Asefa, T., Batelaan, O., Van Campenhout, A., De Smedt, F., 2000,
**Characterizing recharge/discharge areas of Grote-Nete (Belgium) using hydrological modeling, vegetation-mapping and GIS**. In: Verhoest, N.E.C., Van Herpe, Y.J.P. and De Troch, F.P. (eds), Book of abstracts of European Network of Experimental and Representative Basins (ERB) Conference: Monitoring and Modeling Catchment Water Quantity and Quality, Ghent, Belgium, 27-29 September, 2000, pp. 233-237.

# Characterizing recharge/discharge areas of Grote-Nete (Belgium) using hydrological modeling, vegetation-mapping and GIS

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**Abstract**

The recharge/discharge relation is one of the key factors in protecting ecologically valuable areas. But, it is also a prerequisite for an integrated land and water management. An approach which combines hydrological modeling and vegetation mapping within a GIS framework for characterizing discharge and recharge areas is promoted and has been applied to Grote-Nete, Belgium.

## INTRODUCTION

Starting objectives of a land-planning project are protection of ecologically valuable areas and a land organization in support of integrated water management. Such special attention within the land use planning should, therefore, be given to the protection of groundwater discharge areas and recharge-discharge systems. Discharge areas are that portion of the drainage basin in which the net saturated flow of groundwater is directed toward the water table. In this areas the groundwater is at or near the surface. Recharge areas are those portions of the drainage basin where the net saturated flow of groundwater is directed away from the water table.

Knowledge on the recharge-discharge relation is a key factor in understanding how existing hydrological system with regard to regional groundwater movement functions and/or how future land use changes can effectively be implemented without deteriorating a vital functions of the groundwater in a catchment or a region.

In order to be able to formulate a good land use planning strategy, analysis of the flow system connecting recharge and discharge areas is required. This information can be derived from combined technologies like groundwater modeling, hydro-chemical analysis, vegetation mapping, GIS and remote sensing. Batelaan et al. (1998) used this approach by combining analysis of hydrochemistry, remote sensing and groundwater modeling for characterizing discharge areas of Walenbos (Belgium).

The objective of the present study was to characterize 'clusters' of discharge areas and identifying the associated infiltration areas using combined technologies: vegetation mapping, GIS and groundwater modeling.

## STUDY AREA

The study area covers the major part of the Grote-Nete catchment. It is located about 60km north-east of Brussels. The considered catchment area is 525 km$^2$. Topography levels range between 0 m to 73 m above sea level. The area is dominantly flat with mean slope of 0.3 % and most of its part has a slope of less than 1%. Precipitation values are almost uniform throughout the year. The average

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precipitation value in the area ranges from 743mm to a maximum of 800mm. The dominating soil type in the project area is sand, in the valleys also sandy loam, loamy sand and silty loam occur. The land uses in the project area are as follows: 27% crop/mixed farming, 20% deciduous forest, 19% grass, 15% non-vegetated, 11% ever green pine forest, 7% deciduous shrubs and 2% open water.

## METHODOLOGY

A methodology is here suggested for characterizing discharge and recharge areas making use of hydrological modeling and vegetation mapping within a GIS framework. These different techniques are linked closely together by way of a procedure. Such a multi-thematic approach assures an advantage in analysis and understanding of the hydrological system. The suggested procedure consist of:

1. Mapping of phreatophytic vegetation for identification of shallow groundwater table conditions.
2. Application of a groundwater flow model to obtain the groundwater head distribution as well as to identify groundwater discharges.
3. Calibration of groundwater discharge area identification.
4. Delineation of clusters of discharge areas with ‘similar’ characteristics, based on numerical model results and vegetation mapping.
5. Identification of recharge areas associated with each cluster of discharge areas using a particle tracking code.
6. GIS procedural interface.

### Vegetation Mapping

The Biology Department of Free University Brussels (VUB) has performed a concise vegetation (phreatofytes) mapping. An initial list of 23 possible interesting phreatofytic plant species was identified on basis of a literature study and regional field knowledge. The mapping consisted of checking the occurrence and spatial extend of the 23 plant species at 193 locations. Prior information is also available about the degree in which a given species is indicator for acidic/alkaline conditions and the wetness of its ecotope. These so called Ellenberg R- and F-values are ranging from 1-9 and 1-12 respectively. Low R-values indicate highly acidic condition, high values indicate highly basic condition. Low F-values indicate dry environment and high values a wet environment.

An ARC/INFO GIS database (point coverage) is created from the point samples. The attributes of the coverage are the number of phreatofytic species present per locality, the areal extent of the species per locality, the Ellenberg R- and F-values.

This information together with the groundwater flow model results is used in delineating the cluster of discharge areas.

### Groundwater modeling

The well-known USGS modular three-dimensional finite-difference groundwater model, MODFLOW (McDonald and Harbaugh, 1988) code has been used to simulate the groundwater flow. The code has been selected for a number of reasons. It is well documented and a public domain and it has been applied and tested widely. Because of the used block centered finite difference approach in the model, importing and exporting of data between the model and Arc/Info is relatively easy (Gebremeskel, 1999). Other models, which have already been linked with GIS, can easily be connected to MODFLOW.

Recharge to the groundwater model comes from a surface water balance (recharge) model called WetSpass, which is the steady state version of Water and Energy Transfer between Soil, Plant and Atmosphere, WetSpa. Model structure is given in Batelaan et al. (1996) and Wang et al. (1997). The model has also been integrated with Arc/Info and ArcView.

