



Coupling Groundwater Modeling with Biology to Identify Strategic Water Resources

*- Assessment for hydraulic interactions
between rivers and groundwater –*

Rhone Basin Long Term Environmental Research

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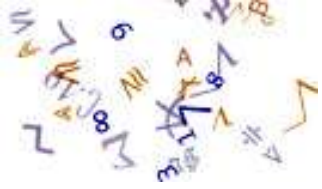
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Université Claude Bernard

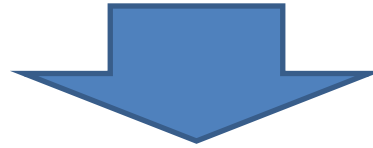


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Purpose and scope

**Quantify interactions between the rivers
and their floodplain through groundwater**



**a relevant issue
for the water resources management
in the long term
and for the preservation of biodiversity**

Rhône River from Switzerland in the Alps to the Mediterranean Sea



545 km in France
Drainage area: 5 220 km²

11 counties, 213 municipalities and 48 hydrographic zones

160 m³/s - 1900 m³/s

540 m³/s - 9600 m³/s

Many different watersheds :

- Free and confined sedimentary aquifers: alluvial aquifers, complex glacial formations, Miocene molasses
- Impervious formations with very small aquifers
- fissured bedrock (granite and schist).

Rhône River from Switzerland in the Alps to the Mediterranean Sea



Groundwater influences strongly surface waters

Downstream section : Many man-made structures

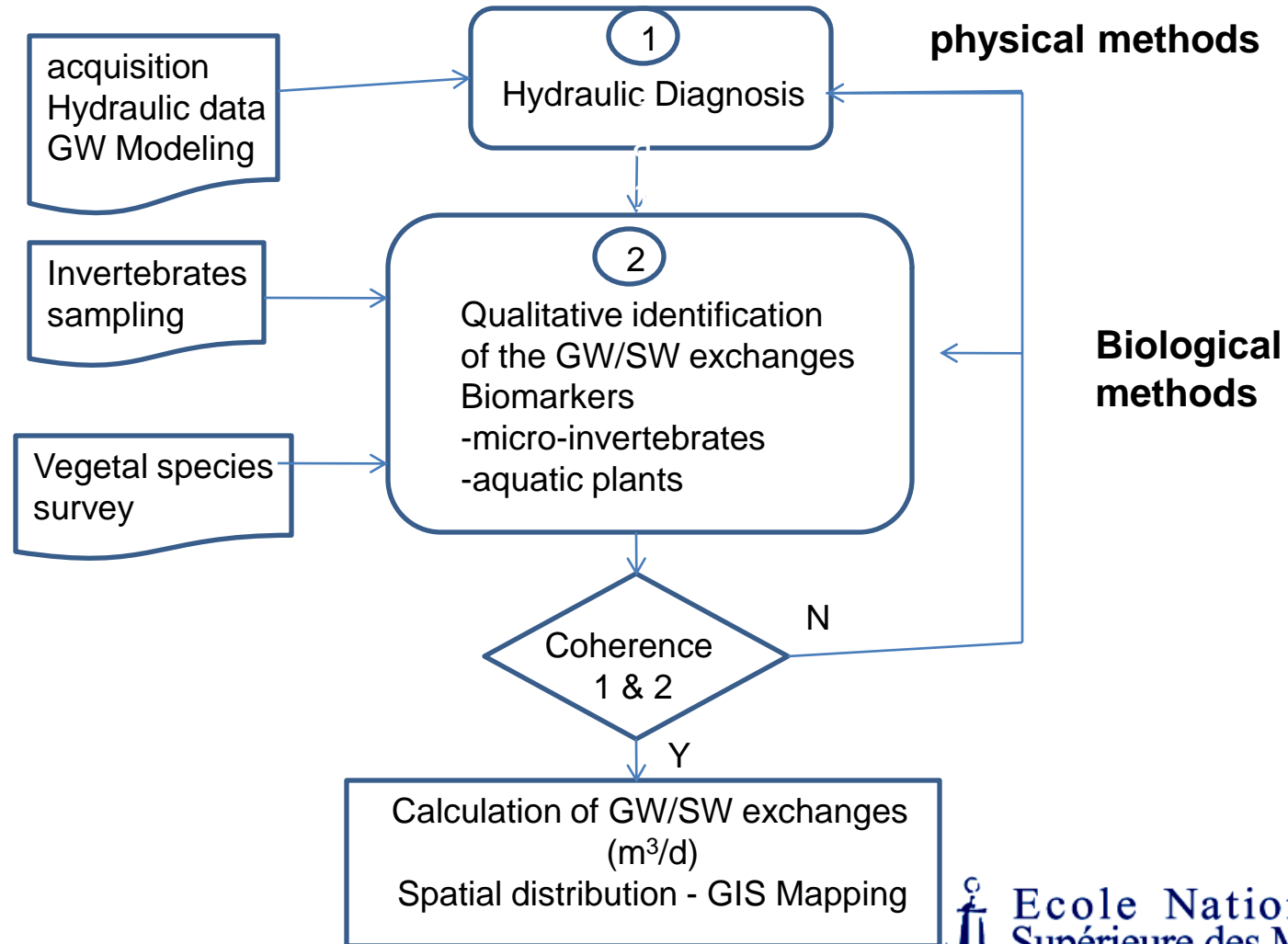
A diversion canal with 300 kilometers of embankments

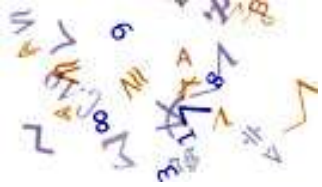
About 40 dams (hydroelectric power, floods prevention, navigation, potable water supplying, water for irrigation)

