# Regional-scale coupled modeling of water pollution by nitrate from agricultural sources

The Seine-Normandy agro-hydrosystem case study

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# PRESENTATION OUTLINE



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01

# GENERAL FRAMEWORK and objectives

# ➢ General framework and objectives

- Ambitious environmental targets set by the **EU directive** to prevent water bodies from nitrate pollution :
  - Identification of **vulnerable areas,**
  - Promotion of more **virtuous** and **efficient** farming practices.

➔ Ever-growing demand from **basin stakeholders** to be provided with elements of :

- Characterization of **N-related pressure** on **regional water resource,** (large scale / long term)
- Evaluation of **efficiency** of **alternative environmental trajectories.** (required time for **water remediation**)

**Two major prerequisites**

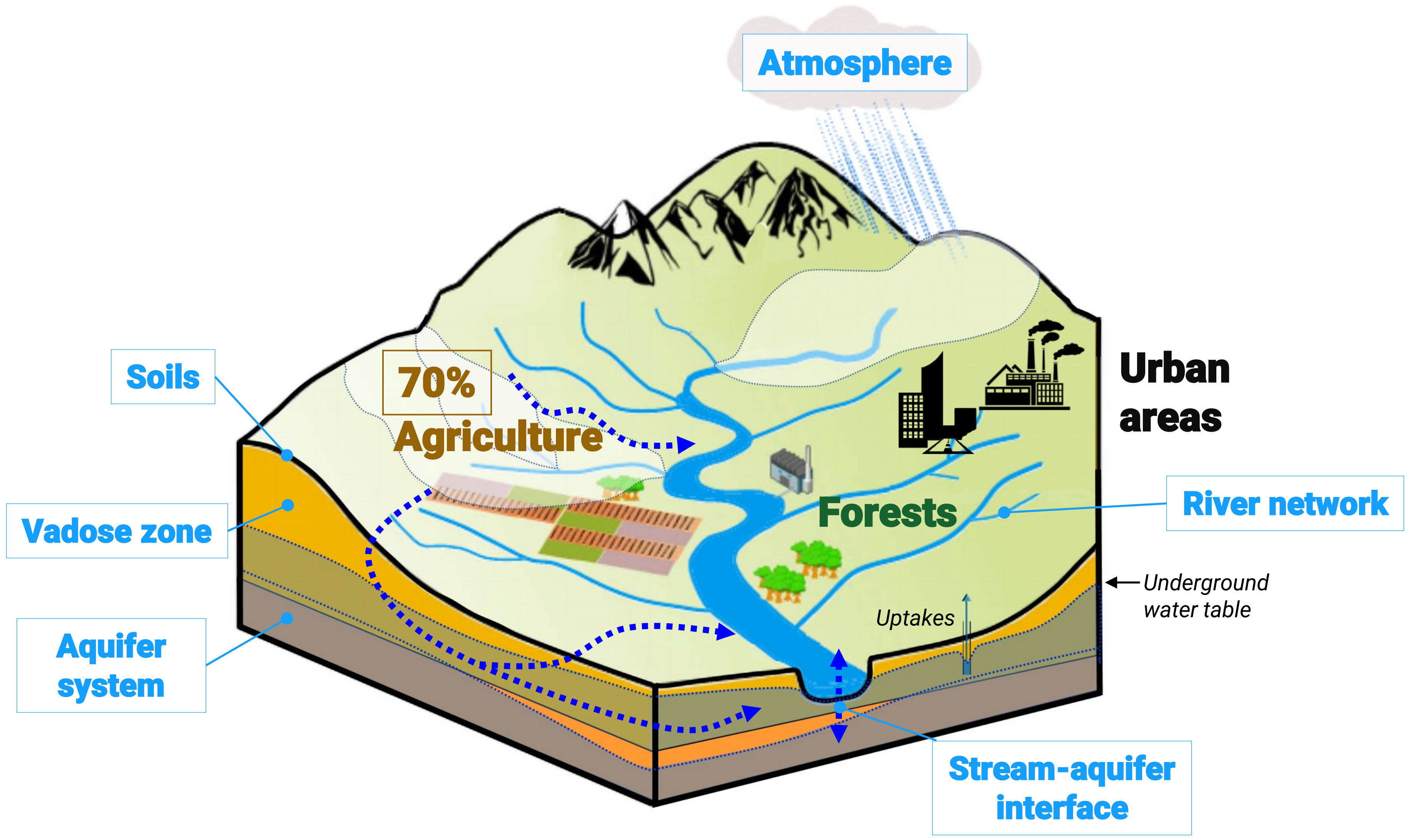
- Being able to **understand, represent and quantify** the way water and nutrients transit through a regional agro-hydrosystem.

