Project no. 505428 (GOCE)

AquaTerra

Integrated Modelling of the river-sediment-soil-groundwater system; advanced tools for the management of catchment areas and river basins in the context of global change

Integrated Project

Thematic Priority: Sustainable development, global change and ecosystems

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Organisation name *and contact* of lead contractor *and other contributing partners* for this deliverable:

P. Goderniaux[1], Ph. Orban[1], A. Dassargues[1], S. Brouyère[1,2]
[1]Group of Hydrogeology and Environmental Geology, [2]Aquapôle ULg
University of Liège, Building B52/3, 4000 Sart Tilman, Belgium
Tel: +32.43.662377/ Fax: +32.43.669520, Serge.Brouyere@ulg.ac.be

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

SUMMARY

In the framework of Workpackage BASIN R3 Meuse, the Hydrology Group of the University of Liège (Belgium) is developing a hydrological model of the Geer sub-catchment, in order to assess climate change impacts on groundwater reserves. This report describes the calculation code used, the general hypotheses chosen to develop the model, the conceptual model, the climate change scenarios and the final objectives of the study.

MILESTONES REACHED (…….)

No milestones are associated to this deliverable

Using the meteorological data available for the Geer basin, HYDRO 1 has generated climate change scenarios which will be used as input to the hydrological model.

The results of this work will be provided to INTEGRATOR 3 and used for socio-economic impacts assessment. Further interactions with COMPUTE 2 are currently planned.

Contents

Glossary

HydroGeoSphere	Finite element calculation code for subsurface and surface flow and solute transport
Smectite clay	Greenish marl constituting the basis of the Hesbaye chalk aquifer
SUFT3D model	'Saturated Unsaturated Flow Transport 3D' – Finite element calculation code for subsurface flow and solute transport (developed by the Hydrology Group – University of Liège Belgium)
Pluri-annual variability	Character of data time series in which cycles of periodicity superior to one year can be observed.
FRAC3DVS	Subsurface module of the code HydroGeoSphere. FRAC3DVS solves 3D, variably-saturated subsurface flow and solute transport equations in non-fractured or discretely fractured media (developed by the University of Waterloo and the University Laval, Canada)
MODHMS simulator	Calculation code for surface water – groundwater modeling (HydroGeoLogic Inc.)
Van Genuchten functions	Mathematical functions that describe relations between the water saturation, the pressure head and the relative permeability, in variably-saturated media
Brooks and Corey functions	Mathematical functions that describe relations between the water saturation, the pressure head and the relative permeability, in variably-saturated media
Leakance factor	Parameter that regulates water flows between to domains. Concerning surface – subsurface coupling in HydroGeoSphere, it is defined as the conductivity of the ground surface divided by the thickness of ground across which flow occurs.
Dirichlet condition	Impose a prescribed hydraulic head value (or pressure head).
Neumann condition	Impose a prescribed water flux value.
Cauchy condition	Impose a linear relationship that specifies water fluxes according to pressure head variations. This condition is usually used to model interactions between river and aquifer
Zero-depth gradient condition	Force the slope of the water level to equal the bed slope
Critical depth condition	Force the water depth at the boundary to be equal to the critical depth
Transient calibration	Model calibration performed through time with transient variables and stresses.

1. Introduction and objectives

In the framework of the AquaTerra project, the Geer basin (Belgium) has been chosen as a test site to study the climate change impacts on groundwater resources. In order to make scientific assessments of these future impacts, the Hydrogeology Group of University of Liège (Belgium) is developing a spatially distributed, physically based hydrological model for this catchment. After a brief overview of the Geer basin context, this intermediate report describes the planned modelling works: general objectives, conceptual model, chosen hypotheses, modelling setup.

2. The Geer basin: general context

The Geer sub-catchment is located in eastern Belgium, North-West of the city of Liège, in the intensively cultivated 'Hesbaye' region. The hydrological basin extends over approximately 480 km², on the left bank of the Meuse River (Figure 1).