Slow flowing former channels



Estimation of Water Gains or Losses Methodology



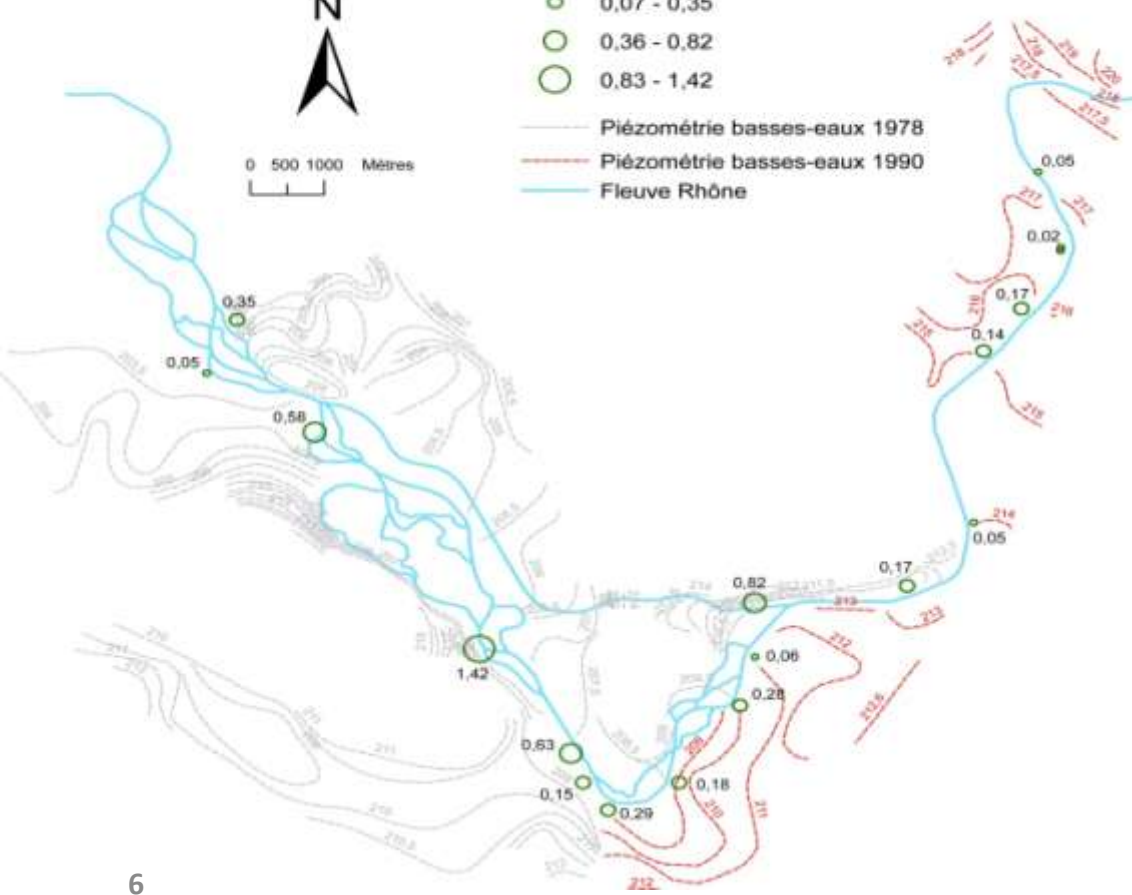


Hydraulic Diagnosis

Legend

GW flow m³/day
 K= 10⁻³ m/s A=1m²

- 0,02 - 0,06
- 0,07 - 0,35
- 0,36 - 0,82
- 0,83 - 1,42
- Piézométrie basses-eaux 1978
- Piézométrie basses-eaux 1990
- Fleuve Rhône



Mapping of the piezometric level in the alluvial aquifer

TIN Model 3D analyst tools



$$i = \frac{dH}{dL}$$

hydraulic gradients

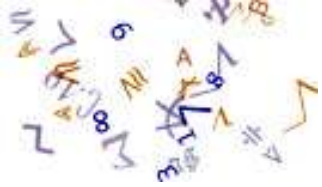
Darcy's law



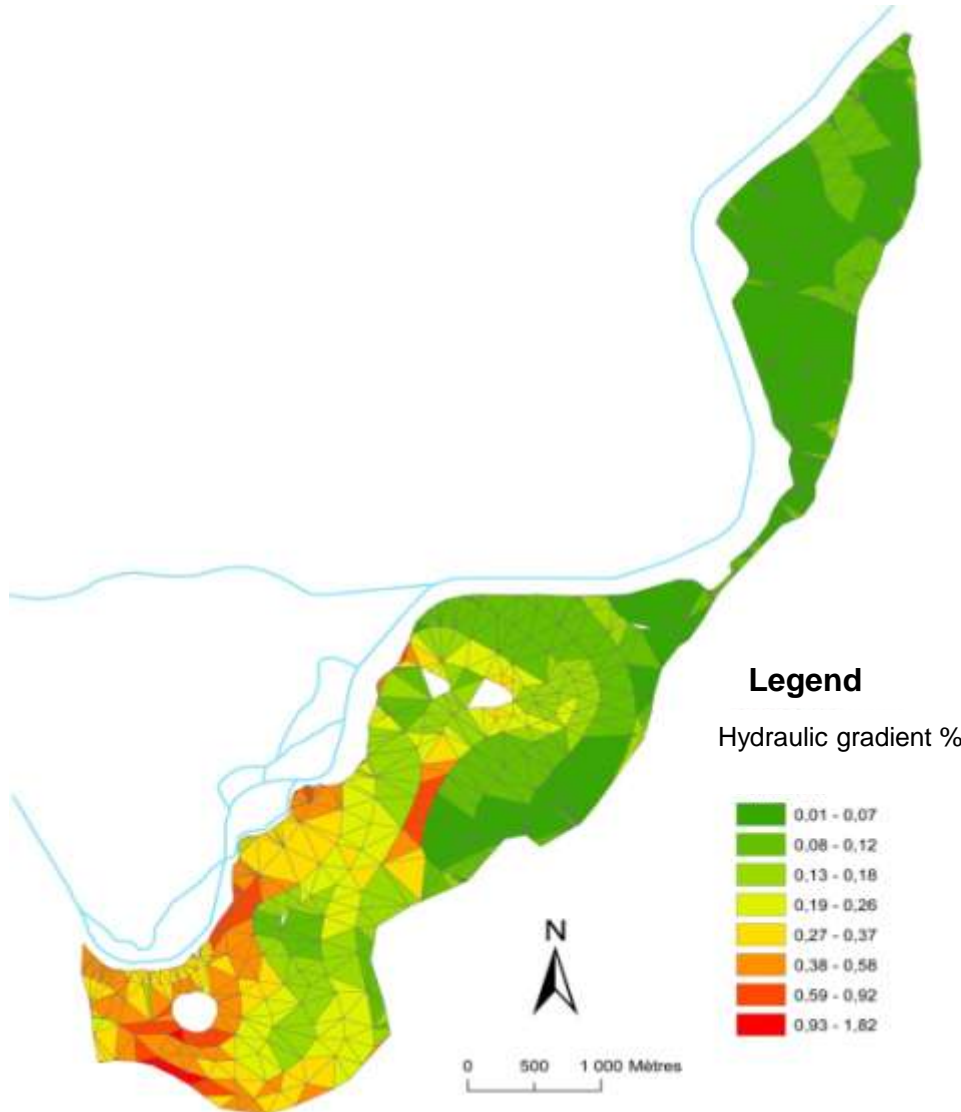
$$q = K.A.i$$

outflow, inflow,
equilibrium





Hydraulic Gradient Determination



**Digitalization of
piezometric curves**



**Calculation of the
GWflow angle**



**Calculation of the
GW / SW
exchanges**

**GW → Rhône : +
Rhône → GW : -**

Comparison with Biological Markers

spatial distribution of hyporheic microfauna

ecological groups:

Stygobionts

in GW

Stygophiles (ubiquitous)

In GW and SW

+

Conductivity (μs)



