New developments in archaeological predictive modelling

ISA Summer School
Tours

29 June 2007

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Outline of lecture

- background: theory and history
- the basics of predictive modelling
- successes and failures
- new developments

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What is archaeological predictive modelling?

a technique that, at a minimum, tries to predict:

"*the location of archaeological sites or materials in a region, based either on a sample of that region or on fundamental notions concerning human behaviour*"

(Kohler and Parker, 1986:400)

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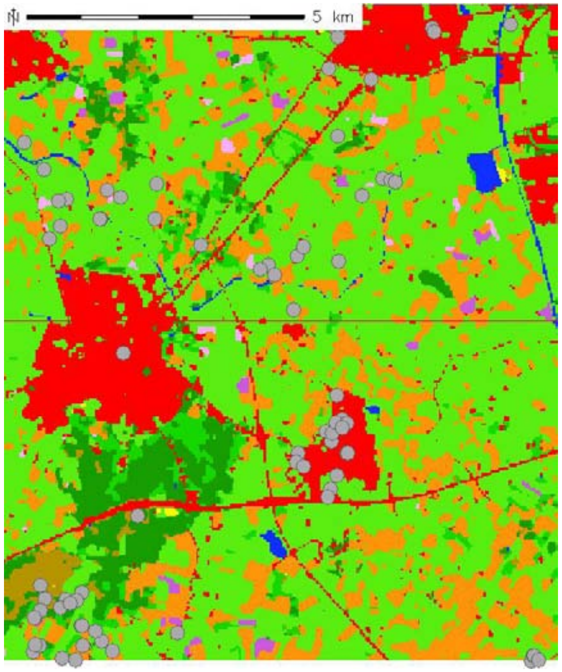
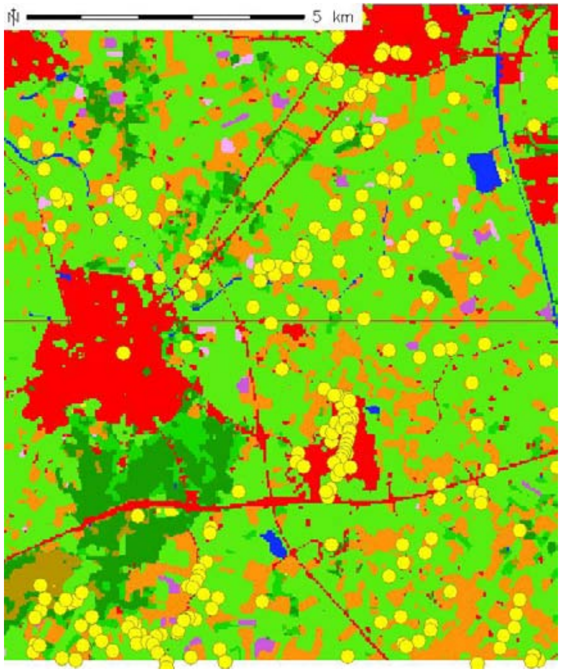
The fundamental problem of predictive modelling



known sites = roughly 1-10% of population



where are the other **90-99**%?

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What can predictive modelling do for us?

Archaeological Heritage Management (AHM)

- avoid destruction of archaeological remains
- help developers with planning
- improved resource allocation, risk reduction

research

- exploring settlement patterns and processes
- test hypotheses (models) against predictions

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The beginnings (1975-1985)

- settlement studies
  - from site-based to regional studies
  - ecological approach

- Cultural Resource Management
  - National Historic Preservation Act (1966)

- New Archaeology
  - ‘scientific’ approach, applying quantitative analysis to archaeological data
  - the ‘inductive’ method

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The golden years (1985-1995)

- GIS
  - quantitative spatial analysis made easy
  - pretty maps
- acceptance in Cultural Resources Management in the USA
  - selection tool
- export good
  - first Dutch predictive maps produced in 1990

Where is it done?

Minnesota Predictive Modeling Project (Mn/Model)
7.000 sites, 230.000 km^2 (France 338.000 km^2)
financed by Department of Transportation

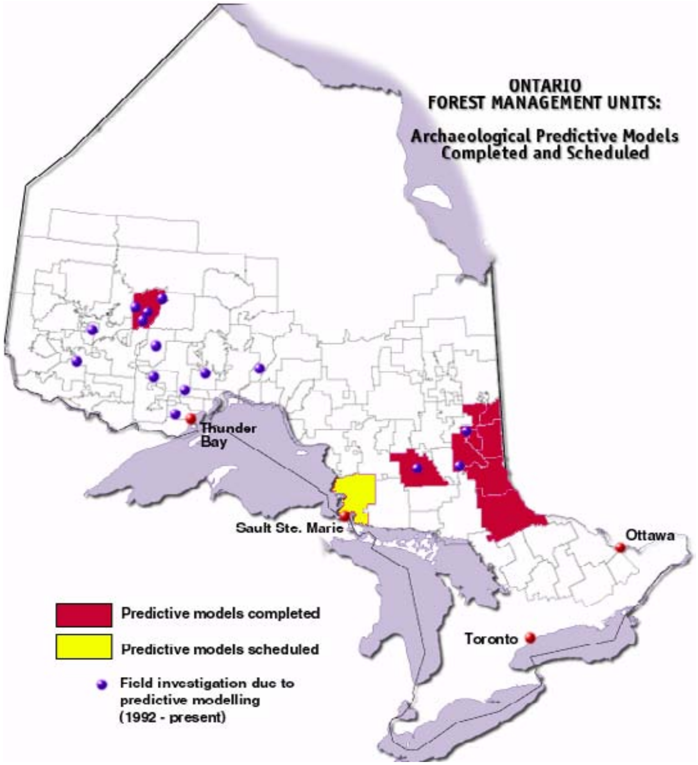
www.mnmodel.dot.state.mn.us/index.html

North Carolina Predictive Model
37.000 sites, 140.000 km^2
Department of Transportation

www.informatics.org/ncdot

Where is it done?

Archaeological Predictive Modelling in Ontario’s Forests



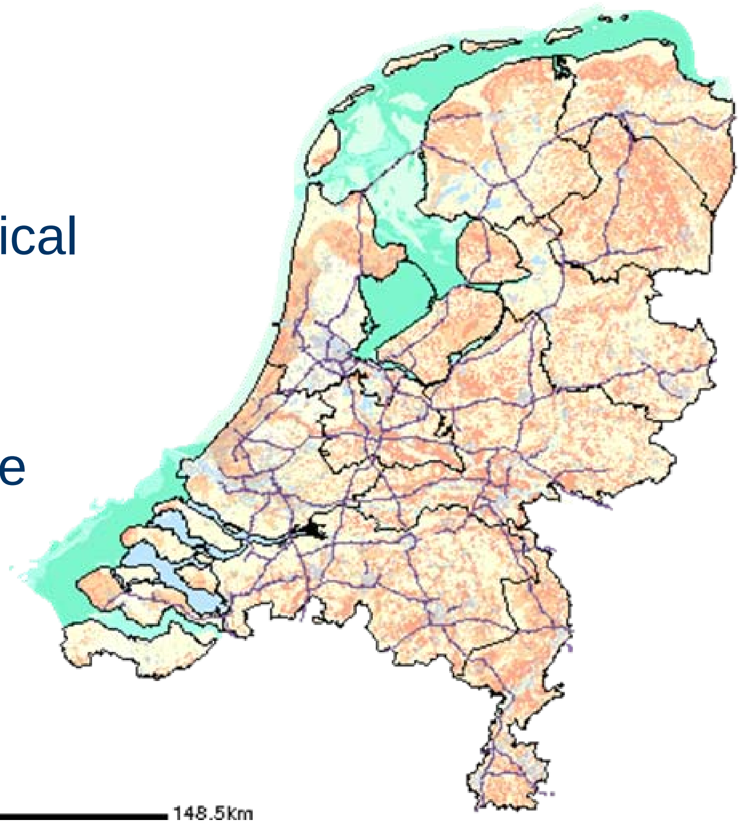
www.pictographics.com

Where is it done?

The Netherlands

Indicative Map of Archaeological Values – IKAW

66.000 sites, 41.000 km^2
financed by Ministry of Culture



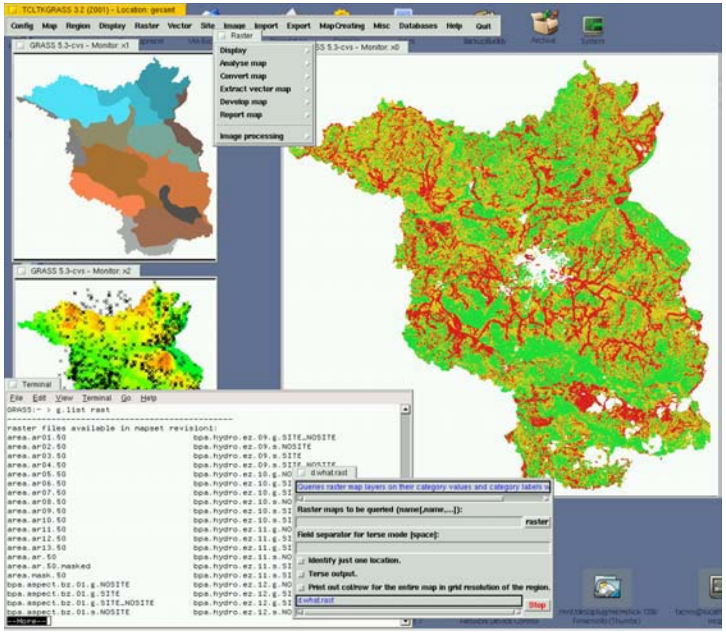
www.kich.nl

Where is it done?