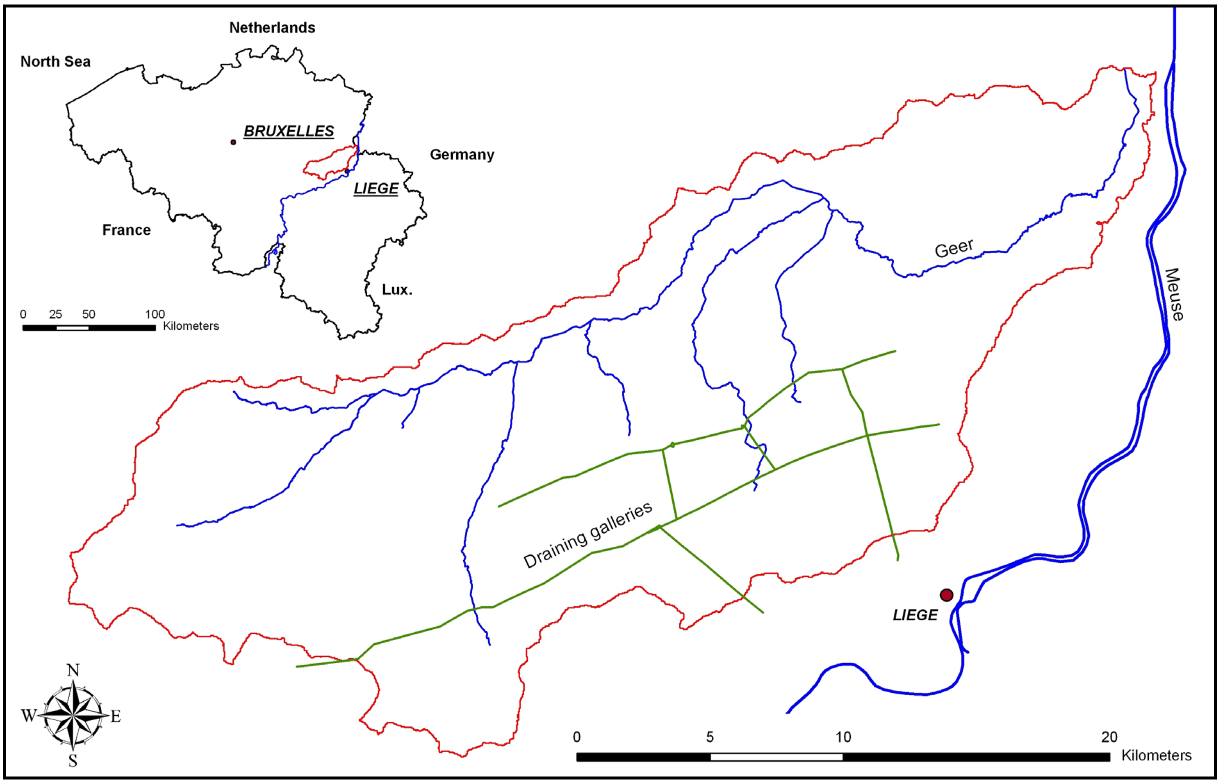

Figure 1 : Geer basin location and hydrographic limits

The geology of the Geer basin essentially consists in cretaceous chalky formations, dipping northward and limited at its base by impermeable smectite clay (Figure 2). Chalk layer thickness ranges from a few meters up to 70 m. It is divided in two parts by a thin layer of hardened chalk, called the 'Hardground'. A flint conglomerate, made of dissolved chalk residues, lies just over the chalk, with a maximum thickness of 10 m. Tertiary sands are locally found above this conglomerate and a thick layer (up to 20 m) of quaternary loess is observed all over the catchment. North of the Geer River, tertiary sands and clays entirely cover chalks (Figure 2) (Orban *et al.* 2006a - R3.16).

The chalk layers constitute the main aquifer formations in the catchment. This 'Hesbaye' aquifer is considered as unconfined in the most important part of the basin. In the northern part, near the Geer River, semi-confined conditions may prevail because of the loess quaternary deposits. North of the hydrologic Geer basin, the chalk aquifer is confined under tertiary clay and sands (Figure 2). Subsurface flow direction is from South to North and the aquifer is mainly drained by the Geer River flowing from West to East (Orban *et al.* 2006a - R3.16). The chalk formations are characterized by a dual porosity made of a porous matrix, which porosity can reach values up to 30 to 45 %, and fractures which generally represent less than 1% in volume. Fast preferential flows occur through the fractures while the porous matrix enables the storage of large volumes of water (Brouyère 2001, Hallet 1998). In the unsaturated zone, the thick loess layer limits the infiltration rate, resulting in smoothed recharge fluxes at the groundwater and attenuation of seasonal fluctuations of hydraulic heads that are better characterized by pluri-annual variations (Brouyère *et al.* 2004a). The Hesbaye aquifer is largely exploited for drinking water, mostly through than 40 km of pumping galleries located in the saturated chalk (Figure 1). The groundwater budget indicates groundwater losses, most probably through the northern catchment boundary, partly governed by groundwater pumping in the basin located North of the Geer basin, in the Flemish region of Belgium. The Hesbaye aquifer suffers from severe nitrate contamination problems, essentially due to intense agricultural activities taking place in the area. In the unconfined part of the aquifer, nitrate concentrations get close to the drinking limit of 50 mg/l (Broers *et al*. 2004, Batlle Aguilar *et al*. 2007).

