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Booklet-Guide of the Montoussé Experimental Agricultural Catchment in Auradé (Auradé Catchment, Gascony)

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Booklet-Guide

of the Montoussé Experimental Agricultural Catchment in Auradé (Auradé Catchment, Gascony)

Probst J.L and Probst A.



*View of the upper part of the Auradé catchment
with the stream lined with grass strips and poplars.*

Web site : <https://bvea.sedoo.fr/>



Preamble

The experimental agricultural catchment of Montoussé in Auradé, called Auradé Catchment (AC), is today integrated into various labeled systems at the regional, national and international levels:

1- Regional scale: AC is today a Regional Research and Innovation Platform initially recognized in 2013 by the Midi-Pyrénées region, which has become the Occitanie Region.

2- National scale:

- AC (<https://bvea.sedoo.fr/>) has been part of the Research Infrastructure (IR) OZCAR (Observatory of the Critical Zone: Applications and Research) since 2016: <https://www.ozcar-ri.org/fr/ozcar-observatoires-de-la-zone-critique-applications-and-research/>

- AC is part of the National Equipex CRITEX (National park of innovative equipment for the spatial and temporal study of the critical zone of watersheds) which started in 2011: <https://www.critex.fr/quest-what-critex/?lang=en>

- AC is also integrated into the regional territory of the Zone Atelier "Pyrénées-Garonne (ZA PYGAR)" (<https://pygar.omp.eu>) which is part of the IR RZA (Réseau des Zones Ateliers: <http://www.za-inee.org/en/network>).

3- International scale :

- since 2018, the IR OZCAR has entered with the IR RZA (Réseau des Zones Ateliers) in a European Research Infrastructure (ESFRI) on European Long-Term Ecosystems Research (eLTER): <https://www.lter-europe.net/>

- AC is also part of the international iLTER network: <https://www.ilter.network/> (DEIMS-SDR database: Dynamic Ecological Information Management System- Site and dataset registry: <https://deims.org/>)

- since 2013, AC has also been part of the "Critical Zone Exploration Network" (CZEN) which brings together all the Critical Zone observation sites around the world: <https://www.czen.org/>.

Probst J.L. and Probst A. 2022- Booklet-Guide of the Montoussé Experimental Agricultural Catchment in Auradé (Auradé Catchment, Gascony). Technical report, · June 2022, CNRS, University of Toulouse, 44 p. [DOI: 10.13140/RG.2.2.29120.61447](https://doi.org/10.13140/RG.2.2.29120.61447)

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This Booklet-Guide is an update of the one published in French in February 2020 by Probst JL and Probst A. with the DOI: 10.13140/RG.2.2.35454.25927

Booklet-Guide realized with the contributions of Marion Tetegan (LEFE), Vincent Bustillo (CESBIO), Francis Macary (INRAE) et Jeanne Laffont (GAGT)

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Presentation of Auradé Catchment



Figure 1- Views of Auradé Catchment in Spring (left) and in Winter (right)

General Characteristics

<https://bvea.sedoo.fr/>

The Montoussé stream which drains the Auradé Catchment (320 ha) is a tributary of the Boulouze river (tributary of the Save river which joins the Garonne river at Larra). Auradé is a small village in the Gers and it is located 40 km west of Toulouse, in the hillsides of Gascony (Fig. 1).

The cultivated area of the catchment covers 298 hectares (93% of the total area of the catchment). Crops in rotation (wheat and sunflower) occupy 90% of the surface of the watershed. The soils - called "Terreforts" - are clayey and belong to the sequence of brown calcareous-brown calcic-leached brown soils and have developed on a clayey and carbonated molassic substrate of Miocene age.

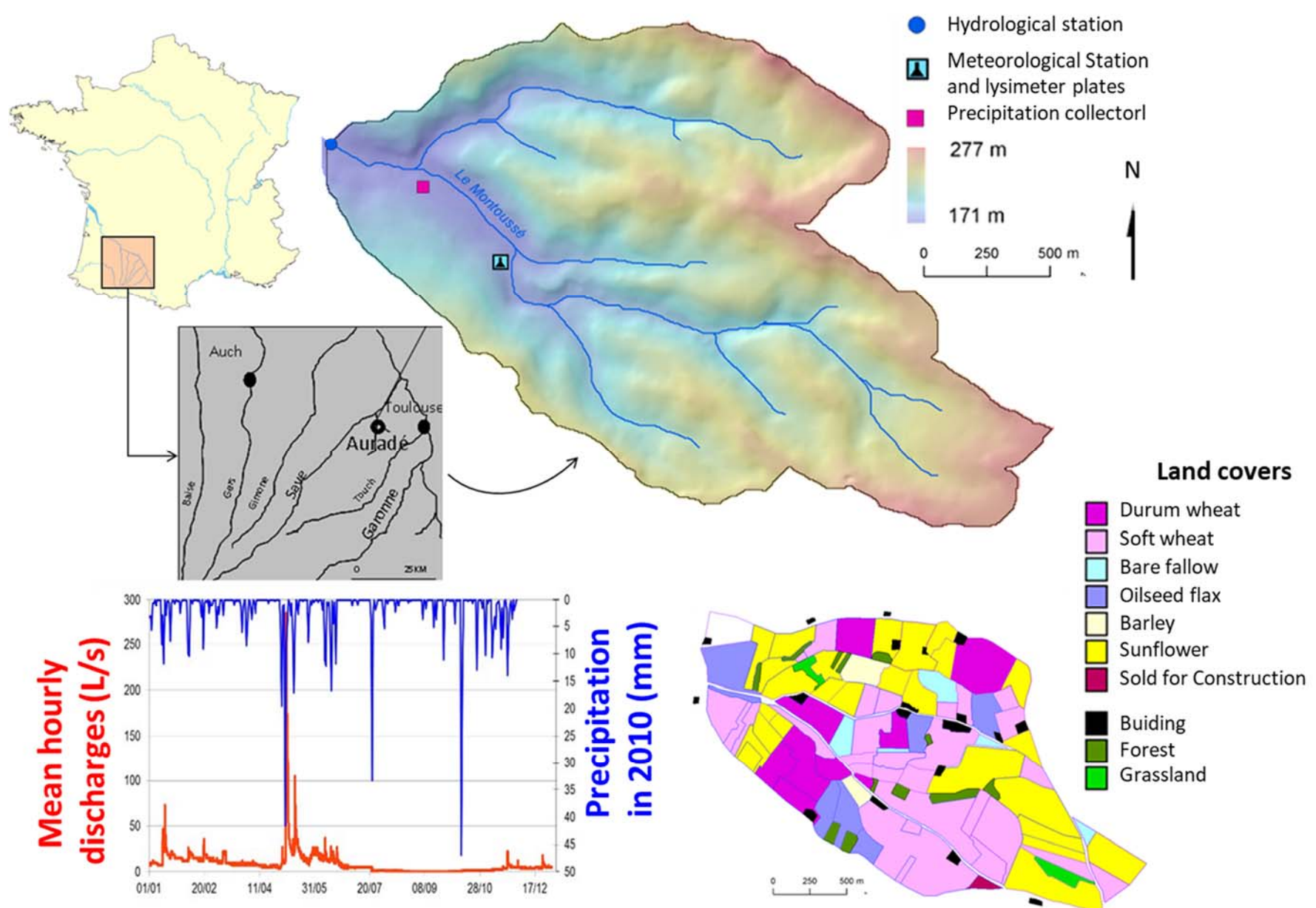


Figure 2- General location of Auradé Catchment (top left), relief map with the location of the different stations in Spring (top right), land cover map and rotation (bottomright) and annual variations of precipitation and discharges (bottom left).

Climate and Hydrology

The climate is of oceanic type according to Köppen Climate Classification. The nearby Atlantic Ocean plays an important role in regulating the temperature. The mean annual regional air temperature is 13.9°C. Since 1985, a significant increasing trend can be observed, even if interannual variations occur (Ponnou-Delaffon et al. 2020).

Moreover, since 1994 the occurrence of positive anomalous annual temperatures was observed, and in a continuous way since 2014 (Ponnou-Delaffon et al. 2020). Average annual rainfall calculated for the last 32 years is 621 mm, with a maximum value in spring. Most of the annual precipitation comes from thunderstorms from November to December and from April to May. Snowfall is rare and does not generate persistent cover.

Despite the temperature increase over the period, no significant trend was observed on annual stream discharge variations for the same period (Ponnou-Delaffon et al. 2020). Whereas, these variations point out a humid period between 1992 and 1996; since 1997, the occurrence of dry years tends to increase. The annual discharge over 34 years (1985–2018) ranges from 44 to 336mm (1985 and 1994, respectively), with a mean of 164 mm. The highest discharge period occurs in February and the major flood events generally occur in May, while the low water flow period is from June/July to September/October. Because the molassic substratum is impermeable and the slopes are steep, the stream discharge is mostly supplied by surface and sub-surface runoff during flash flood events (Roussiez et al., 2013). The underground water reserves are very limited to a few perched layers (sandy lenses) in the molasse and to alluvial and colluvial aquifers. During the summer dry period, the stream discharge is very low and sometimes the stream dries up (Brunet et al., 2011).

Mean evapotranspiration is high (500–600 mm), which refers to this catchment's semi-arid hydroclimatic characteristics (Perrin et al., 2008). Evapotranspiration mainly occurs during high temperature period in summer (86%, Ferrant et al., 2013).

History

This experimental site has been instrumented since 1982 by the AZF Research Center in Toulouse (Grande Paroisse Company) to monitor the evolution of nitrogen transfers. In 1995, GRAMIP (Regional Action Group for the reduction of water pollution by phytosanitary products in Midi-Pyrenees) started monitoring pesticide concentrations in water. In 2004, the Laboratory of Functional Ecology and Environment (LEFE) set up biogeochemical and ecological monitoring in partnership with the Grande Paroisse Azote Company (GPN-TOTAL, agreement signed in 2006) and the Association of Farmers of Auradé (AAA), interface between farmers, local authorities and research laboratories. Currently, climatological, hydrological, geochemical, soil and ecological monitoring is carried out by LEFE and research is carried out in partnership with other laboratories in Toulouse (CESBIO, GEODE, GET, DYNAFOR, EDB) and Bordeaux (ETTIS and EABX of INRAE in Cestas), with the Group of Farmers of Gascony Toulousaine (GAGT) and the company GPN Agriculture (2006-2011). This research is also being developed with all the teams involved in IRs OZCAR and RZA (including ZA PYGAR), and in the Equipex CRITEX and TERRA FORMA.

Scientific Objectives

The main scientific objectives are to determine the impacts of agricultural activities (land use, agricultural practices, inputs of fertilizers and phytosanitary products) and climate change on mechanical and chemical soil erosion, water and carbon fluxes, pollutant transfers (nitrates, pesticides and heavy metals), quality of environments and living organisms (biodiversity, critical loads, ecotoxicology, bioaccumulation and biomarking).

It is therefore a question of establishing the mass-balances and matter fluxes (sediments, pollutants, nutrients) in response to climatic fluctuations and anthropogenic pressures, of understanding the mechanisms that regulate their transfers, of modeling these balances and these transfer mechanisms, of determining the impact of pollutants on living organisms from the organism to the community (diatoms, macro-invertebrates, fish).

From an R & D and management point of view, the main objectives are:

- To diagnose the quality of water, soils, sediments and aquatic ecosystems in these highly anthropized environments,
- To determine the impact of the devices (grass strips, riparian forests, etc.) and agri-environmental measures (rational fertilization) on the quality of water and aquatic environments,
- To establish water and aquatic environment quality scenarios in response to climate change, changes in land use and agricultural practices and the implementation of agri-environmental systems,
- To determine relevant biological indicators of the state of health of aquatic ecosystems and the response of ecosystems to pressures.

Geology

The Auradé Catchment belongs to the geomorphological unit of the Gascony Hillsides. It is cut in Oligo-Miocene molasses, formed from lacustrine and fluvial deposits of Pyrenean origin. The irregularity of their sedimentation induces significant textural variations: sandy lenses mingle with clay-limestone deposits and are sometimes interstratified with limestone or sandstone beds. Three geological units stand out in the catchment area:

- The upper Burgalian which outcrops at the tops of the plateaus and ridges of the hills in the form of an eluvial sandy-clayey mantle 3 to 4 m thick;
- The lower or middle Burgalian: the lower slopes are cut in formations of marl, clay and molasses;
- The formations of the slopes resulting from the molasses: colluvial in nature, they correspond to clayey-loamy deposits, sometimes sandy and decalcified which cover the molasses over 1 to 8 m from the top to the bottom of the slope.

The substratum being impermeable, the water tables are rare and poorly supplied. Springs are fed from sandy lenses included in the molasses.

Soils

The soils come from molasses or molassic colluvium; they are clay-limestone soils, called “terrefort”. The thickness of the soils is very variable according to their position in the toposequence and to the slope. At the top of the rounded hilltops and on the steep slopes, the molasse is close to the surface, which keeps rendzinas in place. The steep slopes are lined with brown limestone soils or even rendzinas when the very steep slope conditions higher than normal erosion. The long, moderately sloping slopes are covered with colluvial deposits on which develop brown calcic soils (on the lower part of the slopes) and brown calcareous soils (on the upper part of the slopes).

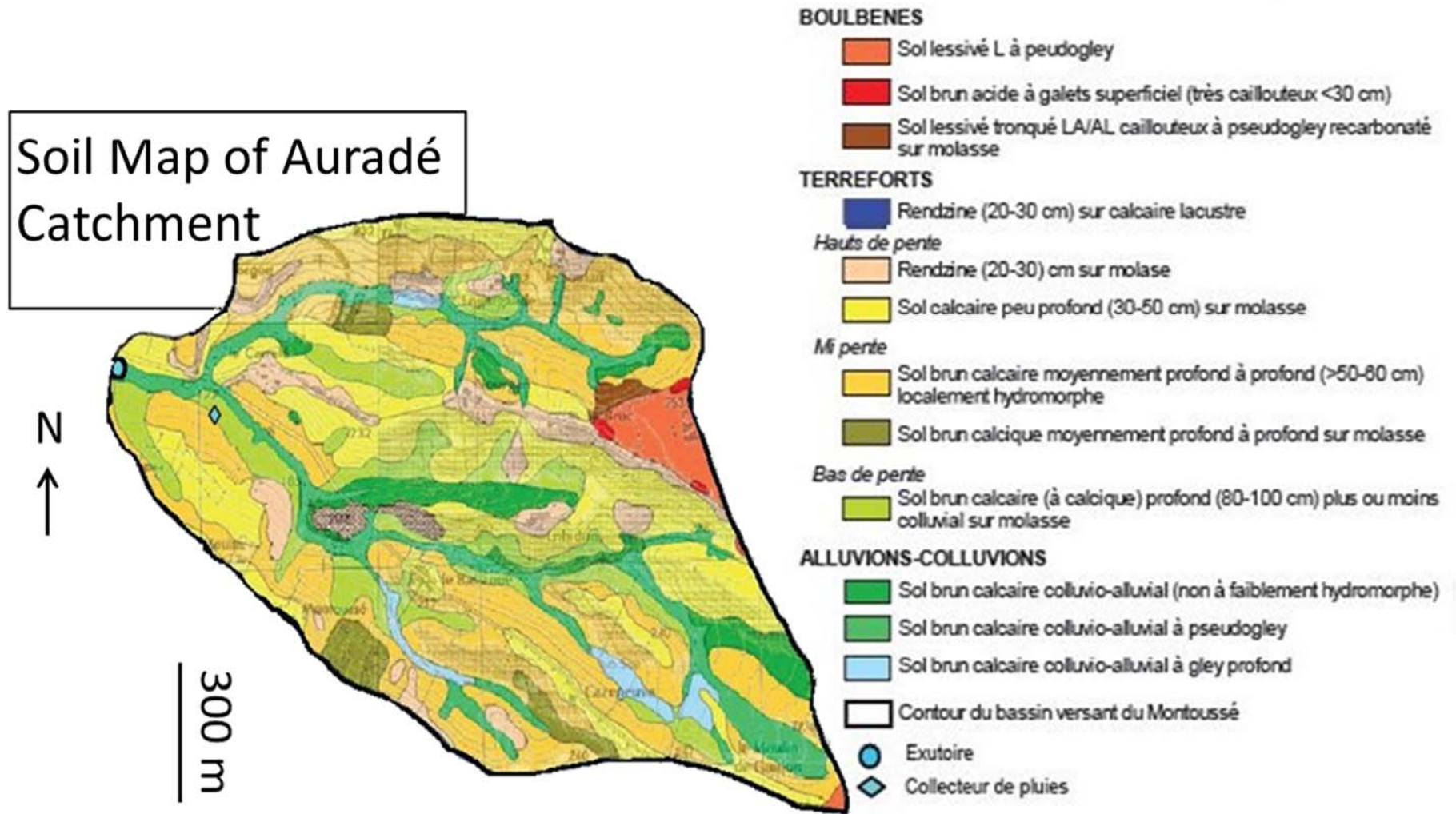


Figure 3- Soil map of Auradé Catchment (after Party and Probst, 2005)



Figure 4- Soil profiles of Auradé Catchment : brown calcareous soil (left), molassic substratum with sand lenses (middle), calcareous soil with carbonated encrustations (right).



Figure 5- Views of soils in the landscape of Auradé Catchment with white spots showing the carbonate soil horizons and even by place, the outcropping molassic substratum.

Topo séquence des types de sols du bassin versant du Montoussé à Auradé

- A- Sol brun calcaire colluvio-alluvial hydromorphe à pseudogley-gley de vallon. Type profil de sol n°1.
- B- Sol brun calcique à calcaire moyennement profond sur molasse à galets résiduels. Type profil de sol n°2.
- C- Rendzine à sol brun calcaire peu profond (érodé) sur molasse. Type profil de sol n°3.
- D- Rendzine sur calcaire lacustre. Type profil de sol n°5.
- E- Sol brun calcique à calcaire profond sur molasse. Type profil de sol n°4.
- F- Sol brun calcique profond plus ou moins colluvial sur molasse. Type profil de sol n°6.
- G- Sol brun calcique profond sur molasse (Calcaire en profondeur). Parcelle agricole cultivée depuis environ 20 ans (bois auparavant). Type profil de sol n°7.
- H- Sol brun à brun calcique profond sur molasse (en voie de lessivage - IIL=1,2). Bois. Type profil de sol n°8.

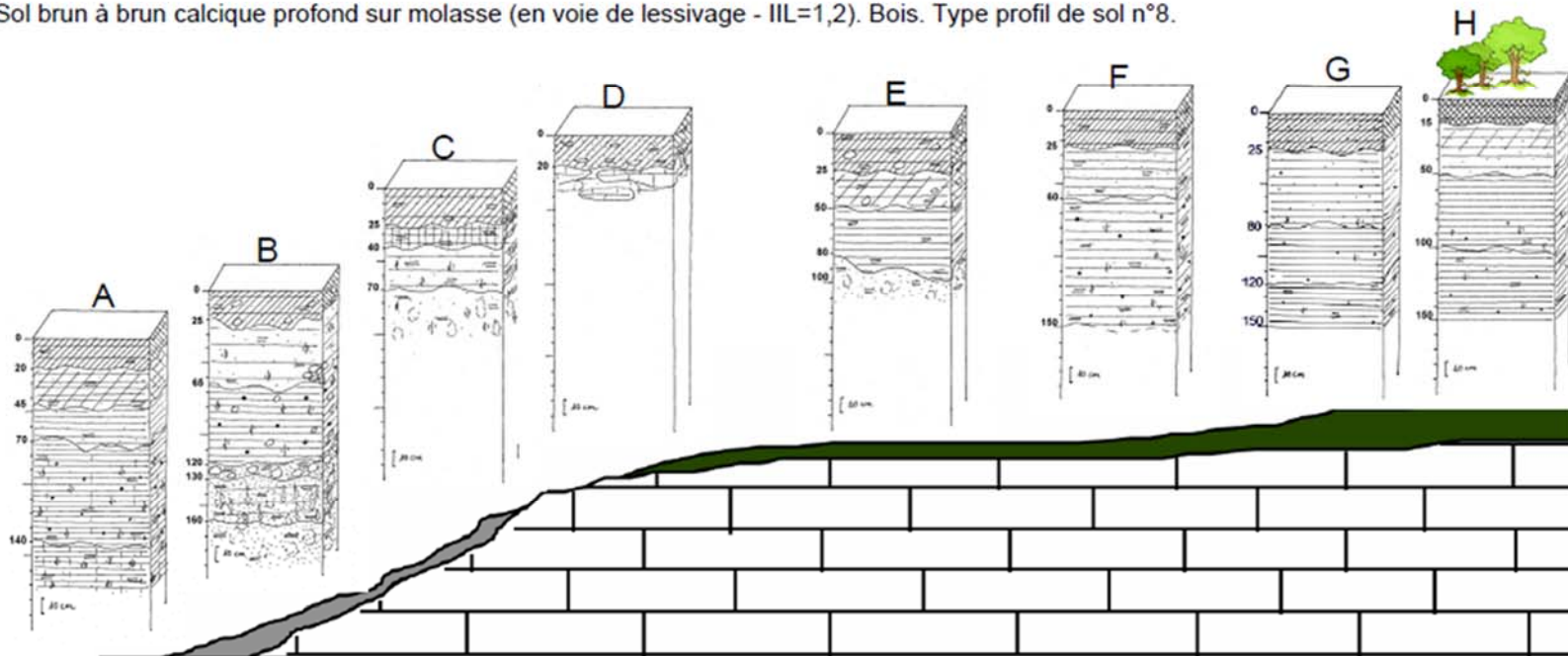


Figure 6- Soil toposequence with the different soil types in the Auradé Cartchment, going (left to right) from brown calacareous soils (A and B) to rendzinas (C and D), to brown calcic soils (E, F and G) and to brown soil (H).

