Probability Modelling of Archaeological Sites with the Use of Geoinformation

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Introduction

Since 1980, considerable research has been made for Archaeological investigation using Remote Sensing and GIS techniques.

The use of Geoinformation offers great potential for archaeological research and predictive modelling facilitates the way of finding new archaeological sites.

A different methodological approach to record and predict new archaeological sites based on probability maps is presented.

Aim of Study

Predictive modelling is a dynamic process that offers new information as soon as new data is available.

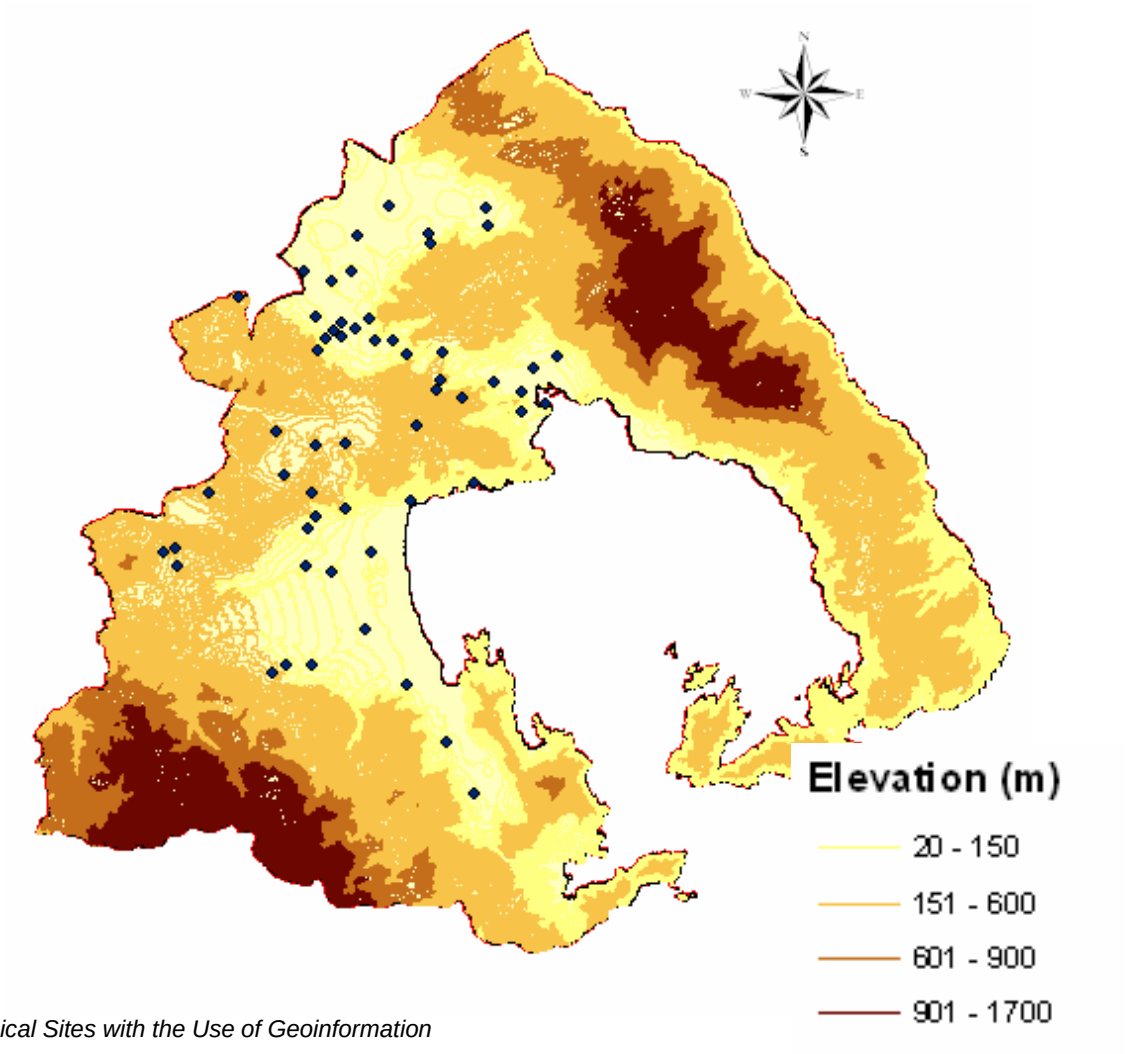
The factors that contribute to the presence of Archaeological sites of the prefecture of Magnesia in Greece by means of geospatial information are analyzed and used in a challenging way to model and predict Archaeological sites using probability maps.

Study Area

The prefecture of Magnesia is one of the four that exist in Thessaly in central Greece, rich in monuments of cultural heritage.

Among the famous archaeological sites Dimini and Sesklo, the area is consisted of a great number of neolithic archaeological sites of all phases.

Spatial Distribution of the Neolithic Archaeological Sites of Magnesia



Theoretical Background (1)

Some probabilistic concepts describe a number of different types of ignorance used in many research programs.

- Random ignorance is best described by the traditional Theory of Probability.

- Subjective ignorance (Bayesian theory) cannot be described by the traditional theory of probability.

Dempster-Shafer theory (A.Dempster, 1967) (Shafer G., 1976), is a generalization of Bayesian theory that “allows for the expression of ignorance in uncertainty management”. Unlike the Bayesian approach, the Dempster-Shafer theory provides a means to account explicitly for unknown possible cause of observational data.

Theoretical Background (2)

In this work the Theory of Evidence (Dempster-Shafer theory) can aggregate sources of heterogeneous information in order to estimate the optimal probability of existence of archaeological sites.

The major advantage of the theory above is that it quantifies and incorporates the user ignorance.

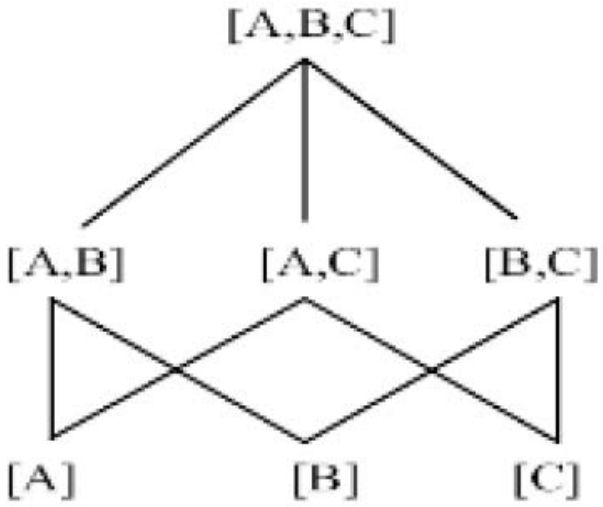
Theoretical Background (3)

If there is a probabilistic value from 0 to 1 for each variable for a site to exist, the sum of the probabilities of the hypothesis is not equal to 1, but up to 1. Additivity doesn't exist in this case and the residual until 1 is the belief interval expressed as ignorance.

In other words, ignorance exists in the body of knowledge, and that belief for a hypothesis is not necessarily the complement of belief of its negation. Dempster-Shafer theory defines hypotheses in a hierarchical structure and will accept all possible combinations of hypotheses.

Theoretical Background (4)

The Hierarchical Structure of the hypotheses subsets in the integral set of the hypothesis [A,B,C].



In this study, two hypotheses are formed:
“Archaeological site”
“Non Archaeological site”

Ignorance can be regarded as a third hypothesis:
“Archaeological-Non Archaeological site”

Probabilistic Assignments for each variable in Dempster Shafer theory (1)

1. Basic probability assignment

   Weighting coefficient of every line of evidence

$$\sum_{i=1}^{2^{\nu}-1} m(\Omega_i) = 1 \qquad \forall \Omega_i \subset \Omega$$

2. Ignorance

   Residual of the basic probability assignment

$$m(\mathrm{A},\mathrm{B},\Gamma) = 1 - [m(\mathrm{A}) + m(\mathrm{B}) + m(\Gamma) + m(\mathrm{A},\mathrm{B}) + \mathrm{m}(\mathrm{A},\Gamma) + \mathrm{m}(\mathrm{B},\Gamma)]$$

3. Belief

   The sum of probabilities that support each hypothesis

$$Bel(\Omega) = \sum_{i=1}^{2^{\nu}-1} m(\Omega_i) = 1 \quad \textbf{when} \quad \Omega_i \subseteq \Omega$$

Probabilistic Assignments for each variable in Dempster Shafer theory (2)

4. Disbelief

The degree to support contradictory hypotheses

$$DisBel(\Omega_i) = Bel(-\Omega_i)$$

5. Plausibility

The sum of probabilities of a line of evidence cannot be rejected.

$$Pl(\Omega_i) = 1 - Bel(-\Omega_i) \qquad \text{where} \quad -\Omega_i = not\,\Omega_i$$

$$Pl(\Omega) = \sum_{i=1}^{2^{\nu}-1} m(\Omega_i) = 1 \qquad \text{when} \quad \Omega_i \cap \Omega = \varnothing$$

6. Belief Interval

The total ignorance after combining the lines of evidence

$$BelInt = Pl(\Omega_i) - Bel(\Omega_i)$$

Probabilistic Assignments for each variable in Dempster Shafer theory (3)