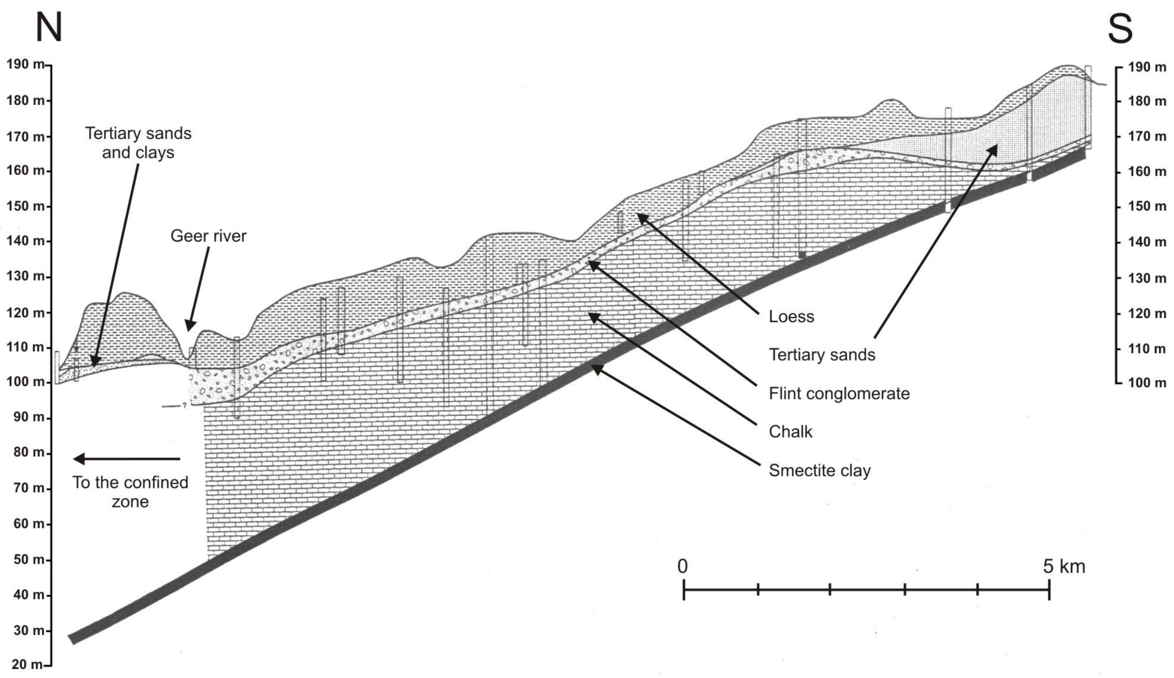

Figure 2 : Geological cross-section in the Hesbaye aquifer (modified from Brouyère *et al*. 2004a)

3. Modelling works

3.1 Introduction

This new Geer hydrological model is specifically developed to deal with climate change impacts assessment. Numerical choices and hypotheses are slightly different from those performed for the SUFT3D model under development that focuses on the problem of nitrate contamination of groundwater (Orban *et al*. 2006b). This new model, will fully integrate surface and subsurface water, and especially focuses on recharge processes, which are key elements in the context of groundwater management and changing climate.

After a brief presentation of a previous study on the impact of climate change in the Geer basin (Brouyère *et al*. 2004), the next chapters describe the general options chosen to develop the Geer hydrological model to be used in AquaTerra.

3.2 Background

Brouyère *et al.* (2004) developed a groundwater flow model to estimate climate change impacts on groundwater reserves, with a first application on several catchments in Belgium, including the Geer basin. For the subsurface flow component, they used a 3D finite elements discretisation, coupled with a soil model and a river model. Without going into details, the soil model was used to calculate infiltration rates, applied at the top of the groundwater model and various lateral flow components (runoff…). The river model dealt with surface water modelling and interaction between surface and subsurface water. The three models were loosely coupled, using a programmed interface in charge of data exchanges (water fluxes) at the different time steps of the simulation.

Various climatic scenarios were tested on this model. They were prepared by the Royal Institute of Meteorology of Belgium (De Wit *et al.* 2001), based on three 'Global Circulation Models' (GCM) from the Intergovernmental Panel on Climate Change (IPCC). These scenarios enabled to compute monthly increments of precipitation and temperature for the periods 2010-2039, 2040-2069 and 2070-2099. These increments were applied on 'reference historical data', to generate precipitation and temperature time series for the 21st century. After calibration and validation of the model using historical data, the use of the climate scenarios as input to the Geer basin model allowed one to compute predicted hydraulic heads and fluxes, to be compared with reference simulation (1969-1995) at observation wells (Figure 3).

Even if some of the tested scenarios led to calculated hydraulic heads that were more or less equivalent to the reference scenario, most of them predicted clear decreases. Figure 3 shows the groundwater level evolution in a specific well for the different climatic scenarios and time intervals. At this well, the largest decrease is up to 7 m, for the worst-case scenario (echam_4: German Climate research Centre). In Brouyère *et al.* (2004), impacts on the groundwater balance in the Geer basin were also evaluated. Results indicate that, for 'dry years', groundwater deficits increase; while for 'wet years', groundwater excesses decrease.

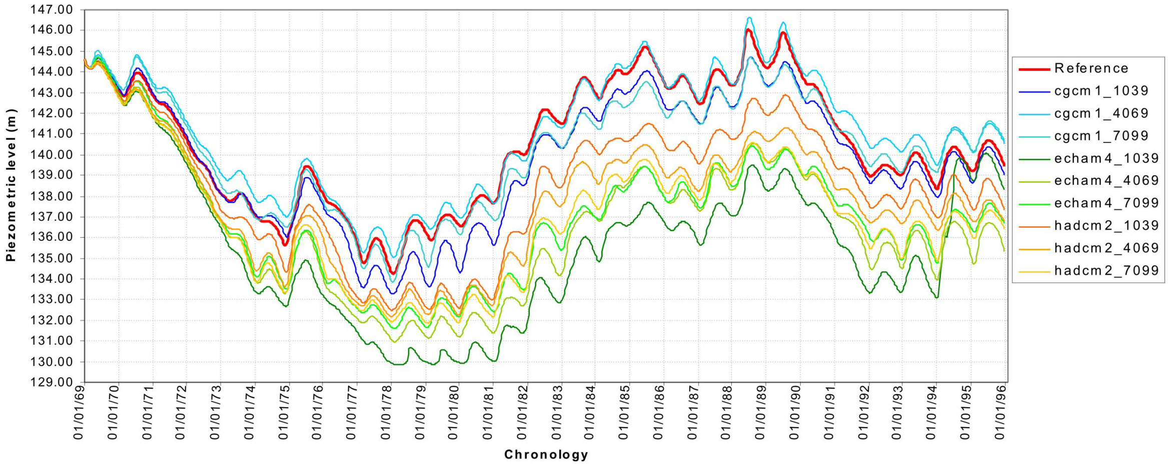

Figure 3 : simulation of groundwater level evolution in well LAN_002 for different climatic scenarios (Brouyère *et al.* 2004b)

