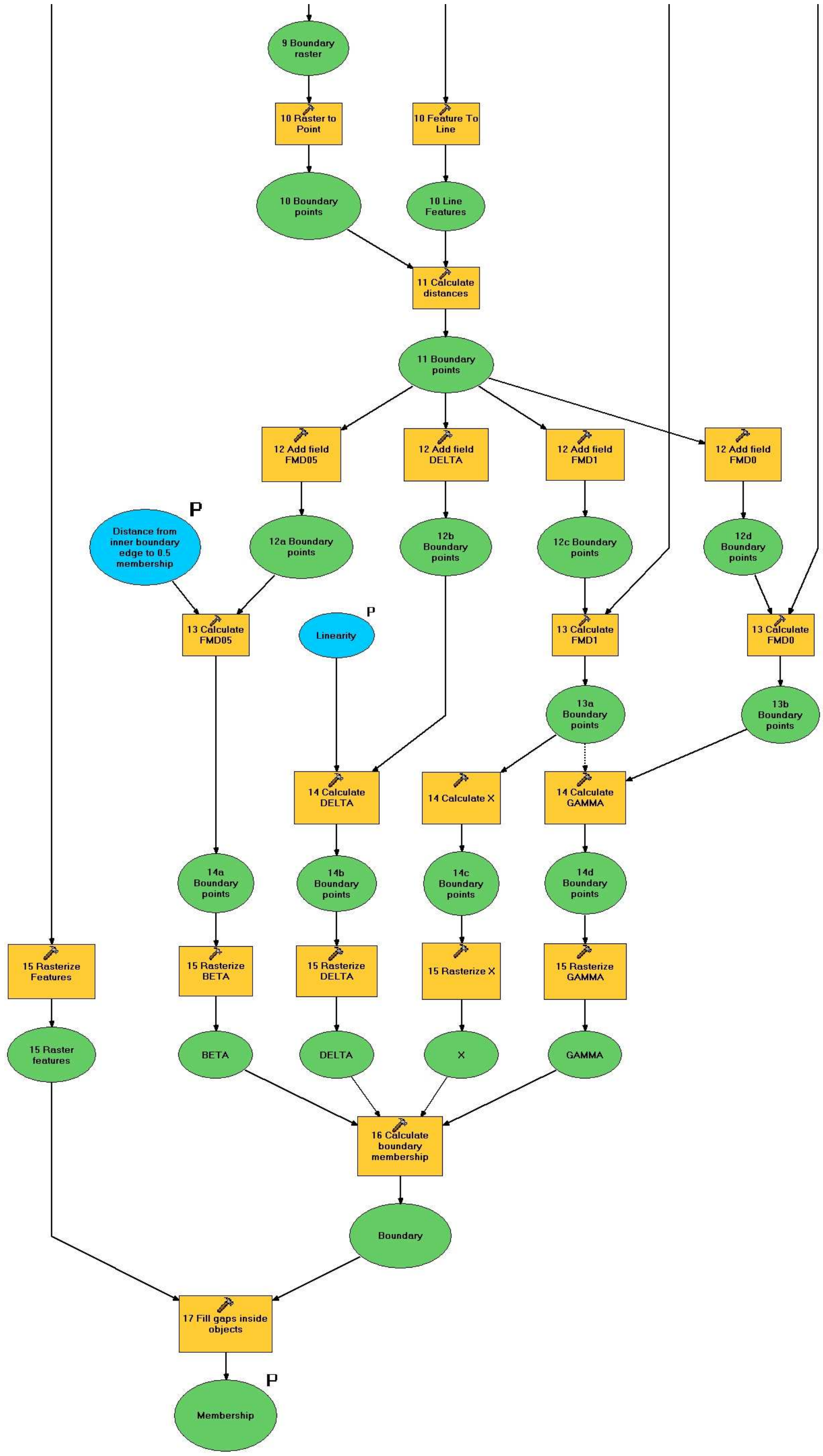
Exponential functions for $\delta=0.25\delta_0$, $\delta=0.5\delta_0$, $\delta=\delta_0$, $\delta=2\delta_0$ and $\delta=4\delta_0$

Other existing membership functions

The linear and s-shaped membership functions are non-parameterized, which means their shape cannot be altered. They both define a monotonous decrease from $\mu=1$ to $\mu=0$ on a definable interval.