The intermediate flats are covered with leached brown soils. The flats at the bottom of the thalweg are covered with colluvium on which brown hydromorphic soils or pseudo-gleys form.

Data available for Auradé Catchment


 **Stream water** : hydrological and geochemical monitoring of the Montoussé stream began in 1983. The following Table presents the details of the data acquired at the level of the watercourse (at the outlet)

Table 1- Available data for stream water in Auradé Catchment.

Start date	End date	Frequency	Parameters
1983	Until today	weekly	Water height and stream discharge
1983	Until today	weekly	nitrates
1995	2008	randomly	pesticides
2004	Until today	Weekly	anions, cations, alkalinity, pH, DOC, silica, Total Suspended Solids (TSS)
2004	Until today	Flood monitoring	anions, cations, alkalinity pH, DOC, silica, TSS
2006	Until today	Continuous monitoring	temperature, pH, conductivity, dissolved oxygen, turbidity, nitrates, dissolved organic carbon (DOC)
2006	2007	weekly	Trace elements (dissolved and particulate)
2007	Until today	weekly	ammonium
2010	Until today	monthly	Particulate Organic Carbon (POC)
2008 and 2020	2008 and 2020	Weekly and flood events	Pesticides, dissolved and particulate
2010	Until today	weekly	¹³ C of Dissolved Inorganic Carbon (DIC)
2010	Until today	weekly	¹⁸ O, ² H of water and ¹³ C of DIC
2013 and 2018	2013 and 2018	Weekly, flood events and spatial campaigns	¹⁵ N of nitrates

- **Rain water** : anions, cations, alkalinity, pH, conductivity, DOC, silica (since 2004), ^{18}O , ^2H (since 2016).
- **Soil solutions** : anions, cations, alkalinity, pH, conductivity, DOC, silica (since 2006), ^{18}O , ^2H (since 2012)
- **Soil profiles** : soil depth, soil dry bulk density, soil mineralogy, pH, carbon content, cation exchange capacity, nitrogen, particle size distribution, texture (once in 2006), the compositions of major elements and metallic traces (by profiles, by typology), the ^{13}C and ^{15}N contents on a type of soil, the mineralogy (DRX, SEM, μ probe, laser-ICPMS), the DEM, Electric resistivity (once in 2012), Seismometry data (once in 2019),
- **Soil map** : for the whole catchment and DEM.
- **Climatological data** : precipitation amount (since 2004), air temperature (since 2007), wind direction and speed, sunshine duration (since 2007),
- **The biological data and agricultural practices**: yearly data on cultivation practices, land use, yield data, fertilizer inputs (quantity and chemical composition by type of fertilizer) and phytosanitary products by plot; by type of crop, the flows of quantifiable inputs in the balance sheets and the chemical composition data (major cations, C, N) of wheat, sunflower, rapeseed (stem, head, grain).

The instrumentation installed on the Auradé Catchment

The site is equipped at the outlet with a flow measurement station (limnigraph, ultrasonic sensor), 2 automatic samplers, 1 of which is controlled by water levels, 1 multi-parameter probe for continuous measurements ($T^\circ\text{water}$, Heau, pH/Redox, conductivity, dissolved O_2 , turbidity, nitrates, DOC) and inside the catchment, a climatological station, 1 rain collector for physico-chemistry, 1 precipitation collector for isotopy and 1 station for measuring soil solutions at 3 depths. A station for measuring water and carbon fluxes at the crop-atmosphere interface (managed by CESBIO) is also located in the immediate vicinity of the site.

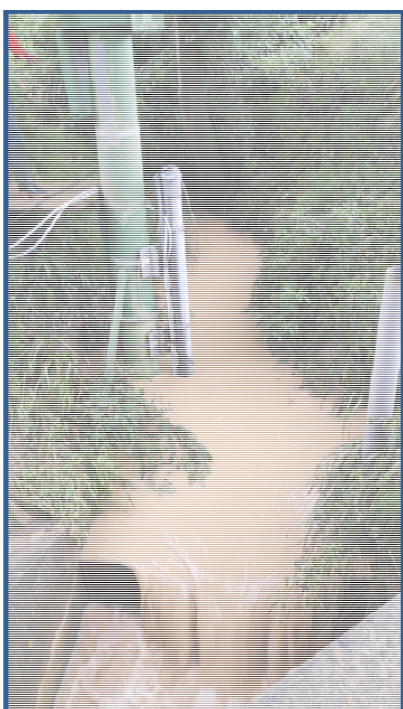



Figure 7- Views of the station at the outlet of Auradé Catchment. The Montoussé stream during a flood event (left), the wooden hut which houses all the equipments (middle), the Montoussé stream during a low water period (right)



Figure 8- The instrumentation installed on the Auradé Catchment for monitoring of the different compartments : soil solution (top left), rain water and climatological station (top right), soil experiments (middle right), stream water (bottom) with water height and discharge, automatic sampler, multi parameter probe with different sensors, DGT and POCIS passive samplers (from left to right).

A catchment at the heart of national and international research




National

- 



Research Infrastructure (IR) OZCAR (Observatory of the Critical Zone: Applications and Research) : The Auradé Catchment is one of the Observatory site of this French research infrastructure.

- 



Equipex CRITEX (national):
National Park of innovative equipment for the spatial and temporal study of the Critical Zone. The Auradé Catchment is one of the CRITEX instrumented sites.

- 



PIA3 Equipex+ : TERRA FORMA :
Designing and testing the intelligent observatory of territories in the era of the Anthropocene


- 


LTSER Zone Atelier Pyrénées Garonne (ZA PYGAR) et IR RZA :
The Auradé Catchment is integrated into one of the workshop site (Valleys and Hills of Gascony) of the ZA PYGAR which is part of the IR RZA (Zone Atelier Network) with 14 other ZA in France.


- 

ANR ESCAPADES (2013-2016) : Evaluation of scenarios on the nitrogen cascade
in agricultural landscapes and territorial modelling. The Auradé Catchment was one of the experimental sites of this ANR project

- Project IRRIS (2012-2016) : Programme Eco industries (IRRIgation Ingénierie Services):
Project Eco-Industries (financed by DGCIS) in collaboration with LAAS-CNRS and industrial partners.

- 

ANR PESTIPOND (2019-2023) : Role of ponds in the transfer and impact of pesticides
in surface waters of the critical zone in agricultural environments ». The Auradé Catchment is one of the 3 experimental sites of this ANR Project with the Bassioué pond.

- 

Project Région Occitanie PACSE (2018-2021): Landscapes and Compromise between
Ecosystem Services. Collaboration with 2 other research laboratories, DYNAFOR and LEREPS on the Auradé Catchment.

International:

ESFRI eLTER : the Auradé Catchment is one of the long term experimental and observation sites of the european research infrastructure (ESFRI) eLTER, European Long-Term Ecosystem Research



iLTER : the Auradé Catchment is one of the sites of the international network LTER



CZEN : the Auradé Catchment is one of the sites of the Critical Zone Exploration Network

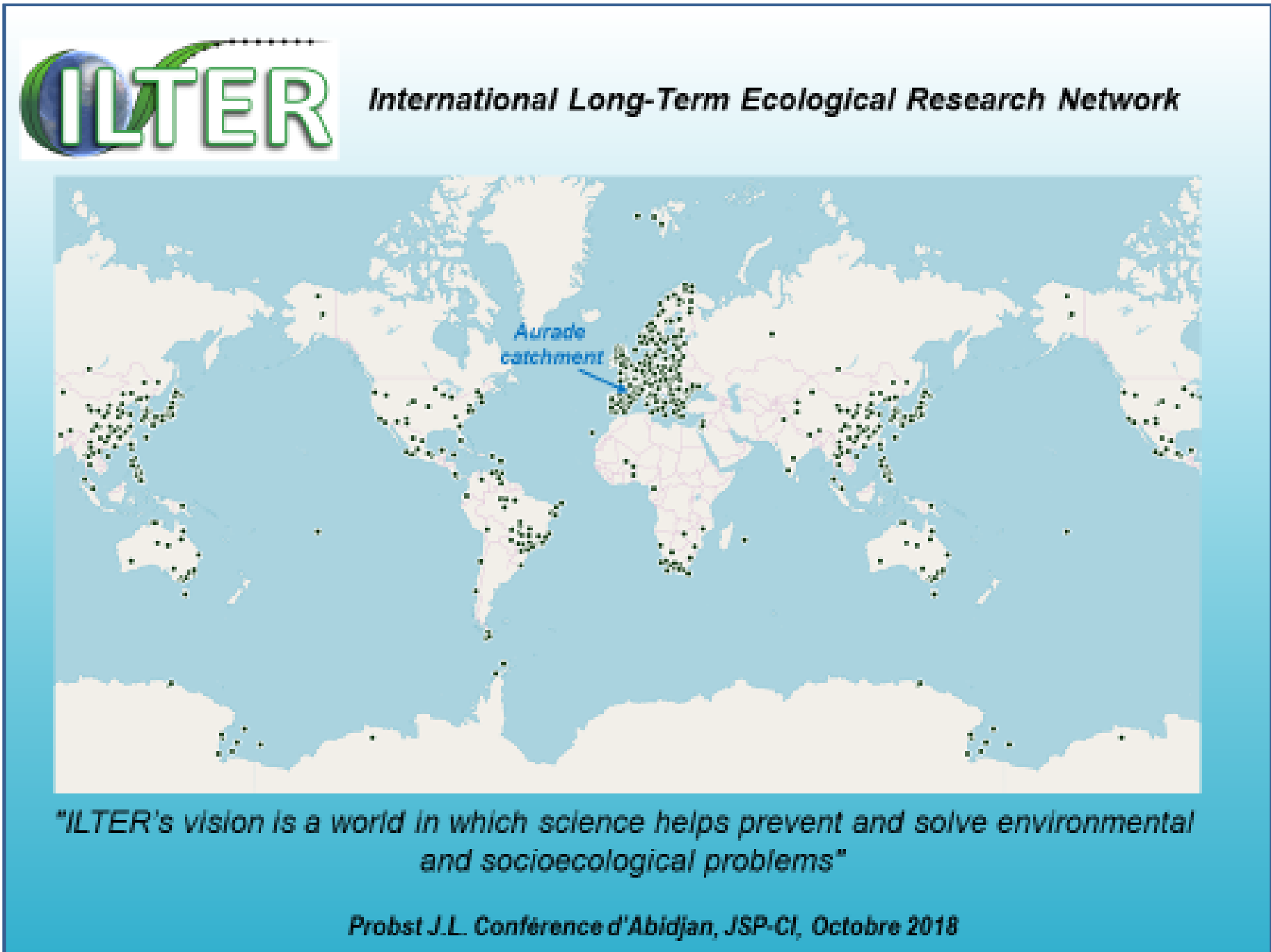


Figure 9- World map of ILTER sites with the location of Auradé Catchment.

Research carried out in the Auradé Catchment

The issues and questions concerning this catchment relate to the impact of **agricultural activities** (land use, agricultural practices, inputs of fertilizers and phytosanitary products) and **climate change** on:

- mechanical and chemical soil erosion
- water and carbon fluxes
- transfers of pollutants (nitrates, pesticides and heavy metals)
- the quality of environments and living organisms (biodiversity, critical loads, ecotoxicology, bioaccumulation and biomarking)

Research objectives for the acquisition of knowledge

- Establish material flow balances (pollutants, nutrients) in response to climatic fluctuations and anthropogenic pressures
- Understand the mechanisms that regulate the transfer of materials from the atmosphere, crops and soils to the watercourse
- Model these balance sheets and these transfer mechanisms.
- Determine the impact of pollutants on living compartment of the critical zone: from the organism to the population and communities (diatoms, biofilms, macro-invertebrates):

- ▶ enrichment effect
- ▶ effect of toxins
- ▶ critère d'exposition
- ▶ "exposure-effects" relationship
- ▶ biodiversity



Research objectives: for management

- Diagnose the quality of water, soil, sediment and aquatic ecosystems.
- Determine the impact of agri-environmental devices and measures on the quality of water and aquatic environments.
- Establish (by modelling) scenarios for the quality of water and aquatic environments in response to:
 - climate change
 - changes in land use and agricultural practices
 - the implementation of agri-environmental systems
- Determine relevant biological indicators of the state of health of aquatic ecosystems and the response of ecosystems to pressures.

In the stream waters: The “electrocardiogram” of nitrates” & Demonstration of the impact of floods on the transfer of pesticides

ECOLAB & AZF-GPN

A positive effect of the establishment of grassy strips along the Montoussé stream in Auradé Catchment has been highlighted thanks to the monitoring of hydrogeochemical measurements. These measurements also showed that the concentrations and fluxes of pesticide molecules increase during periods of flooding, particularly in spring.

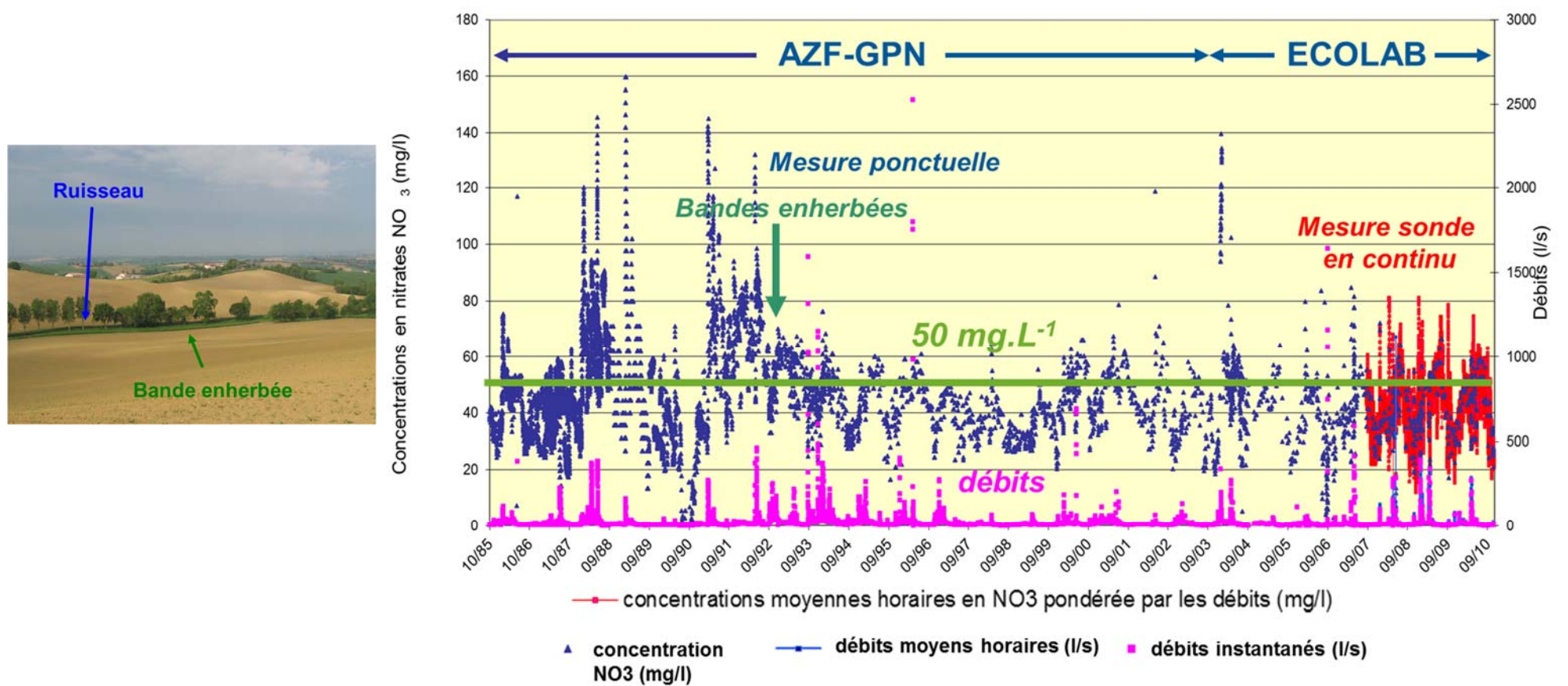


Figure 10. Evolution of nitrate concentrations (NO₃, weekly samples in blue and continuous measurements with the probe in red) and Montoussé stream discharge (in pink) from 01/10/1985 until 30/11/2010

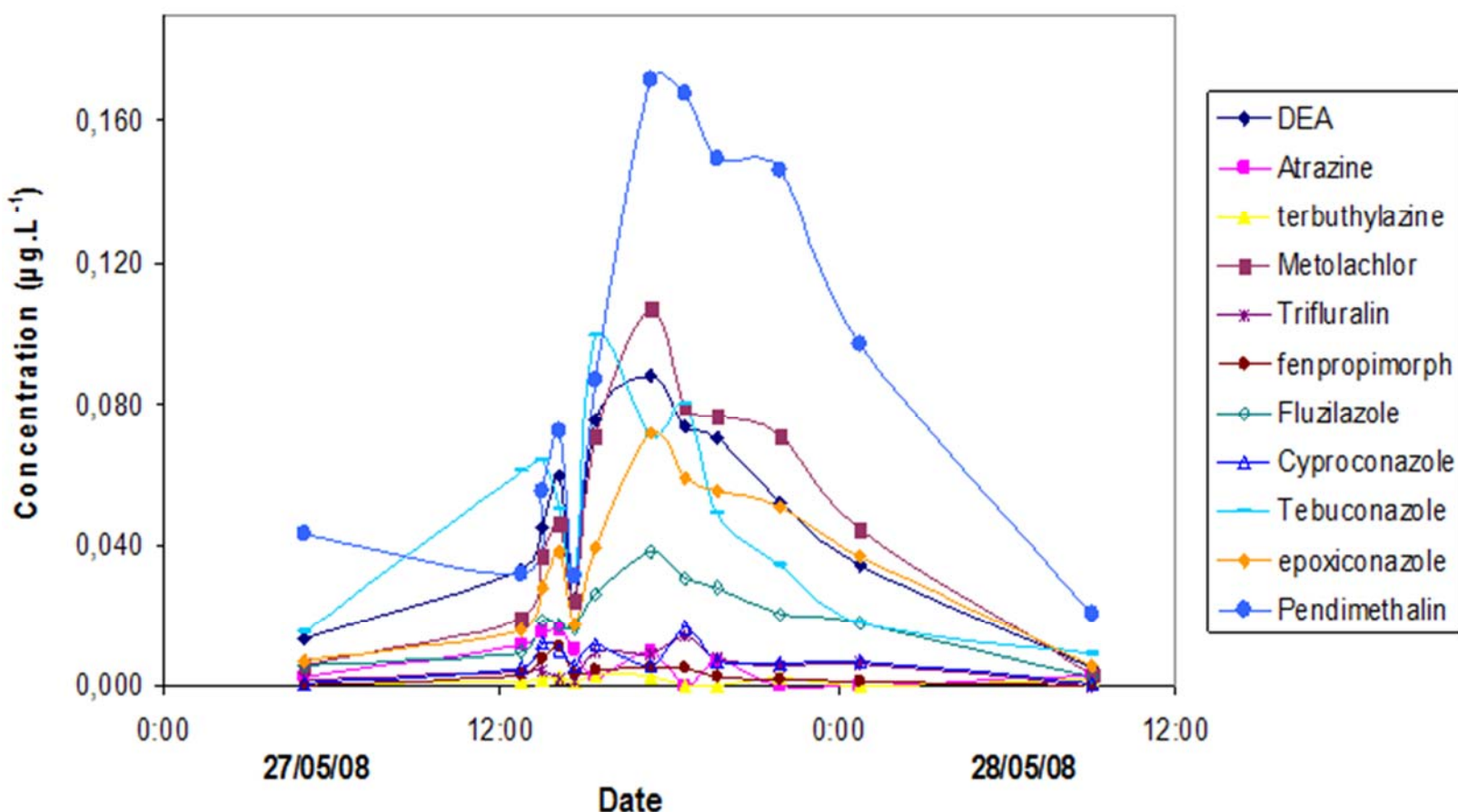


Figure 11. Evolutions of pesticide concentrations for different molecules in the Montoussé stream water during a spring storm event in 2008 (Taghavi et al.,2008).