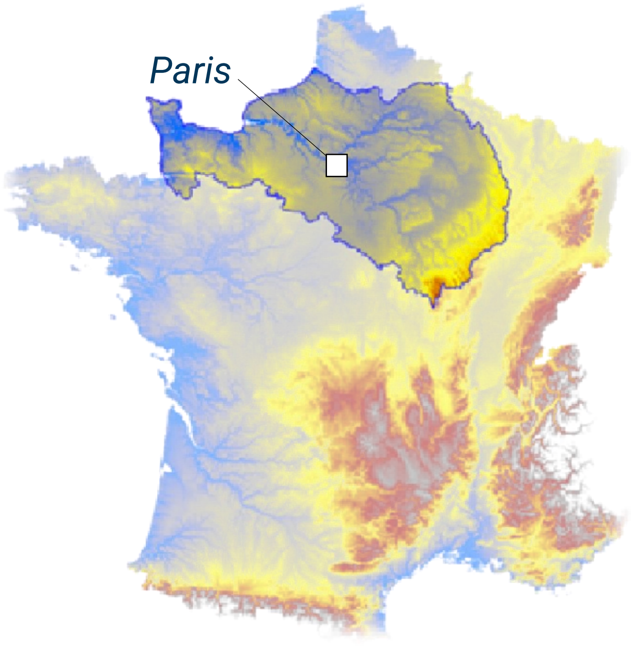
  = physical and biochemical processes involved in nitrogen transfer.

- Having a **precise knowledge** of the system's **constraints**.

  = dependencies on changes **with time and space** in cropping systems, soil, climate, hydrogeological and hydraulic boundary conditions.

