

Towards a General Methodology for Groundwater Protection

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Serge Brouyère & Ileana-Cristina Popescu



Presentation Summary

- Groundwater Pollution vs Groundwater Protection
- Groundwater protection zones
- Groundwater vulnerability assessment
- Generalized groundwater vulnerability & DPSIR
- Conclusions

GW Pollution vs GW Protection

- Location of groundwater in the underground:
 - ➔ Protection generally efficient but not perfect!

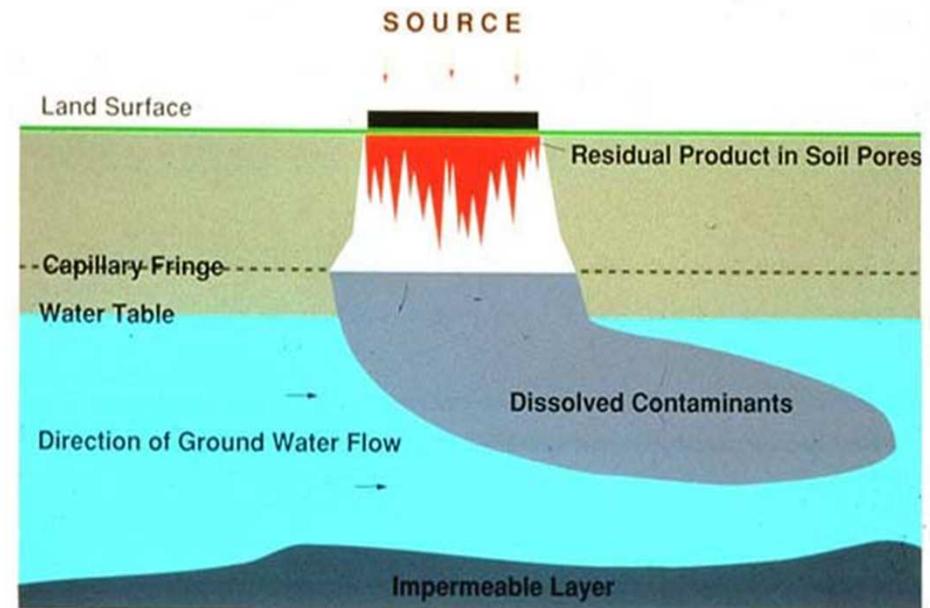
- Surface water: easily contaminated but fast renewal rate

- On the contrary, groundwater are often characterized by very long residence times (from years to decades or more)
 - ➔ When polluted, very difficult to solve the problem posed by the presence of contaminants in groundwater

GW Pollution vs GW Protection

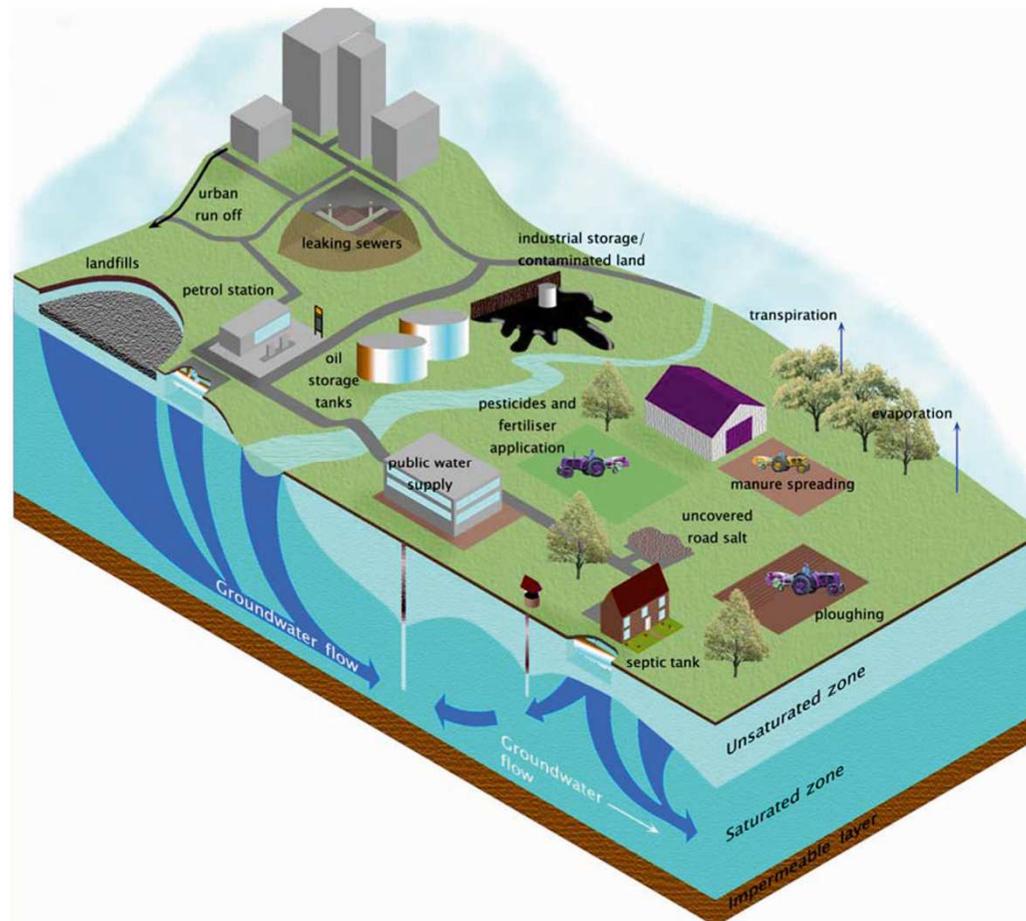
□ Optimal protection =

- to understand, identify and quantify the processes that govern the mobility of water in the underground
- To understand the mechanisms that govern the fate of contaminants in the underground
 - Migration processes
 - Retardation processes
 - Reaction processes



GW Pollution vs GW Protection

- Optimal protection =
 - To identify the potential risks and sources of pollution in the groundwater basin



GW Pollution vs GW Protection

□ Optimal protection =

before

during

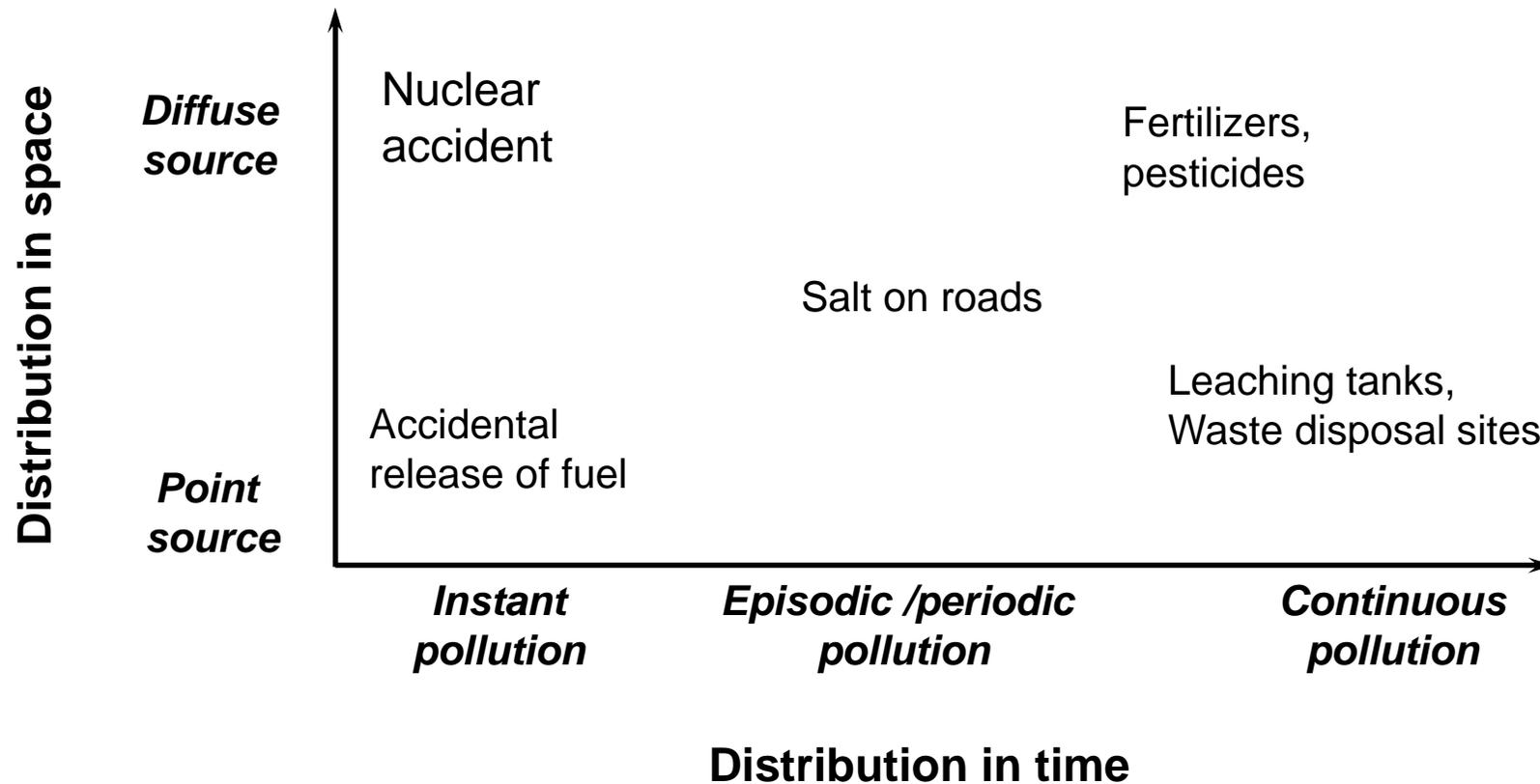
after



- **Prevention:** minimize the risk that pollutants be spread in the environment and contaminate groundwater, at least to have the time required to intervene
- **Natural protection:** whenever a pollution occurs despite the preventive measures, to have tools for evaluating the natural attenuation capacity of the underground (retardation, reaction, degradation, dispersion, dilution...)
- **Remediation:** if the underground medium is not « able » to face the pollution problem, to have techniques and knowledge on how to remediate « artificially »

