Multifunctional theory in agricultural land use planning — case study

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Introduction

By the end of 20th century demands and expectations on land use have changed. Nowadays ecological aspects, economic activities and the society itself are forming the land use structure. But these factors do not segregate in space and time, together characterise the spatial structure.
This is even more true in case of agricultural land use. The expectations on agricultural land use are not only the production, but new socio-ecological functions are being formulated by industrialised societies for the rural areas.
My opinion is that only the acceptance of multi-functional theory in land use leads to implementation of sustainable spatial use. Therefore, in my research I have examined:

- Possible functions of agricultural (arable) lands,
- Suitability of actual and potential land use for a certain land use function,
- Possible conflict between potential utilisation of a certain piece of land (evaluation unit).

In my definition the sustainable (balanced) land use means **utilisation of most suitable land use function** in a certain space of the Earth in given environmental (biotic and abiotic) circumstances. The question is what functions can be determined for a certain land use. Agricultural utilisation of lands is the good example for multi-purpose spatial use, because (1) it has a traditional function (2) stipulates the characteristics of rural areas (landscape), environment (pollution) and society (3) and specifies the interaction between rural and urban regions.
Having considered these three roles of agricultural lands I have defined the following functions:

- Food production for human consumption and fodder (**production function**),
- Protection of nature and environment (**protection function**),
- Satisfy social and human demands (**welfare function**).

Materials and methods

Based on the above-mentioned ideas a planning model was established which (1) integrated the theory of multi-functional land use, (2) applied a trade-off algorithm (compromise programming) and (3) was embedded in GIS environment. This model was used and tested for a wetland area near Tisza River, Hungary (see later).

Multi-functional use of lands

According to the three main functions mentioned above three land utilisation types ($LUT_{1\text{-}3}$) were defined considering the potentials of the study area:

LUT_1 winter wheat production, dry farming, intensive technology, good machinery, average yield

LUT_2 flood protection and (nature and environment) conservation, extensive agricultural activity

LUT_3 expansion of settlements, mainly recreation, protection of water courses, reservoir and floodplain

During the land evaluation a relatively great number (22) of land characteristics (LCs) were adverted. From these attributes according to their importance on the certain land use function a weight matrix was formulated (Table 1). Of course the values of LCs were scored and classified according to their effect on land use function as well. Finally 31 evaluation sheets were prepared. One is presented in Table 2. Weighting of land characteristics and their values based on consultation of experts and literary sources.

GIS technology in analysis

One of the concept of the research was to geographically appoint and figure the suitability and conflict zones. Therefore, the trade-off algorithm was embedded in the grid module, Spatial Analyst of ArcView 3.1. It was inevitable that raster (grid) model should be applied instead of vector one. The only question was if the 0.25 hectare (50 m) resolution, about 70000 pixels and maximum 12 layers in map calculation could be handled by this desktop software on an average PC.

Preparation of GIS analysis consisted of three steps:

- Digitising the paper maps,
- Building-up layers from these maps,
- Classification of layers according to evaluation sheets and standardising the data into [0,1] interval.

The reasons for standardising the values were: (1) To ensure that all natural scales some of which may include nominal or ordinal data, were converted to a common value scale with interval properties, required for the legitimate application of a distance metric evaluation. (2) To account for possibly non-linear or even non-monotonic character of the relationship between natural and value scales. (3) Such a transformation simplifies computation of the various distance metrics.

The resolution of analysis was 50 by 50 meters, which built up a 359-row and 194-column grid matrix.

Compromise programming

Compromise programming identifies the alternatives that are closest to the ideal point as determined by some measure of distance. In the analysis the set of initial functions (x) — set of cells in a given GIS database — were evaluated. Each function was characterised by n attributes (LCs), corresponding to the map layers. The cells can be written as x_i^k that designated the score of an attribute (map layer) i attained by k^{th} cell, where $i = 1, \ldots, n$; $k = 1,\ldots,K$.

