In: Kajander, J. (Ed), 1998. XX Nordic Hydrological conference, Helsinki. NHP Report No 44, pp 484-490

RULE BASED MAP GENERALISATION FOR CLASSIFICATION OF GROUNDWATER VULNERABILITY

Thomas Gumbricht, Lena Maxe and Per-Olof Johansson

Royal Institute of Technology,
Division of Land and Water Resources
S-100 44 Stockholm
e-mail: thomgum@aom.kth.se

ABSTRACT

To identify and protect vulnerable groundwater resources the application of different classification schemes has been widely developed. Most such system are developed for homogeneous aquifers of large spatial extends, and include the DRASTIC methods. These methods rely on overlay of point (textural) information, and are thus easily adopted to Geographical Information Systems. This paper presents an alternative approach for modelling groundwater sensitivity by inferring rules referring both to textural and contextual relations. The system (HYDROSET) incorporates a raster-based geographical information system (IDRISI) and identifies hydrogeological settings based on interpretations of geological maps. The developed system is thus a tool for map generalisation, where hydrogeological experts can formalise knowledge for identifying geological settings based on soil types, geological heterogeneity and proximity to defined aquifers. The application of the system to an area south of Stockholm is described.

INTRODUCTION

Groundwater is increasingly recognised as both a vital and vulnerable resource. To identify and protect valuable groundwater resources the application of different classification schemes has been developed, with the DRASTIC system being one of the most widely used (Aller et al., 1987). The adoption of Geographic Information Systems (GIS) to systems such as DRASTIC is very straight forward since they are based on simple overlay analysis and map algebra (Rosén, 1994). The vulnerability is evaluated for defined hydrogeological settings. The method then considers local (or point) relations. This approach might serve the purpose of mapping vulnerable groundwater resources in areas with homogenous aquifers of large spatial extent. For glacial terrain like in the Nordic countries, however, the contextual setting of the aquifer need to be considered. The spatial variation in hydrogeological properties is very high. Thus also the direct adjacent properties of a certain area is of importance. In the GIS jargon this is the neighbour or focal area (see Tomlin, 1990). And in instances with hydraulic connectivity over larger areas also zonal functions are important for mapping groundwater vulnerability.

This papers presents an alternative approach for modelling groundwater sensitivity to pollution based on inferring rules referring both to local, focal and zonal conditions. The system (HYDROSET) incorporates a raster-based geographical information system (IDRISI) and identifies hydrogeological settings based on interpretations of geological maps. The developed system is thus a tool for map generalisation, where hydrogeological experts can formalise knowledge for identifying geological settings based on soil types, geological heterogeneity and proximity to defined aquifers. The application of the system to an area south of Stockholm (Haninge) is described.

THE GROUNDWATER VULNEARABILITY ASSESSMENT

The HYDROSET system was intended for the use in a newly developed scheme for groundwater vulnerability assessment. The method was developed to be used in the comprehensive municipal planning process and as a support in the case of accidents releasing large amounts of hazardous substances. It is a general vulnerability assessment not aimed at any specific pollutants. The philosophy behind the classification system is elaborated in Maxe and Johansson (1998 a,b) and summarised in figure 1.

The groundwater vulnerability is assessed for two different time perspectives.

Firstly, the vulnerability for large outlets of liquids is assessed. In this case the time available for immediate remedial actions is crucial and therefore the travel time through the unsaturated zone to the depth of 5 m is calculated. The depth was chosen because it is possible to excavate down to this depth. In areas with thin soil cover the possibilities to remove the pollutants by excavation is limited and these are therefore considered to be vulnerable to large outflow of liquid pollutants, as are areas with highly permeable subsoil or a shallow groundwater table. Secondly, the vulnerability is considered in a long-term perspective. In this case the capacity to retain pollutants in the unsaturated zone is evaluated. For the retention, the amount of surfaces available for adsorption and degradation processes is of importance. The vulnerability assessment is based on the total amount of soil surface area in the unsaturated zone. In this context it must however be realised that some pollutants are not retained or degraded.