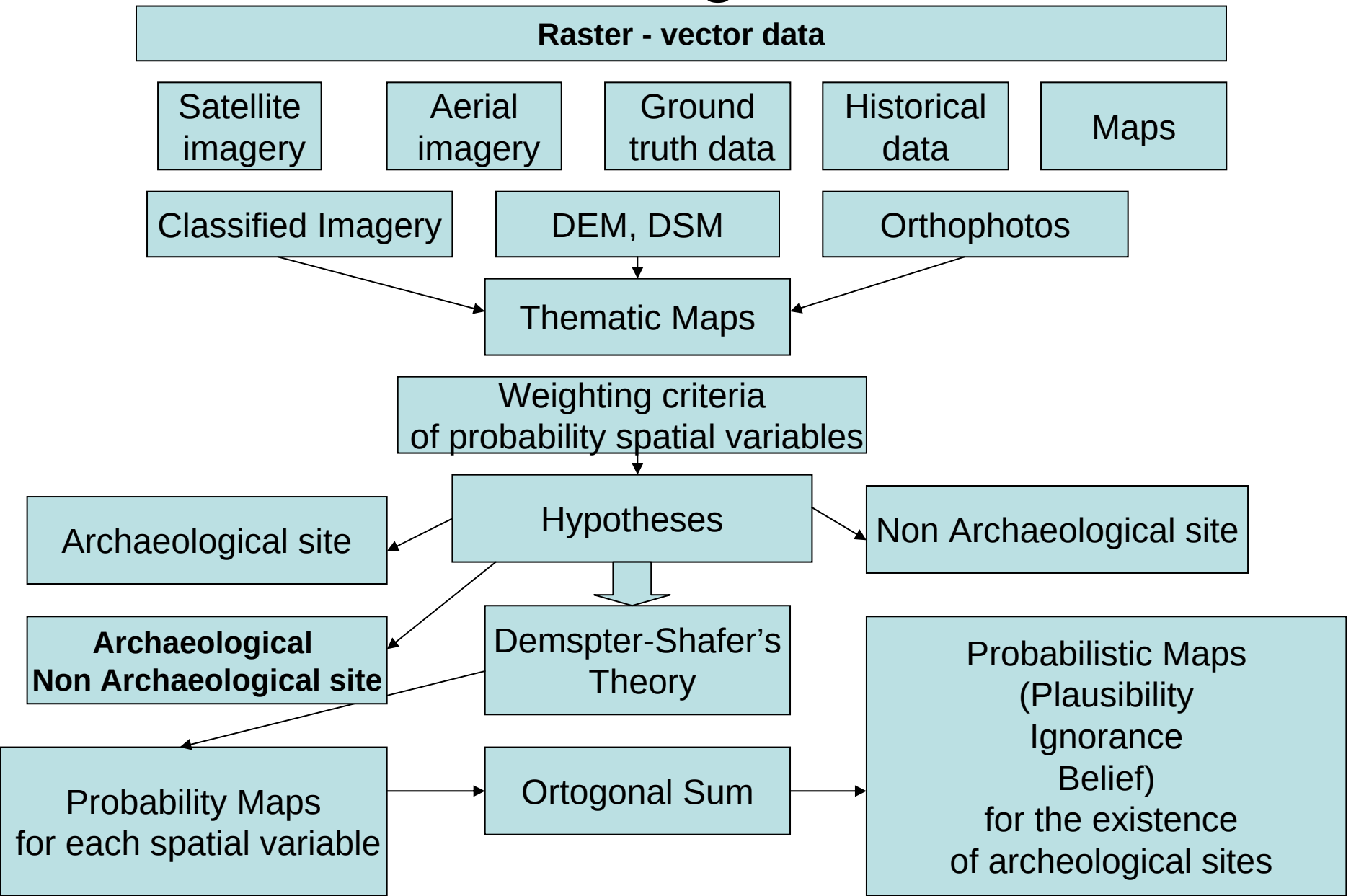
The orthogonal sum operation is defined as follows:

$$m1 \oplus m2(Ci) = \frac{\sum m_1(\mathrm{A}_i) * m_2(\mathrm{B}_j)}{1 - \sum m1(\mathrm{A}_i) * m_2(\mathrm{B}_j)} \qquad \frac{when(\mathrm{A}_i \cap \mathrm{B}_j) = Ci}{when(\mathrm{A}_i \cap \mathrm{B}_j) = \varnothing}$$

$$\text{If} \quad \sum m_1(\mathrm{A}_i) * m_2(\mathrm{B}_j) = 0 \qquad \text{for} \quad \mathrm{A}_i \cap \mathrm{B}_j = \varnothing$$

$$\text{Then} \quad m1 \oplus m2(Ci) = \sum m_1(\mathrm{A}_i) * m_2(\mathrm{B}_j) \qquad \text{for} \quad \mathrm{A}_i \cap \mathrm{B}_j = C_i$$

Methodological Chain



Variables

The hypothesis **“archaeological site”** is supported by the evidence that contribute to this hypothesis. The following variables were considered:

- slope
- known archaeological sites
- current settlements

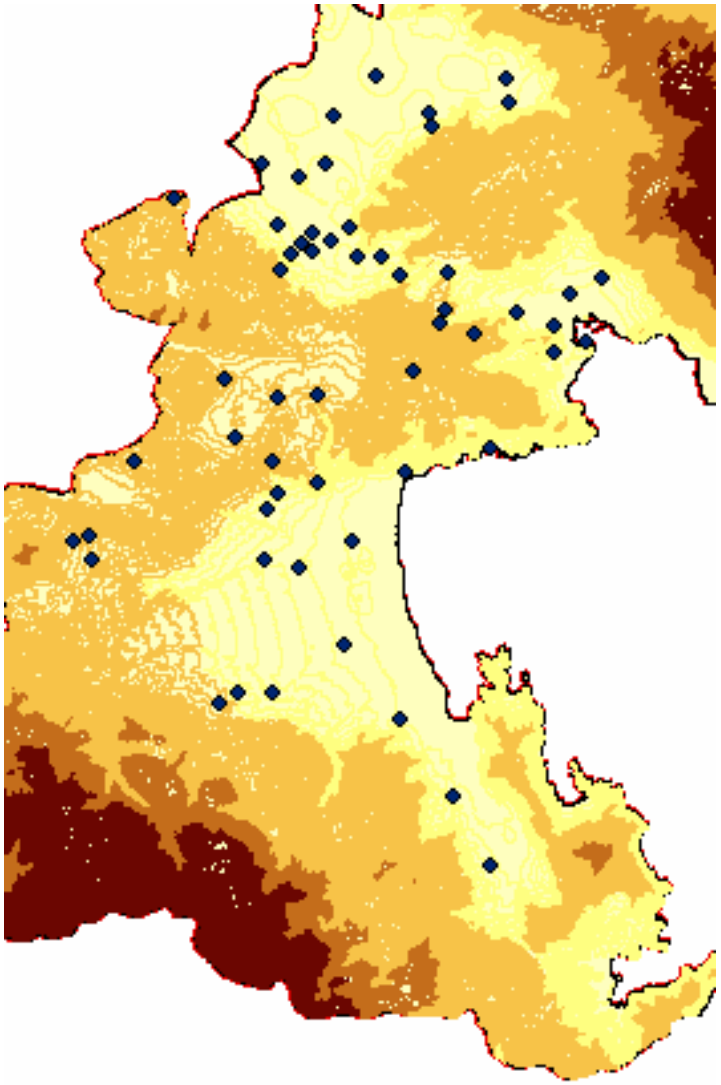
The hypothesis **“non-archaeological site”** is supported by the evidence that contribute to this hypothesis. The following variables were considered:

- aspect
- proximity to water resources

Existing Neolithic Archaeological Sites

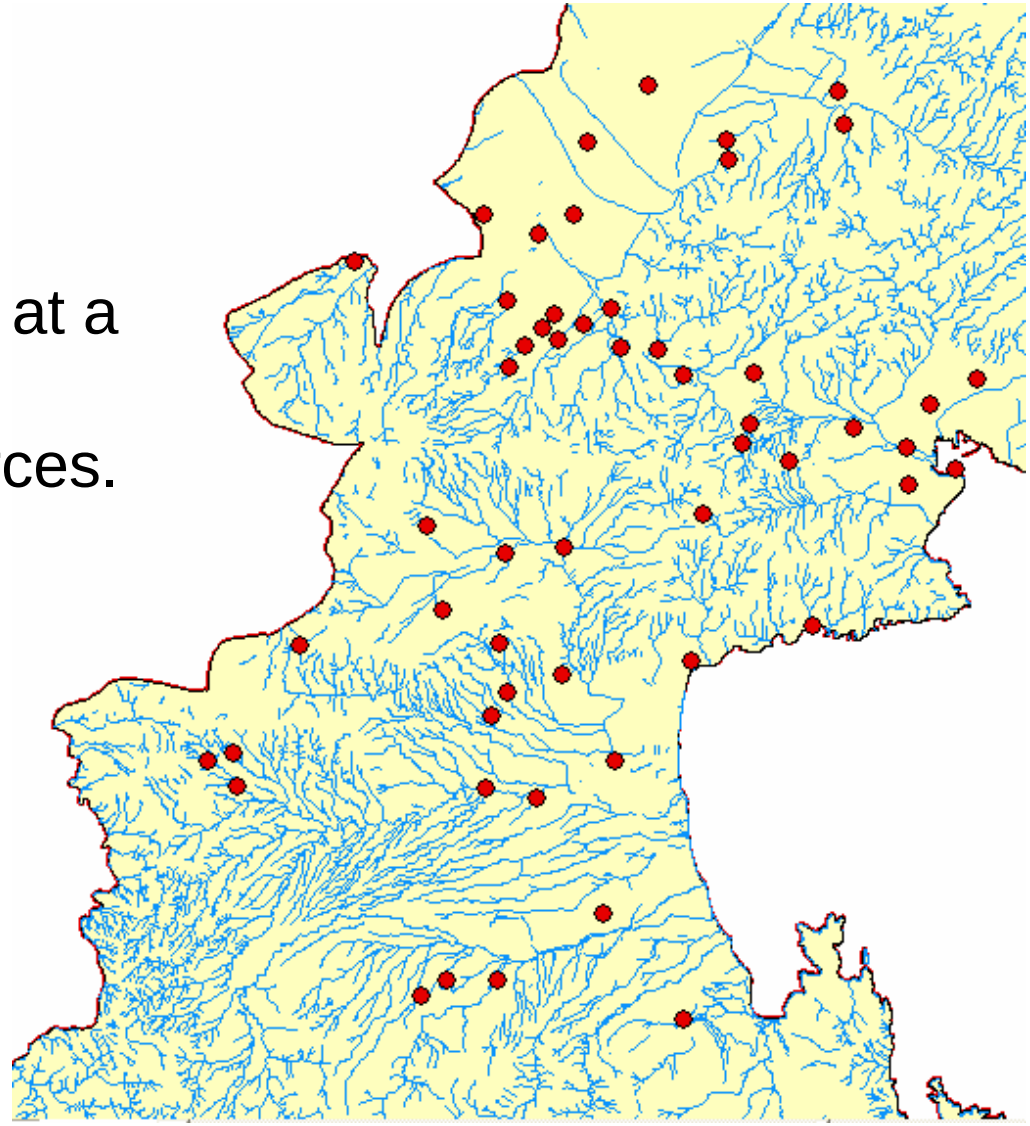
The spatial distribution of the known archaeological sites.