The results presented in this study offered good reliability, largely because the groundwater model used is spatially distributed and based on physical principles describing accurately subsurface flows. More simplistic models using linear reservoirs or transfer functions can possibly substitute elaborated approaches if applied in conditions defined and verified in the calibration stage. However, any extrapolation of such simplified approaches becomes hazardous if stresses go beyond the calibration intervals, what exactly happens, by definition, for climate change issues. In this case, more relevant models are really needed. In this purpose, spatially distributed and physically based models allow more realistic calculation of groundwater fluxes.

However, some aspects of this study could possibly be improved:

- Used climatic scenarios and calculated increments enable to alter, at a monthly scale, precipitation and temperature intensities. Nevertheless, they do not modify the pluri-annual variability. As an example, the temporal distribution between 'dry years' and 'wet years', which is determinant in future groundwater reserves variations, is left unchanged. Additionally, the intensity of rain events may also change in the future and could particularly influence the groundwater recharge: melting snow cap will favor infiltrations while violent rain storms will accentuate run-off.

- The loose coupling between subsurface, surface and soil models could be a limiting factor in case of complex interactions between these three sub-domains.

- The simulations of climatic scenarios were performed keeping all other stresses constant. However, other factors may also affect indirectly but importantly the sensibility of the groundwater resource to the evolution of climate. Some of these indirect impacts may sometimes be more important than direct ones (e.g. Eheart *et* Tornil 1999). Among others, land use change, agricultural practices (e.g. irrigation), increase in water demand, changes in vegetation may surely influence future groundwater recharge and reserves.

- Impacts on groundwater quality were not examined in this study and, more generally, quality aspects in relation with climate change have been very little studied in the past. However, this issue is really of interest because water quality is a determinant factor in water management and supply policies, especially in areas where contamination problems are already observed.

The new Geer basin hydrological model under development here tries to incorporate these aspects and objectives.

3.3 Modelling tool

The Geer basin hydrological model is under development using the finite elements code 'HydroGeoSphere' (Therrien *et al.* 2005), developed by the University of Laval and Waterloo in Canada. This code allows making 3D spatially distributed simulations of variably saturated granular or fractured aquifers. It enables to fully integrate surface flow, subsurface flow and transport aspects, in a spatially distributed, physically-based manner. HydroGeoSphere is able to run with dynamic interactions between all sub-domains at each time step. It provides interesting tools to partition rainfall into components such as evapotranspiration, run-off and infiltration. The code also allows calculating water infiltration or exfiltration between rivers and aquifers. As already mentioned, all these interactions are particularly interesting in the context of climate change for which the recharge processes are very sensible and represent crucial elements for impacts estimation.

HydroGeoSphere is written in FORTRAN 95 and uses the control volume finite element approach. The module FRAC3DVS solves subsurface flow and transport equations. The surface module is based on the Surface Water Flow Packages of the MODHMS simulator. Richard's formulation is used to describe transient subsurface flow in variably saturated medium. A 2D depth-averaged approximation of the Saint Venant equations is used to describe and model surface water flows. Transport processes integrate advection, dispersion, retardation effects and decay. Newton Raphson iterations are used for resolving non linear equations.

In the unsaturated zone, several possibilities exist to relate the pressure head to the water saturation and the relative permeability: the van Genuchten functions, the Brooks and Corey functions or the use of tabular data inputs. Although the three models may be valid, it is likely that the van Genuchten relations, presented here after, will be used in the case of the Geer basin model. Parameters α and β are obtained according to soil types and from experimental results. If a more advanced approach has to be used to account for the dual porosity of the chalk, the model proposed by Brouyère (2006) could be an alternative to be coded in HydroGeoSphere.

$$S_w = S_{wr} + (1 - S_{wr})\left[1 + |\alpha\psi|^{\beta}\right]^{-\nu} \qquad \text{for} \qquad \psi < 0$$

$$S_w = 1 \qquad \text{for} \qquad \psi \geq 0$$

$$k_r = S_e^{0.5}\left[1 - \left(1 - S_e^{1/\nu}\right)^{\nu}\right]^2$$

$$S_e = \frac{S_w - S_{wr}}{1 - S_{wr}}, \qquad \nu = 1 - \frac{1}{\beta}, \qquad \beta > 1$$

S_w = Water saturation [-]
S_{wr} = Residual water saturation [-]
S_e = Effective saturation [-]
α = Van Genuchten parameter [-]
β = Van Genuchten parameter [L^{-1}]
ψ = Pressure head (water column) [L]

HydroGeosphere also offers efficient tools to simulate and estimate the water balance terms at the interface between surface and subsurface domains (precipitation – evapotranspiration – runoff – infiltration). The code allows taking account of interception by canopy, vegetation transpiration which occurs within the root zone, and evaporation at the levels of canopy, soil surface and top subsurface layers. For transpiration and evaporation calculations, it uses root and evaporation distributions, in which density functions decrease with depth. Other used parameters relate to the type of canopy and its storage capacity, potential evapotranspiration, soil moisture and some dimensionless fitting parameters. Two different approaches may be used to couple surface and subsurface flows. The 'common node approach' ensures continuity in pressure head between the two domains. The 'dual node approach' calculates water exchange terms in function of the difference between surface and subsurface water heads, and a leakance factor characterizing the ground surface.

