THE VISUALISATION OF GIS GENERATED INFORMATION QUALITY

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PURPOSE:

Many centuries of tradition and research have contributed to the design of paper maps, and some decades of effort have gone into the design of the screen displays used in GIS. Recently consideration has been given to the error propagated in a GIS as it generates new information but there are no standardised designs for displaying the quality of that information. This paper examines some possible means of displaying information quality, and describes such means now implemented in ILWIS, a PC based GIS. Examples are based on a Land Reallocation project where, in particular, topographic and soils data sets were processed to provide both information needed for reallocation and the quality of that reallocation information.

KEY WORDS: GIS, Data Quality, Information Quality, Cartographic Design Priciples, Graphic Display, Error Propagation in the GIS environment.

1. INTRODUCTION

Although photogrammetrists and other geodesists have long been concerned with the quality of the spatial information gathered by their systems, only recently has data quality within GIS become a "hot topic" - as evidenced in the 1989 publication of Goodchild and Gopal's "Accuracy of Spatial Databases", NCGIA (the United States National Centre for Geographic Information and Analysis) support for comprehensive reviews of data quality [VEREGIN, 1989] and initial attempts to formalize its visualisation [CLAPMAN and BEARD,1991], and numerous degree theses. This recent GIS-centred activity seems to have been started by Chrisman [CHRISMAN, 1982] and Blakemore [BLAKEMORE, 1984] in the early 1980's, with their popularisation of Perkal's "epsilon band" concept. However concerns over the quality of digital land-use data when derived from satellite remote sensing sources generated approaches in the 1970's (e.g. [HORD and BROONER, 1976] and [VAN GENDEREN and LOCK, 1977]), which now (in the 1990's, as raster based display media become the 'norm') are increasingly applied (e.g. [BURROUGH and HEUVELINK, 1992]). A result of recent NCGIA and US National Committee for Digital Cartographic Data Standards activities [NCDCDS, 1988] is the current acceptance of a five part division of the problems of geographic (spatial) data and information quality into: spatial quality; attribute quality; completeness; logical consistency; and lineage. Although other subdivisions (e.g. [RADWAN, SUHARTO and SUTRISNO YONO, 1991]) may be more manageable, in the investigation reported here the well publicised fivefold classification will be used.

One standard 'pre-GIS' technique for the display of data quality and popular with land-surveyors has been to use 'error ellipses' (e.g. [RICHARDUS, 1974]) whereas amongst photogrammetrists discrepancy vectors have been used (e.g. [ASPRS, 1980]), but, despite the popularisation of GIS and the recent interest in GIS data and information quality, no other standard techniques for displaying the quality of that data and information have been widely applied. Error ellipses and discrepancy vectors are probably only suitable for displaying the quality of the spatial information of a very few points at a time, and for some aspects of that information only. Based on established cartographic theory, this paper examines some possible means of displaying GIS generated information quality at different measurement levels, and describes such means now being implemented in ILWIS, a PC based GIS. Examples are based on a Dutch Land Reallocation project where, in particular, topographic and soils data sets were processed to provide both information needed for reallocation and the quality of that reallocation information.

The investigation reported on here will contribute to the eventual completion of a GIS tool handling information quality which will be termed the "Uncertainty Subsystem" of ILWIS. It is hoped it will process quality information in parallel with the information generated for the users' applications, and provide the resulting quality information at the user's request.

This paper will first examine present cartographic applications of graphic semiology, which should identify the most appropriate methods for displaying quality information. Then, after a brief description of ILWIS, an investigation of mainly the cartographic aspects of the (still) prototype "Uncertainty Subsystem" within ILWIS using a land reallocation case study will be described. (Note: further details of the theoretical basis of the "Uncertainty Subsystem" are provided in an ISPRS Congress XXVII Commission III presentation "A GIS Uncertainty Subsystem" [RAMLAL & DRUMMOND, 1992] also published in these Archives.)