So x^k was a vector K numbers, assigned to each alternative/cell and synthesising all available information about that alternative, thus it having defined as “multiple criteria alternative”. Considering the i^{th} individual evaluation criterion (map layer), the set of x was produced a vector with K numbers.

$$x_i = x_i^1, \ldots, x_i^K$$

This vector was represented the all levels of the i^{th} attribute (e.g. all soil type contained in a map layer of that theme). From among these values, there was at least one ideal value which was preferred to all others (e.g. chernozem-typed soils). The concept of CP generalised to the multiple criteria alternatives as the set of individual levels:

$$x^* = (x_{1,}^* \ldots, x_i^*)$$

The vector x^* represented the ideal point — a usually unfeasible state — was characterised by the best attainable score on every criterion.

Having used CP, all available alternatives were rated based on their multidimensional distance of the ideal point, according to a few distinct distance metrics. Generalised family of distance metrics depended on the exponent p:

$$d_p = \left[\sum_{j=1}^{n} \lambda_i^p \left| x_i^* - x_i^k \right|^p \right]^{1/p}, \lambda_i > 0 \text{ and } \sum \lambda_i = 1$$

Here λ_i weighted the criterion (LCs for LUTs) and p ranged $[1,\infty]$.

The p affected the relative contribution of individual deviation from the ideal solution (point), a greater emphasis had being given to larger deviation, as p increased.

When p=1 total compensation was assumed, a decrease of value of one LC could be compensated by an equivalent gain on any other LC (criterion).

In case of p=2 (the shortest distance) there was only partial compensation.

While $p \geq 10$ the largest deviation $\left| x_i^* - x_i^k \right|$ dominated the evaluation. In such case the suitability of a cell for a given function was only as high as its lowest score on all LCs.

Results and Discussion

The results will be presented through a case study done for a reservoir area of Tisza River. The studied area has been basically protected against flood, although the effects of high water are directly manifested far from the dikes. The present land use structure of the region figured in Table 3.

Land use	***ha***	***%***
arable land	7871.462	37.72
pasture	2571.08	12.32
forest	239.78	1.15
other	10185.63	49.96
all	20867.95	100.0
municipal area	687.91	3.30

Table 1 Land use structure of the study area

The three alternative land utilisation functions were studied just on arable lands. However, due to lack of geographical data 6547 hectares was evaluated the 7871 instead.

For the three land use function 9 suitability maps were drawn according to p level. As I endeavoured to achieve the most optimal land use solution p=2 level, a partial compensation was accepted. The calculation showed, that:

1. 38.5% of arable lands were suitable for cropping, while on 57.09 % of land production was not sustainable for physical reasons (Map1).
2. The protection function had high impact on those lands that belonged to ecological network elements or situated close to the river (17.25%). Relatively high percentage of

arable lands meant that here direct protection was not needed (33.8%). This is shown on Map 2.

3. Welfare function showed an explicit situation, as for all *p* value the ratio was the same. 1.39% of arable lands had high welfare role — especially around the villages —, while the rest had not any (Map 3).

The conflict analysis proved that imbalances in land use could be managed yet. Only low percentage (~1%) of lands indicated real conflict, although in some areas (mostly nature reserve) it just being evolved. Here the agricultural activity (cropping) should be altered so to primarily satisfy the protection aims (Map 4).

Conclusion

It can be concluded that geo-information concept — through GIS software, ArcView 3.1 — enables to evaluate and statistically analyse different land use (utilisation) functions accepting multi-funtionality theory in spatial use.
And through making alternative suitability scenarios and appointing conflicting zones a better and more balanced spatial planning can be attained.