# ➢ The Seine-Normandy basin : a regional water *continuum*

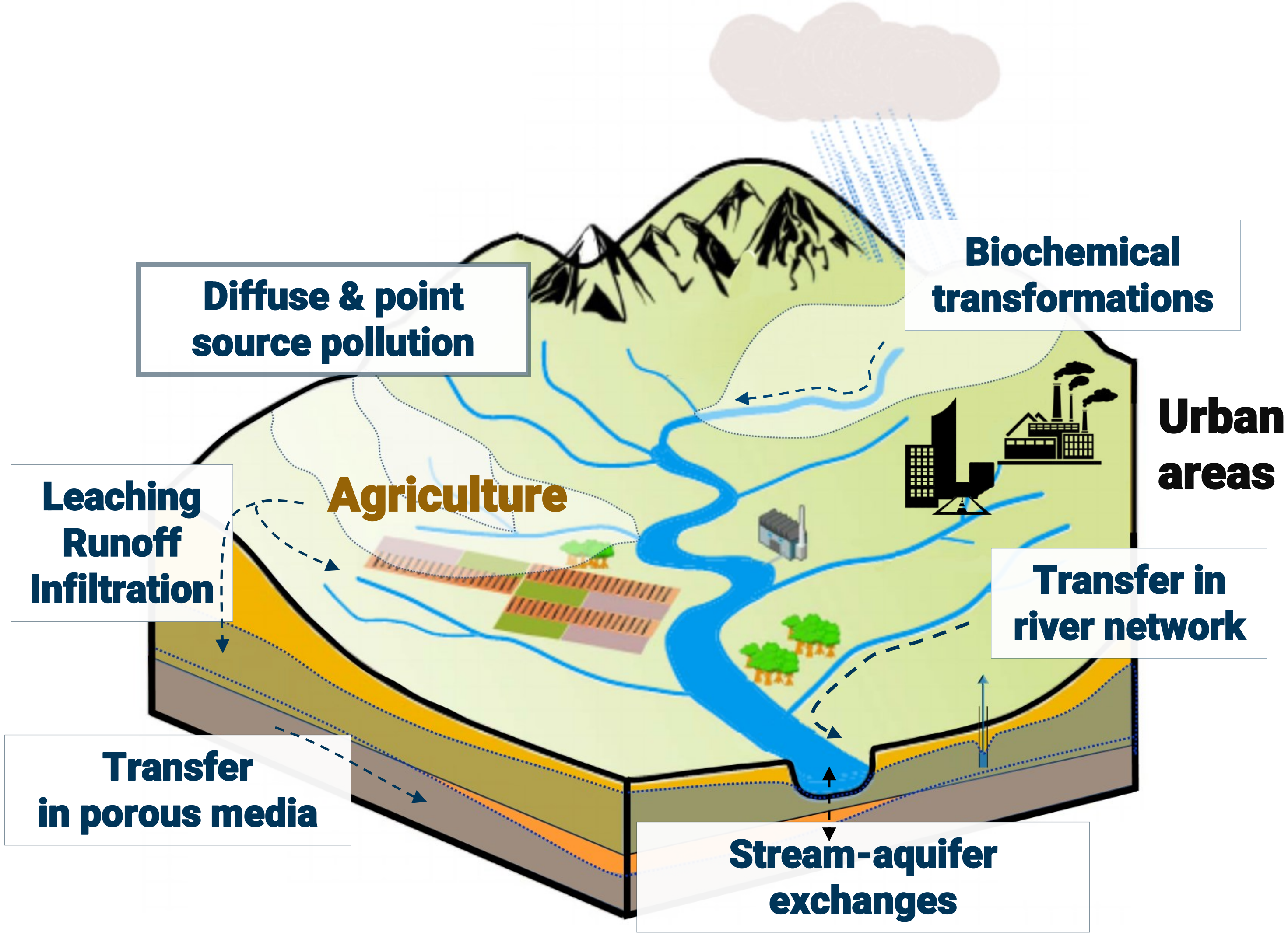



**~ 100 000 km²**

**~ 58 000 km-long river system**

# ➢ The Seine-Normandy basin : a regional water *continuum*




- **Matching interactions** with :
  - dedicated databases
  - model parametrization
  - modeling requirements
- **Multidisciplinarity**

**=**
**A fully integrated modeling approach**

3 linked models

**STICS** → **CaWaQS** → **RIVER-STRAHLER**

# ➢ A multidisciplinary and inclusive research project

- Simulating the **integrated behavior** of a **highly-anthropized** regional agro-hydrosystem
- Allowing a **spatialized and quantitative evaluation** of possible forecast scenarios