2. THE CARTOGRAPHIC REPRESENTATION OF QUALITY INFORMATION

We accept that hardcopy or softcopy maps are the most efficient means for communicating geographic (or spatial) information, thus whenever quality information is also of a geographic nature, it should be communicated very effectively by cartographic means (i.e. maps). So, in a GIS, we can assume that maps will be much more suitable for conveying quality information to the users of a GIS's products than any other graphic, textual or numerical means. The latter will have to be used only if there are no regional (spatial) variations in quality or if these variations are or cannot be specified, as is often the case for information on completeness or logical consistency. If quality information on positional and attribute accuracy (and possibly on lineage) is available for individual mapping units and there is some regional variation in it, this information can be represented cartographically.

2.1 The design of cartographic symbols

In a GIS quality information can be stored, analysed, processed and presented just like any other attribute information related to point, line and area features. As far as the cartographic representation is concerned, the same symbol design principles apply as for other aspects of information. A systematic approach to symbol design, based on and an improvement of the early works of Bertin [BERTIN, 1981 and 1983], has been presented by Bos [BOS, 1984], see Figure 1. In such a systematic approach one of the first steps is to determine the measurement level of the information to be portrayed, and this will be either qualitative (nominal), ordered (ordinal) or quantitative (interval or ratio). The meaning of the information, established by determining the measurement level, should be represented by the so-called visual variable having the corresponding perception property (see Figure 2).

There are seven visual variables (position, form, orientation, colour, texture, value and size), see Figure 3, each with its own perception properties (see Figure 4). The perception property of a visual variable may be regarded as responsible for transferring a certain meaning or concept to map users' minds whilst they are perceiving the cartographic symbols which are differentiated by that particular visual variable.

In a map, the visual variable position is a special case in that it is always applied to the symbols occuring in the map. But also, usually, the visual variable position is combined with one or more of the other six visual variables to represent other aspects of information related to the point, line or area features being portrayed.

Several aspects of information can be represented at the same time in the same map by reserving at least one visual variable for each individual aspect. For example, in a map showing factories by point symbols, their numbers of employees can be represented by the visual variable size (differently sized point symbols) and the nature of manufacturing industries with the visual variable form (differently shaped symbols). Following this approach a visual variable used to represent differences in one aspect of information cannot, anymore, be used to represent differences in another aspect of information related to the same features (e.g. the visual variable size -which was used to represent the numbers of employees - cannot be used anymore to show the annual production figures in the same symbols representing the factories.)

2.2 The design of symbols to represent quality information

From the foregoing, quality information can thus be treated and cartographically represented in the same way as any other attribute information (also see CLAPHAM and BEARD, 1992). In this treatment first of all the measurement level of the information has to be established. Information on (regionally different) data sources (for example part of a data set's lineage information) could be considered to be of a qualitative nature and thus should be represented by means of a visual variable with an associative perception property, for instance form or orientation (see Figure 5). Attribute accuracy information, for instance a probability percentage, could be of an ordered nature, to be represented by means of a visual variable with an ordered perception property, such as (lightness) value (see Figure 6). A difference in currency of the data is also not regarded as quantitative information (but ordered instead) as it is not realistic to think of data being "twice as recent", etc. Absolute quantitative quality information (measured on a ratio scale) should be represented by means of a visual variable with a quantitative perception property, size being the only one. Considering for example, absolute positional discrepancies measured in meters in various directions and represented by error ellipses (see Figure 7), the generation of such hard- or softcopy cartographic displays of quality information is only possible if the GIS provides the required presentation software (modules). This could be in the form of a cartographic design expert shell to assist the non-cartographic GIS-user [MULLER & WANG ZESHEN, 1990]. Such a cartographic expert system may guide the user through the systematic symbol design approach referred to above.

2.3 Integrated or separate cartographic quality information displays?

In the examples given in Figures 5, 6 and 7, the quality is the only aspect of information portrayed by the symbols. Such analytical, mono-thematic map displays may be easily generated from a GIS. Usually, however, the GIS user wants to relate and compare the quality data to the other geographic information to which they belong. That is, it seems to be more useful if the map with the quality data appears as a separate window next to the map showing the related geographical information or to represent the quality data with a separate visual variable in the same map together with the geographic data to which they belong and which are represented by another visual variable. In this context, it is possible to think in terms of "quality overlays", which may be "switched on and off" (or "toggled") on-screen by the GIS-user at will. The ease of so doing is a great advantage of the computerised GIS environment compared to environments when only paper maps could be produced by means of slow manual drawing techniques.