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Annex

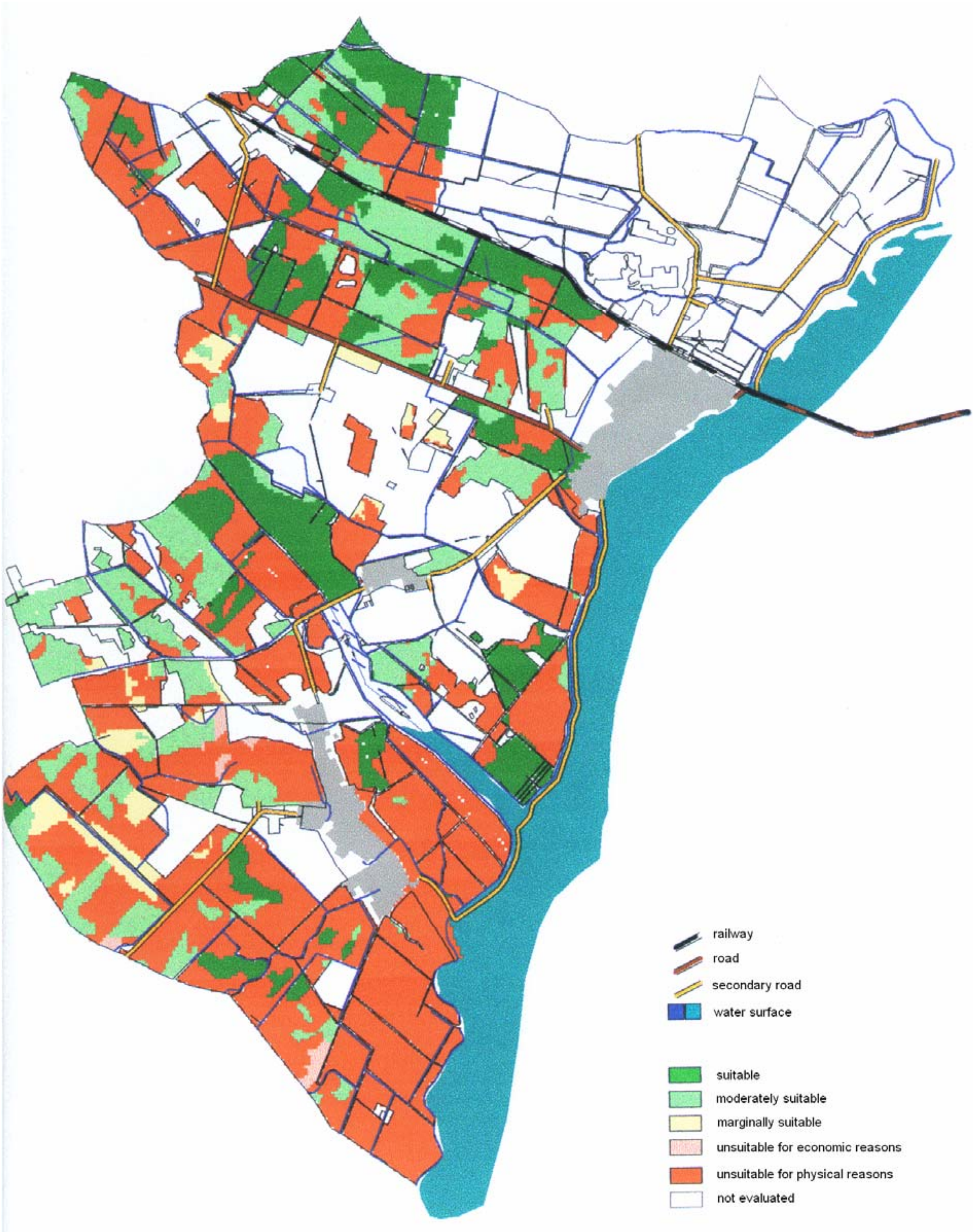
Land characteristics	**Land utilisation types**		
	LUT_1	LUT_2	LUT_3
value of land	*0,13*		*0,11*
soil type and subtype	*0,08*		
soil texture	*0,08*	*0,10*	
pH value of soil	*0,04*	*0,06*	
mould content	*0,04*	*0,04*	
thickness of topsoil	*0,04*		
available water from soil	*0,11*		
water capacity of soil	*0,08*		
depth of groundwater	*0,13*	*0,07*	*0,14*
water management of soils	*0,11*	*0,10*	
land use concept of municipalities	*0,08*		*0,11*
ESA zones	*0,08*		
bird habitats of international importance		*0,07*	
ecological corridor, network		*0,11*	
nature preserve		*0,11*	
buffer of dike		*0,04*	*0,11*
contamination sensitive area		*0,15*	
protected surface water		*0,15*	
holiday zone			*0,16*
potential holiday area			*0,14*
expansion of residential			*0,14*
agricultural land with recreation potential			*0,11*