Germany

Archäoprognose Brandenburg

8.000 sites, 30.000 km^2
financed by Landesamt Brandenburg



www.uni-kiel.de/ufg/projekte_ug/Archaeoprognose/deutsch/sec_willkommen.html

Where is it done?

various other countries:

- Slovenia (Pomurje, highway project, Krištof Oštir *et al.*)
- Croatia (Island of Brač, academic study, Zoran Stančič *et al.*)
- Denmark (Eastern Jutland, academic study, Bo Ejstrud)
- Czech Republic (various regions)
- France (Argonne, Rhône Valley, Philip Verhagen *et al.*; Arroux Valley, Scott Madry; Roussillon, Jean-Michel Carrozza *et al.*)
- and probably many others …

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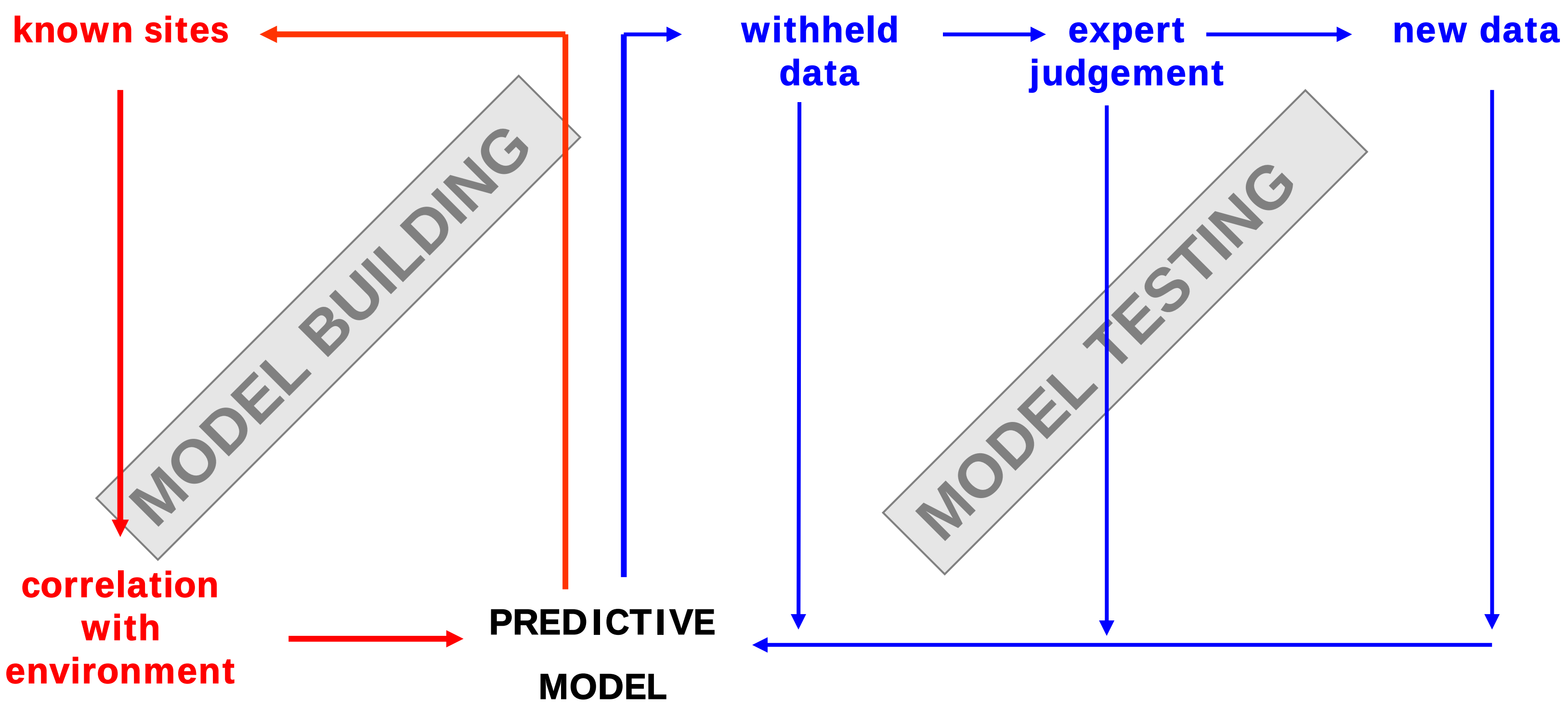
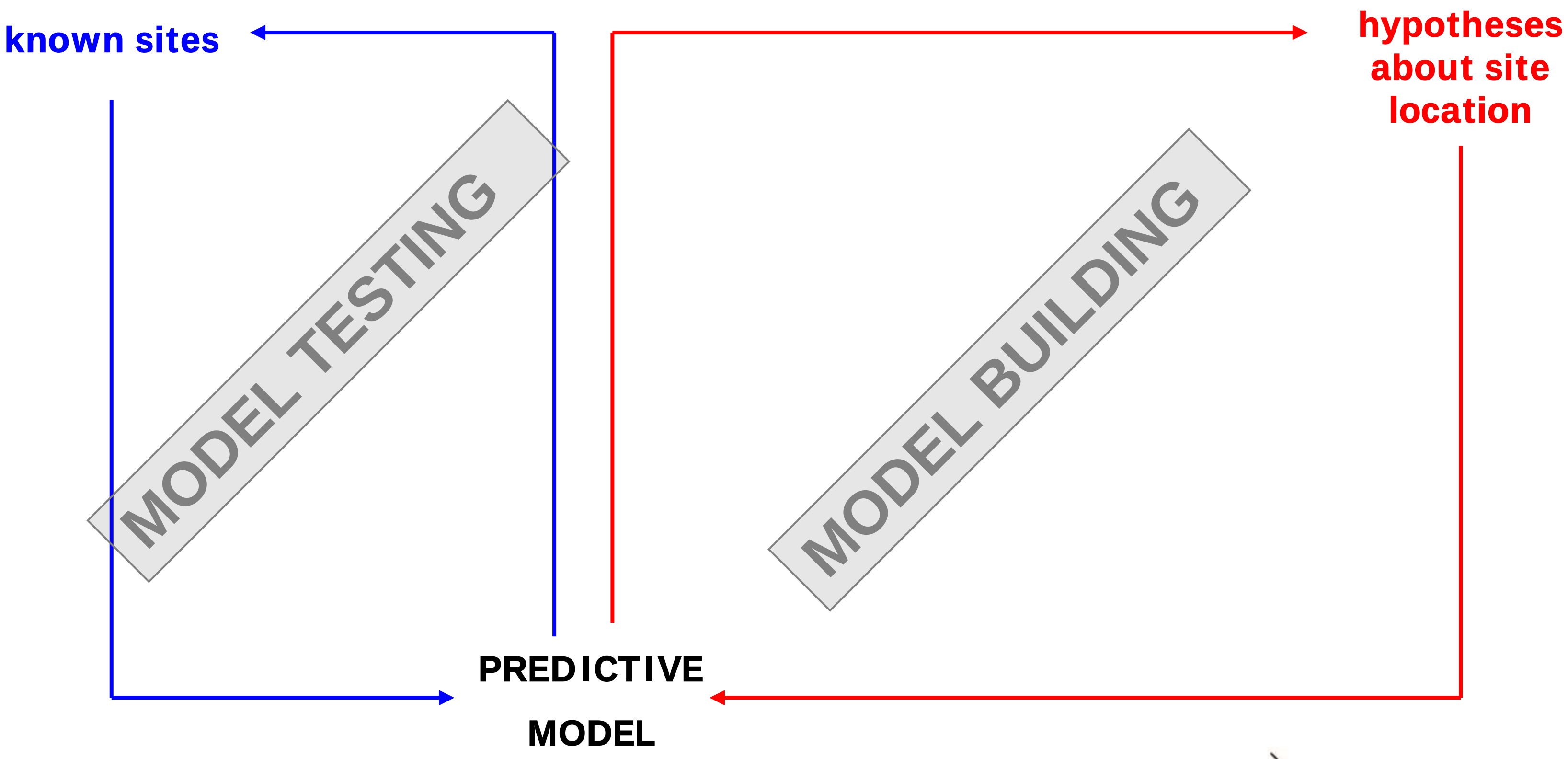
‘inductive’ modelling



‘deductive’ modelling



Modelling techniques (1)

- **expert judgement ('intuitive')**
  - 'single variable'
  - classification into high/medium/low
  - no quantification
- advantages:
  - easy to produce and understand
  - 'deductive'
- drawbacks
  - subjective

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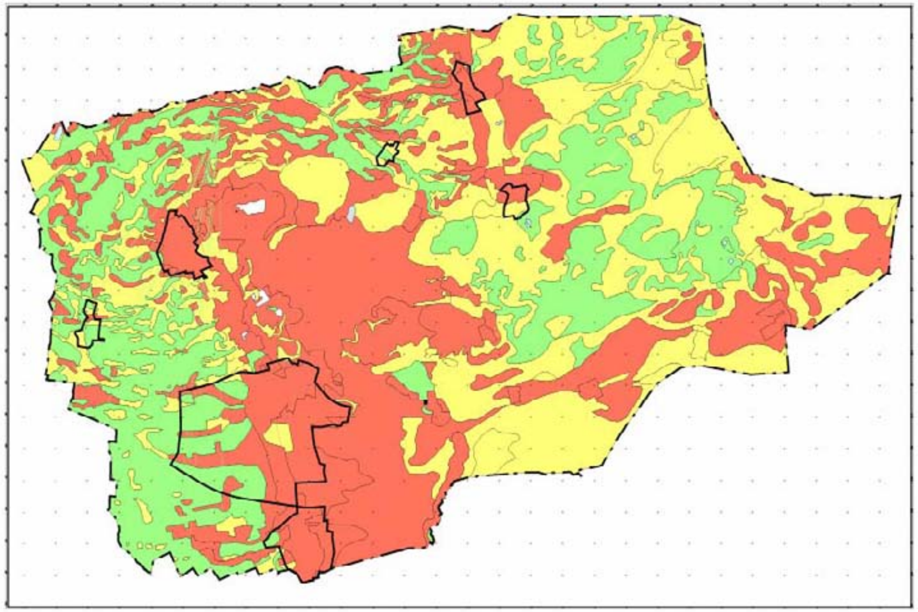
Example: Ede



soil and geomorphology

'landscape units'

categorized into low/medium/high potential

source: Heunks, 2001

Modelling techniques (2)

- **density transfer**
  - ‘single variable’
  - classification into high/medium/low
  - based on relative site density (%sites / % area)

- advantages:
  - easy to produce and understand
  - simple classification rules
- drawbacks
  - no theoretical backup
  - sampling issues

