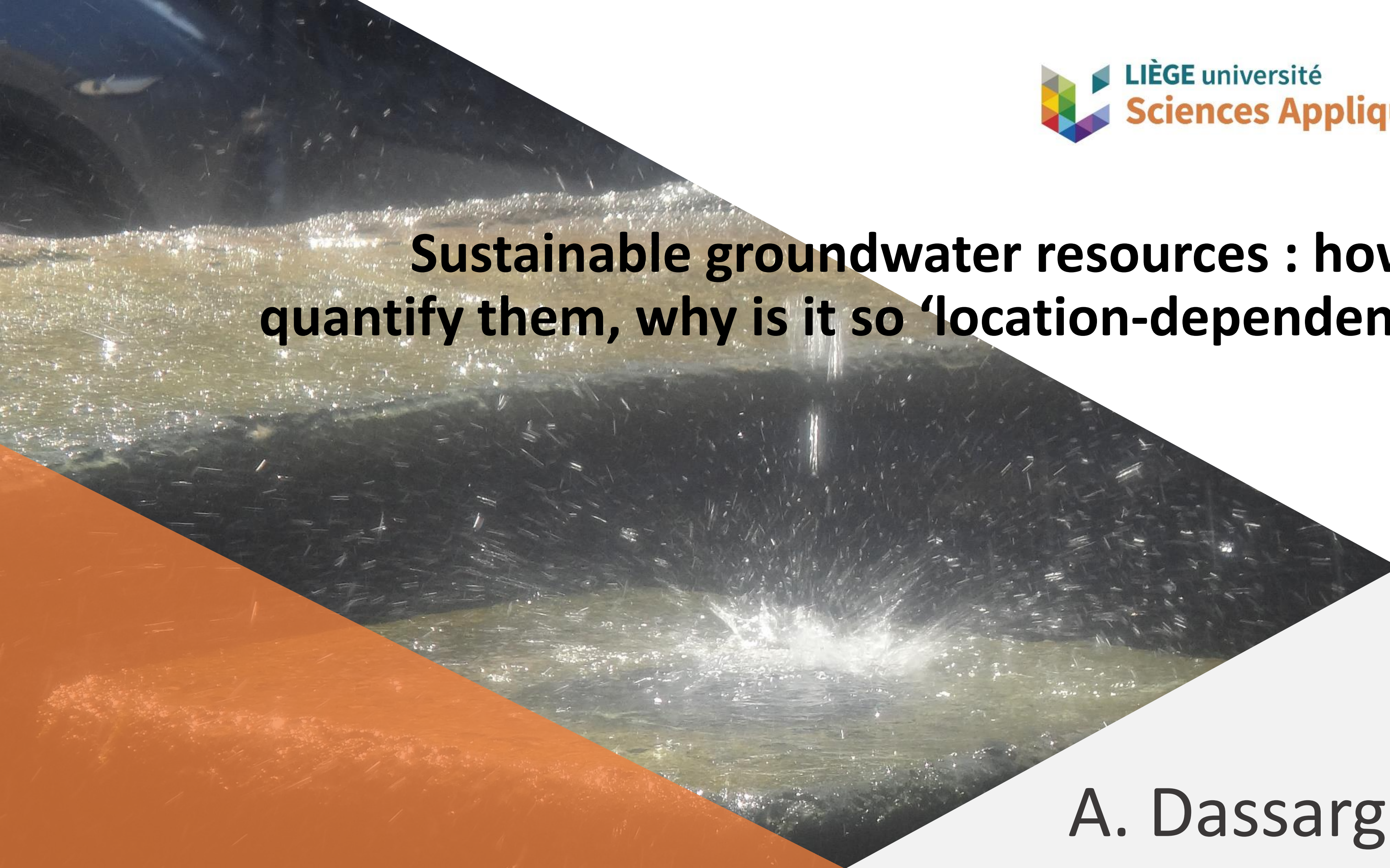


Sustainable groundwater resources : how to quantify them, why is it so ‘location-dependent’ ?