Table 2 Weight matrix for land use functions

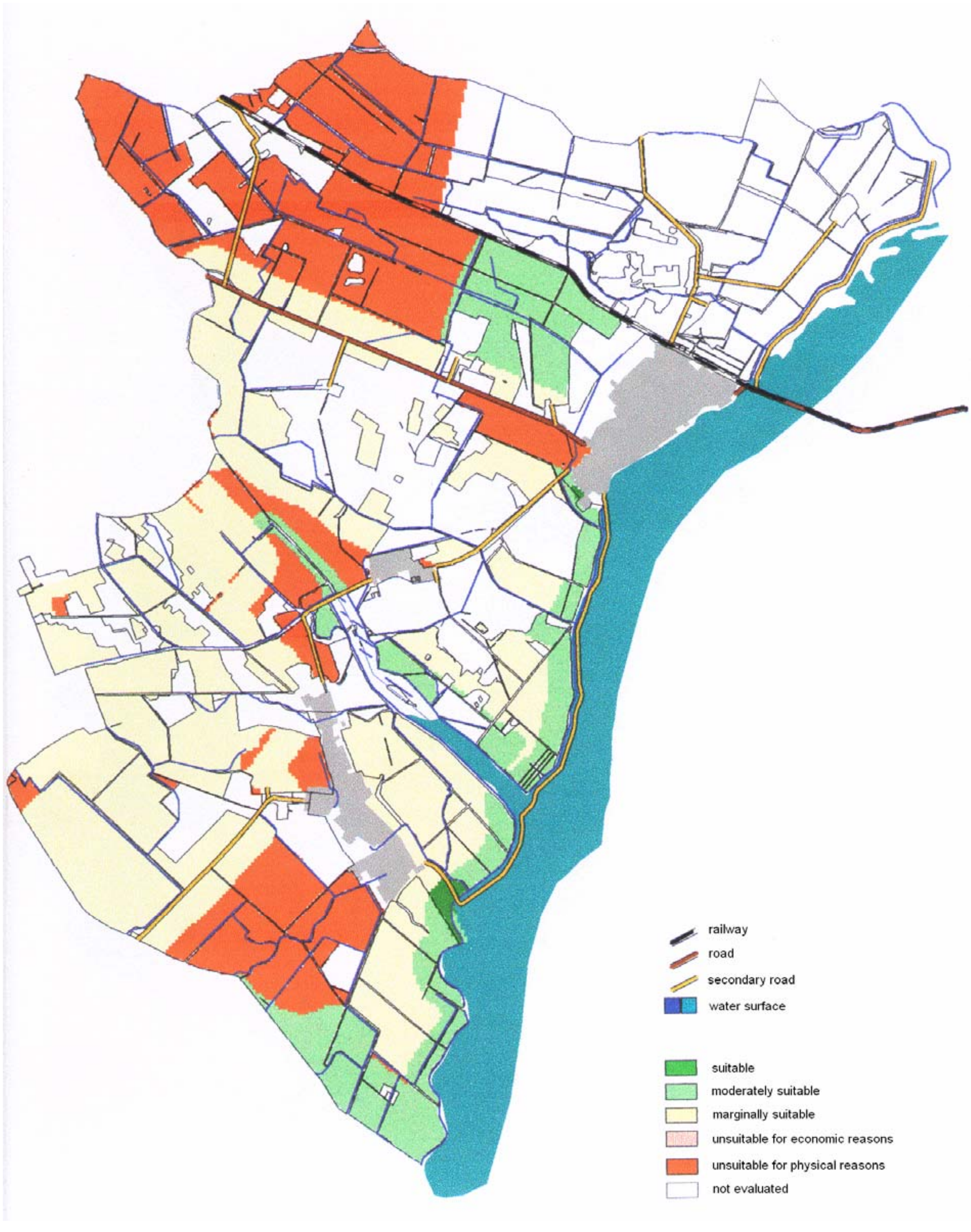
pH value of soil weight for LUT$_1$: 0.04		
Designation/value	***Score****	***Note***
< 4.5 pH	0	
4.5-5.5	1	
5.5-6.8	2	
6.8-7.2	3	
7.2-8.5	2	
8.5-9.0	1	
> 9.0	0	