The use of the hydrogeological setting concept makes it possible to evaluate larger areas of similar hydrogeological features. The hydrogeological function of each of the defined settings is described. In this way we hope to increase the awareness of the groundwater resource. In the test area four hydrogeological settings were defined:

I. Major gravel and sand
II. Bedrock outcrops and thin overburden
III. Clay and silt
IV. Peat

Each setting includes sub-areas of different vulnerability. These are also delineated using HYDROSET. The resulting map, either in printed form or as a part of the municipal digital geographical information data base, is detailed enough to be used for most physical planning purposes. For siting of potentially polluting activities, however, detailed investigations are needed.

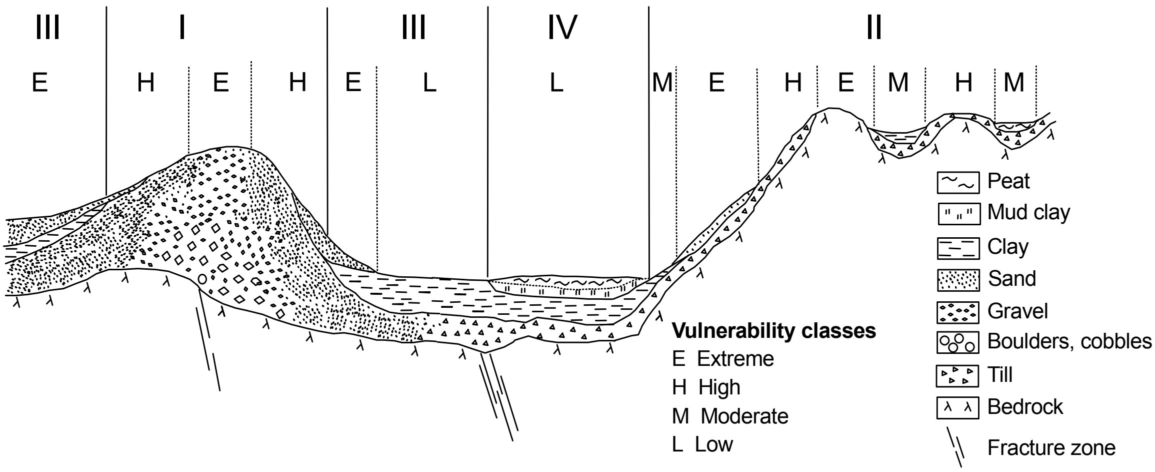

Fig.1 Schematic illustration of definition of hydrogeological settings I-IV and the vulnerability classes used in the HYDROSET system.

The degree of heterogeneity is even larger than what is represented on the map. This makes the use of hydrogeological settings even more important. The map and the descriptions of the settings act as a support when evaluating smaller areas. Another factor that hardly can be represented on the actual map scale is the presence of a soil profile. The occurrence of organic material and microbiological activity in the upper part of the soil is important for the retention and degradation of organic pollutants. In podsolic soils, the anion exchange capacity of the B horizon is important for the retention of anionic pollutants. The lack of an intact soil profile therefore increases the vulnerability.

METHOD - MAP GENERALISTAION

A map is a medium for conveying information about spatial conditions. Generalisation of existing maps is often needed to suit specific user requirements (Schylberg, 1993). The operations in map generalisation include simplification (area smoothing), deletion (omitting areas), amalgamation (merging of two or more areas) and displacement (the exchange of the quality of an area). The program HYDROSET include all four types of operations. The inference of the rules for the generalisation is forward driven, i.e. by the syntax “IF condition THEN conclusion“. This is a simple expert system and the rules are declared by the user in both text files and via a menu.

HYDROSET is based on raster data and is tightly coupled to the GIS program IDRISI. All GIS operations are done by IDRISI by automatic calls from HYDROSET. Additionally HYDROSET contains an advanced filter for definition of fragmentation within a user defined kernel. HYDROSET also automatically calls an expert system (GUIDE - Chmiel and Gumbricht, 1996) for combining information from the different pre-processings.