A. Dassargues

LIÈGE université
Sciences Appliquées

Hydrogeology
Environmental Geology

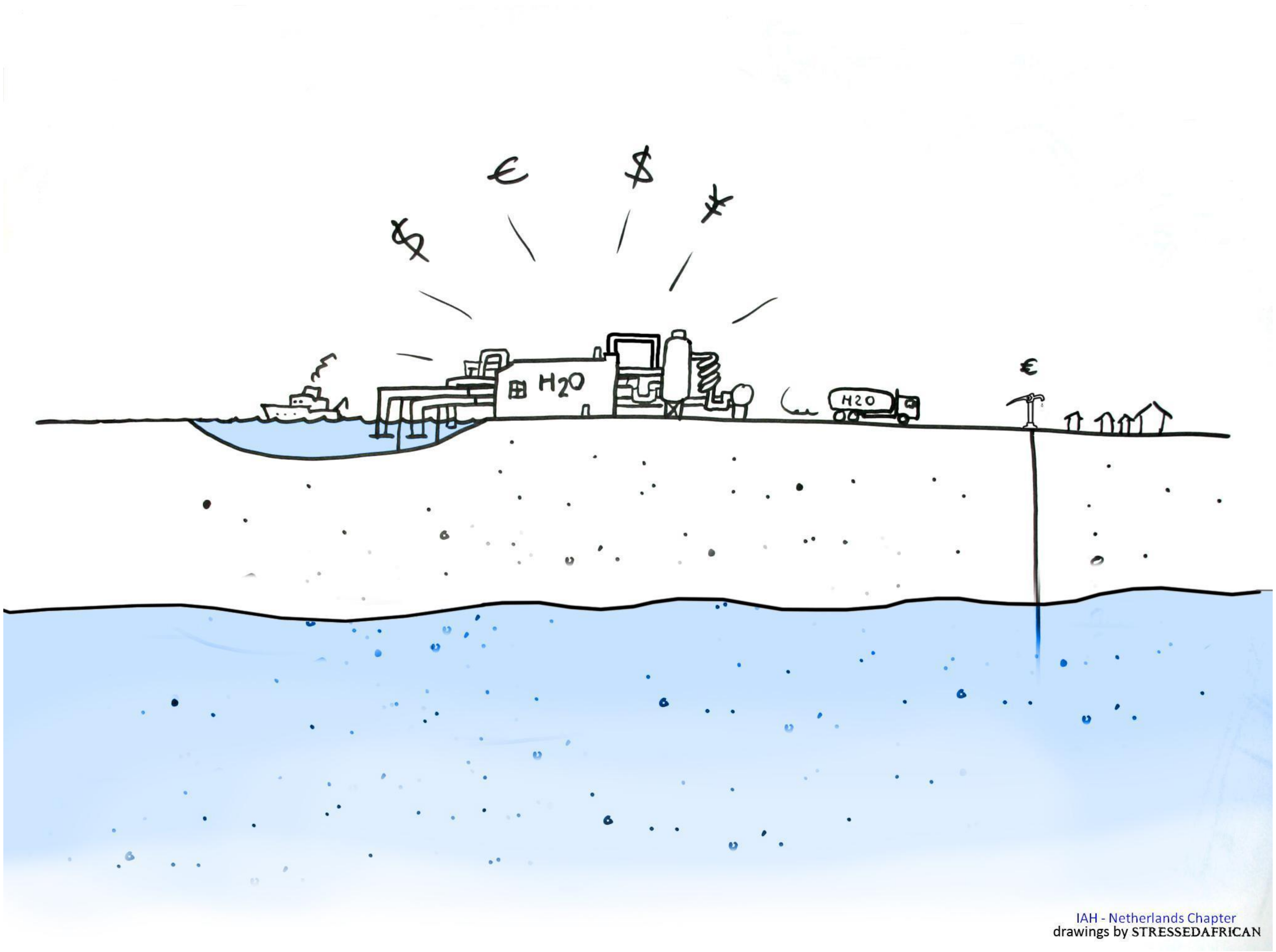
FNRS day LCA 02/12/2019

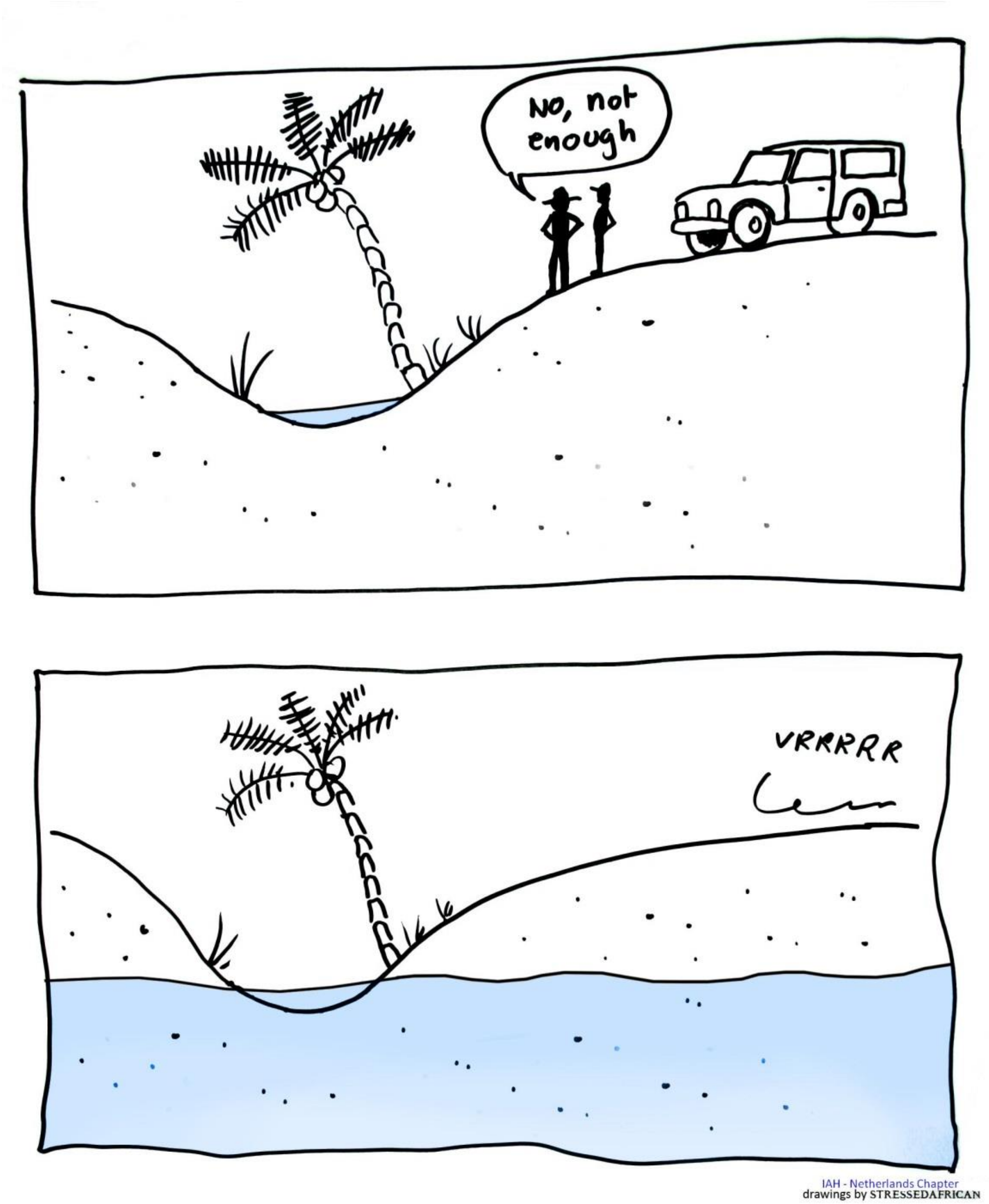
Groundwater resources

- *not well understood*
- *out of sight, out of mind*

aquifers = geological formations with a ‘useful’ permeability

out of sight, out of mind

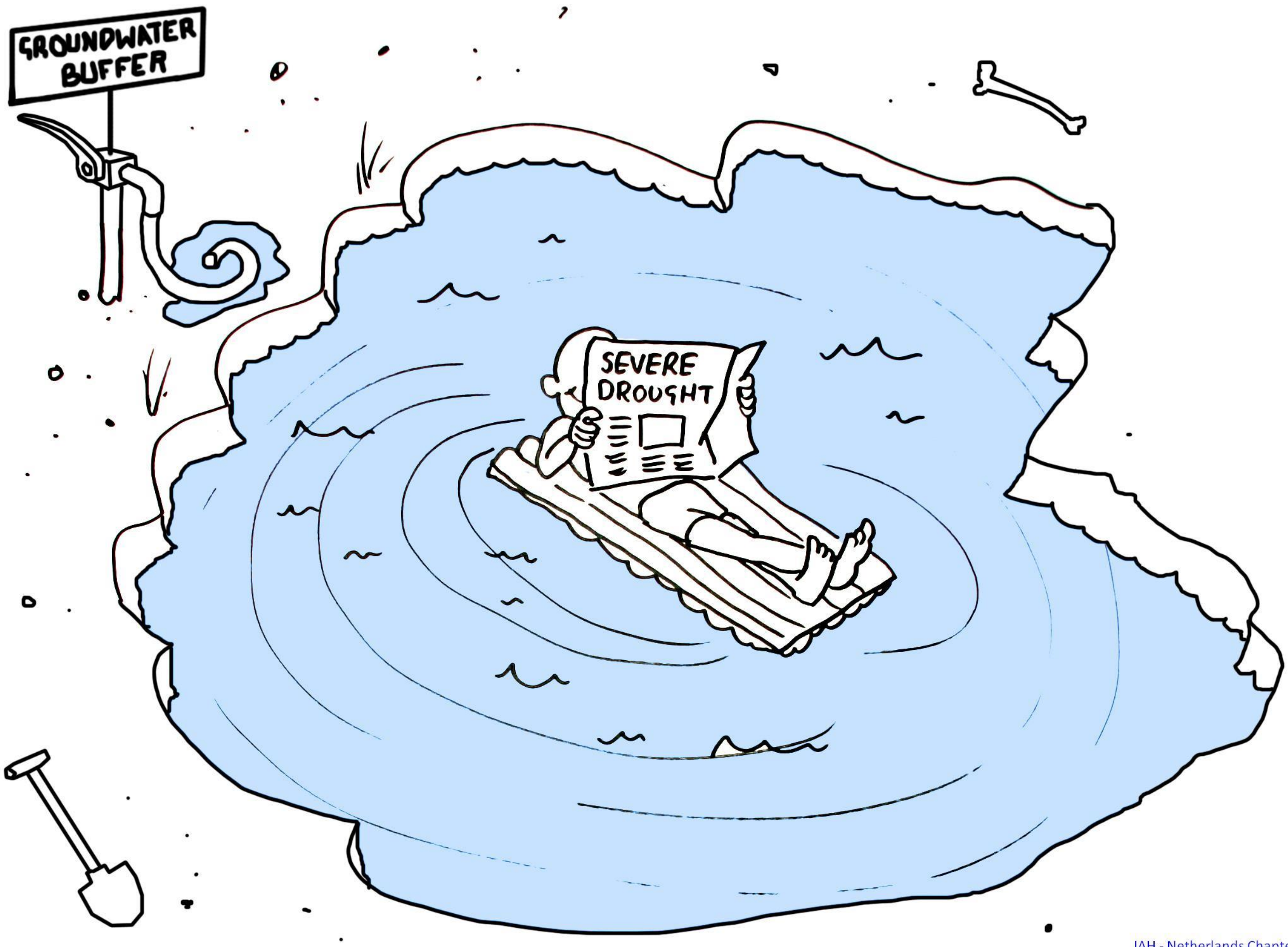




out of sight,

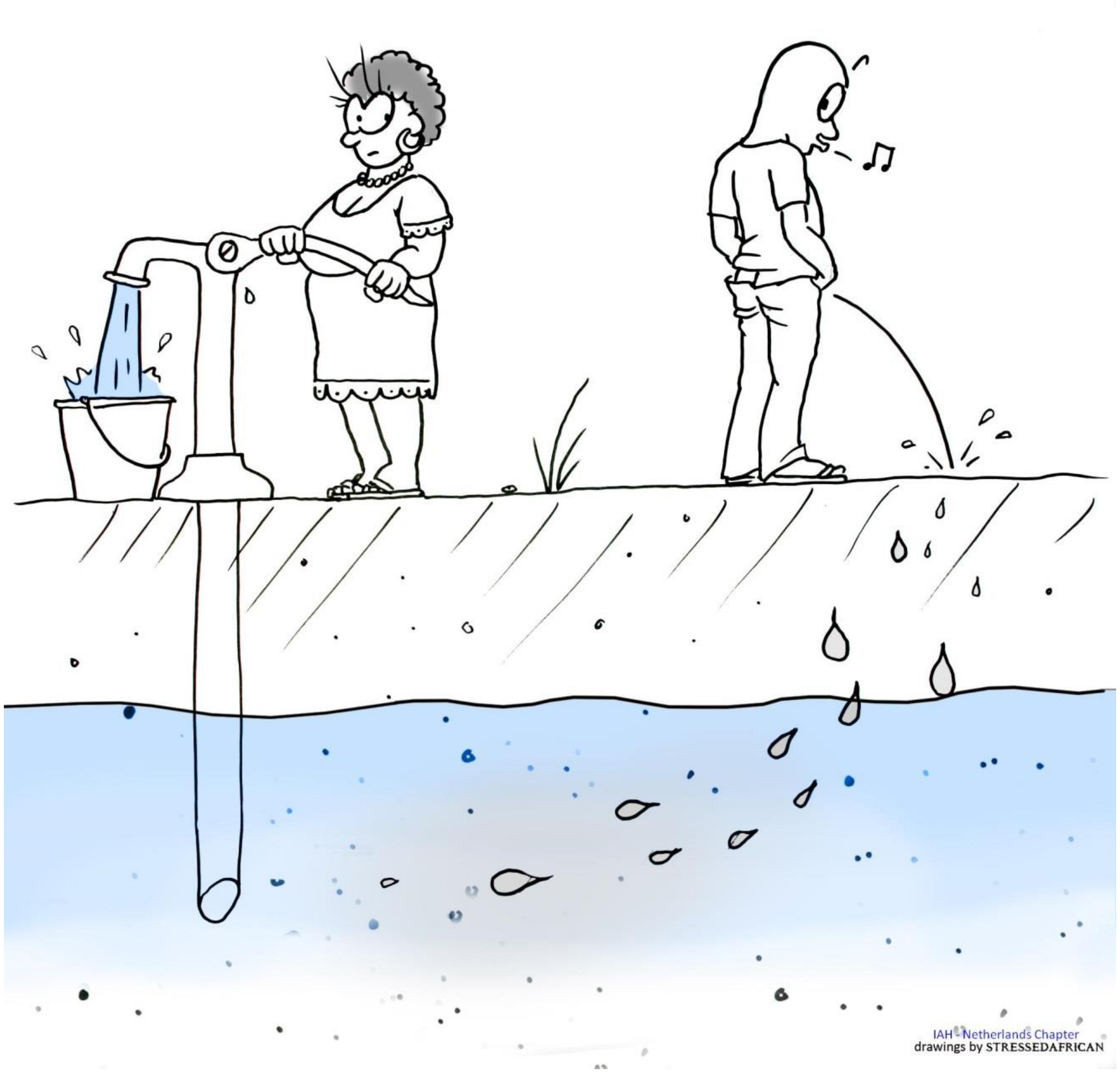
out of mind

out of sight, out of mind



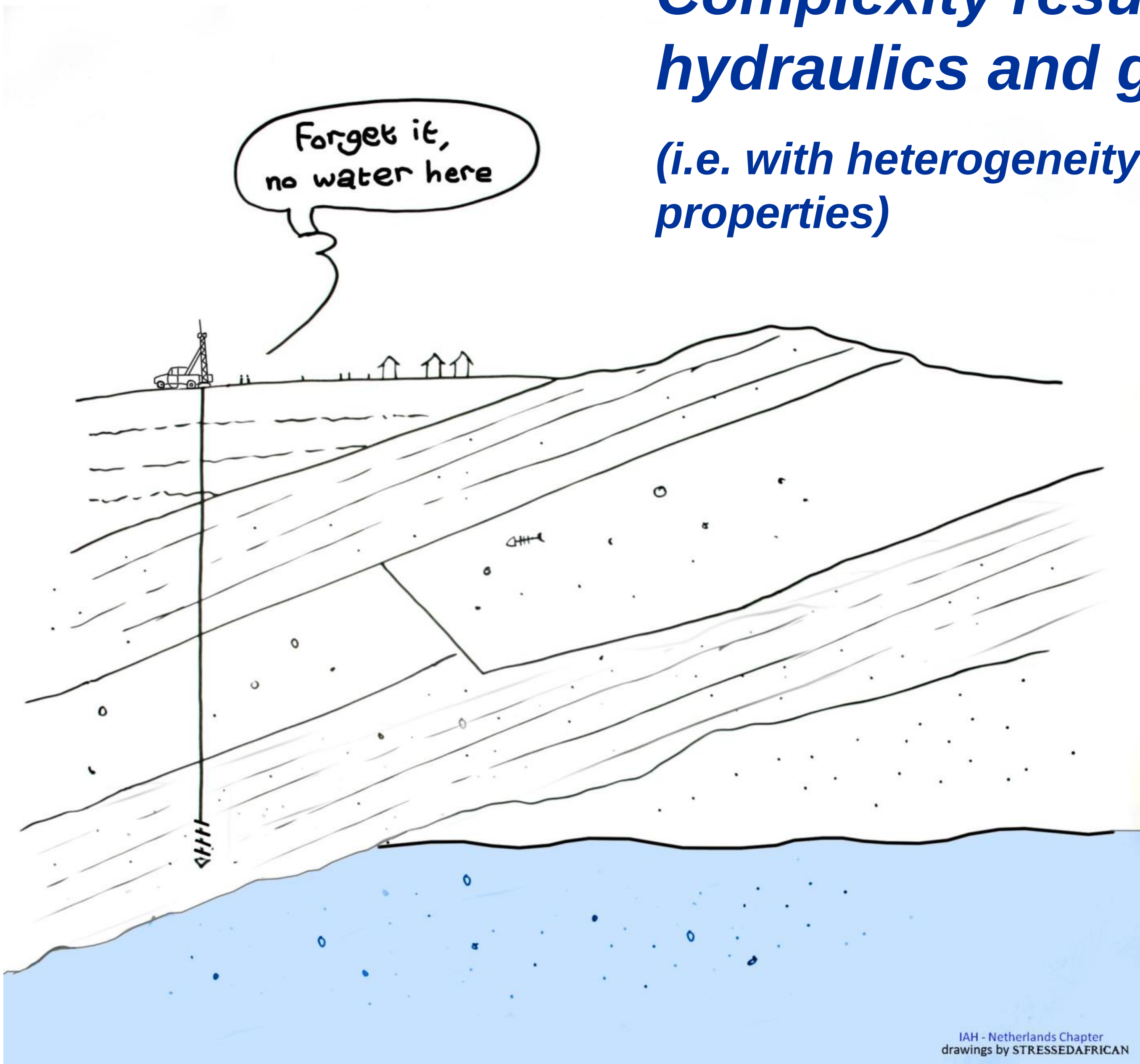
IAH - Netherlands Chapter
drawings by STRESSEDAFRICAN