*The higher the score the more suitable for the given LUT

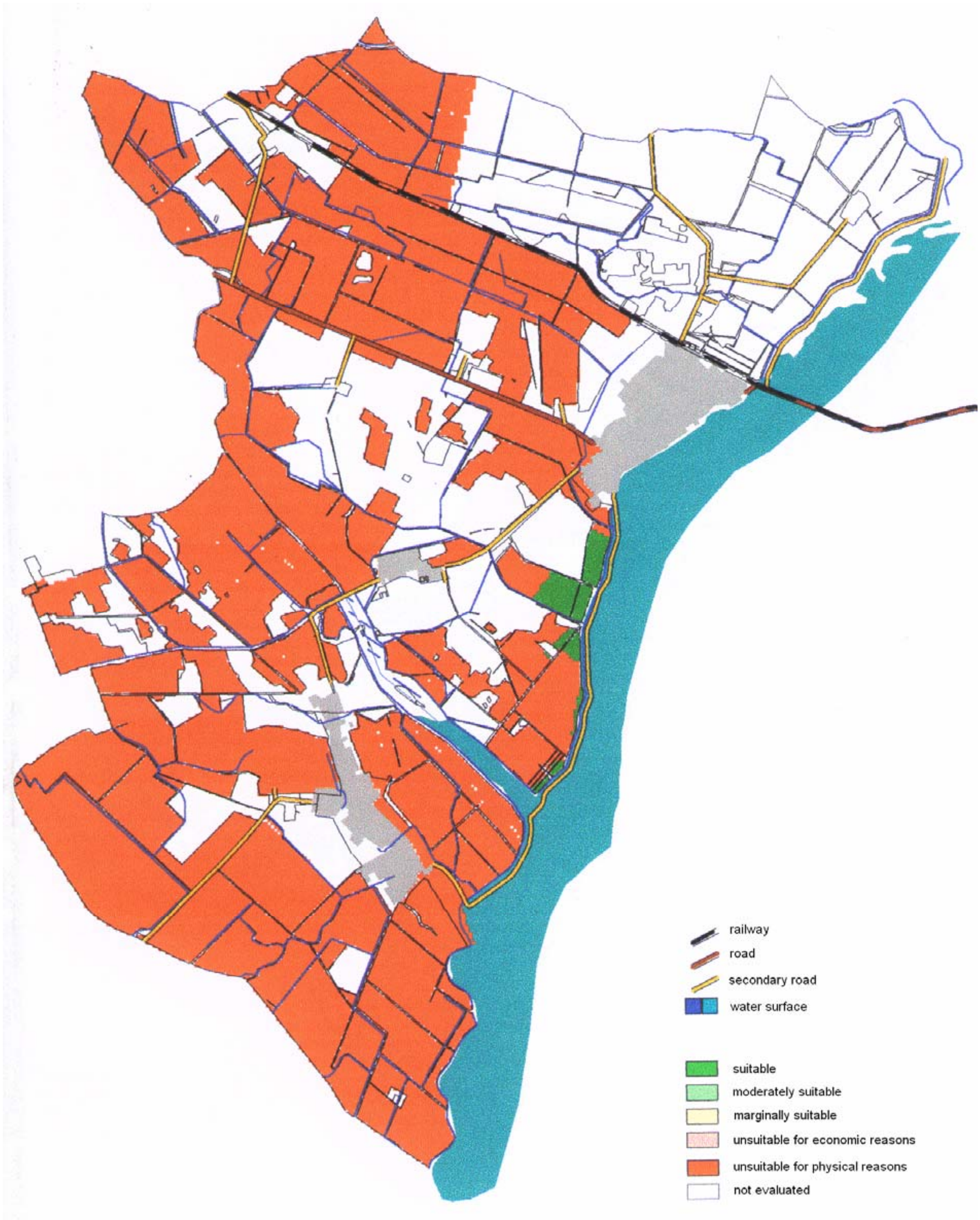
Table 3 Land characteristic evaluation sheet for pH value of soil