= **Evaluation tool** for direct impacts and effects **due to global changes**

**Water cycle**

**Water quality**

**Nutrients** fluxes (Si, P, etc.).

**Pollutant** fluxes (N, pesticides, etc.)

**INRAE**, SAD-Aster, Mirecourt
**INRAE**, UR Agro-Impact, Laon
**INRAE** Infosol, Orléans

**ARMINES – Mines Paris, Centre de Géosciences**
PSL Université, Fontainebleau

**Sorbonne Université**, UMR METIS, Paris
**FIRE**, CNRS, UMR METIS, Paris

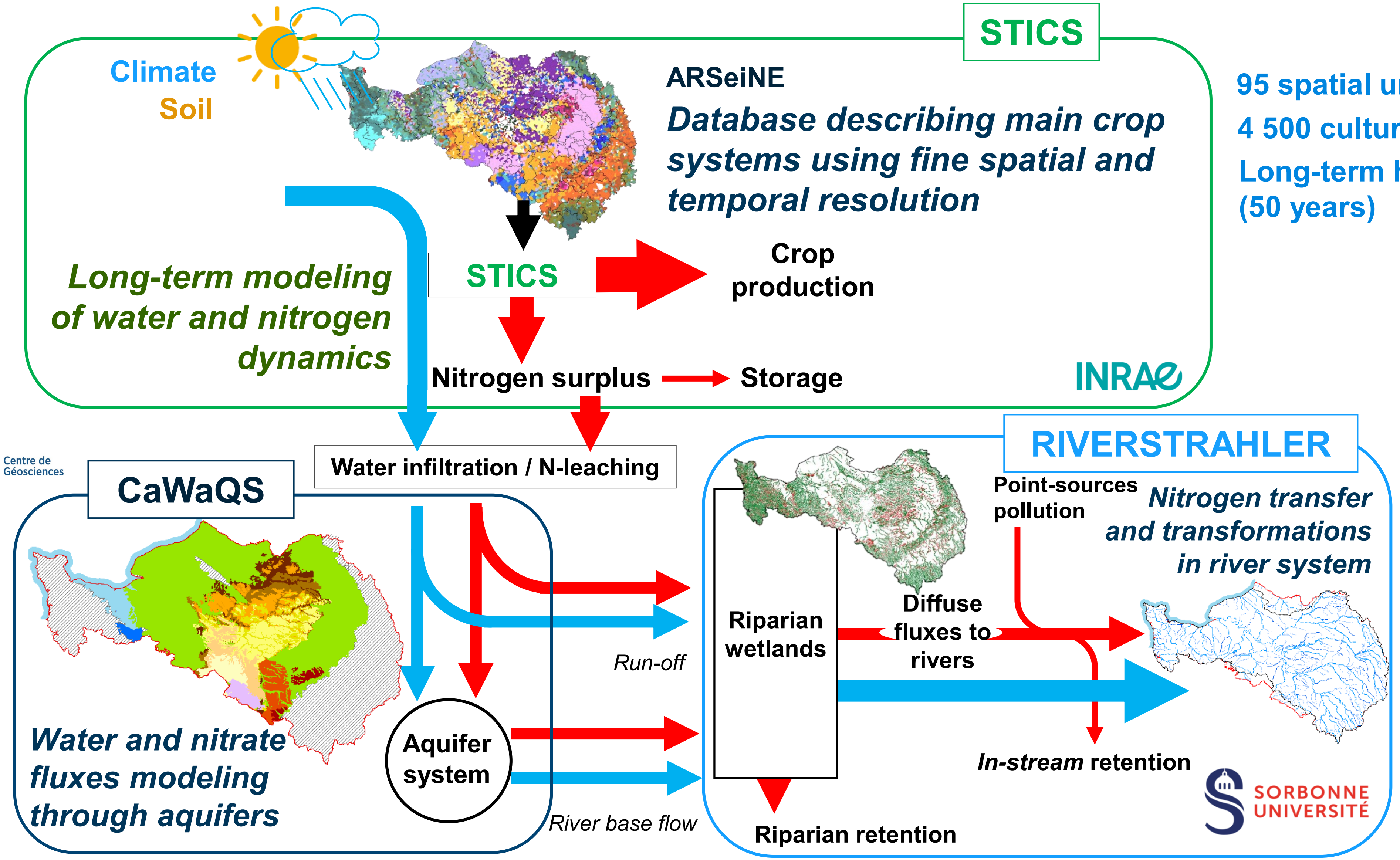
**Agence de l'Eau Seine-Normandie (AESN)**