Which factors contribute to their existence?



Proximity to Water Resources

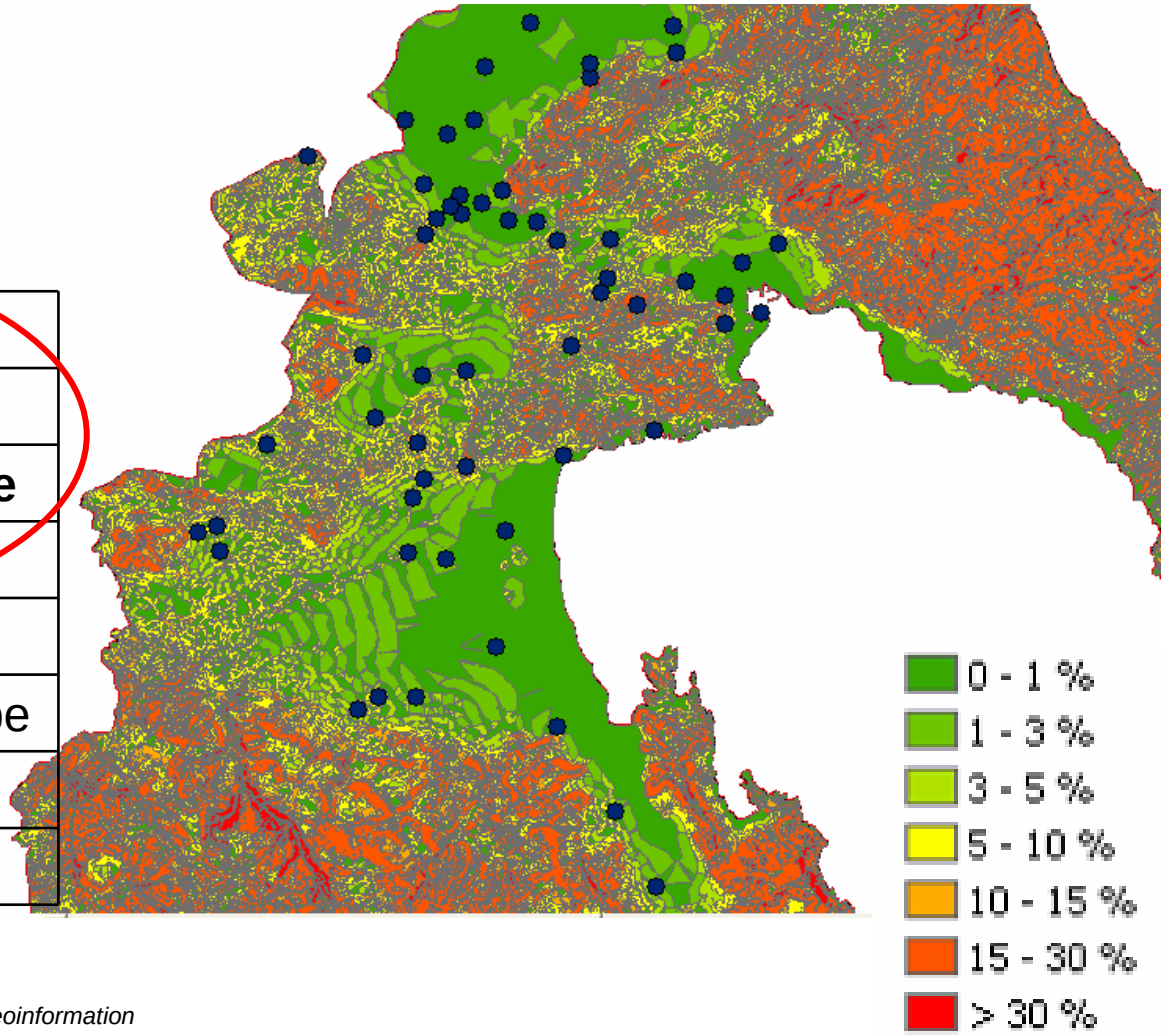
90% of the Neolithic archaeological sites are at a distance of 800m to permanent water resources.



Slopes Compatible with Existing Archaeological Sites

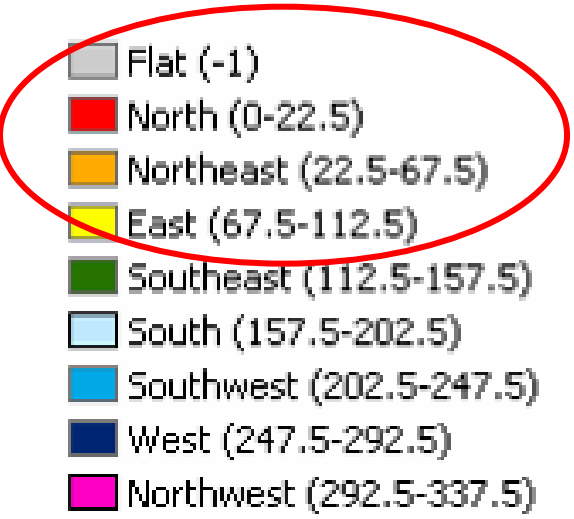
Slope maps have usually eight classes (Schumm,1956)

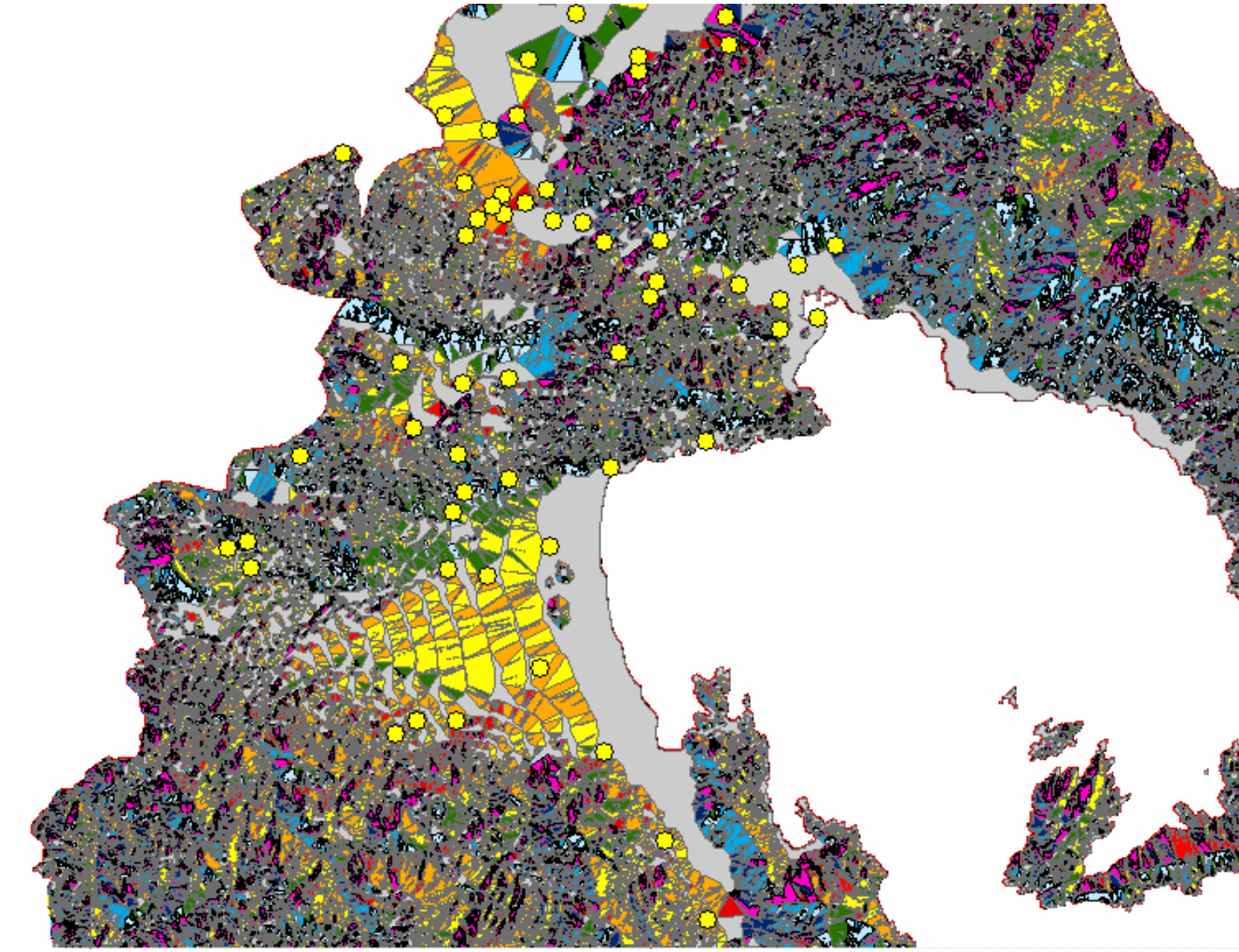
Slope (%)	Type of slope
0 – 1%	**flat - plain**
1 – 3%	**very gentle slope**
3 – 5%	**gentle slope**
5 – 10%	middle slope
10 – 15%	middle rough slope
15 – 30%	rough slope
> 30%	very rough slope