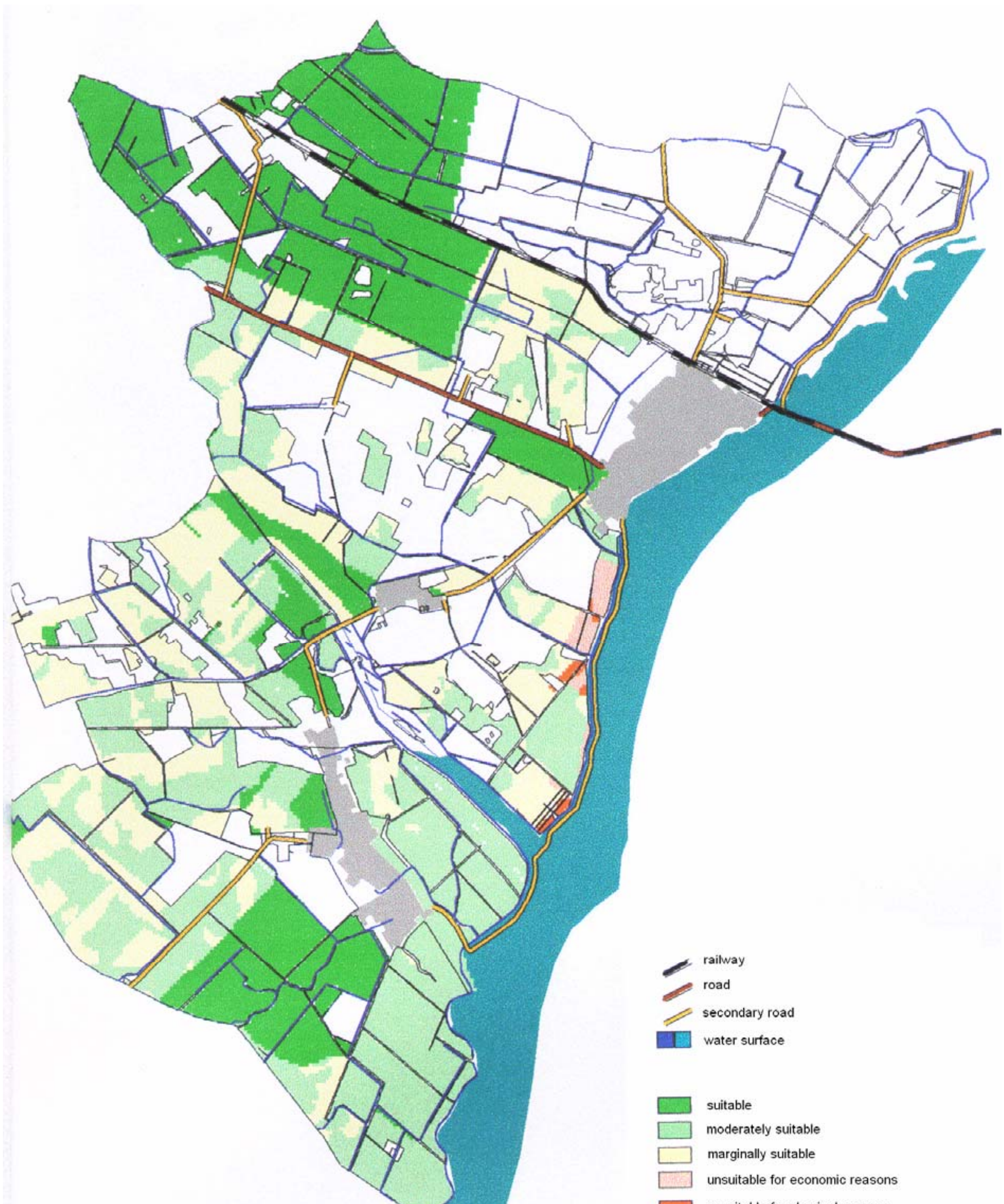
Map 1 Suitability map for production function (p=2)



Map 2 Suitability map for "protection" function (p=2)



Map 3 Suitability map for "welfare" function (p=2)



Map 4 Conflict map for the three functions (p=2)