Appendix 3 – Crisp to fuzzy process flow





Note that the objects with fuzzy boundaries are calculated in *grid* instead of *vector* format. This is not a fundamental or necessary choice, but a practical choice based on the available GIS tool support. Currently, there is hardly any GIS tool that supports vector-based fuzzy boundaries, and it has been much easier to implement the fuzzy objects as grid layers with the cell values being the membership value [0, 1].

Appendix 4 – Questionnaire

Vragenlijst geleidelijke planobjecten

Achtergrond

Deze vragenlijst wordt u voorgelegd in het kader van een afstudeeronderzoek bij het Laboratorium voor Geo-informatiekunde en Remote Sensing van de Wageningen Universiteit. Dit onderzoek richt zich op het omgaan met onzekerheden in planobjecten binnen het Nederlandse proces van Ruimtelijke Ordening (RO). De respons op deze vragenlijst heeft tot doel een beter inzicht te krijgen in de waardering van de onderzoeksresultaten door de gebruikers van RO informatie. Tevens dient het als startpunt van de discussie over zinnigheid en toepasbaarheid van de onderzoeksresultaten.

Inleiding

In veel gevallen is de grens van een planobject niet hard, maar slechts een globale indicatie van de ligging. Aansprekende voorbeelden kunnen worden gevonden in planobjecten als:
- stillere gebieden;
- donkere gebieden;
- ecologische verbindingszones;
- habitatbegrenzingen;
- waterwingebieden.

De onmogelijkheid om een exacte objectgrens te bepalen en de onnauwkeurigheid die daarmee gepaard gaat, wordt in deze vragenlijst *geleidelijkheid* genoemd.

Momenteel is geleidelijkheid binnen het RO veld niet iets dat wordt beschreven in de dataset zelf. Het wordt slechts gemeld in de begeleidende metadata of in een begeleidend rapport. Er staat dan zoiets als “ligging globaal”.

1. In hoeverre is deze geleidelijkheid in het RO proces herkenbaar voor u?

onherkenbaar ☐ ☐ ☐ ☐ ☐ *zeer herkenbaar*

2. In hoeverre heeft u in de praktijk al eens problemen ervaren m.b.t. deze geleidelijkheid?

nooit ☐ ☐ ☐ ☐ ☐ *vaak*

3. Hoe groot schat u de problemen m.b.t. deze geleidelijkheid bij het analoog uitwisselen (kaart, mondeling) van RO data?

geen probleem ☐ ☐ ☐ ☐ ☐ *groot probleem*

4. Hoe groot schat u de problemen m.b.t. deze geleidelijkheid bij het digitaal uitwisselen (GIS-bestand, IMRO-bestand) van RO data zoals dat bij DURP het geval zal zijn?

geen probleem ☐ ☐ ☐ ☐ ☐ *groot probleem*

In de volgende pagina’s worden u 3 cases voorgesteld met steeds een viertal vragen.

Case 1 – Ecologische verbindingszones

1A

1B

In deze kaartjes worden twee **ecologische verbindingszones** getoond, die tot doel hebben om een verbinding tot stand te brengen tussen **elementen van de ecologische hoofdstructuur**.
1A geeft de situatie weer waarbij de geleidelijkheid van de zone niet in het object zelf is gespecificeerd. In dit geval is die informatie niet beschreven, en wordt er alleen een globale breedte-indicatie gegeven in een bijgevoegde rapportage of een metadatabestand. De dikte van de lijn is in dit geval een keuze van de cartograaf.
1B geeft de situatie weer waarbij beschrijving van de geleidelijkheid *binnen het object zelf* plaats vindt. In dit object is kwantitatief vastgelegd in welke mate van 0% - 100% men binnen het RO proces rekening moet houden met het object (de *participatiegraad*). Deze informatie kan ook uitgewisseld worden. Het verloop van de kleur is hierbij gegeven door dit percentage.

5. In hoeverre acht u de methodes een afspiegeling van de werkelijkheid?

	abstract				*realistisch*
1A	□	□	□	□	□
1B	□	□	□	□	□

6. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *binnen het RO proces*?

	ongeschikt				*geschikt*
1A	□	□	□	□	□
1B	□	□	□	□	□

7. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *buiten het RO proces*?

