Stream-aquifer interactions: a combined field - methodological approach in fractured carbonate catchments

Groundwater impacts on biological quality of surface water streams

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American Geophysical Union (AGU) Fall Meeting 2016
San Francisco, CA
December 12-16, 2016

Context of the study : stream – aquifer interactions in the context of the EU Water Framework Directive

« EU Water Directive 2000/60/CE, defining a general framework for a EU common policy on water»

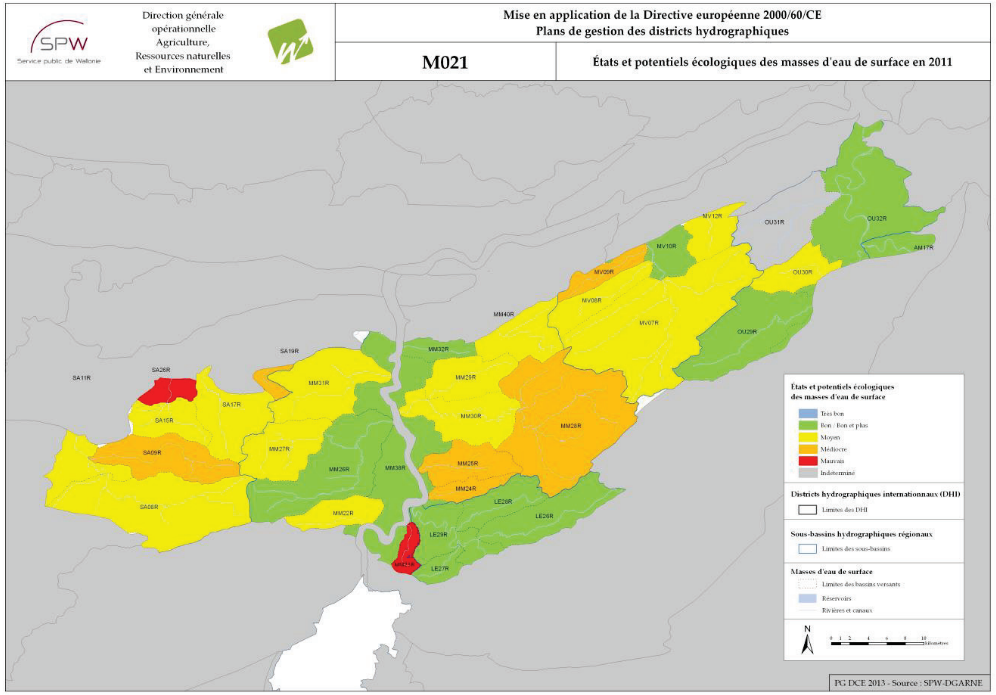
- « ... Necessity to elaborate a **common integrated policy on water** » (9)
- « … required to pursue an objective of good water status for each EU hydrographic districts, in order to have **coordinated measures on groundwater and surface waters in each ecological and hydrological system**» (33)
- « … for environmental protection, it is required to promote a **stronger integration of quatitative and qualitative aspects, for both surface waters and groundwaters**, taking into consideration the natural conditions for water transfers in the hydrologic cycle. » (34)

Context of the study : stream – aquifer interactions in the context of the EU Water Framework Directive

ex: Condroz limestone & sandstone groundwater body in the Walloon Region of Belgium (EU)

Until recently, no clear view/ approach for estimating the importance of GW-SW interactions on the status of both GW ans SW water bodies…