MODFLOW's Drain package has been used to simulate the groundwater discharge. The seepage surface has been set topography minus 0.5m. This value is assumed to represent the average field ditch depth, which drains the groundwater discharge.

### Calibration and Delineation of Groundwater Discharge Areas

Calibration of the groundwater model is based on comparison of observed and calculated groundwater levels as well as mass balances of surface and groundwater models. The outputs from both models are subject to a constraint of river discharge.

The mapped vegetation coverage can be compared to the obtained the discharge map of the region to evaluate the consistency in the occurrence of the phreatofytes and the obtained discharge areas.

Delineation of clusters of discharge areas with 'similar' characteristics is now possible, based on the contiguity of the groundwater model based discharge areas and differences in vegetation types within the discharge areas.

### Recharge Areas

From management point of view it is important to locate the recharge areas linked with each 'cluster' of discharge areas. Identifying recharge areas enables one to know from where and how long it will take for the water particles to reach the discharge areas, as well as paths taken by the water particles.

A particle tracking codes, post-processing the results of the groundwater flow model can be used to identify recharge areas. In this study the three-dimensional tracking code, MODPATH (Pollock 1988, 1989) was used. MODPATH is designed to use the calculated head from MODFLOW. The output from MODPATH has been processed and was converted back to Arc/Info GRID format for displaying and further processing.

### GIS interface

Input to the models as well as out put is processed through a command interface that links the models with GIS Arc/Info. The interface is made up of Arc Macro Language (AML) scripts, C/C++ programs and UNIX shell scripts. The scripts make it very easy to run MODFLOW and MODPATH in a consecutive way. It automatically exports Arc-GRID maps to prepare the inputs for MODFLOW and MODPATH and imports modeling results back to Arc/Info system as GRID maps. By using the Arc/Info tools the interface makes in this way an efficient analysis and visualization of the results possible.

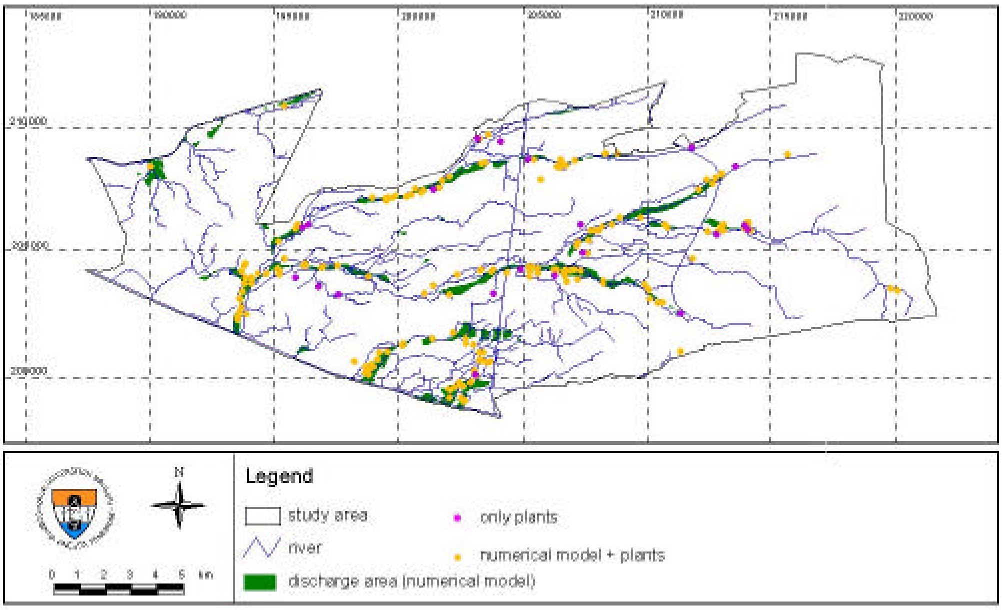


Fig. 1 The discharge areas as indicated by numerical model and/or plants

**RESULTS and CONCLUSIONS**

Fig. 1 shows the comparison between the numerical model and plant indicators for the calculated discharge areas.

Within the study area of Grote-Nete 73 plant locations were found to lie inside a discharge area calculated by the model. Since the model size is 50 by 50m, a buffer a 100m (twice a cell size) is considered around the discharge areas. In this zone another 49 plant sample points are located. This results in 74 points lying outside the discharge areas calculated with the numerical model.

While looking the area extents of these outliers, 53 point samples have area of less than $2500m^2$ (which is one model cell!), which below the resolution of the numerical model. This leaves 21 plant point samples, which do not agree with the numerical model. From 21, 13 have a groundwater depth of less than 1m, 5 a depth of less than 2m, and only 3 a depth of more than 2m. In general can therefor be concluded that a reasonable well fit exists between the calculated groundwater discharge areas and the mapped phreatofytes.

Using areal contiguity of discharge locations and similarity in R-value as a criterion 17 different 'clusters' of discharge areas could be identified.

Characteristics related to each 'clusters' like, discharge area, infiltration area, average travel time to the discharge area could now be determined by using MODPATH. Comparing the individual clusters contributes strongly to increasing the level of understanding the flow systems in the area and the role they play in the landscape.

The combined approach using hydrological models, vegetation mapping and GIS proves to be an effective tool in characterizing discharge/recharge areas. Identifying discharge/recharge areas is helpful for organizing an effective land use planning with regard to conserving ecologically valuable areas. The methodology developed here can also be used for analyzing the effects of land use changes on discharge/recharge relationships.

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