An Observatory for long-term and high-frequency hydro-biogeochemical monitoring.

Vivien Ponnou-Delaffon¹, Anne Probst¹, Virginie Payre-Suc¹, Franck Granouillac¹, Sylvain Ferrant^{1,2}, Anne-Sophie Perrin^{1,3}, Jean-Luc Probst¹

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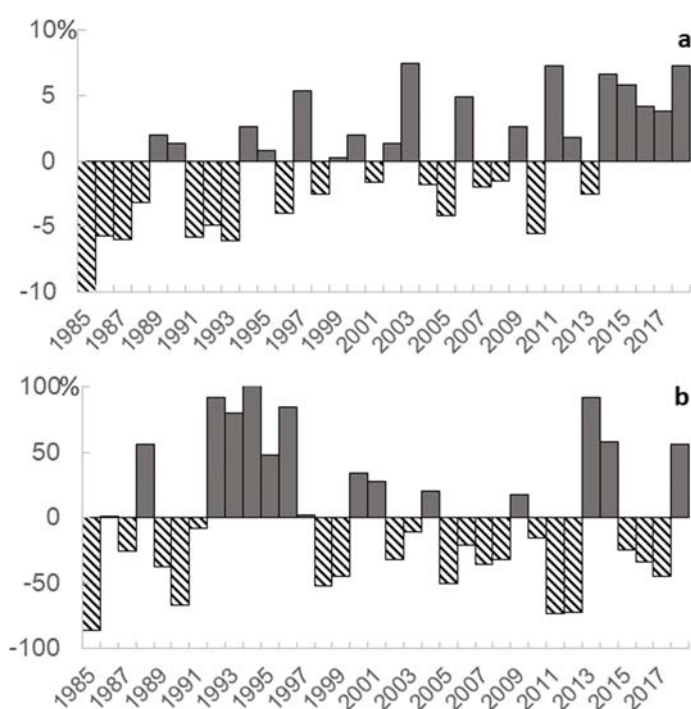


Figure 12- Interannual variations of mean annual air temperature (a) and mean annual stream discharge (b) : deviations (%) from the interannual mean.

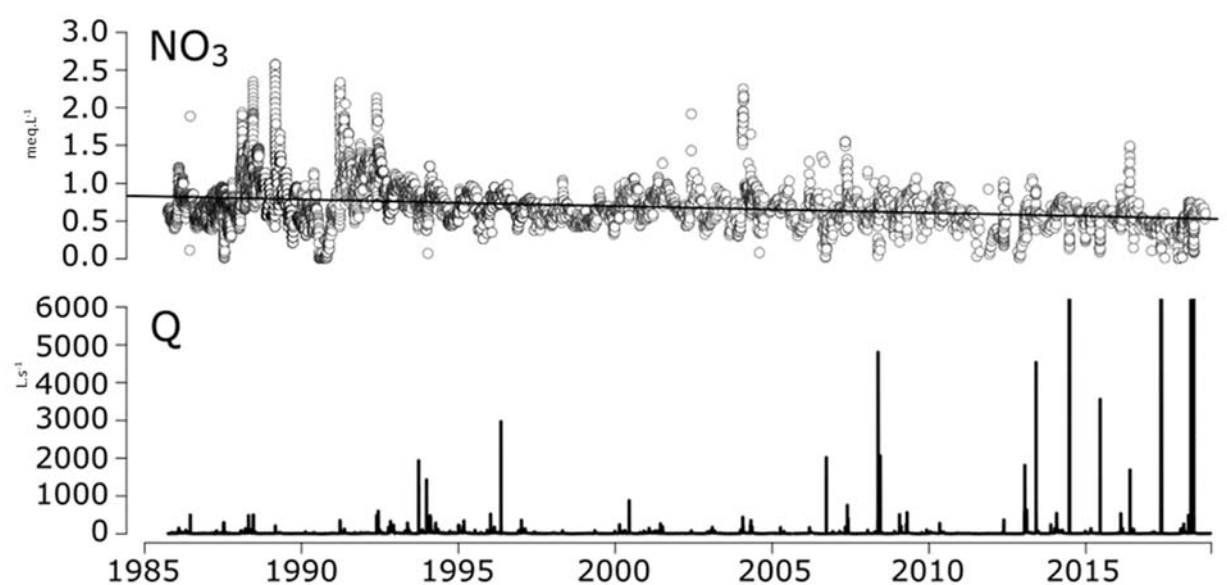


Figure 13- Fluctuations of nitrate concentrations and discharges of the Montoussé stream during the period 1985-2018.

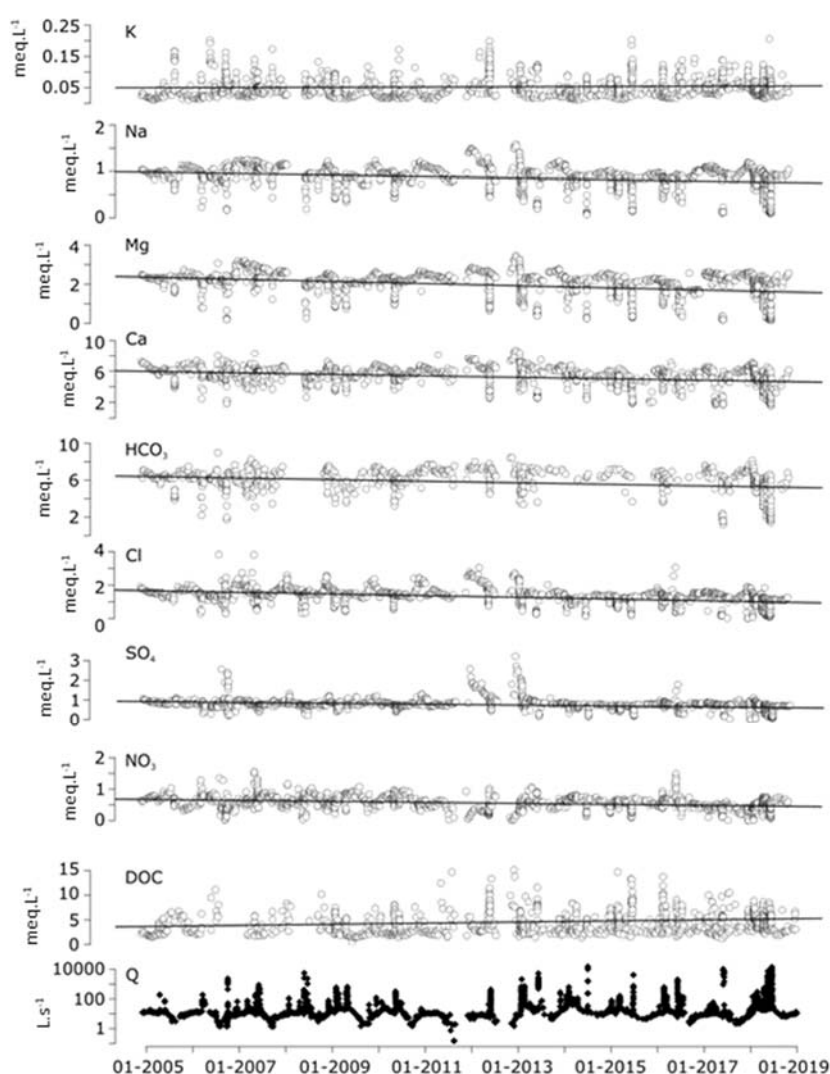


Figure 14- Interannual variations of major element (anions and cations) concentrations, dissolved organic carbon (DOC) contents and Montoussé stream discharges (Q) during the period 2005-2019. Straight lines represent long-term trends (linear regressions)

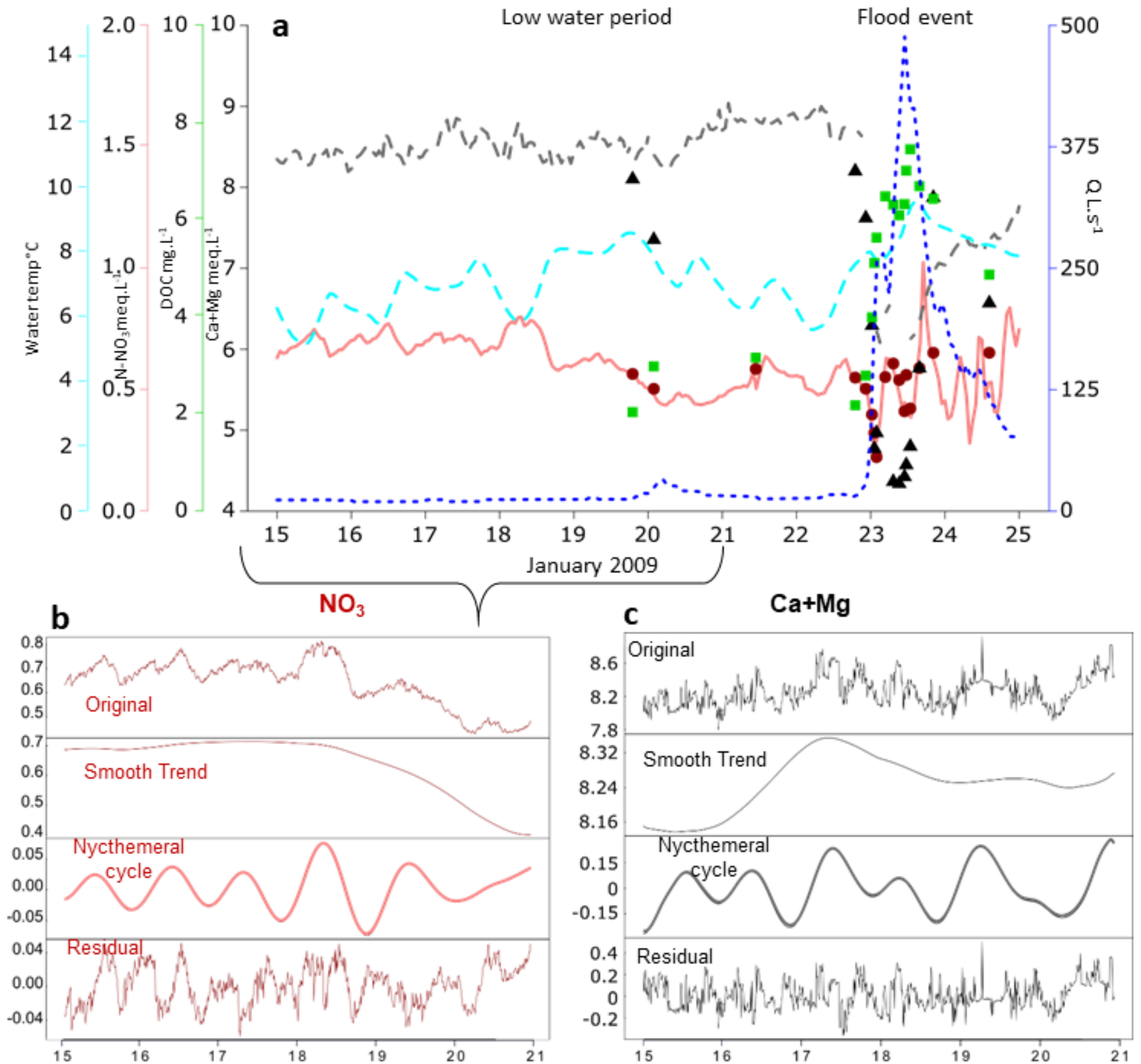


Figure 15- Short-term fluctuations (January 15 to 25, 2009) of nitrate concentrations, dissolved organic carbon, calcium+magnesium and Montoussé flows :

(a) continuous measurements of nitrate contents (with the multiparameter probe (red line), instantaneous nitrate measurements (red circles), Ca+Mg contents reconstituted from the conductivity measured continuously with the probe (dotted lines gray) and measured (gray triangles), measured dissolved organic carbon (green squares), water temperature (turquoise dotted line) and water discharge (blue dotted lines)

(b) and (c) decomposition of the original signals for the nitrate (b) and Ca+Mg (c) contents into 3 components: signal smoothed over the period, nycthemeral cycle (day/night alternation) and residual.

These results are taken from an article published in 2020 in Ecological Indicators (Ponnou-Delaffon et al., 2020).

An Environmental Observatory to monitor pesticide transfers in the various compartments of the critical zone.

J.L. Probst, L. Taghavi, G. Merlina, A. Probst
LEFE, GRAMIP, FREDEC, GAGT



Figure 16- The Auradé Catchment (center) with hydrological station (left) and the automatic samplers (right).

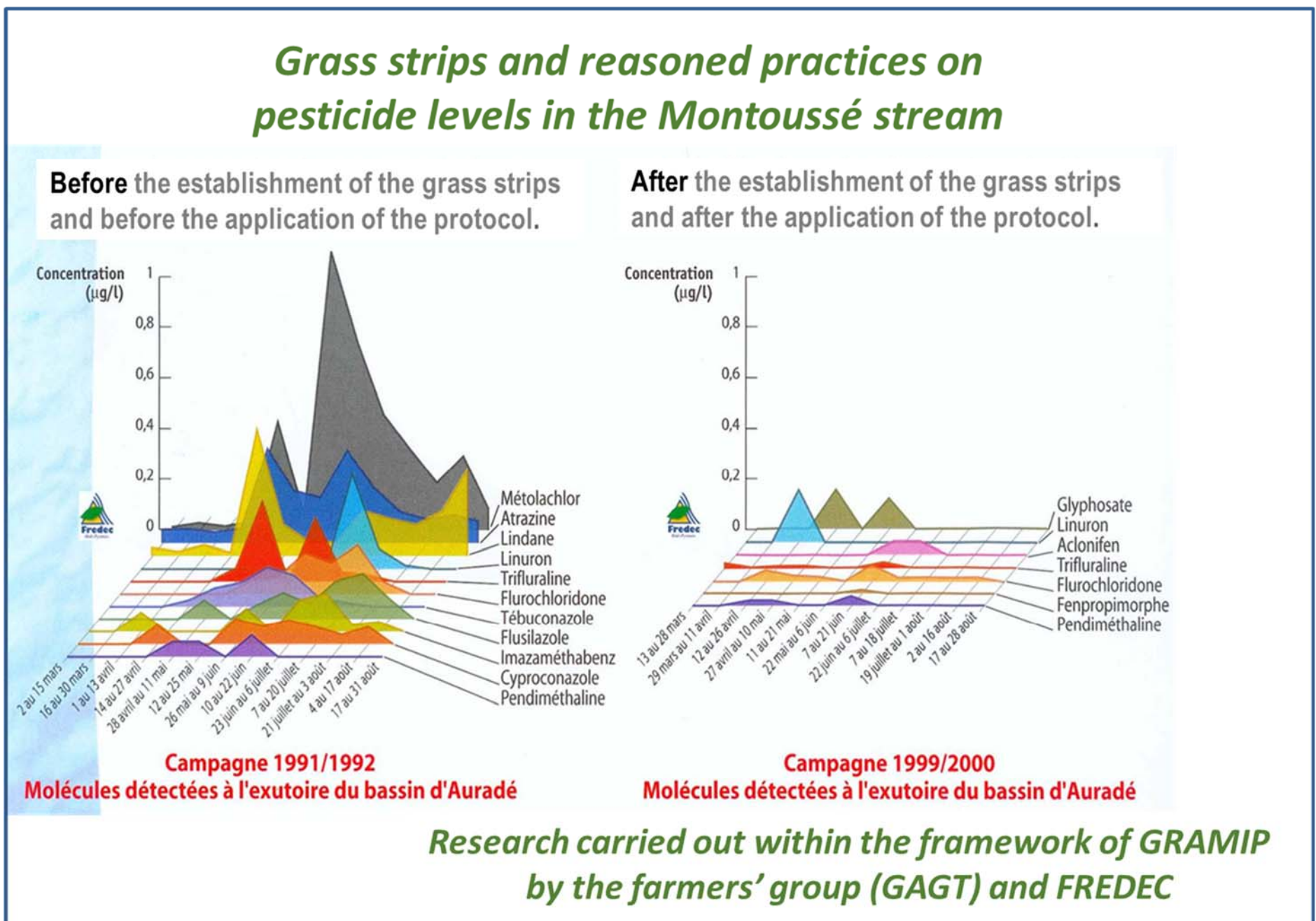


Figure 17- Seasonal variations of pesticide concentrations in the Montoussé stream water during the water years 1991-1992 (before the grass strips, left) and 1999-2000 (after the grass strips, right).

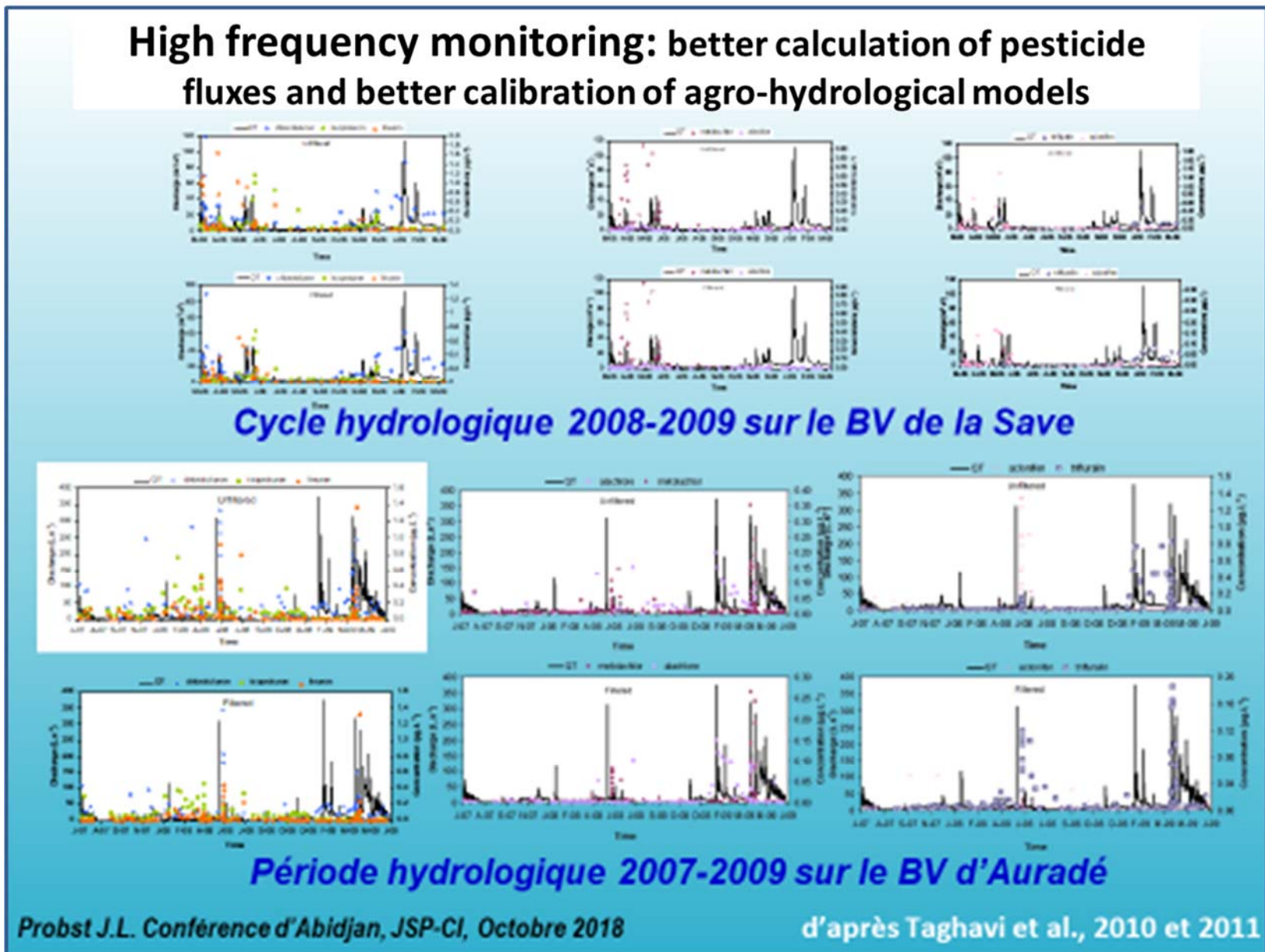


Figure 18- High frequency fluctuations of pesticide concentrations and stream discharges in the Save river basin (top) during the period 2008-2009 and Auradé Catchment (bottom) for 2007-2009.

