

## Project in Natural Resources Management

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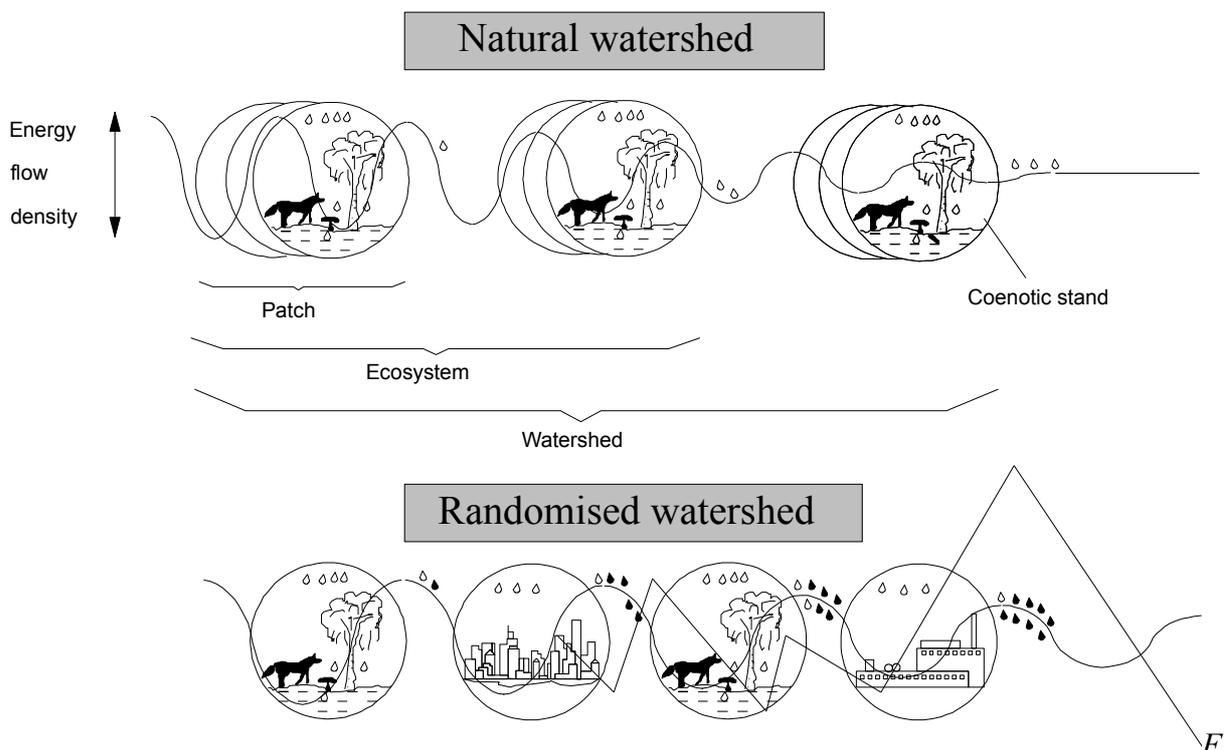
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## MULTI CRITERIA EVALUATION OF SITES FOR ECOLOGICAL VILLAGES

### Introduction

Modern city life is highly dependent on import of structured energy and matter from its environment. Energy costs are high in terms of transportation, water and wastewater treatment, distribution of food and other commodities, heating and lightning of houses and offices, etc. The city exports large amounts of degraded energy and matter to its surroundings. Simultaneously the loss of vegetation structure in urban environments leads to changes in natural dynamics of energy dissipation. The tight coupling of reciprocal processes in the natural landscape is loosened, leading to increases in weathering, erosion and irreversible outflow of vital nutrients and minerals (Ripl and Gumbricht, 1995a<sup>1</sup>; Gumbricht et al., 1996a<sup>2</sup>) (Fig. 1). A new land use planning strategy for sustainable housing and living in the spirit of the Brundtland commission (WCED, 1987) and Agenda21 is needed (cf. Merret, 1995). Such a strategy should emphasise human communication patterns and systems, in order to minimise energy demands under economic considerations (e.g. Lamm and Görling, 1992).



ig. 1. Schematic hierarchical energy pulse dissipation in a) natural watershed with a maximum of parallel dissipative structures in space resulting in low sequential changes with stable spatial and temporal patterns and high efficiency, and b) watershed with randomised spatial and temporal patterns resulting in a transient state of low efficiency.