GW Pollution vs GW Protection

□ Pollution types

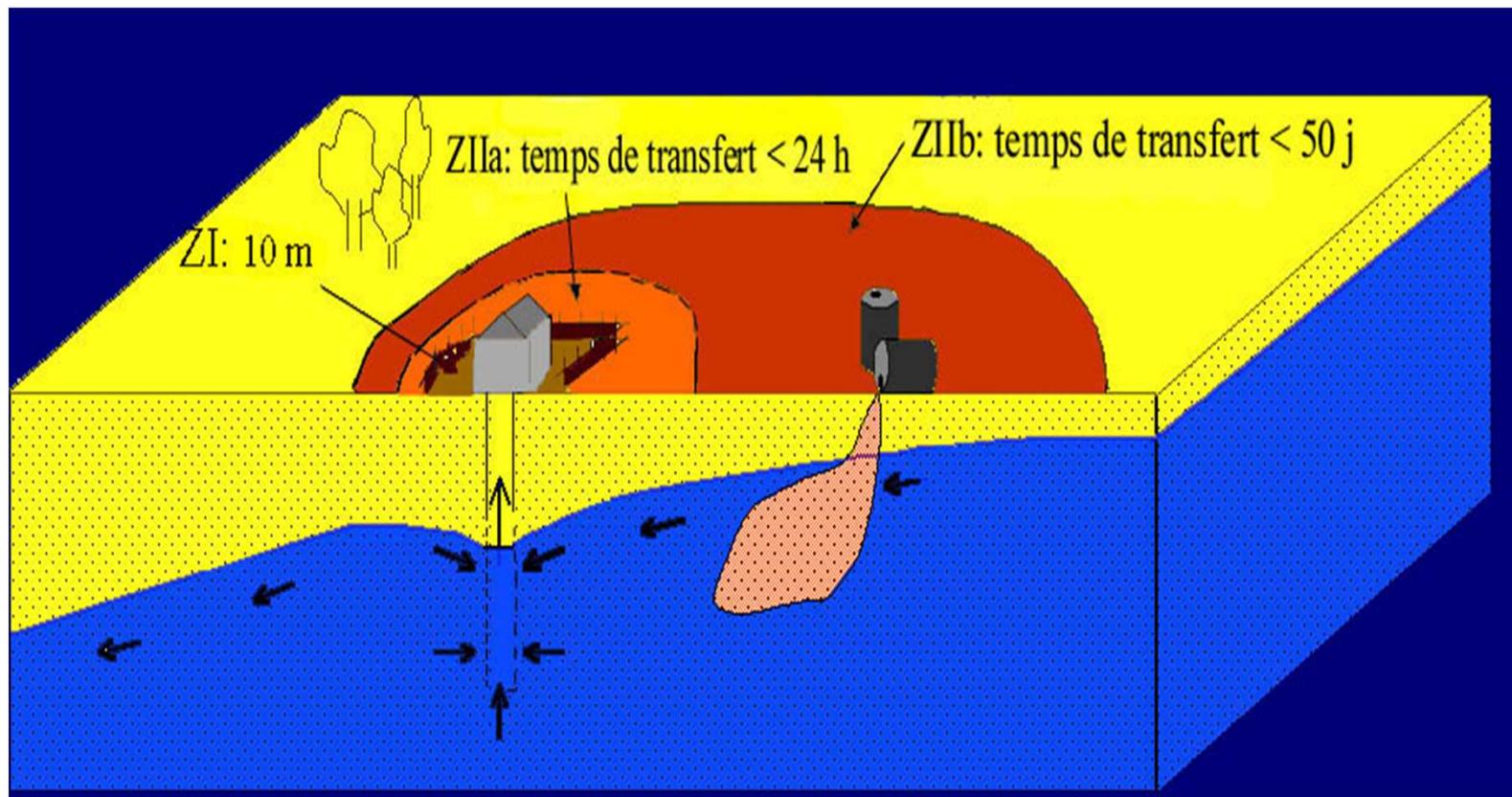


Groundwater Protection Zones

- In the Walloon region (and in other regions!), protection zones defined around each GW abstraction point:
 - GW abstraction zone (Zone I)
 - minimum 10 m around the water catchment installation
 - « Close » prevention zone (Zone IIa)
 - pollutant travel time of 24 h in the saturated zone towards abstraction point or min 35 m around
 - « Extended » prevention zone (Zone IIb)
 - pollutant travel time of 50 days in the saturated zone towards abstraction point or default distances (100,500 ou 1000 m depending on geology)
 - Monitoring Zone (Zone III)
 - (part of) groundwater catchment

Groundwater Protection Zones

- In each zones: regulations on product storage and spreading, equipments, activities...



Groundwater Protection Zones

□ Advantages ...

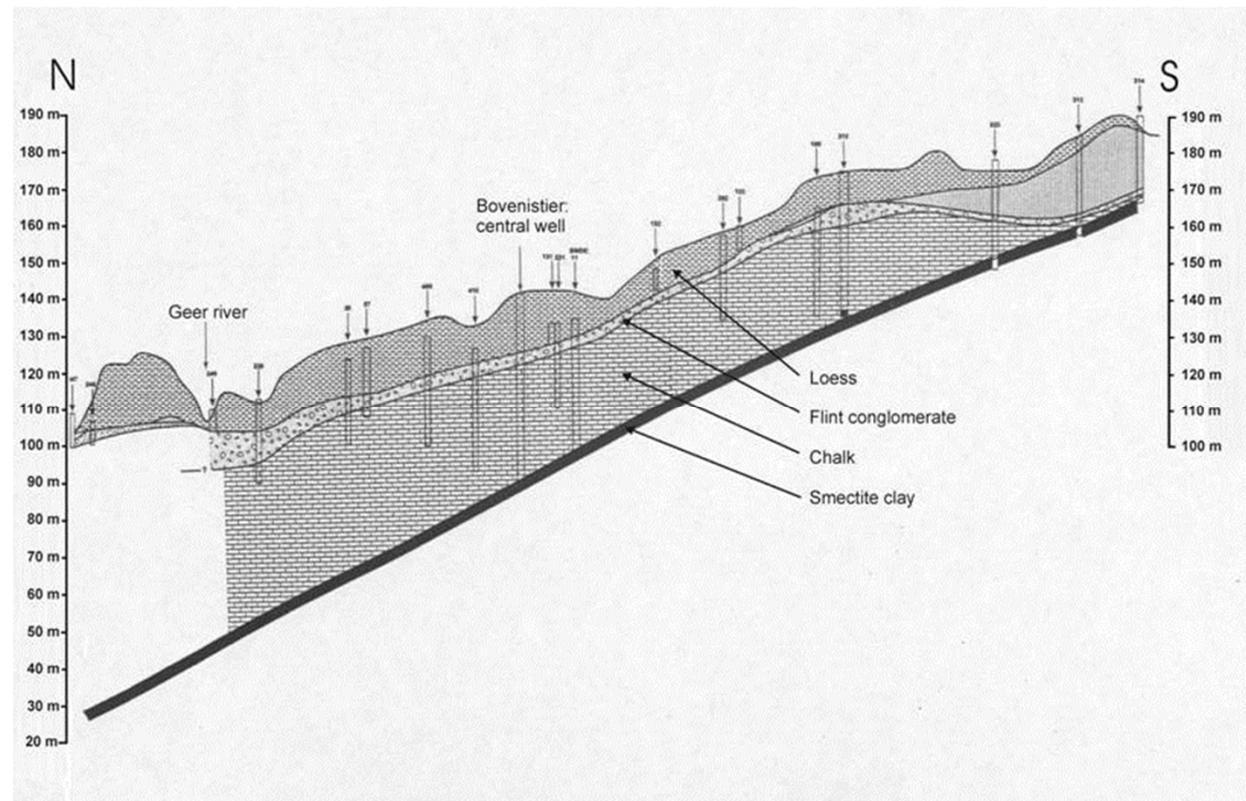
- GPZ based on a physical criteria: **travel time**
- Theoretically « easy » to determine... e.g.: tracer tests and groundwater flow & transport modelling