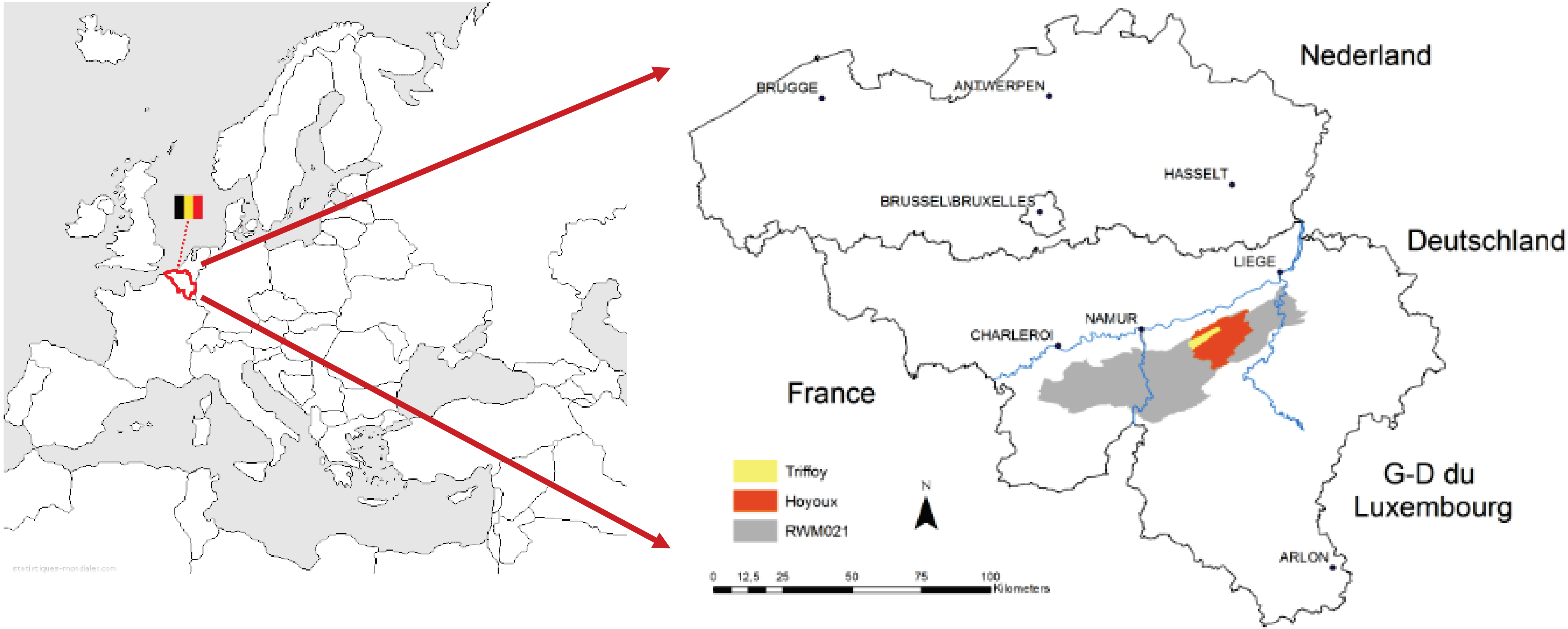
Code MESU	Nom (cours d'eau principal)	Superficie (km²)	Typologie	Risque chimique ESU	Risque écologique ESU	Risque total ESU	Risque vs ESO
AM17R	Amblève IV	88	Grandes rivières condrusiennes à pente moyenne	à risque	pas à risque	à risque	Indéterminé
LE26R	Ywenne	51	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Indéterminé
LE27R	Ruisseau de Mahoux	12	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Indéterminé
LE28R	Ruisseau de Forges	30	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Indéterminé
LE29R	Lesse VI	38	Grandes rivières condrusiennes à pente moyenne	à risque	pas à risque	à risque	Indéterminé
MM22R	Ruisseau de Féron	26	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
MM23R	Ruisseau de Falmagne	10	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
MM24R	Ravin de Sorinne	15	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
MM25R	Ruisseau des Fonds de Leffe	34	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
MM26R	Molignée I	92	Ruisseaux condrusiens à pente moyenne	à risque	à risque	à risque	Possible
MM27R	Molignée II	47	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Possible
MM28R	Bocq I	148	Ruisseaux condrusiens à pente moyenne	à risque	à risque	à risque	Possible
MM29R	Ruisseau de Crupet	36	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Possible
MM30R	Bocq II	51	Rivières condrusiennes à pente moyenne	à risque	pas à risque	à risque	Possible
MM31R	Burnot	67	Ruisseaux condrusiens à forte pente	pas à risque	risque possible	risque possible	Indéterminé
MM32R	Ruisseau de Tailfer	15	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Indéterminé
MM38R	Meuse I	144	Très grandes rivières condrusiennes à pente faible	à risque	à risque	à risque	Indéterminé
MM40R	Samson	115	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Indéterminé
MV07R	Hoyoux I	169	Ruisseaux condrusiens à pente moyenne	risque possible	risque indéterminé	risque possible	Possible
MV08R	Ruisseau du Triffoy	30	Ruisseaux condrusiens à pente moyenne	risque possible	à risque	à risque	Possible
MV09R	Ruisseau de Lilot	19	Ruisseaux condrusiens à pente moyenne	risque possible	à risque	à risque	Indéterminé
MV10R	Hoyoux II	37	Rivières condrusiennes à pente moyenne	à risque	pas à risque	à risque	Possible
MV12R	Ruisseau d'Oxhe	45	Ruisseaux condrusiens à pente moyenne	risque possible	risque indéterminé	risque possible	Indéterminé
OU29R	Néblon	79	Ruisseaux condrusiens à forte pente	pas à risque	pas à risque	pas à risque	Possible
OU30R	Ruisseau de Blokai	30	Ruisseaux condrusiens à forte pente	risque possible	risque indéterminé	risque possible	Indéterminé
OU31R	Ruisseau du Fond de Martin	62	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
OU32R	Ourthe III	174	Grandes rivières condrusiennes à pente moyenne	à risque	pas à risque	à risque	Indéterminé
SA08R	Eau d'Heure II	125	Ruisseaux condrusiens à pente moyenne	risque possible	à risque	à risque	Possible
SA09R	Thyria	54	Ruisseaux condrusiens à pente moyenne	risque possible	à risque	à risque	Indéterminé
SA11R	Eau d'Heure III	66	Rivières condrusiennes à pente moyenne	pas à risque	à risque	à risque	Indéterminé
SA15R	Ruisseau d'Hanzinne I	29	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
SA17R	Biesme I	68	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
SA19R	Ruisseau de Fosses I	24	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé
SA26R	Ruisseau d'Hanzinne II	34	Ruisseaux condrusiens à forte pente	risque possible	à risque	à risque	Indéterminé



… and no clear referential / methods for establishing the potential impact of GW on the biological quality of surface water bodies, in particular on groundwater aquatic associated ecosystems