However, in a GIS environment one should not think merely of physical overlays, or separate layers or levels of data, but of a genuine combination of visual variables in one set of symbols. If, for instance, in a soil map different soil classes are represented by means of the application of the visual variable colour (i.e. hue) to the mapping units, it would be appropriate to represent the related ordered reliability information by means of application of the visual variable value (i.e. lightness (in some software packages referred to

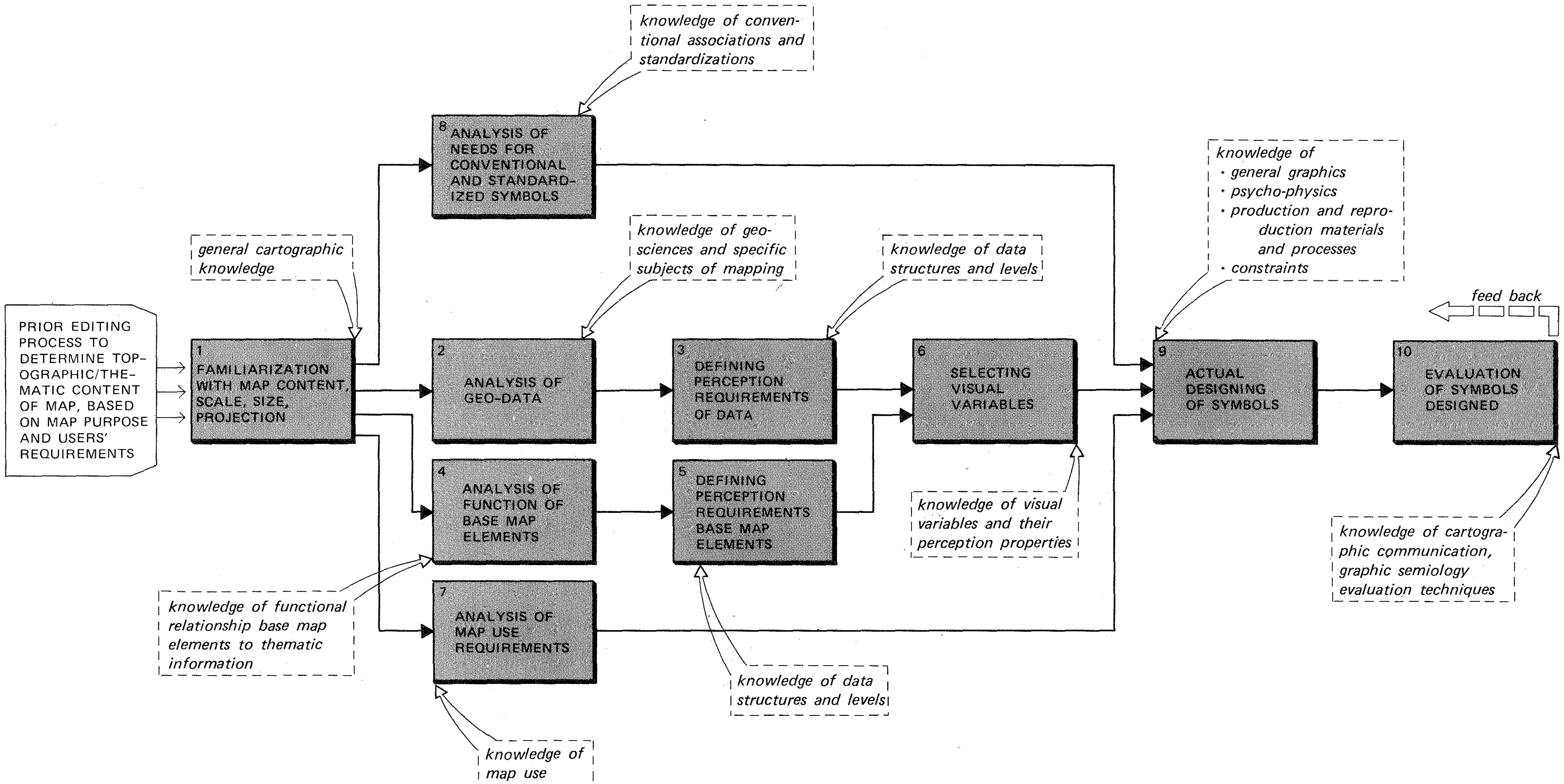


Figure 1 - A systematic approach to symbol design
(source: BOS, 1984, p.25)