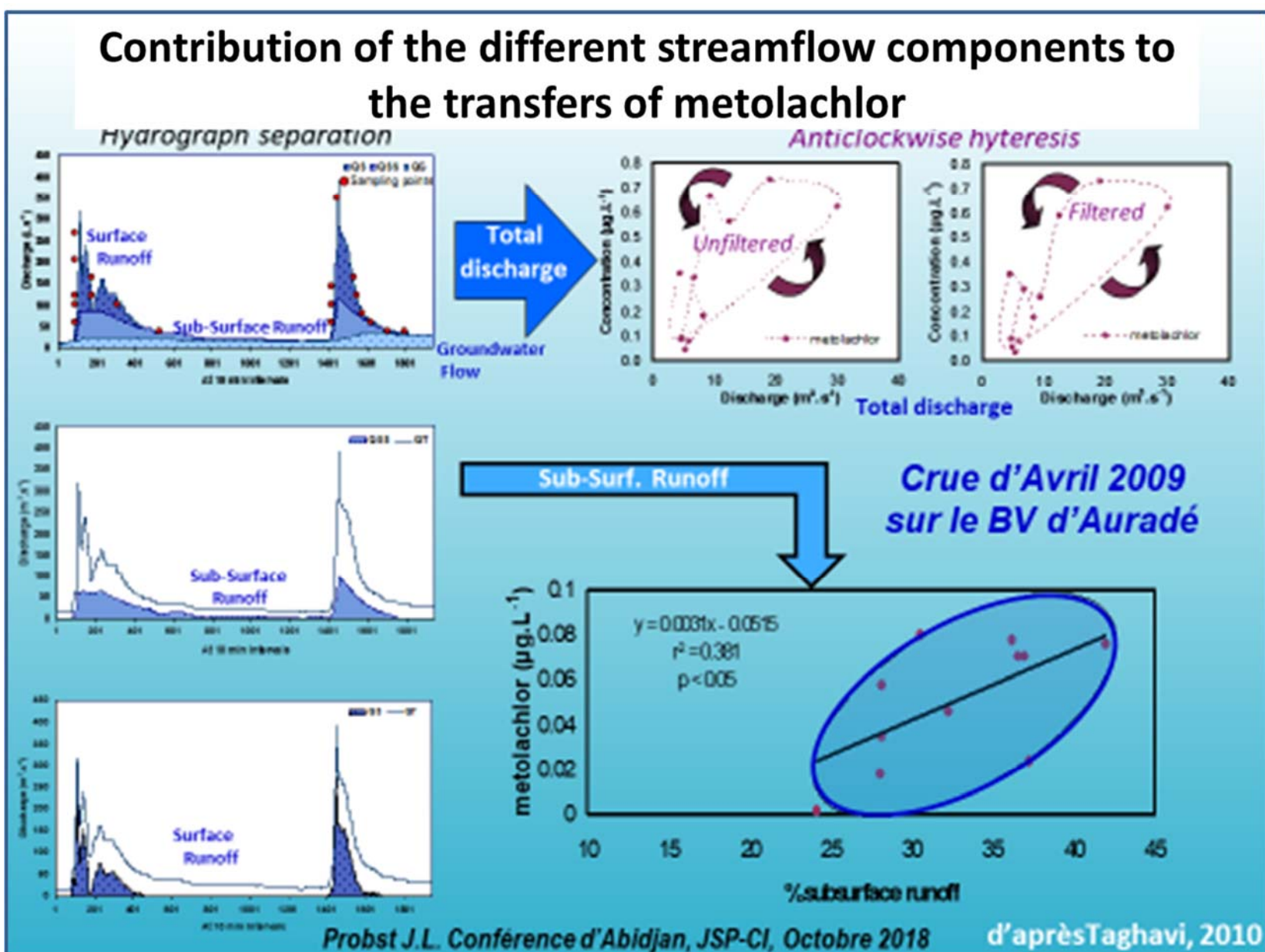


Figure 19- Contribution of the different streamflow components to the transfers of metolachlor : hydrograph separation (left), C-Q relationships (total Q (top right), % subsurface runoff (bottom right)).

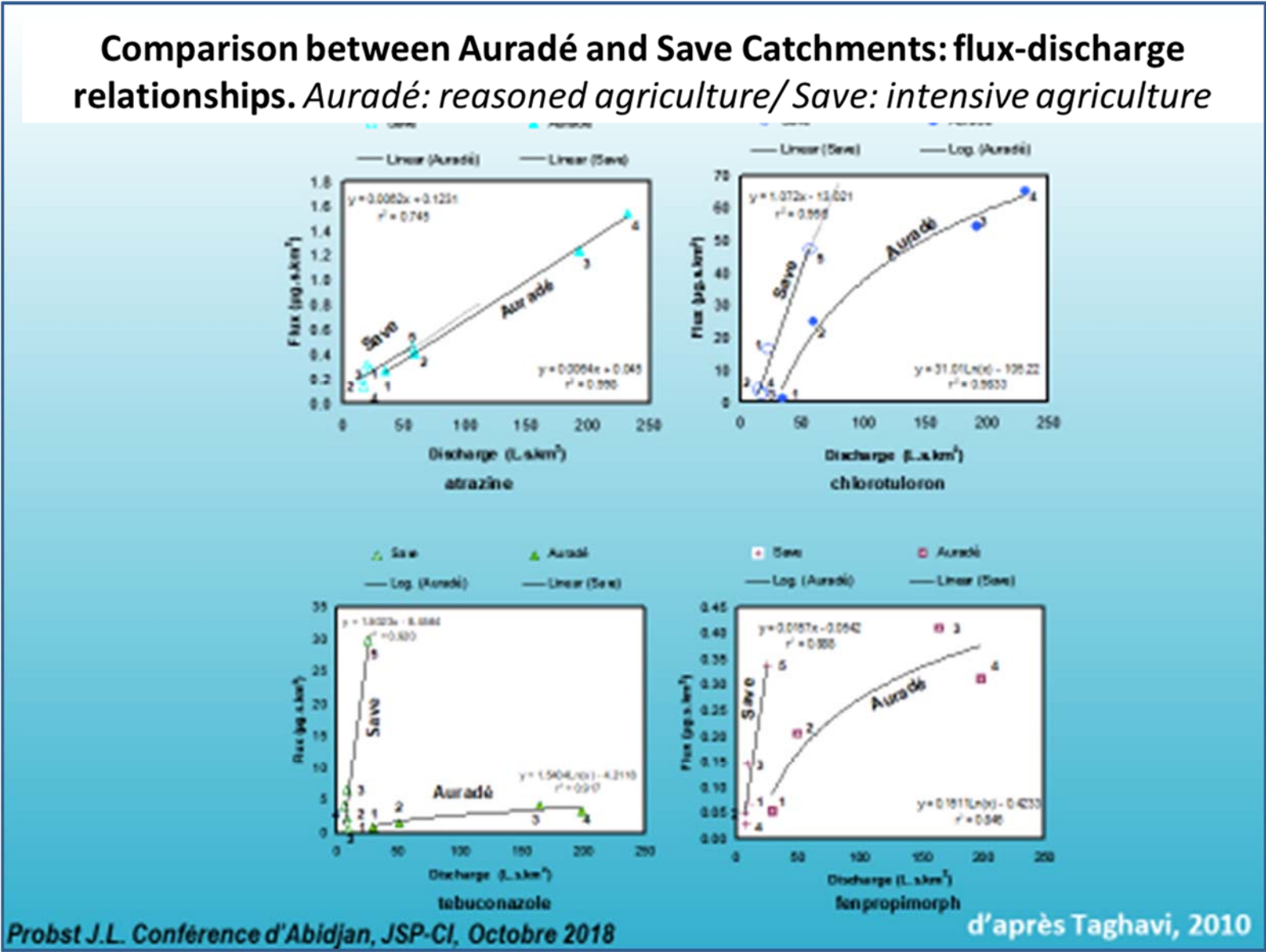


Figure 20- Pesticide flux-Discharge relationships : comparison between Save and Auradé.

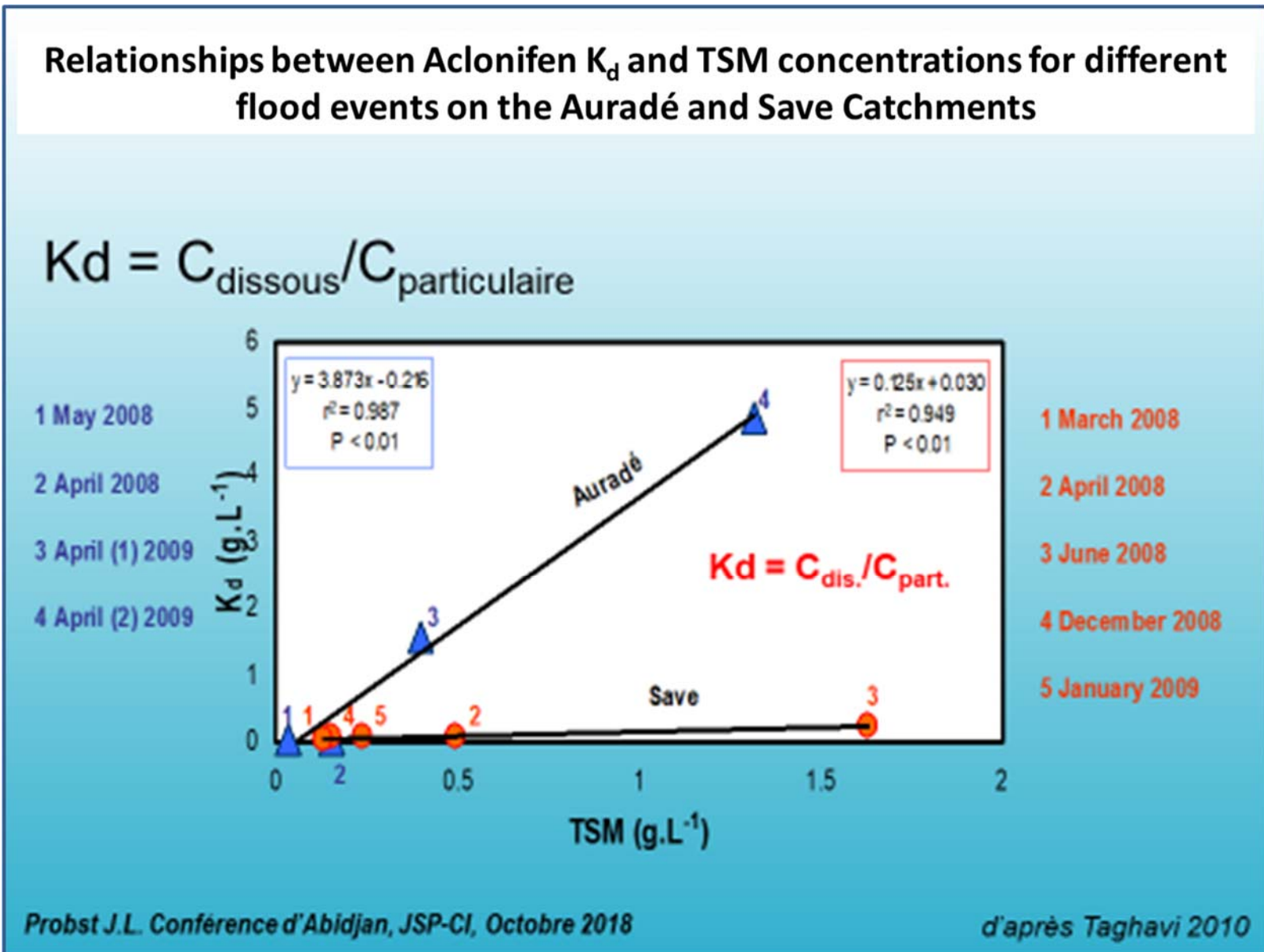


Figure 21- Relationships between K_d and TSM for Auradé and Save river basins.

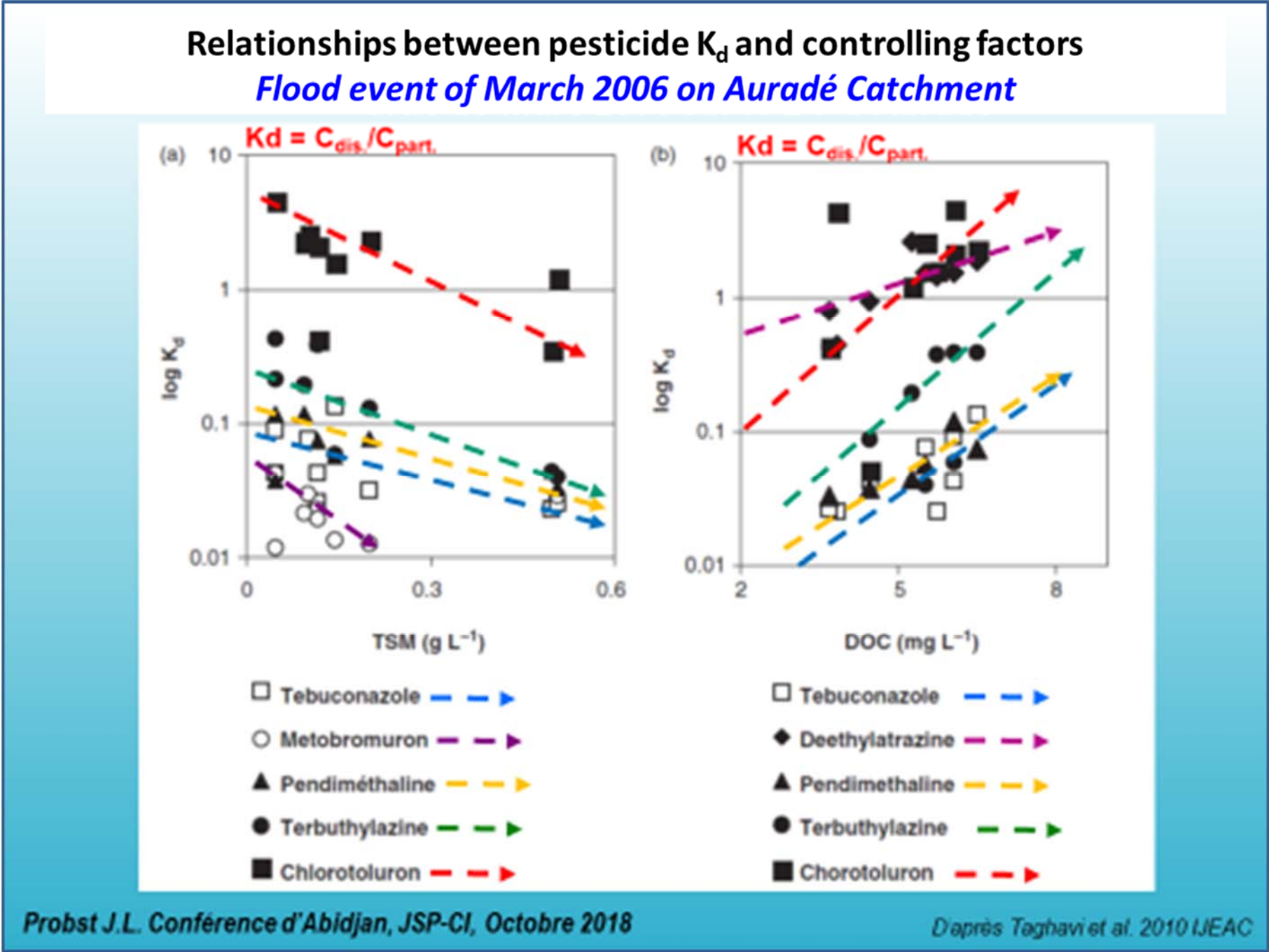


Figure 22- Relationships between pesticide K_d and two controlling factors (TSM (left) and DOC (right)).

Flood events: Effects on soil erosion and fluxes of metallic trace elements

V. Roussiez ^{1,2}, A. Probst ^{1,2} et J.-L. Probst ^{1,2}

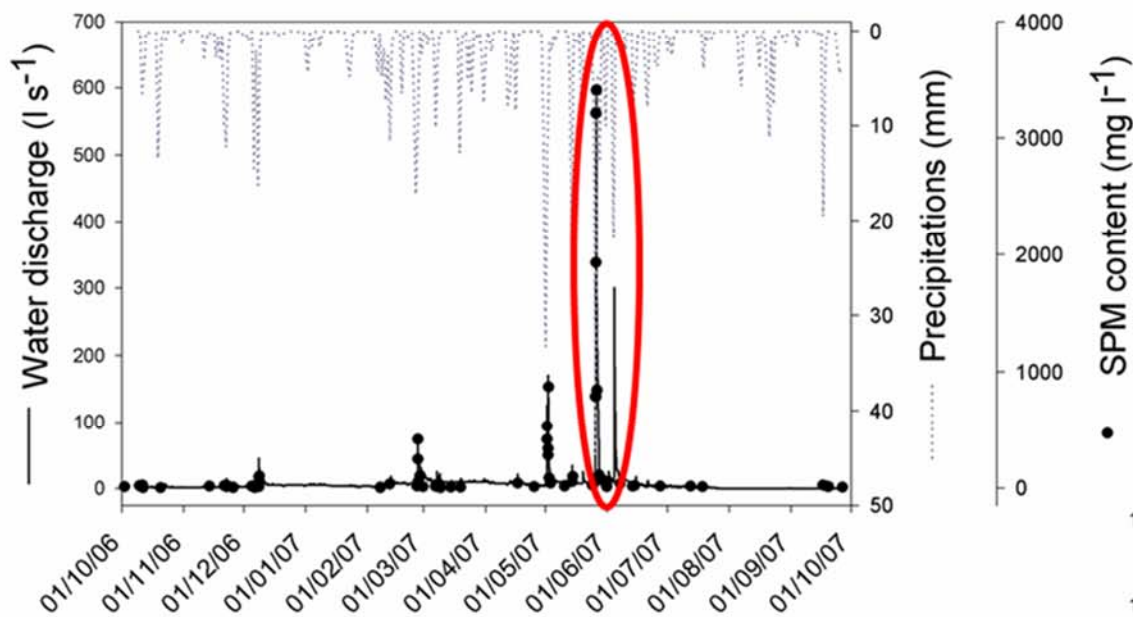
¹Université de Toulouse, UPS, INPT, LEFE (Laboratoire d'Ecologie Fonctionnelle et Environnement), ENSAT, Avenue de l'Agrobiopole, 31326 Castanet Tolosan Cedex, France

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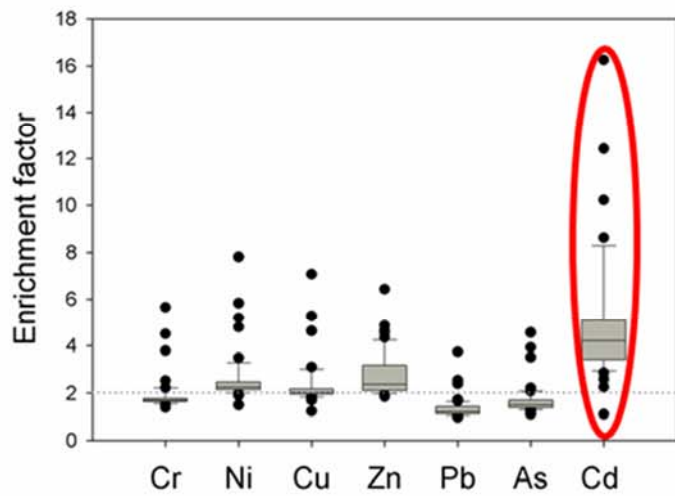
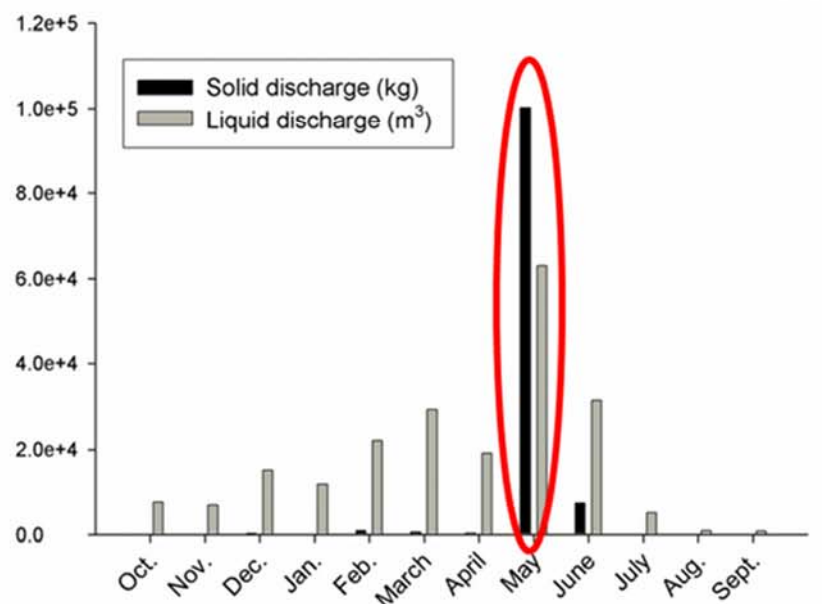
As shown in the graphs below, the suspended solids (SPM) in the waters of the stream are all the more important as the precipitation is high. This is more particularly what we observe in the catchment in May and June 2007; where 95% of the annual SPM flows are exported. These results are taken from an article published in 2013 in the Journal of Hydrology (Roussiez et al., 2013).