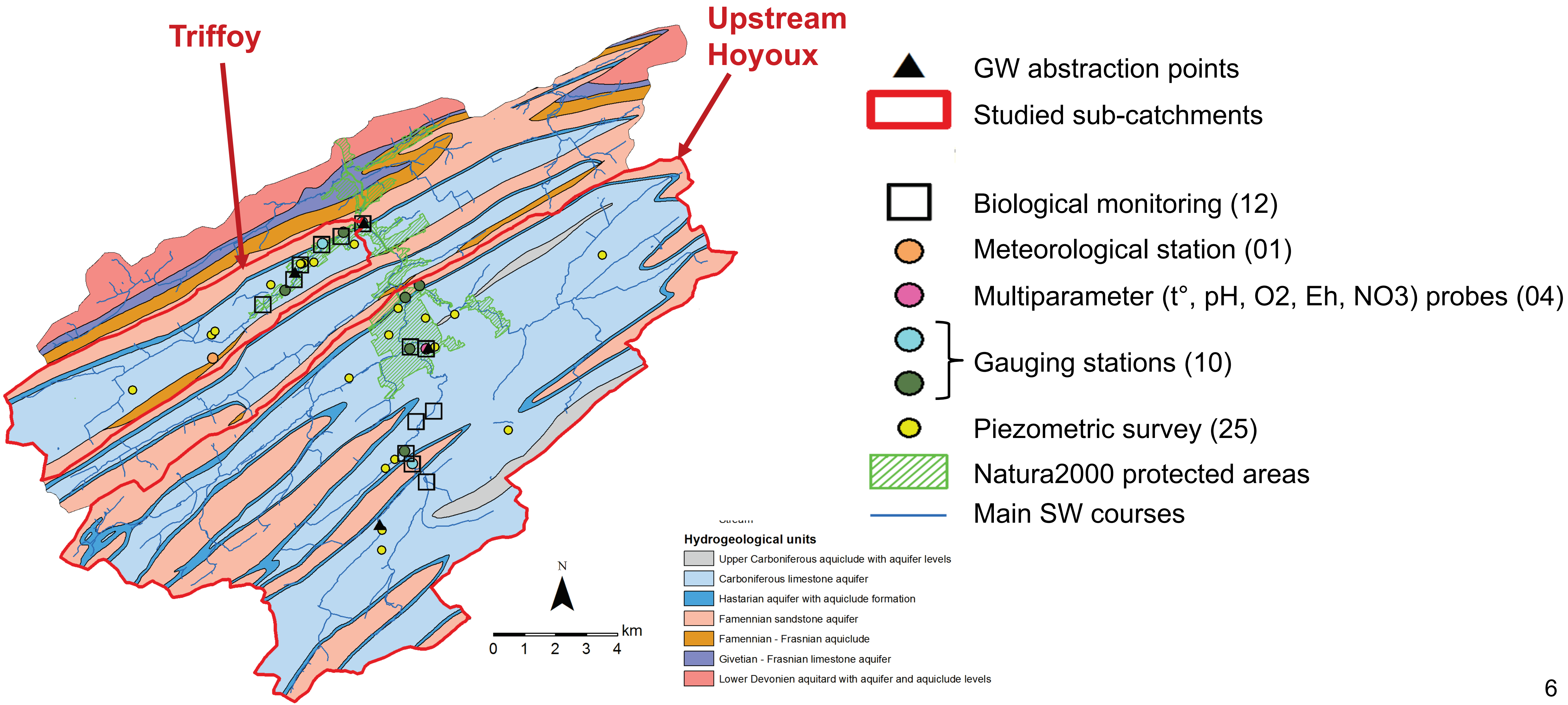
Case study : Hoyoux River catchment

Triffoy & Upstream Hoyoux sub-catchments – Belgium



- **Important GW resources and intense GW abstraction** (galleries, private wells)
- Agricultural catchments with **NO_3 close to threshold values for SW** (25 mg NO_3 /L)
- **Moderate ecological status** for the River Triffoy (based on GBNI referential)