as 'intensity' see [CLAPHAM and BEARD, 1991])) to the same area symbols. In this way the relative lightness or darkness of the colours portraying the soil classes varies with the reliability of the classification (e.g. dark green when a particular soil is most reliably classified as 'clay' and light green when a particular soil is less reliably classified as 'clay' - that is, the darker the tint, the more likely a correct classification). Such a variation of the lightness value of a hue, depending on the (ordered) reliability information it represents, can be introduced relatively easily in both a hard- and soft-copy environment (the only technical problem being the relationship between the colour tints as they appear on the screen and as they are printed on paper). Ordered reliability information can better not be shown by overprinting with black dot patterns of varying density. The differences in value thus created are not wrong in principle, but the black dots may make the colour underneath less recognizable.

On the other hand, the combination of visual variables in the same set of symbols may sometimes lead to unwanted effects on the perception properties. Besides, overprinted (open) black dot or line patterns of varying density will be needed if the visual variable value has already been used to represent another aspect of information, for instance in a suitability map (the darker the colour, the more suitable). It goes without saying that there are also limits to the maximum number

INFORMATION	represented by a visual variable with	PERCEPTUAL PROPERTY
Quantitative	----------------->	Quantitative
Ordered	----------------->	Ordered
Qualitative	----------------->	Associative (c. Selective)

Figure 2 - Essence of the grammar of cartography

of aspects of information which can be represented in the same set of symbols or in the same map. Often, some kind of grouping (classification) of the information (e.g. on lineage) is needed before representation in a single map is possible.

2.4 Other cartographic ways of dealing with quality information and accuracy

Next to its representation by means of visual variables as applied to symbols, there are also other ways in which quality information can be reflected in maps.

For instance, the positional accuracy of soil boundaries is often not very high. The generation of solid, fine and intricate boundaries in a soil map often gives a completely wrong impression of the accuracy of these boundaries to the map user. Therefore, it can also be considered to completely omit the boundaries as line symbols in the map; the more or less contrasting colours for the different soil units will automatically provide a boundary, but a boundary which is less prominent.

The consequences of cartographic generalization (both graphic and conceptual) should also be considered carefully. Not only has cartographic generalization negative effects on data quality (especially on positional and attribute accuracy and on completeness), but also there are often differences in the levels of generalization of cartographic data sets to be integrated. In soil mapping, for instance, there are often marked differences in the accuracies of the topographic base map details and the soil information. Cartographic generalization methods may have to be applied to adjust the information qualities.

A final example of a cartographic way of dealing with data quality is the so-called dasymetric mapping technique, which can be applied in cases where (often socio-economic) data are available for administrative regions only. These data are often represented by choropleth maps in which each region receives a uniform tint, suggesting a homogeneous distribution of the data over the area, which is normally not the case (e.g. think of a population density map). With the dasymetric mapping technique, the quality of the attribute information can be improved by adjusting the boundaries of the mapping units to the phenomenon represented, with the help of, for instance, topographic information (e.g. populations normally do not live in swamps, nor in lakes or on the tops of high mountains).

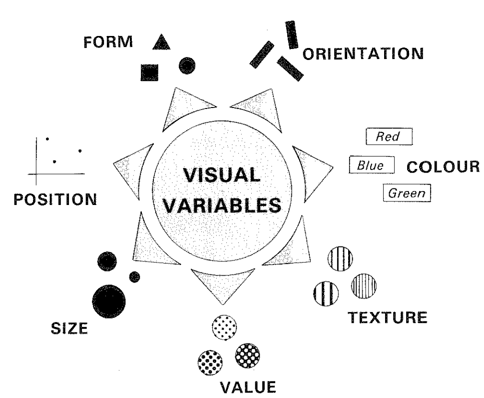


Figure 3 - The seven visual variables (source: BOS, 1984, p.22)