Aspect in Relation to Archaeological Sites

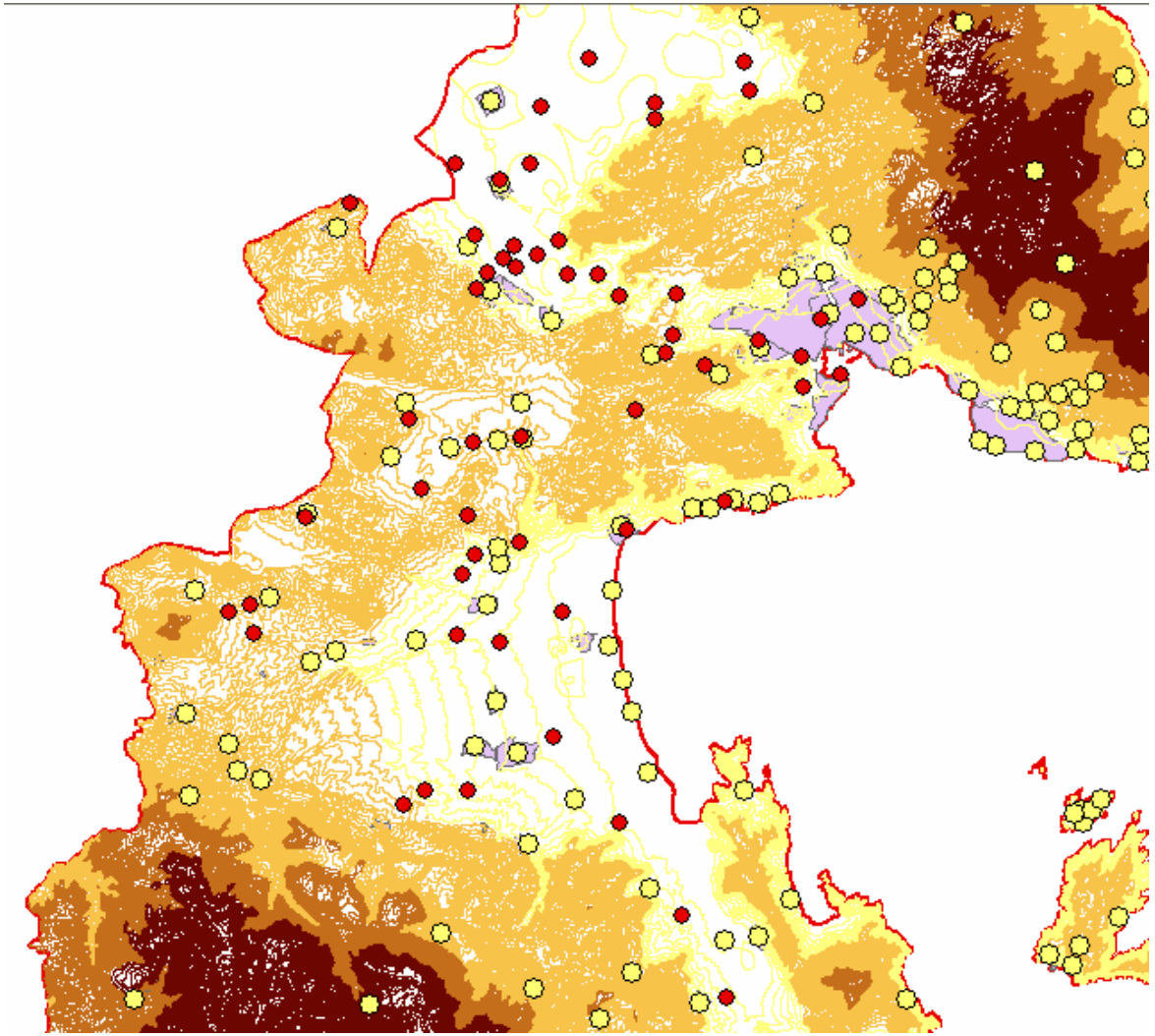
Aspect maps have usually nine classes (Burrough, 1986).





Proximity to Current Settlements

85% of the Neolithic archaeological sites are within a distance of 3500m. of existing current settlements.



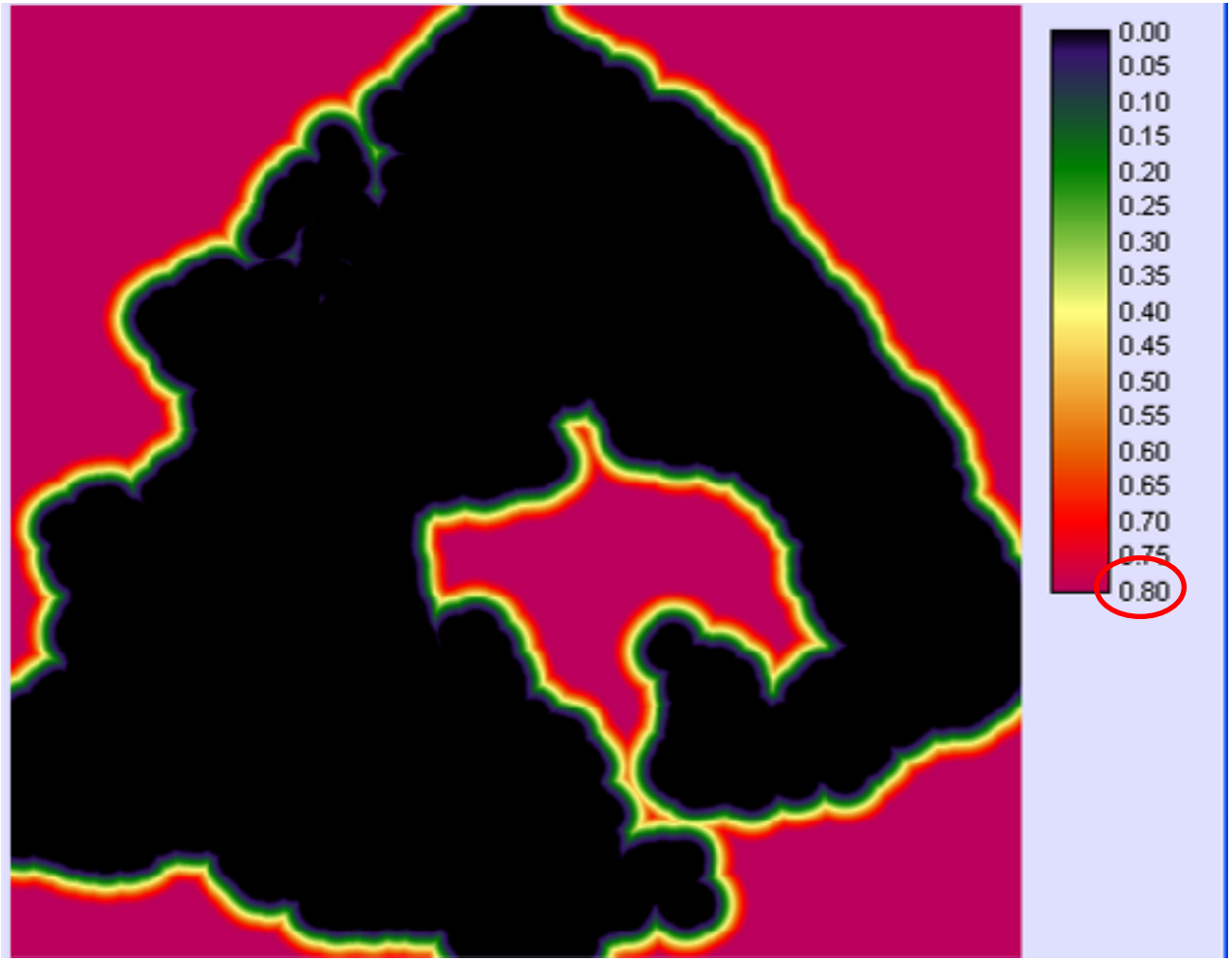
Conversion of Spatial Variables to Probability Maps

Fuzzy sets are used in order to transform the discrete values of variables in a probabilistic scale from 0 to 1.