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<sup>2</sup> Can be found under G:\KURSER\AOM\1B1636\NRM\ARTICLES \Urbwien.doc

The city is a parasite on the natural and domestic environments (Odum, 1993; Gumbrecht et al., 1996a). Life in the city thus causes both environmental problems as well as alienation to nature and ecological principles (Lorenz, 1973). Today, hence more and more people search for an alternative to life in the city. This has led to the development of ecological villages, small societies with 50 to 100 households. Ecological villages are situated near nature, and built up around local supply of energy, water and food (Eronn, 1991; Malbert, 1993; Berg, 1993; Kullinger and Strömberg, 1993). The first generation of ecological villages started to grow up in Sweden during the 1970's. They were located to sites with favourable soil and moisture conditions for building and construction purposes, as well as with beneficial micro climate. Those villages focused more on internal social and ecological patterns; environmentally accepted materials, low energy demand by sharing common space and structures, etc. The second generation ecological villages, now being planned for, aims at finding local supply for primarily food, but also for energy and water (Günther, 1993). A major scope is to minimise the need for transportation. A futuristic concept is to put a pattern of communicating ecological villages in the landscape. A pattern of villages composing a rural centre (or diffuse urban centre), also being able to support social services, job places etc. A third generation of ecological villages will hence aim at functioning in a holistic, beneficial mutualism with the surrounding rural and natural environment.

## **Objective**

The objective of this project is to use decision support embedded in a geographical information system (GIS) and to evaluate the pros and cons with ecological villages from an optional perspective. In the compulsory part multi criteria evaluation (MCE) will be used to localise 5 to 6 sites for ecological villages in the area Stockholm SV. The robustness of the decision rule shall be evaluated. After having completed the compulsory part you should understand the ideas of ecological villages, and how to find sites for environmentally adopted living, minimising environmental impact. You shall also have acquired knowledge about techniques for multi criteria evaluation, and improved your skills in using GIS.

Optional subjects to study include the GIS-alternatives of a) penetrating MCE techniques and decision rules and compare and evaluate the different outcomes, and b) construct a GIS model for localisation of a diffuse urban centre. Alternatively you can also choose to study ecological villages (or diffuse urban centres) from a societal, economical and/or historical perspective by a literature and/or interview approach.

## **Decision support systems and GIS**

A decision is a choice between alternatives. For natural resources decision, GIS can be a powerful tool base for evaluation of choice alternatives based on spatially related criteria (Carver, 1991; Bishop and Hull, 1991; Gumbrecht et al., 1996b<sup>3</sup>). A variety of analytical techniques have been developed to help decision makers solve location problems with multiple criteria. Embedded in a GIS such a tool is the base of a Spatial Decision Support Systems (SDSS). However, GIS software development have been fuelled by inventory need rather than decision support need. The technology is also seen as complex, inaccessible and alienating to decision makers. Thus still only few SDSS are operational in GIS-environments (cf. Openshaw, 1991; Worrall, 1991). IDRISI, however, has recently incorporated multi criteria evaluation (MCE) and multi objective land evaluation in a decision support module (Eastman et al., 1993).

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<sup>3</sup> Can be found under G:\KURSER\AOM\1B1636\NRM\ARTICLES\Ecoeng.doc

MCE techniques emerged during the early 1970's from a critique of traditional neoclassical environmental economics (cf. Carver, 1991). MCE (and other multidimensional decision and evaluation models) provide tools for analysing the complex trade-offs between choice alternatives with different environmental and socio-economic impacts. The integration of MCE techniques with GIS provides the user with means for evaluating various alternatives on the basis of multiple and conflicting criteria and objectives. The procedure by which criteria are combined is a decision rule, rules structured in the context of a specific objective. The outcome of applying decision rules (i.e. evaluation of the decision rules) in GIS is either a Boolean map (showing included (1) or excluded (0) areas) or an index map (i.e. suitability map). Finding the best solution can either be done mathematically by searching maximum or minimum values (choice function), or by ranking an index map (choice heuristics). The latter process is rather an iterating participatory procedure to follow than a function to be evaluated.