3. INTEGRATED LAND AND WATERSHED INFORMATION MANAGEMENT SYSTEM (ILWIS)

Turning now to the computer environment in which the cartographic ideas presented in the previous sections will be investigated, ILWIS was initiated some seven years ago at ITC by Meijerink [GORTE et al., 1988], where it was developed by the Computing Department, for a Watershed Management project in Indonesia. It integrates raster (particularly satellite), vector (particularly cartographic) and tabular data. It is MS DOS PC based, but is now being upgraded to run on HP UNIX Workstations. Because of its low-cost it has rather become an educational 'workhorse' at ITC, being used (along with other higher-cost systems) in several of our postgraduate courses for those educational components dealing with image processing, ortho-image and ortho-photomapping, digital terrain modelling, digital monoplotting, on-screen and tablet digitizing, database design, and geographic analysis. Furthermore its nature is such that researchers (M.Sc. students or staff) can implement their own developments as 'add-ons' to ILWIS. A tradition is emerging at ITC that new scientific developments within the institute produce an enhancement of ILWIS. (Chaos is prevented by a team of professional programmers!)

Figure 4 - Perception properties of the visual variables (source: BOS, 1984, p.23)

	Position	Form	Orient.	Colour	Texture	Value	Size
Associative	+	+	+	+	0	-	-
Selective	-	-	0	++	+	+	+
Ordered	-	-	-	-	0	++	+
Quantitative	-	-	-	-	-	-	++

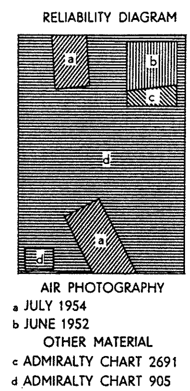
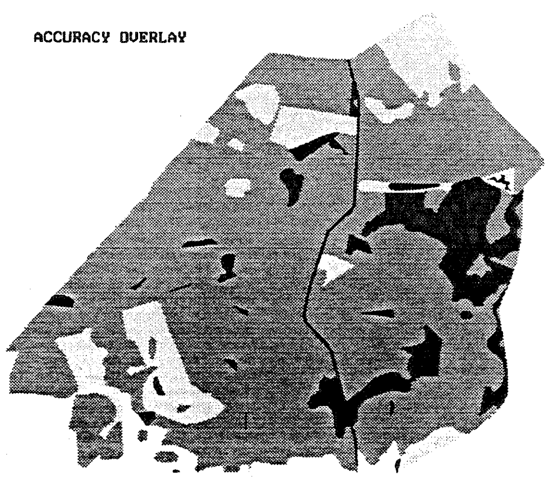


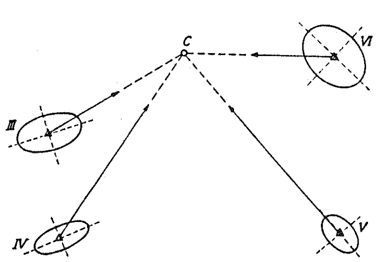
Figure 5 - Typical example of a reliability diagram which may be found on a topographic map. The visual variable orientation has been used to show the various data sources (Fiji 1:50 000, DOS, 1964).

Figure 6 - The representation of attribute accuracy by means of the visual variable value in a choropleth map



Soil Classification Accuracy Overlay

Figure 7 - Error ellipses used to show positional inaccuracy (the larger the ellipse, the greater the inaccuracy) (Source RICHARDUS, 1974, p429)



It was in this context that in 1991 an internally funded ITC project was established for the creation of an "Uncertainty Subsystem" for ILWIS.

3.1 The ILWIS "Uncertainty Subsystem"

The general concept of the "Uncertainty Subsystem" is that for any information generation operation in ILWIS there will be a near parallel production of information describing the quality of that generated information at the GIS user's request, as shown in Figure 8. This will require a means of storing control points and their quality statistics, positional and attribute data quality for all database objects, for propagating error through the selected GIS processing models, and finally for displaying the quality of the generated information in an appropriate manner as discussed in section 2 of this paper. This paper deals mainly with the last of these (displaying the quality of the generated information), but other students and colleagues are working on different aspects of the "Uncertainty Subsystem".

