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A large-scale hydrogeological database and groundwater model for Flanders: a tool for integrated groundwater management

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Abstract. Existing groundwater models in Flanders (Belgium) are local small-scale models, which serve various goals and therefore often lead to conflicting results. Furthermore, these models are under management of different organizations and public data are presently insufficient to couple these models to a large-scale groundwater model for the whole of Flanders. Therefore, a centralized, hydrogeological, relational database is being developed. The database is based on the new hydrogeological code for Flanders (HCOV), which classifies formations by their water supplying capacity and age. The general purpose of the large-scale model is to stimulate integrated groundwater management.

Key Words: Groundwater management, relational database, geographic information systems (GIS), Flanders, Belgium

1. Introduction

The present groundwater policy of most European countries is based on administrative and legislative tools. Policy decisions and measures, based on assumptions, are prone to misjudgment. Therefore, integrated groundwater management requires decision-supportive technological tools. These will be provided by the Flemish Groundwater Model (Vlaams Grondwater model - VGM), in which the MODFLOW groundwater modeling code (McDonald and Harbaugh, 1988) is linked to a relational database in a GIS (Geographic Information System) environment.

The existing groundwater models in Flanders (Belgium) are local small-scale models, which serve various goals and often lead to conflicting results. Comparison and linkage of these models will therefore, if even

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possible, result in an incomplete (because of lacking data) and non-uniform model. Hence, the Flemish government has taken the initiative for integrated groundwater management with the help of a centralized hydrogeological database (namely DOV, *Databank Ondergrond Vlaanderen*), a central governmental GIS-department and a future Flanders-covering groundwater model (VGM).

2. Description of the study area

Belgium is a federal country consisting of three largely independent regions: Flanders, Wallonia and the Brussels-capital region. Flanders is situated in the North of Belgium and covers an area of 13.524 km² (44 % of Belgium, but populated by 60 % of all Belgians), bordered by the Netherlands, Germany and France (Belgian Federal government, www.fgov.be) (Fig. 1).

Flanders has a temperate, oceanic climate. The average annual rainfall in Flanders is 780 mm and the average temperature is 9,8°C (Alexandre et al., 1992). The major rivers in Flanders are the Scheldt and its main tributaries (Dender, Zenne, Dijle, Demer, Nete and Leie) with a catchment area of 19.141 km². The Meuse with a catchment area of 31.181 km² is only partly covering Flanders inasmuch as it forms the administrative border in the East. The Ijzer, with a catchment area of 1.116 km², drains the South-West of Flanders (De Smedt et al., 1992). Flanders is relatively flat with the highest point (156 m) at the '*Kemmelberg*' in the South-West of Flanders.

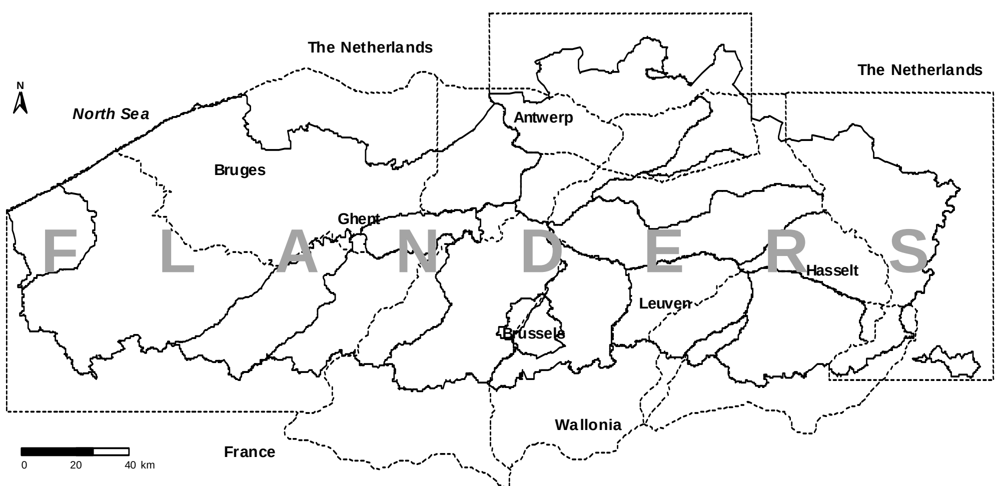


Figure 1. Map of Flanders and its main rivers. The dotted lines represent the nine subregions used in the model

Geologically seen, Flanders mainly consists out of sedimentary rock, though from various age and composition. The oldest (Paleozoic and

Cretaceous) rocks are present as base material throughout Flanders, but only outcropping in the more hilly South-West of Flanders. The largest part of Flanders is covered with Tertiary or Quaternary sediments, up to several hundreds of meters in the Campine (N-Flanders) and Limburg (E-Flanders), mostly alternations of sandy and clayey formations. Outcropping formations in the North and East of Flanders are generally more sandy than the more clayey ones in West-Flanders (Maréchal, 1992).