2,5 years of intensive monitoring and experiments

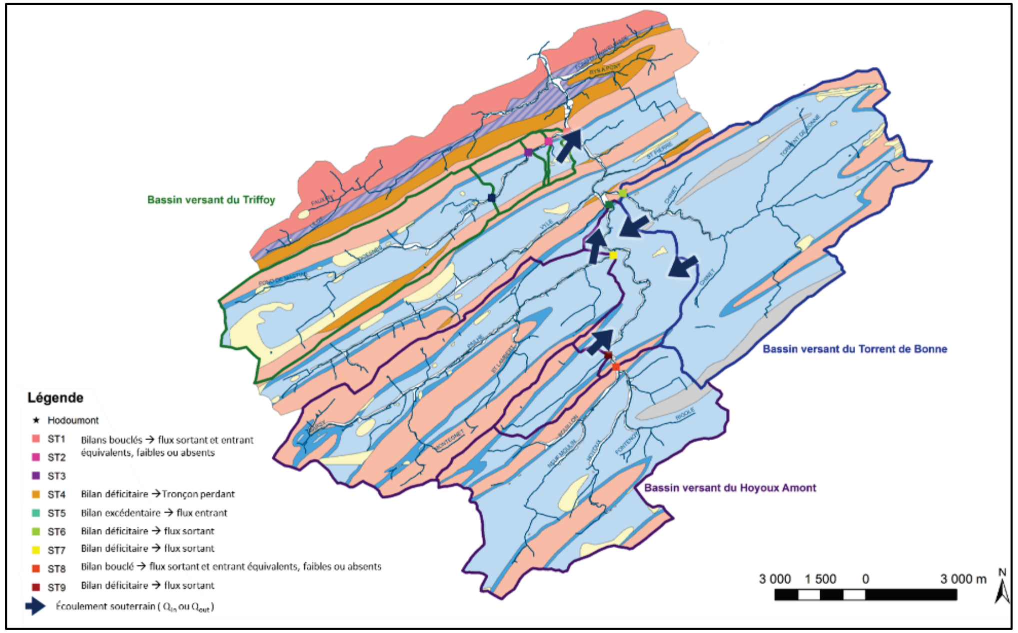


Water budgets at catchment scale + hydrograph separation methods

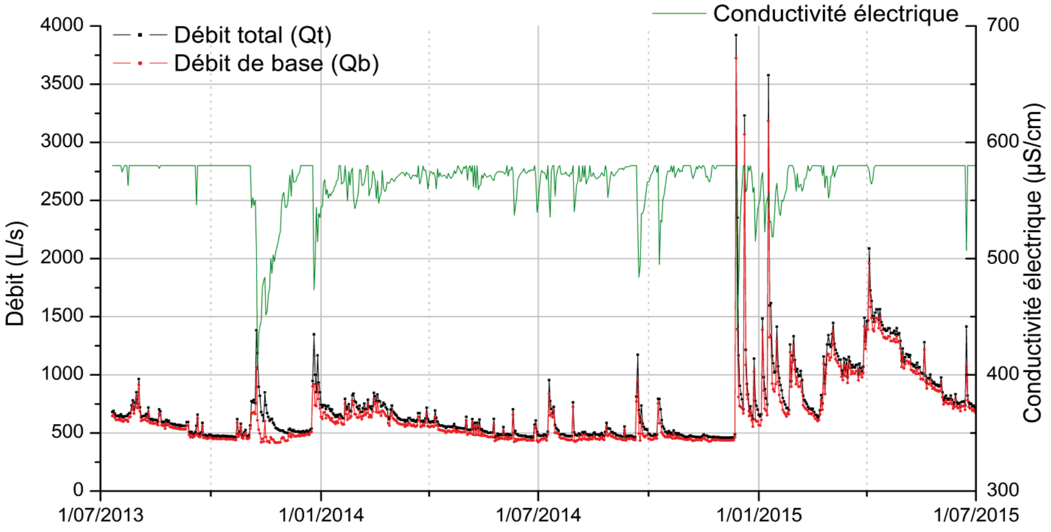
*(French VCN3, **CMB**, Hypes)*

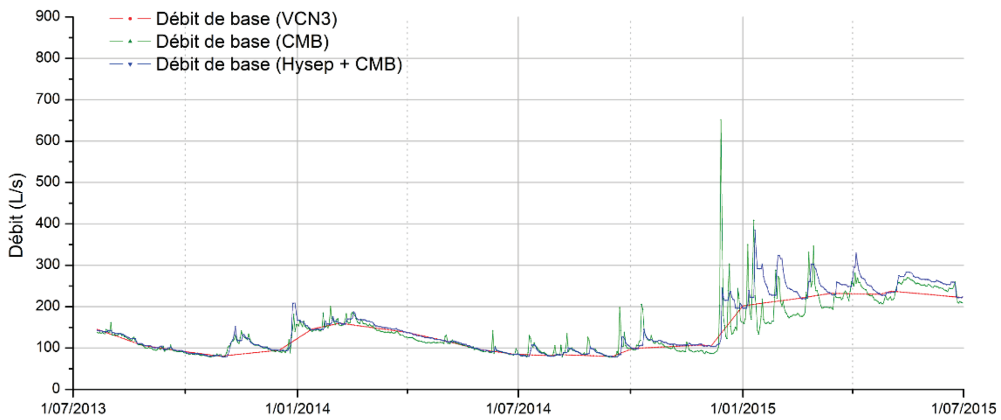
Bassin versant / Sous- bassin / Tronçon	P	ETR	Q_{capt}	Q_t	ΔR	$\varepsilon_{fermeture}$	Résultat du bilan annuel
Triffoy (ST1)	100%	68.27 %	13.15%	14.41%	6.13%	-1.96%	Bouclé
Source de Marchin (ST2)	100%	68.27 %	5.34%	14.99%	7.26%	4.14%	Bouclé
Jamagne (ST4)	100%	68.27 %	0%	5.22%	7.32%	19.18%	Déficitaire
Hoyoux Amont (ST5)	100%	68.27 %	28.06%	21.83%	3.87%	-22.04%	Excédentaire
Ruisseau de Pailhe (ST7)	100%	68.27 %	0%	10.43%	8.11%	13.19%	Déficitaire
Ruisseau d'Havelange (ST9)*	100%	28.5 %	1.80%	7.36%	0.20%	88.95%	(Déficitaire)
Petit Avin (ST8)	100%	68.27 %	4.67%	24.26%	8.17%	-5.37%	Bouclé
Torrent du Bonne (ST6)	100%	68.27%	0.04%	2.29%	7.41%	22%	Déficitaire

* Bilan réalisé sur une durée de 3 mois, en période hivernale.