More information is available in Therrien *et al.* (2005).

3.4 Modelling setup

3.4.1 Conceptual model

This part briefly summaries the general options and assumptions chosen before modelling operations. It conceptualizes and simplifies the real problem considering the general objectives.

The Geer hydrographical catchment defines the limits of the modeled area. The smectite clays are considered as completely impervious and the contact between clays and chalks constitutes the base of the model. Along the West, South and East boundaries, hydrogeological limits are considered to correspond to hydrographical limits. So, by definition, there are no water exchanges across these boundaries. On the contrary, groundwater fluxes through the north-western boundary must be taken into account. Along this border, hydrogeological limits differ from hydrographical ones, and water flows northwards, underneath tertiary deposits, in the adjacent basin.

The Geer River, at its confluence with the Meuse River, is considered as the main outlet of the catchment. Elsewhere along the limits of the modeled area, no superficial water exchanges are observed, as these boundaries correspond to topographical limits.

Except near the Geer River and in the northern part of the catchment, where conditions become confined under tertiary and quaternary deposits, the saturated zone is exclusively located in the chalk formations. The vadose zone is then composed by unsaturated chalk, local sandy lenses and the thick loess layer. Hydraulic properties of the chalk formations vary vertically and laterally. Lower chalks (Campanian) are usually less permeable than upper chalks (Maastrichtian). According to Dassargues and Monjoie (1993), hydraulic conductivities vary from 10^{-5} to 5×10^{-4} $m.s^{-1}$ and from 2×10^{-4} to 5×10^{-3} $m.s^{-1}$, respectively. Laterally, zones of higher hydraulic conductivity are observed and associated with 'dry valleys', oriented in the South – North direction. These zones, characterized by a higher degree of fracturation, are associated with slight drawdowns of the hydraulic head. On the largest part of the Geer catchment, the tertiary deposits lying above the chalks represent unsaturated sand lenses of small extension. Their hydraulic properties are more or less similar to chalk properties and their presence does probably not influence strongly the infiltration, more affected by the thick loess layer located above. On the contrary, at the North of the Geer River, tertiary deposits become larger and some formations are clearly clayey. These layers are responsible of the confined character of the aquifer, in the northern part of the catchment, and must not be neglected. The thick loess layer, lying above chalks and tertiary deposit, is observed all over the catchment. Characterized by a low hydraulic conductivity (between 10^{-9} $m.s^{-1}$ and 2×10^{-7} $m.s^{-1}$ (Dassargues and Monjoie, 1993), it constitutes an important part of the unsaturated zone and significantly slows down the water infiltrations from the surface to the chalky aquifer.

3.4.2 Discretisation

The hypotheses chosen in the conceptual model are used to build the three dimensional finite element mesh, made up of several layers of 6-nodes triangular prismatic elements. These elements have lateral dimensions of approximately 700 m. The top and bottom nodes layers represent the soil surface and the contact between smectite clay and chalk, respectively. Each geologic layer is discretized by, at least, 1 layer of elements. Near the water table and in the unsaturated zone, where water pressure variability may be more important, a denser discretization is required. The elevation of nodes layers, representing contacts between geologic formations (smectite clay, chalk, tertiary and quaternary deposits), is interpolated based on available information from existing boreholes. The elevations of the surface nodes are calculated using the Geer basin DTM (Digital Terrain Model) which pixels dimensions are 30×30 m (Figure 4). Based on this DTM, a triangulated mesh of the soil surface were also generated and provided by the University of Tuebingen (Germany). Hydraulic properties can vary within a same layer, in order to represent lateral variations, as observed at the level of 'dry valleys' (see above) or in other more fractured areas. In the subsurface domain, zones of constant hydraulic properties will be adjusted during the calibration step, considering geologic and hydrogeologic data. At the surface level, hydraulic parameters will be calibrated, based on the soil map (Figure 5), available for the Walloon part of the Geer basin, and land use information. All the layers of elements must be continuous on the whole modeled area. In order to discretize local formations, such as tertiary deposits in the case of the Geer basin, a thin layer is kept where the target formation does not exist. At these locations, elements have the same hydraulic properties of those from the adjacent layer (upper or lower).