3. Goals and potentials of the VGM

Purpose of the VGM is to create an environment, in which a regional insight in the groundwater resources in Flanders can be obtained. More in detail, the VGM could be used to calculate the direction and magnitude of groundwater flow, from which e.g. vulnerability maps could be created. In addition, groundwater recharge, discharge and storage can be calculated, as well as groundwater capture and protection zones.

Furthermore, causal relations (i.e. between cause and effect) and predictive studies could be made. In this way, the impact of external influences and management decisions can be assessed, on a regional scale.

The model results will be of importance in quantitative studies, such as environmental studies (e.g. desiccation of wetlands). Likewise, the analysis of the groundwater table fluctuations (because of drainage or irrigation, changes in land use, or hydraulic construction works, reduced infiltration because of urbanization or changes in water storage resulting from groundwater pumping) can be modeled. Qualitative studies concerning pollution transport research (e.g. originating from waste dumps or overuse of agricultural fertilizers and pesticides) can also be executed. As the previous study themes are not be solved only through hydrogeological calculations, a link with external extra-disciplinary models, such as agricultural, economic, or ecological models will be foreseen (Fig. 2).

The VGM is additionally to be used as a starting point for hydrogeological schematization and boundary conditions, as well as a reference of accuracy for other, more detailed or externally executed, groundwater flow and pollution transport simulations. Hence, it will be an essential tool for integrated groundwater management.

4. Development of the VGM: methodology

4.1. General overview of the VGM-environment

Executing large-scale groundwater models requires long calculation times and huge computer storage capacities. The Flemish region is therefore divided in nine subregions (geographic location on Fig. 1; position in VGM-environment on Fig.2) along existing hydrogeological boundaries (main rivers, water divides or dominant strata outcrops). However, not all subregions have unique boundaries, in that way that overlapping zones will be necessary to couple these submodels. These nine submodels are part of the larger VGM environment (Fig.2) in which the submodels are linked to a recharge model, the hydrogeological data, parameters and boundary conditions.

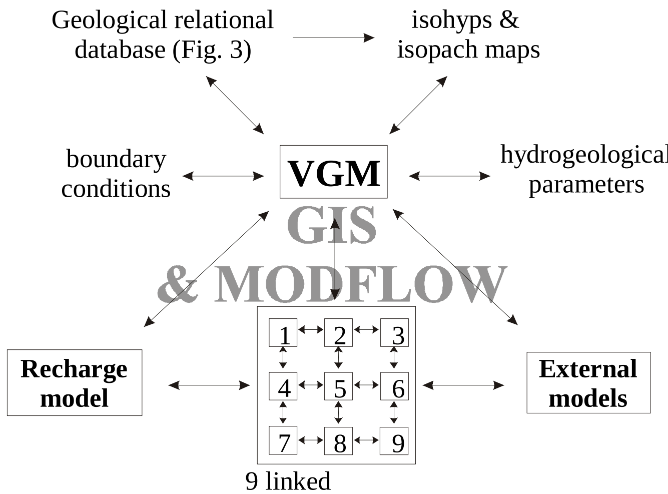


Figure 2. The VGM environment: MODFLOW groundwater models linked in a GIS-environment to hydrogeological data, a recharge model and external models.

The VGM-environment consists of data of four main types: (1) the geological relational Foxpro-database, (2) a database with isohyps and isopach maps, (3) the hydrogeological parameter database and (4) the boundary conditions database. Currently, the geological relational database is developed (Fig. 2). As all data will become available publicly as DOV (http://dov.vlaanderen.be), the geological relational database will further be referred to as the VGM-DOV database.

This relational database is a centralized database containing all existing geological and hydrogeological data (borelogs, wells, parameter estimates, maps, GIS-data, etc.) for each subregion. Moreover, stratigraphical data, was converted into a new uniform hydrogeological code for the underground in Flanders (*Hydrogeologische Codering van de Ondergrond van Vlaanderen* - HCOV). Based on HCOV, isohyps and isopachs maps for each hydrogeological unit were produced in ArcInfo. The georeferenced hydrogeological parameters (mostly hydraulic conductivity and storage coefficient), were collected independently from the hydrogeological data. Nevertheless, they originate from the same companies and institutions, and analogous general data have been gathered, such as used method, origin of data, coordinates, etc. Likewise, all data on boundary conditions (river data, pumping rates, recharge rates, and piezometric data) exist, but is not centralized and not standardized. Recharge rates will be calculated with the distributed model WetSpass (Wang et al., 1996; Batelaan and De Smedt, 2001).