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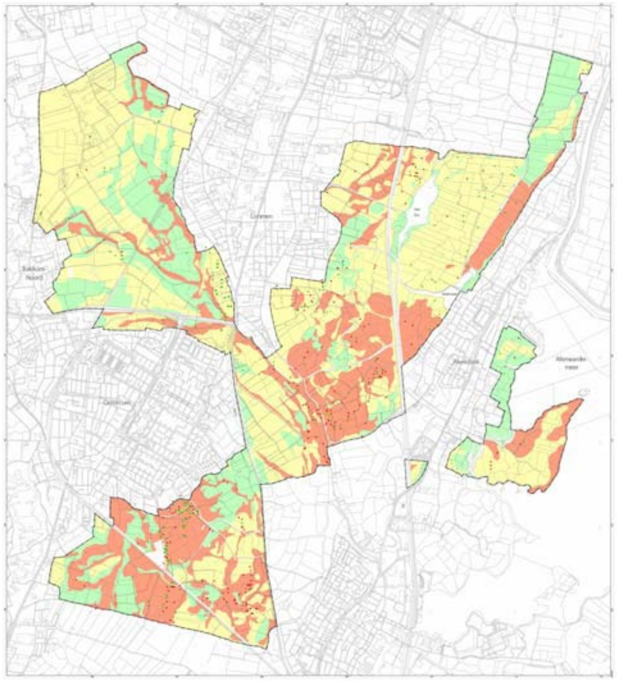
Example: Castricum



source: Soonius et al., 2005

soil map 1:20.000

relative site density calculated

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Modelling techniques (3)

- **weighted overlay**
  - ‘multi-variable’ (multi-criteria analysis)
  - based on expert opinion
  - individual factors are weighted
  - weighted factors are added to arrive at final classification
- advantages:
  - easy to produce and understand
  - ‘deductive’
  - simple classification rules
- drawbacks:
  - subjective weighting
  - danger of ‘overfitting’ (too many parameters)

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Example: Ontario

CATEGORY (W)	*SUBCATEGORY*	*VARIABLE*	*VALUE (V)*	*WEIGHTED VALUE (W x V)*
proximity to water (W=3)	Order 4-5 Water	0-100m	3	9
	Order 3 Water	101-250m	2	6
	Order 1-2 Water	251m+	1	3
slope (W=2)	Slope	0-5°	3	6
		6+°	1	2
drainage (W=3)	Drainage	Dry	3	9
		Mixed	2	6
		Wet	1	3

source: Dalla Bona, 1994

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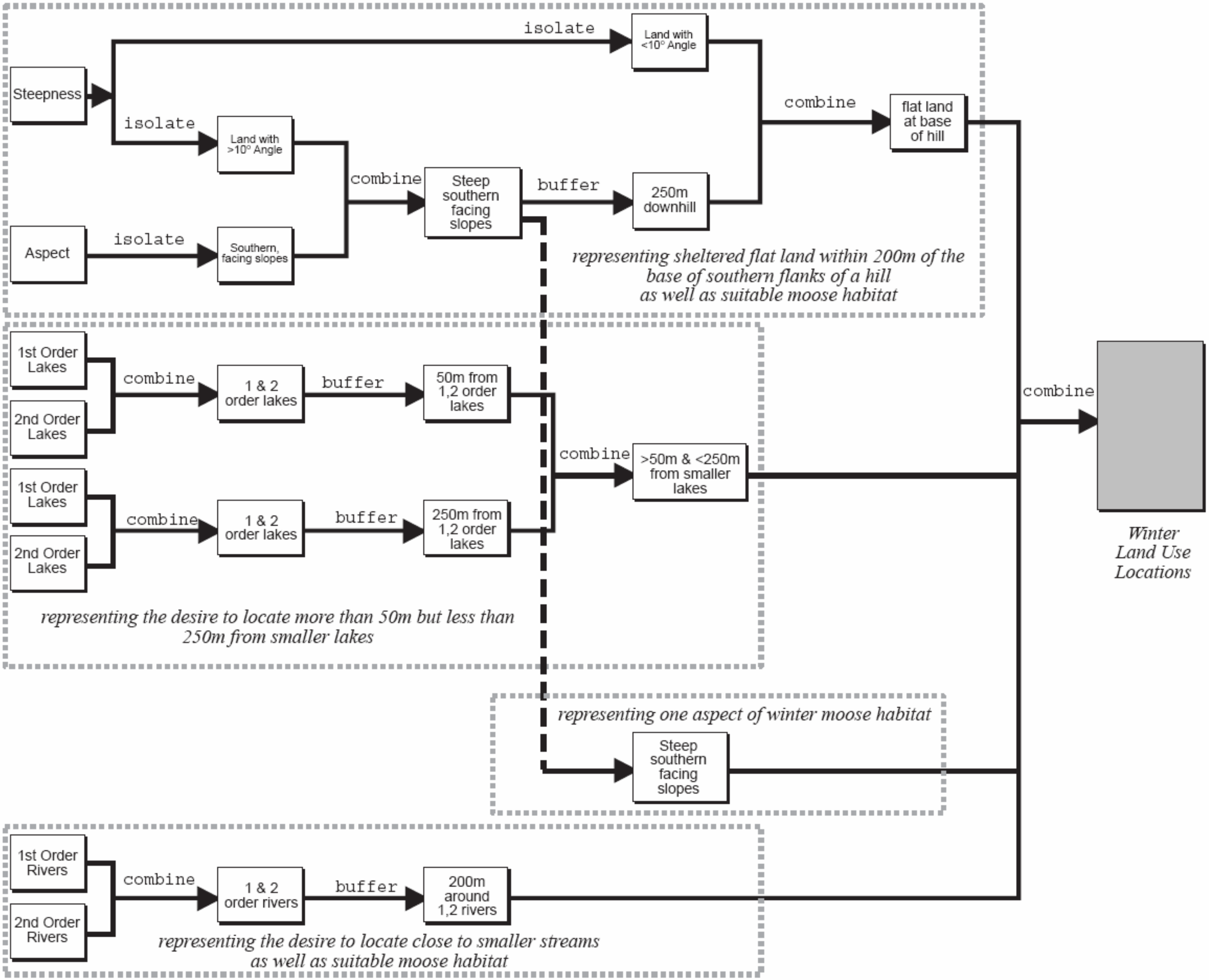

Figure 1.2. Flowchart illustrating the development of a winter land use model

source: Dalla Bona, 1994

Modelling techniques (4)

- **logistic regression**
  - robust statistical technique, multi-variable
  - seeks the best model by step-wise regression
  - produces site and non-site model
  - final classification through intersection of site and non-site model
- advantages:
  - statistical, ‘objective’ method
  - weights of variables calculated instead of estimated
  - ‘overfitting’ can be analyzed and reduced
- drawbacks:
  - no theoretical backup
  - sampling issues

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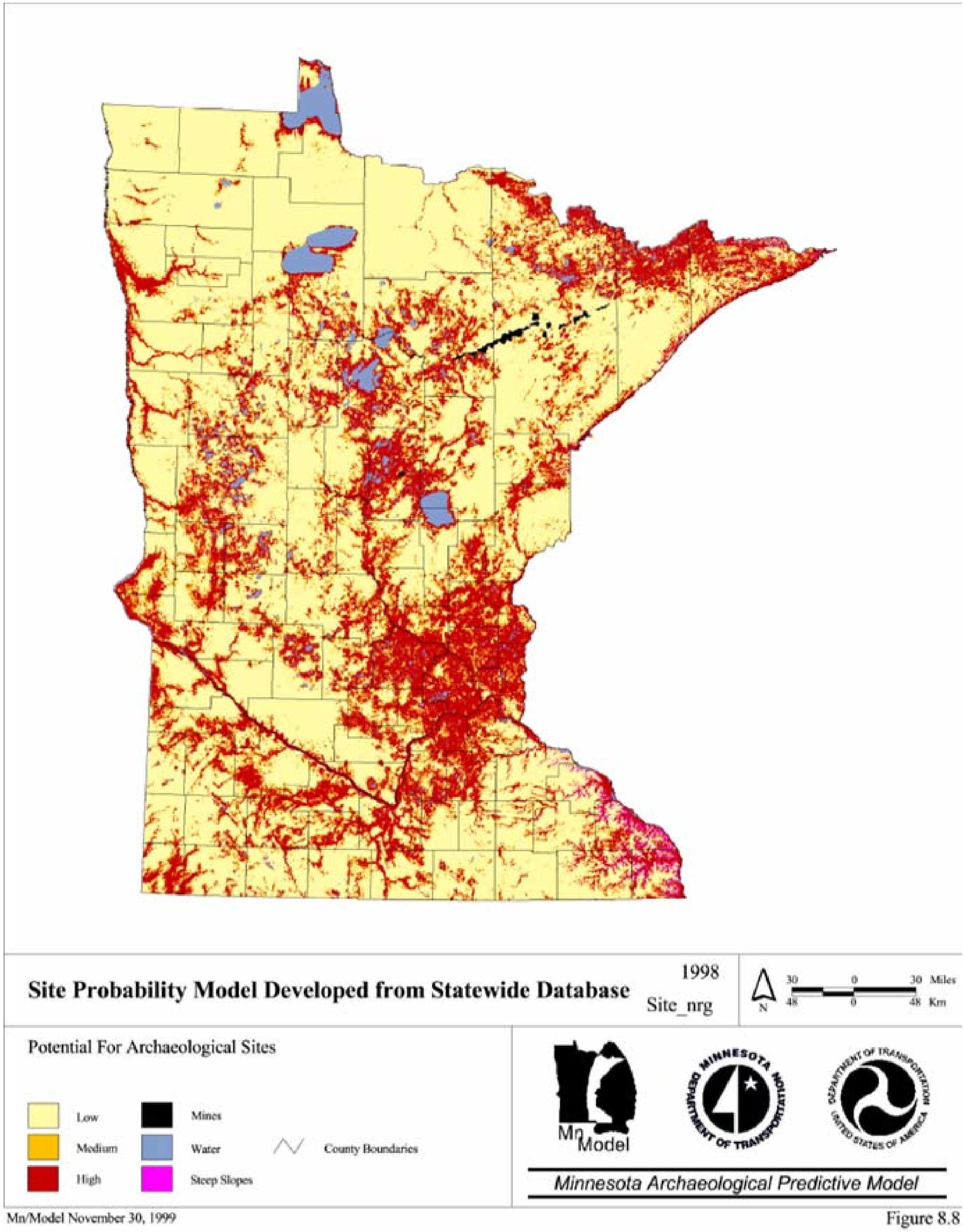
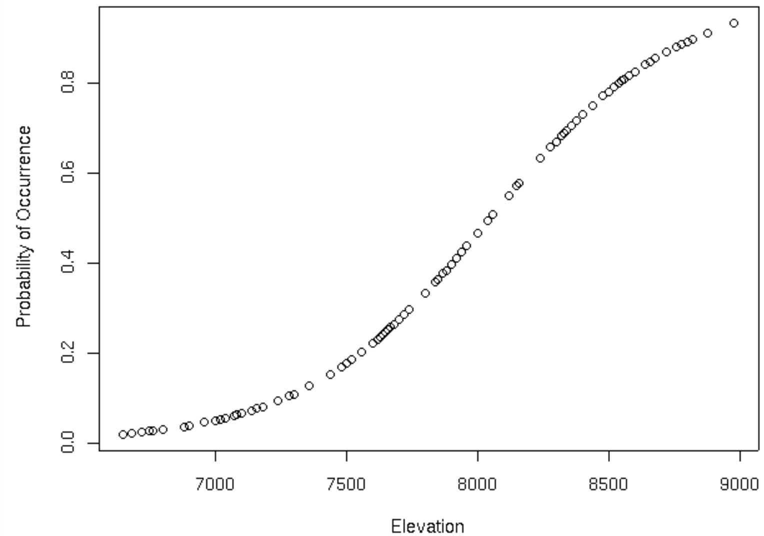


Example: Minnesota



source: Hudak et al., 2002

Arising doubts (1995-2000)

- post-processual archaeology
  - environmental determinism
  - the problem with induction

- data problems
  - David Wheatley (2003): ‘archaeological reality is too complex to be modelled’

- quality control
  - how certain are we?
  - how do we deal with new data?