Flood flows, essential vectors of SPM exportations from soil erosion



In a few hours, 95% of the SPM annual flux are exported



Cd-enriched SPM from fertilizers

Figure 23. Significance of flooding in the export of metal from small-scale agricultural watersheds: the case study of the Montoussé River. (Roussiez et al., 2013)

During floods, there is a rapid enrichment of water in the dissolved phase of metals. This is linked to surface runoff; as well as the desorption mechanisms of the particulate phase of the soil. These graphs highlight a potential threat to ecosystems.

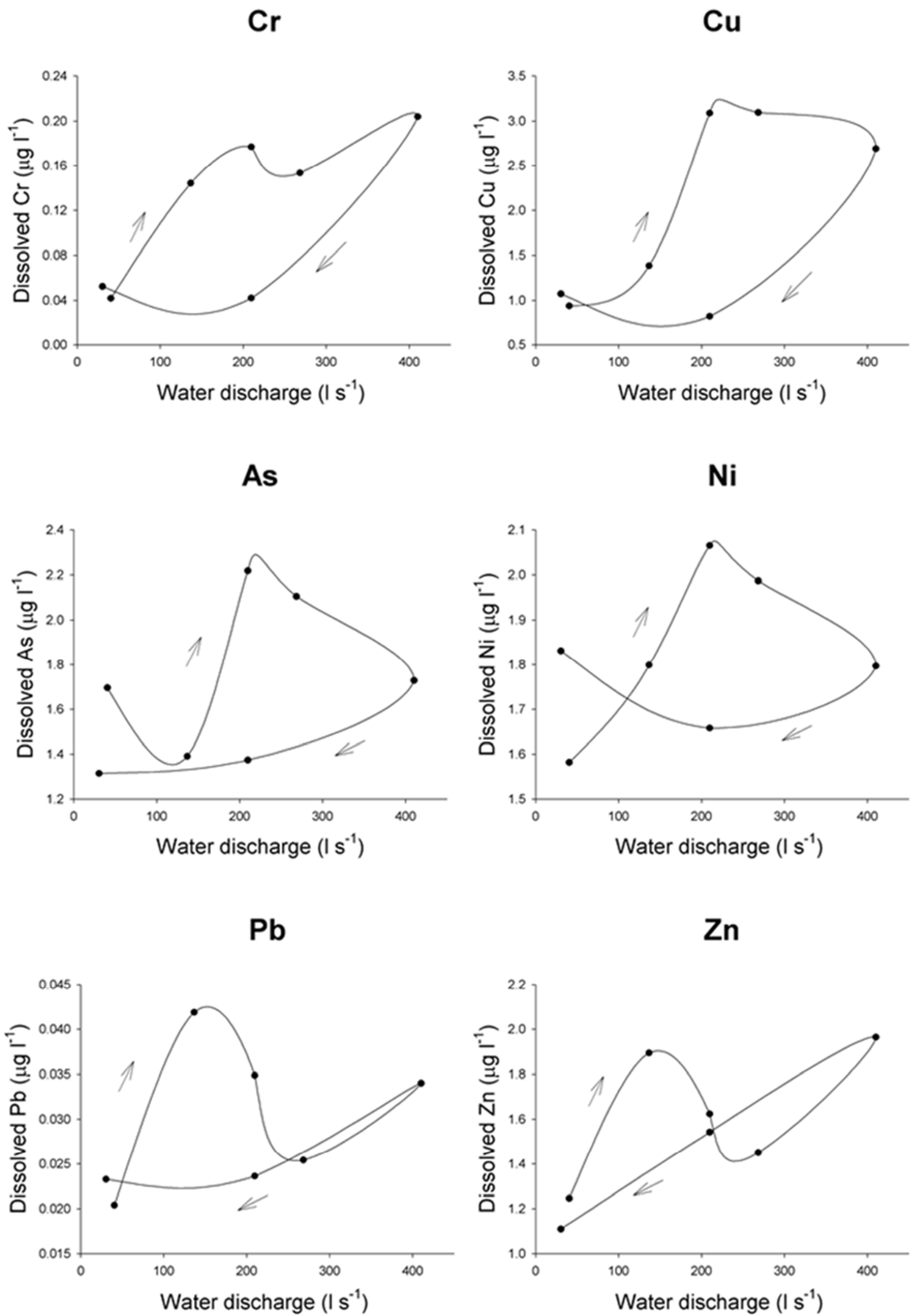


Figure 24. Dextral hysteresis showing the evolution of the dissolved phase of metals in the streamwaters of the Montoussé watershed. (Roussiez et al., 2013)

Fate of metals and enrichment factors in soils

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On certain calcosols of the catchment area, an accumulation of TME in the form of shotgun pellets has been observed: at the surface for profile 2 and at mid-depth for profile 4. These accumulations are strongly linked to variations in groundwater which thus cause hydromorphy.

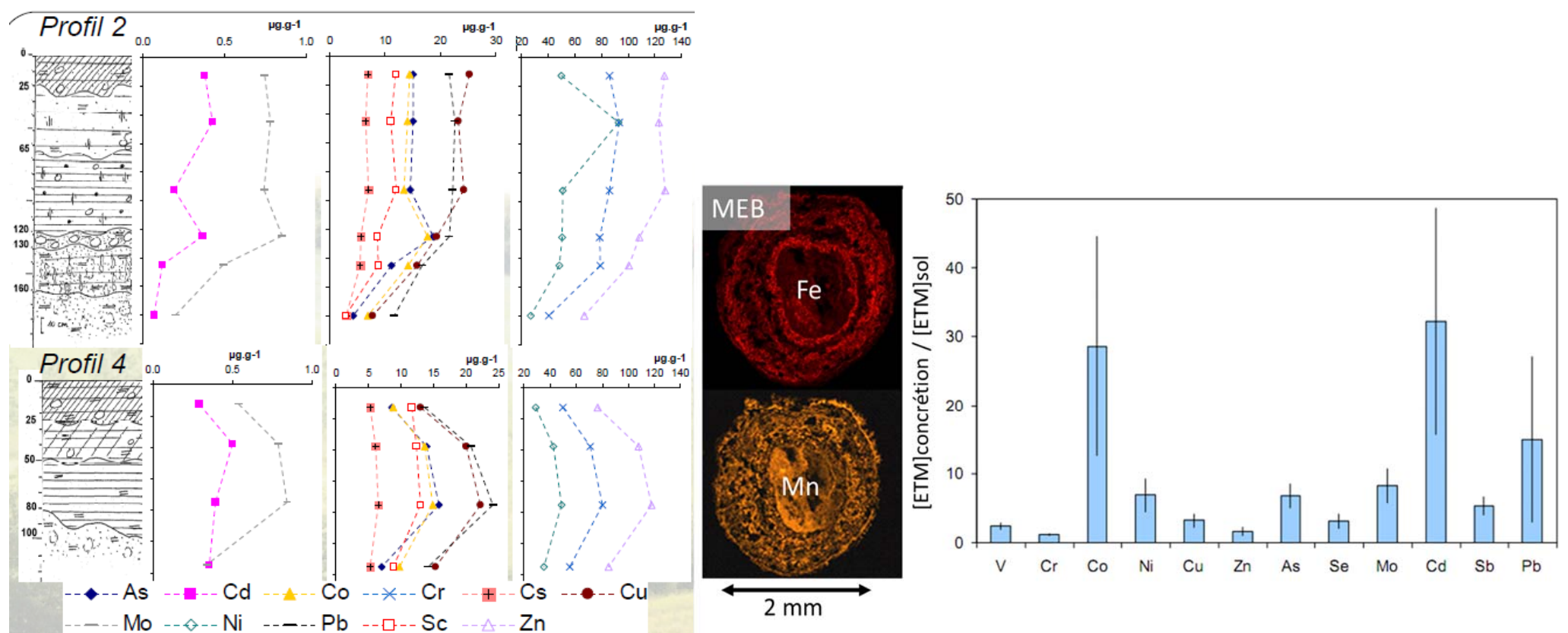
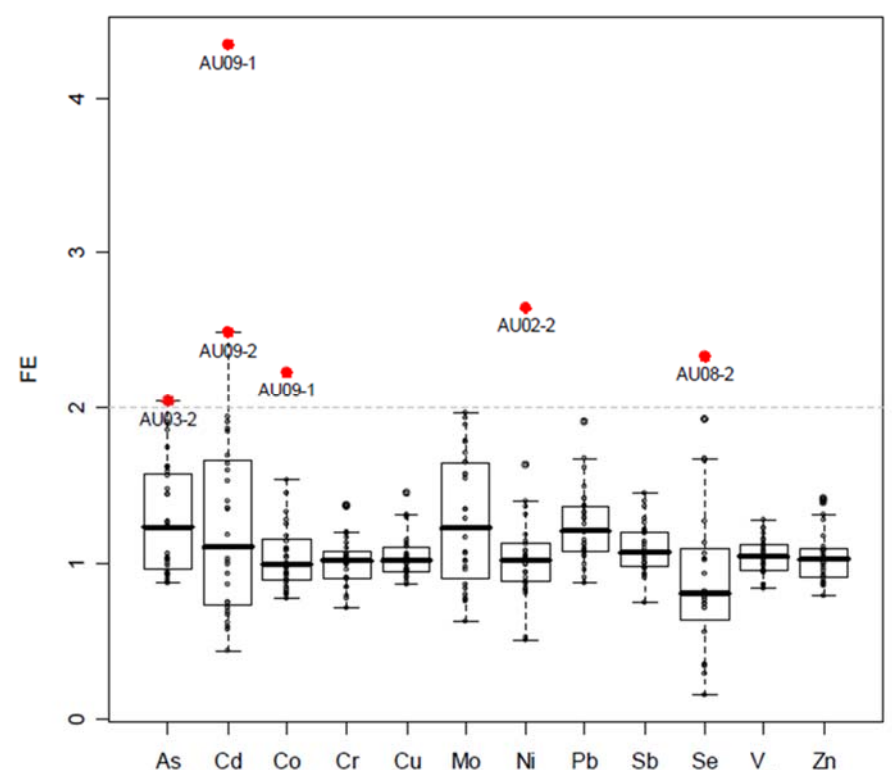


Figure 25. From left to right: Concentrations of various metals within calcosol profiles; Ratio between the concentration of ferro-manganic concretions and that of the soil (Bur et al., 2009, 2010, 2012).

Ferro-manganic concretions are therefore sequestration agents formed by alternating saturation/desaturation. The concentrations of major elements and TME have a mass of less than 1% but it is possible to quantify a stock of up to 10% Cd.

The enrichment factors, all soils included, vary between 0.5 and 2. The environments are very little contaminated. With few exceptions, enrichment factors are highest for Cd, Mo and As

Figure 26. Metal enrichment factors in the soil (Bur et al., 2009, 2010, 2012).



Toxicity of TME for springtails

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An experiment carried out on natural soils in Midi-Pyrénées has made it possible to observe various relationships between the bioaccumulation factor of metals in springtails and the fractions of metallic trace elements available in the soil. The biogenic elements (Zn, Cu for example) are the most bioaccumulated. The bioaccumulation of cadmium is all the higher as the availability of the metal in the soil is important.

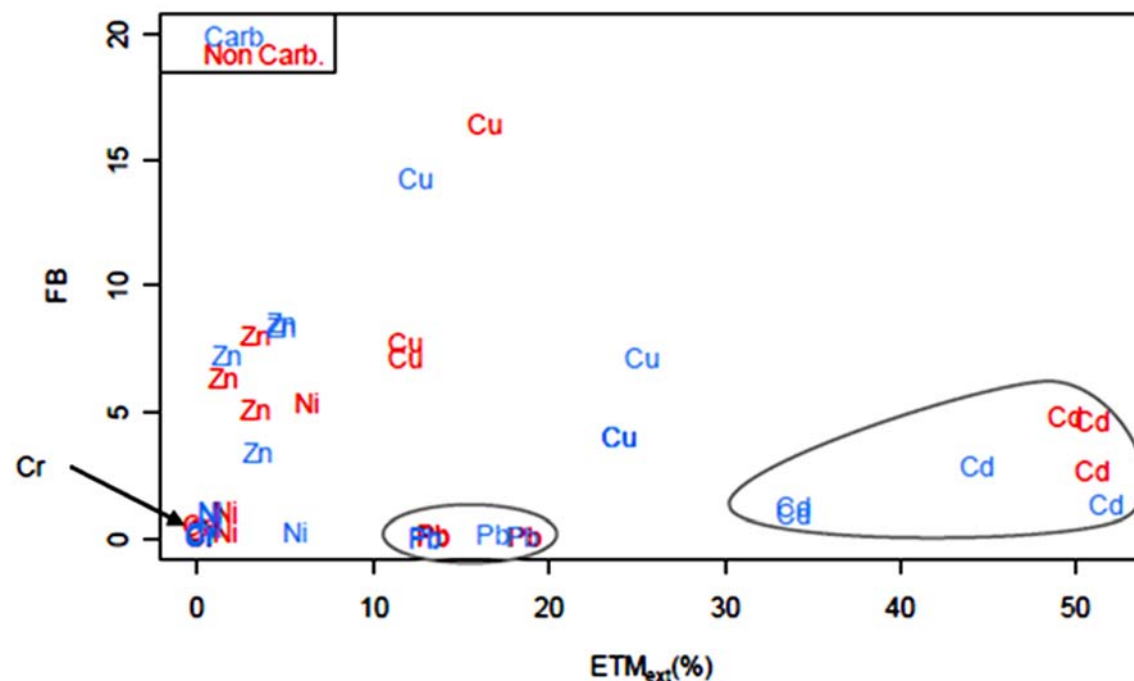
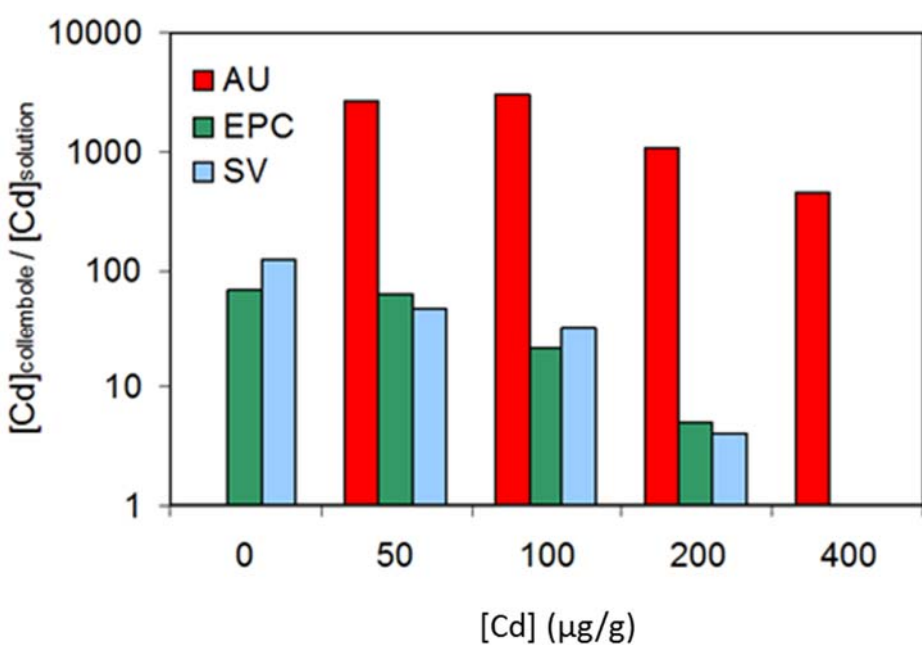


Figure 27. Metal bioaccumulation factors according to metals extractable from the soil (Austruy 2007 and Bur, 2009).



Observation of bioaccumulation:

$[TME]_{springtail} / [TME]_{soil\ solution}$

- Decrease → Maximum bioaccumulation reached.
- Strong bioaccumulation for carbonated soils.

Two hypotheses: effect of pH

- Facilitates Cd penetration (weak competition with H⁺)
- Adsorption on non-dosed ingested particles (filtration).

Figure 28 Comparison between soils with different pH of the relationship [Cd] springtail / [Cd] solution. AU = Auradé (pH8, 2% MO). EPC = forest floor (pH4.5, 16% MO). SV = agricultural soil (pH6, 2%Mo). (Bur et al., 2009, 2010, 2012).

Annual hydro-chemical mass balances

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Annual hydro-chemical mass balances for the period 2004-2004.

Chemical weathering of the molassic substratum : $20 \text{ t.km}^{-2}.\text{y}^{-1} \text{ CaCO}_3$ et $8,4 \text{ t.km}^{-2}.\text{y}^{-1} \text{ MgCO}_3$, i.e. $28,4 \text{ t.km}^{-2}.\text{y}^{-1} \text{ Ca(1-x)MgxCO}_3$

↳ Chemical denudation rate : 14,2 mm per 1000 years.

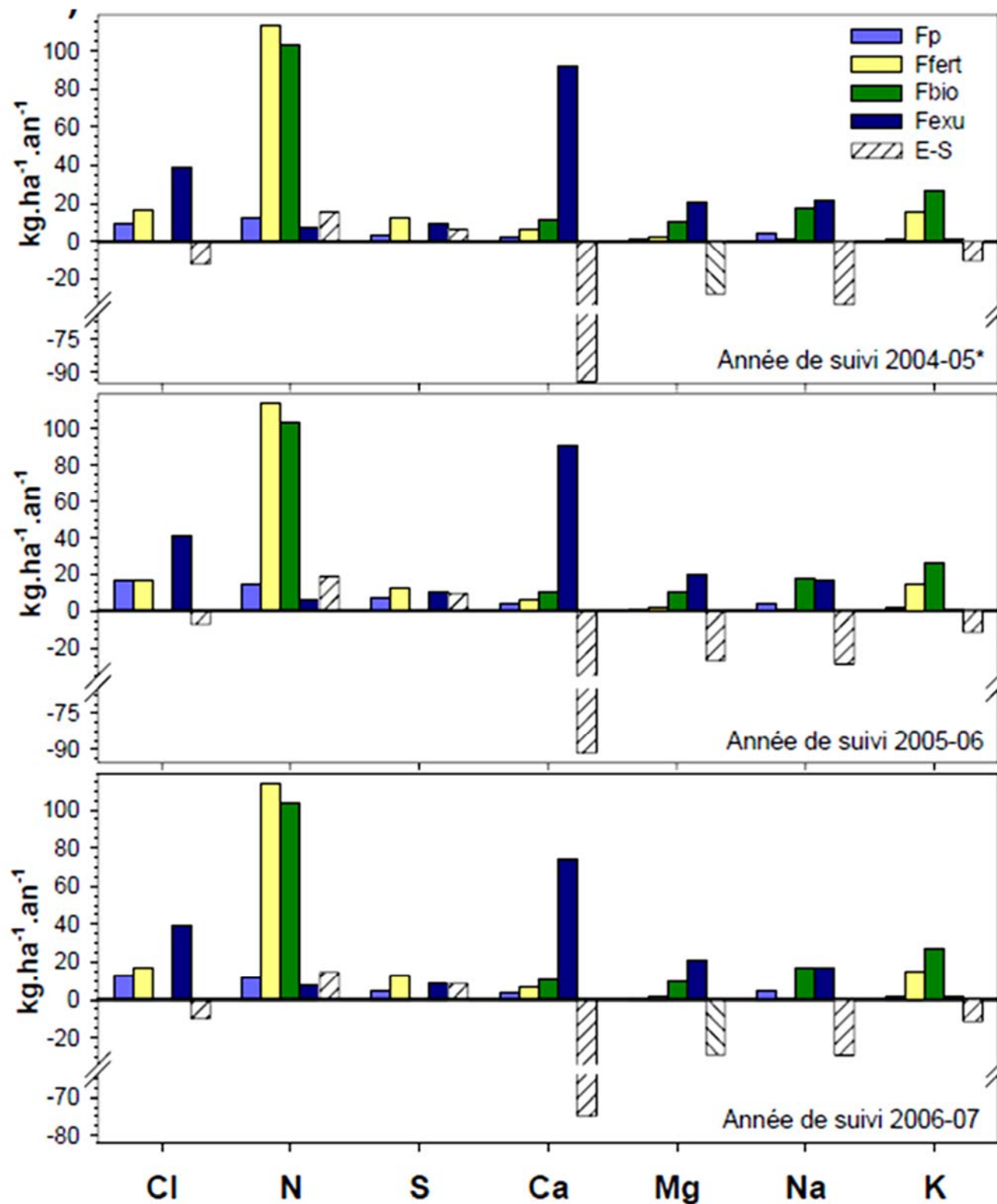


Figure 29. Annual hydro-chemical mass balances for the period 2004-2007 (Perrin et al., 2008).

Impacts of nitrogen fertilizers on weathering, constrained by carbon isotopes in the Auradé Catchment

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Tracing of carbon sources was carried out on the Montoussé watershed in Auradé with a view to analyzing the effect of fertilizers on chemical weathering. For this study, the relationships between atmospheric CO₂ and soil alteration were taken into account.