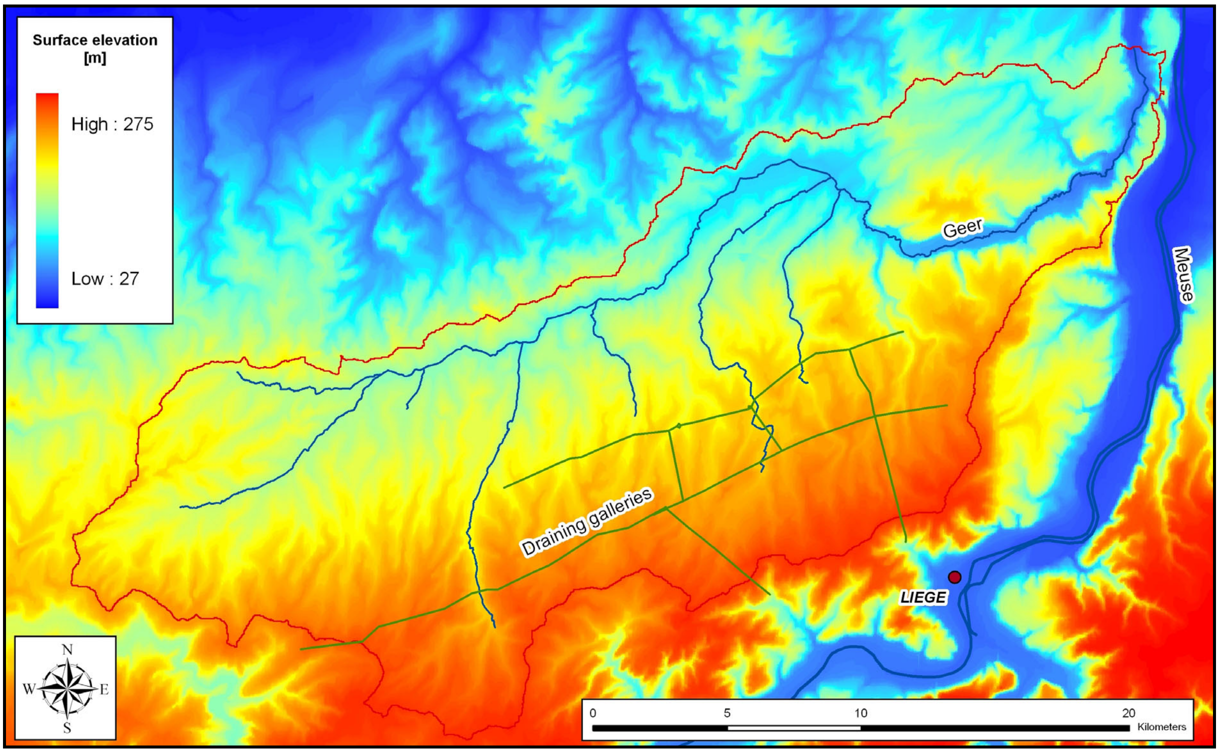

Figure 4 : Digital terrain model of the Geer basin

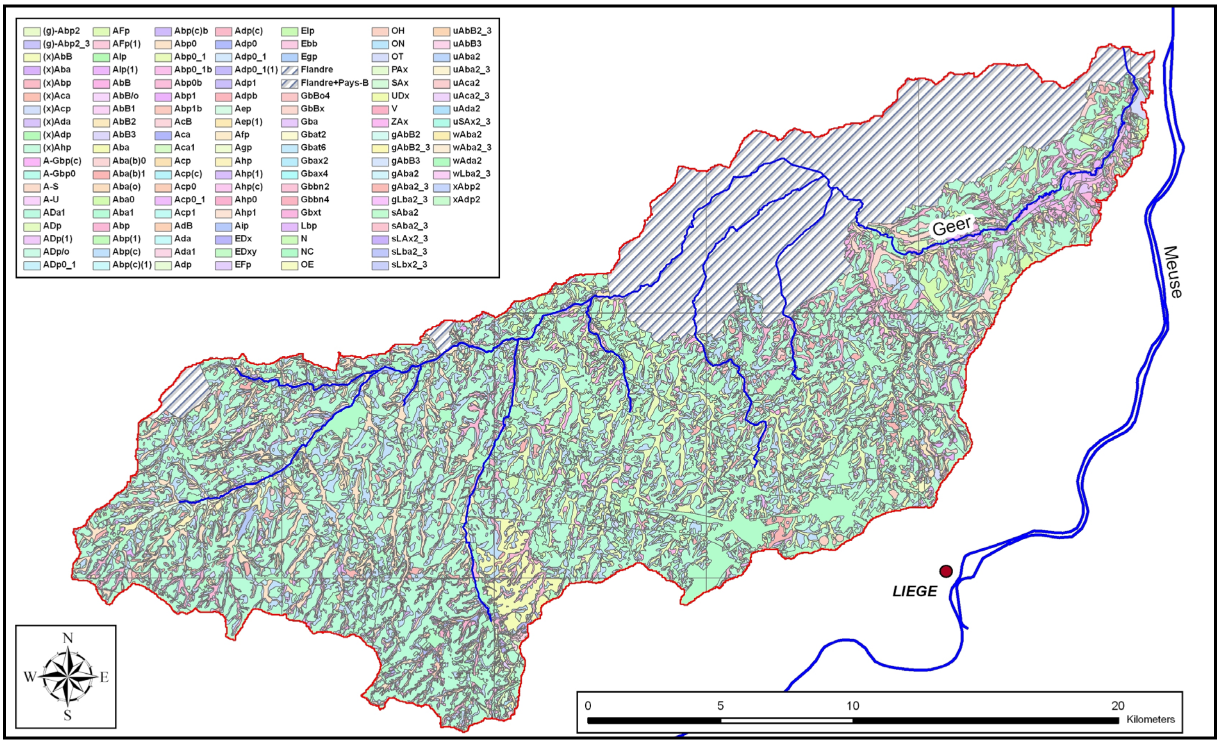

Figure 5 : Soil map of the Geer basin
(Data available only for the Walloon part of the Geer basin, not available for shaded areas)

In order to take into account of water extraction stresses applied on the Hesbaye aquifer, draining galleries and pumping wells are explicitly represented in the discretized structure (by nodes lines). Stream channels are automatically represented in the depressions of the land surface. Indeed, the surface water module of HydroGeoSphere calculates water depth and flux values for each node of the top most layer, based on the topography and the nodes hydraulic properties. The streams positions can thus be implicitly retrieved by considering the nodes where the water depth is not equal or very close to zero.