Fuzzy classes are sets without sharp boundaries and characterized by a fuzzy probability from 0.0 to 1.0

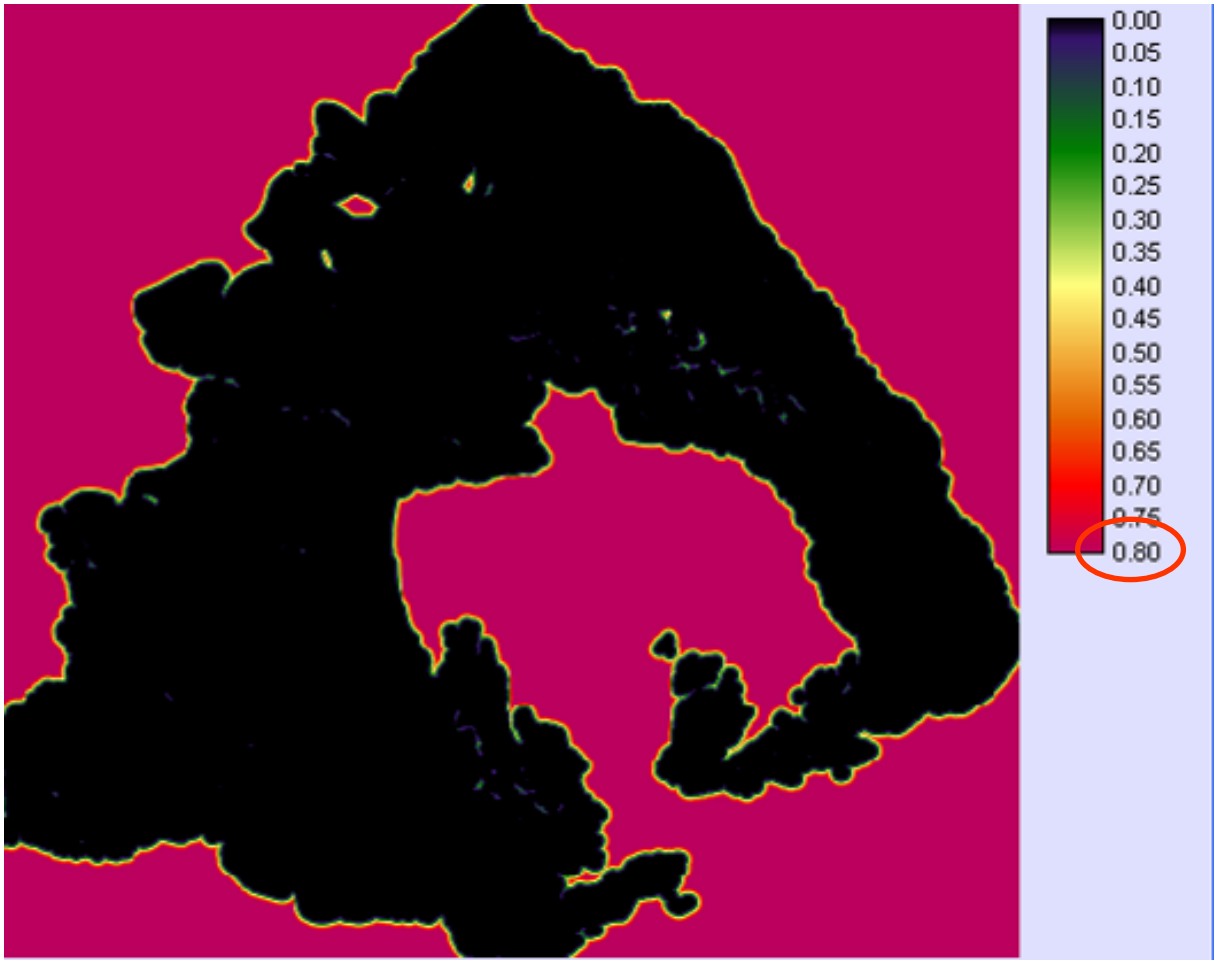
Probability Maps of “Non-Site” Hypothesis

Water Resources



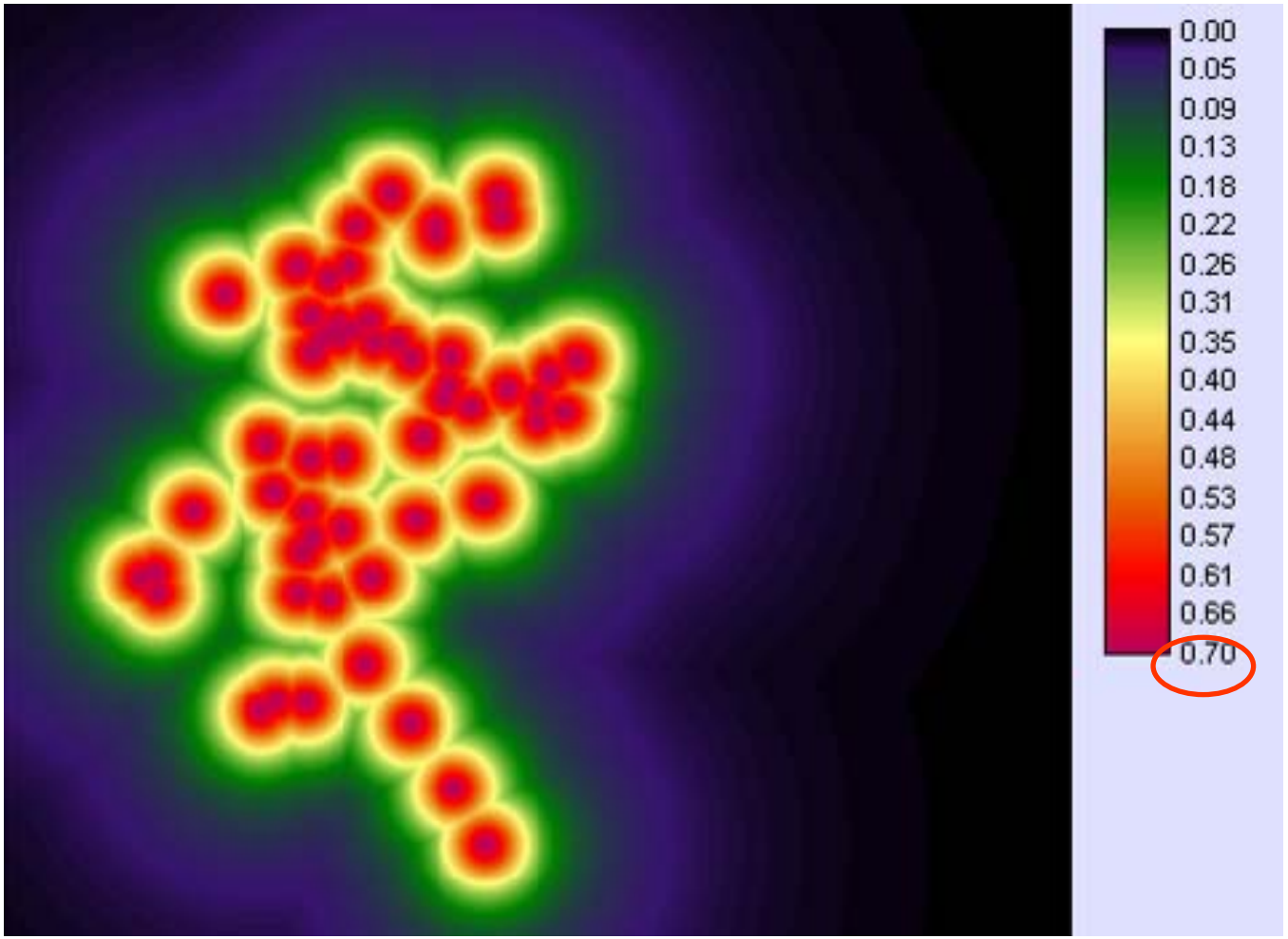
Probability Maps of “Non-Site” Hypothesis