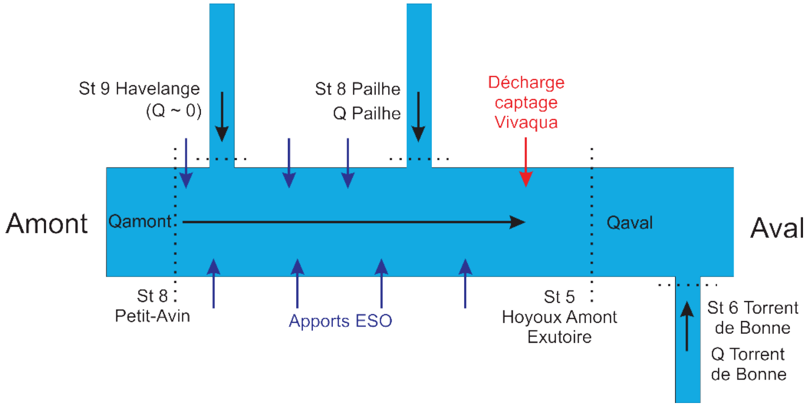


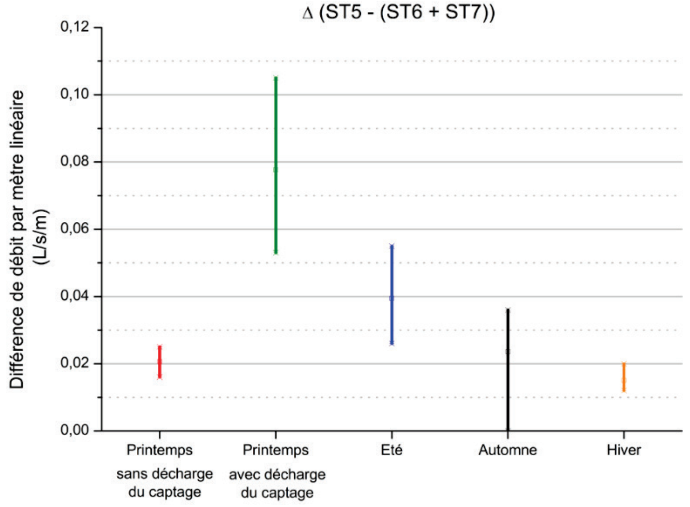
Groundwater flow between subcatchments

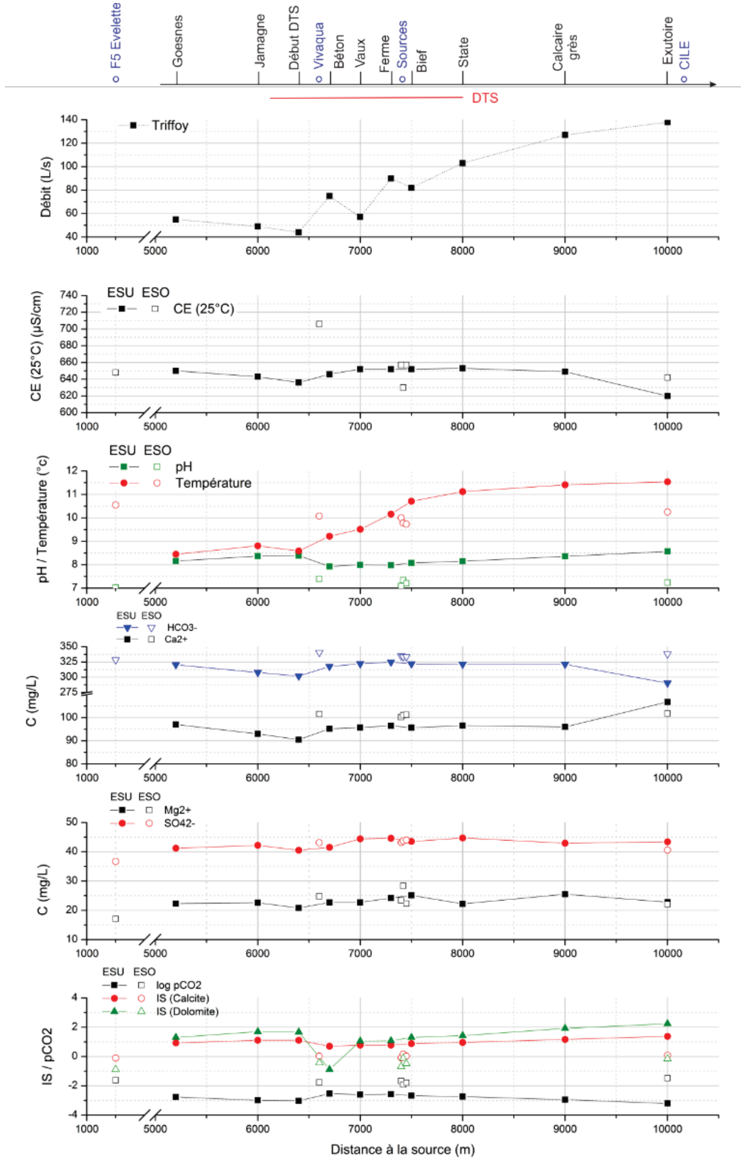


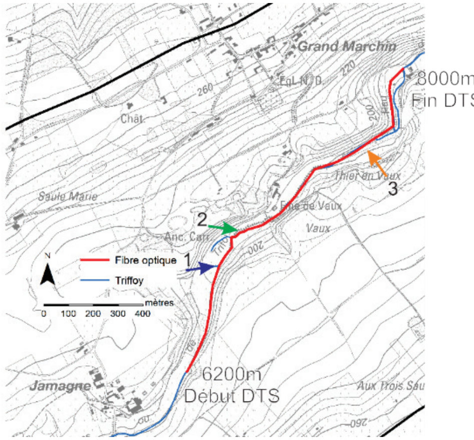


Quantification of groundwater – surface water exchanges at the scale of river courses / sections