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Reassessment (2000-2005)

- debate

- flaws
  - bad data produce bad models
  - limited theoretical perspective
  - lack of field testing
  - no quality norms

- opportunities
  - uncertainty mapping
  - loads of new survey data

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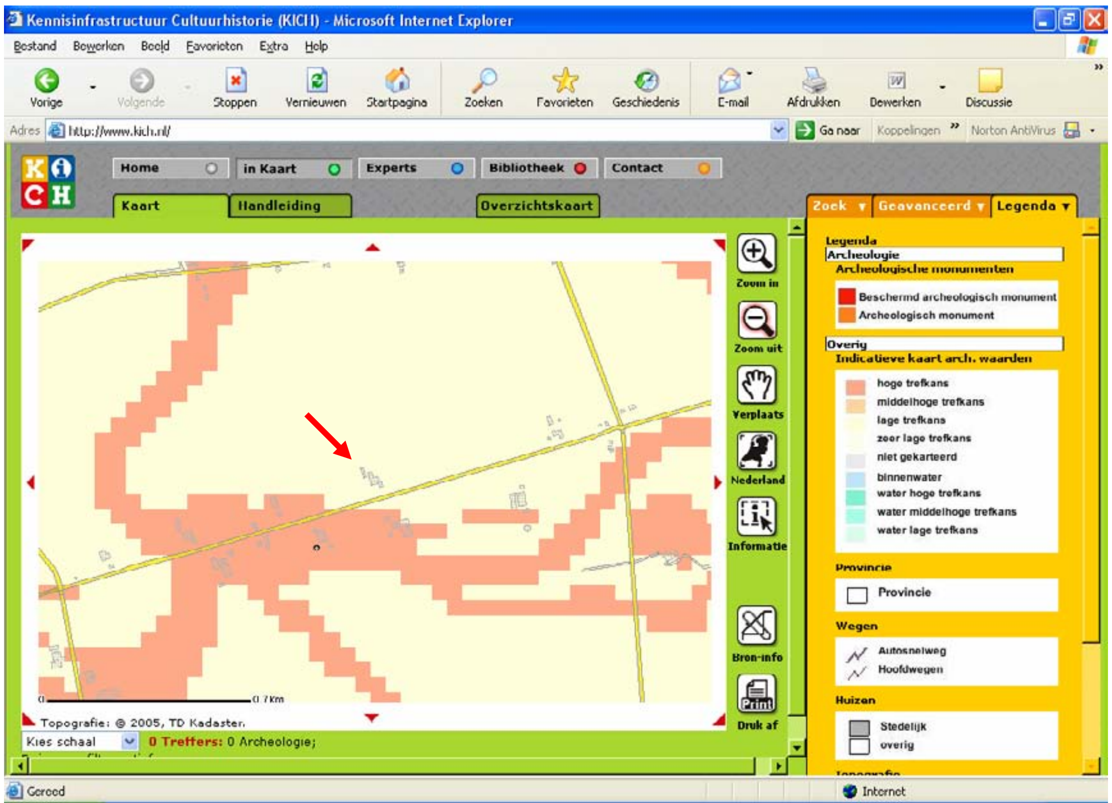
Archaeological reality in the vicinity of my office ?



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New developments (1): Bayesian inference

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}$$

- integrates expert judgement and empirical data in a quantitative framework
- model-based statistics, multi-variate
- uncertainty measures (confidence limits)
- ‘inductive learning’
- proved successful in radio-carbon dating, but not (yet) in many other archaeological fields
- problem: how do you quantify expert judgement?

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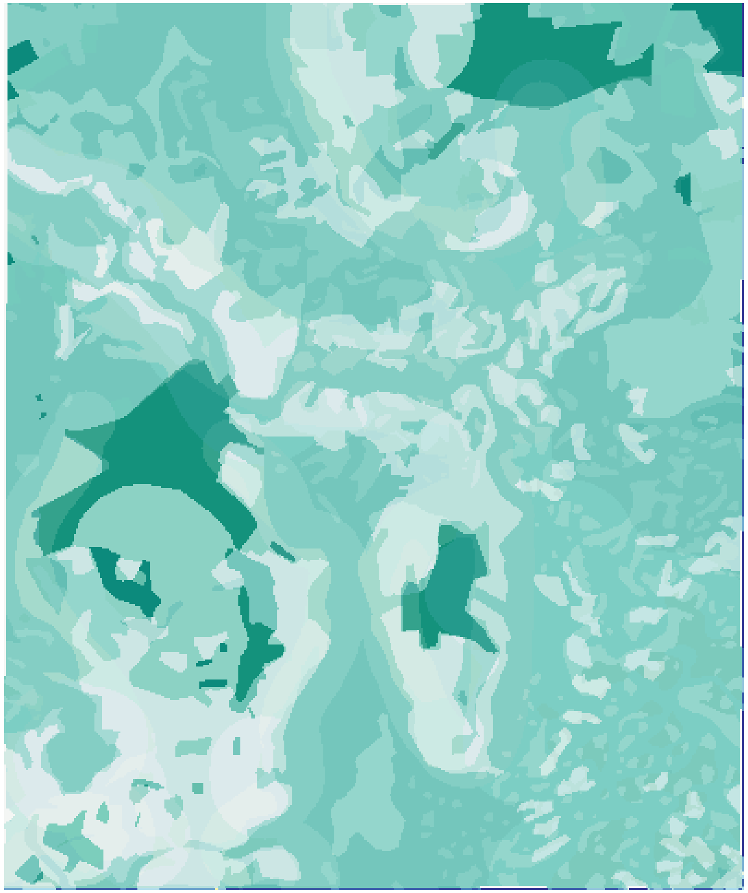
Example: Rijssen-Wierden (1)



- experts asked for quantification ('prior')
- archaeological data added ('conditional')
- prediction ('posterior') + uncertainty mapping

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New developments (2): Dempster-Shafer models

$$\mathrm{bel}(A) \leq P(A) \leq \mathrm{pl}(A)$$

- needs two, mutually exclusive, hypotheses (site/non-site)
- belief = evidence in favour of hypothesis
- plausibility = maximum possible belief
- the rest is indeterminate (uncertainty hypothesis, ‘ignorance’)
- evidence from multiple sources combined through *Dempster’s rule of combination*
- only works if evidence from multiple sources is not in conflict

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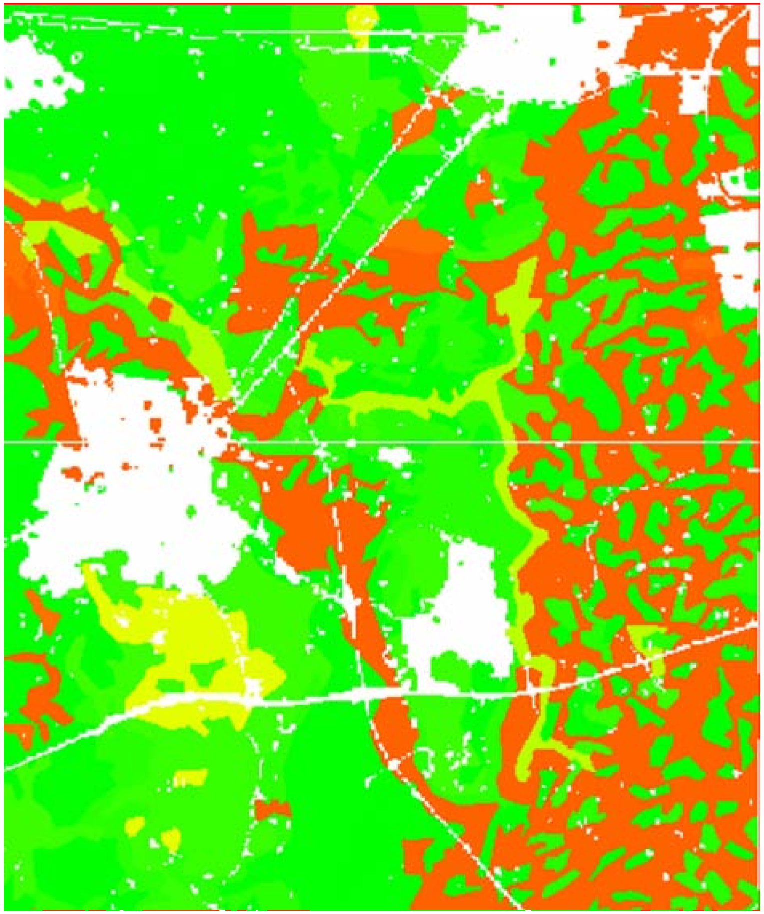
Example: Rijssen-Wierden (2)



- 3 maps:
  - site prediction
  - non-site prediction
  - uncertainty

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Dempster-Shafer models: problems

- how do you decide whether the evidence ‘supports’ a hypothesis?
- sampling issues
- role of expert judgement

Looking at model quality

- how do we decide what modelling procedure produces the best results?