Boundary conditions represent the strict application of the assumptions described in the conceptual model. Generally, three kinds of boundary conditions may be applied on subsurface nodes. They can be constant or vary according to time.

- *Dirichlet condition*: impose a prescribed hydraulic head value (or pressure head). Exchanged fluxes between external and modeled domains are calculated according to these prescribed heads.

- *Neumann condition*: impose a prescribed water flux value. Corresponding hydraulic heads are calculated during the simulation.

- *Cauchy condition*: impose a linear relationship that specifies water fluxes according to pressure head variations. This condition is usually used to model interactions between river and aquifer.

No-flow Neumann conditions are applied on subsurface nodes belonging to Western, Southern and Eastern boundaries. Cauchy conditions are applied on the subsurface nodes of the Northern boundary. This type of boundary condition enables to simulate the water losses to the adjacent North catchment.

For subsurface domain, HydroGeoSphere enables to impose several types of boundary conditions for surface water modeling.

- *Dirichlet condition*: impose prescribed water depth values on nodes.

- *Neumann condition*: impose prescribed water flow rate values on nodes.

- *Zero-depth gradient condition*: force the slope of the water level to equal the bed slope.

- *Critical depth condition*: force the water depth at the boundary to be equal to the critical depth.

No-flow Neumann boundary conditions are applied along the hydrographical limits of the Geer basin. Critical-depth boundary conditions are applied on the few nodes corresponding to the catchment's outlet (at the confluence between the Geer and the Meuse Rivers).

3.4.3 Stress parameters

Stresses on the Geer catchment consist in precipitations and groundwater abstraction.

Water collected through the 70 km of draining galleries represents the biggest part of groundwater abstraction in the Geer basin. Other pumping wells belonging to water supply companies or farmers are located all over the basin. Extracted volumes data, from the most important production sites, have been collected by the Walloon administration and are updated annually (for more details, see Orban *et al*., 2006a).

In the context of climate change impacts assessment, special care is devoted to using precipitation and temperature data for assessing as accurately as possible the recharge rate. Historical climatic data are available for several stations located inside or in the vicinity of the Geer basin (Figure 6). Records begin from 1960, for the oldest stations, to 2005 (more details in Orban *et al*. 2006a). In order to analyze the effects of climate change on groundwater resources, extrapolated climatic scenarios have to be used. In previous studies, different methods were tested, from simple sensitivity analysis (Allen *et al*. 2003) to the use of more sophisticated scenarios (Brouyère *et al*. 2004b, Yussof *et al*. 2002) obtained by the application, on historical data, of monthly scaling factors. As already evoked in Chapter 3.2, this approach constitutes a serious simplification of simulated climate changes. Incrementing historical data does not change the frequency of dry and humid periods. Fowler *et al*. (2003) have improved climatic models in order to enable variability in the frequency and persistence of some meteorological events. Within Workpackage HYDRO H1, the University of Newcastle Upon Tyne has produced new climatic scenarios integrating these aspects, for the Geer basin case study. A simple bias-correction method of regional climate model data were used to generate precipitations and temperatures, at a weekly time step, for three different periods (2010-2040, 2040-2070 and 2070-2100). Observed data from 1961 to 1990 were used as a baseline for calculation, and only stations presenting a reasonable length of records were selected. The following stations present complete 30 years time series, for precipitation (P) and/or temperature (T):

- Ans (P) (X = 232055 m, Y = 150597 m)[1]
- Awirs (P) (X = 223700 m, Y = 144138 m)
- Bierset (T,P) (X = 226460 m, Y = 147928 m)
- Jeneffe (P) (X = 220260 m, Y = 149000 m)
- Maastricht (T, P) (X = 249561 m, Y = 179371 m)
- Visé (P) (X = 243005 m, Y = 160143 m)
- Waremme (P) (X = 212400 m, Y = 154500 m)

Lacking data in the precipitation time series available for the Riemst (X = 235550 m, Y = 166518 m), Juprelle (X = 230914 m, Y = 155832 m) and Fumal (X = 207468 m, Y = 145183 m) stations were completed by using correlations with nearby stations. Data from Thisnes-Hannut (X = 200702 m, Y = 151149 m), Fize-Fontaine (X = 214719 m, Y = 142011 m) and Rutten (X = 225355 m, Y = 160520 m) stations cannot be used due to too short recorded time series.