Criteria can be of two types: constraints and factors. Constraints are Boolean, and serve to exclude or open certain areas for considerations. Factors are continuous (scores of 0 to 255 in the MCE module in IDRISI) and serve to enhance or diminish the suitability of the land for a particular application depending on the magnitude of the variable in question. In other nomenclature factors are equivalent to decision variables or structural variables.

Both rules and objectives can be single or multiple. The simplest case being a single rule and a single objective. When multiple criteria are to be evaluated (as in our project) we have a multi criteria evaluation (MCE). The most common decision procedures for MCE are weighted linear combinations and concordance-discordance analysis (cf. Carver, 1991). We will use a modification of the former, where each pair of non-Boolean criteria (i.e. factors) will be compared in a pre-set ratio scale from 1/9 to 9/1 (Eastman et al., 1993). This simplified process is known as Analytical Hierarchy Process (AHP). For computational reasons the sum of pairs must add to 1. Weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between factors (done by *weight* in IDRISI). Normally the participants must iteratively change pairwise weights in order to reach consistency for the eigenvector. Suitability is then evaluated by combining the criteria in the form of a weighted linear combination:

$$S = \sum w_i x_i \quad \text{where} \quad \begin{array}{l} S = \text{Suitability} \\ w_i = \text{Weight of factor} \\ x_i = \text{Criterion score of factor } i \text{ (0-255)} \\ \sum w_i = 1 \end{array}$$

The evaluation is completed by multiplying the resulting suitability map with the (Boolean 0/1) constraints. The outcome of the decision can sometimes be another set of criteria describing the screened areas. In our case not only the score is of interest, but also size of contiguous areas and mean and variance of the score within those areas large enough to host an ecological village. The final decision on which areas to choose must hence be based on this new set of multi-criteria. The decision rule for this choice can be created within or outside the computer. Whichever you do, you must include this rule in your results.

For many applications of spatial complex problems, the decision should be divided into two steps. A primary step of site evaluation and a secondary step penetrating conflicting interests arising from the exploitation of the selected site(s) from the first step (cf. Carver, 1991). The

latter step could be in the form of an environmental impact assessment (EIA). In this project we will only conduct the primary step.

### Decision under uncertainty

Clearly, information is vital to the process of decision making. However, we recognise that we rarely have perfect information. This leads to uncertainty, of which three sources can be identified (fig.1).