- we need criteria to judge the model's performance
  - explanatory framework
  - transparency
  - best possible prediction with given dataset
  - good prediction in future
  - assess uncertainty in prediction

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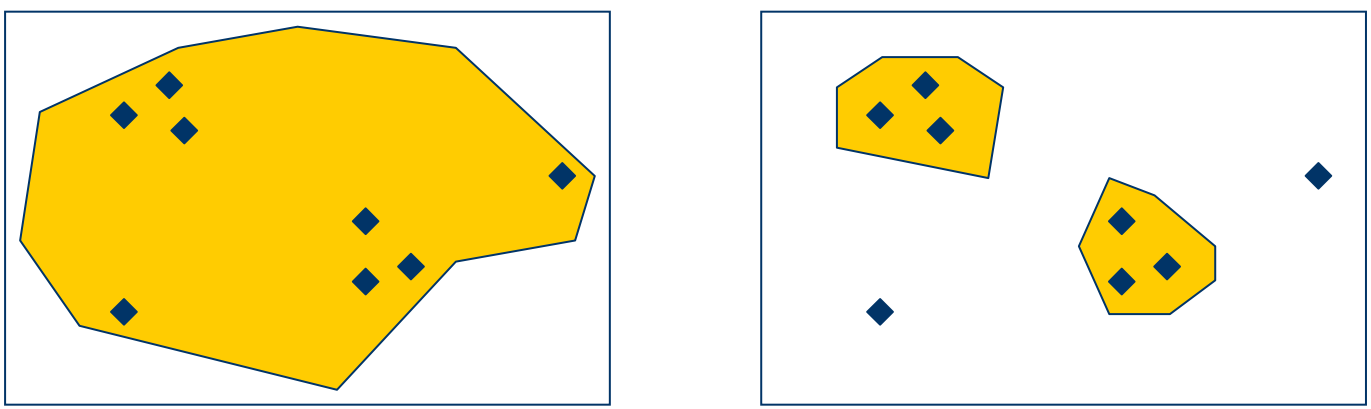
Model performance issues

- accuracy: how many sites in the model?
- precision: how small is the zone of high probability?



model performance measures

- popular model performance measures:
  - Kvamme's gain $1 - p_a/p_s$
  - relative gain $p_s - p_a$
  - indicative value p_s/p_a

- a model that captures 60% of the sites in 30% of the area has
  - Kvamme's gain 1 – 0.3/0.6 = 0.5
  - relative gain 0.6 – 0.3 = 0.3
  - indicative value 0.6/0.3 = 2.0

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which model performs best?

	.v.	i.v. ratio
Mo	2.0 0.57	3.5
Mo	2.0 0.33	6.0
Mo	1.5 0.25	6.0

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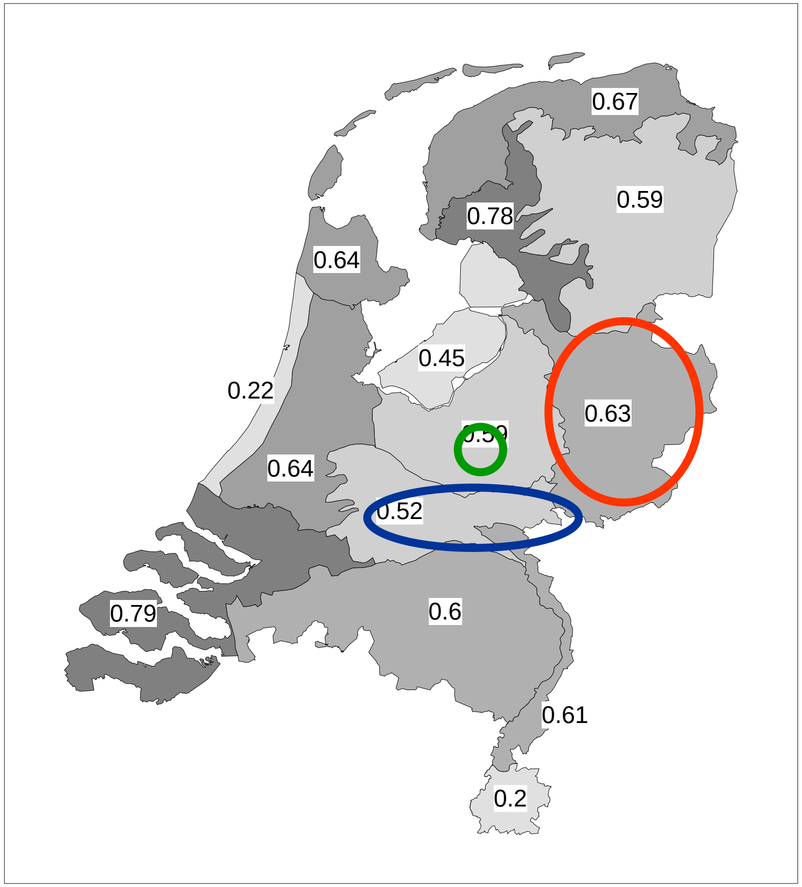
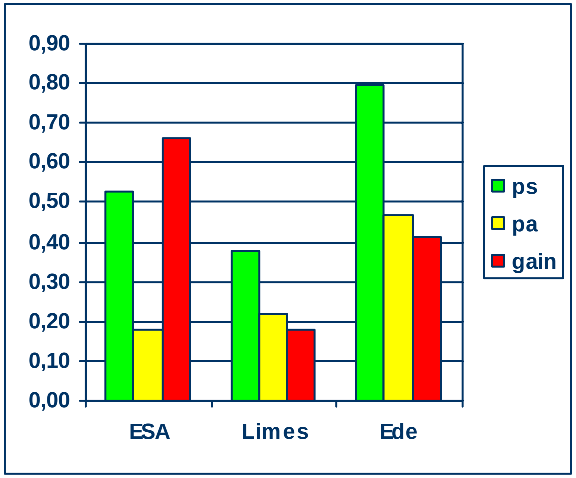
How do Dutch predictive models perform?

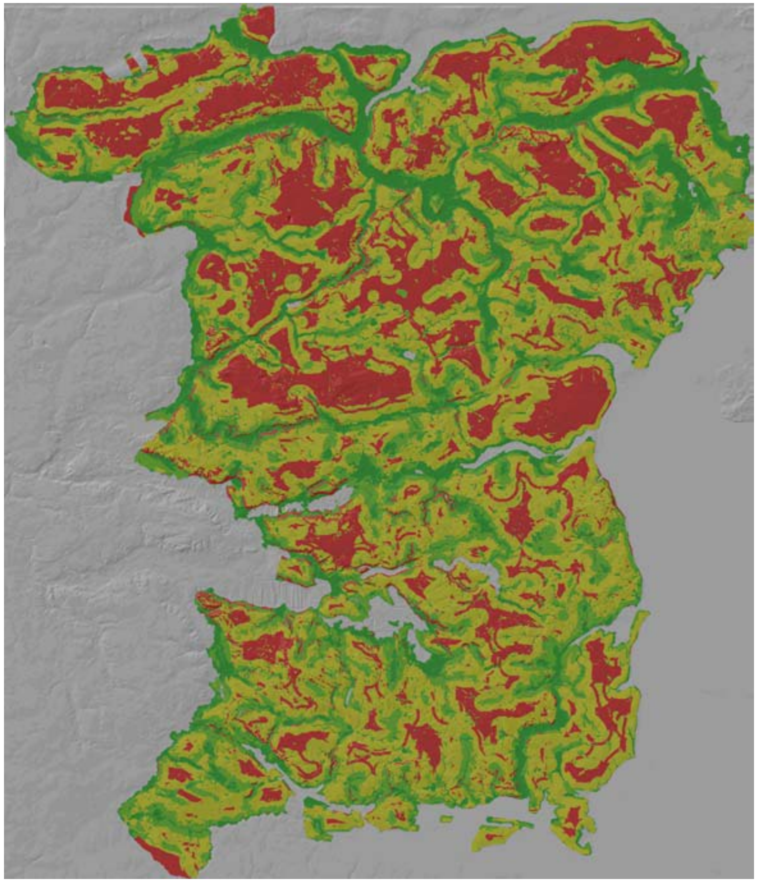




performance statistics
for three different models:

- IKAW, Eastern Sandy Area
- Limes Gelderland
- Municipality of Ede

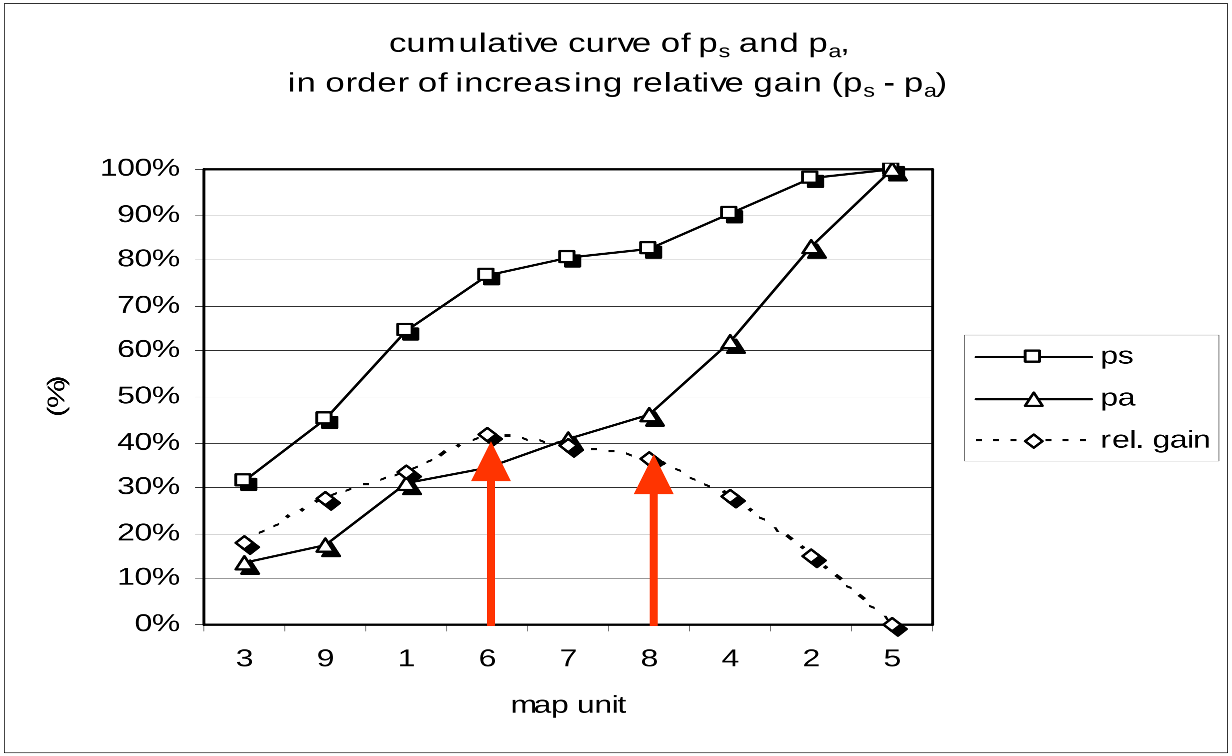
comparison of modelling procedures



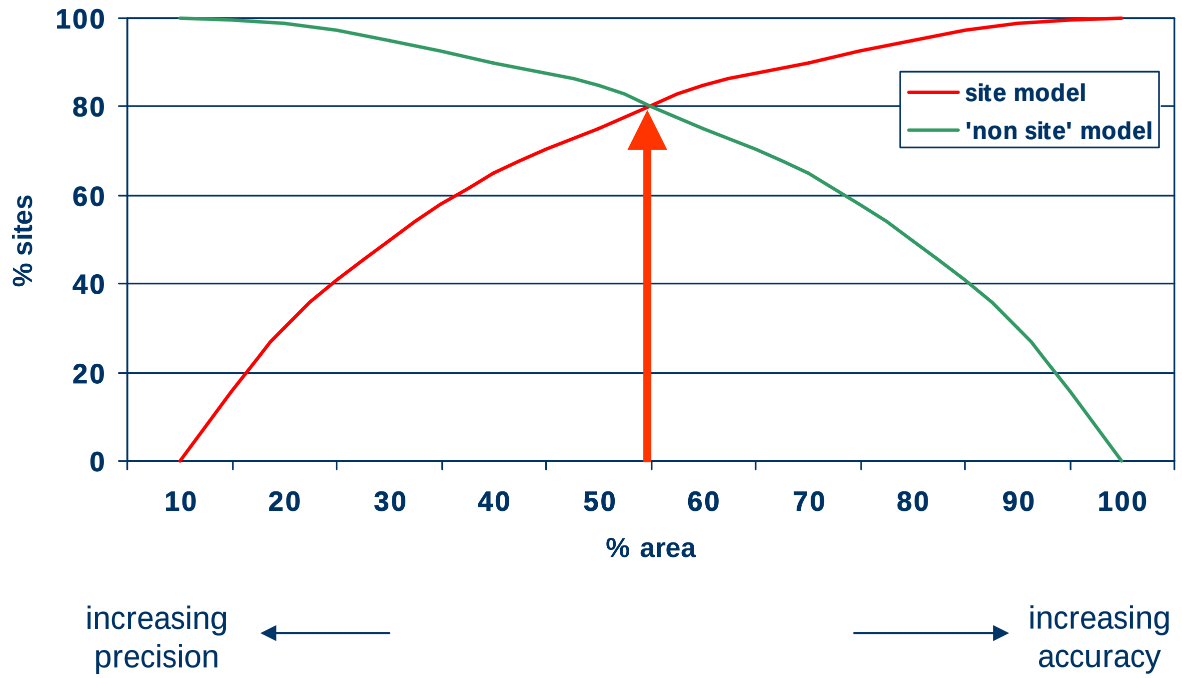
- weighted overlay (0.41)
- logistic regression (0.29)
- Dempster-Shafer (0.47)

source: Ejstrud, 2003

model optimisation

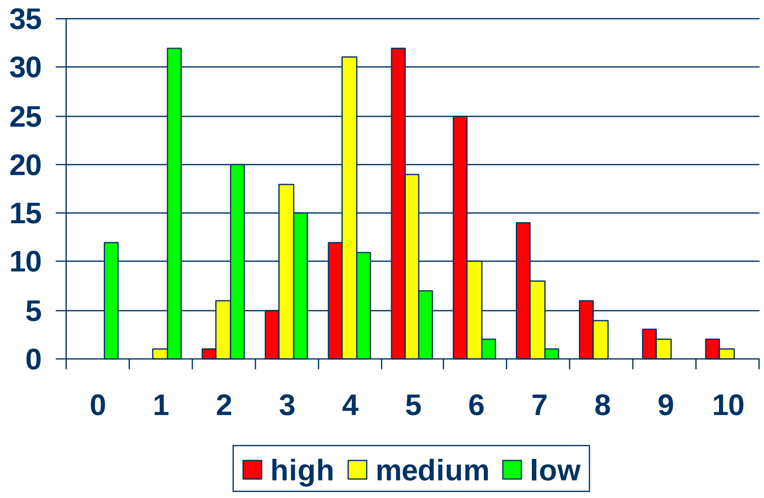


intersection method



resampling

- re-uses sample data
- criticized in the past, but in fact good practice
- useful for error estimation and statistical inference



sampling, sampling, sampling

- unbiased samples of sufficient size needed

- potential sources of bias
  - surface visibility
  - artifact density
  - site size
  - preferential sampling
- can only be analyzed and corrected when we have sufficient information about data collection

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data sources in the Netherlands

	sampling depth	coverage	preference for high probability
field walking	ploughzone	vegetation dependent	moderate
core sampling	> 7 m	small	moderate
trial trenching	< 2 m	partial	strong
excavation	< 2 m	full	very strong
watching brief	< 2 m	full	weak

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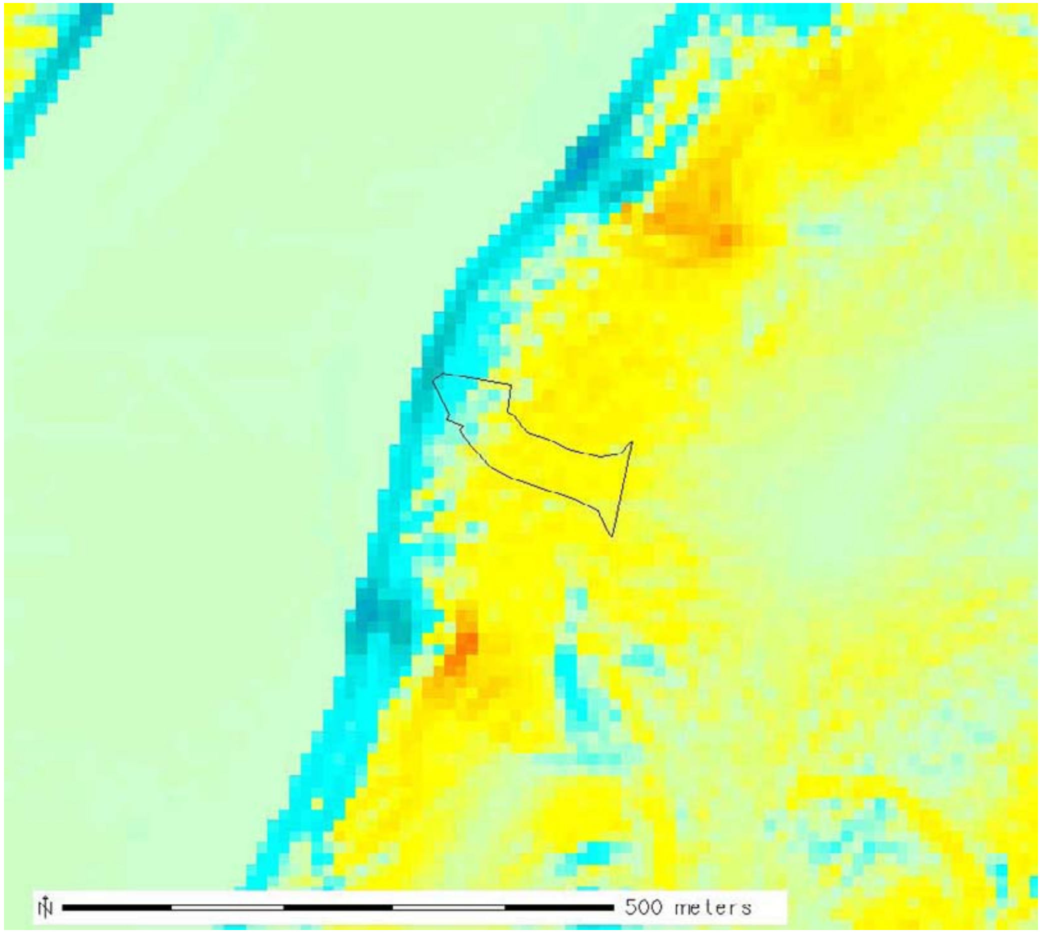
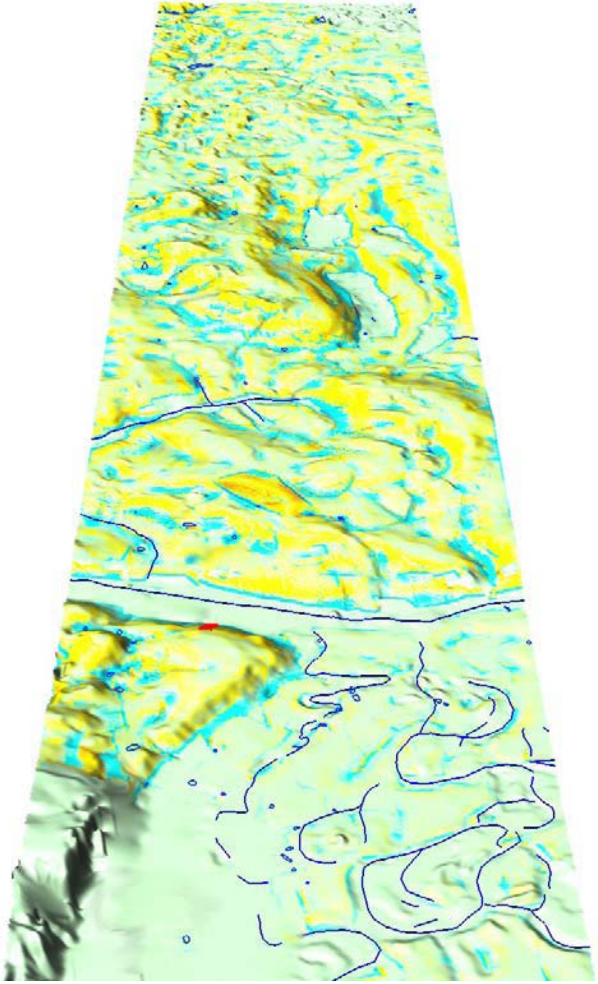
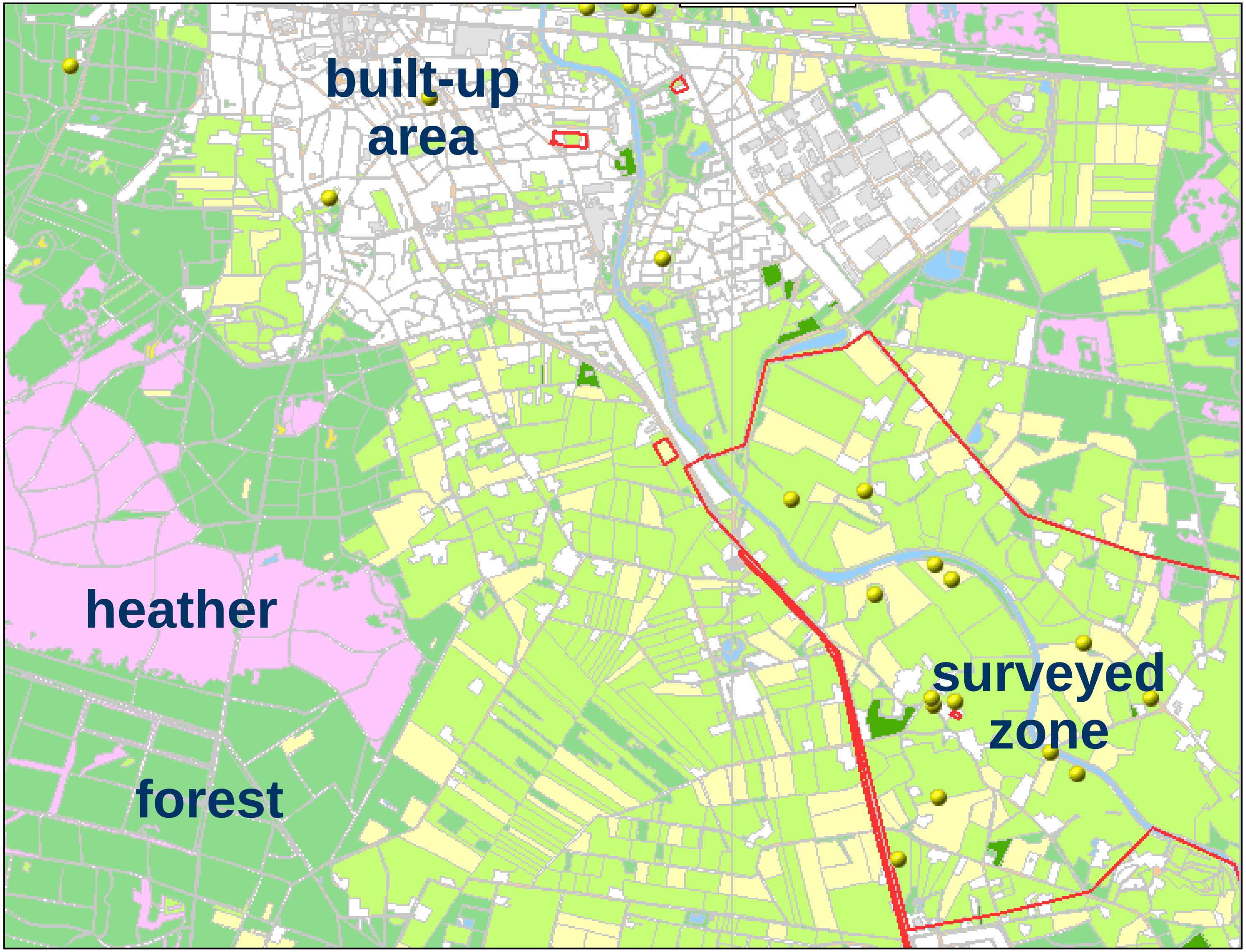
erosion/accumulation modelling