□ ... and Drawbacks

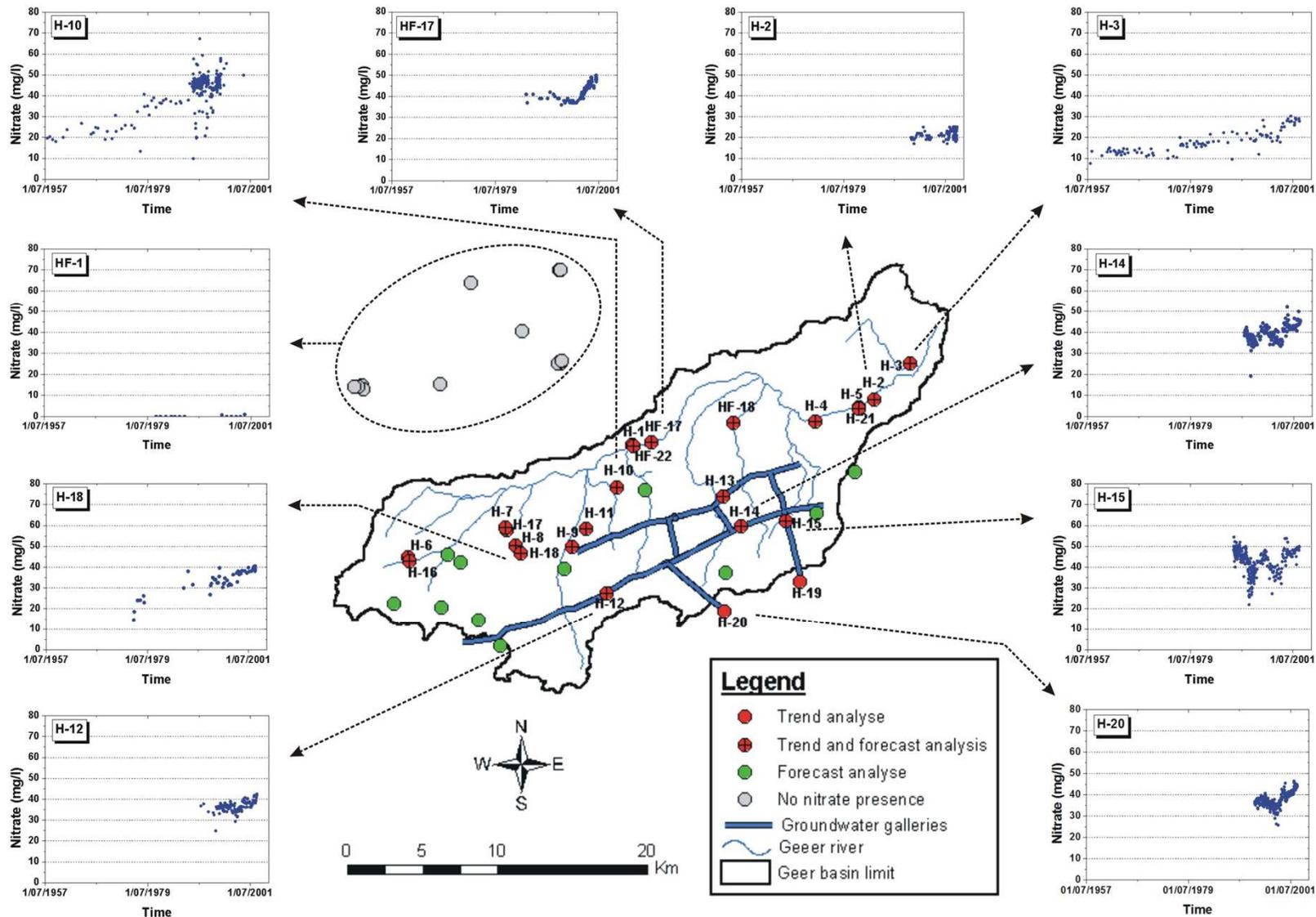
- GPZ not adapted to all contamination issues: how to compute a travel time for a diffuse pollution?
- GPZ do not consider the protective capacity of the unsaturated zone, nor attenuation processes

Groundwater Protection Zones

- The Geer basin in Belgium ($\sim 400 \text{ km}^2$)
 - 40 km of pumping galleries in a fractured, dual-porosity chalk
 - Intensive agriculture all over the basin (nitrates etc)



Groundwater Protection Zones



Groundwater Protection Zones

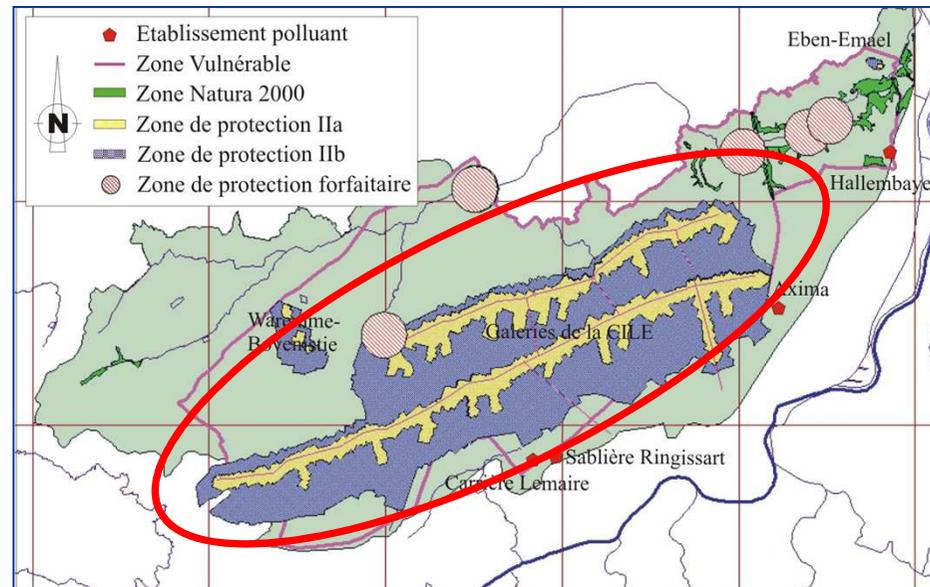
□ The Geer basin in Belgium

- GPZ defined based on tracer experiments in the vicinity of the galleries + GW flow & transport modelling
- Very fast tracer travel times across the fractures, of the order of m/day to m/h!
...to be compared to travel times in the thick unsaturated zone (1m/year)

Groundwater Protection Zones

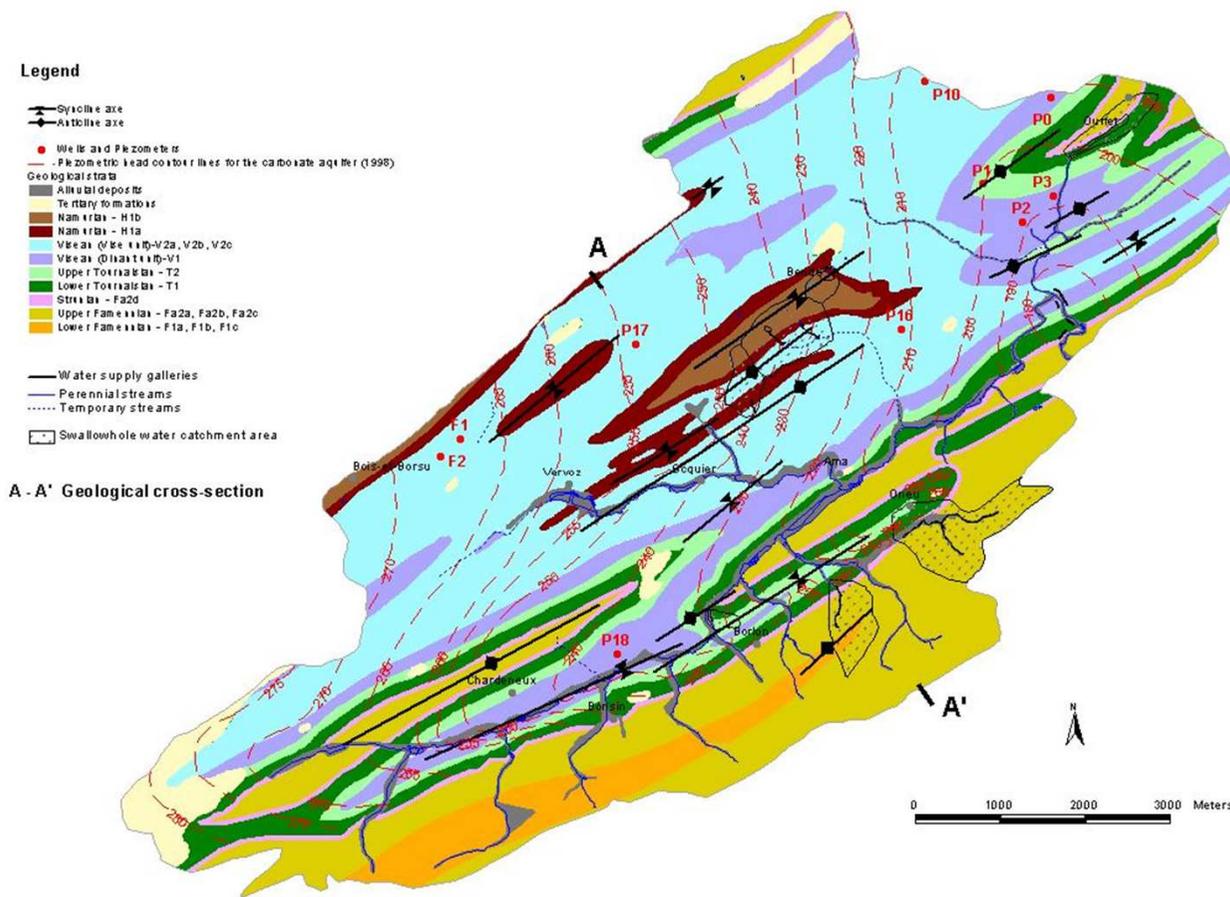
□ The Geer basin in Belgium

- Very large protection zones along the fractured axes (>>100 km²!)
- Excessive budget required to making the activities comply with the regulation
- Unsuited for the problem with nitrates
- Other regulations/ infos considered, e.g. NO₃ vulnerable zones, loess thickness etc