out of sight, out of mind

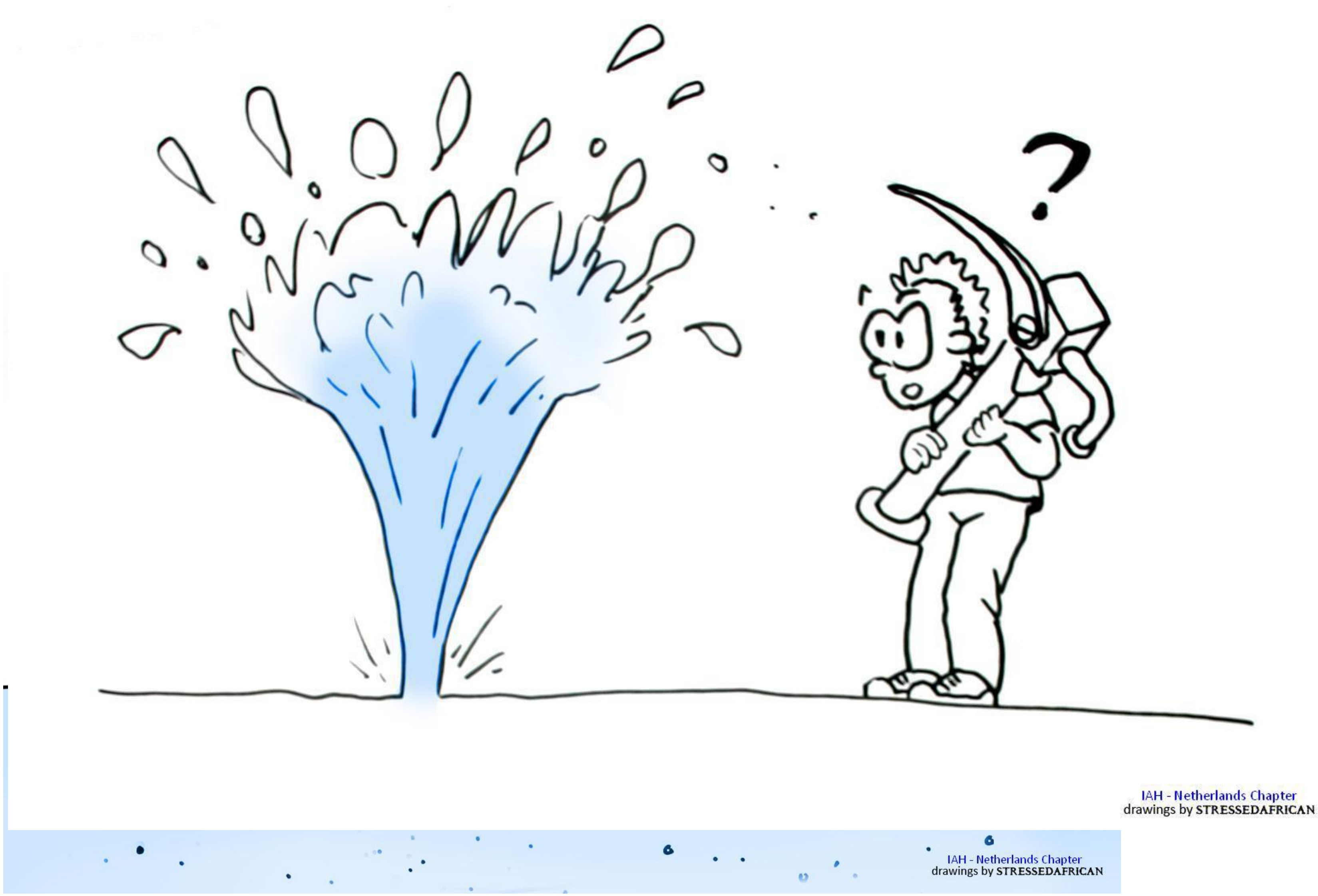


Complexity resulting from: hydraulics and geology

(i.e. with heterogeneity of the subsoil properties)



explaining… a lot of different situations


?
IAH - Netherlands Chapter
drawings by STRESSEDAFRICAN
IAH - Netherlands Chapter
drawings by STRESSEDAFRICAN

Groundwater advantages and drawbacks

→ **two aspects:**
- **quantity**
- **quality**

Advantages :

- a better protection against contaminations
- a quasi-constant temperature
- a short distance between production and consumption places
- a very constant answer to the demand in function of time and delayed maxima/minima with regards to stress factors (i.e. rainfall)
- natural remediation and degradation of contaminants by bio-physico-chemical processes

Drawbacks :

- *pumping costs*
- *uncertainties linked to the heterogeneity of the geology*
- *many solute compounds and sometimes high solute concentrations*
- *expensive and uncertain protection and risk assessment*
- *groundwater quality and quantity remediation is long, complex and expensive*

Key issues :

- *overexploitation and decrease of groundwater levels*
- *management and permission of groundwater accesses and uses*
- *salinization problems*
- *various contaminations*

Groundwater in Belgium

*Groundwater = … more than 70 % of the **drinking** water production in Belgium (81 % in Wallonia and Brussels; about 60 % Flanders)*

Productivity of a few main groundwater bodies (aquifers) in Belgium (in % of the total groundwater production):

*1. Carboniferous **limestones** (and **sandstones**) of the 'Synclinorium de Namur'*	*18.6 %*
*2. Miocene **sands***	*15.9 %*
*3. Carboniferous **limestones** (and sandstones) of the 'Synclinorium de Dinant'*	*11.4 %*
*4. Cretaceous **chalk** of the Mons basin*	*9.7 %*
*5. Brussellian **sands***	*7.9 %*
*6. Cretaceous **chalk** of Hesbaye (~ 100.000 m^3/d)*	*5.0 %*
*7. Meuse **alluvial sediments** (Wallonia)*	*4.0 %*
*8. Maastrichtian **chalk** (others)*	*3.0 %*
*9. Cretaceous **chalk** of the Brabant*	*2.6 %*
10. Alluvial terraces of the Meuse	*2.6 %*
11. Ardennes bed-rock	*2.5 %*
12. Landenian sands	*1.8 %*
13. ...	
14. ...	
15. ...	

Comparaison with surface water :

Reference: Cretaceous chalk of Hesbaye ~ 100.000 m^3/d

1) Rivers and canals :

- *Albert canal ~ 120.000 m^3/d (Antwerpse Water Werken)*
- *Nethe canal (Lier-Duffel-Rumst) ~ 350.000 m^3/d (Antwerpse Water Werken)*
- *Meuse (Taillefer - Namur) ~ 260.000 m^3/d (VIVAQUA)*

2) dams:

- *Eupen ~ 80.000 m^3/d*
- *Gileppe ~ 45.000 - 75.000 m^3/d*
- *Nisramont ~ 1500 m^3/d*
- *Couvin ~ 8000 m^3/d*

3) reservoirs:

- *Kluizen ~ 40.000 m^3/d*
- *Blankaart (Yser) ~ 40.000 m^3/d*

(numbers from Belgian Geological Survey, 1990)

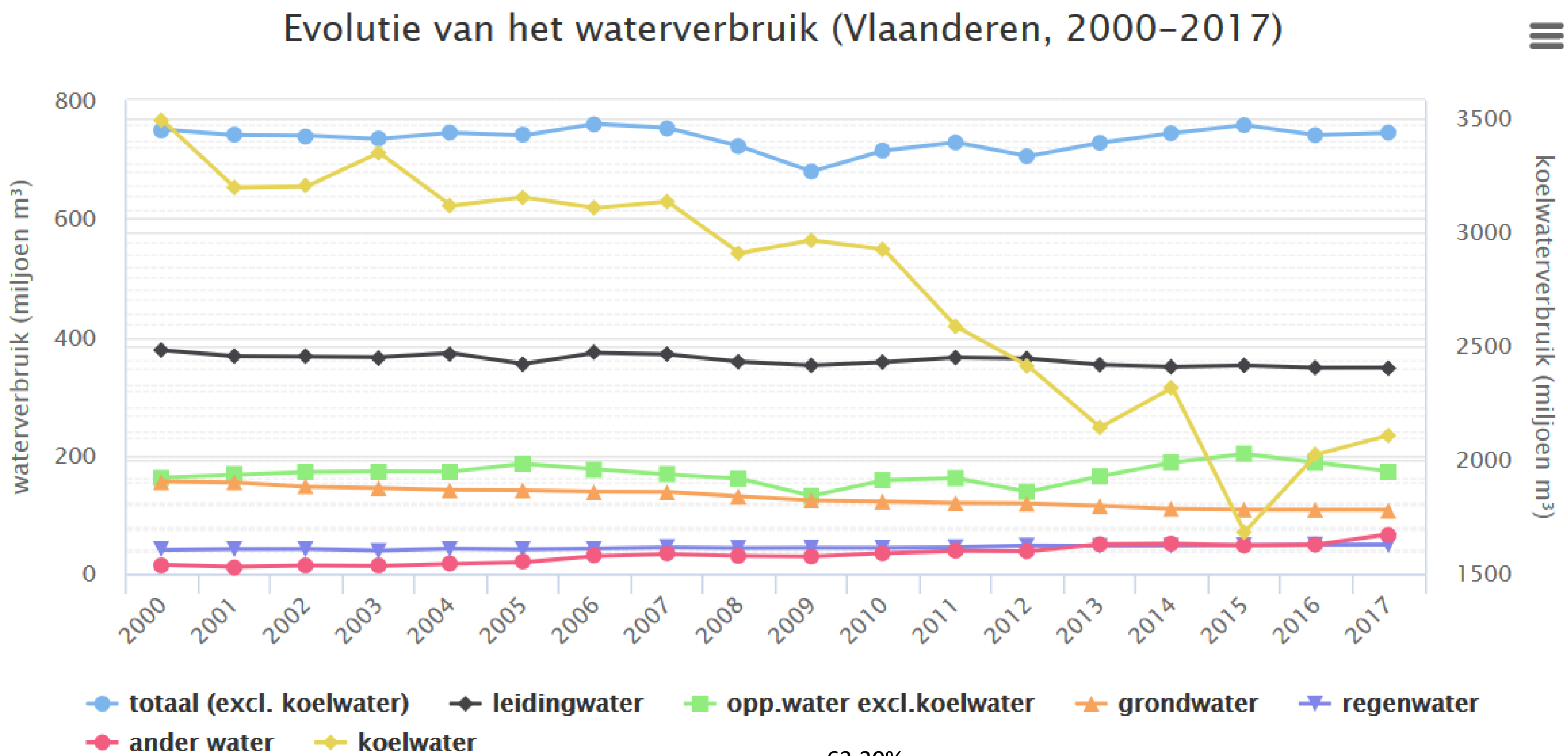
Water use in Belgium is stable or even decreasing (-10% from 1990)

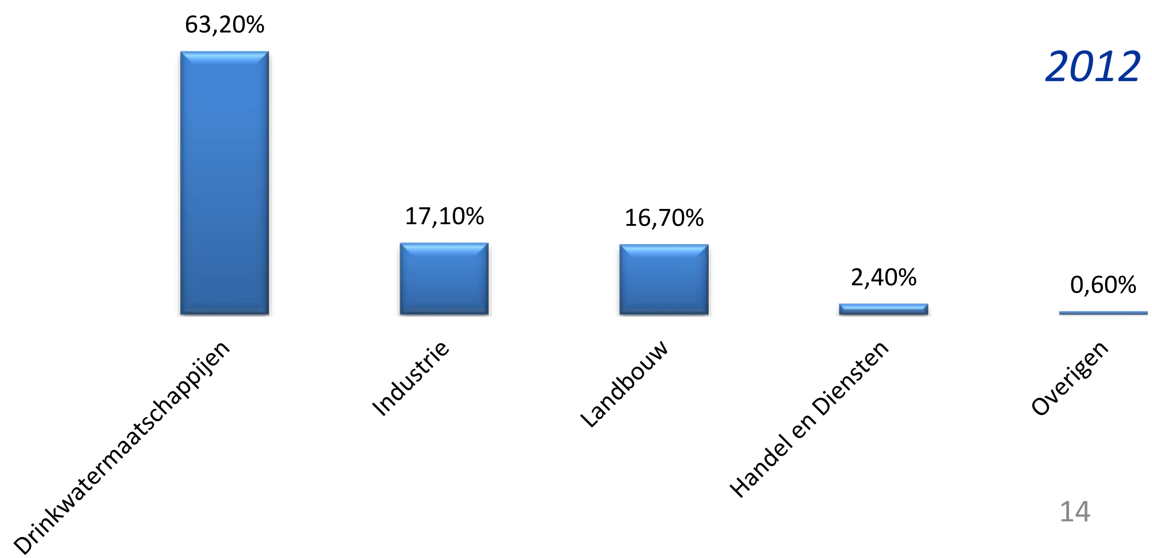
a lot of misleading infos in the medias:
'Les chiffres affolants de la consommation en eau en Belgique' (Télémoustique)
'La Belgique parmi les régions les plus menacées par une pénurie en eau' (LLB et Le Soir))
'Watertekort in Belgïe…' (De Morgen, De Standaard, …)
…

*The problem is the **spatial** and **temporal** distribution of water availability …*
→ *that is more and more sensitive due to increasing population and climate changes*