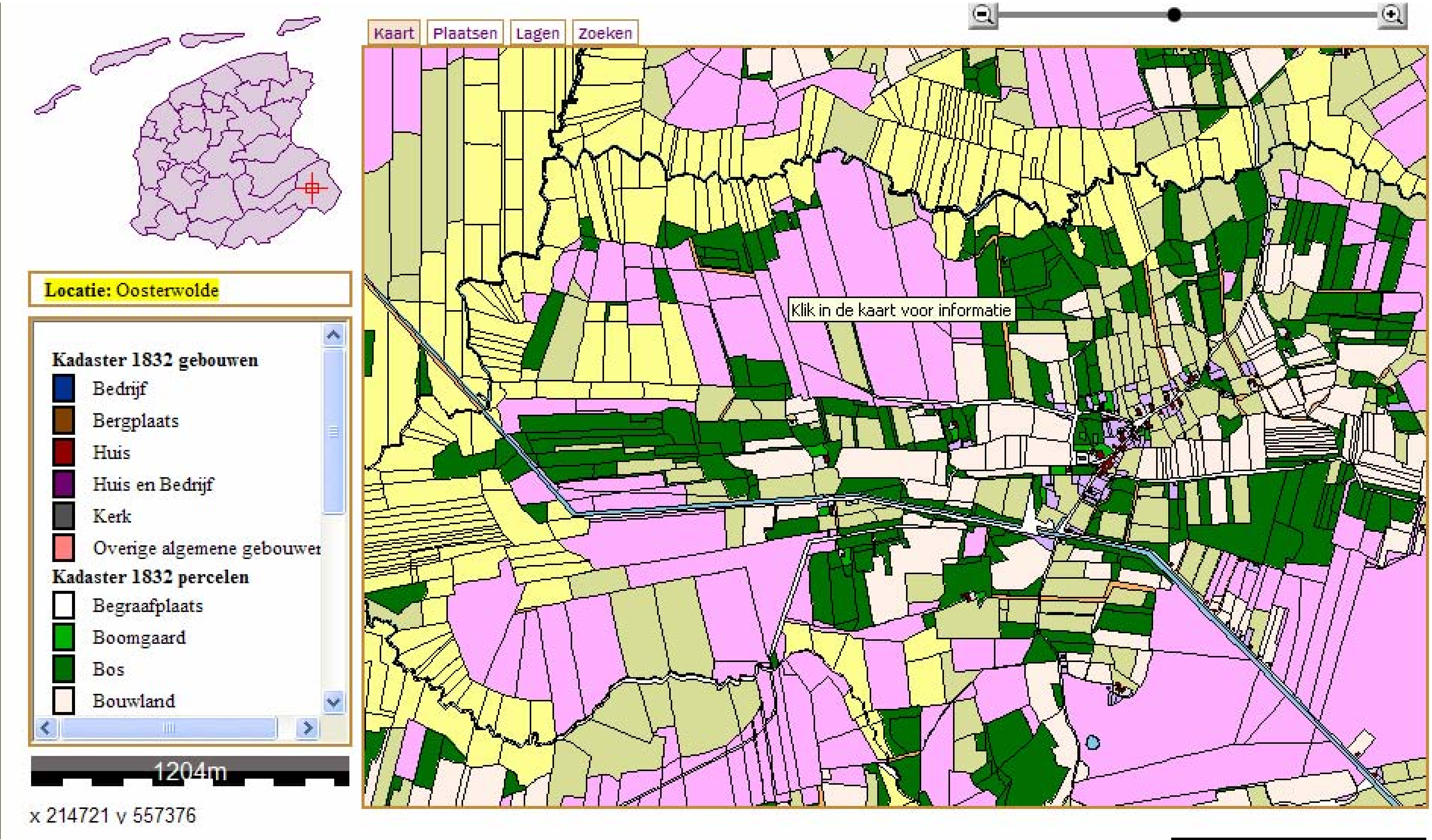




discovery probability model



historical land use maps



www.hisgis.nl

conclusions

- predictive modelling is there to stay
- but model quality is insufficiently addressed
- we need
  - methods to incorporate uncertainty
  - source criticism
  - field testing

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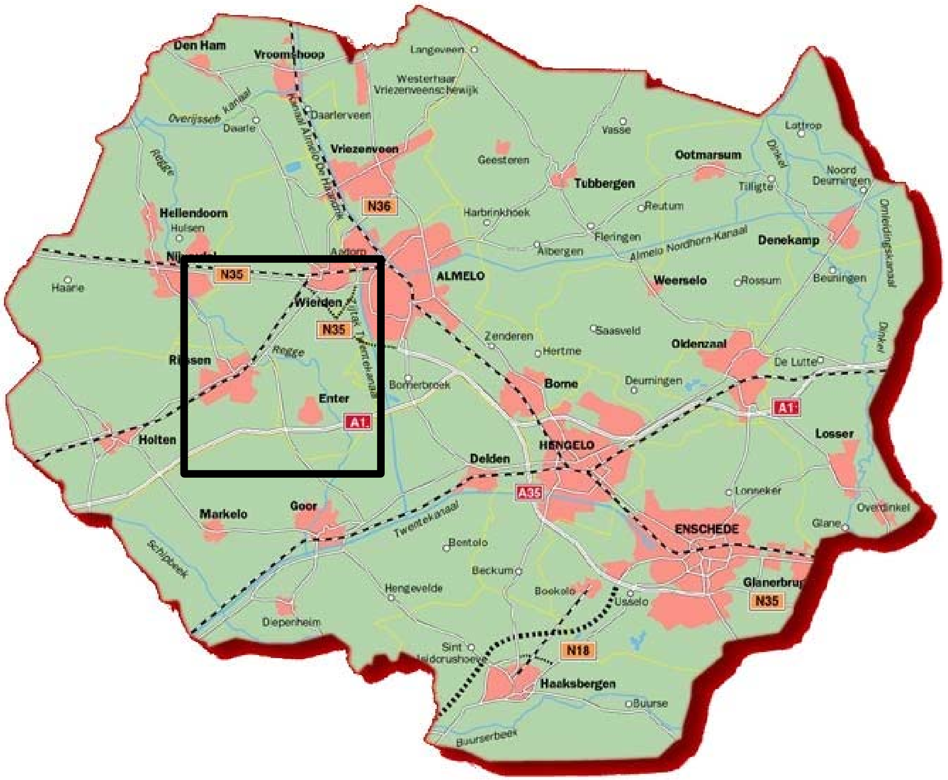
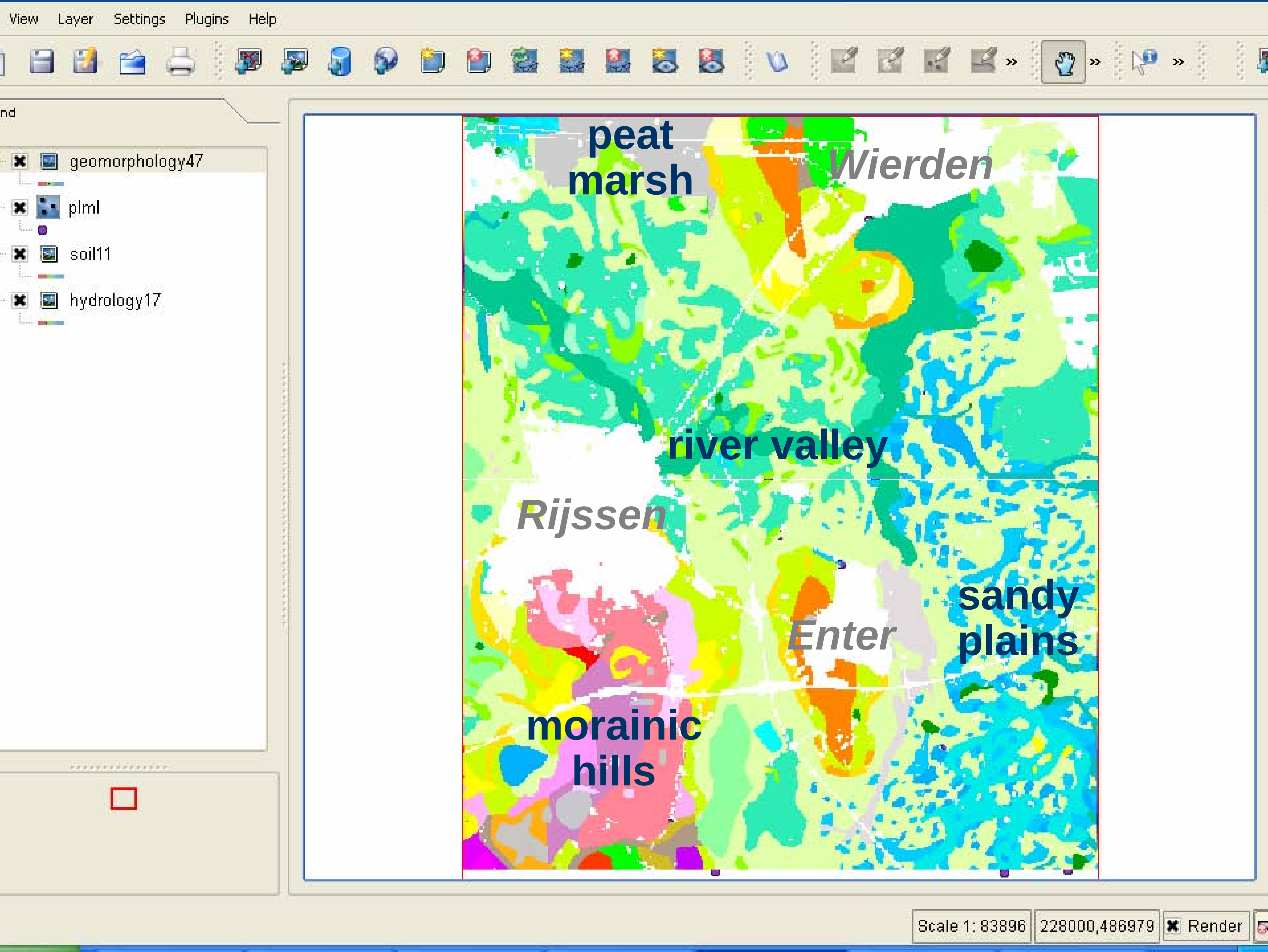
Rijssen-Wierden: area introduction