4. A LAND REALLOCATION PROJECT TO EXAMINE THE DISPLAY OF INFORMATION QUALITY IN GIS

To test our approach to the display of quality information, data and processing models from an ongoing land reallocation project located near our institute were examined. Land reallocation is performed when agricultural land holdings in an area have become highly partitioned as a result of inheritance; the holdings are consolidated, with the owner being guaranteed a holding of the same value. The determination of a holding's value involves several valuation submodels - one of which determines the holding's grazing suitability, land parcel by land parcel. This grazing suitability model, treated as a GIS processing model in which the quality of the input data and generated information is to be displayed, is considered here.

4.1 Grazing Suitability Model

As a processing model the grazing suitability model is Boolean or logical [DRUMMOND and RAMLAL, 1992] and uses three sets of information [RAMLAL, 1991] to provide Grazing Suitability (3 classes):

1. soil drainage status (5 classes);
2. soil moisture supply capacity (5 classes); and
3. topsoil bearing capacity (3 classes),

The model was checked [MARSMAN and DE GRUIJTER, 1986] and found to provide correct grazing suitability predictions in 95% of cases. The model is shown in tabular form:

Drainage Status	1	2	3	4	5
Bearing Capacity	1 2	1 2	1 2	1 2 3	2 3
Moisture Supply Capacity					
1	1 1	1 1	1 1	1 2 3	2 3
2	1 1	1 1	1 1	1 2 3	2 3
3	2 2	2 2	2 2	2 2 3	3 3
4	3 3	3 3	3 3	3 3 3	3 3
5	3 3	3 3	3 3	3 3 3	3 3

and can be explained by the following examples:

if drainage status is 1,2 or 3 and moisture supply capacity is 1 or 2 then the grazing suitability is 1

if drainage status is 4 and bearing capacity is 2 and moisture supply capacity is 1 or 2 then the grazing suitability is 2

if drainage status is 5 and bearing capacity is 2 and moisture supply capacity is 3 then the grazing suitability is 3

if moisture supply capacity is 4 or 5 then the grazing suitability is 3

etc.

4.2 Soil Drainage Status

Drainage status is linked to the height of the water table, and more particularly its Mean Highest Water Level (or GHG value), as follows:

Drainage Status Level	GHG cm below land surface
1	>80
2	40-80
3	25-40
4	15-25
5	<15

Following field testing [MARSMAN and DE GRUIJTER, 1986] it was found that the standard deviation of the GHG is 14cm. Using estimation by confidence intervals the probability of a land parcel with a certain measured GHG value being in a specified Drainage Status Level can be calculated (see [DRUMMOND and RAMLAL, 1992]). For example with a GHG value of 60cm, the probability of the parcel being in Drainage Status Level 2 is 85%.

4.3 Soil Bearing Capacity

Bearing capacity (3 classes) is related to Soiltype (5 classes) and GHG, as follows:

Soiltype	1	2	3	4	5
GHG(cm)					
0-12	3	3	3	3	3
13-24	3	3	3	3	2
25-33	3	2	2	3	2
34-40	2	1	3	2	1
41-60	2	2	2	2	1
61-80	1	1	2	2	2
80-140	1	1	1	2	1

Thus, eg, Soiltype 3 with a water table 41-60 cm below the surface has a Bearing Capacity Class of 2.

Soiltype is related to Soiltexture (the organic and clay content of the soil) as follows:

Soiltype	Organic content	Clay content
1. Peat	15-100%	0-8%
2. Clay with peat underlay	22- 70%	8-100%
3. Clay	0- 15%	25-100%
4. Clayey sand	0- 2.5%	8-25%
5. Sand	0- 2.5%	0-8%