Be careful: there are plenty of 'pseudo-scientific' blogs…

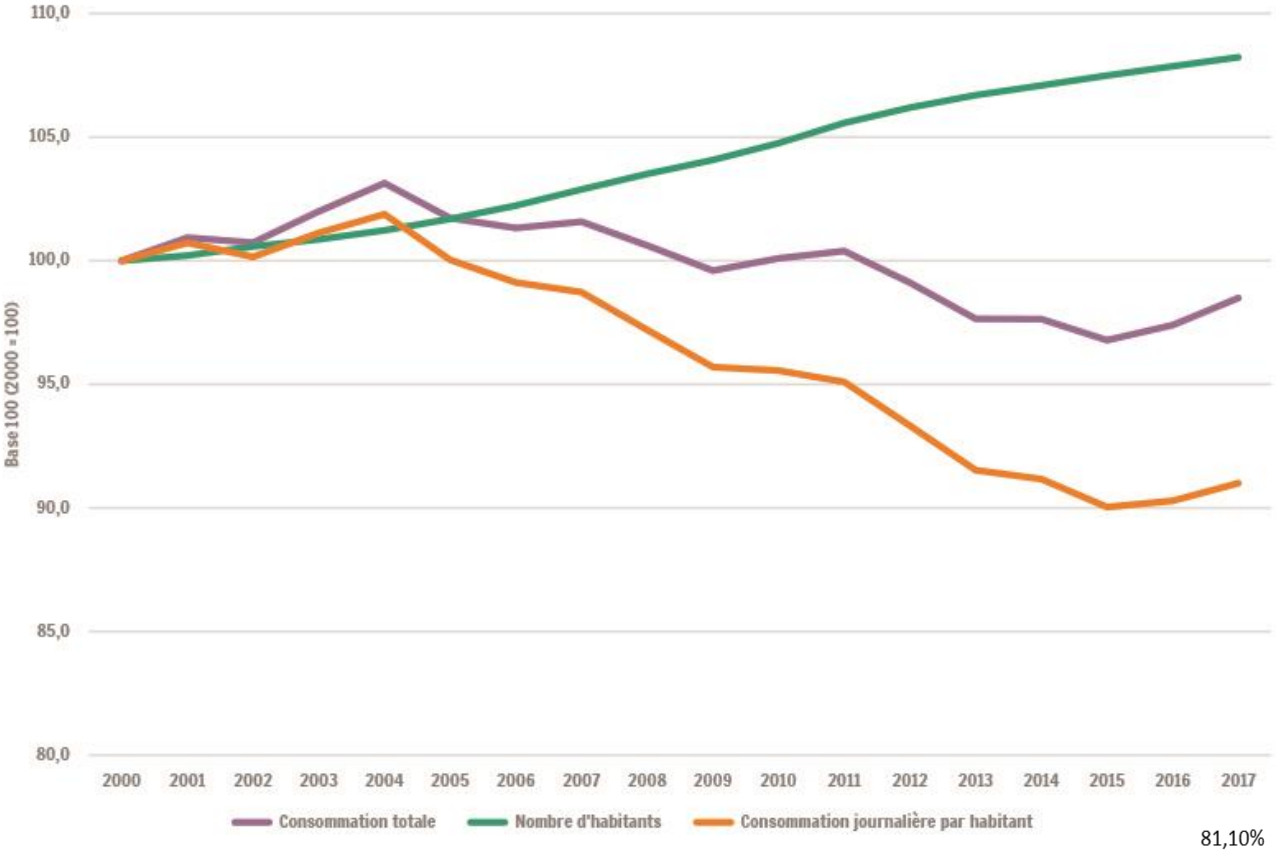
Water use in Flanders

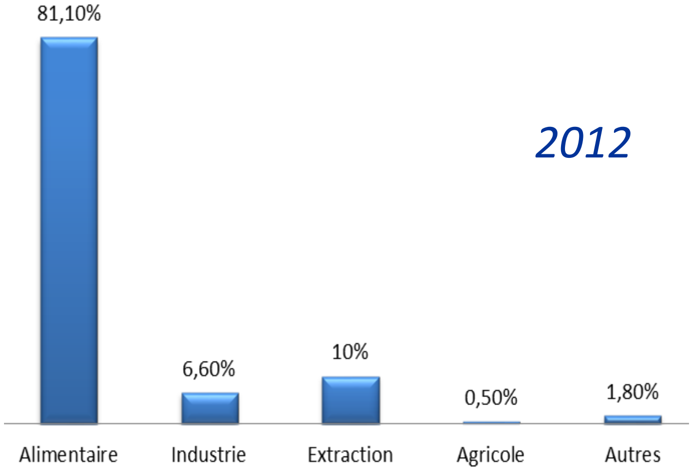




2012

Water use in Wallonia





2012

Hydrological cycle : complex network of fluxes and storage … more an more influenced by human activities !

(1) & (2) climate change and climate variability changes
(3) deforestation and accentuated erosion
(4) humid zones drainage (wetlands)
(5) & (6) agriculture and irrigation
(7) & (8) dams, sedimentation and evaporation in the reservoirs
(9) industrialisation, industrial cooling = losses
(10) inter-basins transfers
(11) urbanisation, constructions and mining
(12) saltwater intrusions
(13) decreased discharge in the rivers
(14) delta and coastal zones erosions
(15) & (16) sluices, pipes, urbanization of floodplains
(17) livestock wastes (manure)
(18) atmospheric transports and acid rains
…

Thinking about water availability

de Marsily 2009: *'This is not so much a global problem as it is a regional problem of availability to satisfy our needs for improving human health, food security, biodiverse natural ecosystems and effective energy production.'*

Scanlon *et al.* 2017, Cai *et al.* 2018 :
multiple feedback effects, interconnections and couplings among these four main domains dependent on water resources
➡ *the 'water – energy – food nexus'*

… natural resources may limit the development of our well-being and of our growing human communities

Ringler *et al.* 2013: *'win-win strategies must be developed for preserving environmental sustainability together with producing efficiency gains to balance the imposed growth from the demographic issue'*

The global picture

Water on Earth (currently estimated) at
1,387 million km^3
100 % *-96.5 % seawaters*
-0.96 % other saline waters
➡ *2.54 % freshwaters*
-1.75 % ice caps and glaciers
-0.02 % vapor in the atmosphere, soil moisture and permafrost
➡ *0.77 % 'available' freshwaters*
0.01 % lakes and rivers
0.76 % groundwaters

➡ ***ratio (lakes + rivers) / groundwater = 1/77 !!!***

Freshwater is quite unevenly distributed or easily accessible
➡ *groundwater takes a critical importance (especially in arid zones)*
Renewability of groundwater ?
… in arid zones, water production from very old groundwater reserves, referred to as 'fossil groundwater' (i.e., not renewed for thousands of years), automatically brings up the question of sustainable development

… hides huge regional differences

Terminology

Simmons 2015 : *'confusion exists between used water, consumed water and produced water or withdrawn water'*

Used water:

➡ *water can be used many times, ensuring different successive functions or services:*
- *recycled water (with water treatment)*
- *reused water (without treatment)*

Consumed water:

➡ *water that is not (at least locally) recycled or reused (i.e., evaporated, transpired or transformed into food)*

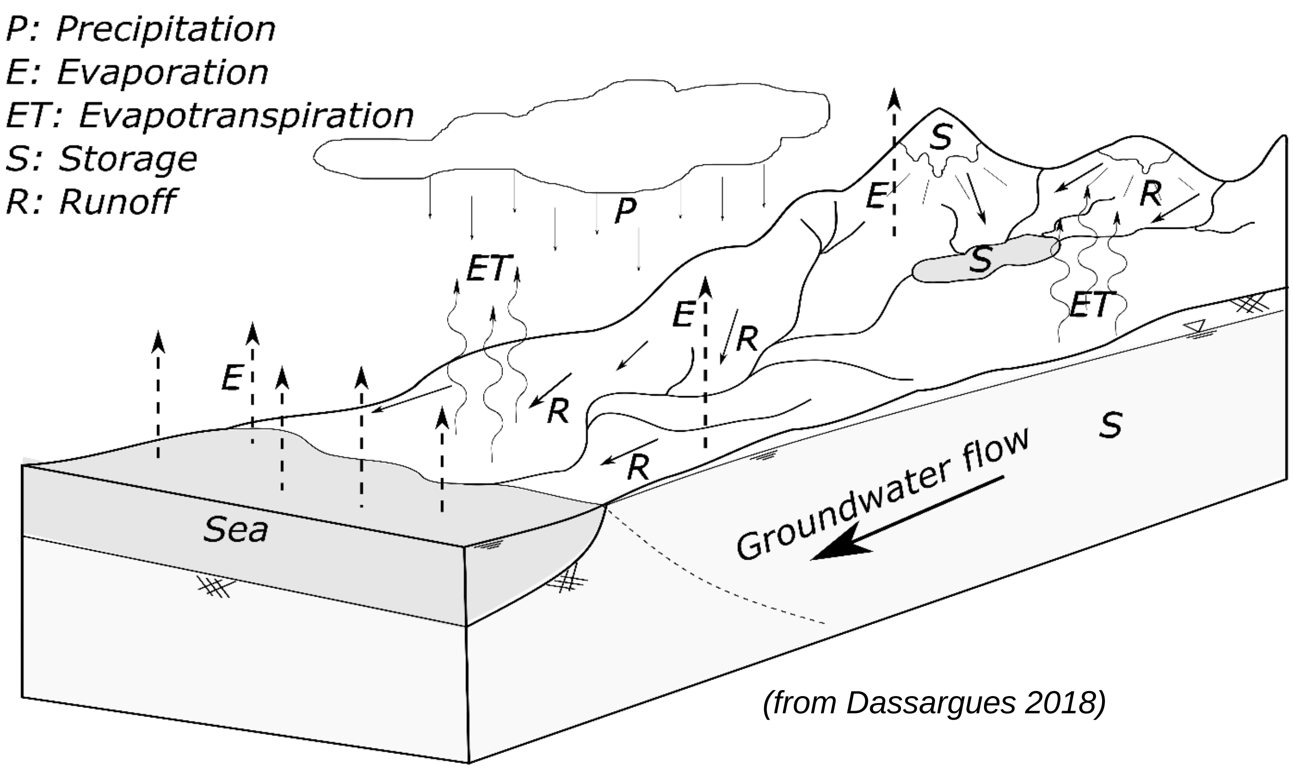
Produced water:

➡ *withdrawn water, extracted from a source: a part can actually be reinjected (recycled) or reused, while the other part is consumed*

Main problem:

➡ ***irrigation (as the water is mostly evapotranspirated) (quantity + quality problem)***

Hydrological cycle

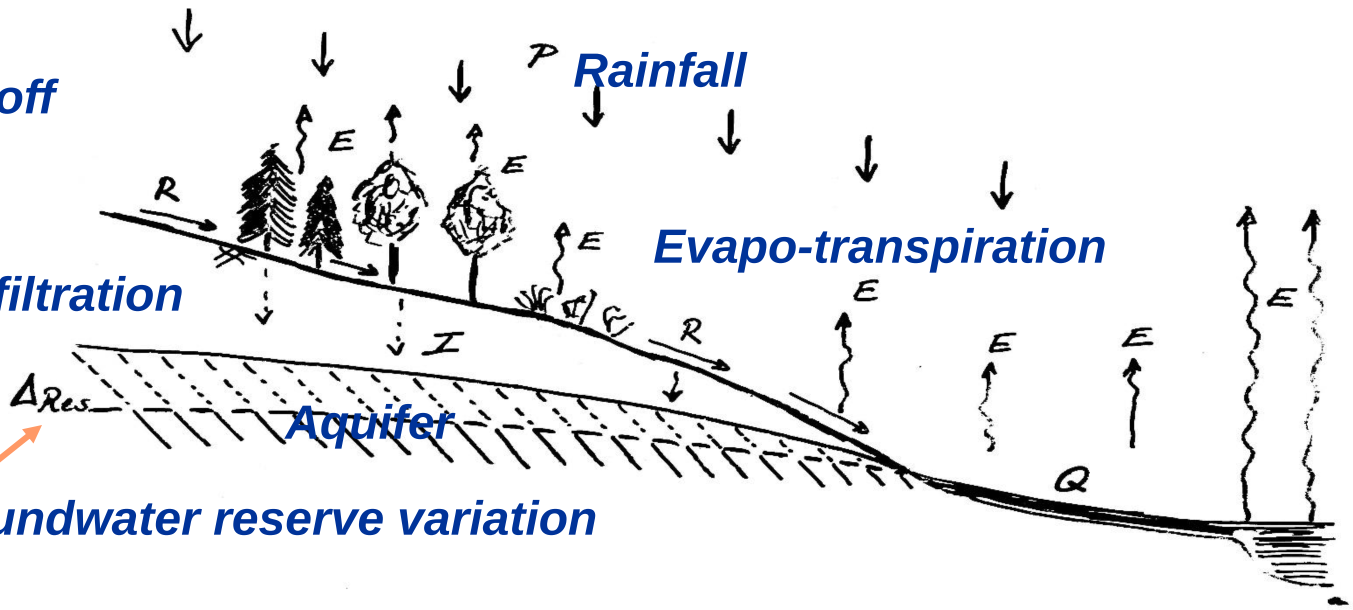


(from Dassargues 2018)