4.2. Hydrogeological code for the underground in Flanders (HCOV)

As no standard tool for the characterization of the underground in Flanders existed, the exchange and comparison of groundwater data as well as the creation of a 'model of reality' were hampered. Therefore, a steering committee composed of representatives of the Flemish universities, drinking water companies, Belgian research centers and the Flemish Administration, Department Water, Environment and Nature (AMINAL), reviewed the existing codes and created a new uniform and widely accepted hydrogeological code for the underground of Flanders (HCOV) (Meyus et al., 2001).

HCOV is a purely hydrogeological code, which is general, recognizable and complete for Flanders as well as vertically complete (all strata from primary to quaternary strata are included). On the one hand, some different (chrono)stratigraphical strata, with equal hydrogeological properties were joined into one hydrogeological unit. For instance, sand layers deposited in consecutive time periods but with similar conductivities and water storage capacities were classified as one hydrogeological unit. On the other hand, some stratigraphical strata were subdivided into several hydrogeological units, when hydrogeological properties within the stratum differed significantly, e.g. alternating clay and sand depositions in the same era.

The code is numerical (4 digits), hierarchical (3 levels) and chronological (numbering from young to old strata). The first 2 digits represent the main units (14 classes from 0000 to 1300; Table 1). Depending on the requested level of detail, the main units can be specified further, thereby using the second digit, which represents the subunits and possibly the last digit that indicate the base units. Although the main units form one hydrogeological unit, the code '0100' (Quaternary aquifer systems) groups all local aquifer systems of quaternary period.

Table 1: main units of the HCOV hydrogeological code

HCOV main units	Description
0000	Undetermined
0100	Quaternary aquifer system
0200	Campine aquifer system
0300	Boom aquitard
0400	Oligocene aquifer system
0500	Bartoon aquitard system
0600	Ledo-Paniselian-Brusselian aquifer system
0700	Paniselian aquifer system
0800	Yperian aquifer
0900	Yperian aquitard system
1000	Paleocene aquifer system
1100	Cretaceous
1200	Jurassic-Trias-Perm
1300	Paleozoic

4.3. Technical aspects of the geological relational database

For optimal data representation, accurate assessment of all types of data and data formats is extremely important prior to database development. As the VGM-DOV database will become publicly available, it is developed from the existing database used by the Flemish Administration for Natural Resources and Energy. However, in order to increase the transparency and accessibility of the data, its structure is simplified, though without loosing information.

Data provided within the original database, is controlled on its validity by comparison with the original analog profile description and completed with the hydrogeological and lithological code. However, the publicly available data does not cover Flanders completely. As more suitable data becomes available, though under management of different organizations, no extra field measurements are planned. In order to optimize data spreading (horizontally and vertically), point data is selected with a minimum density of one borehole per 2 km². Consequently, only one drilling is selected from borehole clusters. In water catchment areas and the harbours, where large volumes of water are pumped and more hydrogeological detail is needed, a smaller density of 1 borehole per km² is considered.

Data collection is not limited to the Flemish region, because groundwater zones do not follow the administrative boundaries. Using the Flemish border as a boundary condition would therefore be erroneous.

Additional data, collected from various sources, has strong dissimilarities in data type, in quality and in quantity, as well as in storage media: paper, spreadsheets or existing databases, having distinct structural schemes. All data are analyzed for digitalization into the VGM-DOV database. The main providers of data in Flanders are the water companies, the department Water and Natural Resources and Energy of the Flemish government, the Belgian Geological Survey (for Flanders and Wallonia), Flemish universities and geological engineering bureaus.

The VGM relational database was developed in 'Microsoft FoxPro' and therefore consists of related tables in dbf-format (Fig. 3). The data is stored in tables. Each row across the table is a record whereas the columns are the fields. As repetitive information takes up space in a single table, it is better to have some related tables where data is only recorded once.