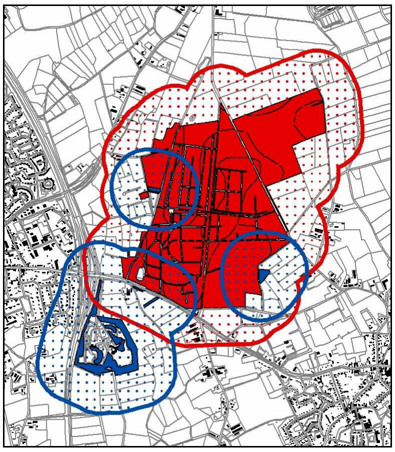
	ongeschikt				*geschikt*
1A	□	□	□	□	□
1B	□	□	□	□	□

8. In hoeverre acht u de methodes geschikt om verschillende ruimtelijke plannen in een digitaal proces onderling te toetsen op consistentie?

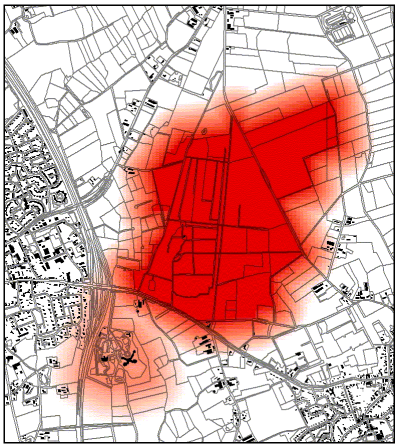
	ongeschikt				*geschikt*
1A	□	□	□	□	□
1B	□	□	□	□	□

Case 2 – Emissiegevoelige gebieden

2A



2B



In deze kaartjes worden gebieden getoond die **gevoelig** of **extra gevoelig** zijn voor verzuring, en om die reden worden uitgesloten voor landbouwdoeleinden. (NB. de werkelijkheid ligt iets genuanceerder, maar is hier niet van belang.)
2A geeft de situatie weer waarbij de geleidelijkheid van de gebieden als aparte bufferobjecten (rode + blauwe lijnen) wordt weergegeven rondom de kerngebieden (rode + blauwe vlakken).
2B geeft de situatie weer waarbij de geleidelijkheid is beschreven binnen het object zelf, en waarbij óók onderscheid is gemaakt tussen gevoelige en extra gevoelige gebieden. In dit geval hebben de gevoelige gebieden een lagere participatiegraad (%) gekregen dan de zeer gevoelige gebieden.

9. In hoeverre acht u de methodes een afspiegeling van de werkelijkheid?

	abstract				*realistisch*
2A	□	□	□	□	□
2B	□	□	□	□	□

10. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *binnen het RO proces*?

	ongeschikt				*geschikt*
2A	□	□	□	□	□
2B	□	□	□	□	□

11. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *buiten het RO proces*?

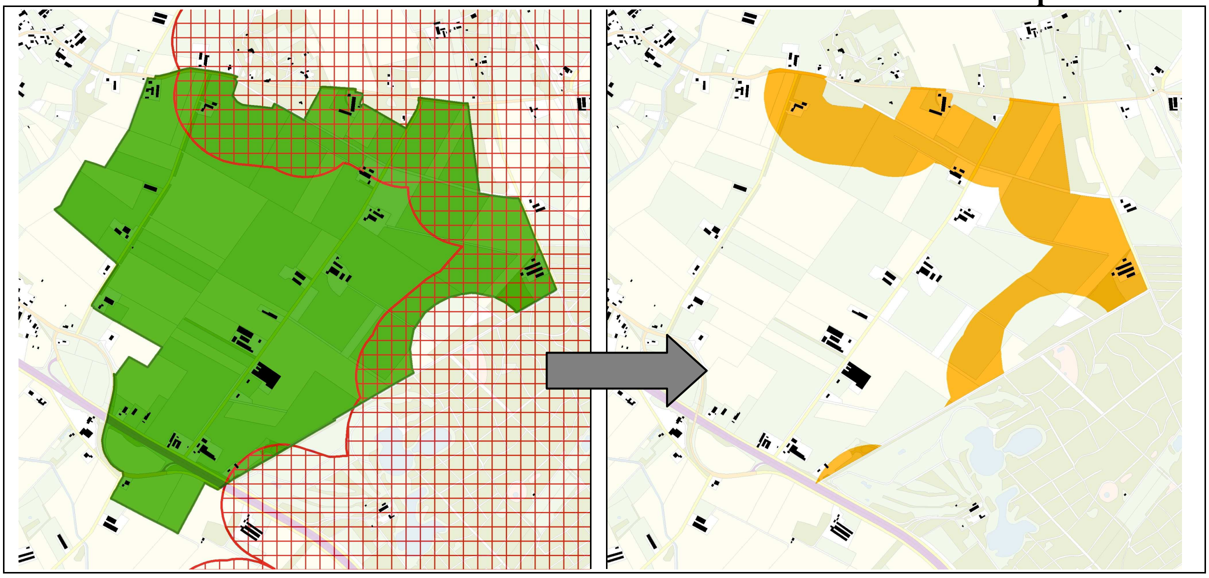
	ongeschikt				*geschikt*
2A	□	□	□	□	□
2B	□	□	□	□	□