- ***precipitations***
- ***storages***
- ***runoff***
- ***evaporation***

Hydrological balance

Inflow = Outflow +/- Storage variations



in a point (or a small surface) … $P = E + R + I$

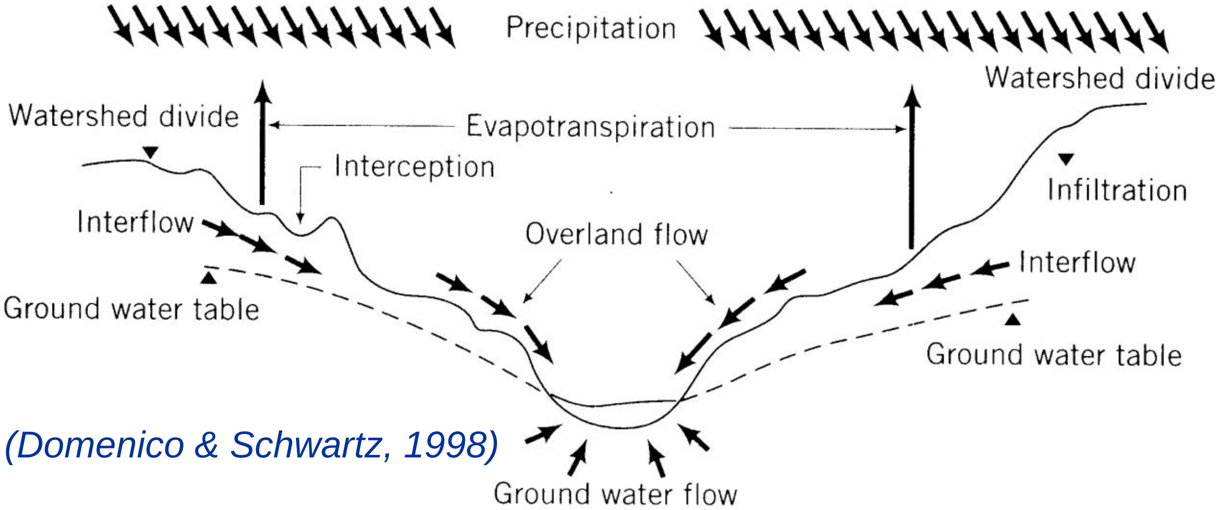
Precipitations/rainfall — Evapotranspiration — Runoff — Infiltration

in a basin … $P = E + Q + \Delta Res$

total surface discharge

Gw reserve variation

Hydrological balance



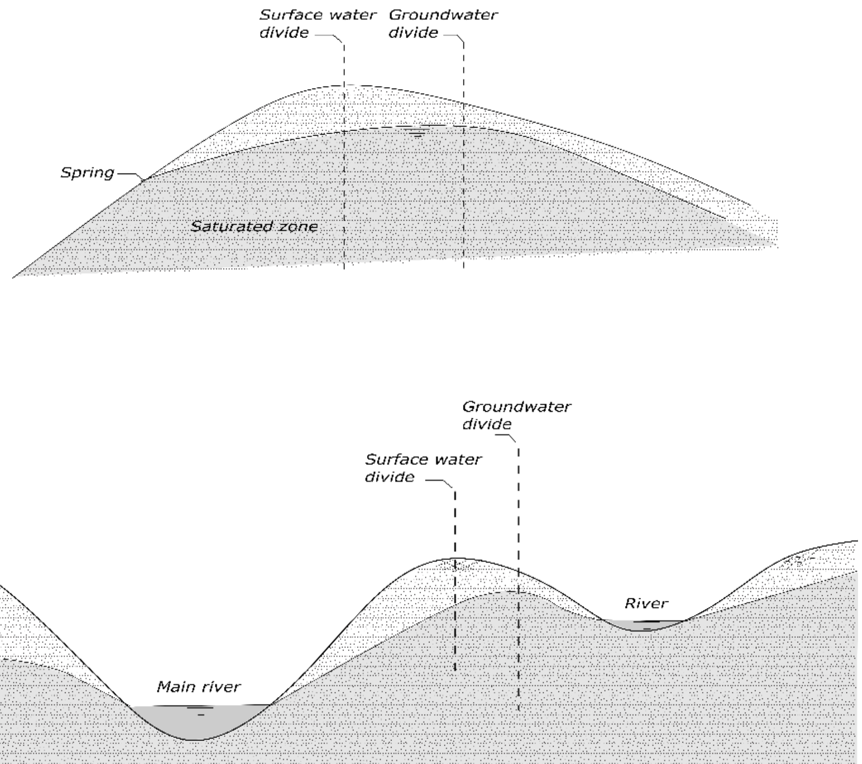
(Domenico & Schwartz, 1998)

$$P = E + R + Q_{gw} + \Delta Res$$

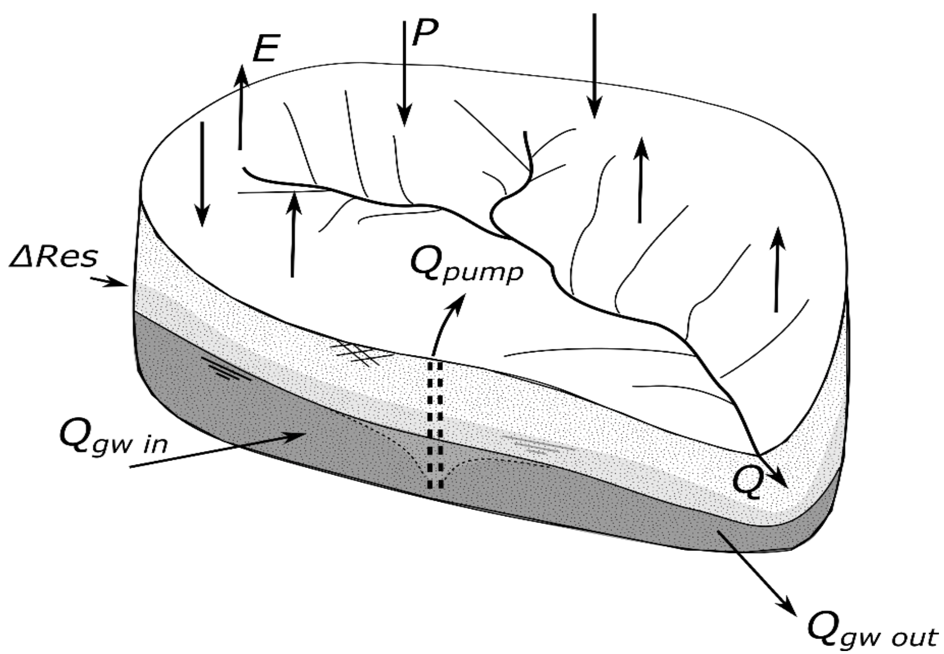
Q measured at the basin outlet

… but applicable on which basin ?

Hydrological basin ≠ hydrogeological basin



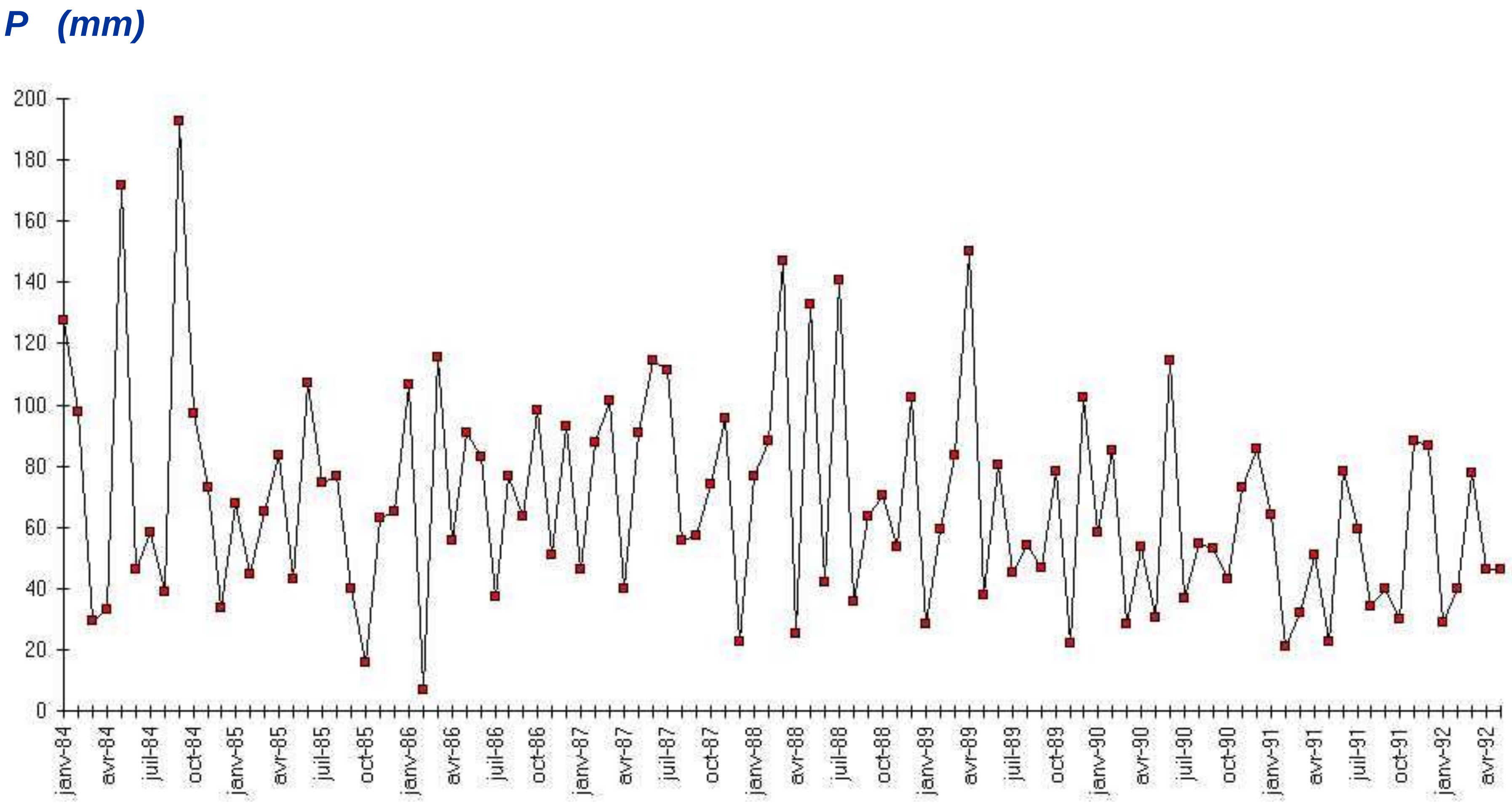
(from Dassargues 2018)