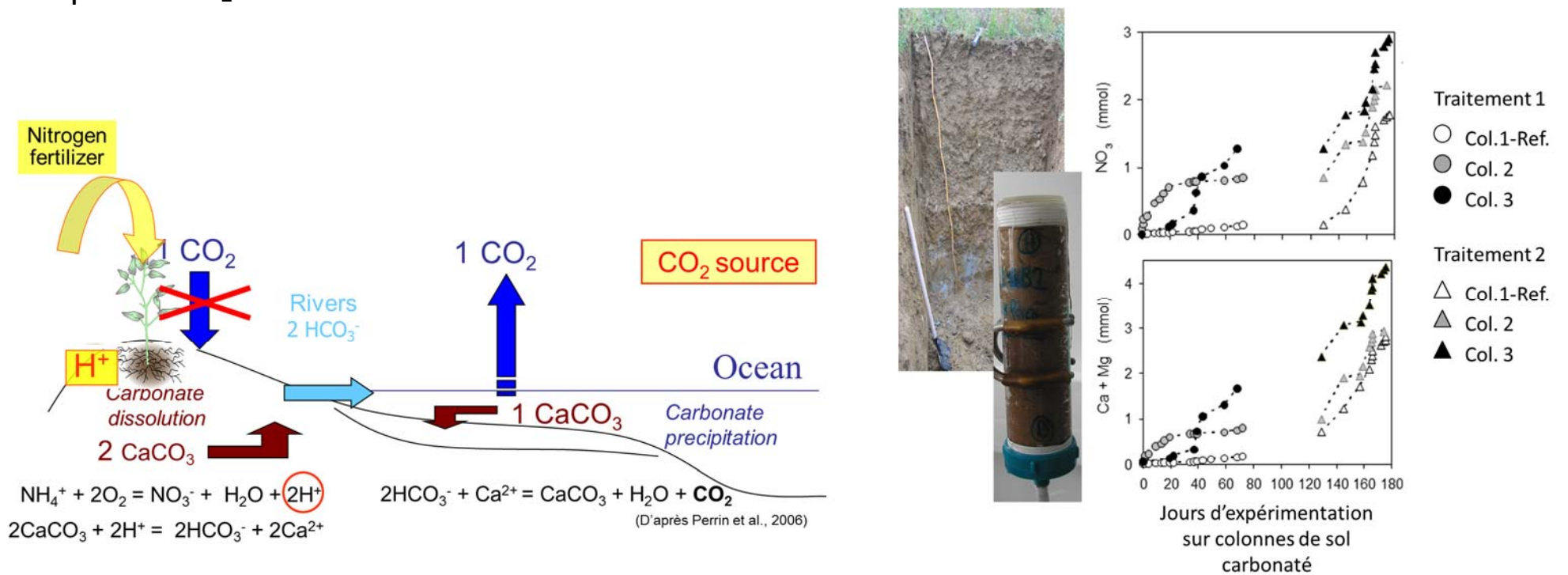


Figure 30. Impact of nitrogen fertilizers on carbonate dissolution and atmospheric CO₂ consumed (left) and the release of fertilizer protons induced on cultivated soils with contrasting carbonate contents (right), (Gandois et al., 2011).

An impact of nitrogen fertilizers on the chemical alteration of carbonated soils has been demonstrated. On a global scale, there is an increase in Ca Mg stream fluxes of 2.5.10¹² mol.ha⁻¹.

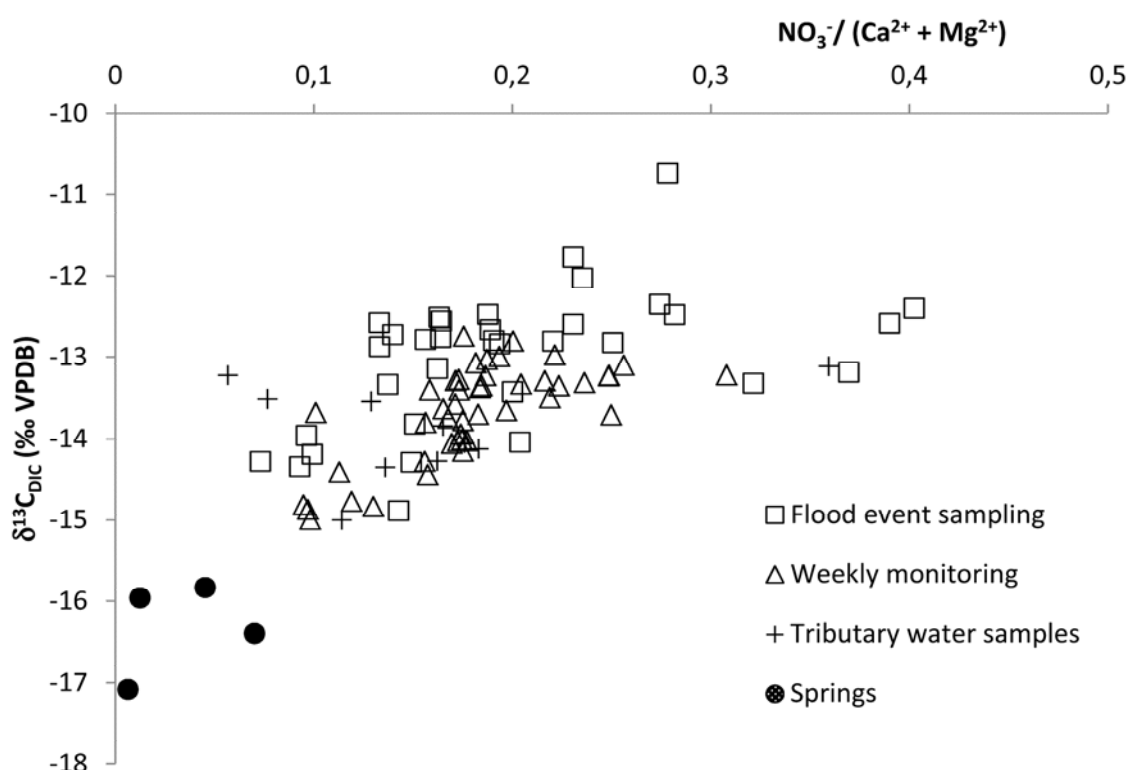
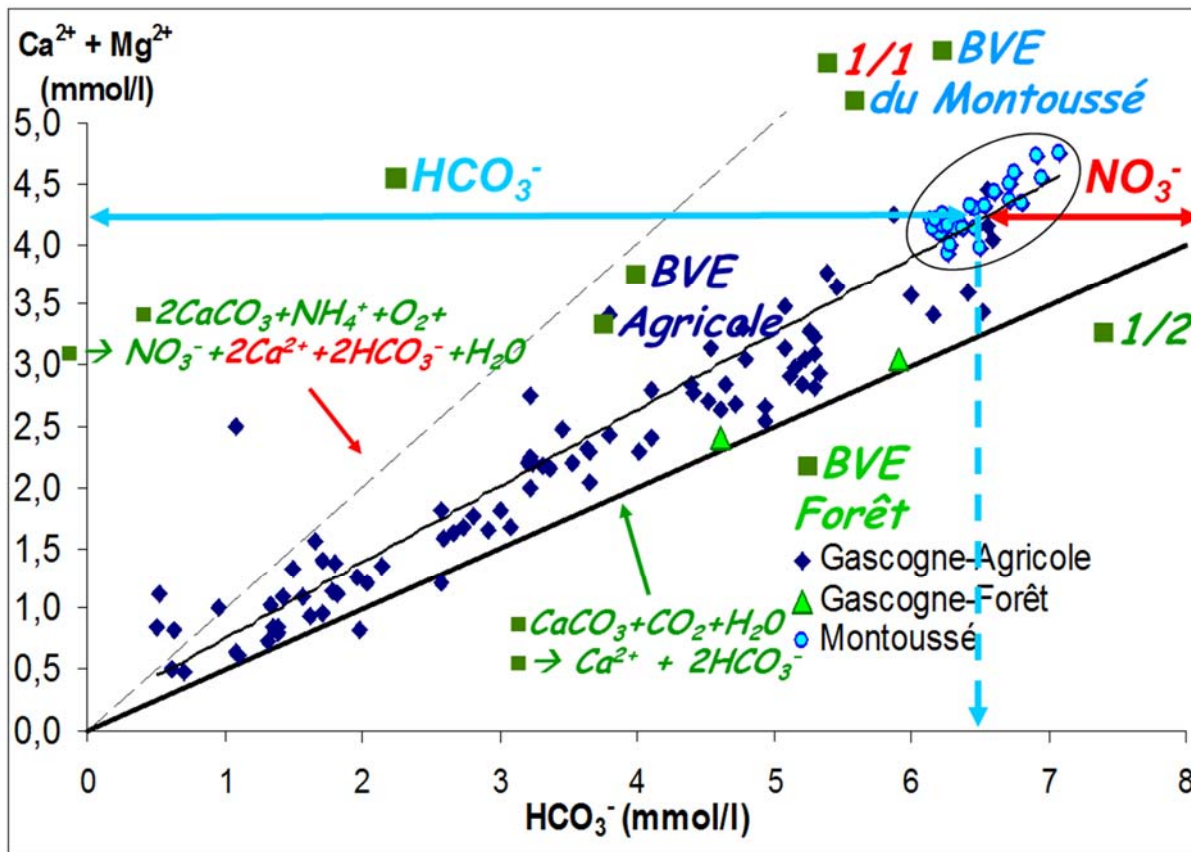


Figure 31. Relationship between δ¹³C_{DIC} (‰) and the molar ratio NO₃⁻ / (Ca²⁺ + Mg²⁺) for the surface waters (springs, tributaries and Montoussé main course) of the Auradé Catchment during the period March to December 2010. (Brunet et al., 2011).



Thèse Perrin
2008
Perrin et al.,
2008, GCA

Figure 32. Relationships between Ca+Mg and HCO₃ in the stream waters of the Gascony region, including the Montoussé in Auradé Catchment. Line 1/2 corresponds the natural weathering pathway of carbonate with carbonic acid. Line 1/1 : anthropogenic weathering of carbonate with nitric acid. (Perrin et al. 2008)

**The Auradé Catchment : modeling support.
Nitrate transfer modeling.**

LEFE-AKKA technologies-INRAE

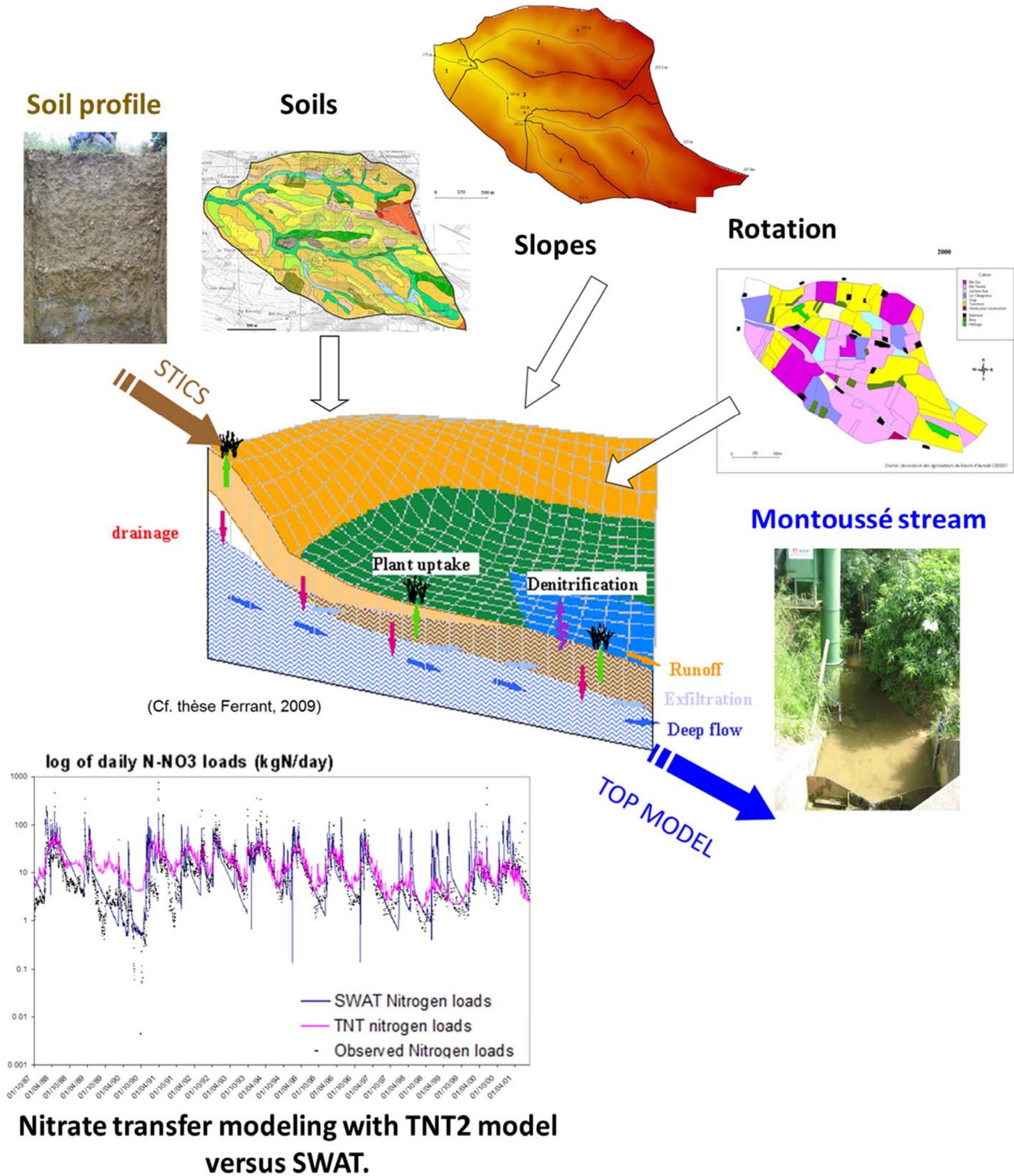


Figure 33- Modelling of nitrate transfers in Auradé Catchment using SWAT and TNT2 models (Ferrant, 2008).

These results were obtained as part of Ferrant's thesis (2008) for nitrates and in numerous scientific articles (Ferrant et al., 2011, 2012, 2013).

The quality of surface water in the Auradé Catchment. Agri-environmental risk assessment and analytical measures.

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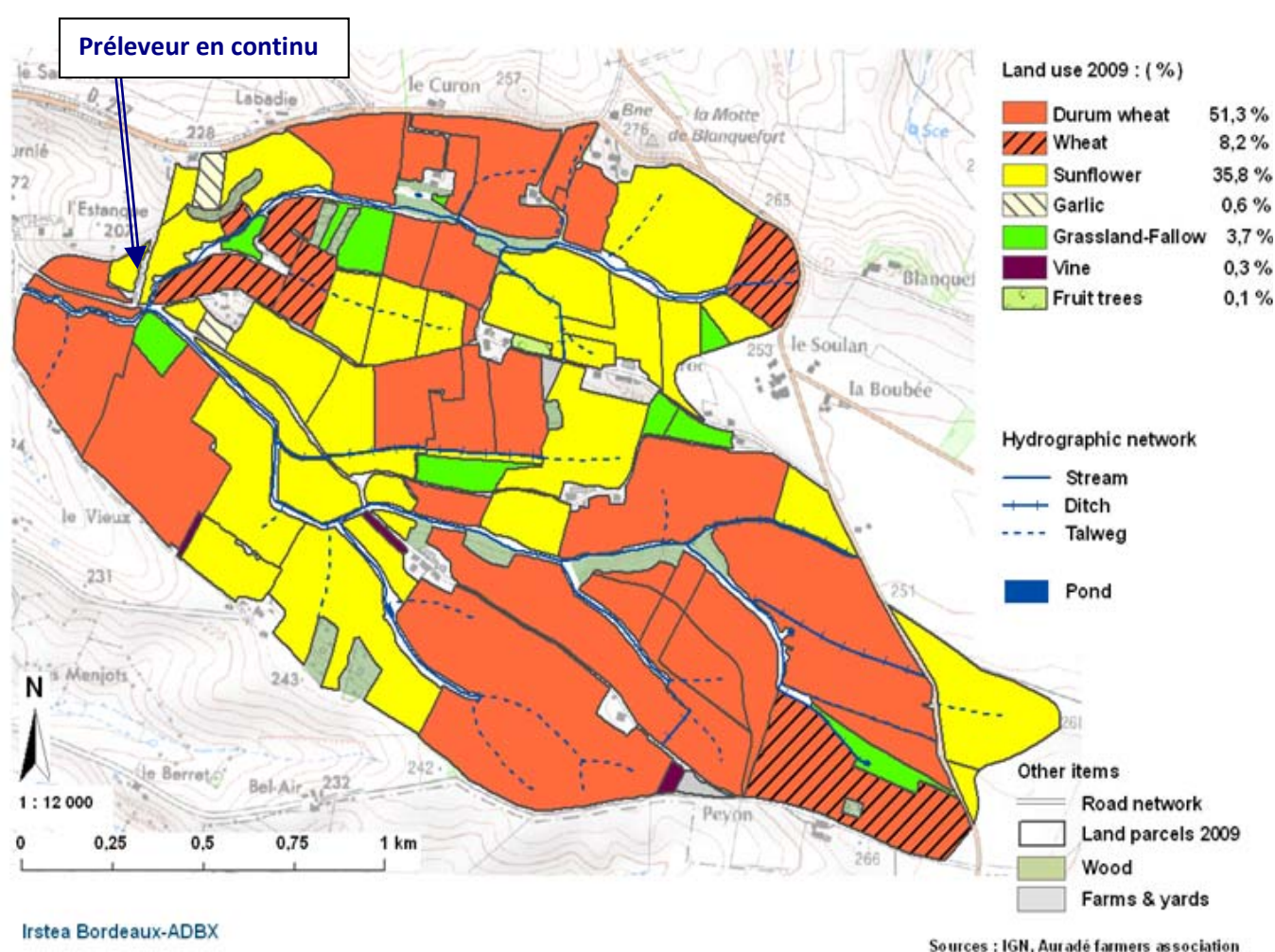
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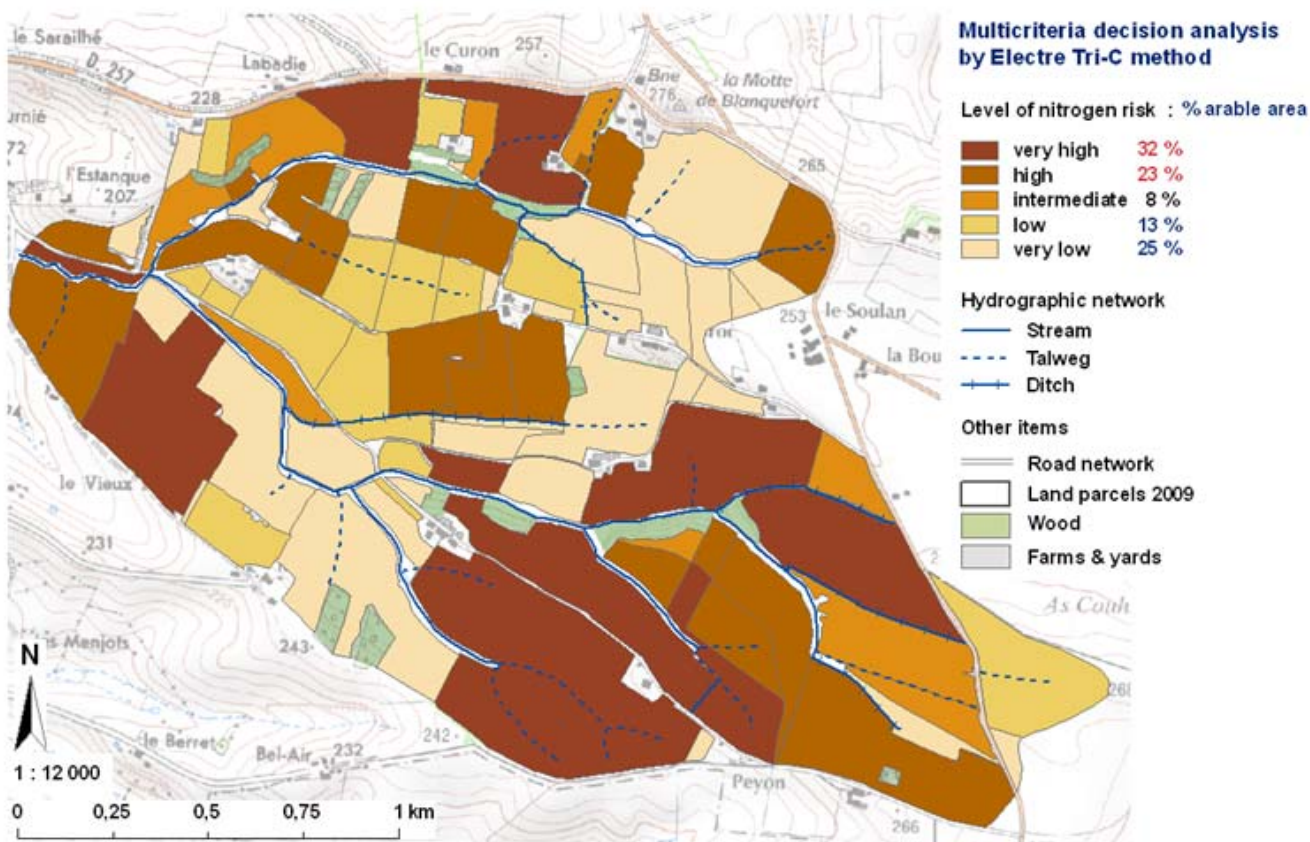
The experimental catchment of Auradé (320 ha), a few km from the pumping station and water treatment of the city of L'Isle Jourdain is located in an agricultural production area whose intensive practices have a strong impact on the quality of surface water (fertilizers, phytosanitary products, very simplified rotations). This catchment has been the subject of hydro-chemical monitoring of the quality of the surface waters of the Montoussé stream since the beginning of the 1980s (Grande Paroisse Company, ex AZF for NO₃ monitoring), then by LEFE since 2006 which also controls the concentration of phytosanitary products. Good environmental practices (GEPs) have been implemented along the watercourse since the creation of the farmer's association (Association des Agriculteurs d'Auradé, AAA) in 1992. A method for assessing the risks of contamination of the waters of the Montoussé was developed by INRAE (Bordeaux-Cestas) taking GEPs into account, with comparison with the nitrate concentrations.