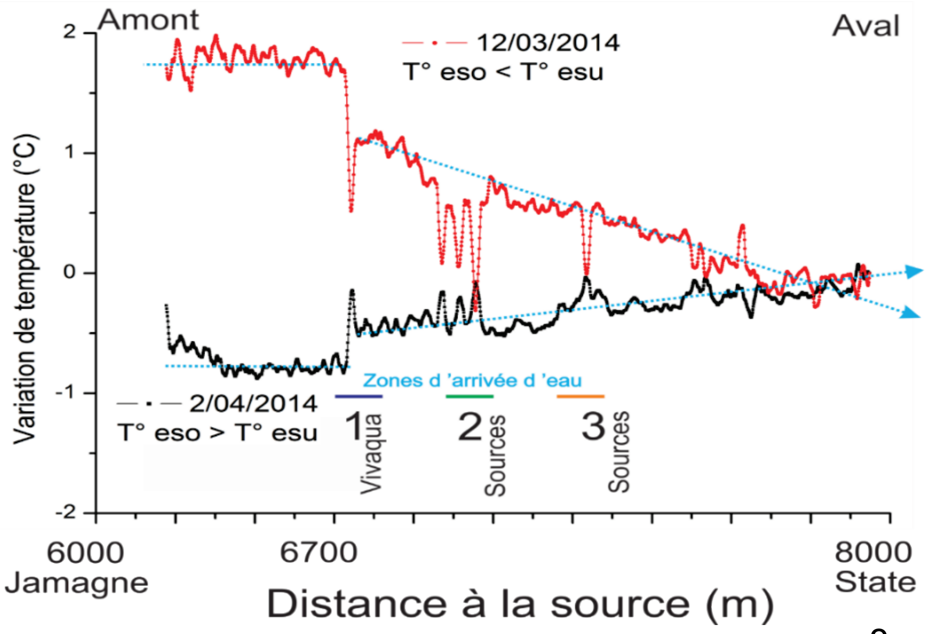






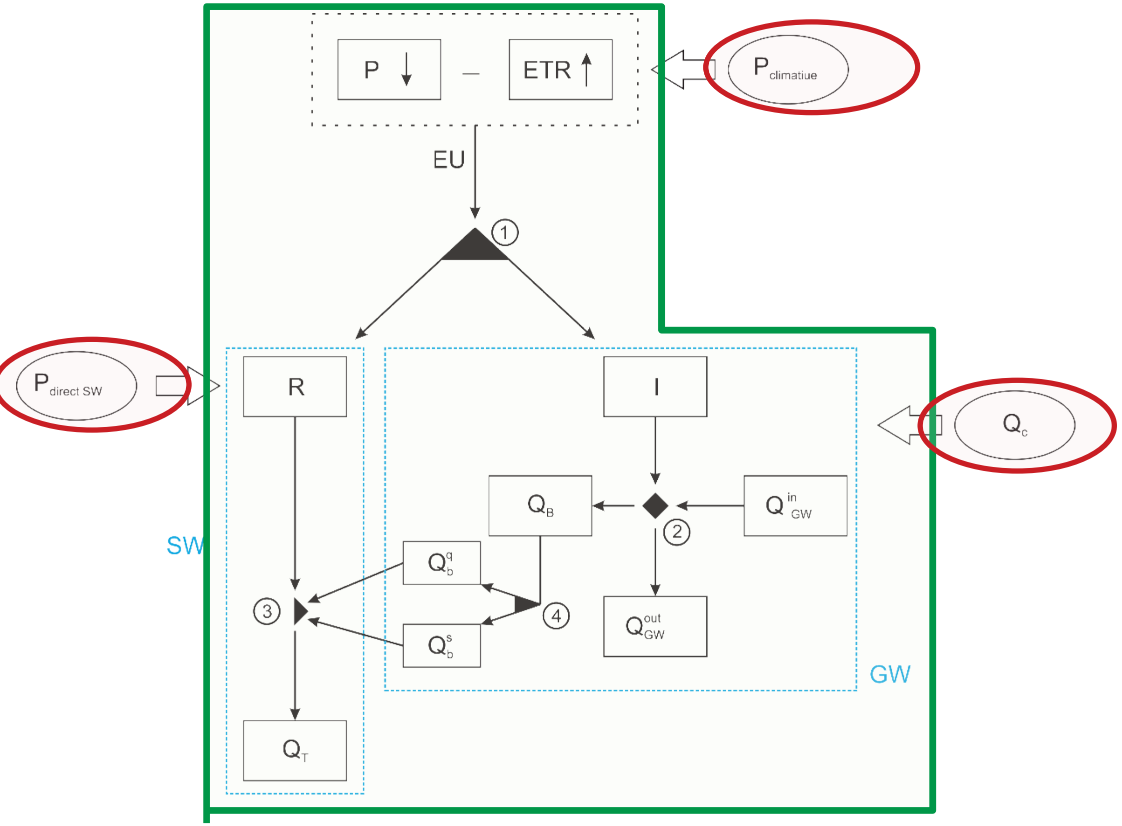


Distributed Temperature Sensing (DTS) over 1800m in the Triffoy



Quantitative indicators and related typology of GW-SW interactions: *catchments strongly dependent on groundwater*

Based on GW-SW water balance terms, definition and calculation of intrinsic and pressure indicators



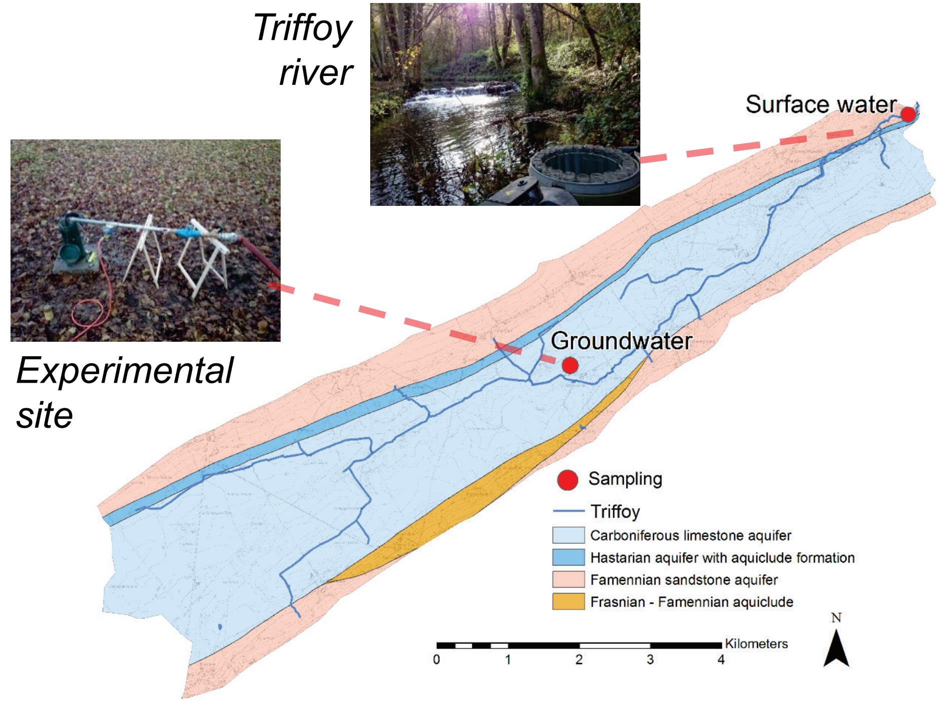
Triffoy						
Indicator	**Symbol**	**Formula**	**Description**	**07/2013 - 07/2014**	**07/2014 - 07/2015**	**Mean**
Intrinsic	I^1_{GW}	I/EU	Infiltration index	0,97	0,94	0,95
	I^1_{SW}	R/EU	Run-off index	0,03	0,06	0,05
	I^2_{GW}	Q_{GW}/I	Extent of groundwater losses towards other catchments	0,16	0,03	0,09
	I_{SW}	Q_B/I	Extent of baseflow on infiltration	0,43	0,64	0,54
	BFI	Q_B/Q_{SW}	Baseflow index	0,93	0,91	0,92
	I^3_{GW}	Q^q_B/Q_B	Quick baseflow index	0,06	0,10	0,08
	I^4_{GW}	Q^s_B/Q_B	Slow baseflow index	0,94	0,90	0,92
Pressure	P_1	Q_C/EU	Groundwater abstraction on available water	0,40	0,31	0,36
	P_2	Q_C/I	Groundwater abstraction on infiltration	0,41	0,33	0,37
	P_3	$Q_C / (Q_C + Q_T)$	Groundwater abstraction impact on streamflow	0,47	0,32	0,39

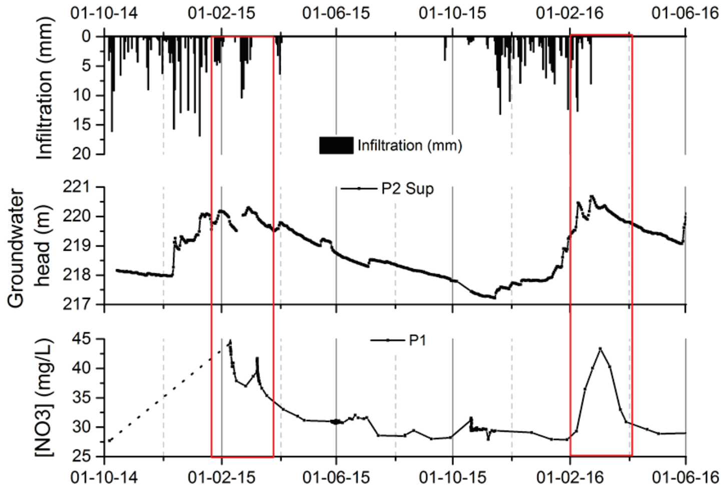
First conclusions on quantity aspects:

- Catchments strongly groundwater-dependent (large I^1_{GW} and *BFI*)
- Strong impact of GW abstraction on the hydraulic regime in the catchment (large P_i)