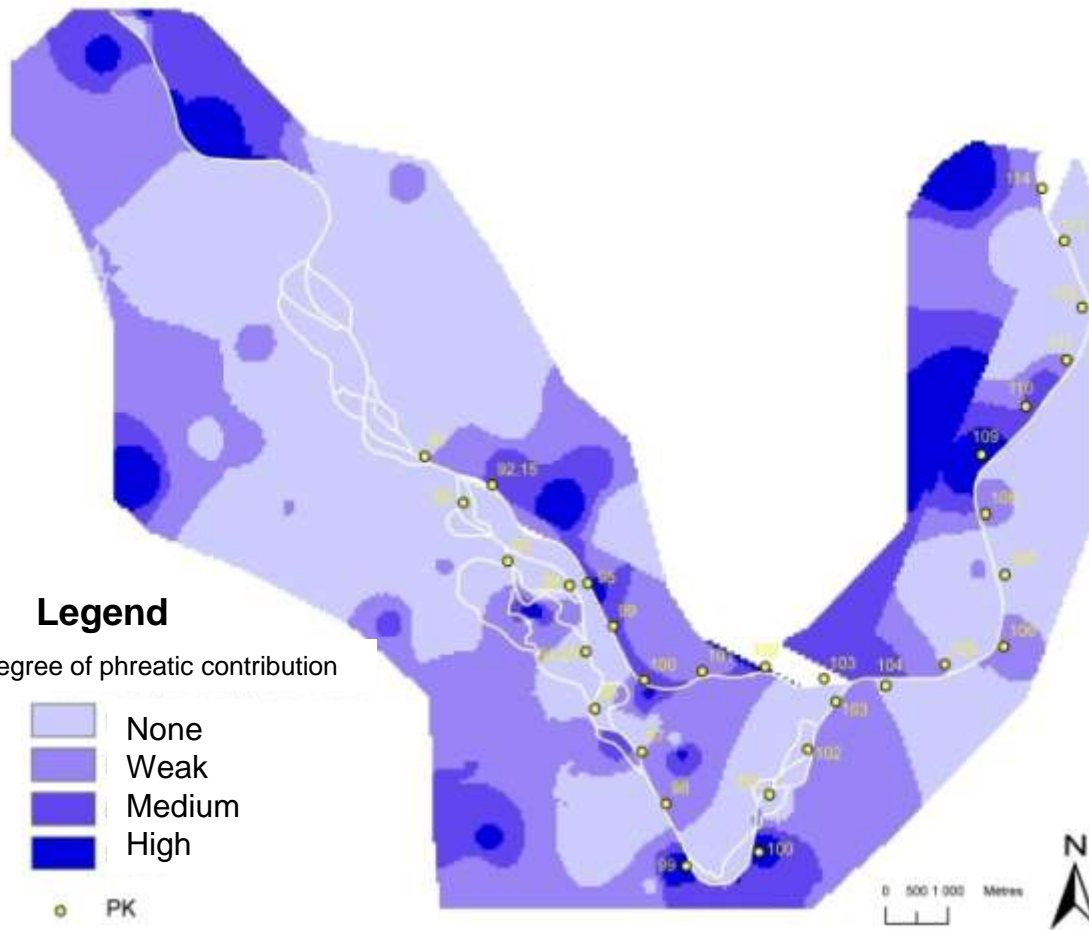
Phreatic conditions



Graeteriella unisetigera
Photo : HBES-Lyon 1

Groundwater infiltration & hydrological exchanges

Comparison with Biological Markers



Trophic degree
oligotrophic,
mesotrophic,
eutrophic
+
Thermal variability



Aquatic vegetation
Macrophytes



**Groundwater
infiltration**

Legend

Degree of phreatic contribution



PK

9

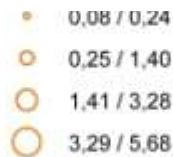
Comparison with Biological Markers

% stygobionts



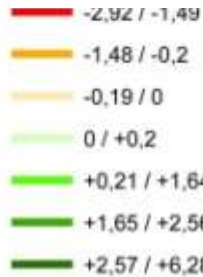
Legend

GW flow m³/day
K= 10⁻³ m/s A=4m²



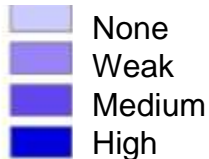
GW flow m³/day
K= 10⁻³ m/s A=4m²

- : from SW to GW
+ : from GW to SW



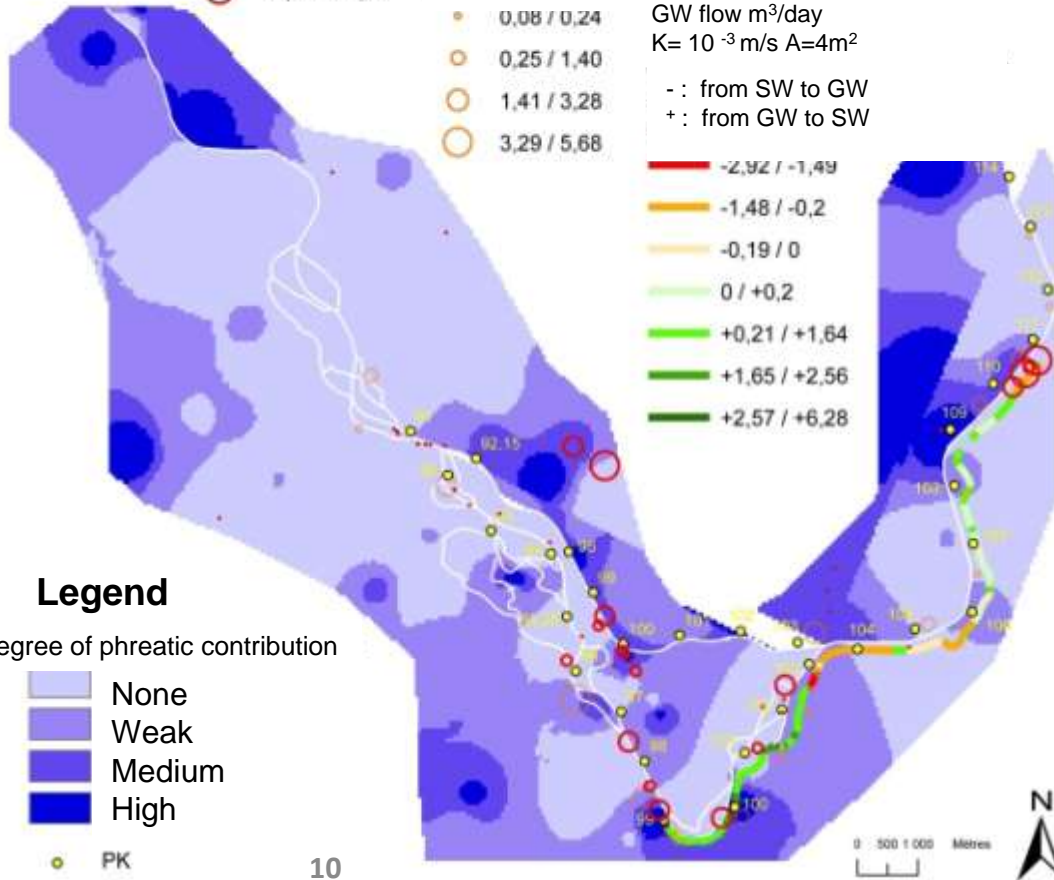
Legend

Degree of phreatic contribution



PK

10



3 metrics:

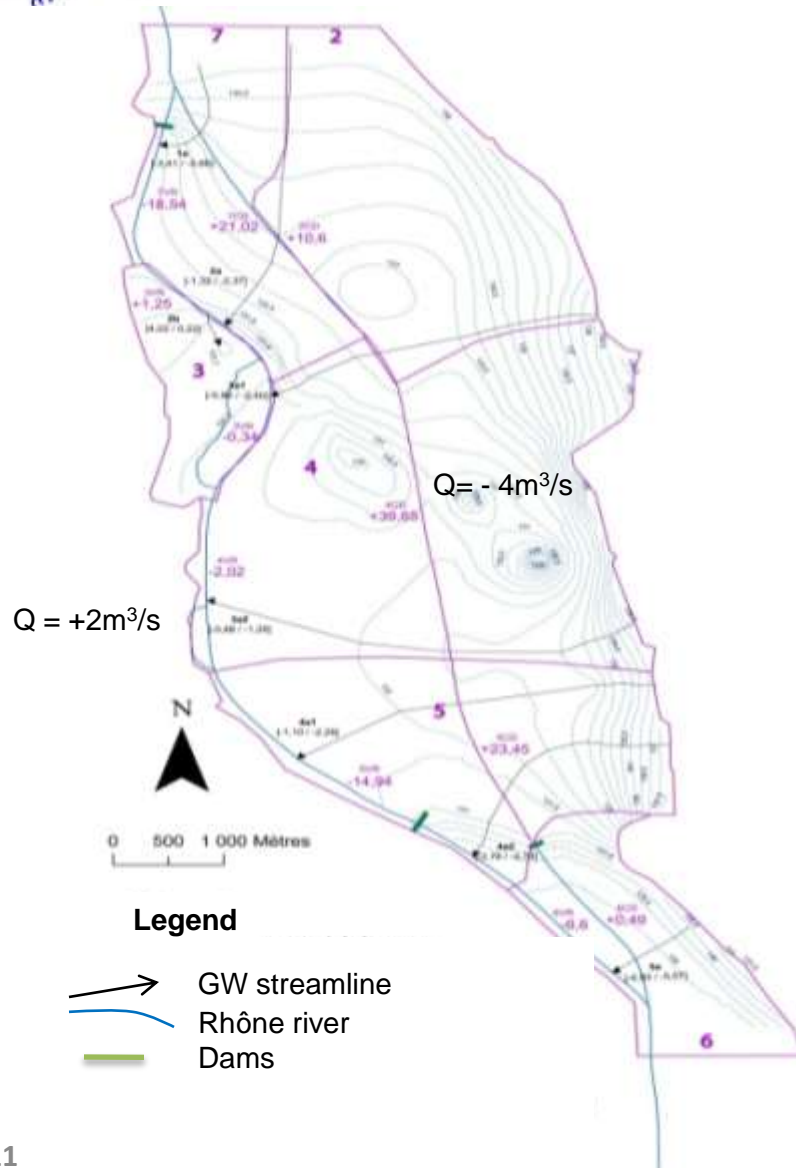
- 1) Hydrophysics
- 2) Aquatic vegetation
- 3) Subterrean invertebrates