Results



- An experimental catchment area of 320 ha: 90 agricultural plots.
- Steeply sloping plots; cambisols ("terreforts") on molasse.
- Circulation of water flows very largely by surface runoff.
- Short rotations: Wheat / Sunflower: 60% and 36% UAA.
- For 20 years: environmental measures (grass strips, poplars along the watercourse, riparian forest).

Figure 34. The rotation in Auradé Catchment during the year 2009



Irstea Bordeaux-ADBx

Sources : IGN, Auradé farmers association

Figure 35. Risks of contamination of surface water by agricultural activities on the Auradé Catchment in 2009

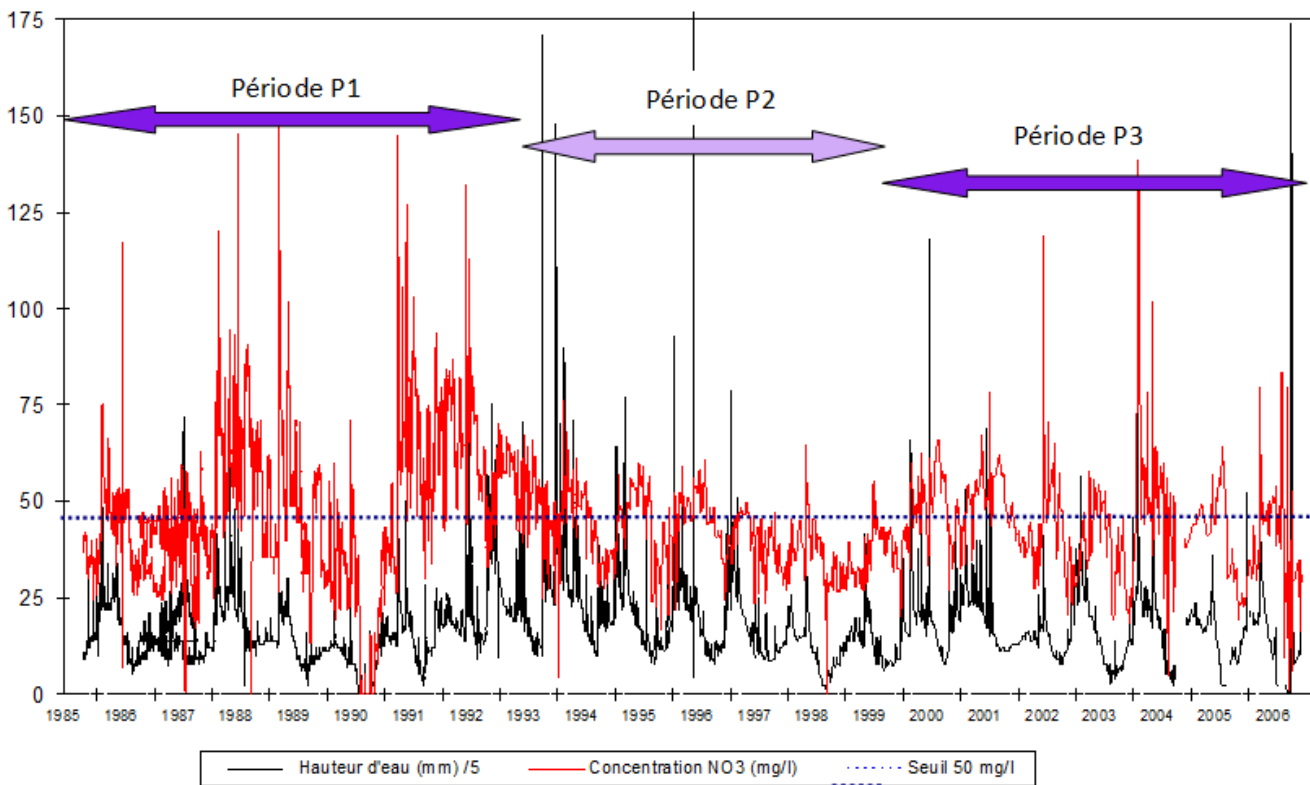


Figure 36. Fluctuations of nitrate concentrations in the Montoussé stream, Auradé Catchment, since 1985 (Sources : Ferrant, 2009, after the nitrate concentration monitoring by Grande Paroisse and LEFE

- Evaluation of agro-environmental risks (NO₃) by analysis and spatialized multi-criteria modeling for decision support.
- 55% UAA classified as high to very high risk of surface water contamination.
- The plots concerned are steeply sloping, well connected with the stream with a high level of inputs.
- Confrontation > 0 of the high level of risks with in situ measurements.

- P1 (1985-1992): higher [NO₃] values. Strong intensification, without regulation of GEPs.
- P2 (1993-2000): decreasing trend [NO₃]. Effects of GEPs and the 1992 CAP.
- P3 (Post 2000): stagnation, but...level > P2 and above all ~ 50 mg/l => very worrying

Synthesis

Despite the implementation of public policies aimed at the protection of natural resources and environmental devices in the field, the concentrations of inputs: nitrates, but also phytosanitary in a catchment such as that of Auradé remain a concern. Hydro-chemical monitoring is more necessary than ever, as well as the reinforcement of good agricultural and environmental practices.

These results are taken from the theses of Macary (2013) and Ferrant (2009) and the following publications: Ferrant et al., 2011 J. of Hydrol., Macary et al., 2013 Int. J.MCDM

Fusion of geophysical and spatial remote sensing data to estimate the useful reserve of soils: towards a 3D vision of catchments

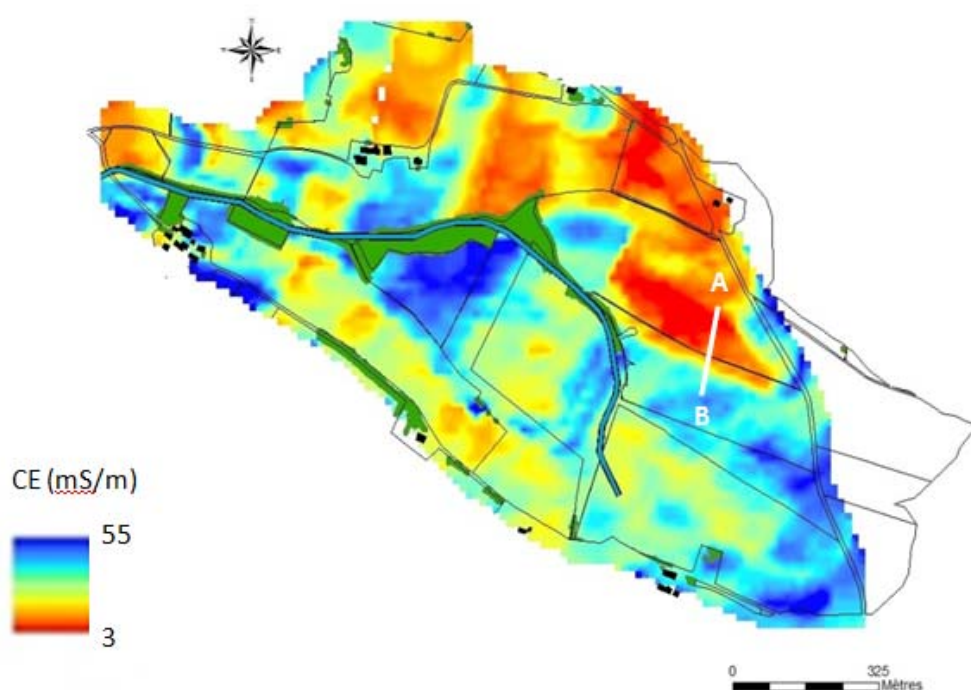
V. Bustillo^{1,2}, S. Ferrant¹

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The useful soil reserve (UR) is an essential factor in the spatial variability of agricultural production, but also in the transfer of water and pollutants. Its estimation is a major knowledge issue to understand the vulnerability of crops to climate hazards, but also the resilience of agro-hydrosystems, i.e. the memory of water inlets/outlets and past pollution. We were able to establish a UR map of the soils of the Auradé catchment by taking advantage of geophysical acquisitions (electromagnetic and geoelectric methods) and an inverse modeling exercise based on Formosat satellite images at very high spatial and temporal resolution.

Results

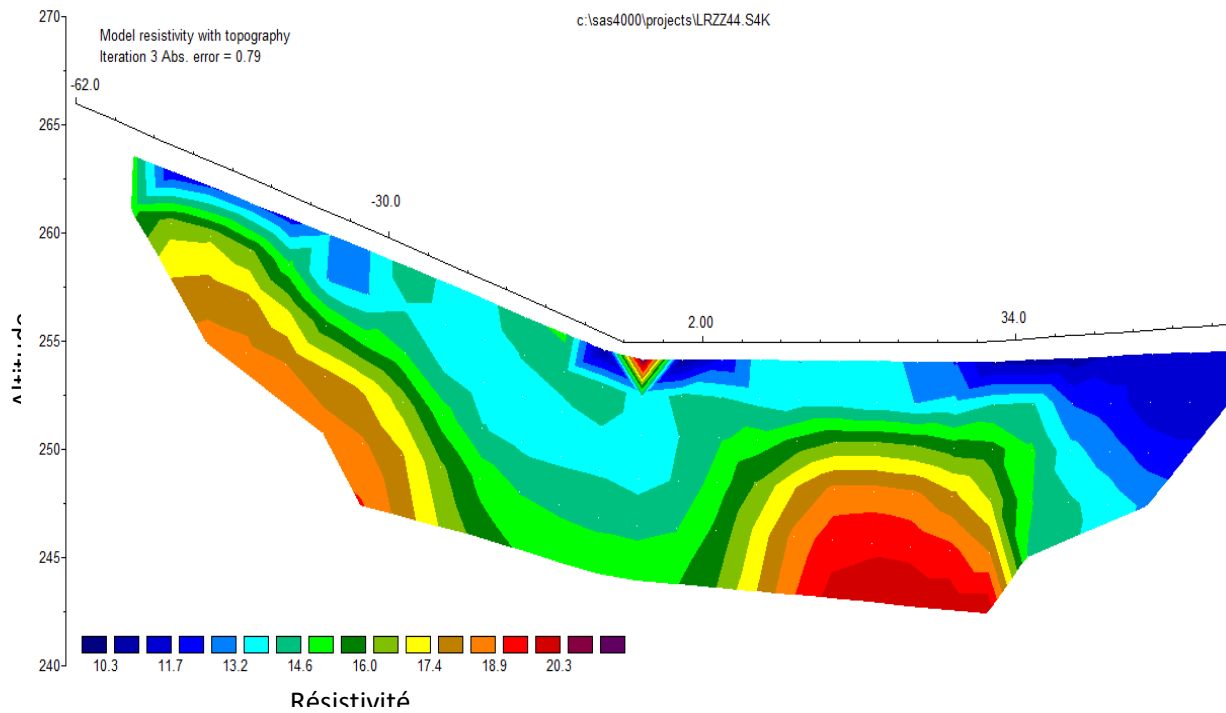
The itinerant acquisition of geophysical data by electromagnetic induction (EM38) makes it possible to map the electrical conductivity (EC) of soils, which accounts for the combined effect of dynamic variables (e.g. soil moisture) and static soil properties (i.e. texture, mineralogy and depth). Given its multifactorial nature, EC does not provide direct access to soil UR and must therefore be approached by diachronic monitoring and concomitant monitoring of soil moisture at different control points to isolate the static and dynamic components of the recorded signal.



At the scale of a 120 ha sub-catchment, we observe specific geophysical signatures at the level of slope breaks which are places of erosion (if convex) or of deposition (if concave). The microtopography therefore appears to be the main determinant of the intra-plot variability of UR. The exposure of the slopes also seems to closely control the variability of EC at the sub-catchment scale. The detailed knowledge of the topography (e.g. by Lidar) suggests a real ability to extrapolate off-site the results acquired on intensive monitoring sites

Fig.37- Electric Conductivity (EM38 : 1 m) of soils in a sub-catchment of 120 ha. July 2012.

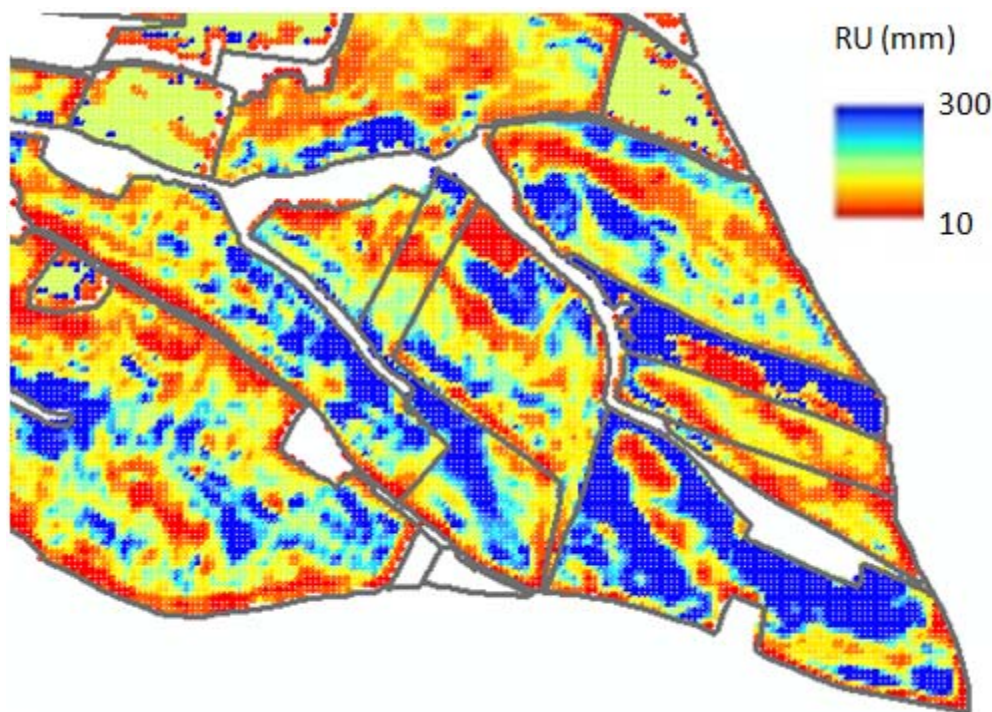
The EM38 method provides an integrated picture of the properties of the first meter of soil. However, a 3D view of the ground can be accessed by resistivimetric tomography methods (Fig. 2), which make it possible to deduce the depths of the ground and to document the main spatial patterns depending, in particular, on the DTM and the geomorphology.



This very characteristic profile illustrates the preponderant effect of topography on the redistribution of molassic materials along the slopes: the asymmetry of slope coincides with a pattern of asymmetrical soil thickness. The deepest soils (> 2m) are typically located downstream of molasse outcrops which are the site of intense physical erosion

Fig. 38- Electrical resistivity profile and overview of profile thicknesses along a typical toposequence of folded terrains.

A robust estimate of the useful soil reserve was obtained by inverting an ecophysiological model (SAFYE) calibrated to the spatio-temporal variations of leaf indices on 8-meter-sided grids, from time series of Formosat images.



The inversion of SAFYE on a series of 78 images (2006 to 2010) made it possible to estimate the UR of the soils of the Auradé catchment at the pixel scale (grid cells of 8 m). Sunflower is a particularly appropriate plant model for this inverse modeling exercise, given the particularly explicit phenotypic expression of the effects of limiting access to water. The patterns identified by geophysics (i.e. UR gradients along the slopes related to slope failures and the geometry of the molasses outcrops) manifest themselves very clearly.

Fig.39- Estimate of the useful reserve of the Auradé catchment (zoom on sub-catchment 4 of 120 ha).

Synthesis

The challenge for the future will be to access a 3D vision of the soil from THRS satellite images, thanks to (1) a geophysical calibration on a representative selection of intensive monitoring sites, and (2) the use of crop models that deduce the causes (limited access to water) from the observed effects (vegetation dynamics). The geophysical/remote sensing fusion uses a Bayesian approach taking advantage of an a priori estimate obtained by interpreting information (e.g. DEM and soil maps) via geophysical acquisitions.

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The brochure of the ANR project PESTIPOND

ANR PESTIPOND

Rôle des retenues d'eau artificielles et naturelles dans le transfert et l'impact des pesticides dans les eaux de surface de la zone critique en milieu agricole

Role of ponds in the transfer and impact of pesticides in surface waters of the critical zone in agricultural environment

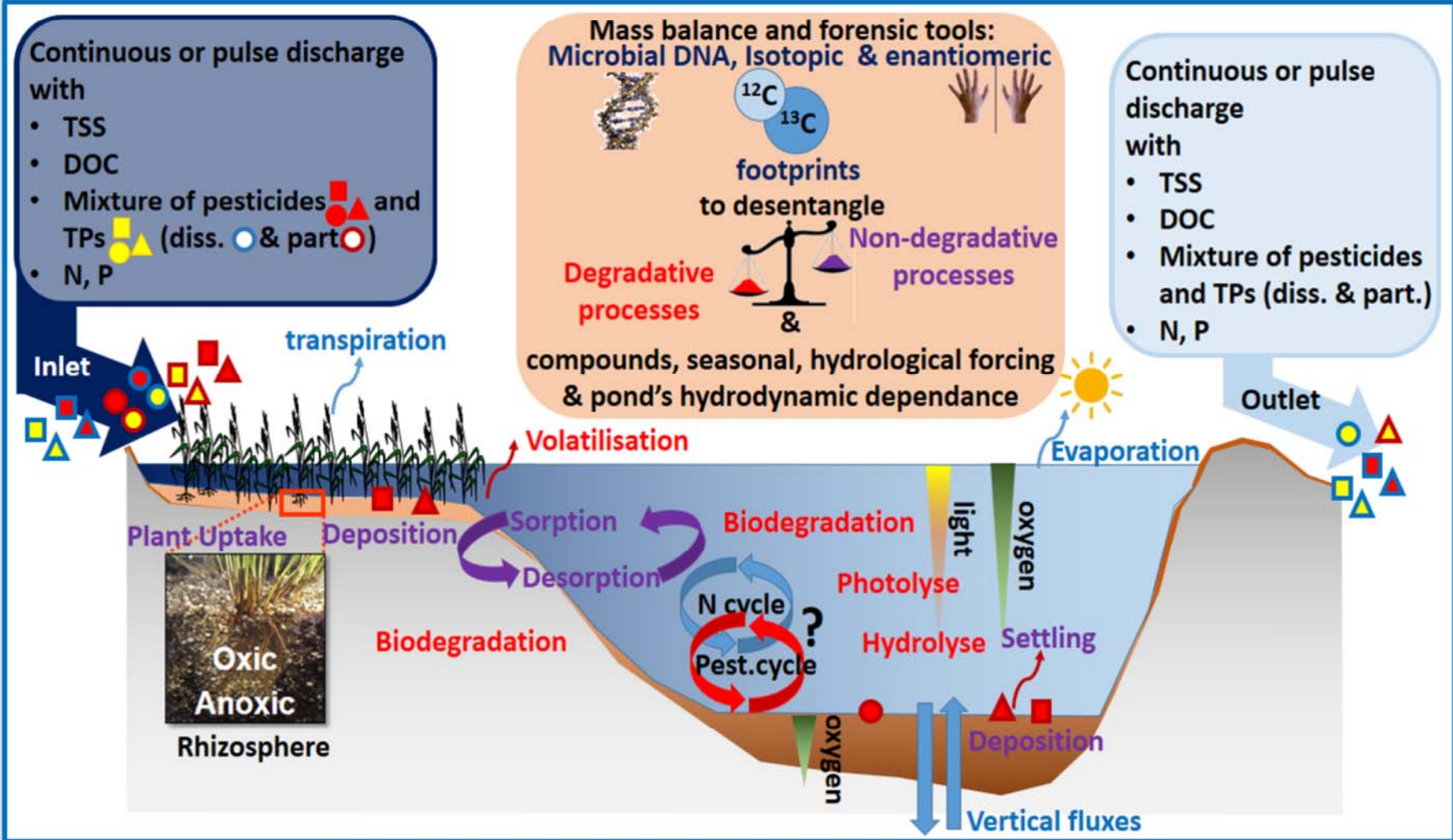


Site Web:
<http://pestipond.cnrs.fr/>





Biogeochemical and pesticide dissipation processes in artificial pond systems





Project ANR PESTIPOND



Role of ponds in the transfer and impact of pesticides in surface waters of the critical zone in agricultural environment

CONTEXT

In agricultural catchments, wetlands, and natural or artificial ponds are complex and dynamic ecosystems acting as biogeochemical reactors degrading pollutants. However, their role in pesticide transfer at the catchment scale remains largely unexplored. Most processes involved in pesticide dissipation or accumulation remain largely unknown.