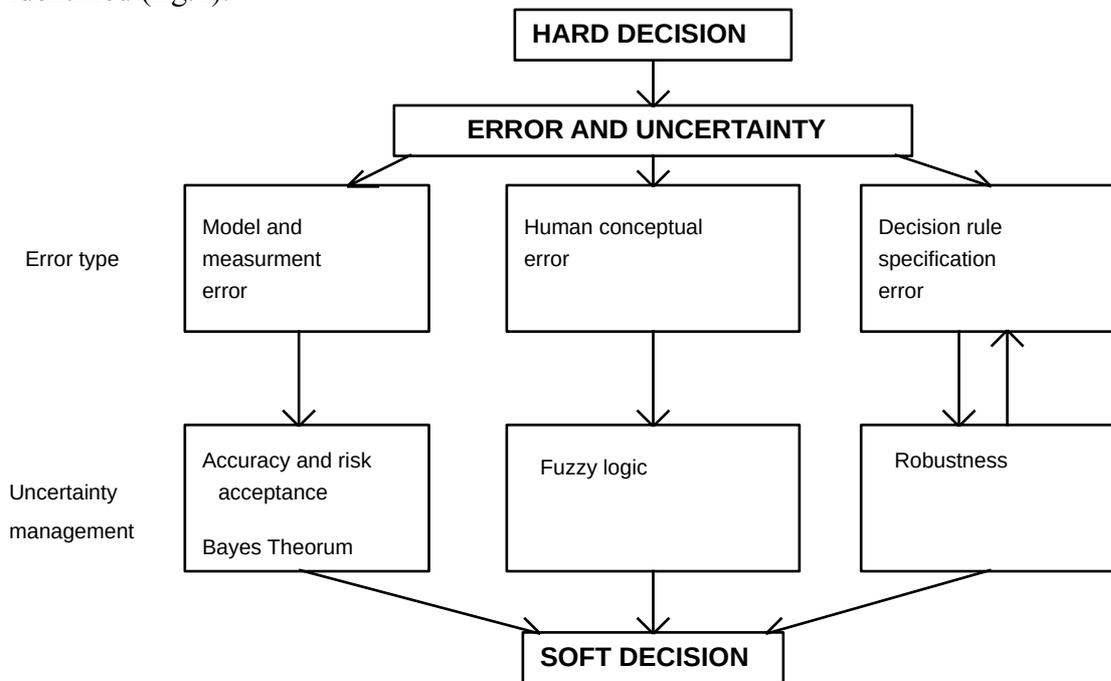


Figure 1. Uncertainty and risk in decision making; different types of errors, and management of uncertainty.

*Measurement uncertainty* is that which resides in the data. This error is often assumed to be random with a normal distribution. It can thus be handled by identifying levels of risk based on standard deviations, and accepting a certain risk in the decision. If some a priori knowledge is available, uncertainty can be decreased by applying Bayes' Theorem (fig. 1). *Human conceptual uncertainty* stems from difficulties in setting precise (numerical) thresholds. For instance, if we identify steep as more than 20 degrees, does that make 19.99 non-steep and 20.01 steep? The same principle could be applied for for instance radon-gas risk. This type of uncertainty can be resolved by applying fuzzy logic. Finally we have *decision rule specification uncertainty*. A decision rule might be biased towards some single factor, which was not intended by the decision maker. To resolve this the robustness of the decision rule should be evaluated by an iterating procedure. In our MCE of sites for ecological villages we will only be concerned with the latter uncertainty. However, if you are interested in the other types you can have a look at the acidification project.

Incorporating risk and uncertainty in the decision making is sometimes referred to as going from a hard to a soft decision (fig. 1).

## Criteria for ecological villages

When finding spots for ecological villages in the Stockholm SV area, the following criteria could be considered:

### Jurisdictions

Beach protection law. In Sweden it is in general not allowed to construct residential areas closer to a lake or sea shore than 150 meter.

### Nature

There is both a positive and a negative side of constructing residential areas in, or close to, nature reserves, wildlife areas etc. A certain closeness is of interest due to availability for recreational purposes, but the recreational value arises from the fact that there is no human settlements in the area.

### Energy

Constructing houses in southern slopes means a favourable micro climate for energy conservation. Wind energy production is facilitated by using hills. Heat pumps can be used on any ground, even water. Closeness to renewable energy sources like forest products or farm products (energy forestry, vegetable oils) could also be important.

### Food

Food supply should be locally arranged, close proximity to agricultural areas is thus important.

### Water

Local water supply is dependent on an aquifer (sandy or gravelly soils, eskers etc.), or a stream or lake with continuous supply of water with good quality (unlikely in the area). Close proximity to aquifer hence is important. If supply is to be taken from the city, close proximity to water pipes (other built up areas) will be important instead.

### Waste and sewage

Waste products should be recycled when possible. This means that organic substances should be returned to soil, and close proximity to agricultural land is hence important (again). Sewage water that can not be recycled should be treated by ecologically adopted methods, for instance wetland treatment. Close proximity to wetlands is thus important (and, of course, areas that are already exploited).

### Service and job places

The need for services (medical, technical, school, social etc.) and job places calls for at least some smaller city. Close proximity to services centres is thus important, also for reducing (energy) costs of transportation. Alternatively a cluster of ecological villages could be put together forming a diffuse urban centre.

### Technical accessibility

Some areas are obviously not suited for construction of residential areas, including water areas and wetlands, productive farm land, areas with clayey soils and steep slopes.

### Radon-gas risk

Coarse soil composed of granitic material has a high risk of containing radon, producing radon gas. Such areas are hence not favourable for ecological villages. Apart from the listed criteria, also a certain size is required for an ecological village encompassing 50-100 households. (Note that there are many criteria that we do not include, but nevertheless are very important: land ownership, planning status, archaeological sites etc. We simply do not have this data available in digital format.)