12. In hoeverre acht u de methodes geschikt om verschillende ruimtelijke plannen in een digitaal proces onderling te toetsen op consistentie?

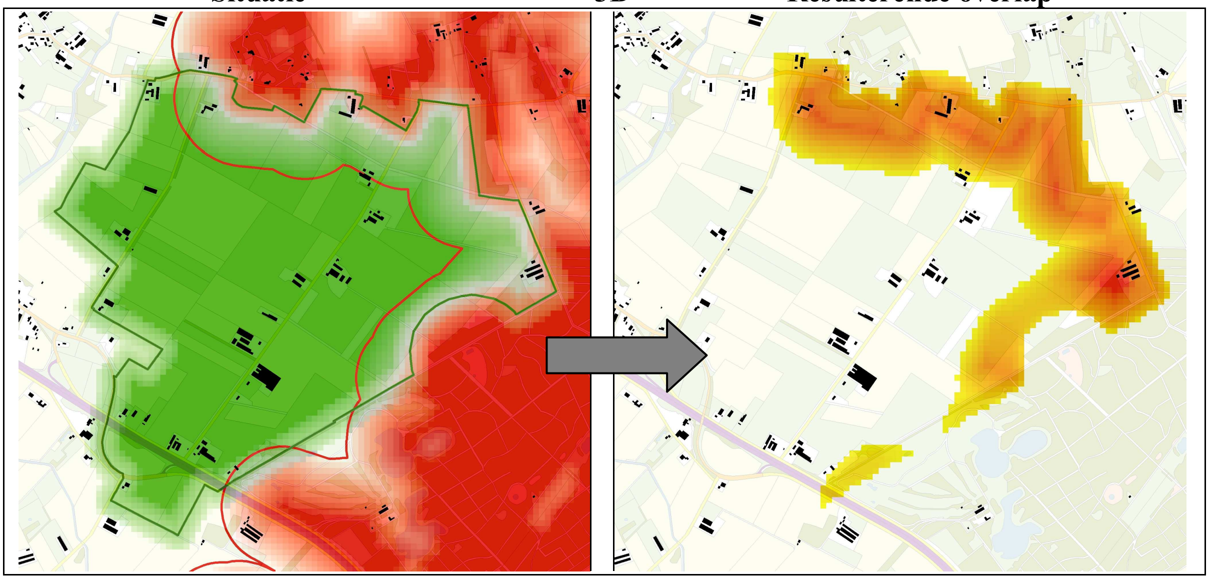
	ongeschikt				*geschikt*
2A	□	□	□	□	□
2B	□	□	□	□	□

Case 3 – Plannen vergelijken

Situatie **3A** **Resulterende overlap**



Situatie **3B** **Resulterende overlap**



In deze kaartjes worden gebieden die **gevoelig zijn voor verzuring** vergeleken met plannen voor nieuwe **landbouwontwikkelingsgebieden**, door deze plannen met behulp van een Geografisch Informatie Systeem (GIS) over elkaar heen te leggen. In principe is de overlap ongewenst, en in deze case kijken we vooral naar deze overlap.