Confirmation of exchanges between Groundwater and surface water

GIS Mapping

Comparison with Groundwater Modeling



Finite Differences 2D model implemented with Modflow on this river section

Cauchy condition

$$Q = \frac{(H_{sw} - H_{gw})}{C}$$

Q (m^3/s): infiltration flow

H_{sw} (m): surface water level

H_{gw} (m): groundwater level

C (s/m^2): resistance of the bank



Validation of exchanges between Groundwater and surface water



Results

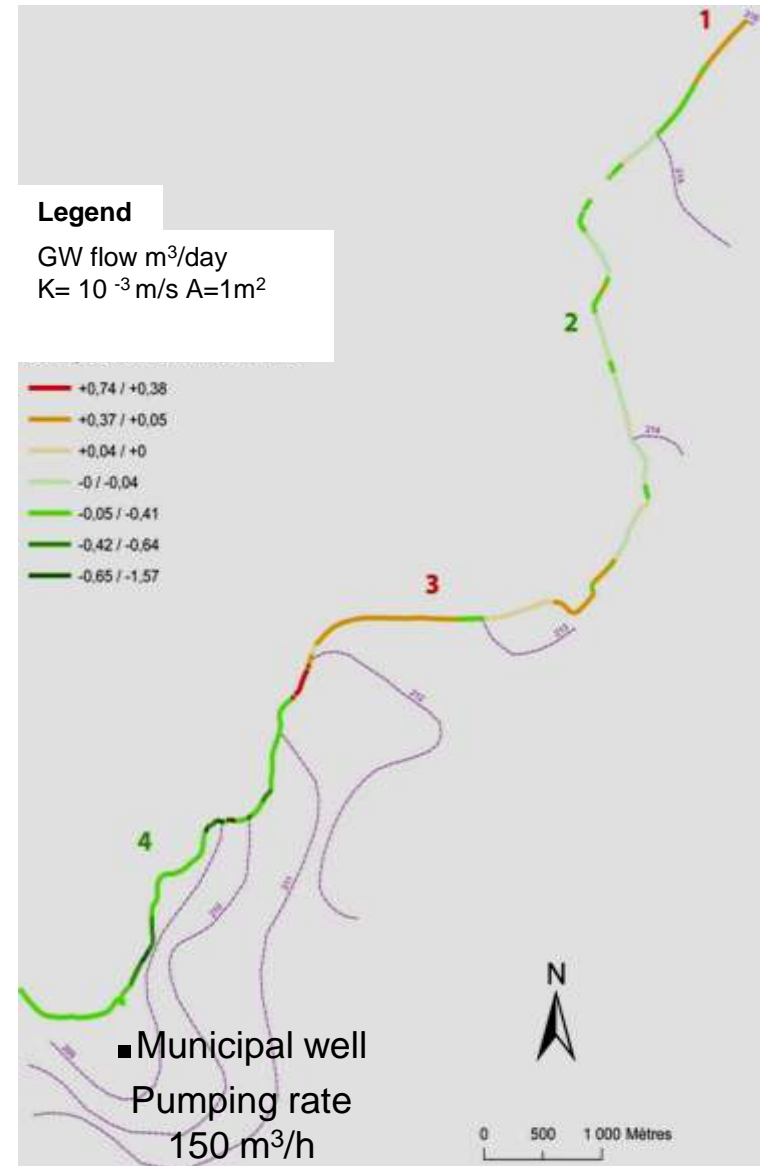
Upstream of this section :
groundwater discharge
limited to **160 m³/day** per km

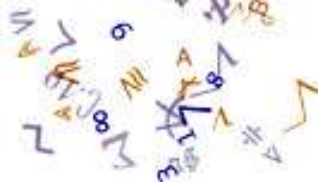
Downstream of this section:
The flow of groundwater into the
channel beneath the river is higher
1680 m³/day per km



***European Water Framework
Directive:***

**additional harvesting for potable
water or irrigation is not possible
in these catchment areas**





Method Limitation and Accuracy

Heterogeneities in the alluvial aquifer
Possible clogging of the banks

.....disturb the hydraulic diagnosis

Biological field sampling procedures

.....induce errors

Comparison with Biological Markers

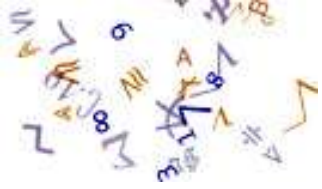
..... vegetal species not always available at different latitudes

Complementary isotopic analysis
and environmental tracers (Cl^- , $\delta^{18}\text{O}$ and $\delta^2\text{H}$)



Future Research

- 1) Confirmation on other Rhône sections** (latitude, climate, geological context and anthropic conditions).
- 2) seasonal variations** (low-flow period, high flow period)
- 3) Modifications** of the hydraulic exchanges **induced by climate changes**
- 4) Potential application on other rivers** : Danube, Murray River, Snake River



Conclusions

Biological markers aid in assessing GW/SW interactions

Combination of hydraulic and biological metrics:

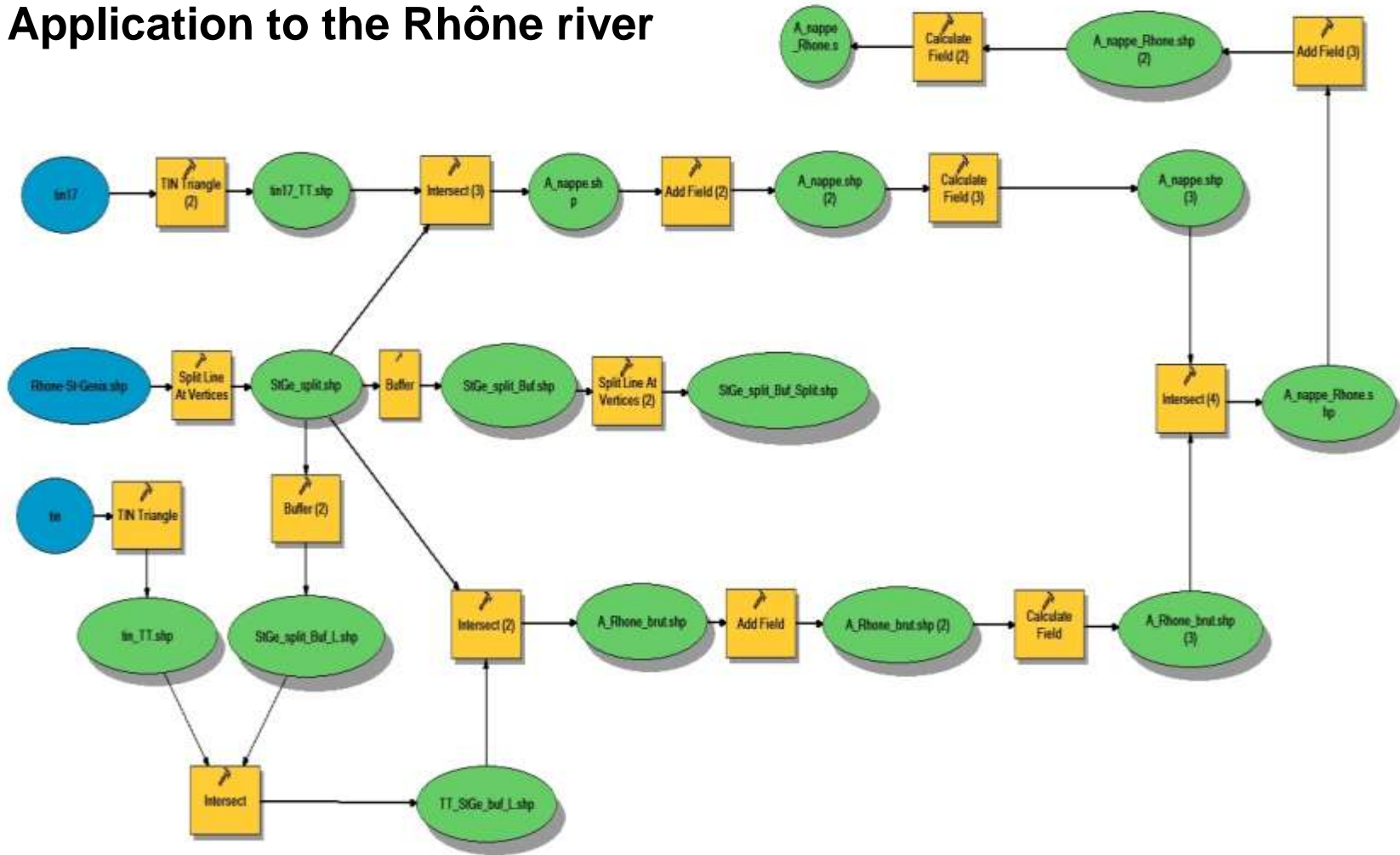


**An innovative and holistic modeling approach
at the scale of a river basin**

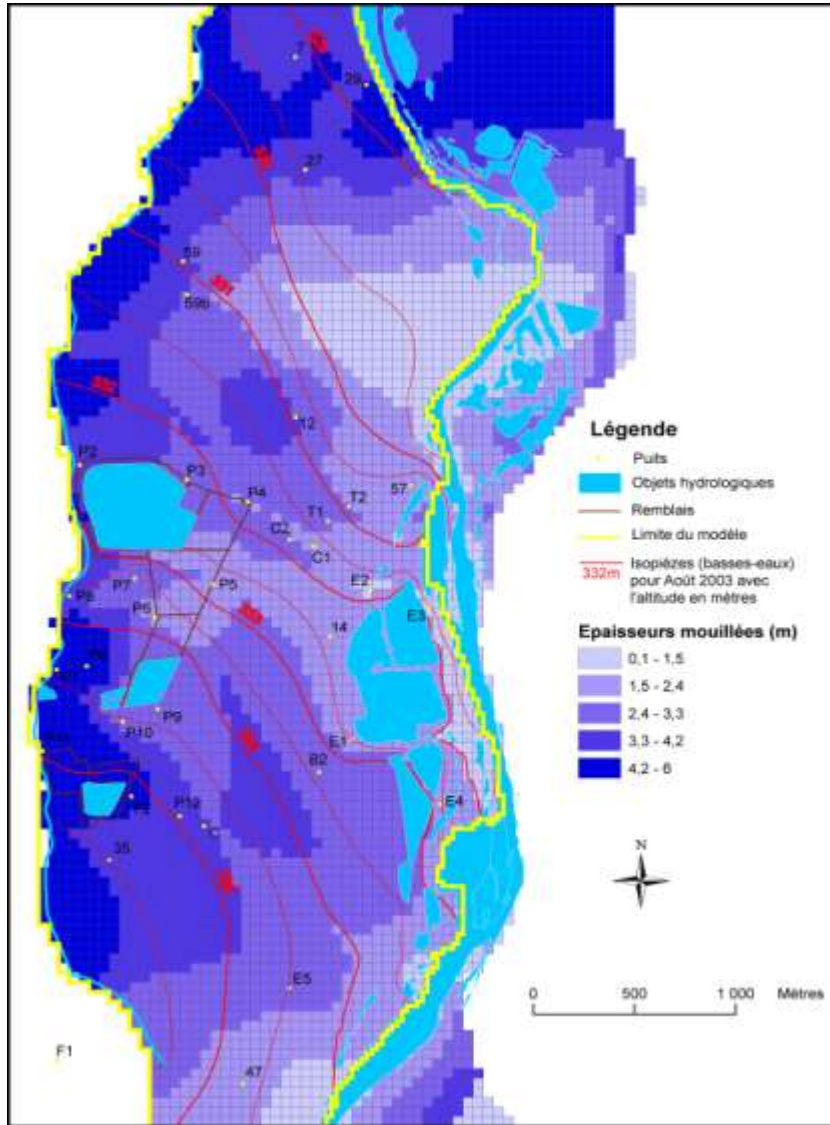
Acknowledgment: This research program is supported by the French Water Agency of Rhône-Méditerranée-Corse with the collaboration of the National Company of Rhône.