OBJECTIVES OF PESTIPOND

The PESTIPOND project aims to provide answers to these issues. The project combines well-referenced field survey data and a hydro-biogeochemical approach, which, together with integrative modeling at different spatial scales, will allow to evaluate key processes of basin compartments involved in cycle, storage and dissipation of pesticides.

PESTIPOND is an innovative collaborative research project of 48 months involving partners from four research units in France and 15 social-economical partners. Our fields of expertise is complementary, and include hydrology, biogeochemistry, microbiology, isotopic analysis and chemistry of pesticides, soil and sediment sciences, agronomy, ecology, database management, multi-criteria modeling coupled with a GIS, agro-hydrological and biogeochemical modeling, landscape ecology as well as management of territories.

PESTIPOND focuses on water reservoir and natural and artificial wetlands in the agricultural landscape to provide innovative concept to evaluate pesticide storage and transformation in different compartments (water, sediments, vegetations, etc.). These processes are eventually included in a spatialized and integrative multi-criteria modeling framework to improve risk predictions of pesticide transfer to surface water at the catchment scale.

EXPERIMENTAL SITES

PESTIPOND relies on the pilot sites of 3 agricultural catchments in France: Aurade in Gascony (IR OZCAR and RZA, LTSER ZA PYGAR), Rampillon in Brie (LTSER ZA SEINE) and Hohrain in Alsace (Regional Platform, RECOTOX network, INTEREG projects , IDEX)



A pond within Aurade catchment (Gers)



A wetland within Rampillon catchment (Brie)



A pond within Hohrain catchment (Alsace)

Organisms, universities & laboratoires involved





Project ANR PESTIPOND



LINKS WITH PARTNERS

The project is conducted in close collaboration with social-economical partners participating with the PESTIPOND scientists to elaborate various structure and organization scenarios of buffer zones and ponds in the agricultural landscape. These scenarios will be incorporated into the modeling to define favorable configuration to reduce pesticide transfer.

The results of PESTIPOND will be useful to decision-making processes to protect water quality at the catchment scale: water and environmental agencies, water agencies, local cooperatives, engineering consulting firms, etc. Overall, the project targets factors and processes controlling the capacity of ponds to store and degrade pesticide mixtures, far beyond their primary role of delaying pesticide transfer or transforming parent molecules into degradation products.

PROJECT ORGANIZATION

The project is organized in three interconnected experimental tasks:

- ◆ Biogeochemistry of pesticide behavior in real conditions, in ponds and in response to hydroclimatic conditions in different agricultural contexts;
- ◆ Role and contribution of pesticide dissipation pathways in ponds: *in situ* and laboratory experiments;
- ◆ Modeling and evaluation of the impact of pesticide transfer to surface waters (simulation of pond-scale pesticide dissipation, and cumulative effects of successive ponds in the landscape to generate management scenarios for ponds at the catchment scale).

CONTACTS

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LABORATORIES INVOLVED

- ◆ Laboratoire d'Hydrologie et de Géo chimie de Strasbourg, LHyGeS, UMR 7517 CNRS-UNISTRA-ENGEES, Strasbourg - <https://www.lhyges.unistra.fr/>
- ◆ Laboratoire Ecologie fonctionnelle et environnement, ECOLAB, UMR 5245 CNRS-UPS-INPT, Toulouse <http://www.ecolab.omp.eu/>
- ◆ Environnement, Territoires et Infrastructures, ETBX, UR IRSTEA, Bordeaux-Cestas - <https://www.irstea.fr/fr/recherche/unites-de-recherche/etbx>
- ◆ Hydrosystèmes continentaux anthropisés-Ressources, Risques, Restauration, HYCAR, UR IRSTEA, Antony - <https://www.irstea.fr/fr/recherche/unites-de-recherche/hycar>

SOCIO-ECONOMIC PARTNERS

From a socio-economic viewpoint, PESTIPOND will facilitate the development of novel management scenarios, in particular through the involvement of 15 socio-economical partners for the conception and the evaluation of different agro-environmental and transition scenarios used for predictive modelling.

- ◆ French Water Agencies Adour-Garonne (AEAG), Seine-Normandie (AESN) and Rhin-Meuse (AERM)
- ◆ French Biodiversity Agency AFB
- ◆ Regional Directions of Agriculture and Forest (DRAF): Occitanie, Alsace-Champagne Ardenne-Lorraine
- ◆ Company Jean-Voisin-Beaumont La Rone (37)
- ◆ EPLEFPA Les Sillons de Haute Alsace-Rouffach (67)
- ◆ Association AQUI'Brie-Dammarie Les Lys (77)
- ◆ Company Aquatiris-Bréal-sous-Montfort (35)
- ◆ Coopérative UNICOQUE (KOKI)-Cancon (47)
- ◆ Coopérative Agricole de Stockage de Céréales et d'Approvisionnement (CASCAP)- L'Isle Jourdain (32)
- ◆ Groupement des Agriculteurs de la Gascogne Toulousaine (GAGT)-Auradé (32)
- ◆ Chambre d'Agriculture du Gers
- ◆ Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt

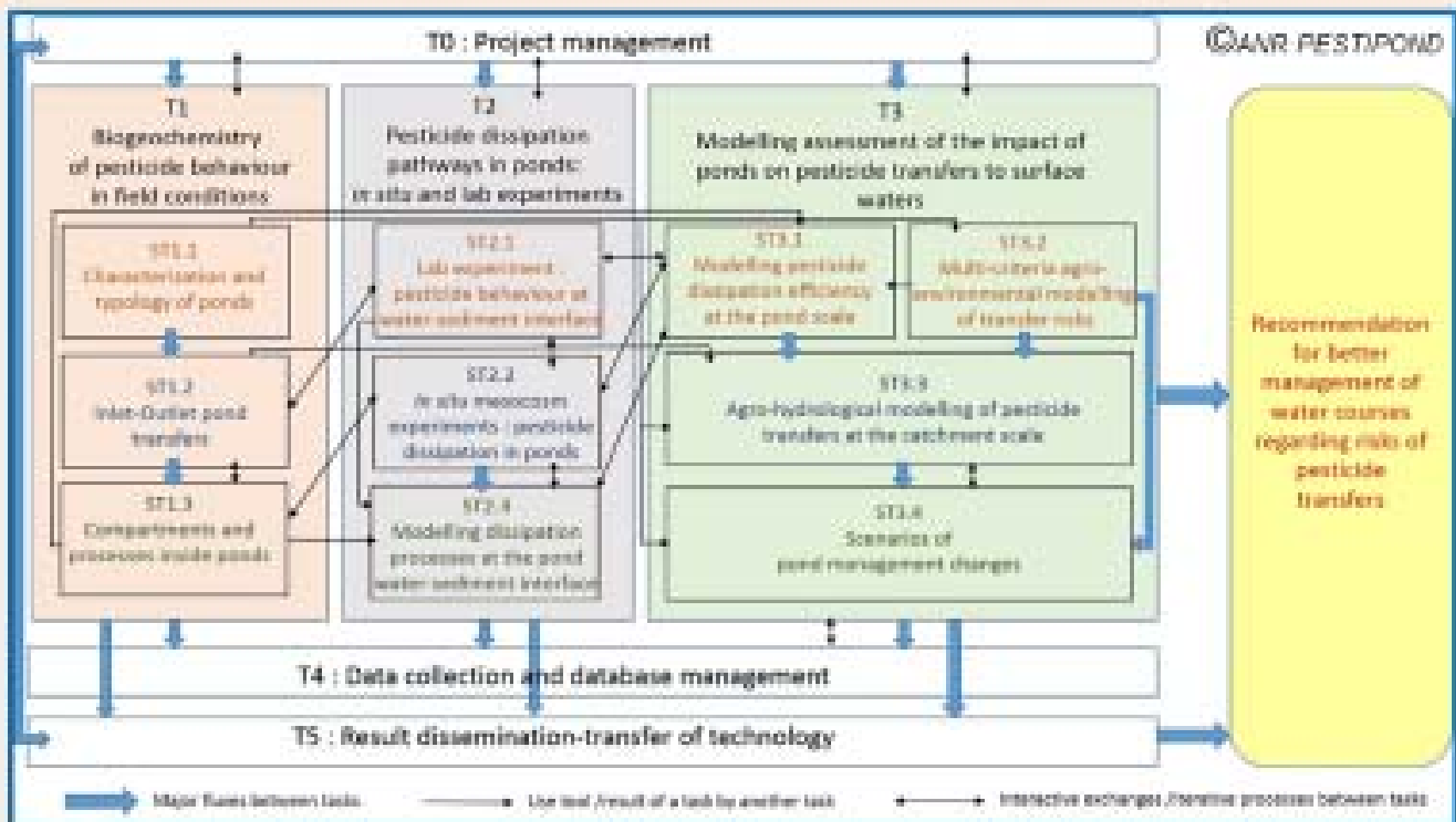
WEB SITE: <http://pestipond.cnrs.fr/>

Socio-economic partners involved





Structure & Organization of PESTIPOND





ANR PESTIPOND

Projet collaboratif entre scientifiques



et partenaires socio-économiques



SITE WEB : <http://www.pestipond.cnrs.fr/>

**The brochure of Auradé
Farmer's Association
(AAA), today Groupement des
Agriculteurs de la Gascogne
Toulousaine (GAGT)**

<http://groupementdesagriculteursdelagascognetoulousaine.e-monsite.com/>



La qualité de l'eau,
notre préoccupation depuis plus de 30 ans

L'ASSOCIATION DES AGRICULTEURS D'AURADÉ



DÉVELOPPER UNE AGRICULTURE PERFORMANTE DANS UN ENVIRONNEMENT PROTÉGÉ

Depuis 1982 les agriculteurs d'Auradé innovent, expérimentent, agissent, se battent pour faire exister leur parole, conscients des effets sur l'eau de leur métier, à l'échelle d'un bassin versant.

Objectif, optimiser un maximum de moyens pour pénaliser le moins possible l'environnement.
Dès 1982 quelques agriculteurs exploitant dans les bassins versants d'Auradé travaillent avec des ingénieurs de Grande Paroisse sur les transferts des fertilisants azotés dans le sol et vers les cours d'eau. On ne parle pas encore de pollution.

Deux au départ, puis cinq, ils fédèreront progressivement jusqu'à 42 fermes. Ils sont encore aujourd'hui 35, exploitant 70 ha en moyenne en grande culture, souvent double actifs, producteurs d'ail, etc.

L'ASSOCIATION
DES AGRICULTEURS D'AURADÉ

PIONNIÈRE

C'est à Auradé que se construit le concept de bande enherbée. Ces précurseurs se constituent en association pour concourir au prix de la fondation Pierre Sarazin qu'ils remportent en 1992. La bourse leur permet d'embaucher leur premier animateur.

Le site accueille de nombreuses recherches et expérimentations, portées par des laboratoires comme Ecolab (CNRS-Toulouse III-INP), le Cesbio (CNRS-CNES-IRD-Toulouse III), ou la recherche appliquée, à travers Arvalis, le Cetiom et les Chambres d'Agriculture, etc. Ecolab vient de faire labelliser le bassin versant du Montoussé dans le réseau d'expérimentation national et international du CNRS.



INDÉPENDANTE

L'association régie par la loi de 1901, sans but lucratif, gère également le Plan d'Action Territorial « Boulouze Save Lisloise Amont » sur 21 communes en limite des départements du Gers et de Haute-Garonne, financé en partie par l'Agence de l'eau Adour-Garonne.

Cas unique, c'est l'aboutissement de plans d'action conduits pendant 20 ans sur des sujets comme la qualité de l'eau dans les ruisseaux, les transferts des phosphates, nitrates et des molécules phytosanitaires dans le sol, l'érosion, l'impact des techniques culturales simplifiées, etc.

Avec de multiples partenaires, publics, privés ou associatifs (Protection des Végétaux, Fredec, Chambres d'Agriculture, Arvalis, Syngenta, GPN etc.)

OUVERTE

Situé à la limite du Gers et de la Haute-Garonne, le site se trouve en lisière de l'agglomération toulousaine. L'association est impliquée dans différentes missions des collectivités (préfiguration des trames verte et bleue en lien avec le Scot, surveillance de la qualité de l'eau, etc.).

Son expérience et la qualité de ses travaux lui permettent d'intervenir véritablement dans le concert des élus et techniciens. L'association a une politique de communication active, avec de nombreuses visites organisées pour les élus, les scolaires, les étudiants, les professionnels.

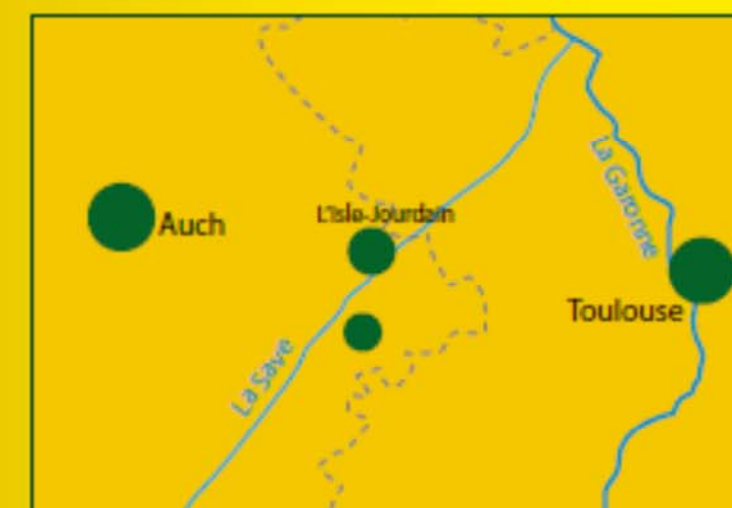
De nombreux étudiants, thésards français et étrangers ont travaillé sur le bassin versant d'où une bibliographie très riche, constituant peu à peu un réseau de référence sur les problématiques agro-environnementales.

Curieux, passionnés par l'expérimentation, les agriculteurs d'Auradé partent régulièrement à la découverte d'autres régions agricoles françaises voire européennes.

« Notre vision, c'est le long terme ».

LES CONTACTS

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- Mail : agriculteurs.aurade@orange.fr
- www.agriculteurs-aurade.fr



www.agriculteurs-aurade.fr



Gasco-
val



Ecolab



GPN



Third Days of the French Catchment Network (RBV)

17 and 18 october 2013
Toulouse - Auradé

Visit of the Montoussé catchment in Auradé (Gers) &

Thematic discussion on the question: "What are the minimum parameters required for monitoring common to all the observatories in the Critical Zone?"



Schedule of days

17 october : Visit of Auradé Catchment

- ▶ 9h – 11h : Arrivée à l'hôtel à l'Isle-Joudain (voir encadré ci-contre)
- ▶ 12h : Déjeuner à l'auberge du lac
- ▶ 14h – 17h30 : Visite du bassin versant
 - Présentation du bassin versant, des équipements installés et des résultats scientifiques acquis sur le site
 - Exercice d'inter-calibration géochimique
 - La tour à flux : présentation de la parcelle et des mesures de flux
- ▶ 18h : Rencontre à la mairie d'Auradé avec l'Association des Agriculteurs d'Auradé
- ▶ 19h30 : Dîner à l'auberge du lac
- ▶ 21h – 23h : Réunion du comité de pilotage du Réseau des Bassins Versants. Divers sujets seront abordés :
 - L'avenir du RBV
 - La base de métadonnées
 - Le CRITEX ...

Logis Hostellerie du Lac
Avenue Corps Franc Pommies
32600 L'Isle-Jourdain
05 62 07 03 91

- 3 itinéraires depuis Montpellier
 - A9 puis A61
 - D999
 - D612

- 2 itinéraires depuis Bordeaux
 - A62
 - A62 puis D930

- 1 itinéraire depuis Toulouse
 - N124

18 october : Scientific and technical discussions

- ▶ 7h - 8h : Petit-déjeuner à l'auberge du lac
- ▶ 9h - 12h : Echanges scientifiques à la salle des fêtes de la mairie d'Auradé (1^{ère} partie)
- ▶ 12h30 : Déjeuner à l'auberge du lac
- ▶ 14h - 16h : Echanges scientifiques à la salle des fêtes de la mairie d'Auradé (2^e partie)

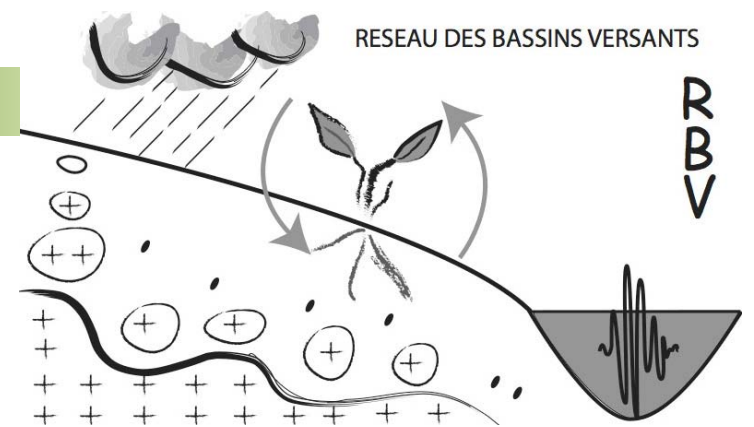
Items to be discussed during the scientific discussions on October 18

Discussions and reflections on the list of parameters allowing the monitoring of the critical zone:

↳ Soil, water, rivers, soil water, hydrological parameters, edaphic parameters, soil parameters...:

Creation of an exhaustive list of measured parameters

- Présentation de tableaux synthétiques.
 - Tableaux d'instrumentation des sites présents sur le site internet du RBV.
- Regard sur les paramètres mesurés sur d'autres sites.
 - ▶ Nouvelles mesures qui devraient être faites sur les sites du RBV.
 - ▶ Exercice à faire pour :
 - Les CZO américains.
 - D'autres réseaux européens.



Which measurements for which scientific question?

- Questions scientifiques à définir pour l'ensemble du RBV.
 - Conservation des interrogations scientifiques propres à chaque observatoire.
 - Discussion focalisée sur les variables concernant uniquement le long terme.

Debate over measurement frequencies

- Quelles fréquences?
- Lien avec le CRITEX.
- La haute fréquence est-elle nécessaire toujours ?
- Dépendance de la fréquence de mesure par rapport au processus observé.

Link to operational systems

- Lien avec l'opérationnel ?
- Nos variables sont-elles d'intérêt public?
- Y a-t-il eu dans l'opérationnel une réflexion sur les paramètres qui doivent tous être mesurés ?

Representativeness and genericity

- Un site ne documente-t-il que des processus particuliers ?
- Sites : intérêt régional versus intérêt global ?
- Peut-on montrer que la mise en réseau des observatoires SIC actuels est un plus pour les organismes de recherche ?
- Particularité de certains sites :
 - ▶ Sites instrumentés auxquels s'ajoutent des actions expérimentales ponctuelles :
 - Majorité des ORE et observatoires du RBV.
 - ▶ Sites d'expérimentation mono variable :
 - Les observatoires atmosphériques.
 - Les observatoires océaniques.

Pour contribuer de manière active à cette journée, en fonction de ces quelques items (et d'autres qui vous paraîtraient intéressants à aborder), vous êtes invités à préparer éventuellement une diapositive illustrant une de vos figures ou une figure tirée d'un papier emblématique de votre discipline. Que cette discussion interdisciplinaire nous permette d'aboutir à une liste de paramètres communs ainsi qu'à une construction plus claire de la base de métadonnées.

Merci pour votre participation.

List of participants

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*The Bassioué pond, instrumented site of the Auradé Catchment
within the framework of the ANR PESTIPOND*