3A geeft de situatie waarbij de geleidelijkheid van de gebieden niet in de objecten zelf is gespecificeerd. Deze gebieden hebben daardoor binnen het GIS een schijnbaar “harde grens”, hoewel bekend is dat deze grens in werkelijkheid geleidelijker is. De resulterende overlap is een tweetal gebieden met ook harde grenzen.

3B geeft de situatie waarbij de werkelijke geleidelijkheid *wel* in de objecten zelf is opgenomen. De resulterende overlap is verkregen door de participatiegraden van beide typen objecten met elkaar te vermenigvuldigen. De resulterende overlap is een tweetal gebieden met een variabele participatiegraad.

13. In hoeverre acht u de methodes een afspiegeling van de werkelijkheid?

	abstract				*realistisch*
3A	□	□	□	□	□
3B	□	□	□	□	□

14. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *binnen het RO proces*?

	ongeschikt				*geschikt*
3A	□	□	□	□	□
3B	□	□	□	□	□

15. In hoeverre acht u de methodes geschikt voor het uitwisselen van de geleidelijkheid met partijen *buiten het RO proces*?

	ongeschikt				*geschikt*
3A	□	□	□	□	□
3B	□	□	□	□	□

16. In hoeverre acht u de methodes geschikt om verschillende ruimtelijke plannen in een digitaal proces onderling te toetsen op consistentie?

	ongeschikt				*geschikt*
3A	□	□	□	□	□
3B	□	□	□	□	□

Slotvragen

17. In deze enquête is een vernieuwende manier van omgaan met geleidelijkheid gepresenteerd. Hoe schat u de kansen voor implementatie van de gepresenteerde concepten in een daadwerkelijke kennisinfrastructuur binnen Nederland in?

	eenvoudig				*problematisch*
Conceptueel	□	□	□	□	□
Technisch	□	□	□	□	□
Juridisch	□	□	□	□	□
Politiek	□	□	□	□	□

18. Uw relevante achtergrondgegevens:

opleiding **:**

huidige organisatie **:**

huidige functie **:**

19. Eventuele slotopmerkingen uwerzijds:

Heel Hartelijk Dank voor uw medewerking aan de wellicht hoofdbrekende vragenlijst!

Arie Duindam, Wageningen, 20 januari 2005

Appendix 5 – Background of questionnaire respondents

#	**Education**	**Current organisation**	**Current function**
1	Mathematics	Alterra	researcher
2	Geo-information and landscape planning	Ministry of Housing, Spatial Planning and the Environment (VROM)	Policy maker
3	Landscape architecture and geo-information	Van Hall Larenstein	Advisor public space / geo-information
4	Physical geography	Province of Zuid-Holland	GIS operator
5	Economic geography	Municipality Haarlemmermeer	GIS policy maker sector Spatial planning
6	Social geography	ESRI	Business consultant
7	City planning	Province of Zuid-Holland	Environmental planner
8	Spatial soil science and geo-information	Alterra	Researcher GIS
9	*unknown*	PNB / ITC	*unknown*
10	Land use	Nexpri	Advisor geo-information
11	Academic	Delft University	researcher
12	Physical geography	ITC	Researcher
13	Academic	Alterra	Researcher / project leader GIS
14	Geodesy	Ministry of Agriculture, Nature and Food Quality (LNV)	GI-advisor
15	Academic	Ministry of Housing, Spatial Planning and the Environment (VROM)	Policy maker
16	Geography	Province of Noord-Brabant	Team leader Geo-information
17	Higher vocational education	Province	GIS operator

N.B. This list is in random order.