Aspect



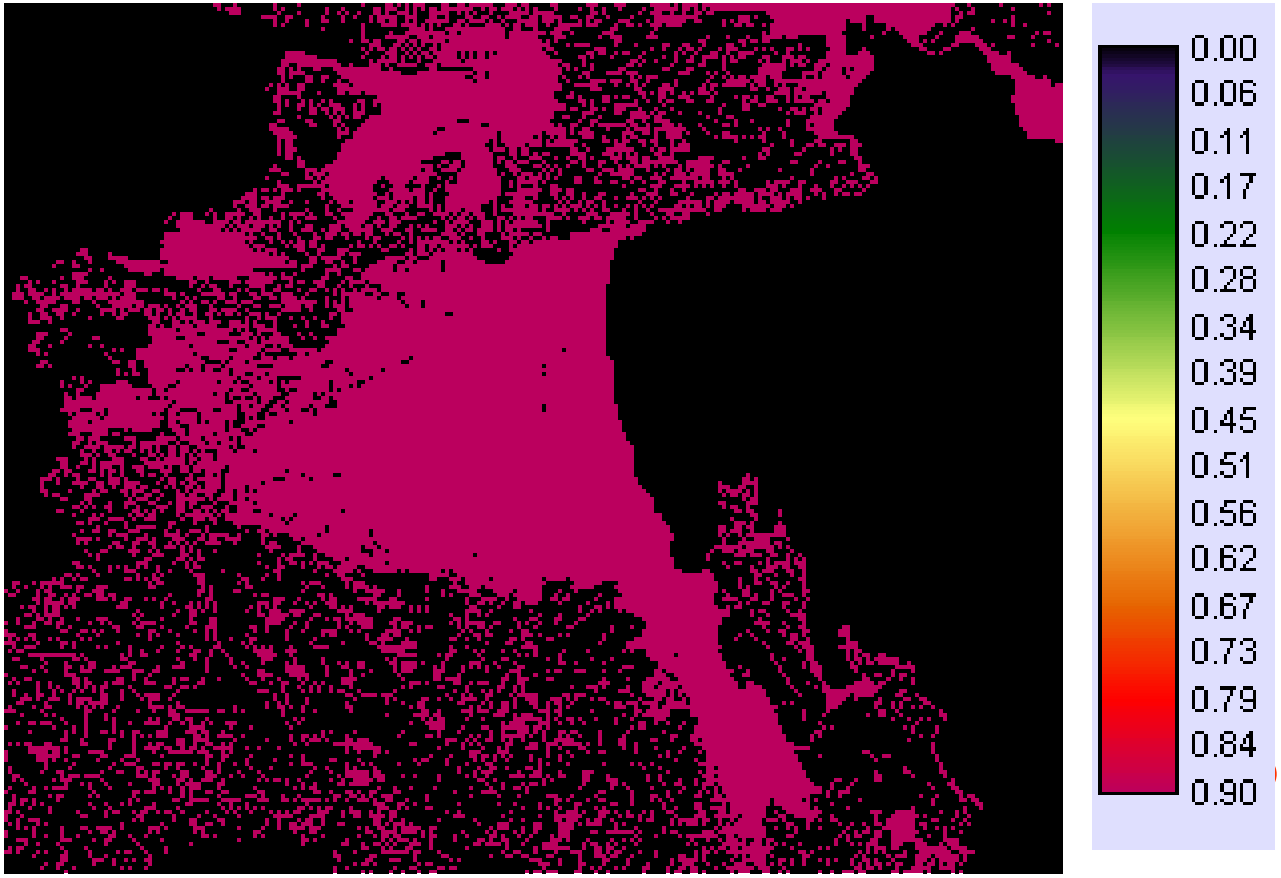
Probability Maps of “Site” Hypothesis

Site neighbor to existing sites



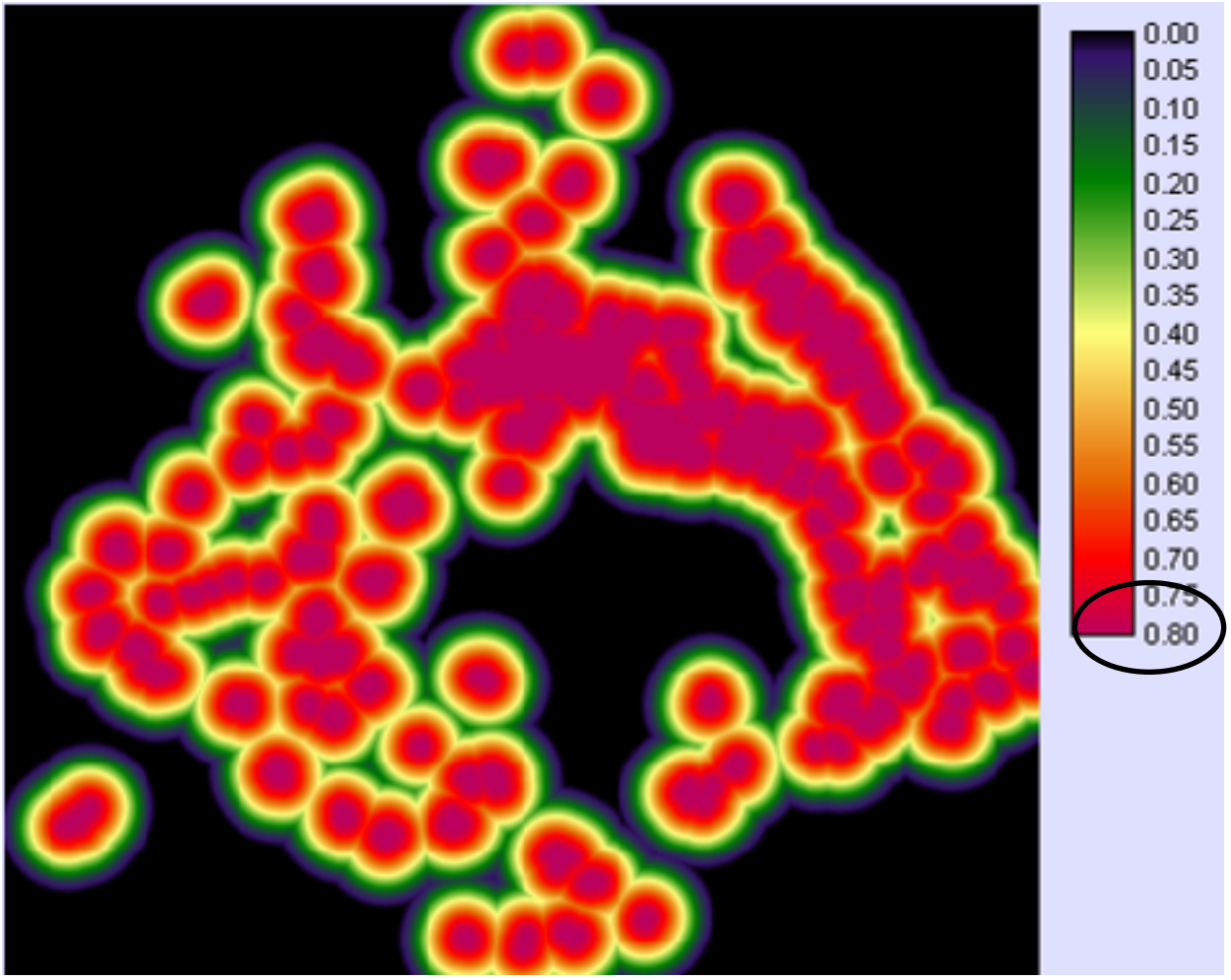
Probability Maps of “Site” Hypothesis

Slope



Probability Maps of “Site” Hypothesis

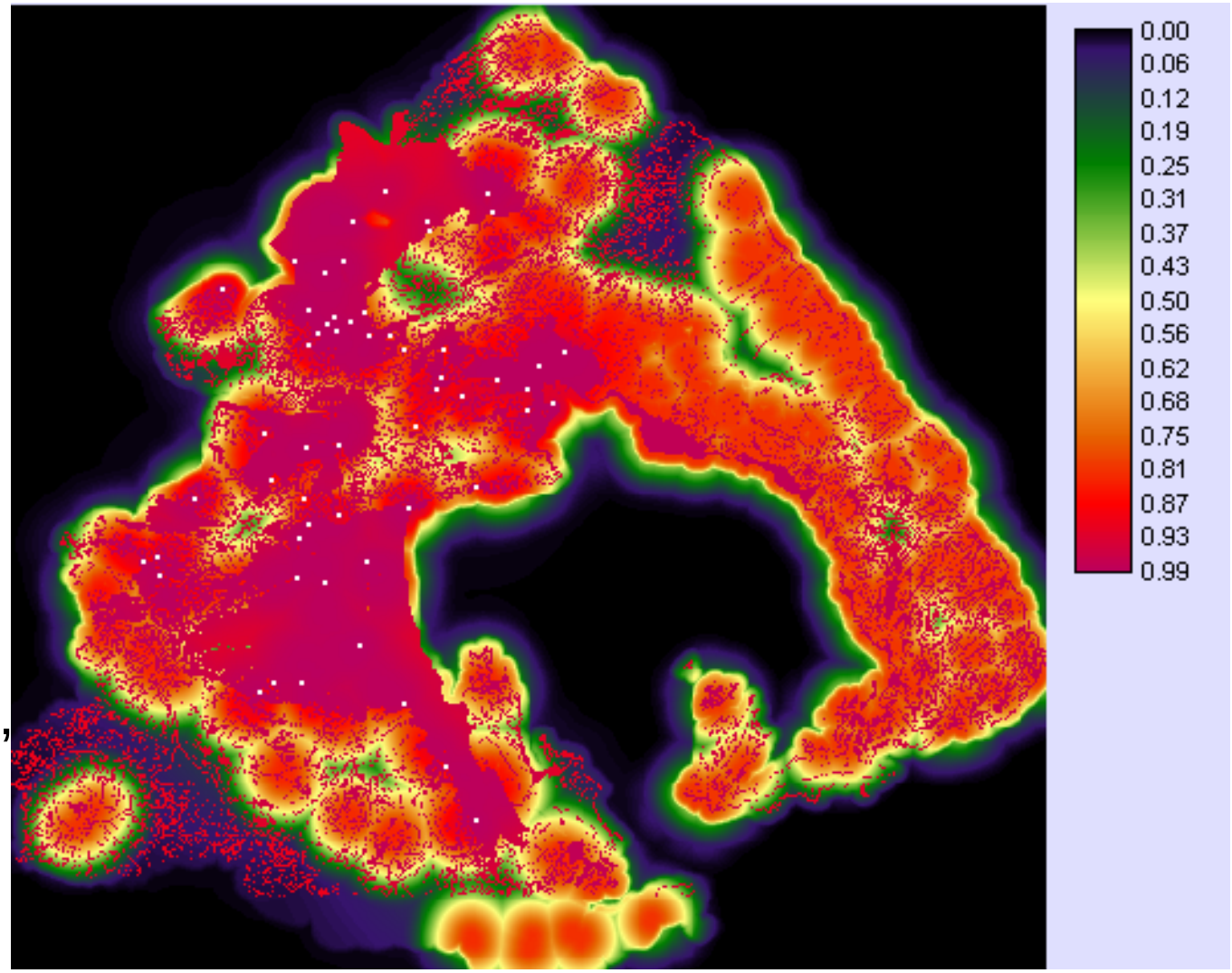
Current Settlements



Belief for Site Hypothesis

This image shows the aggregated probability that support the hypothesis.