$$P + Q_{in} = Q + EvT + Q_{out} + Q_{pump} + \Delta Res$$

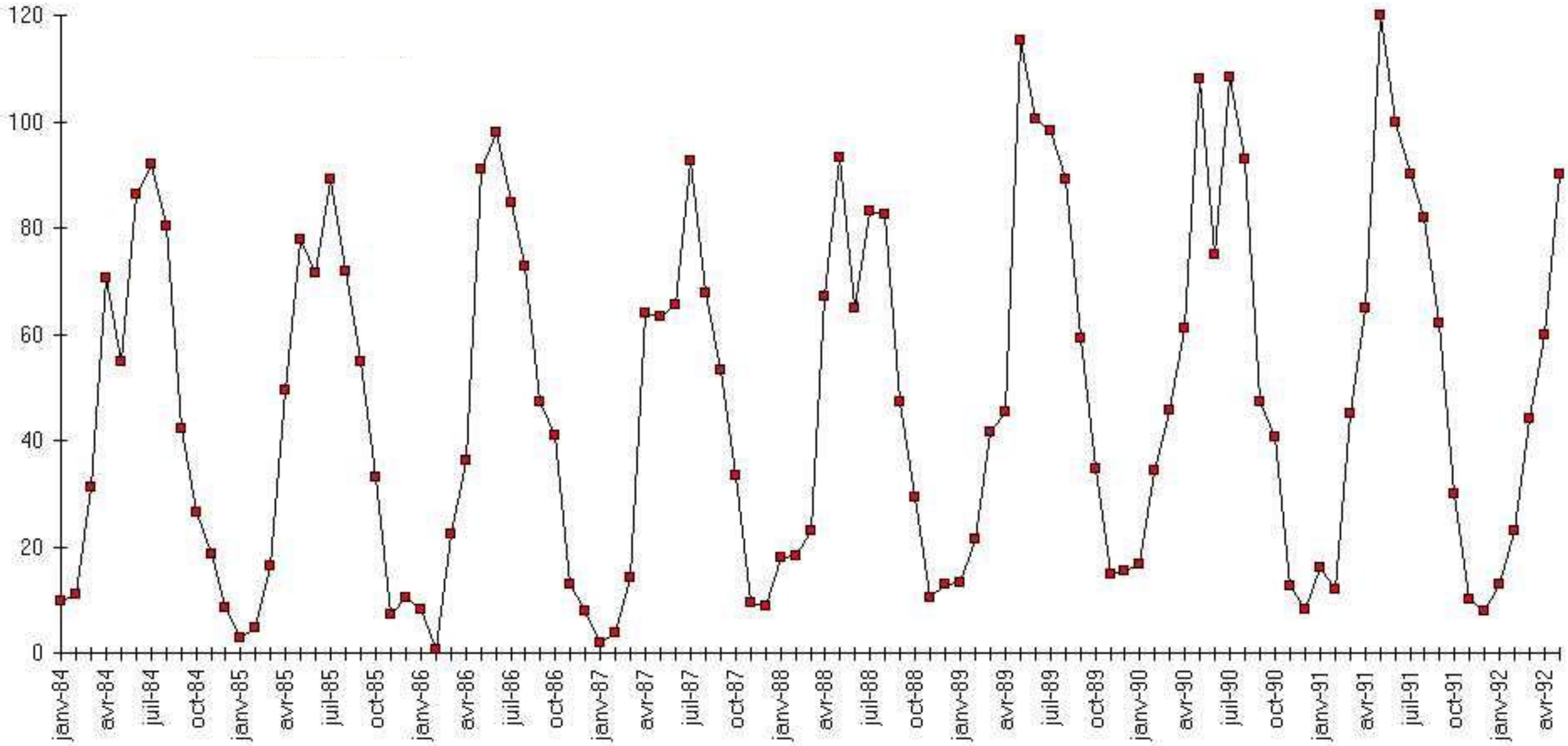
This balance equation should be balanced on a multiple year basis to consider full renewability and sutainability

P = EvT + R + I   example of the Geer basin



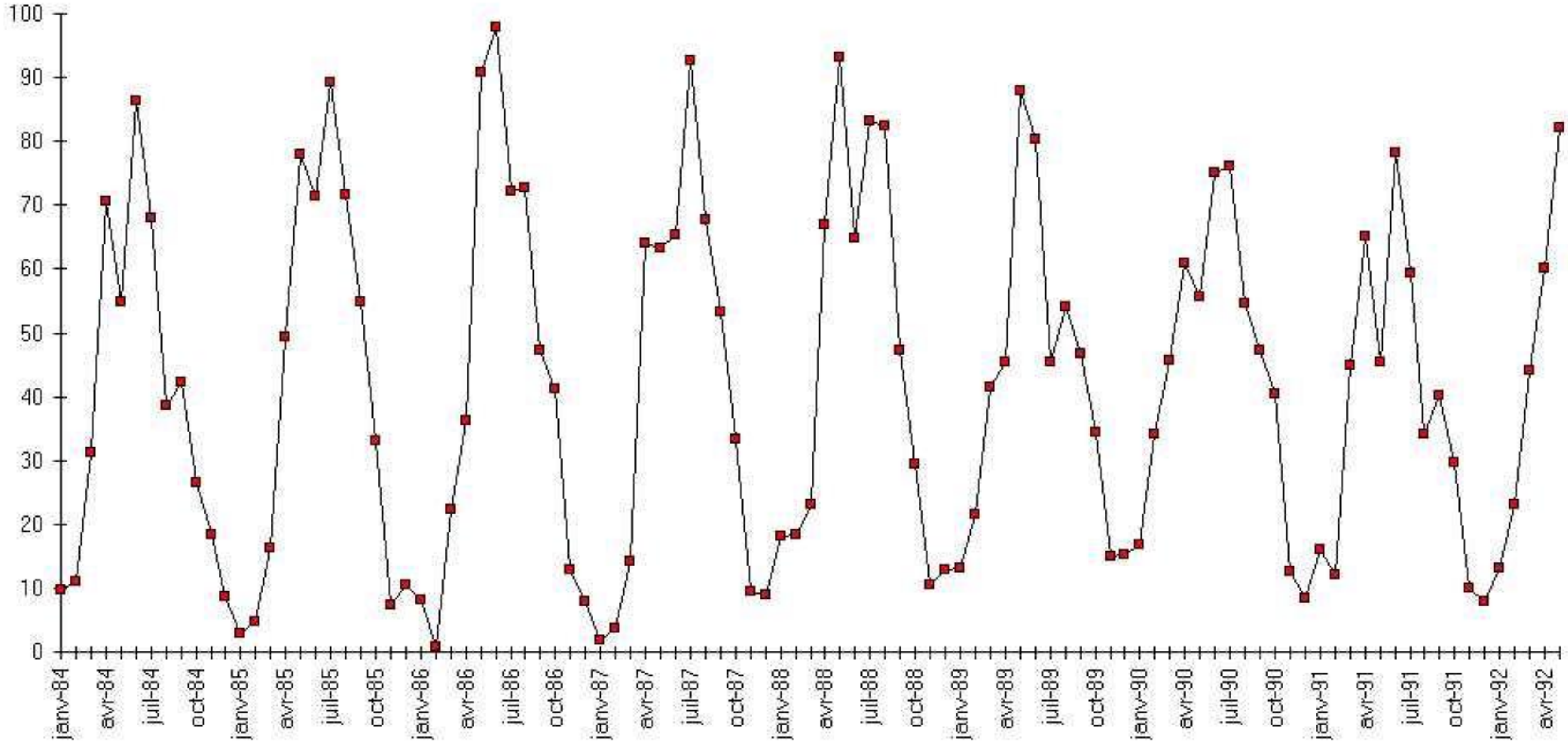
Simple example: Geer basin

PEvT (mm)

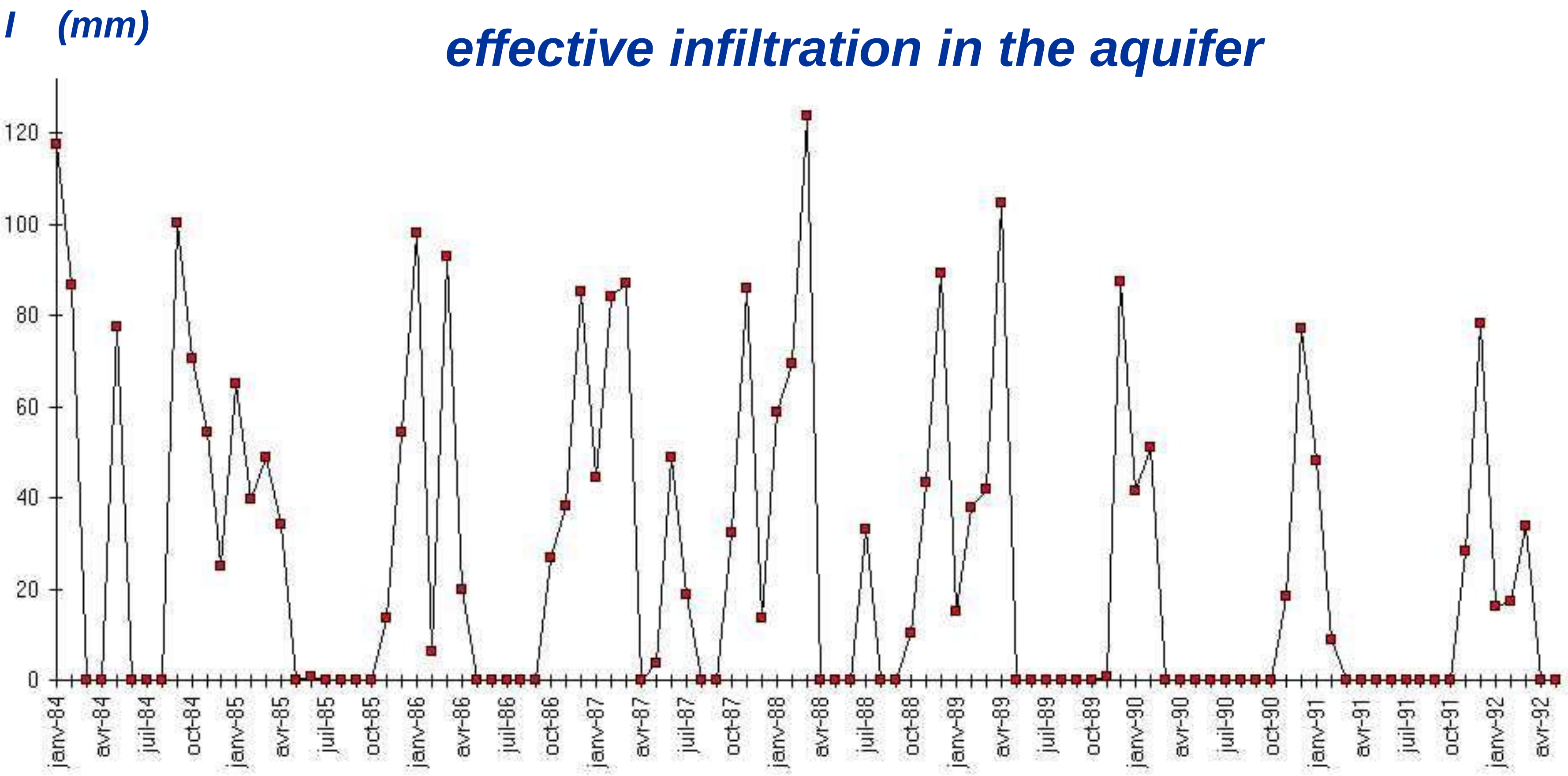


Simple example: Geer basin

AEvT (mm)