Appendix 6 – Questionnaire response

Question	Response															
1	2	5	5	5	4	4	5	5	4	4	3	5	4	2	5	5	4
2	4	5	4	4	4		2	4	5	5	1	5	3	1	4	3	3
3	3	5	4	3	2	4	2	5	2	3	3	3	2	4	4	1	4
4	5	5	4	5	5	3	3	2	4	4	4	4	4	4	4	1	4
5a	1	1	4	4	1	2	3	4	2	5	1	3	1	2	1	1	2
5b	3	5	4	4	5	4	4	2	2	2	4	1	2	5	3	5	2
6a	2	1	3	3	2	3	4	5	4	3	3	3	2	1	1	5	4
6b	4	1	4	5	4	4	4	3	2	5	4	5	4	5	2	5	4
7a	1	1	4	5	1	2	3	5	3	2	2	1	2	2	1	1	3
7b	3	5	3	3	4	4	5	5	2	2	4	5	3	4	1	5	3
8a	1		2	3	2	1	4	5	3	5	3	3	2	4	1	2	4
8b	3		4	5	4	5	4	3	3	4	4	2	3	2	2	5	4
9a	1	5	2	3	2	4	4	5	2	5	3	1	3	3	2	1	4
9b	5	5	4	4	4	3	4	4	4	4	3	4	4	4	3	5	3
10a	2	1	3	4	2	3	4	5	3	5	2	5	3	2	2	5	4
10b	4	1	4	4	4	4	4	3	3	5	3	3	3	4	3	5	4
11a	2	1	3	4	1	2	3	3	2	5	3	4	3	2	2	1	4
11b	4	1	4	3	5	5	5	5	4	3	4	5	2	5	2	5	3
12a	1	5	4	3	5	4	5	5	3	5	3	2	4	3	1	2	3
12b	3	5	4	5	5	5	5	3	3	5	4	4	3	3	1	5	4
13a	1	5	2	2	1	2	3	3	2	4	2	5	2	2	2	1	3
13b	5	5	4	4	4	4	5	5	3	4	3	2	3	4	3	5	5
14a	1	1	3	2	2	3	4	3	3	4	4	2	4	3	3	2	3
14b	4	1	4	4	4	4	4	5	2	4	4	4	4	5	3	5	5
15a	1	1	4	2	2	2	4	3	3	4	3	4	3	3	1	1	4
15b	4	5	3	4	4	5	5	5	2	3	4	5	5	5	1	5	5
16a	1	5	3	2	4	4	4	4	3	4	3	4	3	3	2	1	3
16b	3	5	4	4	5	5	4	4	3	5	4	3	5	4	1	5	5
17a	2	1	4	3	3	2	3	3	1	4	2	5	4	2	4	1	1
17b	2	1	2	2	4	4	2	1	1	1	3	1	1	3	3	1	2
17c	5	5	4	5	5	5	4	5	5	5	4	4	5	3	5	5	3
17d	3	5	4	5	5	3	4	3	4	3	3	2		3	5	4	2

Appendix 7 – Wilcoxon Matched-Pairs Signed-Ranks Test

H0

The difference (d = x - y) between the members of each pair (x, y) has median value zero. To be complete, x and y have identical distributions.

Assumptions

The distribution of the difference (d) between the values within each pair (x, y) must be symmetrical; the median difference must be identical to the mean difference.
As members of a pair are assumed to have identical distributions, their differences (under H0) should always have a symmetrical distribution, so this assumption is not very restrictive.

Scale

Between ordinal and interval (also called an ordered metric scale). It must be possible to rank the differences.

Procedure

Rank the differences without regard to the sign of the difference (i.e., rank order the absolute differences). Ignore all zero differences (i.e., pairs with equal members, x=y). Affix the original signs to the rank numbers. All pairs with equal absolute differences (ties) get the same rank: all are ranked with the mean of the rank numbers that would have been assigned if they would have been different.
Sum all positive ranks (W+) and all negative ranks (W-) and determine the total number of pairs (N).

Level of Significance

The level of significance is calculated by dividing the number of all distributions of signs over the ranks that have a SUM(+ranks) <= W+ (if W+ < W-) by 2**N (i.e., the total number of possible distributions of signs).
These values are tabulated and the level of significance can be looked up.

Note that the Wilcoxon Matched-Pairs Signed-Ranks Test uses the sizes of the differences. The result can differ from that of the Sign-test, which uses the number of + and - signs of the differences.

Example

The observation pairs from question 16 of the questionnaire

1	3
5	5
3	4
2	4
4	5
4	5
4	4
4	4
3	3
4	5
3	4
4	3
3	5
3	4
2	1
1	5
3	5

lead to the following result:

W+ = 9
W- = 82
N = 13
p <= 0.008057

Source: http://www.fon.hum.uva.nl/Service/Statistics/Signed_Rank_Test.h