ADDITIONNAL SLIDES

Dynamical model dedicated to GW / SW Exchanges Application to the Rhône river



Comparison with Groundwater Modeling



Finite Differences 2D model implemented with Modflow on this river section

Cauchy condition

$$Q = \frac{(H_{sw} - H_{gw})}{C}$$

Q (m^3/s): infiltration flow

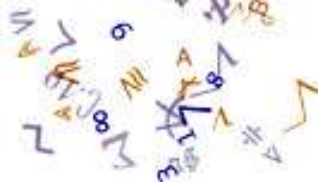
H_{sw} (m): surface water level

H_{gw} (m): groundwater level

C (s/m^2): resistance of the bank



Validation of exchanges between Groundwater and surface water



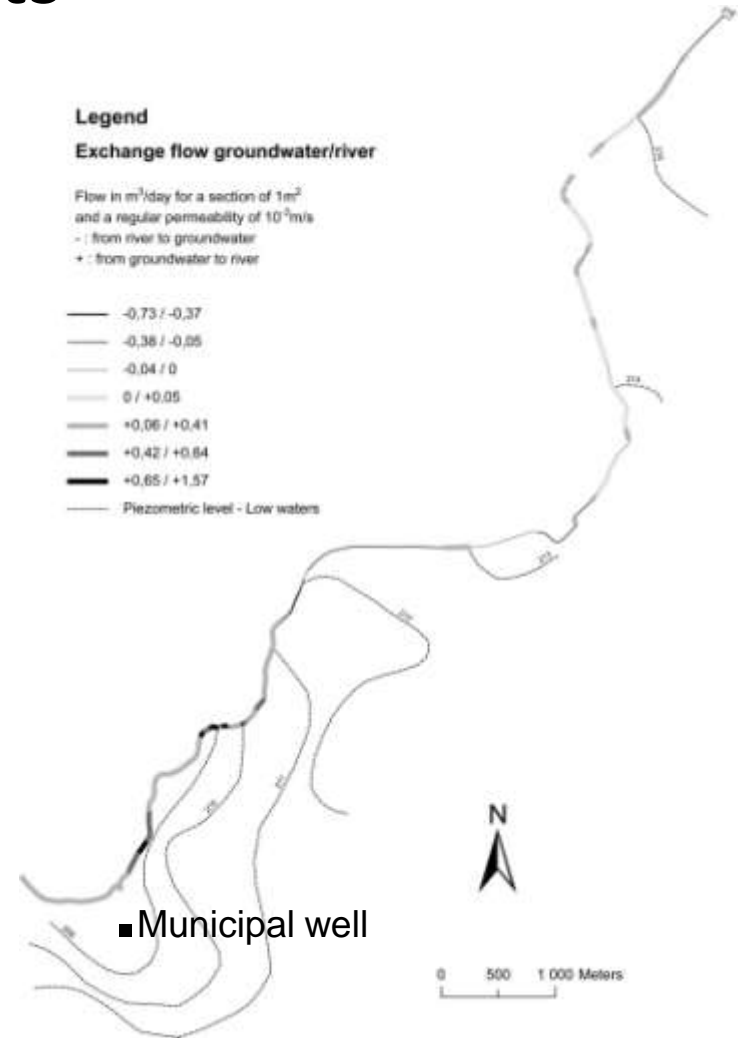
Results

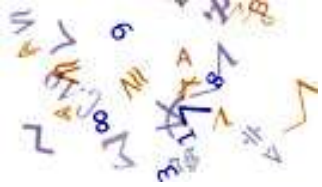
Upstream of this section :
groundwater discharge limited to
100 l/s per km
(350l/s along 7.5 km)

Downstream of this section:
The flow of groundwater into the
channel beneath the river is higher
(660 l/s per km).



***European Water Framework
Directive:***
**additional harvesting for potable
water or irrigation is not possible
in these catchment areas**





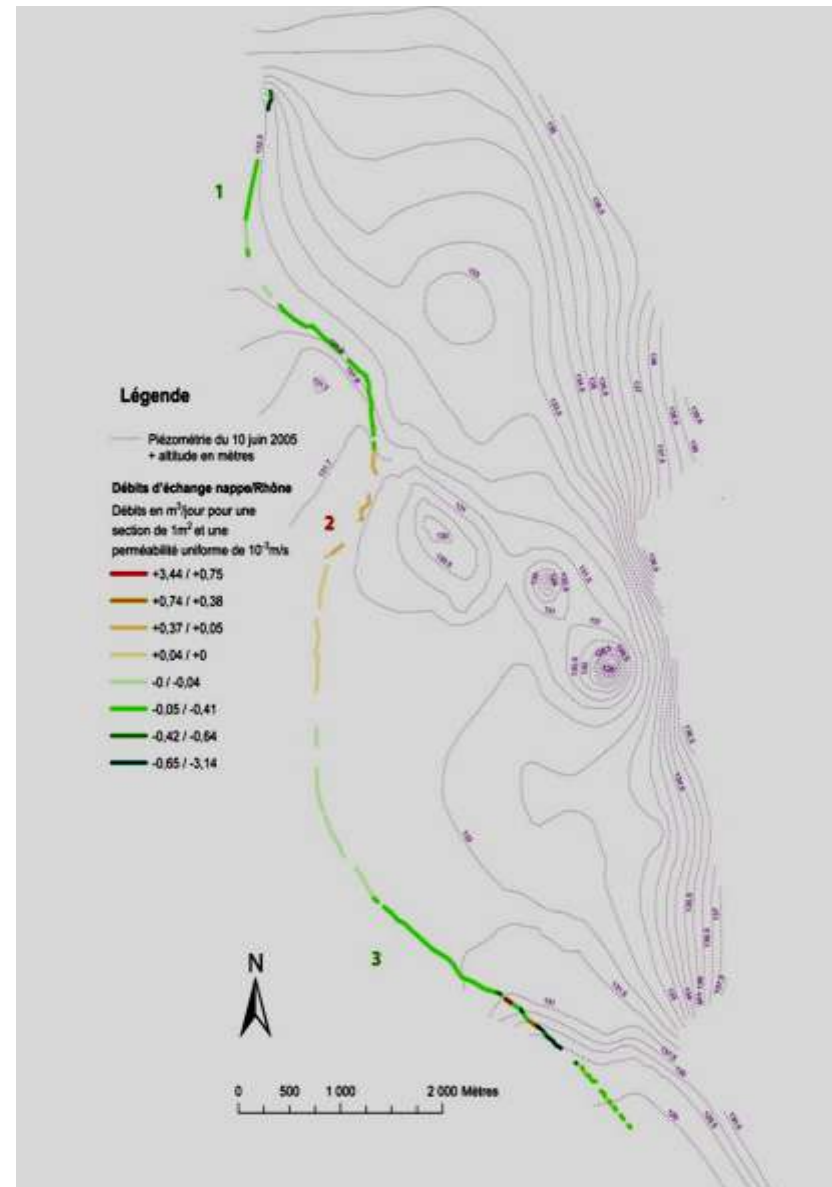
Results

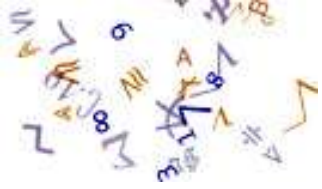
Upstream of this section :
groundwater discharge limited
to **200 m³/day** per km

Downstream of this section:
Groundwater discharge is
higher : **2500 m³/day** per km