Groundwater Vulnerability

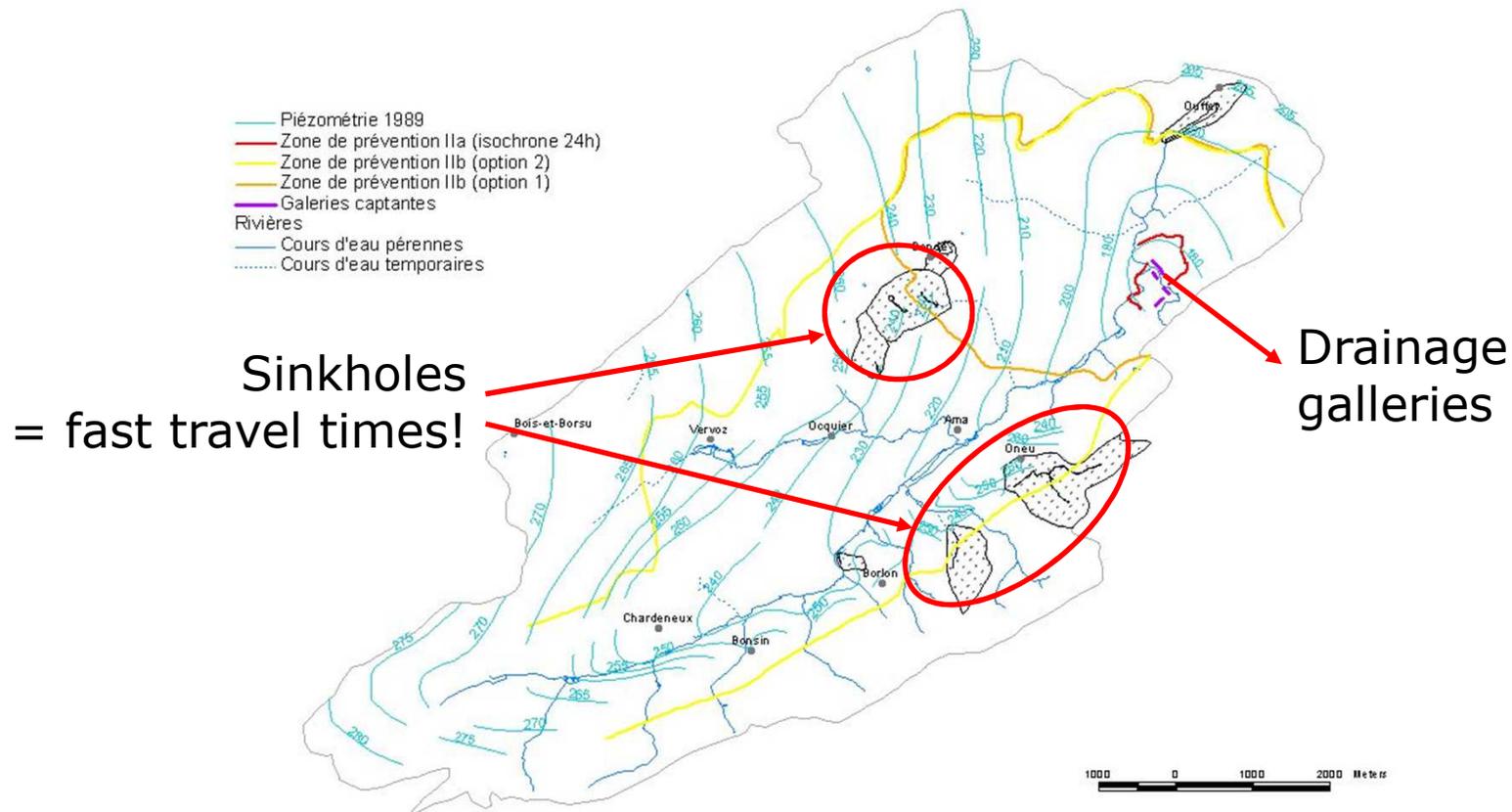
□ e.g. the Néblon basin in Belgium



Groundwater Protection Zones

□ Néblon basin in Belgium

- Quid in karstic basin? Relevance of travel times?



Zones de prévention des galeries captantes de Néblon (Derouane, 1995)

Groundwater Vulnerability

- To evaluate and to map the spatial variability of groundwater sensitivity to contamination / protective capacity of the underground medium
- Contrarily to protection zones, not restricted to the saturated zone, also (mainly!) considers the unsaturated zone
 - **Resource vulnerability:** impact on GW seen as a whole of a contamination occurring at the land surface (unsaturated zone)
 - **Source vulnerability:** impact on GW abstraction or discharge points of a contamination occurring at the land surface (unsaturated + saturated zone)

Groundwater Vulnerability

Risk assessment

Specific vulnerability

Intrinsic vulnerability

inherent geological, hydrological and hydrogeological characteristics that control the impulse response of the aquifer system to a Dirac-type input of conservative contaminant

+ chemical behaviour of contaminant
in the underground

- + mass of contaminant
- + critical concentration
- + input function

Groundwater Vulnerability

□ Advantages ...

- Considers also the effect of the unsaturated zone (often predominant!)
- Potentially deals with any kind of contaminant source (point or diffuse)
- Well suited for use with GIS

□ ... and Drawbacks

- GWV methods are most often very empirical (rating and weighting methods)
- No clear definition and criteria for the concept of vulnerability
- Results difficult to validate, to interpret and thus to use in practice

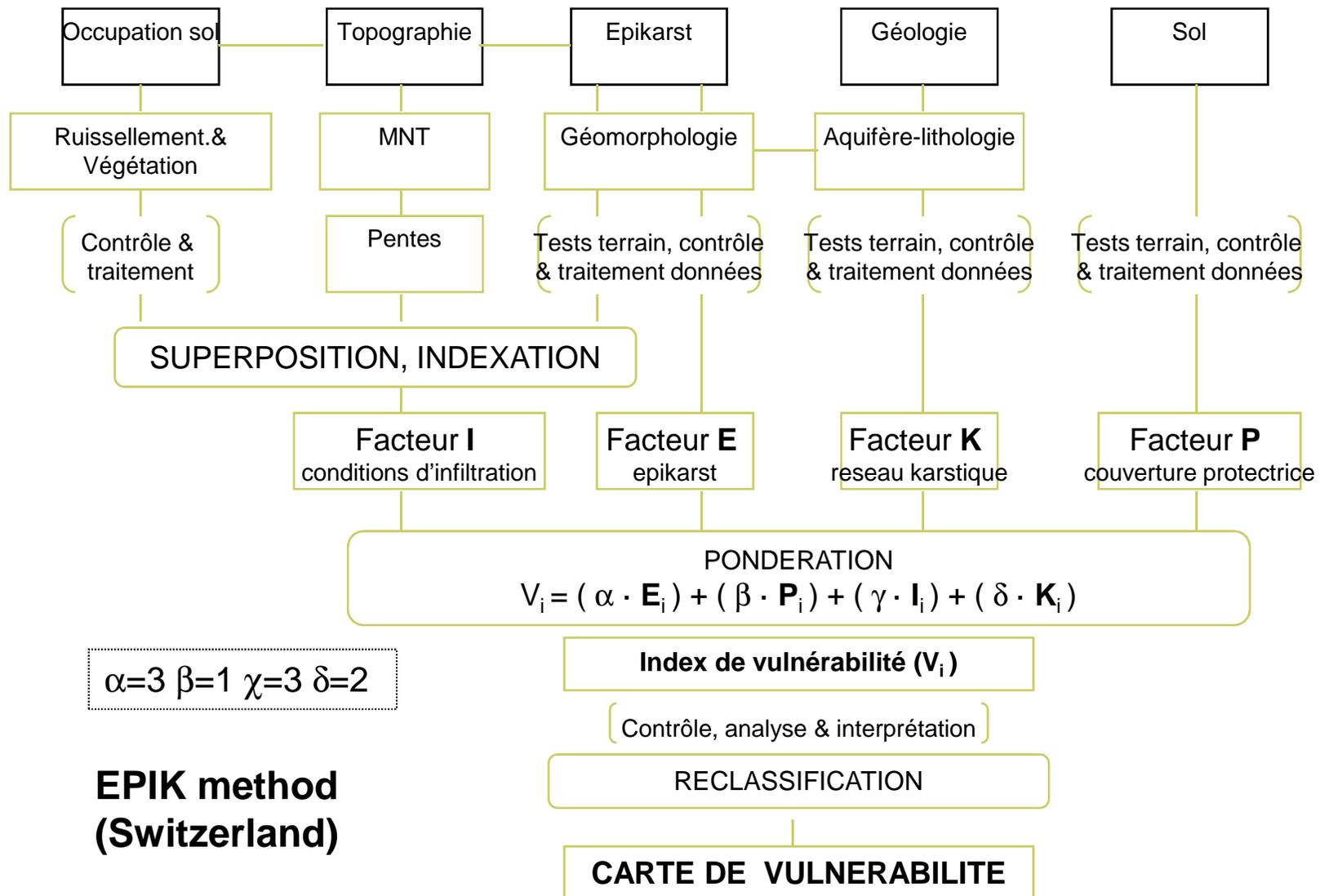
Groundwater Vulnerability

□ E.g. the DRASTIC method (EPA-USA)