HYDROSET includes the following steps:

- definition of areas with the most valuable groundwater resources (defined in a text file by the user, i.e. eskers),
- identification of valuable areas in hydraulic contact with those areas (defined by the user in a text file, i.e. sand adjacent to eskers),
- simplification of the original geological image by reclassification (defined by the user in a text file, i.e. into a map representing hydraulic properties),
- calculation of the size of contiguous areas in the simplified map (the user define if diagonal links are allowed or not, and the threshold for small areas to be omitted),
- filtering of the simplified image to define fragmented areas (the user define both the size of the filter and the fragmentation index to use as threshold),
- growth of fragmented area into apriori un-fragmented areas (the user define the shape and size of the allowed growth of the fragmented area),

- identification of areas with thin coverage of sorted sediments in the transition areas between hills and valleys (the user define the transition area and extension of thin coverage given adjacent material),
- combination of information from the data layers with i) the simplified geology, ii) fragmented areas, and iii) thin coverage in valley bottoms (this combination is done with the expert system GUIDE).

DATA SET

The sample data set used for developing the HYDROSET system covers an area south of Stockholm (Haninge). The data is the standard soil map (1:50 000) in digital format produced by the Swedish Geological Survey. The resolution of the information is 10 m.

RESULTS

Figure 2 illustrates the application of HYDROSET to a small part of the geological map of Haninge. The first map shows the original geological map, the second map is the simplification with sand areas adjacent to the esker being reclassified. For reclassification the condition of 250 m proximity in Euclidean distance and hydraulic contact over this area must be satisfied. It can be seen that a small area is within Euclidean distance but has no connection within this distance. The third map shows areas defined as fragmented using a filter size of 15x15, a fragmentation index (FI) threshold of 3 and minimum area for non-fragmentation of 225 cells. The three images in the left column then produces the bottom image of the right column. The upper and middle images in the right column represent other parametisations of the filter and minimum area. The growth in all maps refers to the allowed growth of fragmented areas in to surrounding apriori non fragmented areas. Note that with a very large (35x35) filter also the wetland and clay areas (both in the upper right corner of the map) are displaced to the class bedrock and thin overburden because of the surrounding rock outcrops. With smaller filter size this does not happen.