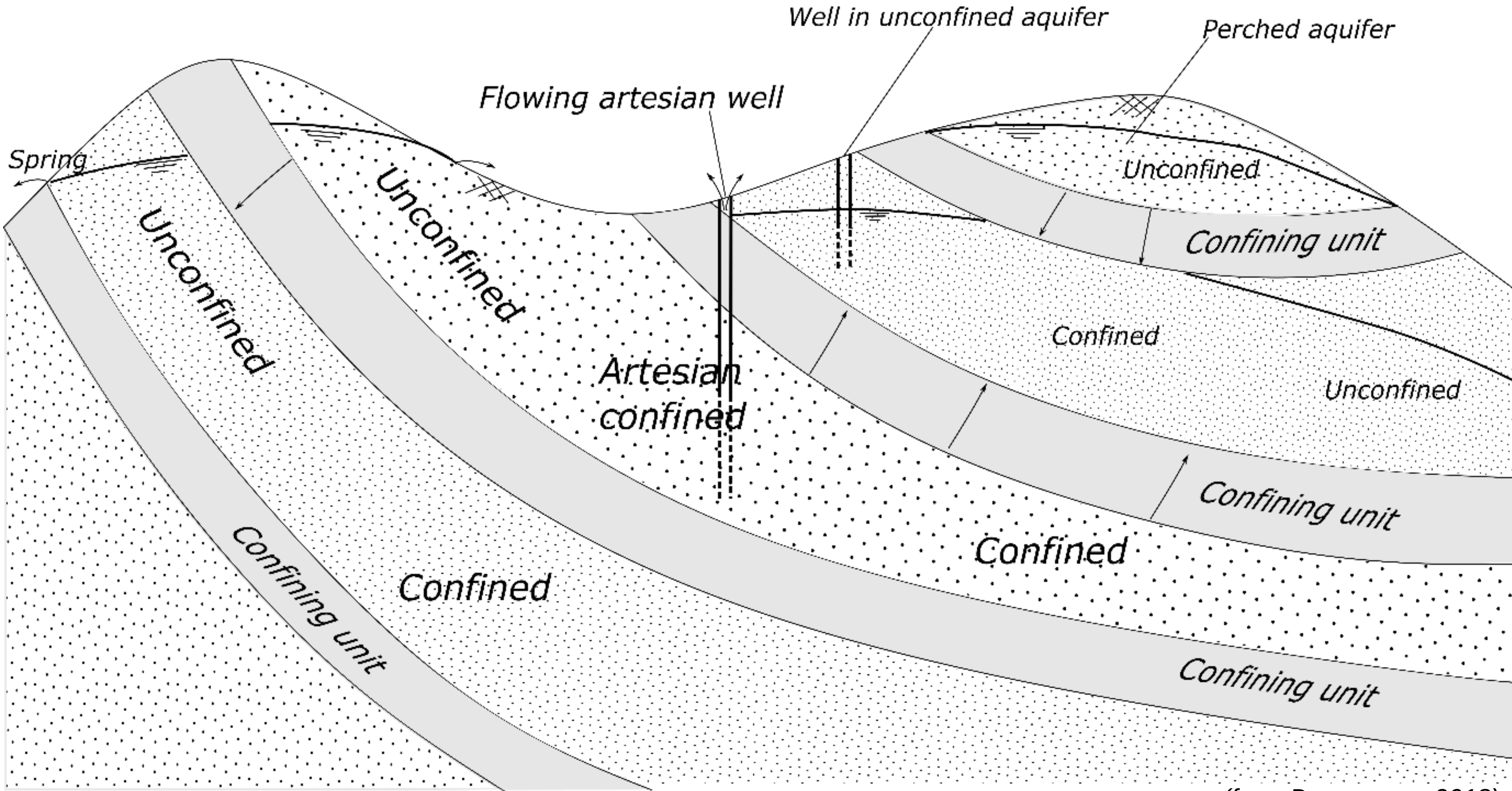


Geer basin



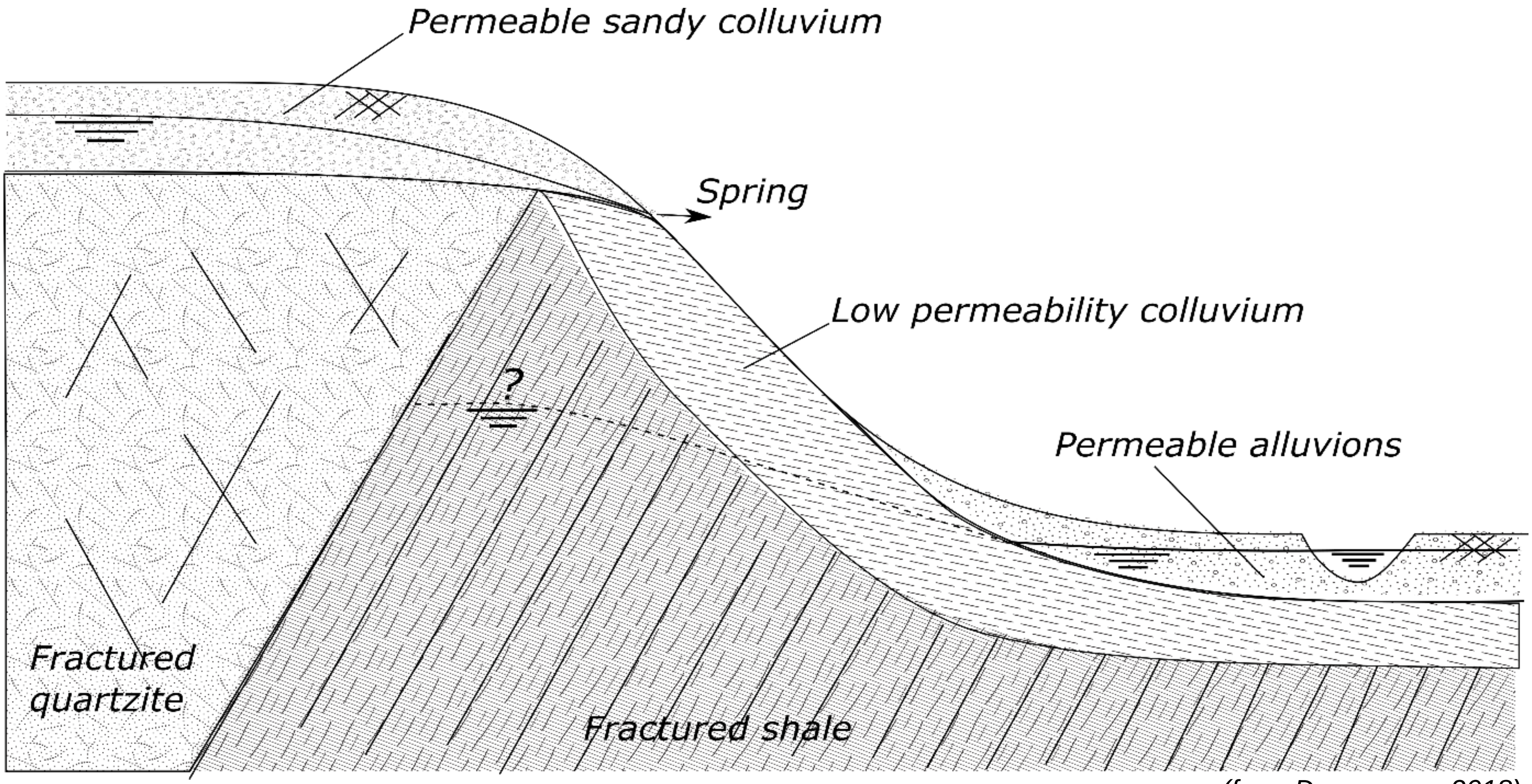
… showing the preferential infiltration/recharge period between October and March

+ geological complexity



(from Dassargues 2018)

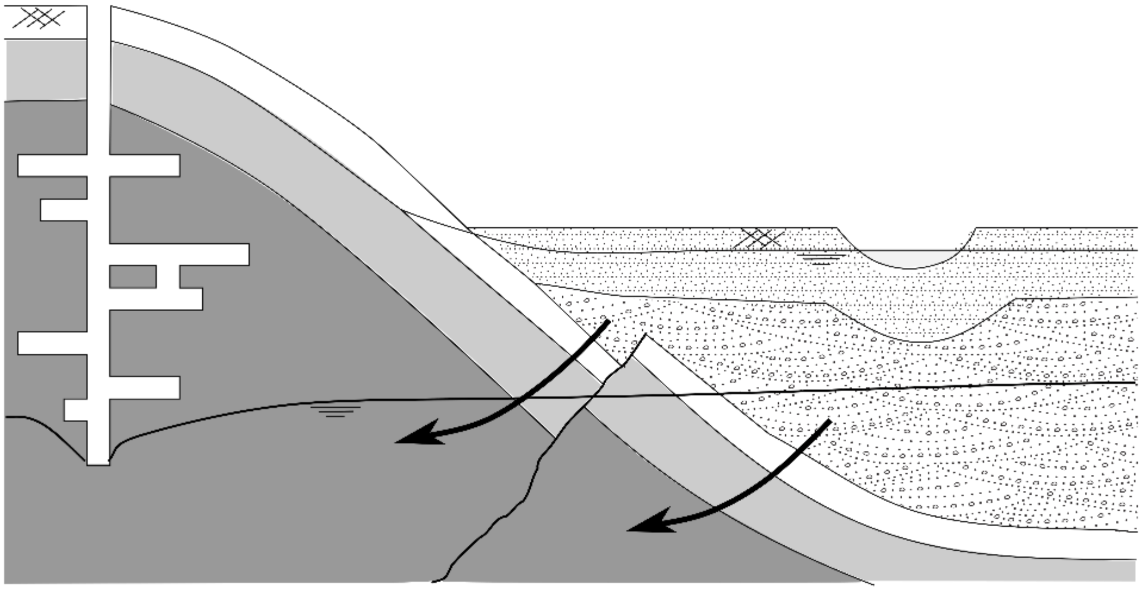
+ geological complexity



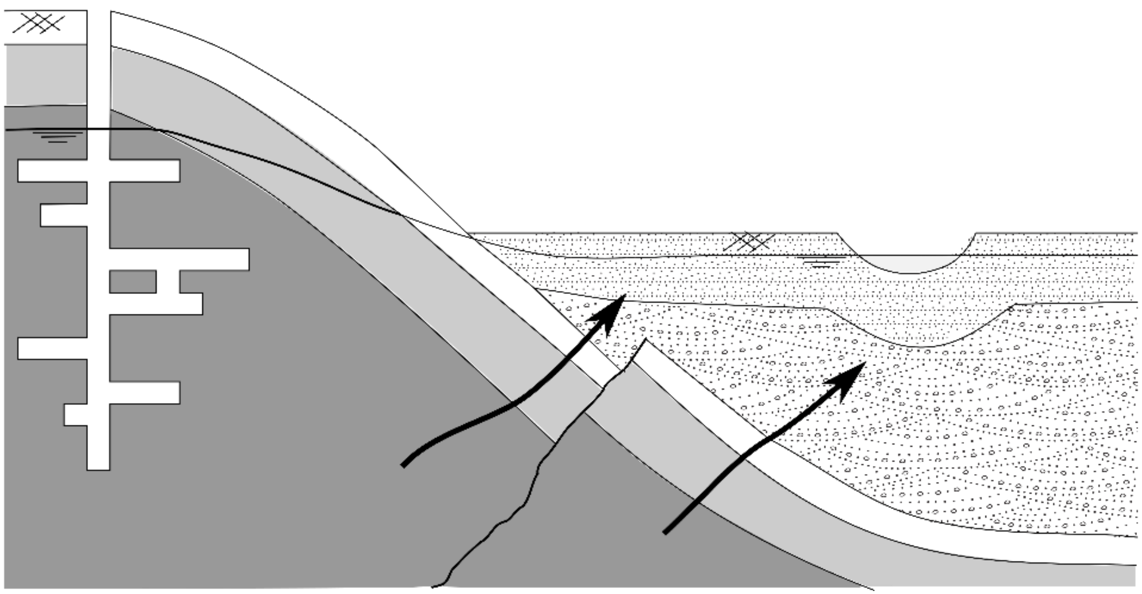
(from Dassargues 2018)

+ *geological complexity*

(a)



(b)



(from Dassargues 2018)

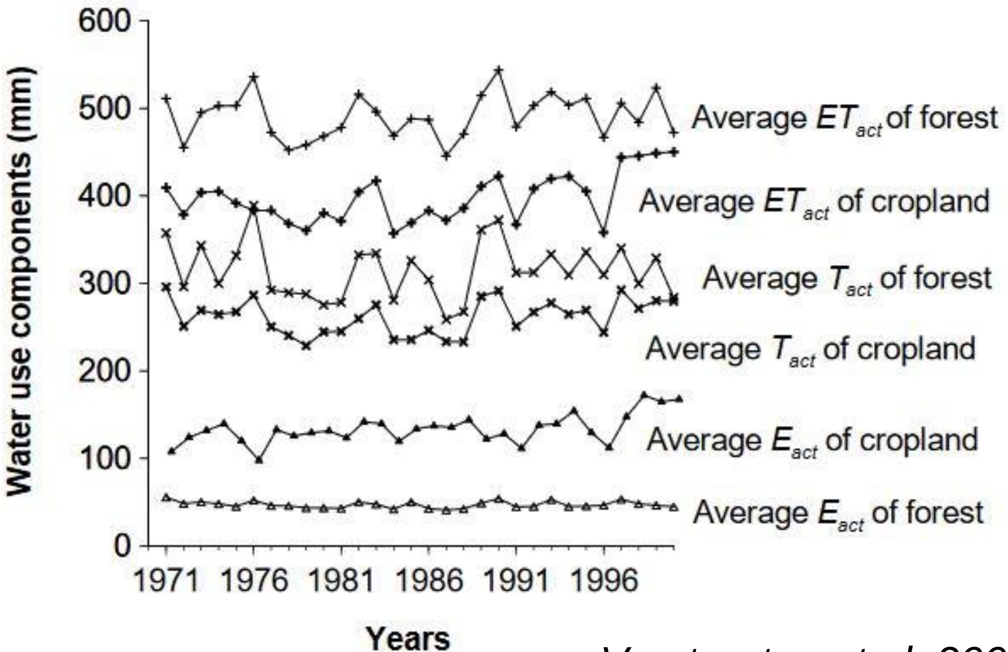
The global picture again

Irrigation is the most negative process as it increases evapotranspiration !