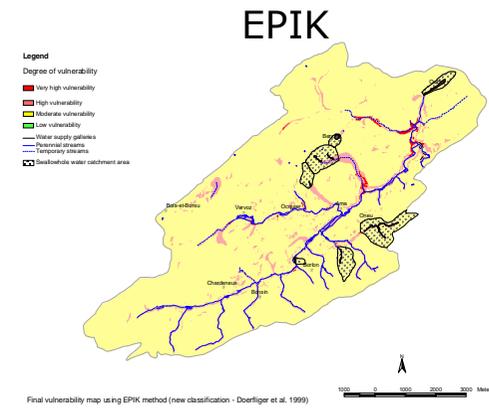
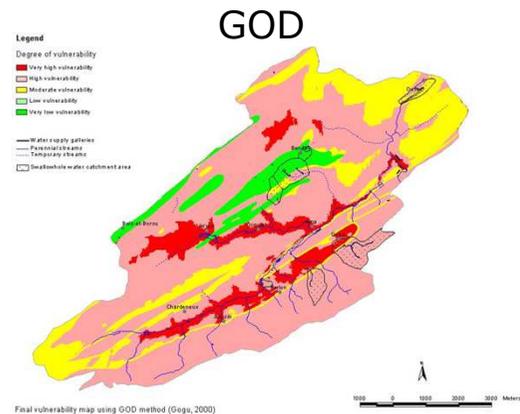
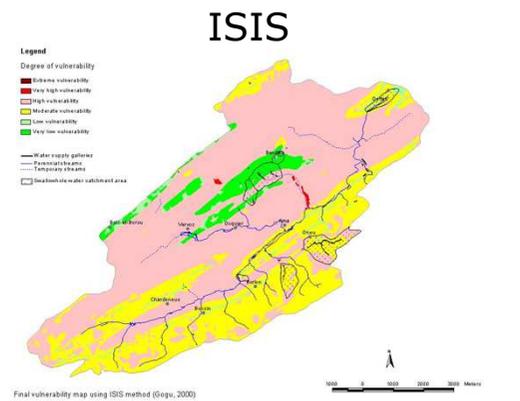
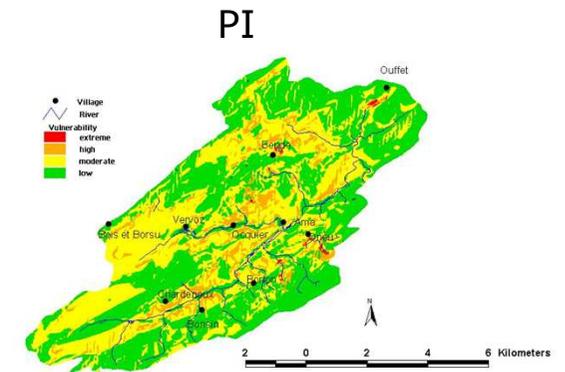
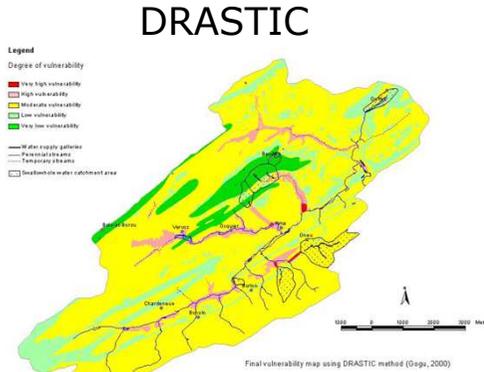
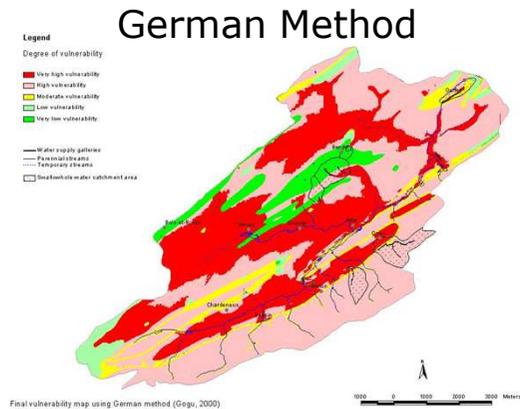
		DRASTIC	Pesticide DRASTIC
» D epth to water		5	5
» Net R echarge	Indexation	4	4
» A quifer media		3	3
» S oil media	1, 2, 3, ..., 10	2	Pondération 5
» T opography		1	3
» I mpact of the vadose zone		5	4
» Hydraulic C onductivity		4	2

$$D_i = \sum_{j=1}^7 (R_j \times W_j)$$

Groundwater Vulnerability



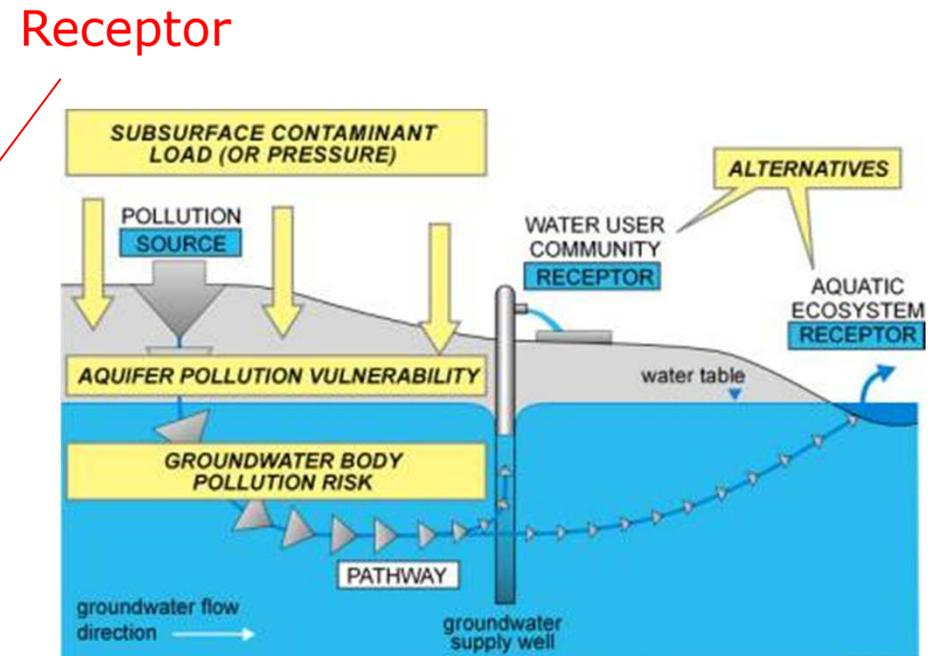
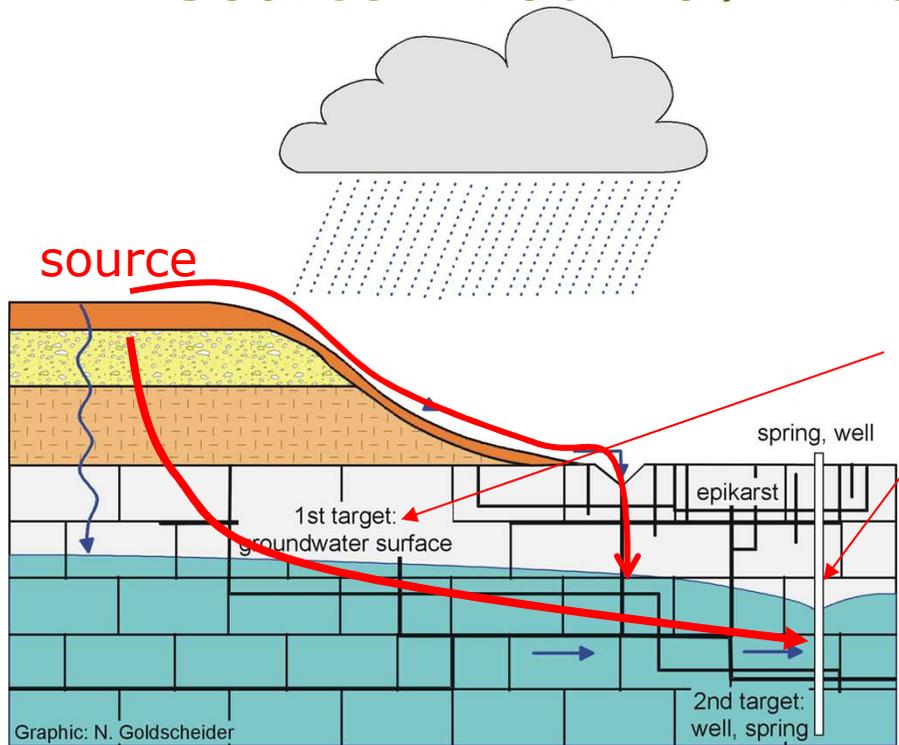
Groundwater Vulnerability



6 GWV methods → 6 completely different GWV maps!

Groundwater Vulnerability

- Physically based GW Vulnerability mapping
 - Source – Pathway – Receptor approach



Groundwater Vulnerability

□ Physically based GW Vulnerability mapping

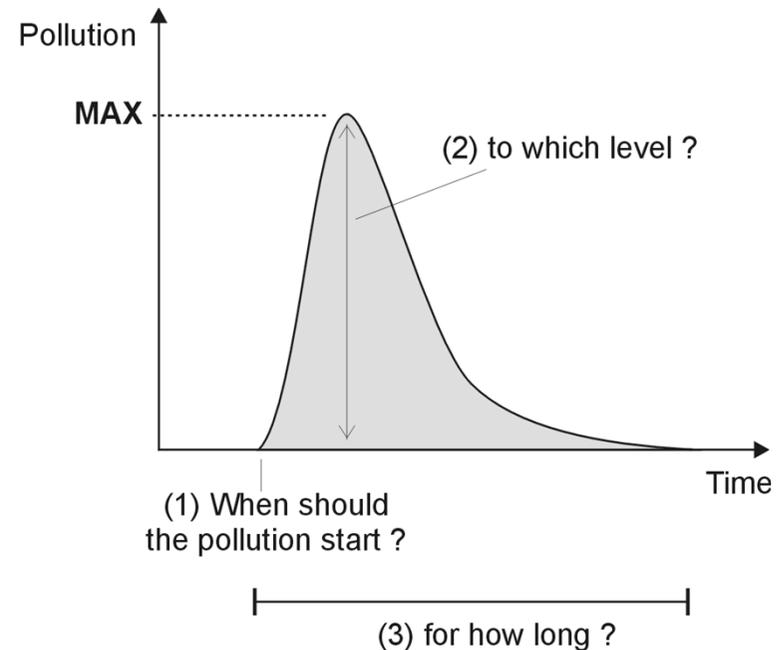
□ Protection zones : If a pollution occurs somewhere, how long to fix the problem ?

□ Vulnerability : If a pollution is likely to occur :

(1) **when** could the contaminant reach the target ?

(2) **For how long** could the target be contaminated?

(3) **To which extent** could the target be contaminated ?

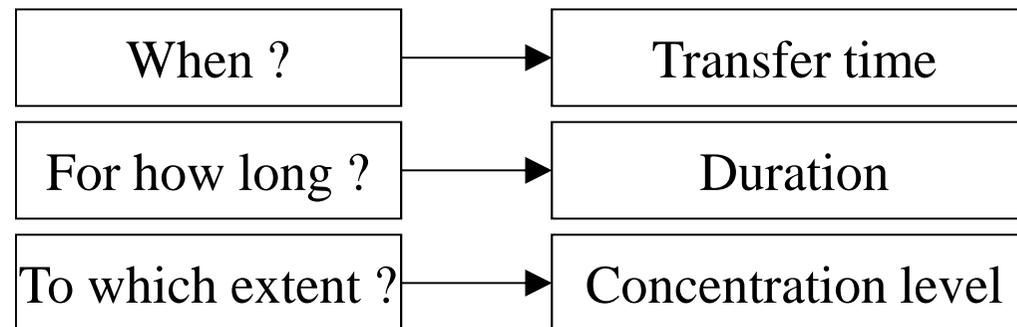


Groundwater Vulnerability

- Aspects to be considered in order to quantify intrinsic vulnerability :
 - Advective transport time;
 - Contaminant attenuation (dispersion, dilution, retardation ...);
 - Relative quantity of contaminants that can reach the target (a portion of the contaminants may never reach the target but might leave the catchment in surface runoff).