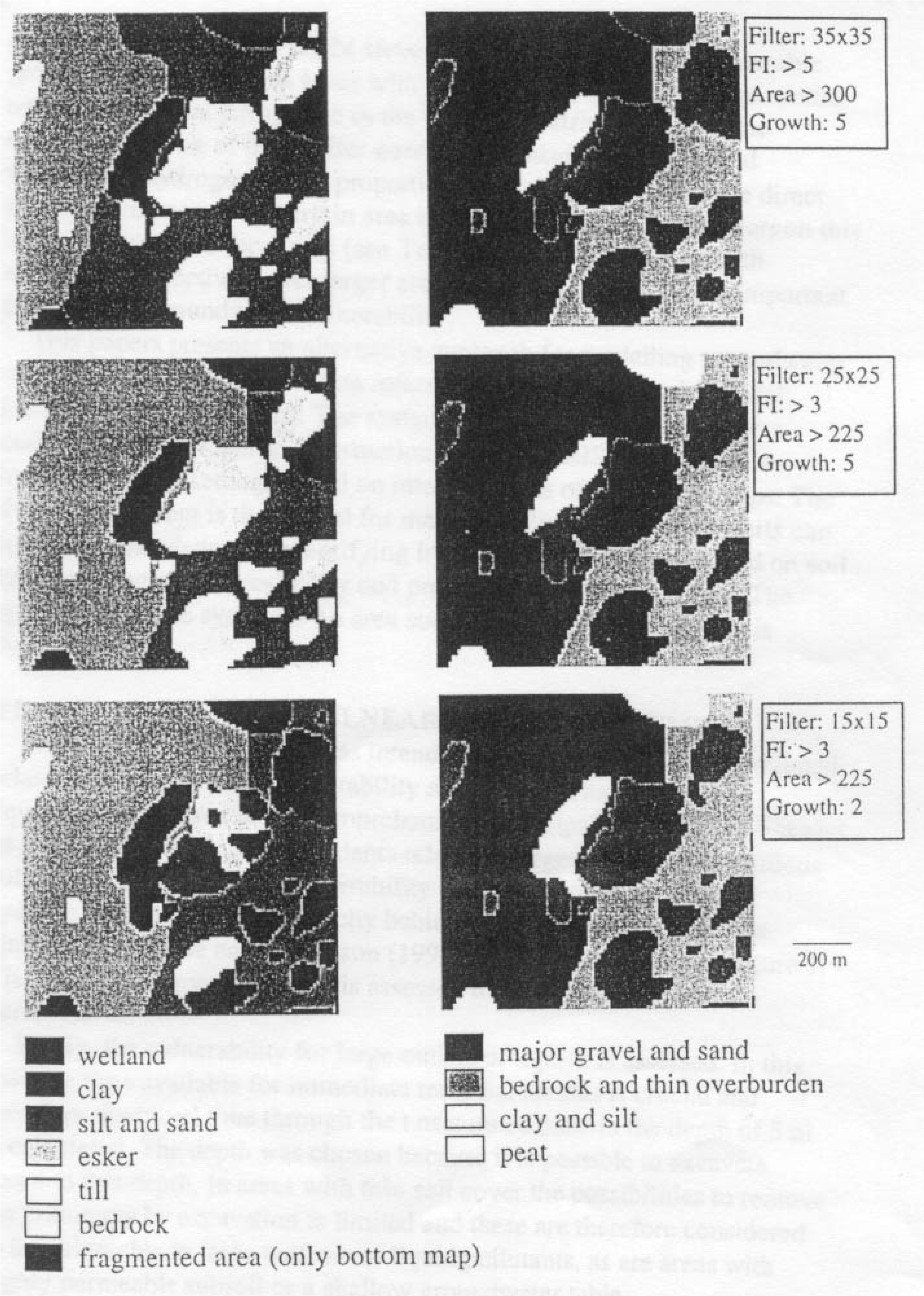

Fig. 2 Left column from top to bottom: original geological map, simplified geological map and fragmented geologiscal map.
Right column: hydrogeological settings (FI = fragmentation index).

DISCUSSION AND CONCLUSION

As the system is only using the standard geological map produced by the Swedish Geological Survey, it can easily be adopted to any area covered by the digital version of this map. As the qualitative classes are generic the files and rules created in the presented application can be used as default.

The user need to define several values for creating the generalised map on groundwater settings and their vulnerability. Some of them are connected, for example filter size and number of areas when defining fragmentation. To apply the system to a new type of area thus means a trial and error effort before a satisfactory generalisation has been achieved. However once it has been achieved it is easily used for regions with similar conditions. And we also feel that the trial and error work is a good discussion tool for defining hydrogeological settings and their vulnerability to pollution. As some of the rules area transparent and straight forward, we also believe that the system can be used as a pedagogic tool for laymen, including planners and politicians.

REFERENCES

Aller, L. T., Bennet, T, Lehr, J.H. Petty, R.J. and Hacket, G. 1987. *DRASTIC a standardised system for evaluating ground water pollution potential using hydrogeological settings*. U.S. EPA/600/2-87/035. Washington D.C., 455 pp.

Chmiel, J. And Gumbricht, T., 1996. Knowledge based classification of landscape objects combining satellite and ancillary data. In: K. Kraus and P. Waldhäusl (Eds), *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXI, part B4, pp 183-187, Vienna.

Maxe, L. and Johansson, P.O. , 1998a. *Bedömning av grundvattnets sårbarhet - utvecklingsmöjligheter*. Swedish Environmental Protection Agency. Report 4852. In press.

Maxe, L. and Johansson, P.O., 1998b. *Assessing groundwater vulnerability using travel time and specific surface area as indicators*. Accepted for publication. Hydrogeology Journal

Rosén, L. *A study of the DRASTIC methodology with emphasis on Swedish conditions*. Groundwater 32: 278-285.

Schylberg, L. 1993. *Computational methods for generalization of cartographic data in a raster environment*. Photogrammetric reports No 60. Royal Institute of Technology, Department of Geodesy and Photogrammetry, Stockholm, Sweden. Dissertation, 137 pp.

Tomlin, D., 1990. *Geographic Information Systems and Cartographic Modelling*. Prentice Hall, New York, 249 pp.