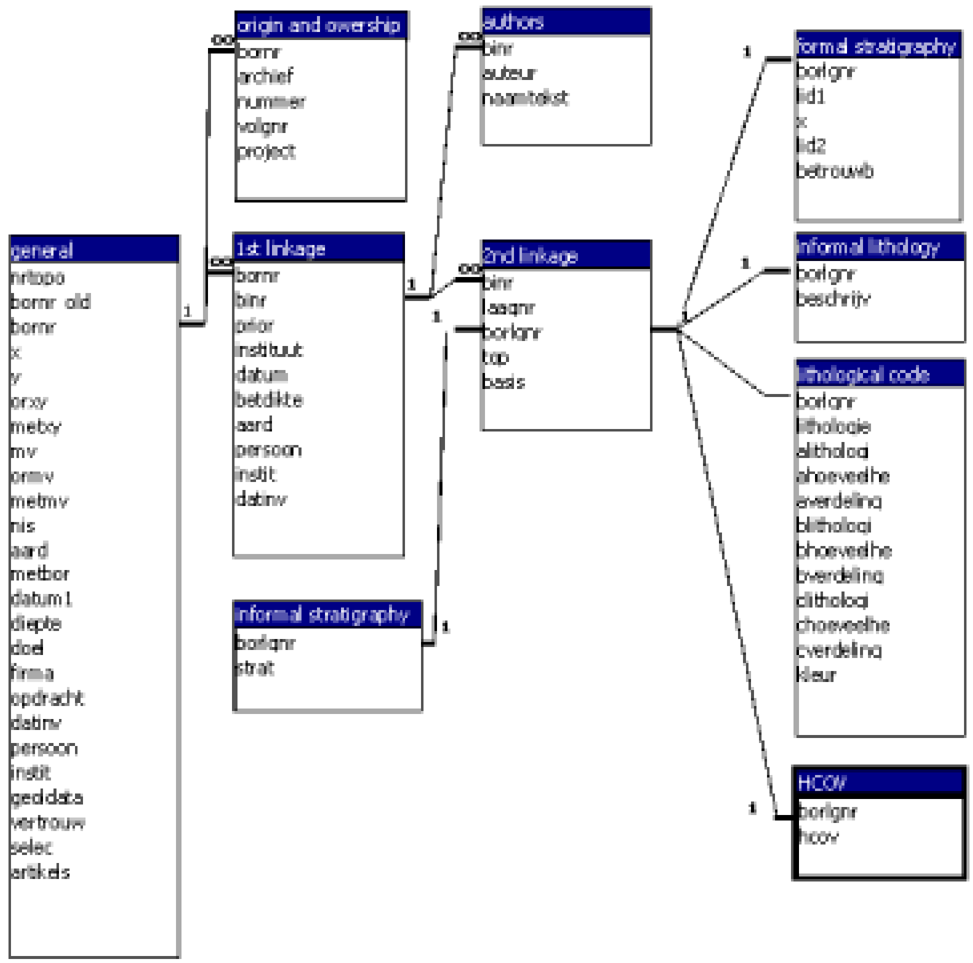


Figure 3. Structure of the geological relational database with connection to the hydrogeological HCOV-coding (in bold).

Stratigraphy (formal code and original description), lithology (formal code and original description) and HCOV-code are therefore stored in distinct tables and can be accessed either independently or related. For each strata, observed in borehole profiles, a code or description is entered and identified by an unique numerical key (*borlgnr*). The uniqueness of the identification keys results in one different number for each record. These tables are linked to metadata, which on its turn is stored in a table with general data (such as x and y coordinates[1], surface level, borehole depth, methods used, reliability and the unique identification key *bornr*), a table with the origin and owner of the data (key *bornr*) and a final table stating the interpreter/geologist who described the borehole profile (key *binr*). Yet, the metadata is attached to a certain interpretation of a complete borehole profile, whereas the (hydro)geological data exists per strata. Moreover, for each borelog, taken