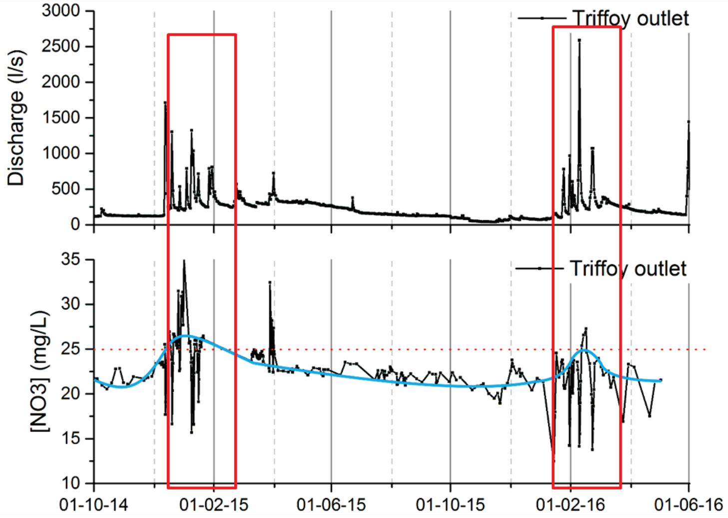
Nitrate dynamics in the connected soil – GW – SW system

fast transfer, strong GW dependence and critical concentrations





NO_3 variations in GW

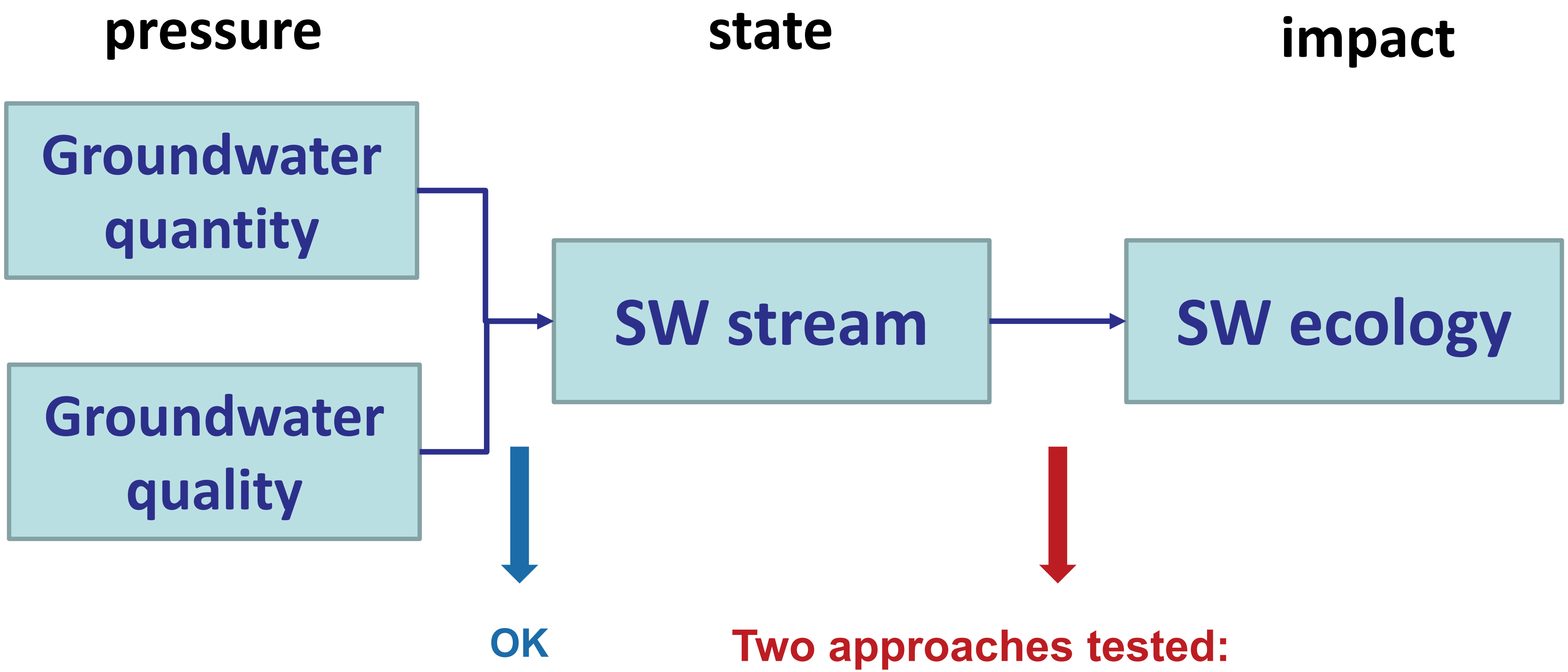


NO_3 variations in SW

First conclusions on quality aspects:

- Fast transfer of NO_3 at catchment scale in the soil – VZ – GW – SW system
- SW quality strongly dependent of GW quality, with NO_3 close to SW threshold (25 mg NO_3/L)

Impacts of groundwater on the biological quality of surface water streams



Two approaches tested:

- Diatoms (sensitivity to excess nutrients)
- Benthic macroinvertebrates

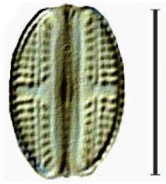
(Dawson et al. 2007)

Impacts of groundwater on the biological quality of surface water streams
Investigations on diatoms

Sampling at 11 locations, diatoms analyses by the consulting company Bi-Eau (Angers, France)

IPS : Polluosensitivity index, TDI : trophic diatom index

		H6	H5	H4	H2	H1	RP
HOYOUX	IPS (sur 20)	12.8	12.5	13.6	12.0	14.1	13.2
	TDI (sur 100)	71.6	79.1	74.3	76.2	87.7	77.7
	Richesse taxinomique (nb. taxons/récolte)	64	56	68	67	60	71
	Indice de diversité de Shannon (bits/ind.)	4.76	4.95	4.99	4.99	4.37	5.05
	Equitabilité	0.79	0.85	0.82	0.82	0.74	0.82
		T1	**T2**	**T3**	**T4**	**T5**	**T6**
TRIFFOY	IPS (sur 20)	15.4	15.2	18.6	15.6	15.3	15.8
	TDI (sur 100)	90.3	80	48.2	73.9	80.5	78.8
	Richesse taxinomique (nb. taxons/récolte)	28	55	20	39	51	42
	Indice de diversité de Shannon (bits/ind.)	2.54	4.13	2.53	3.68	4.23	4.23
	Equitabilité	0.53	0.71	0.59	0.70	0.75	0.78