The impact of any agricultural production could be assessed
depending on many factors

➡ *BUT it is fundamental to distinguish between* - *rain-fed agriculture*
- *irrigated agriculture*

In our regions, agriculture consumes less water than the natural land use (i.e. forest)



Verstraeten et al. 2005

➡ ***… be careful with too simplistic impact or water footprint assessments !***

Thinking 'green' : more complex impact than usually thought on groundwater resources

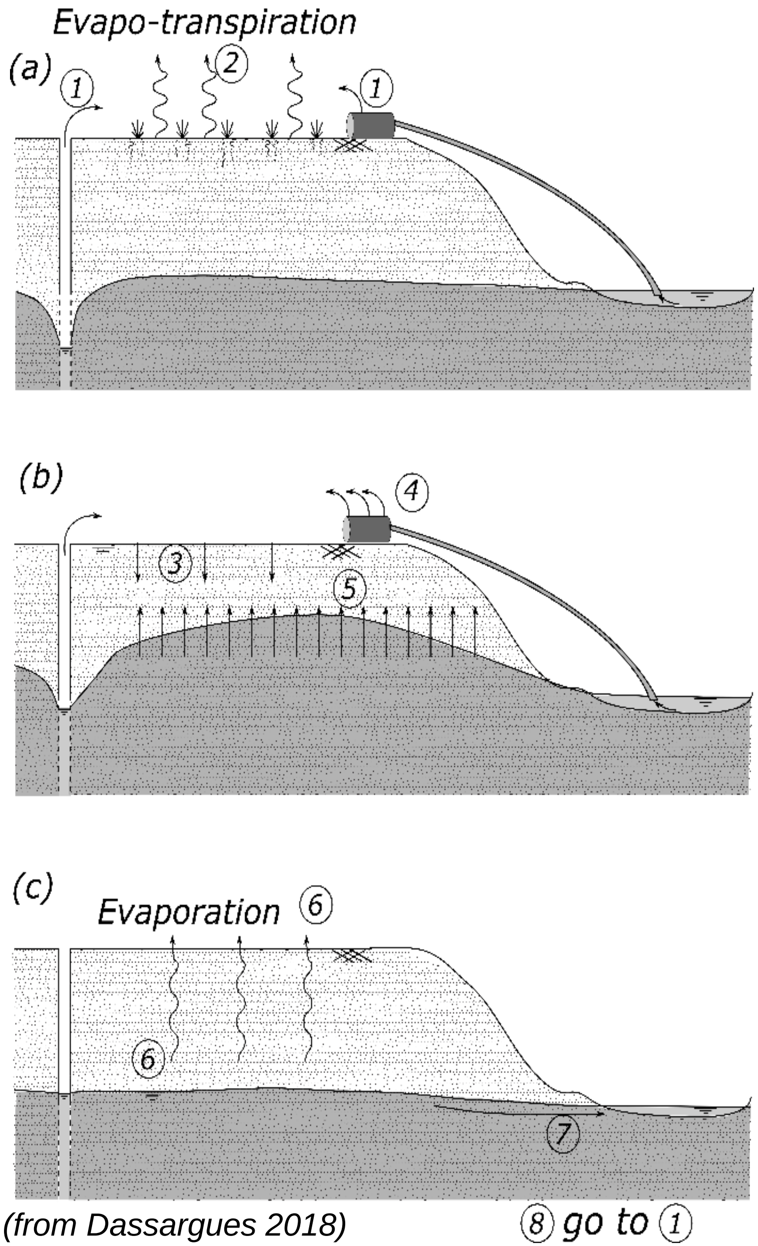
In our regions, transformation of natural landscapes into impervious areas leads to a considerable increase in groundwater recharge due to the reduction of evapotranspiration that more than compensates for the increase in runoff and due to the contribution of water main leakages (Minnig et al. 2018, JoH)

➡ ***… be careful with too simplistic impact assessments !***

Irrigation has a lot of (negative) consequences

- *increase of EvT (thus consumed water)*
- *deep percolation losses (i.e. the lower the irrigation efficiency, the higher the losses)* ➡ *partial remediation: sprinkler irrigation and drip irrigation (but expensive)*
- *rising groundwater levels* ➡ *increased evaporation, reduced agricultural efficiency*
- *waterlogging and drainage problems*
- *needed 'leaching out' of the salt increases groundwater salinity*
- *stagnant water tables at the soil surface increasing water-borne diseases (e.g. malaria, filariasis, yellow fever, dengue, and bilharzia)*
- *groundwater levels control, soil salinity control, drainage and drainage system controls …*
- *nutrients (fertilizer-based or naturally occurring) such as nitrates are mobile with water increasing concentrations in aquifers*
- *…*

Irrigation has a lot of (negative) consequences



(from Dassargues 2018)

(1) irrigation with surface water or groundwater

(2) evapotranspiration at the land surface, in the soil and root zone

(3) leaching out the soil salinity by infiltration towards the groundwater

(4) if the groundwater salt content is known to be high, surface water is preferred

(5) possible waterlogging at the surface and rising of groundwater piezometric heads

(6) easier groundwater evaporation from the partially saturated zone and the shallower saturated zone

(7) groundwater drainage by the river network, (8) the cycle returns to (1) for the next growing season....

Conclusive messages to take home…

- *renewability of freshwater can only be assessed at a local (regional) scale*
- *water 'consumption' = evapotranspiration **not to be confused with** 'use', 'production', 'withdrawals', …*

  (e.g. high withdrawals do not automatically imply high consumption and even less induced water scarcity)
- *water issues is not only a quantity problem, but also a quality problem*
- *in terms of water balance, rain-fed agriculture should be encouraged wherever possible …*

  as irrigation is the main (but not the only one) driver increasing evapotranspiration
- *globally, in 2000, about 30% of the available and renewable freshwaters are 'used', about 15% are 'consumed' (de Marsily et al. 2006)*
- *water shortages are due to the uneven spatial and temporal distributions of freshwaters*

  and inadequate management !
- *groundwater reserves = 77 x surface water reserves*
- *in terms of LCA ? … very important to distinguish rain-fed products from irrigation products !*

References *(among others)*

- Allen, R.G. 2008. Why do we care about ET? *Southwest Hydrology* 7(1): 18-19.
- Alley, W.M. 1984. On the treatment of evapotranspiration, soil moisture accounting, and aquifer recharge in monthly water balance models. *Water Resources Research* 20(8): 1137-1149.
- Brouyère, S., Carabin, G. and Dassargues, A., 2004, Climate change impacts on groundwater reserves: modelled deficits in a chalky aquifer, Geer basin, Belgium, *Hydrogeology Journal* 12(2):123-134.
- Brutsaert, W. 2005. *Hydrology: an introduction*. Cambridge: Cambridge University Press.
- Cai, X., Wallington, K., Shafiee-Jood, M. and L. Marston. 2018. Understanding and managing the food-energy-water nexus – opportunities for water resources research. *Advances in Water Resources* 111: 259-273.
- Condon, L.E. and R.M. Maxwell. 2014. Feedbacks between managed irrigation and water availability: diagnosing temporal and spatial patterns using an integrated hydrologic model. *Water Resources Research* 50(3): 2600-2616.
- Cosgrove, W.J. and D.P. Loucks. 2015. Water management: current and future challenges and research directions. *Water Resources Research* 51: 4823-4839.
- Dassargues A., 2018. *Hydrogeology: groundwater science and engineering*, 472p. Taylor & Francis CRC press, Boca Raton.
- de Marsily, G. 2009. *L'eau, un trésor en partage (in French)*. Paris : Dunod.
- Devlin, J.F. and M. Sophocleous. 2005. The persistence of the water budget myth and its relationship to sustainability. *Hydrogeology Journal* 13: 549-554.
- De Vries, J.J. and I. Simmers. 2002. Groundwater recharge: an overview of processes and challenges. *Hydrogeology Journal* 10: 5-17.
- Doble, R.C. and R.S. Crosbie. 2017. Review: Current and emerging methods for catchment-scale modelling of recharge and evapotranspiration from shallow groundwater. *Hydrogeology Journal* 25: 3-23.
- Foster, S. and A. MacDonald. 2014. The 'water security' dialogue: why it needs to be better informed about groundwater. *Hydrogeology Journal* 22 (7): 1489-1492.
- Goderniaux, P., Brouyère, S., Fowler, H.J., Blenkinsop, S., Therrien, R., Orban, P. and A. Dassargues. 2009. Large scale surface–subsurface hydrological model to assess climate change impacts on groundwater reserves. *Journal of Hydrology* 373(1-2): 122-138.
- Goderniaux, P., Brouyère, S., Blenkinsop, S., Burton, A., Fowler, H.J., Orban, P. and Dassargues, A., 2011, Modelling climate change impacts on groundwater resources using transient stochastic climatic scenarios, *Water Resources Research* 47(12), W12516
- Healy, R.W. 2010. *Estimating groundwater recharge*. Cambridge MA: Cambridge University Press.

References *(among others, following)*

- Kim, J.H. and R.B. Jackson. 2012. A global analysis of groundwater recharge for vegetation, climate, and soils. *Vadose Zone Journal* 11(1).
- Klose, S. 2012. *Regional hydrogeology and groundwater budget modeling in the arid Middle Drâa Catchment (South-Morocco)*. PhD dissertation, Bonn: Rheinischen Friedrich-Wilhelms Universität Bonn.
- Loáiciga, H.A. 2003. Sustainable groundwater exploitation. *Int. Geology Review* 44(12): 1115-1121.
- Minnig, M., Moeck, Ch., Radny, D. and M. Schirmer. 2018.Impact of urbanization on groundwater recharge rates in Dübendorf, Switzerland, *Journal of Hydrology* 563: 1135-1146.
- Monteith, J. L. 1965. Evaporation and environment. In: *The state and movement of water in living organism.* 19th Symp. Society of Experimental Bioloy 205-234.
- Peck, A.J. and D.R. Williamson. 1987. Effects of forest clearing on groundwater. *Journal of Hydrology* 94: 47-65.
- Ringler, C., Bhaduri, A. and R. Lawford. 2013. The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency?, *Current Opinion in Environmental Sustainability* 5(6) : 617-624.
- Rocha, D., Feyen, J. and A. Dassargues, A. 2007. Comparative analysis between analytical approximations and numerical solutions describing recession flow in unconfined hillslope aquifers. *Hydrogeology Journal* 15: 1077-1091.
- Scanlon, B.R., Ruddell, B.L., Reed, P.M., Hook, R.I., Zheng, C., Tidwell, V.C. and S. Siebert. 2017. The food-energy-water nexus: transforming science for society. *Water Resources Research* 53: 3550-3556.
- Simmons, J. 2015 Water in the energy industry. *Geoscientist* 25(10) 10-15.
- Smerdon, B.D. and J.E. Drewes. 2017. Groundwater recharge: The intersection between humanity and hydrogeology*. Journal of Hydrology* 555: 909-911.
- Van Camp, M., de Viron, O., Pajot-Métivier, G., Casenave, F., Watlet, A., Dassargues, A. and M. Vanclooster. 2016. Direct measurement of evapotranspiration from a forest using a superconducting gravimeter. *Geophysical Research Letters* 43(10): 225-231.
- Verstraeten, W.W., Muys, B., Feyen, J., Veroustraete, F., Minnaert M., Meiresonne,L. and A. de Schrijver. 2005. Comparative analysis of the actual evapotranspiration of Flemish forest and cropland, using the soil water balance model WAVE*. Hydrology and Earth System Sciences Discussions*, EGU, 9 (3): 225-241.
- Walraevens K., Biron J.-P., Dassargues A., 2014, Introduction générale et description du contexte hydrogéologique en Belgique - Algemene inleiding en beschrijving van de hydrogeologische context in Belgïe, in *Watervoerende lagen & grondwater in Belgïe – Aquifères & eaux souterraines en Belgique*, pp. XI-XXIV. Academia Press.
- Wheeling, K. 2016. The coming blue revolution. *EOS* 97(4):29.