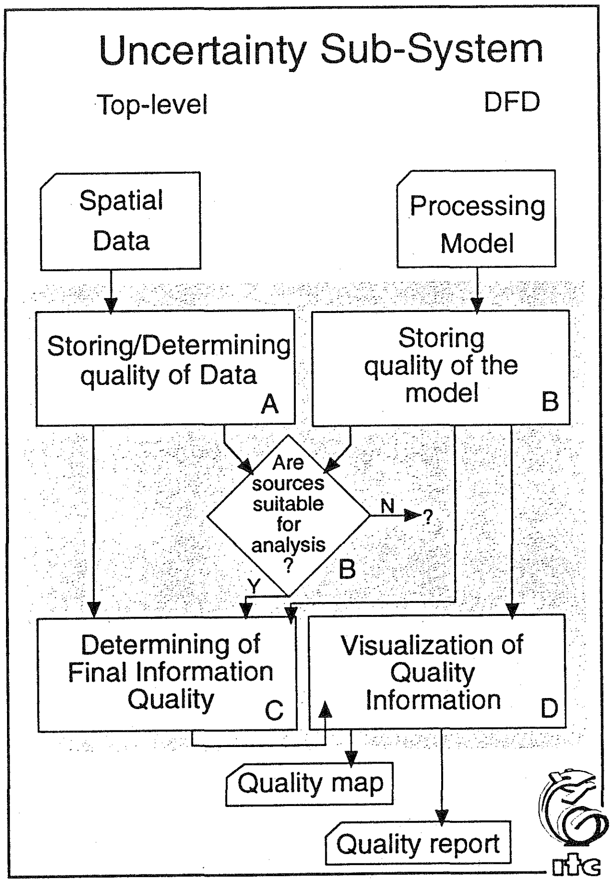


Figure 8 - An Overview of the ILWIS Uncertainty Subsystem

As bearing capacity is determined from GHG, organic content, and clay content, the qualities of all three need to be known. Tests have shown that the probability of these particular organic content and clay content classes being correct is 98% [MARSMAN and DE GRUIJTER,1986]. The quality of GHG data was discussed in the previous section, and an example landparcel was shown to have a probability of 85% that it was in its stated Drainage Status Level (or GHG level). Taking the same example landparcel, the probability of its Bearing Capacity Class (Pbc) being correct is:

$$Pbc = 0.85 * 0.98 * 0.98 = 0.82 = 82\%$$

4.4 Soil Moisture Supply Capacity

Moisture supply capacity is recorded in millimeters and is calculated using a polynomial of twenty coefficients and three variables (rooting depth, mean lowest water-table depth, and mean spring water-table depth) [RAMLAL, 1991]. In this application it is reclassified into 5 discrete classes:

Moisture Supply Capacity Class	Moisture Supply Capacity (mm)
1	>200
2	150-200
3	100-150
4	50-100
5	<50

Following error propagations carried out by the Dutch Soil Research Institute [MARSMAN and DE

GRUIJTER, 1986] it was found that the standard deviation of Moisture Supply determinations is 17mm. With this information, and using estimation by confidence intervals the pro- bability (e.g.) of a landparcel having Moisture Supply Capacity Class 2, when its Moisture Supply Capacity has been measured to be 166mm is 81%.

4.5 Quality of the Grazing Suitability Classification

Taking into account the quality of the model (see section 4.1), the quality of the Soil Drainage Status Level (section 4.2), the Soil Bearing Capacity Class (section 4.3), the Moisture Supply Capacity Class (section 4.4), and using Crisp Set Theory it is possible to estimate the probability of the given landparcel (referred to in sections 4.2, 4.3, 4.4) having the predicted Grazing Suitability to be:

$$P = 0.98(0.85 * 0.82 * 0.81) = .55 = 55\%$$

Applying Fuzzy Sub-Set Theory [KAUFMANN, 1975] and using these probabilities as Certainty Factors, the overall Certainty Factor associated with the predicted Grazing Suitability would be 0.81.

It is such probabilities or certainty factors which may be displayed, along with grazing suitability either by cartographic or other means, to provide the GIS user with information on the quality of the generated information.

4.6 Results of the exploration of the Land Reallocation Model

In this study a database was built in ILWIS which held the land parcel boundaries supplied by the Dutch Topographic Service, Soil Polygons supplied by the Dutch Soil Research Institute, and database tables holding the soil characteristics and the relevant soil characteristics quality parameters of the those soil polygons.

First using the available ILWIS facilities and selecting a low-cost ink-jet plotter as output device a map showing just the quality of the soils data was produced, in 4 classes represented by means of the visual variable value (Figure 6). Then using the same ILWIS facilities the Grazing Suitability Model was inserted and a multicoloured 5-class grazing suitability map produced. Thereafter using the procedures outlined in Sections 4.1 to 4.4 and implemented in ILWIS the quality parameters were processed to give i) a 2-class probability map (<50% probability, >50% probability); ii) a 3-class probability map (low, average, and good probability); and iii) a 5-class probability map (<10%, 10-30%, 30-40%, 40-50%, and 50-60%). The 3-class map is shown in Figure 9 .

