

PHYSICALLY-BASED GROUNDWATER VULNERABILITY ASSESSMENT FOR GROUNDWATER PROTECTION AND LAND-USE MANAGEMENT

I.-C. Popescu^{1,2}, S. Brouyère², J. Derouane¹, A. Dassargues²

¹ Walloon Public Services, Directorate-General Agriculture, Natural Resources and Environment, Environment and Water Department, Groundwater Service, 15 Avenue Prince de Liège, B5100 Jambes – Namur, Belgium

² Université de Liège, Dpt ArGenCo Geo3- Hydrogeology and Environmental Geology & Aquapôle, Building B52/3, 4000 Sart Tilman, Belgium
Serge.Brouyere@ulg.ac.be,

1. Context and Objectives

- Groundwater vulnerability maps = useful tools for groundwater protection, pollution risk management and land-use planning
- Most common techniques empirical, based on fuzzy concepts, using weighting and rating methods → no clear results (colour maps) difficult to use for decision-making
- needs for advanced concepts and methodologies for groundwater vulnerability assessment, with quantifiable, physically-based criteria

→ Development of the **APSU Method** (for **A**quifer **P**rotection based on **S**ensitivity – vulnerability) applicable to aquifer and groundwater bodies of Wallonia, including karst aquifers

2. Physically-based groundwater vulnerability assessment

If a pollution is likely to occur somewhere in a catchment, what is the potential sensitivity of the groundwater resource to this pollution?

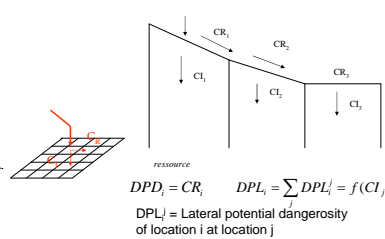
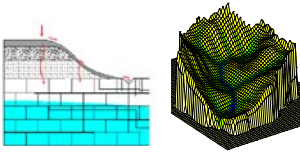
→ Identify relevant questions to be answered and associated physically-based criteria for groundwater vulnerability assessment

| | | |
|---|---|--|
| Which quantity of contaminant is likely to reach groundwater? | → Infiltration capacity of water and contaminant (how much and where?) → attenuation capacity of the underground | → Infiltration and runoff components at each location of the catchment + potential contaminant dispersion on the land surface → degradation, transformation, sorption of contaminants |
| What are the potential consequences for groundwater quality / management / use? | → Travel time of contaminant to groundwater → potential duration of the pollution event → pollution level | → Contaminant transport and dispersion in the underground |

3. The APSU Method : General concepts

Land surface dangerousity (at location i)
Water and contaminant infiltration capacity based on land surface properties

- Direct potential dangerousity (DPD_i): direct infiltration of water and contaminants at the pollution location
- Lateral potential dangerousity (DPL_i): lateral infiltration of water and contaminants after runoff



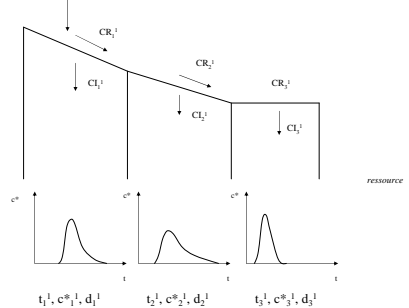
$$DPD_i = CR_i \quad DPL_i = \sum_j DPL_j^i = f(CI_j)$$

$$DPL_j^i = \text{Lateral potential dangerousity of location } i \text{ at location } j$$

$$\text{Total potential dangerousity at location } i: DP_i = DPD_i + DPL_i \quad 0 \leq DP_i \leq 1$$

$$\text{Cumulative lateral potential dangerousity at location } j: DPLC_j = \sum_i DPL_j^i$$

Groundwater vulnerability (at location i)
Groundwater vulnerability = Potential dangerousity « weighted » by attenuation capacity



$$\text{Weighted first arrivals} \quad t_i = DD_1 d_1^i + DL_2 d_2^i + DL_3 d_3^i$$

$$\text{Weighted attenuations} \quad c_i^* = DD_1 c_1^i + DL_2 c_2^i + DL_3 c_3^i$$