02

# LARGE-SCALE MODELING

## Tools and methodology

# ➢ A multi-model platform




95 spatial units

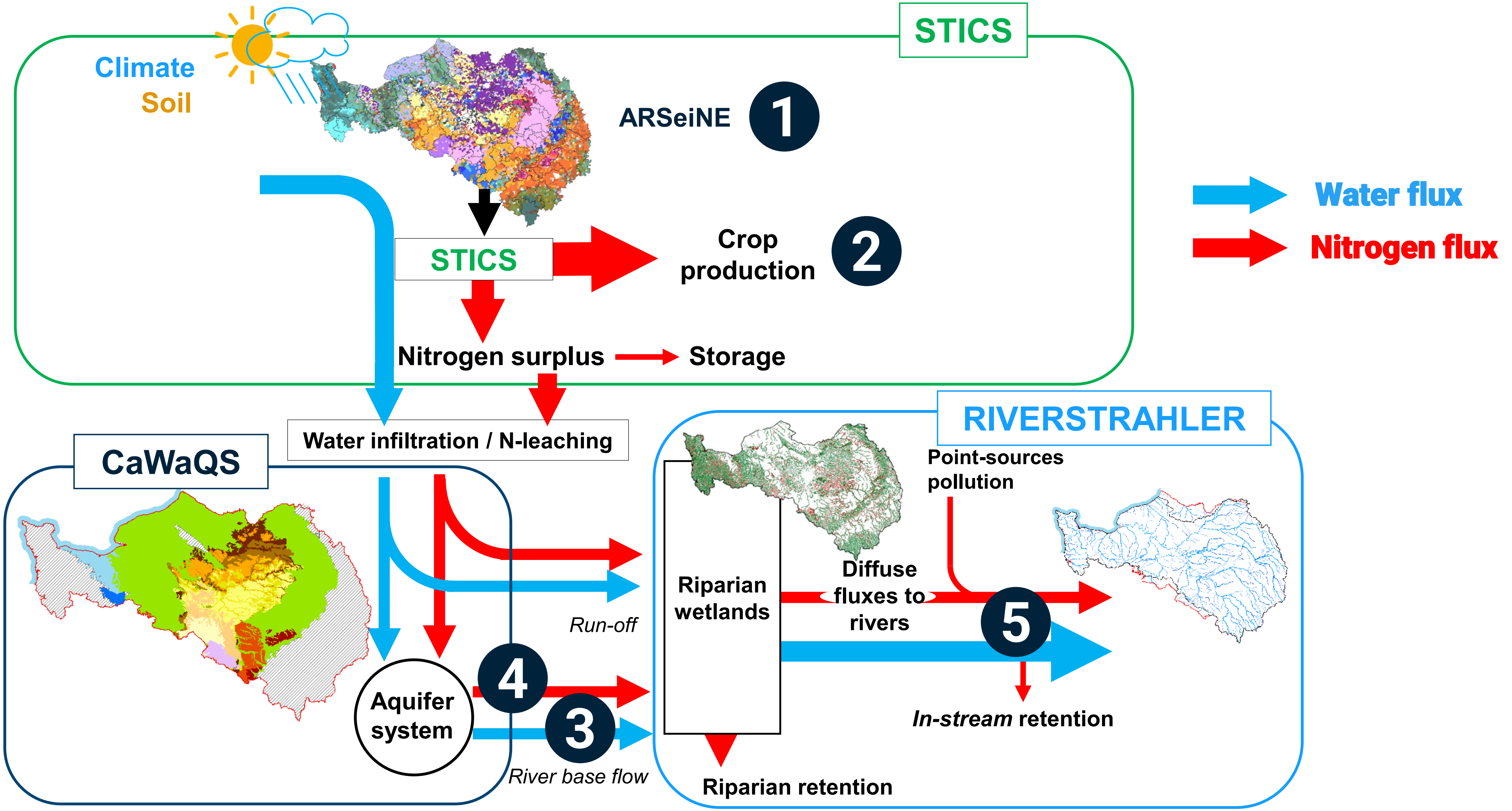
4 500 cultural systems

Long-term hindsight (50 years)