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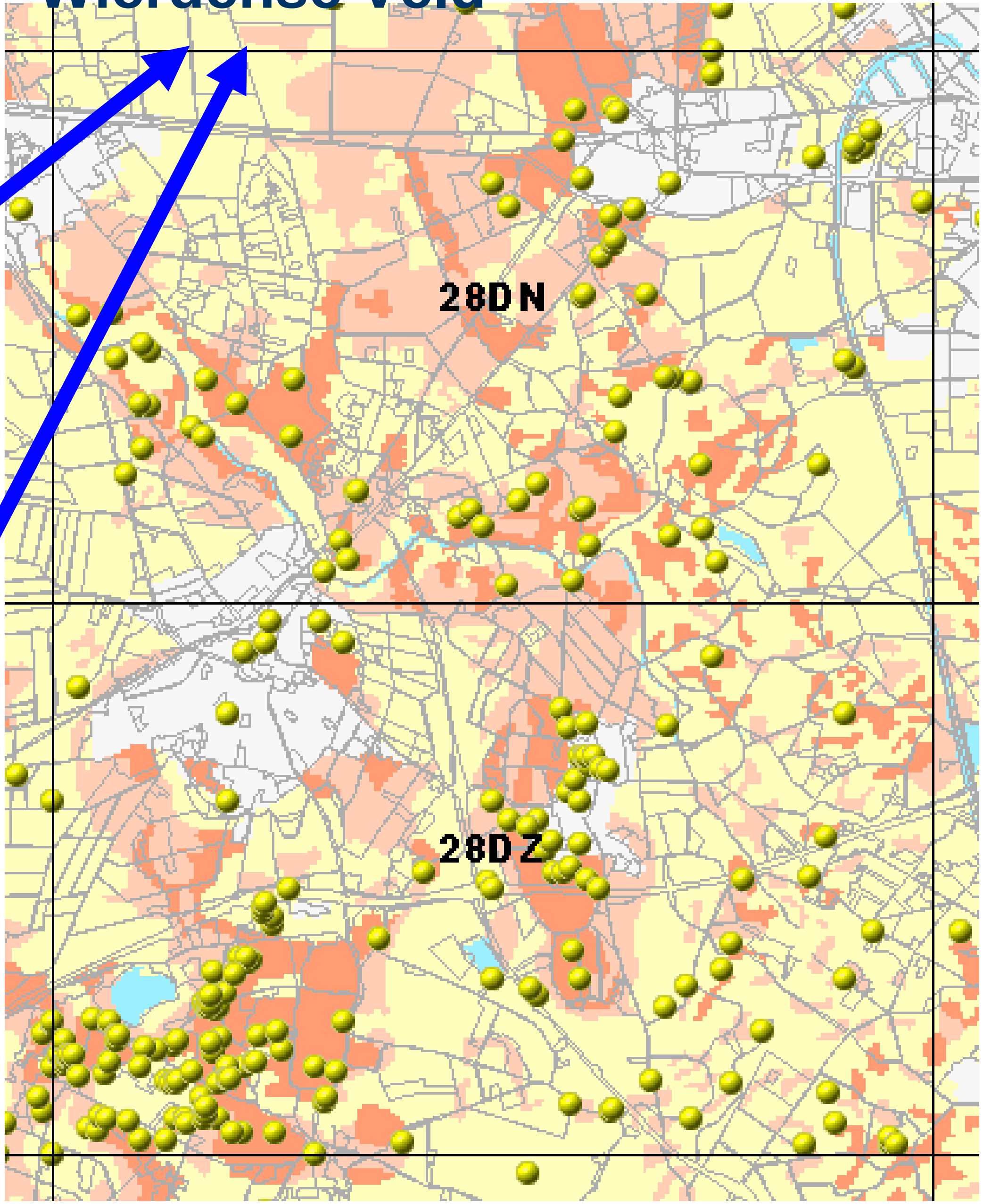

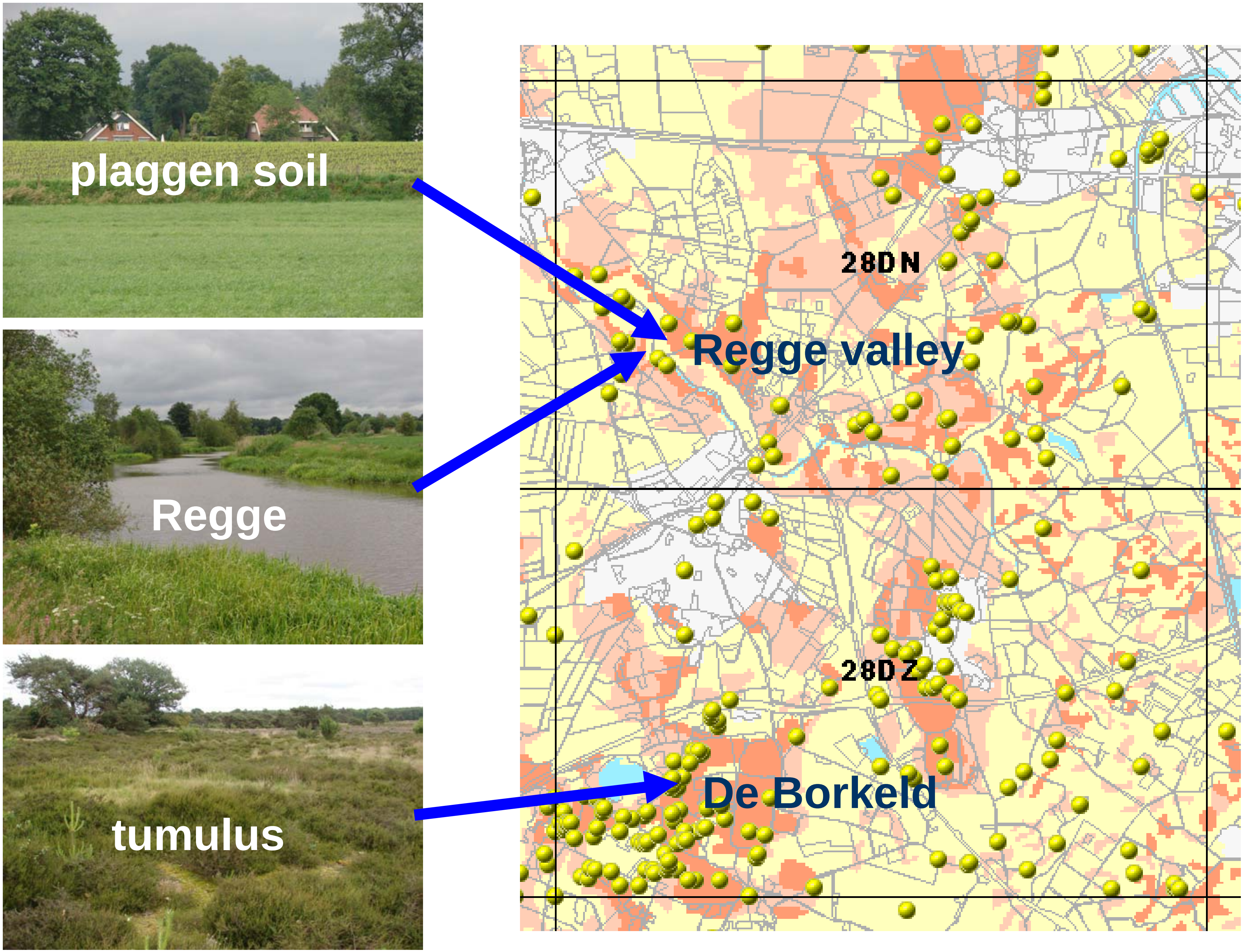
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tumulus
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28D Z
De Borkeld