### **Compulsory task**

Your compulsory task is to find sites for ecological villages in the Stockholm SV area using MCE. The result should consist of a suitability map, and a map where you suggest 5 to 6 villages, each able to support 50 - 100 families. You can find detailed help for how to go ahead in the compulsory part in appendix 1. It is strongly recommended to complete the compulsory task before starting an optional.

### **Optional subtasks**

An optional subtask is requested to receive a higher grade. Options include both GIS and non-GIS applications:

- Compare and evaluate the outcome of different MCE techniques and decision rules. Alternative techniques can be found with the help of the references given.
- Use GIS to construct and evaluate a MCE decision method for localising a diffuse urban centre. The decision must consider communication, and possible synergy effects of sharing resources, closing energy and matter cycles.
- Historically ideas of green living in well planned villages have occurred from, at least, the time of Thomas Moore's Utopia. Social and economic relations in ecological villages or their forerunners have also been studied. An optional subtask is to review literature studies of ecological villages from any perspective, also futuristic or in other sense connected to the above (see Gumbrecht, 1996<sup>4</sup>).
- Make a literature study of energy demands and economical feasibility for ecological villages, and compare the ideas and results of the project with demands for sustainability, *inter alia* as discussed in the Brundtland commission (WCED, 1987) or Agenda21 (cf. Merret, 1995).

The project must be reported in an article. Your subtask should be presented as an interwoven part in the paper. Use times roman, size 12, with double spacing and margins on all sides of 2.5 cm. It should contain the following:

Title	
Abstract	
Key words	
Introduction	Why did you start?
Material and methods	How did you do it?
Results	What answer did you get?
Discussion	What does it mean?
References	Written as in this instruction!

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<sup>4</sup> Can be found under G:\KURSER\AOM\1B1636\NRM\ARTICLES\utopia.doc

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## Appendix 1

### Some help in front of the computer

Start the project by login, go to G:\KURSER\AOM\1B1636 and write *eco\_p* to start a batch program that will create a directory (H:\ecovilla) with the necessary files. Note that if you repeat this command later you can loose all your information you have created. Write *connect* to open the path to IDRISI.

Begin by deciding what factors and constraints to take into account in your MCE.

As we are interested in finding 5 to 6 areas, each being able to house 50-100 families, we look for areas of say 1/4 to 1/2 km<sup>2</sup> in size. A problem that can arise in the evaluation is that many small areas in the input images will render a highly fragmented suitability map. To avoid this you must exclude small areas giving rise to this scattered pattern. This is more important concerning factors than constraints.

We suggest the following procedure to remove the problem of small areas. When creating criteria you must start with a *reclass* (see below), identifying the criteria in a Boolean image. Before continuing the spatial analysis, this Boolean image should be manipulated in order to skip areas too small to be significant in the following MCE. Thus use *group* to find and define isolated areas in your Boolean criteria images. Then use *area* with output as an attributes values file (with unit of hectare). Run *assign* using the group file and the attribute values file that you just created. Output will be in hectares. Now *reclass* the created file, excluding areas smaller than a certain threshold. Relevant minimum sizes for the factors could be:

Agricultural areas	20 ha
Aquifers	5 ha
Wetlands	5 ha
Service and job centres	10 ha

Note that a batchfile MINSIZE.BAT is available under the course directory that contains command line syntax for the minimisation of aquifers and agricultural areas. The remaining images you do by following the same routine.

Start with creating images for constraints. Examples of three constraints are available in CONST.BAT. For the constraints all that is required is the development of a Boolean image - an image containing only zeros (excluded areas) and ones (permitted areas). In the simplest cases this is done by *reclass*. For instance to create the constraint excluding wetlands, just *reclass* <geology> or <landuse> into ones, except where wetlands occur, in which case you classify into zero. Note that using *assign* (*idrsign* if in commandline mode) instead of *reclass*, might save time and effort. The most complex constraint map is probably energy constraint due to aspect (energy micro climate). We suggest that you exclude all areas facing north west to north east, or even west to east (over north). To create this constraint you have to first run *surface* and *aspect* on the <dtm> file, and then *reclass* the resulting map. When creating the constraint for the beach protection law, you have to start with finding an image with all lakes and sea shores, then run *distance*, and then reclass into a Boolean constraint image. As beaches of streams and ponds are not included in the law, you must use the procedure suggested above for removing small areas. This must be done before doing the proximity analysis. Identifying areas with risk for radon-gas must be done via *overlay* analysis combining information on soil <geology> and bedrock <bedrock>.