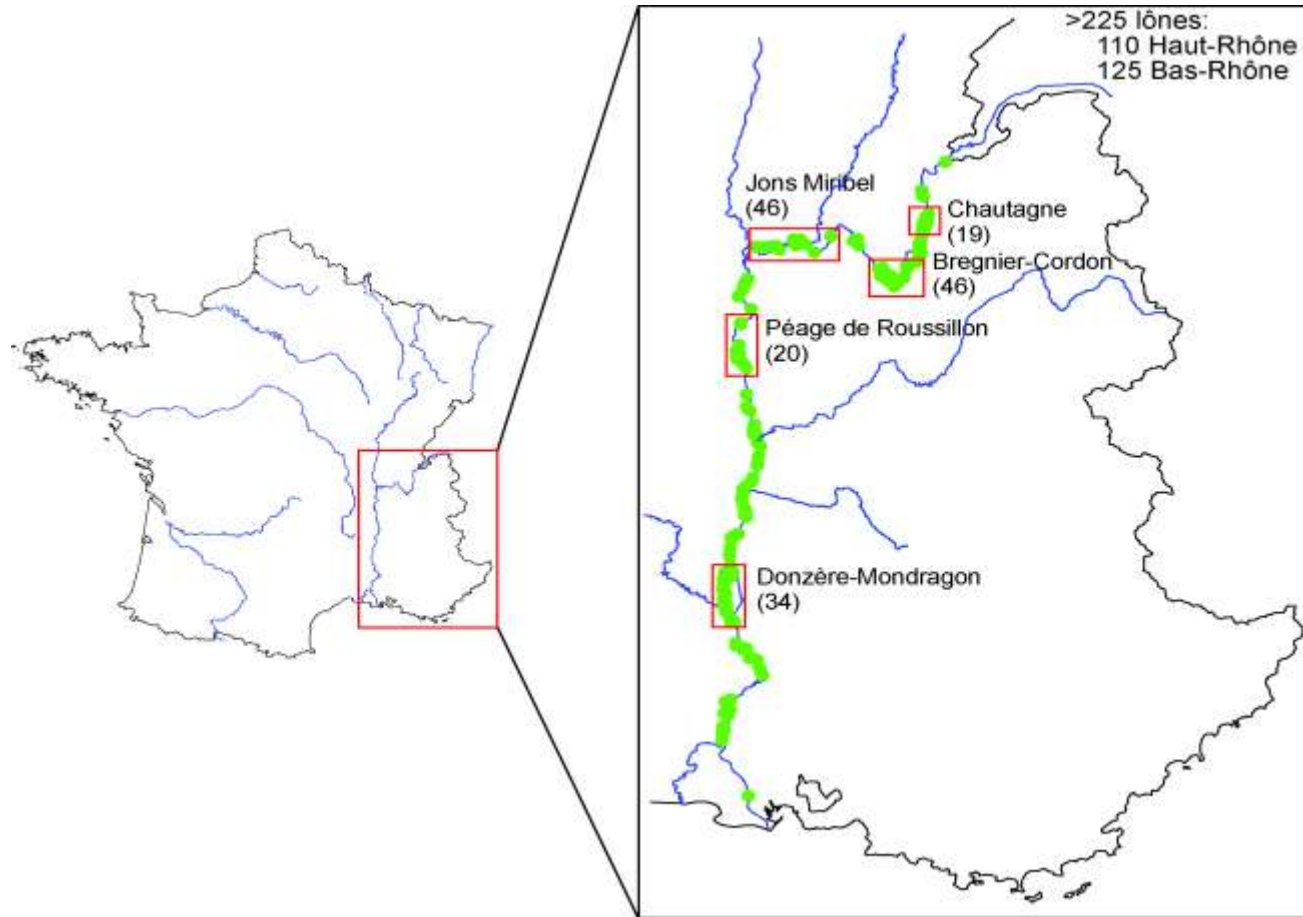


***European Water Framework
Directive:***
additional harvesting for
irrigation is prohibited at
upstream but possible
downstream





ADDITIONNAL SLIDES



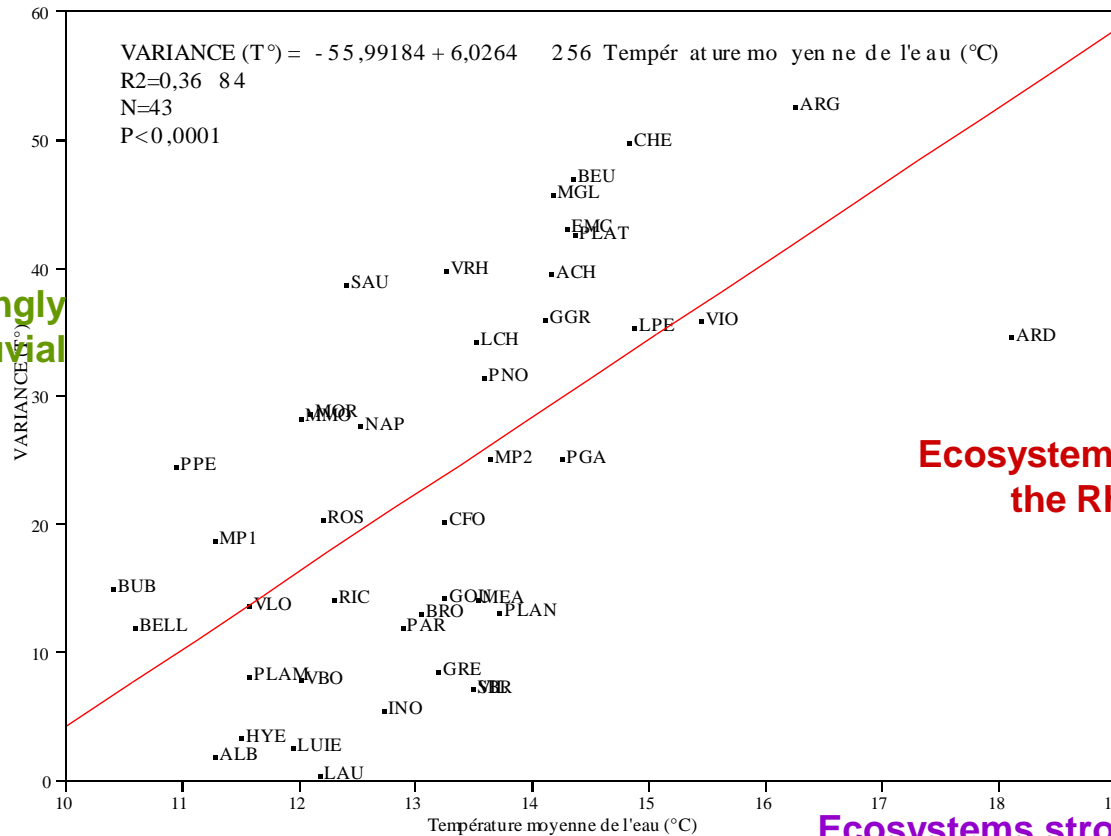
Biological Markers: aquatic vegetation

ADDITIONNAL SLIDES

Thermal variations : intensity of deep groundwater exchanges (Rivoire & Bornette 2006)

Ecosystems strongly influenced by alluvial aquifers

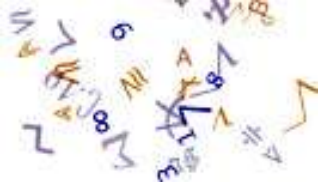
Ecosystems connected to the Rhône river



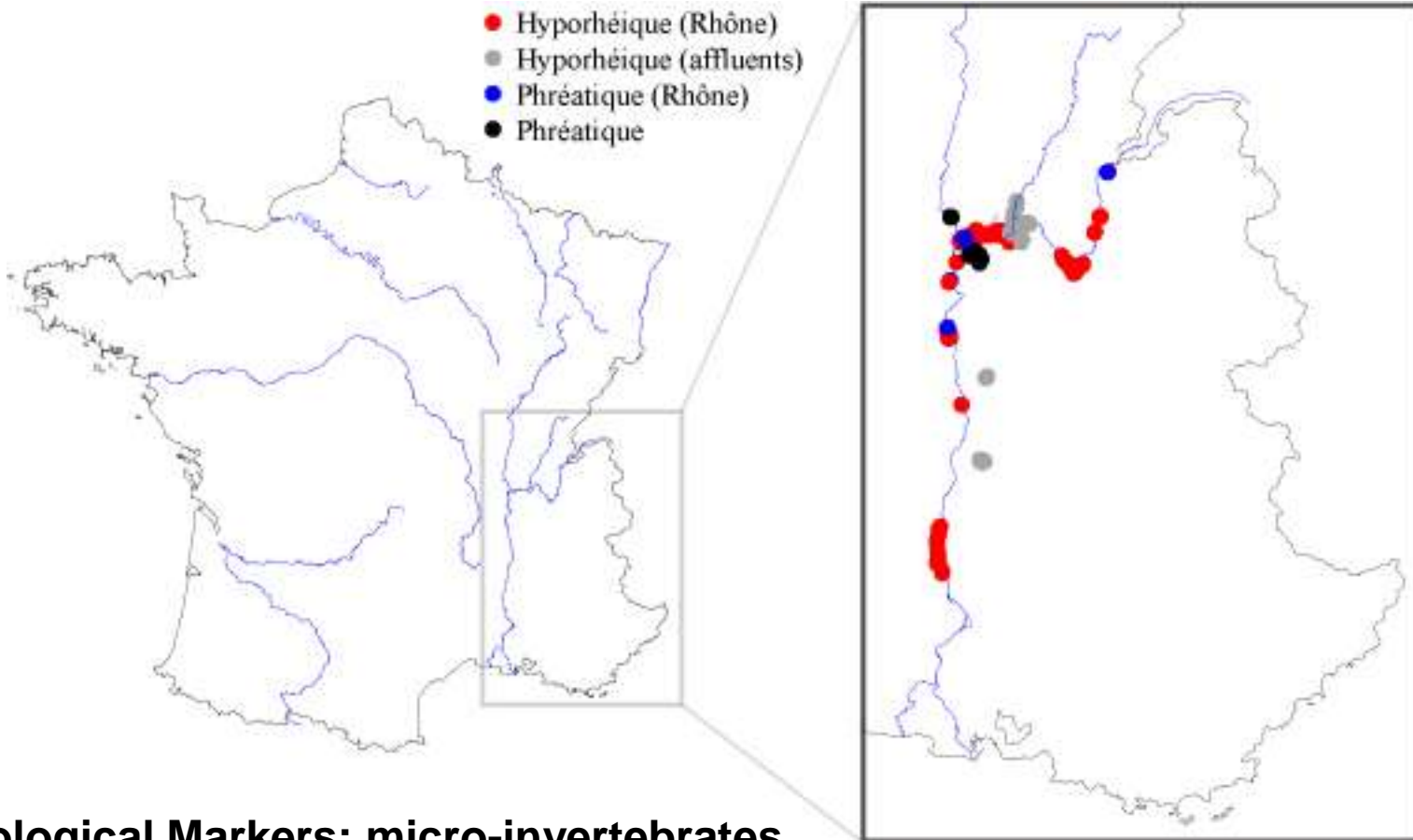
Ecosystems strongly influenced by deep aquifers