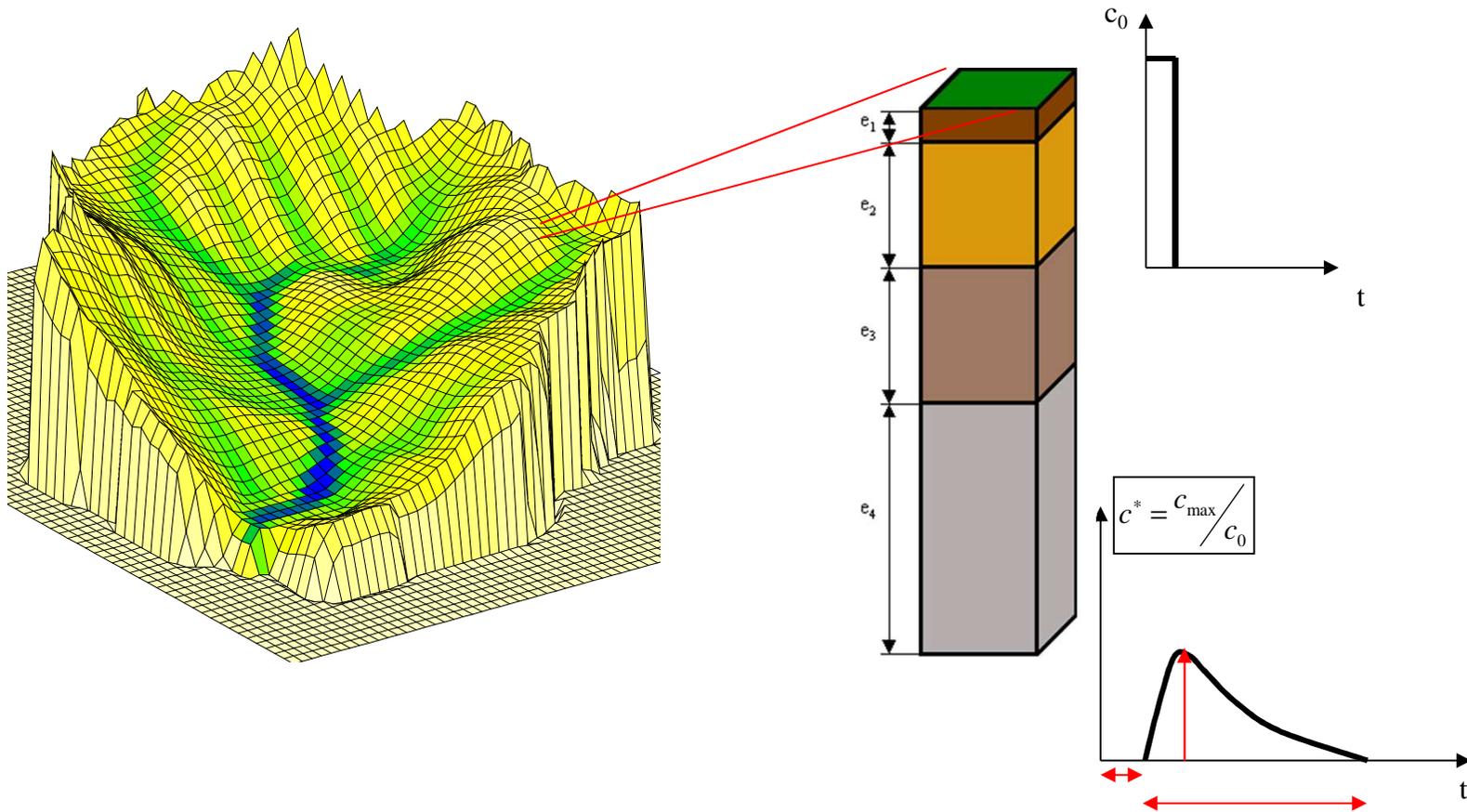
Three questions

Three contamination
describing criteria



Groundwater Vulnerability

- Calculation of vulnerability criteria by modelling transport of contaminants

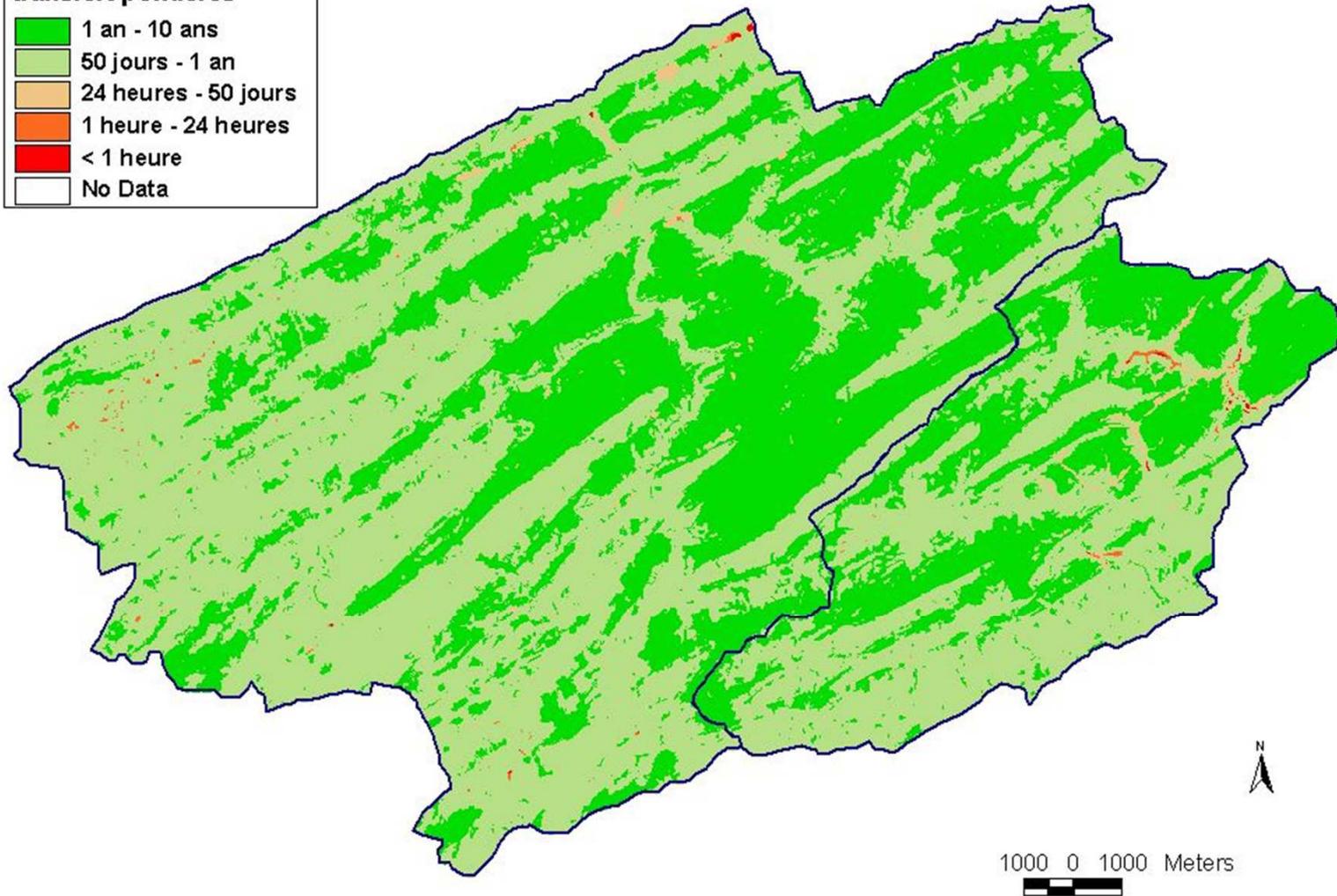


Groundwater Vulnerability

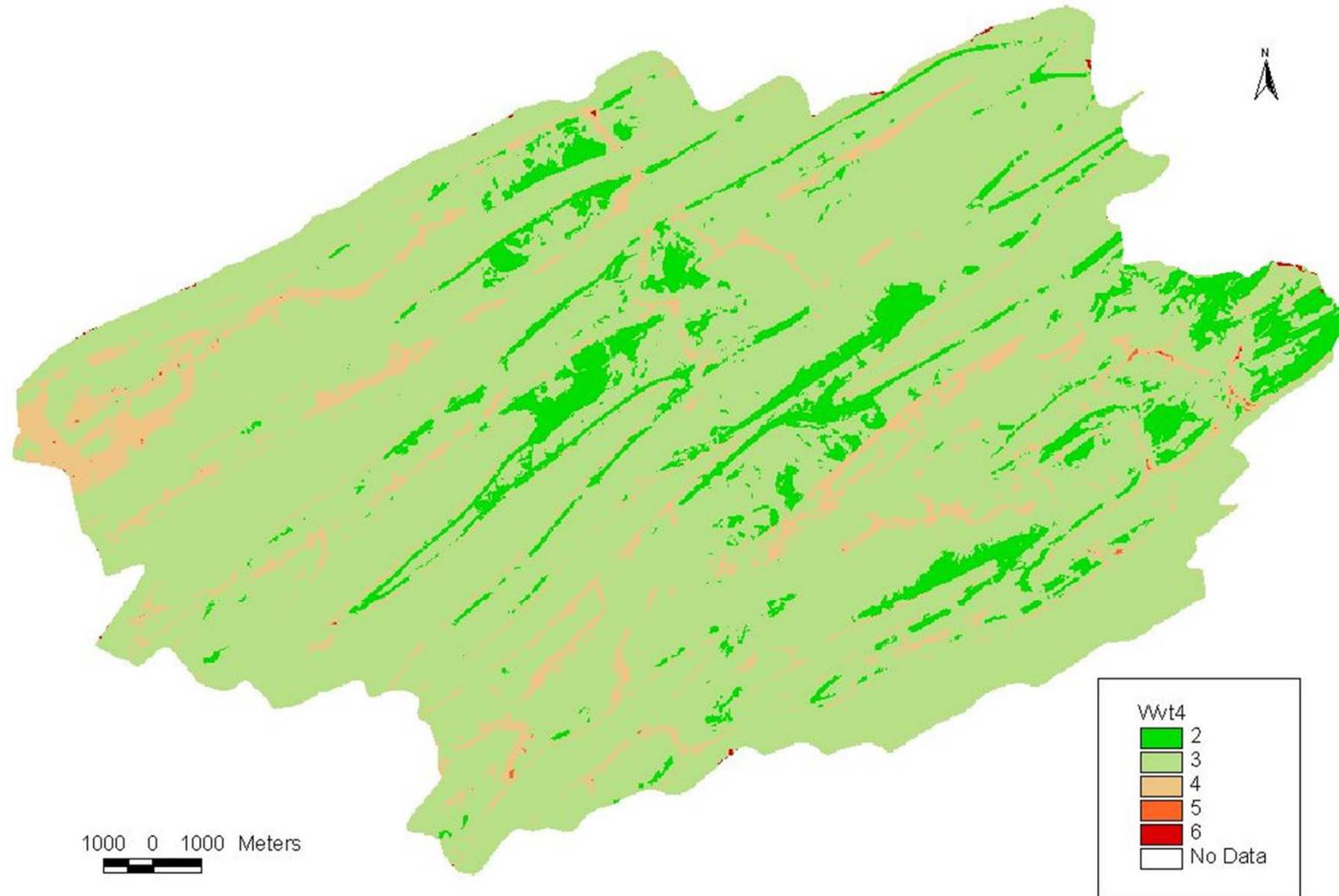
□ Groundwater vulnerability criteria

Criteria	High vulnerability	Moderate vulnerability	Low vulnerability
t	short (eg: 24 h)	medium (eg: 50 days)	long
c	high	moderate	low