[1] Projected coordinate system: Belgian Lambert 1972

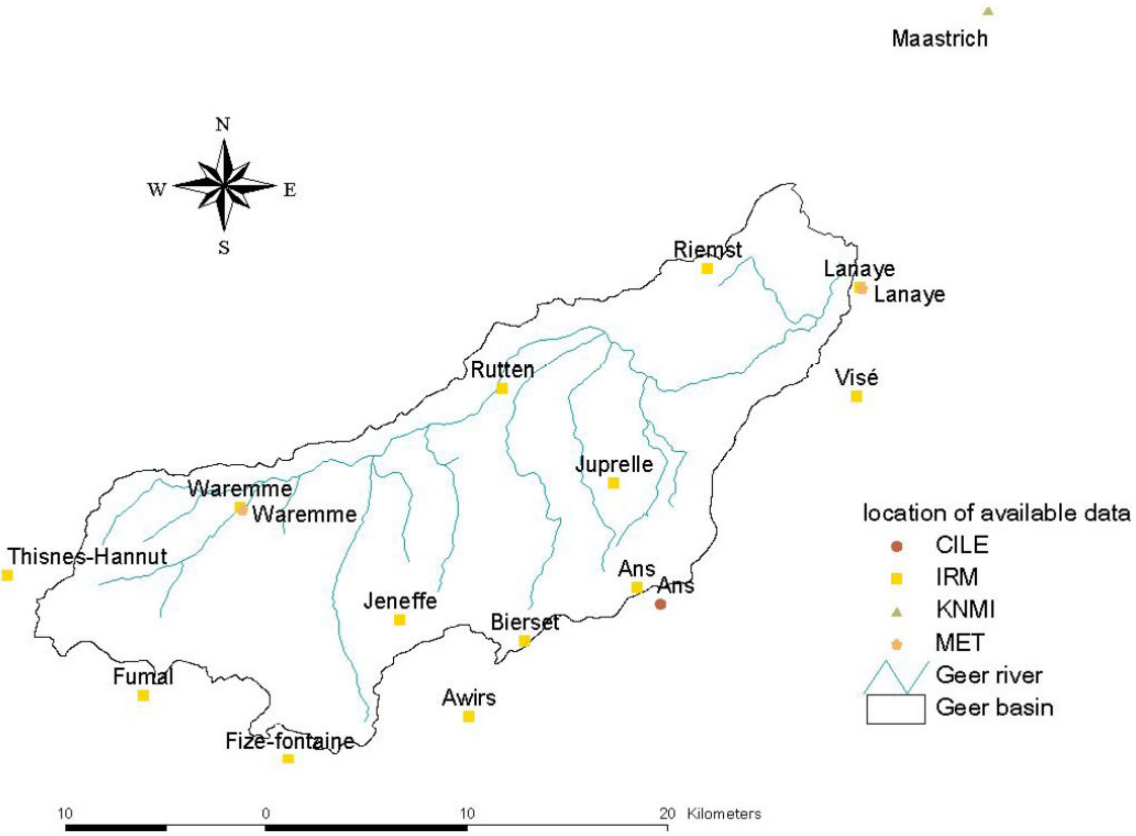

Figure 6 : Location of available climatic data (from Orban *et al*. 2006a)

Potential evapotranspiration is available for the Bierset station, where complete climatic data are recorded. For other stations and future climatic scenarios, the Thorntwaite equation will be used for potential evapotranspiration calculation, which calibration of the fitting parameters may be performed based on land use and pedology information. Other approaches, such as the Penmann method, require more data, not available in this case.

3.5 Calibration

A first calibration of the Geer model is performed in steady state conditions, using two contrasted situations: high groundwater levels (year 1983-1984) and low groundwater levels (year 1991-1992). It is also planned to perform a transient calibration, on a 30 years period. As described by Orban *et al*. (2006a, deliverable Basin R3.16), numerous observed data exist for the last few decades and are available for calibration. Groundwater level data have been recorded in more than 250 points in the Geer basin through time. Although some of them represent only punctual measurements, very long time series also exist, sometimes for more than 50 years. Surface water flow rates are measured hourly in five locations, since 1985 approximately.

3.6 Simulations

Using the calibrated model and the generated climatic scenarios, direct climate change impacts will first be evaluated on the period 2010-2100. Special concerns will be dedicated to quantitative effects on the Hesbaye aquifer. The objective is to analyze groundwater variations under changing climate, and to evaluate the aquifer resources available for exploitation. The problem is more particularly to assess whether the current exploitation rate of the aquifer is still possible and sustainable under new climatic conditions. Regarding these changes, impacts on surface water streams could also be examined, especially during drought periods. As a second step, a transport model should be implemented to evaluate climate change impacts on water quality. More particularly the evolution of nitrate contamination should be examined. Other factors may also affect indirectly but importantly the sensitivity of groundwater resources to the climate evolution. Vegetation evolution, agricultural practices, land use may influence water recharge or even the exploitation rate of groundwater. These indirect impacts could be more important than direct ones. Some of them are difficult to integrate in the study but others, like an increase in water demand, intensification of irrigation practices by groundwater extraction or land use changes, could more easily be tested.

4. Conclusions

The Geer basin model, for climate change impacts assessment, is under development. This intermediate report describes the general hypotheses and assumptions chosen the build the numerical model, and the general objectives of the study. Using sophisticated climatic scenarios, generated in collaboration with HYDRO H1, the goal is to estimate direct quantitative impacts of climate change on groundwater resources. As far as possible, impacts on water quality and nitrate contamination, as well as some indirect impacts, are also attempted to be evaluated. The results of this work will serve as input to INTEGRATOR.

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