The probability information represented in this FIGURE 11 was then combined with the grazing suitability information as shown in the multicoloured suitability map referred to above. As the visual variable value had to be reserved for the representation of the (ordered) suitability information already, data quality could not be shown by varying the relative lightness or darkness of the colours of the suitability classes. The solution selected was a coarse grey stipple overlay of three desity classes corresponding to the probability classes.

5. CONCLUSIONS

A team at ITC is continuing to work on developing this "Uncertainty Subsystem". This includes Cartography staffmembers with an interest in graphic semiology and the optimization of soft-copy display in a GIS environment, as well as students who are now concentrating on other aspects of the subsystem - including error propogation in dynamic diffusion models relating to industrial hazards, and developing a user-friendly interface for variance propagation in any mathematical processing models. We aim to have the ILWIS "Uncertainty Subsystem" completed by the end of 1993.

6. ACKNOWLEDGEMENTS

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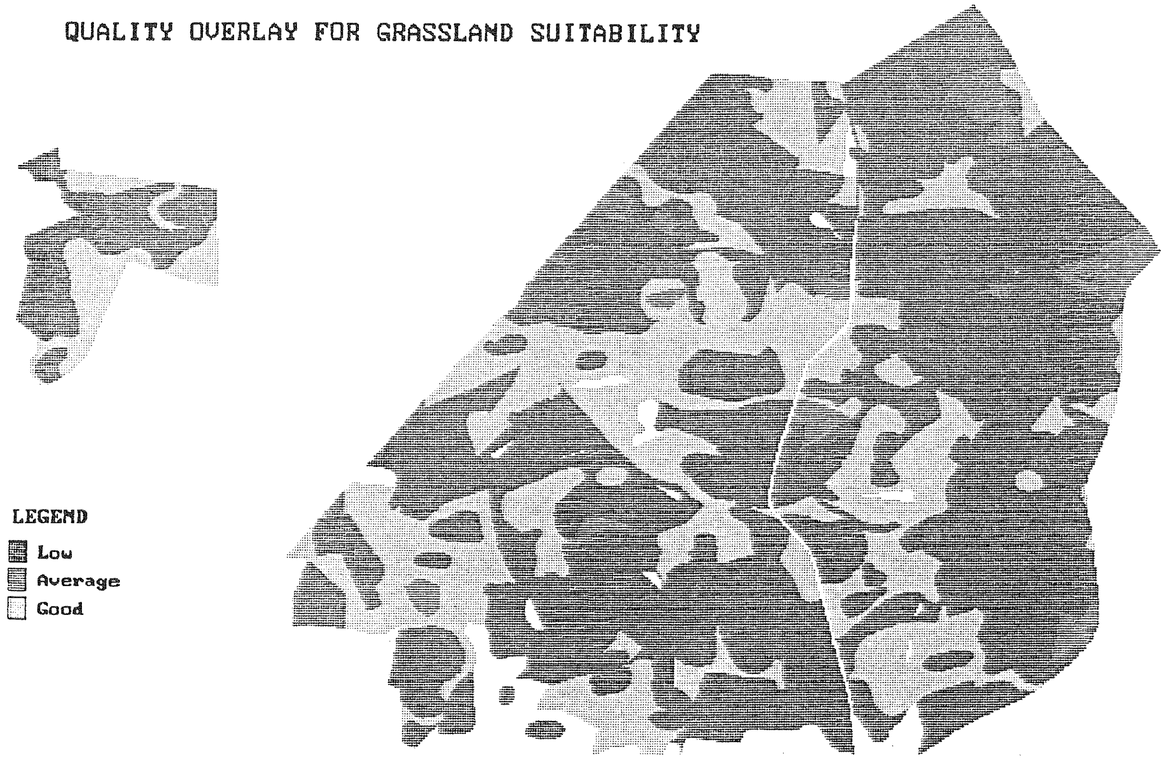

Figure 9 - Probability Overlay for Grazing Suitability

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