d	long	moderate	short

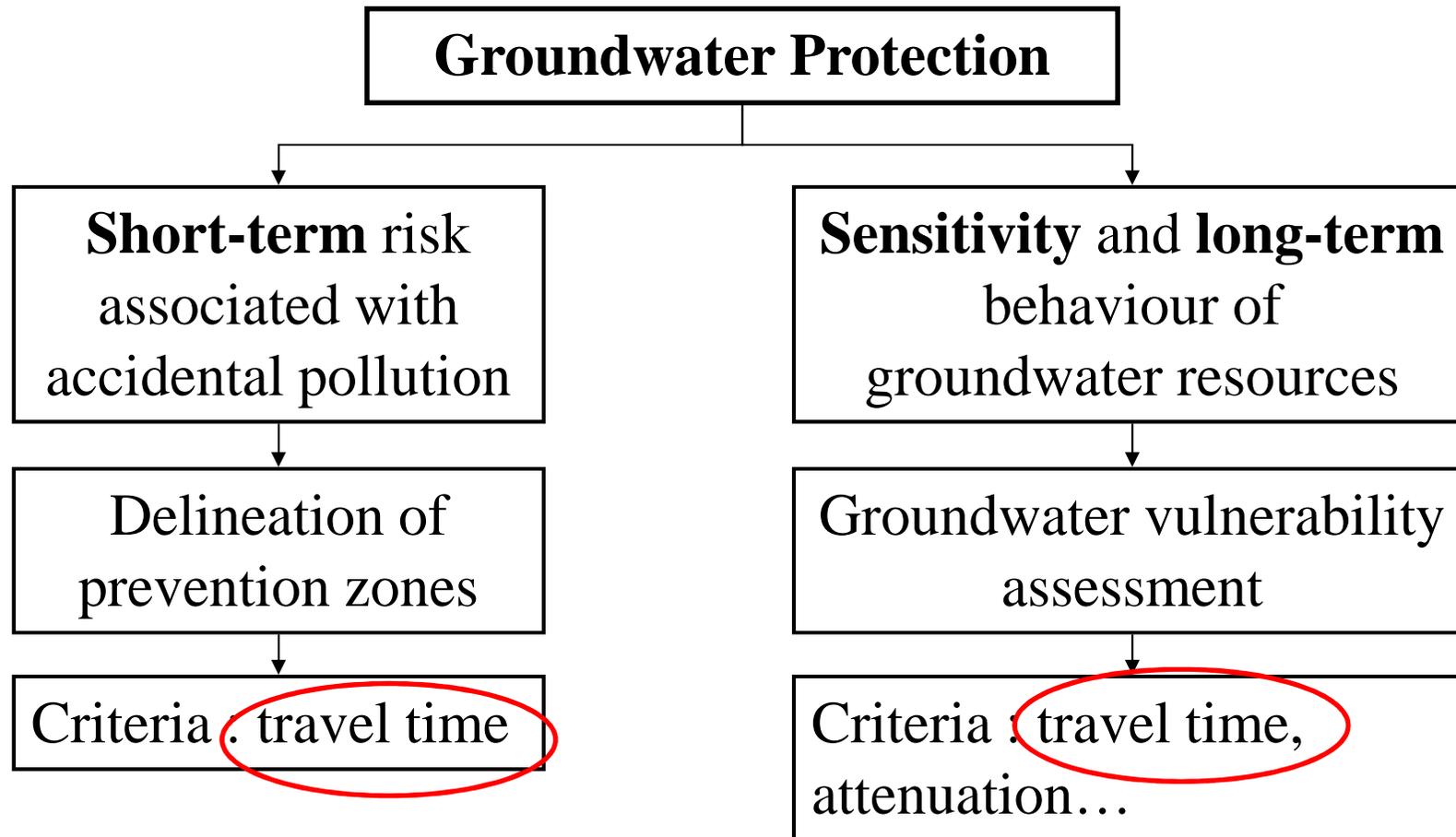
Groundwater Vulnerability



Groundwater Vulnerability

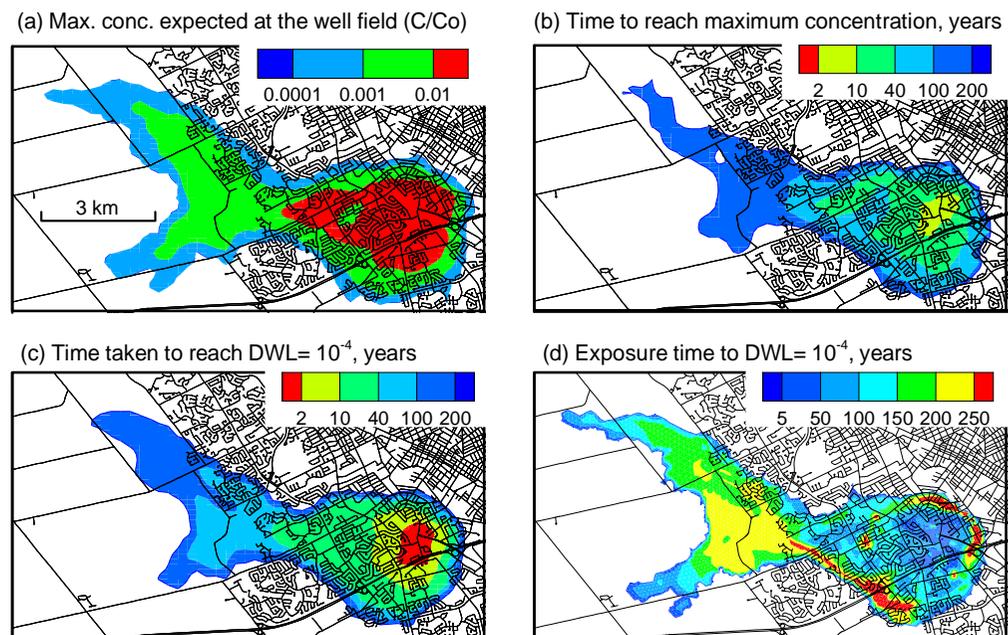


General Methodology for GW Protection



General Methodology for GW Protection

- Combination of GW Protection Zone & GW Vulnerability
 - Integrate concentration and duration criteria in the assessment of GPZ → Well vulnerability to contamination (cf works of Frind et al. in Ground Water 2006)
 - Backward in time transport modelling