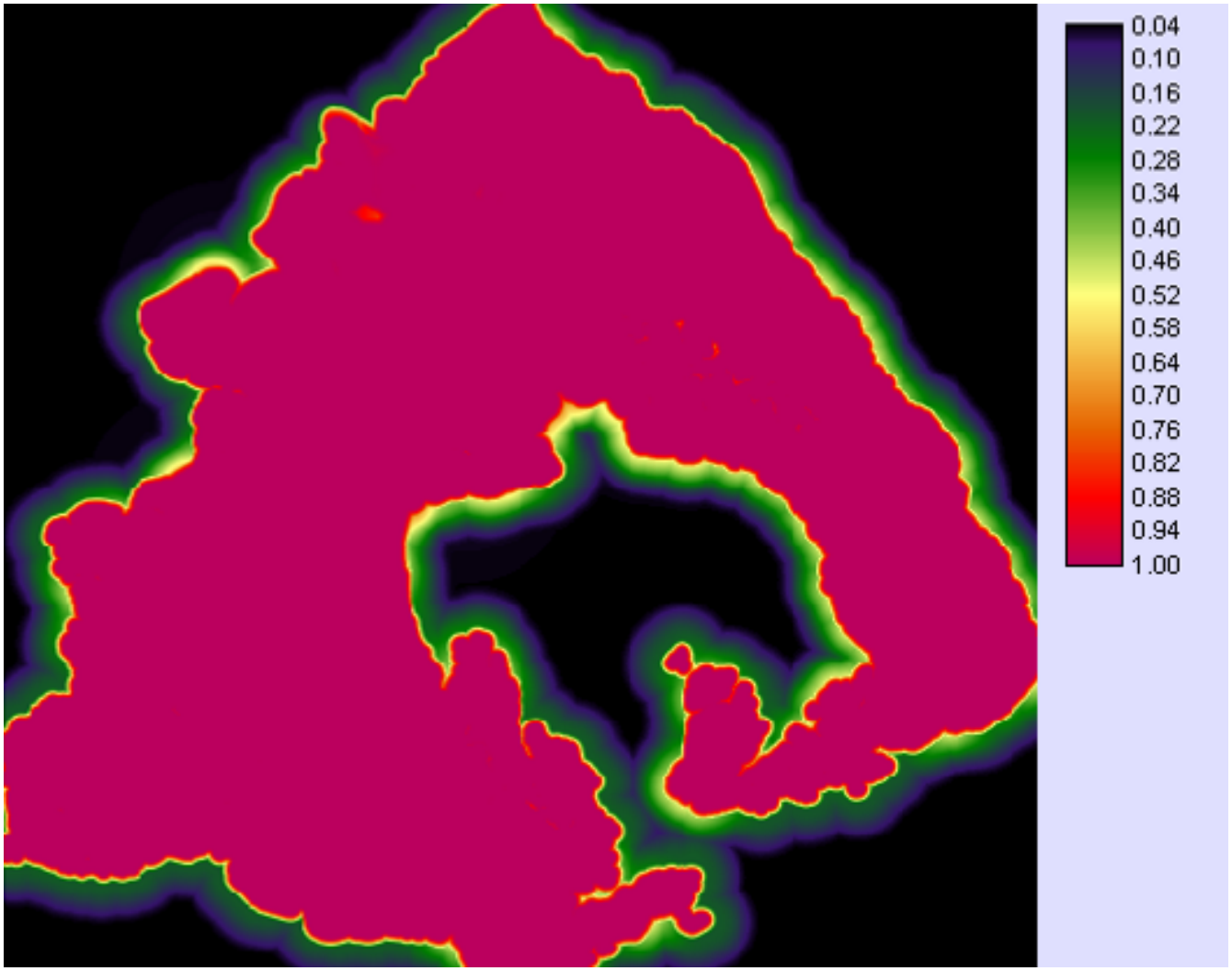
It represents the minimum probability of the "site" hypothesis"



Plausibility for Site Hypothesis

This image shows wider areas that have high probabilities provided that these probabilities associated with the “site” hypothesis proves to support it.

It represents the maximum probability of the “site” hypothesis”.

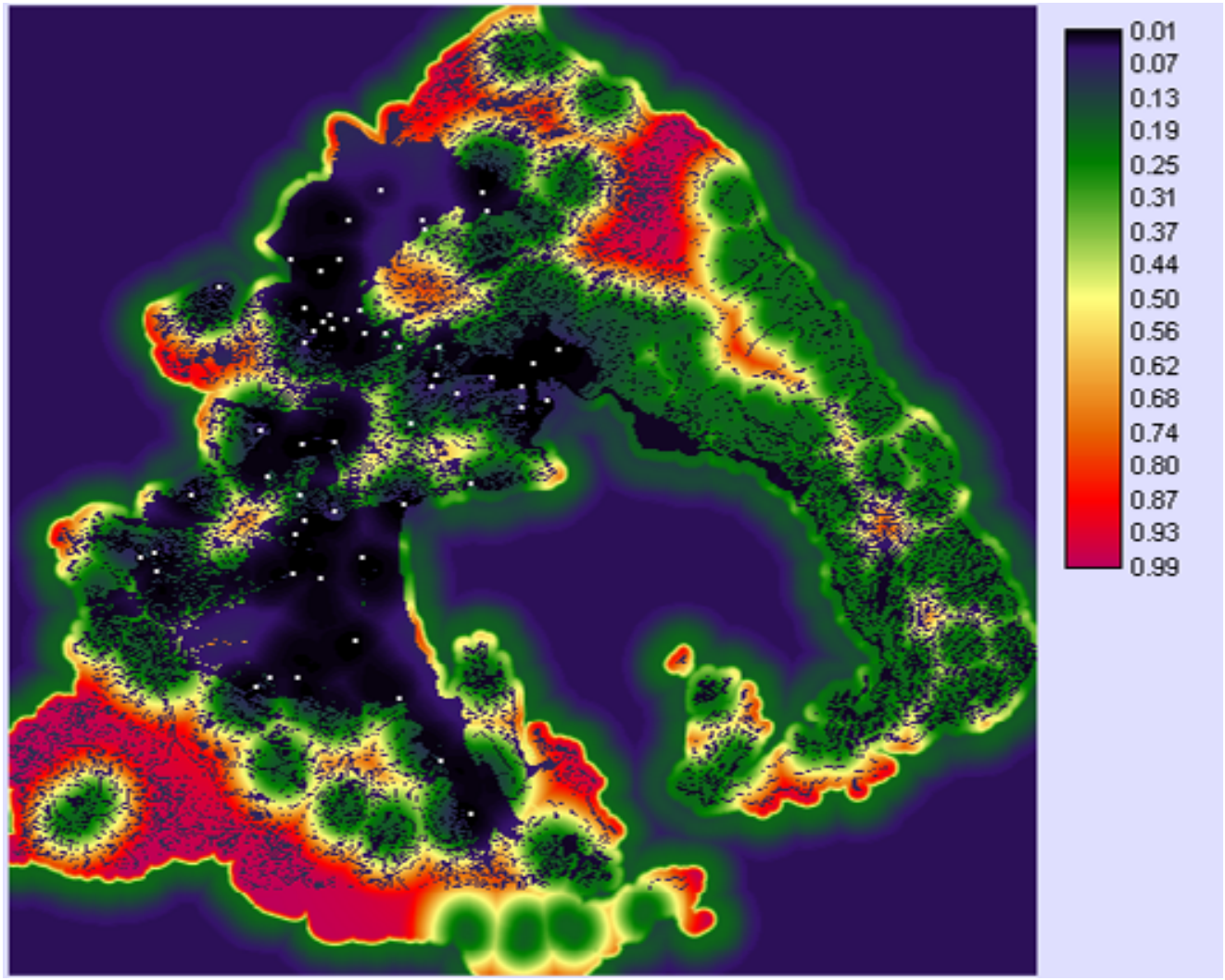


Belief Interval for Site Hypothesis

This image shows the probability of potentials.

The higher the probability, the more valuable further information will be in a location.

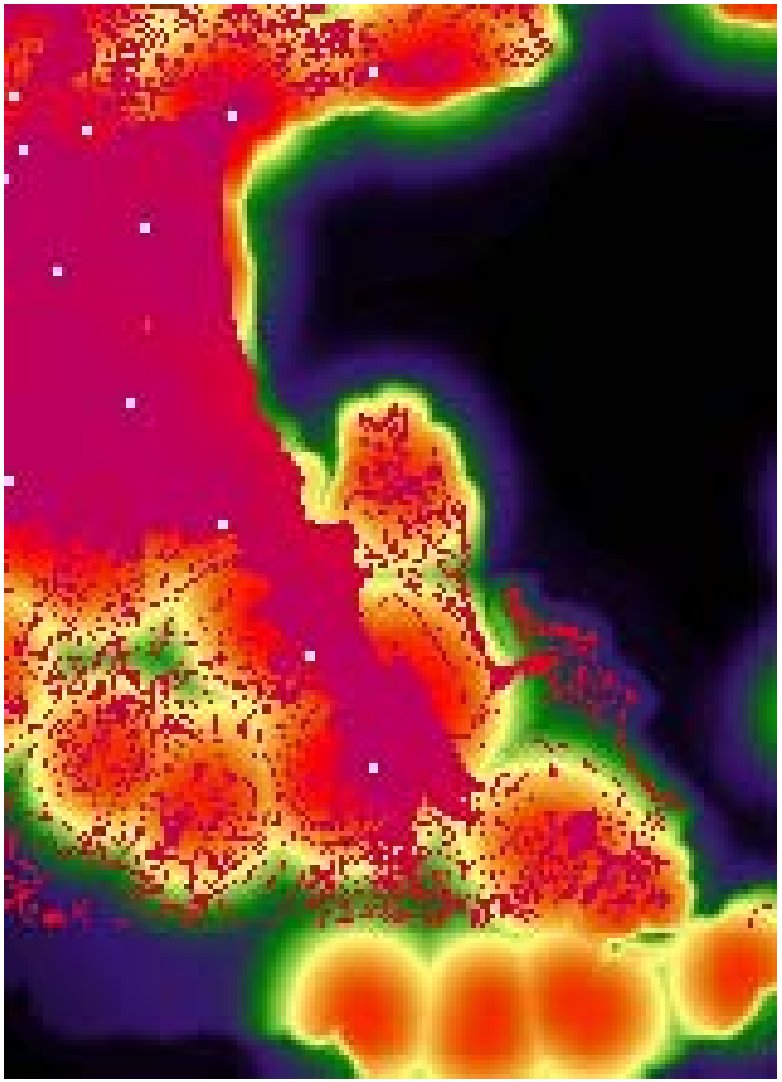
Areas for further research.