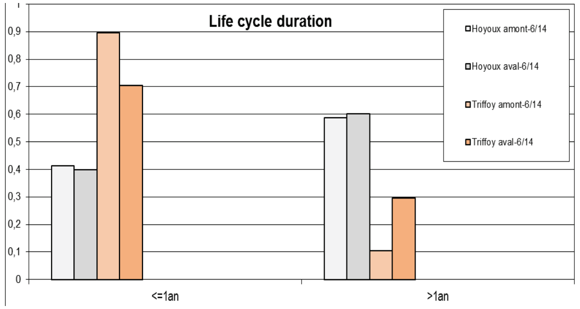
Downstream a excess water discharge of a groundwater abstraction gallery

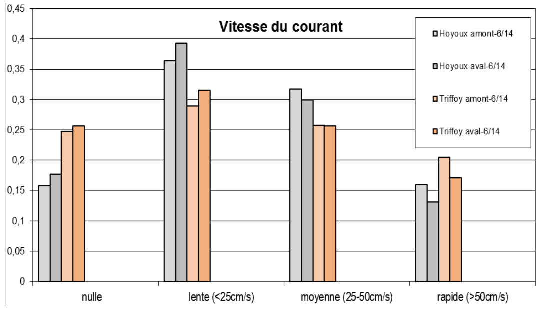
Good to very good quality in both rivers, despite high nitrate concentrations
High species richness in most sites and non-specific response to nutrients

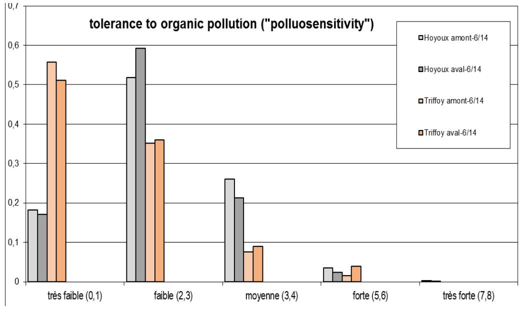
Impacts of groundwater on the biological quality of surface water streams
Investigations on benthic macro-invertebrates

Sampling at 1 station in 2013 (Triffoy), 4 stations (2 in each catchment in 2014), with 8 velocity-substrate combinations in each site
Macro-invertebrates analysed by URBE using Usseglio & Beisel (2002) expert system

Biological and ecological traits of the invertebrates

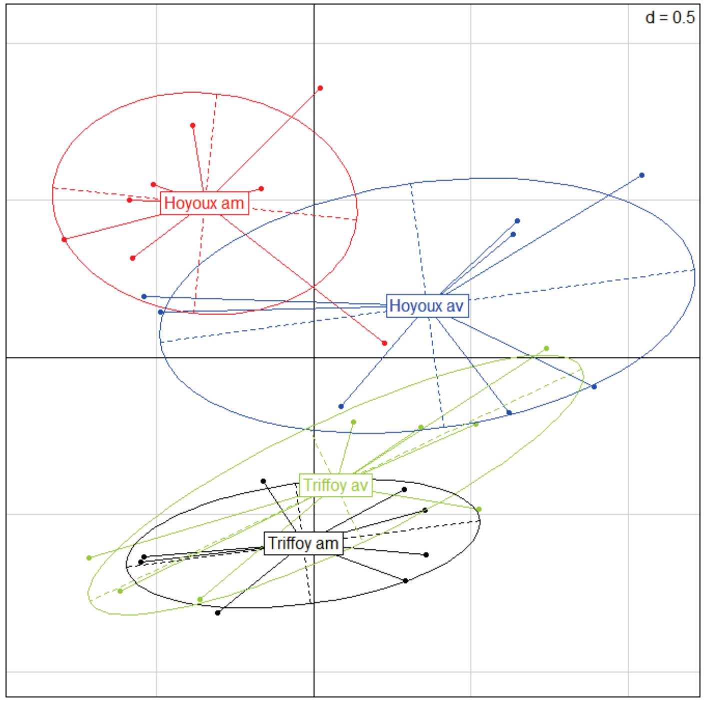






Triffoy: shorter life cycles, low current and pollution tolerant species compared to Hoyoux

Correspondence factor analysis on the taxonomic composition



Contrasted macro-invertebrate assemblages between the two rivers
→ Greater diversity of velocity-substrate combinations in Hoyoux

Globally: determinent influence of the SW flow regime on SW biological diversity and quality

Research outcomes and perspectives

In terms of GW impacts on stream biological quality

1. Despite elevated NO_3, no evidence of « local » impact of GW quality on stream biological quality
2. Clear influence of stream morpho-hydrological conditions, in particular velocity-substrate combinations, on the taxonomic and functional diversity of the macroinvertebrate assemblage
   Possible disturbance of the ecosystem due to groundwater abstraction!

Perspectives: develop a **robust link between the quantitative status of groundwater (flow rates, velocities…) and the biological quality of rivers** (first by reinterpreting RW databases within this framework)

Research outcomes and perspectives

In terms of GW – SW interactions in general:

1. Investigations from river section to catchment scale, with the objective in mind of obtaining robust water balance and reliable estimates of fluxes in and across the water compartments
   GW-SW interdependence is function of the relative importance of GW-SW interaction compared to the global balance of water fluxes in the catchement
2. Detailed time monitoring to capture all the variability of water and chemical fluxes in and across the different compartments.
   Important proxy: CE as a good tracer of GW fluxes, at least in groundwater dominated streams (alkaline rivers)

   Perspectives: extend the work to other contexts (more runoff…)

Acknowledgements

Research was funded by the administration of the Walloon Region of Belgium (DGARNE, Department for Water and Environment)

Service public de Wallonie

Selected case study by EU Groundwater Working Group :

Technical Report on Groundwater Associated Aquatic Ecosystems, 2015, *Technical Report n°9 - Unit C1 Water*, European Commission

Thanks to CILE, VIVAQUA for providing data, Hoyoux River Contract and many other people for continuous support and help

Thanks to project partners for efficient collaborations during the project (F.Schmit, V.Hallet, C.Sohier, A.Degre)

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