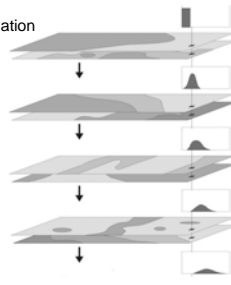
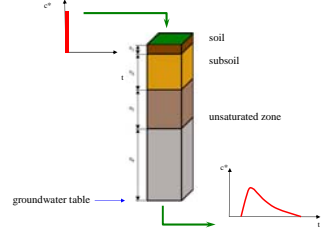
$$\text{Weighted durations} \quad d_i = D_{11} d_1^i + D_{12} d_2^i + D_{13} d_3^i$$

| Vulnerability class | high | moderate | low | |
|-------------------------|-------------------|--------------------|----------------|---------|
| critera | | | | |
| Travel time | short (e.g.: 24h) | medium (e.g.: 50d) | long (e.g. 1y) | → V(t) |
| Contaminant attenuation | low | moderate | large | → V(c*) |
| Pollution duration | long | medium | short | → V(d) |

Final vulnerability map: $V = \alpha V_t + \beta V_c + \gamma V_d$

Underground attenuation capacity (at location i)

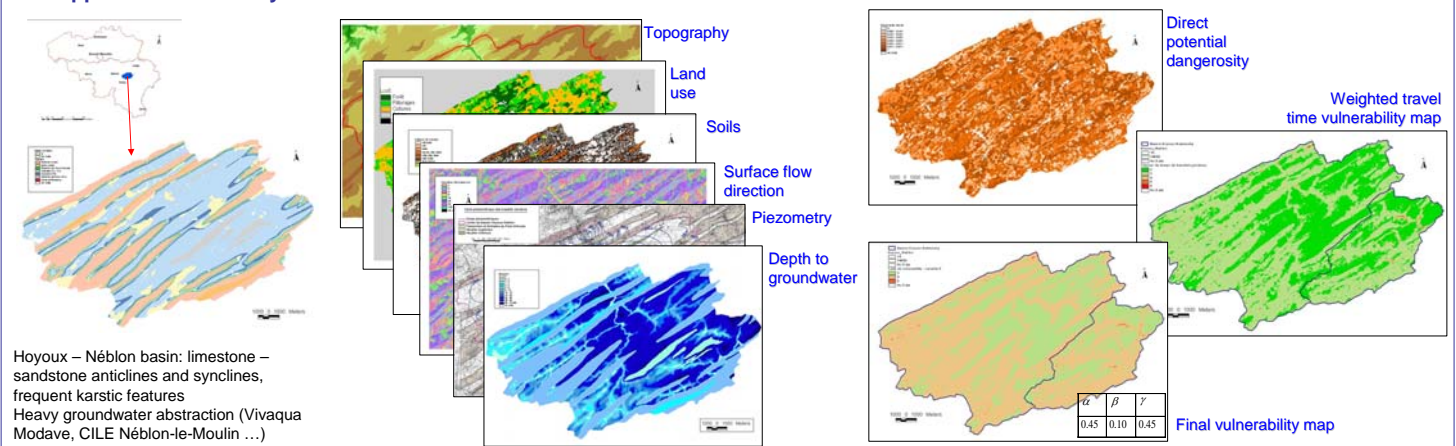
- 1D vertical contaminant leaching through the unsaturated zone
- Intrinsic vulnerability : no sorption, no degradation
- 1D advection – dispersion equation



$$\frac{\partial(n_e c)}{\partial t} = \frac{\partial}{\partial z} \left(D \frac{\partial c}{\partial z} \right) - v_e \frac{\partial c}{\partial z}$$

- In each pixel i:
- Contaminant 1st arrival t_i
 - Contamination duration $C_i^* = C_i^{\max} / C_0$
 - Concentration attenuation d_i

4. Application to the Hoyoux – Néblon Basin



Hoyoux – Néblon basin: limestone – sandstone anticlines and synclines, frequent karstic features
Heavy groundwater abstraction (Vivaqua Modave, CILE Néblon-le-Moulin ...)

5. Conclusions

- Physically-based, yet simple to use APSU method provides useful maps for groundwater vulnerability and related concepts → groundwater protection at catchment to water body scale, land-use planning, risk assessment
- Groundwater intrinsic vulnerability concepts easy to extend to specific vulnerability of contaminants (pesticides ...) by considering specific processes such as sorption and degradation in soils and for risk assessment by superposition with land use maps
- Other applications performed : Berwinne catchment, Kou basin in Burkina Faso ...