Further Investigation

Why do some of the known sites follows a linear pattern?

According to the literature review, these sites were found during road construction works between 2001 and 2005.

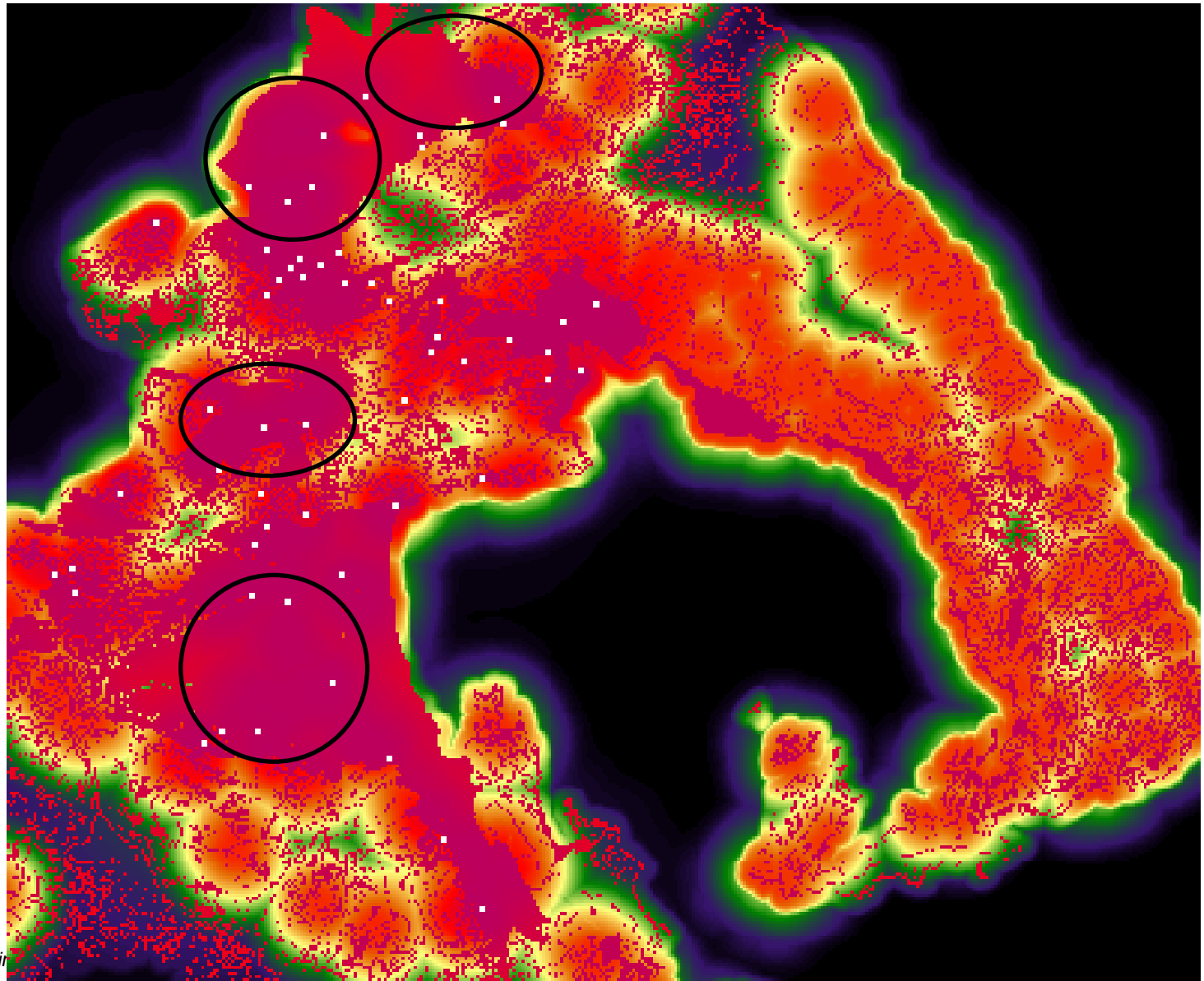


Further Investigation

The LANDSAT image shows this relationship.

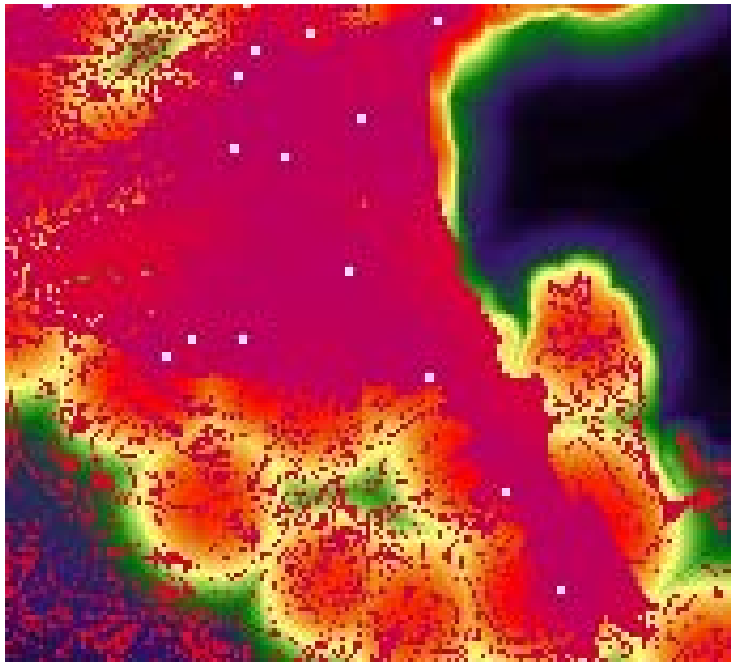
This means that there are probabilities for other sites to exist in a broader area.

Further Investigation

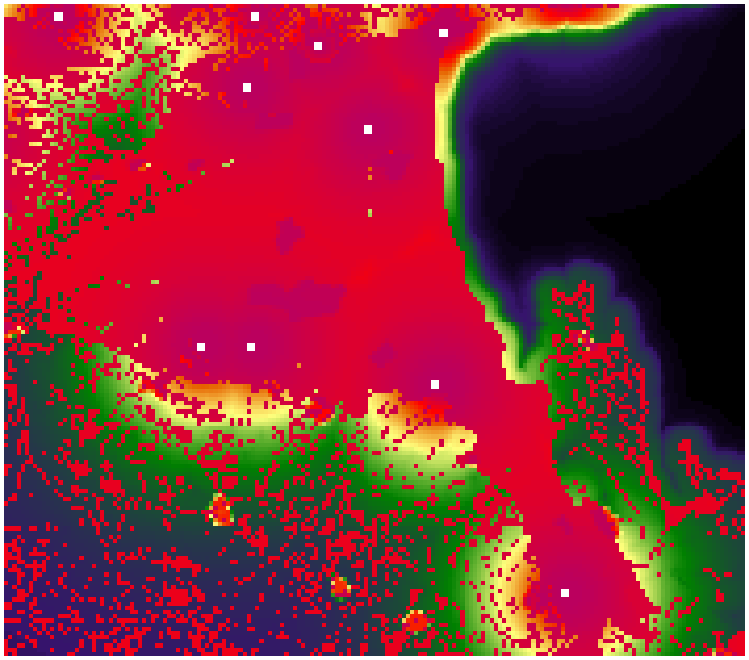


Belief Comparison

Some sites were treated as unknowns and the model was rebuilt. The results on the right image show that these sites can be identified even though with smaller probability.



All sites used in the model



Much fewer sites used in the model

Concluding Remarks(1)

- Dempster Shafer theory takes into account the “ignorance” to deal the lack of knowledge, social, economical, political changes.

- Thematic spatial data should be converted into probability maps.

- Ignorance can be represented spatially in a quantitative way.

- Although fuzzy logic used for archeological investigation outputs to a single final map, belief, plausibility, and ignorance can be mapped separately and compose a more complete output in the Dempster-Shafer theory.

Future Research (1)

Incorporation of more variables into the model such as:

- geology
- spring distribution
- mining distribution

will be used in order to approximate the surface suitability and the people needs during the Neolithic period.

But:

The more variables used, the more complicated becomes the model.

Future Research (2)

Archaeological excavation combined with geophysical prospection techniques such as:

- soil resistivity and conductivity techniques,
- microgravity,
- ground penetrating radar,
- susceptibility measurements

will be performed to assess the relative strength and weakness of the model.

Future Research (3)

The analysis has been made based on current information of the landscape.

- The Archaeological problem requires the landscape reconstruction in order to approach the time of living during the Neolithic period.

- The support of each variable to the hypothesis is phase dependent, therefore the model will be tested in separate Archaeological phases of the Neolithic period.

Thank you for your attention!