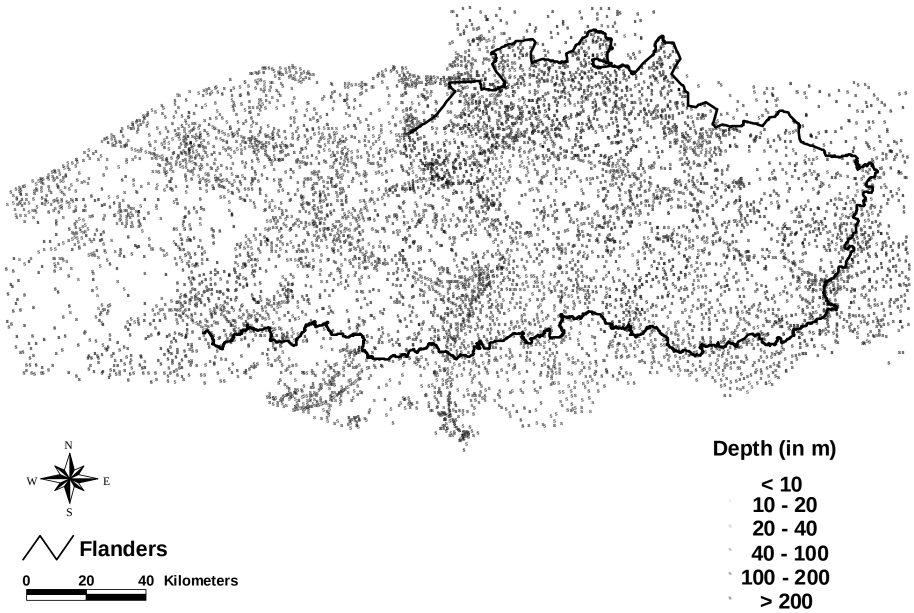
[1] The VGM-DOV database uses the same coordinate system as the current geological and topographic maps of Belgium, namely the Lambert Conformal Conical projection.

from the same coordinates with the same method, several interpretations exist (e.g. lab or field interpretation). To connect these different data levels, two linkage tables are used. The first linkage table connects metadata per profile (identified by *bornr*) to the existing interpretations of that profile (identified by *binr*) in a one-to-many relationship. The linkage table will therefore use two keys to match two tables with different identification keys (in this case the 'general data' table and the second linkage table). The second linkage table, then, subdivides an entire profile (key *binr*) into data per strata (key *borlgnr*).

The VGM-DOV database is built in a modular way. For example users can use the VGM relational database in the absence of a GIS-tool. The database user can therefore decide which data is needed, e.g. only the hydrogeological codes of a profile (from table 'HCOV') located at a certain site (from table 'general') together with the top and bottom of these strata (from table '2nd linkage table') (Fig. 3). With a GIS-interface, the point data for that site can be selected. Next, a query, written in SQL – Structural Query Language, will then search for the selected records throughout all related tables. Eventually, these output files will be formatted in such a way that import to MODFLOW will become easy.

5. Spatial overview of the hydrogeological data

The VGM-DOV database provides an unified database system which offers besides an organized scheme for storing and editing of hydrogeological data, as well a method for displaying and analyzing geographically referenced data in a GIS-environment. Correspondingly, the spatial criteria (horizontal and vertical occurrence) are evaluated. For Flanders, the total number of borehole profiles is 8961, of which 74 % are originally public domain. New data was mostly collected outside of the Flemish borders. Figure 4 shows the location, density and depth. Figure 5 shows the discrete depth classes of the data. After conversion to a grid file (cells of 2 km², the requested density), it was calculated that 88 % of the area in all subregions was covered by the VGM-DOV database. Regions that are covered insufficiently include West-Flanders (clayey substrata) and the graben system in East-Belgium. Best covered are the Campine and Antwerp region (sandy region in the central-North of Flanders) where the National Centre for Nuclear Energy (planning for nuclear storage), the Antwerp harbor, and a large groundwater abstracting company is located. From Figure 5 can be seen that the depth of 74 % of the data is between 10 and 100 m, 21.5 % is deeper than 100 m. A general trend is that wells are deeper and data density higher in water capturing zones, in need of a more detailed insight in the hydrogeology.


N
W
E
S
Flanders
0
20
40 Kilometers
Depth (in m)
< 10
10 - 20
20 - 40
40 - 100
100 - 200
> 200

parameters when new insights arise or new, e.g. more detailed, modeling goals are requested.

Currently, the geological database is developed. Further steps consist of the development of the three remaining parts of the VGM-DOV database: the hydrogeological parameter database (conductivity and storage coefficient), the database of GIS-maps (isohyps and isopach), the database of boundary conditions (river data, pumping rates, recharge rates, piezometric levels). Recharge rates will be calculated with the distributed model WetSpass (Wang et al., 1996; Batelaan and De Smedt, 2001). Likewise, a Flanders-covering digital elevation model (DEM) is under construction. From these data, a groundwater model can be created for each subregion. Later on, these submodels will be linked and managed by a GIS interface and ODBC-connection (Open Database Connectivity).

Further research is needed on the transition between the large-scale model and more detailed models, i.e. it is researched how ‘zooming in and out’ could be performed. Suggestions were given by Leake (1998), Leake et al. (1998), Székely (1998) and Kamps and Oltshoorn (1996).

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