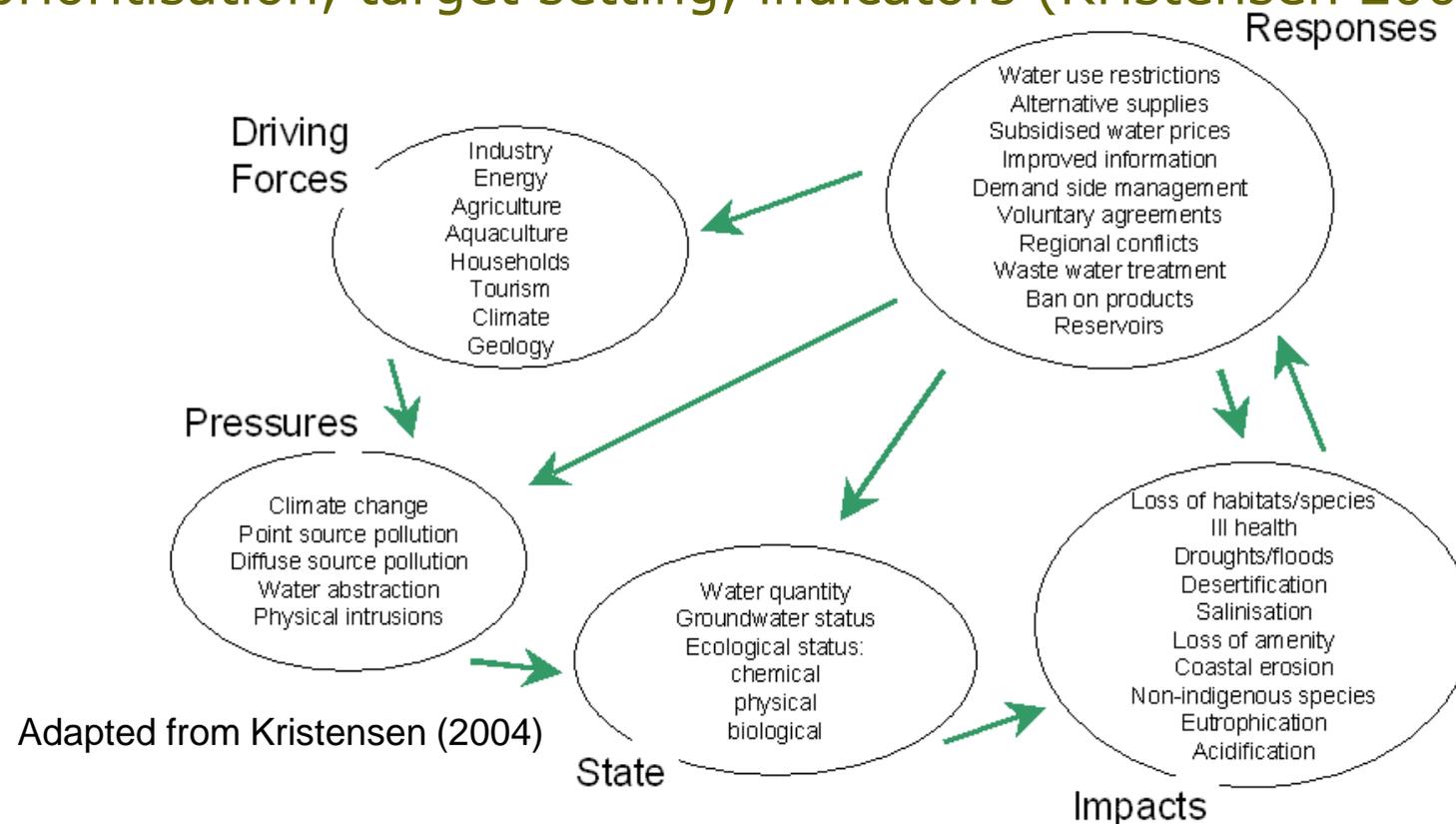


Generalized GW Vulnerability & DPSIR

- Up to now: GW vulnerability in terms of quality (impact of contaminants)
- However: other aspects should be considered:
 - GW quantity (overexploitation...)
 - Changes in reservoir properties (clogging...)
 - Changes in physico-chemistry (salinity, pH, conductivity...)
- Further developments: generalized GW vulnerability

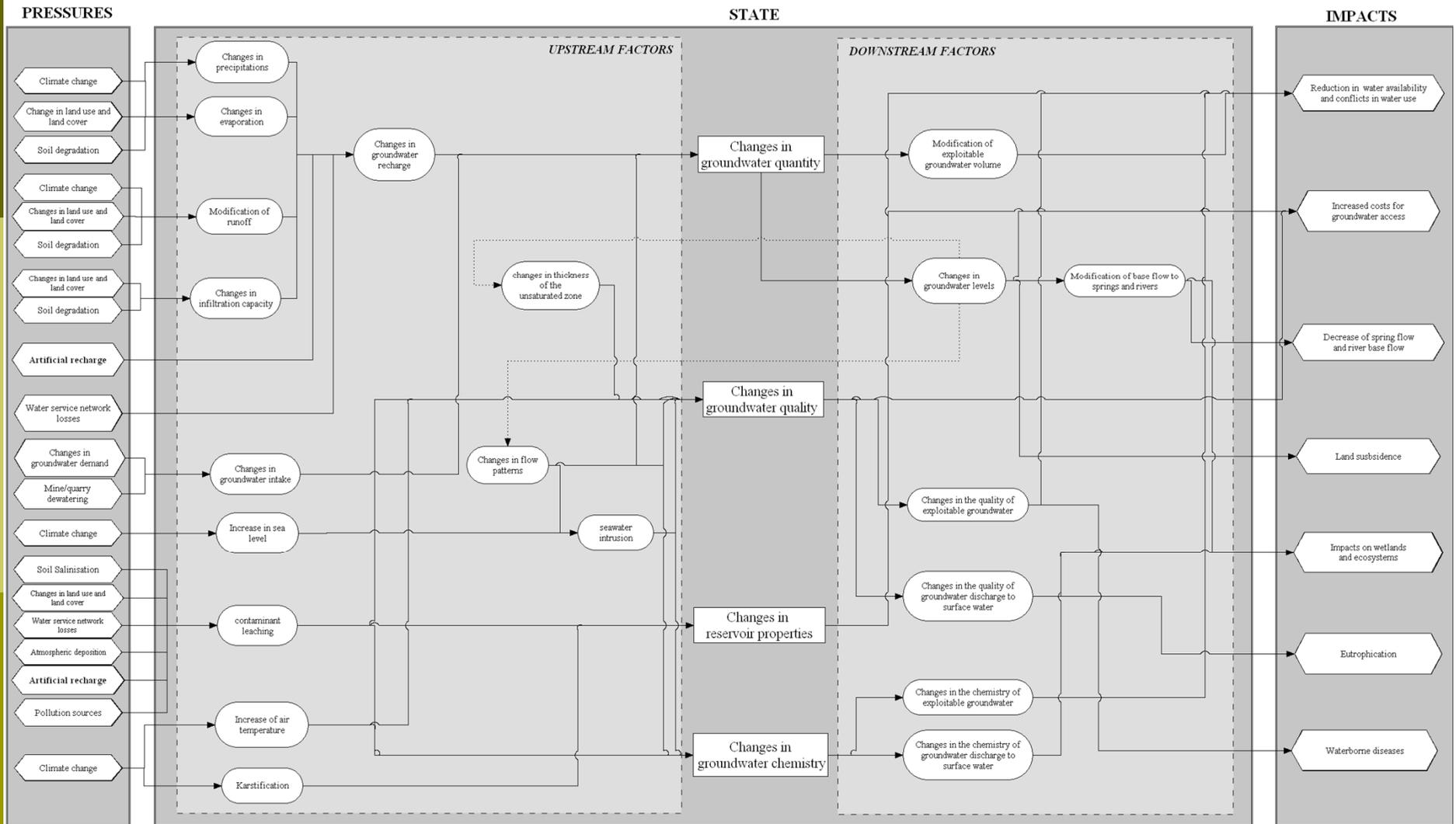
Generalized GW Vulnerability and DPSIR

- DPSIR : general framework presenting a chain of causal links between **Driving forces** (economic sectors, human activities), **Pressures** (emissions, waste), **States** (physical, chemical and biological) and **Impacts** on the ecosystems, human health and socio-economical development, leading to **Responses** such as prioritisation, target setting, indicators (Kristensen 2004).



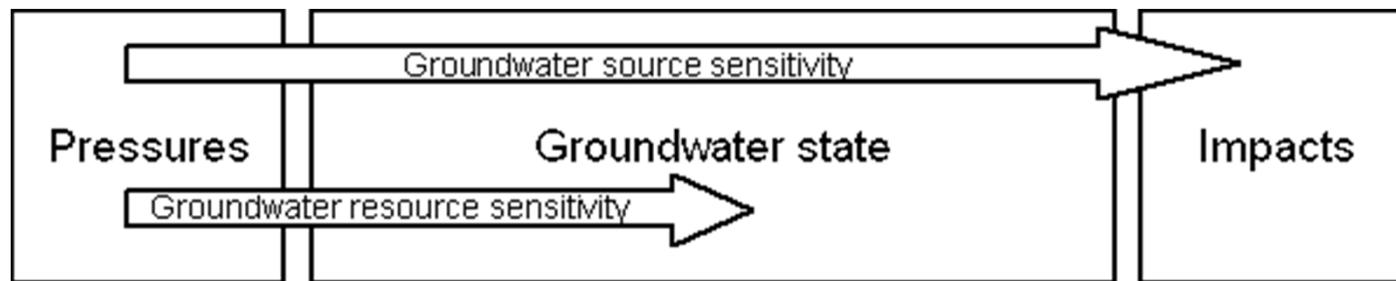
Adapted from Kristensen (2004)

Generalized Vulnerability & DPSIR



Generalized Vulnerability & DPSIR

- Once the causal chain is defined and quantified, one can assess the sensitivity (vulnerability) of the Groundwater State
 - to given pressures (GW «resource» sensitivity S^{GWR})
 - or in terms of potential impacts that can be expected (GW «source» sensitivity, S^{GWS}) in relation with the various functions of GW (water supply, base flow...)



Methodology for Integration & DS

□ Groundwater sensitivity indicators

- Sensitivity of GW state element j to pressure i : $V_{ij}^{GWR} = \frac{\partial S_i}{\partial P_j}$

- Sensitivity of impact j to pressure i : $V_{ij}^{GWS} = \frac{\partial I_i}{\partial P_j}$

- In the case of GW quality: $V_{ij} = M_{out}/M_{in}$ or C_{out}/C_{in} or ...

□ Result = GW sensitivity matrix V_{ij} which terms reflect how changes in the pressures affect, more or less easily, the GW resource and/or its ability to assure its various functions

□ Based on that, definition of a sensitivity index:

$$I_S = |\underline{V}|?$$

$$I_S = \sum_{i,j} \alpha_{ij} V_{ij}?$$

General Conclusions

- ❑ There is no single or universal approach to protect groundwater
- ❑ However, several aspects should be kept in mind for developing a rigorous methodology
 - **Physical criteria should be behind** to support the concept of GW protection/ vulnerability and are the only one to be able to provide useful tools for sustainable GW management & protection
 - Groundwater protection should not be viewed as just a «quality problem » : IWRM!
- ❑ Understanding the GW system is the first element of the chain!
 - GW investigations
 - Data organisation & management
 - Hydrogeological mapping
 - GW flow and transport modelling