Biological Markers: aquatic vegetation

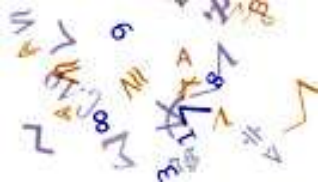




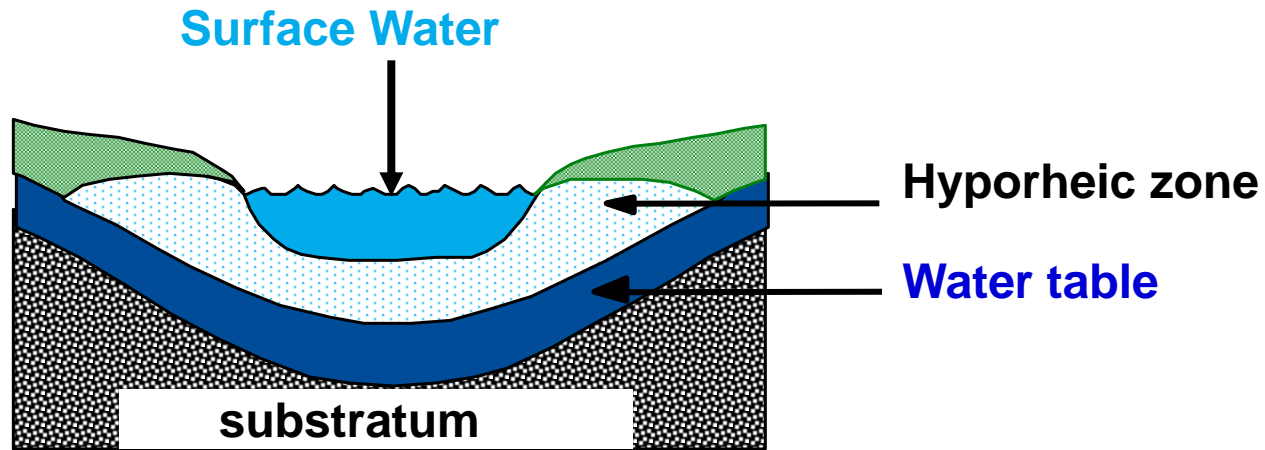
ADDITIONNAL SLIDES



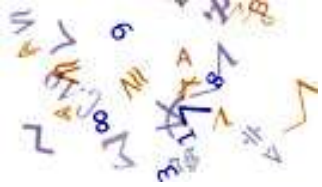
Biological Markers: micro-invertebrates



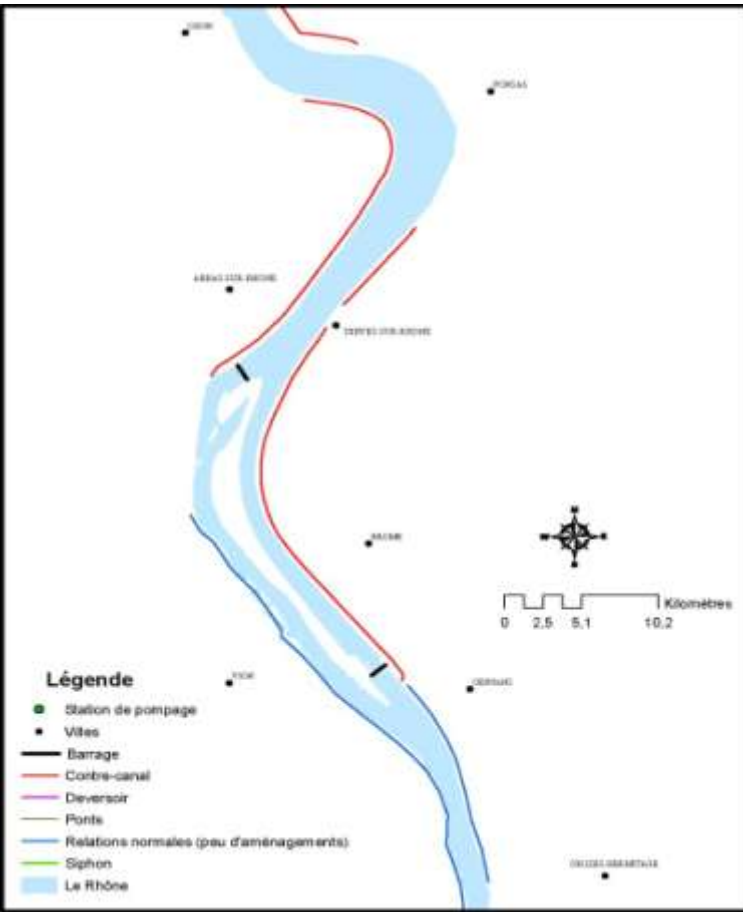
ADDITIONNAL SLIDES



Biological Markers: micro-invertebrates



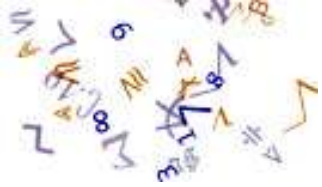
ADDITIONNAL SLIDES



Gervans Dam on the Rhône river



Influence of Dams Canals and Channels on the GW/SW exchanges



ADDITIONNAL SLIDES

Biological Markers:

Vegetal species

Phragmites australis

B : *Chara vulgaris* + *C. major*
Elodea canadensis
Sparganium emersum
Hottonia palustris
Callitriche platycarpa
Ranunculus trychophyllus

D : *Berula erecta*
Mentha aquatica
Potamogeton coloratus

Fauna

- Crustacés (Syncarida, Harpacticoida, Ostracoda, Cladocera, Amphipoda)
- Annélides (Oligochaeta, Aphanoneura)
- Nematoda, mollusca, tardigrada, Diptera, Hydracarina

52 taxons identified :
15 Hypoges et **37 Epiges**