Factor maps are a bit more complicated to create. Examples of three factors are available in FACTOR.BAT. They should all have scores between 0 and 255 (where a high value is favourable). The range can be linear or non-linear, according to the relative importance decided by the user (decision maker). All the suggested factor maps should get scores according to proximity to different desired resources (nature, aquifer, wetland, farm land and service centre). Hence for all you must *reclass* input maps for those categories, and then run *distance* followed by linear *stretch* (to get the interval 0-255). If you want to change from linear to non-linear relationship you have to do this by using *scalar* or *transfor*. Note that before doing the proximity analysis you must remove areas too small to be considered (see above).

An example (following FACTOR.BAT): to create the factor map for proximity to wetlands *reclass* <geology> or <landuse>, giving ones to wetland areas and zeros everywhere else. Use *group*, *area*, *assign* and *reclass* (as described above) to remove wetlands less than 5 ha in size. Then run *distance* from this reclassified image. Check the maximum value (using *document* or *describe*), then use *stretch* to change the interval to 0 - 255. The stretched image will have low values for close proximity, and should hence be inverted (since close vicinity is favourable and should have a high score). To do this create a file with *initial* defining a byte image with an initial value of 255. Use *overlay* to subtract your stretched image from this file. Use *color* to examine your result. Go through the same procedure to create the other factor maps. Make use of *maint* to erase files now and then.

Note that your directory there are images on nature reserves (<nature>), greenbelts (<greenb>) and recreational areas (<recreat>) that also can be used for deriving criteria maps.

After having completed, and checked all your criteria maps, you need to develop a set of weights for your factor maps. The weights should be real numbers that sum to 1.0. You will do this by determining relative importance of pairwise factors, which is a good way to create a vehicle for a participatory approach. The relative importance should be given values from 1/9 to 9/1. The best thing to do is to create a matrix (Fig 1:1).

	wetland	aquifer	centre	farmland
wetland	1			
aquifer	3/1	1		
centre	7/1	2/1	1	
farmland	1/5	1/4	6/1	1

Fig 1:1 Example of matrix for relative importance of pairwise factors.

After having discussed the relative importance, use *edit* to create a pairwise comparison file (option 6). Using the data from Fig 1:1 the file should look like this:

```
4
wetland
aquifer
centre
farmland
1
3 1
7 2 1
1/5 1/4 6 1
```

The first line indicate number of factors, the rest is fairly obvious. Once the file is created, run *weight*. You will be presented with best fit weights and a judgement of the consistency of the weights. Repeat the pairwise weighing iteratively until you get a consistent set of weights. Note those weights.

Now it is time to run the multi criteria evaluation (*mce*) module. Use *color* to have a look at your result. If the areas indicated are too small and scattered, you must try to restate your criteria. Repeat the *mce* and check if your image is less scattered. Repeat the MCE until you have a satisfying result.

To select the best areas for ecological villages you must find a suitable measure of the scores of each identified area. You must also find areas that are large enough to hold 50-100 households. Use *group* to identify your contiguous areas. Then use *area* to determine the size and *extract* to find out mean and variance of the score for each of the areas.

Evaluate the robustness of your decision rule by slightly altering the weights assigned to the factors. Re-evaluate the decision by repeating the *mce* procedure iteratively. Compare the result of your decision rules by using *crosstab*. At least one iteration is required (and should be included in the report).

Finally select the five to six most suitable areas. The selection is a choice between alternatives, and you must decide how to combine the criteria: size, average score or stability in score. You must hence again apply some sort of decision rule. You can do this in IDRISI, or in a non-digital manner. However, you must include your decision rule in the report.

Prepare a final image where your villages are shown relative to the surrounding environment (e.g. an image containing infrastructure, water and agriculture).

Choose an optional task.