Water flux

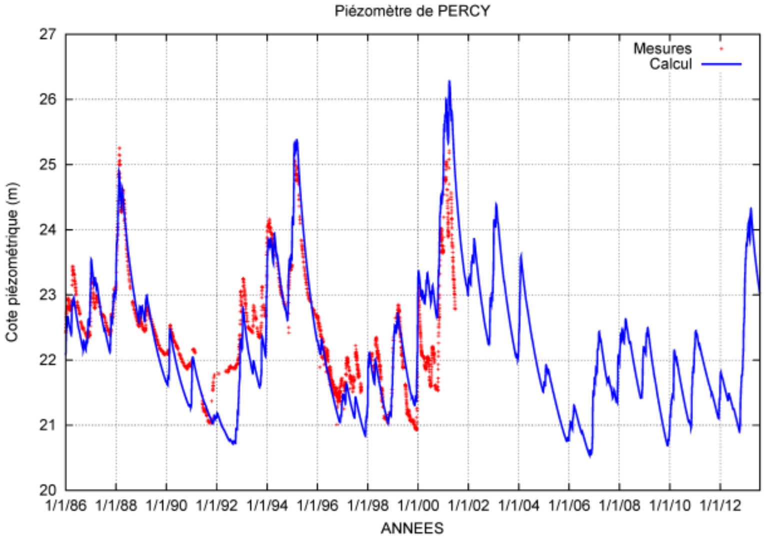
N flux

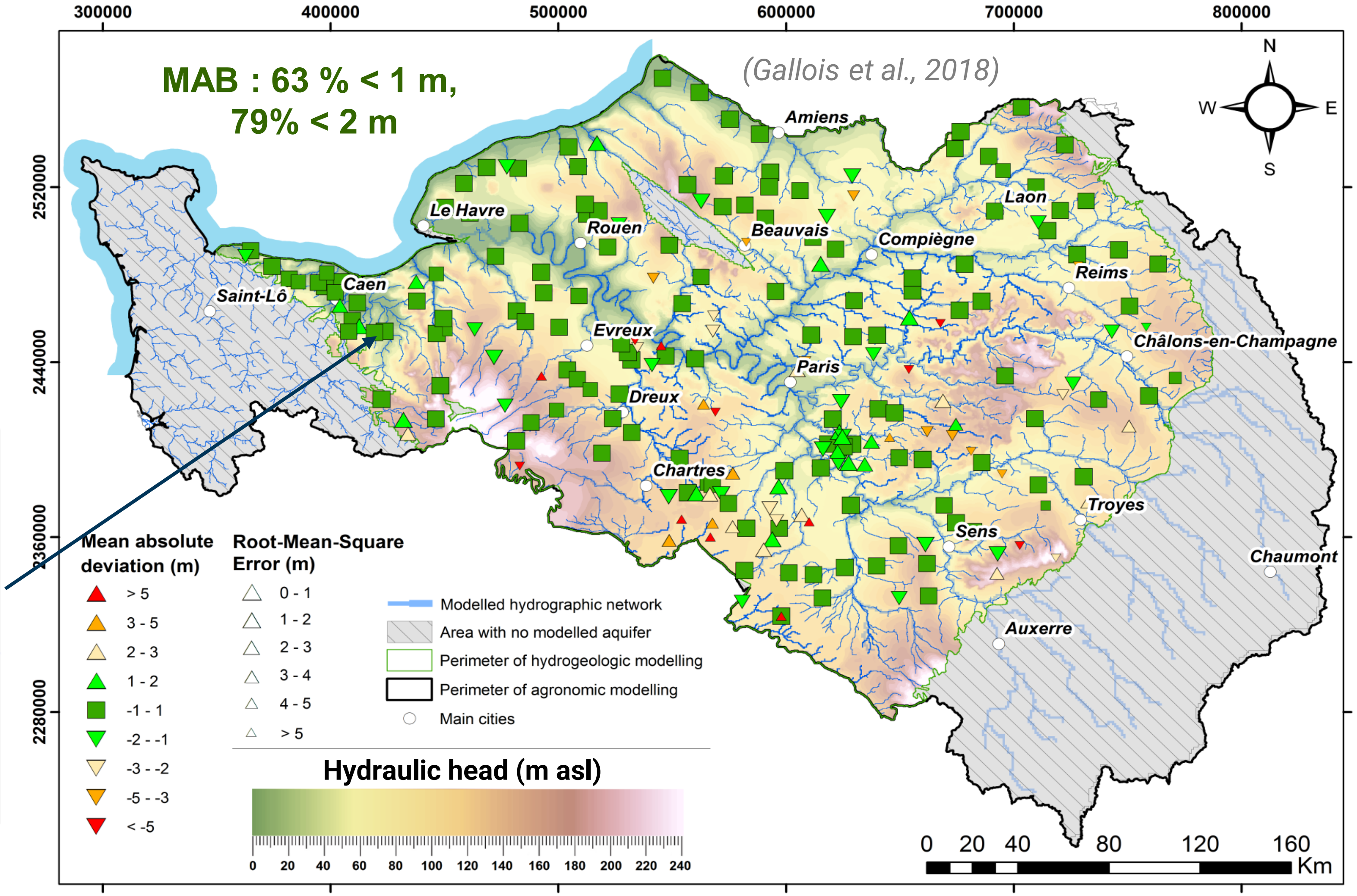
# ➢ 5 retrospective validation levels



# ➢ Retrospective validation of the platform (1970-2018)

**3** **Water dynamics** in **aquifer system =** Direct validation against measured **hydraulic head** data (~ **250** sites).



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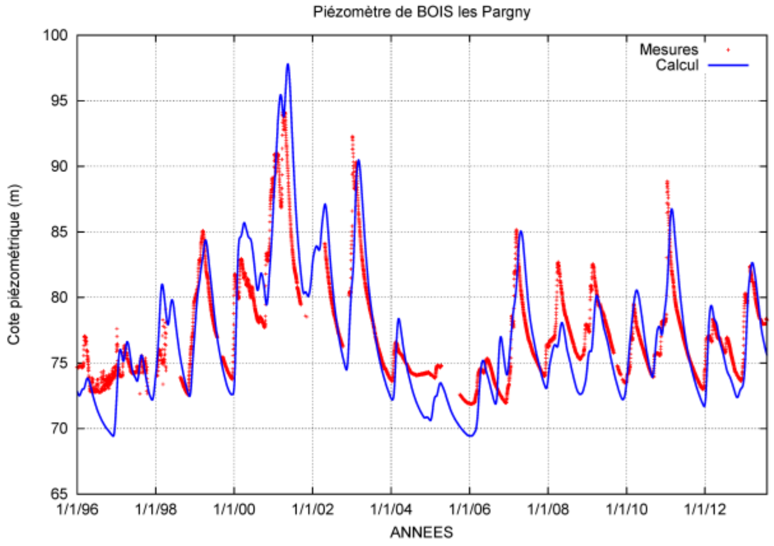


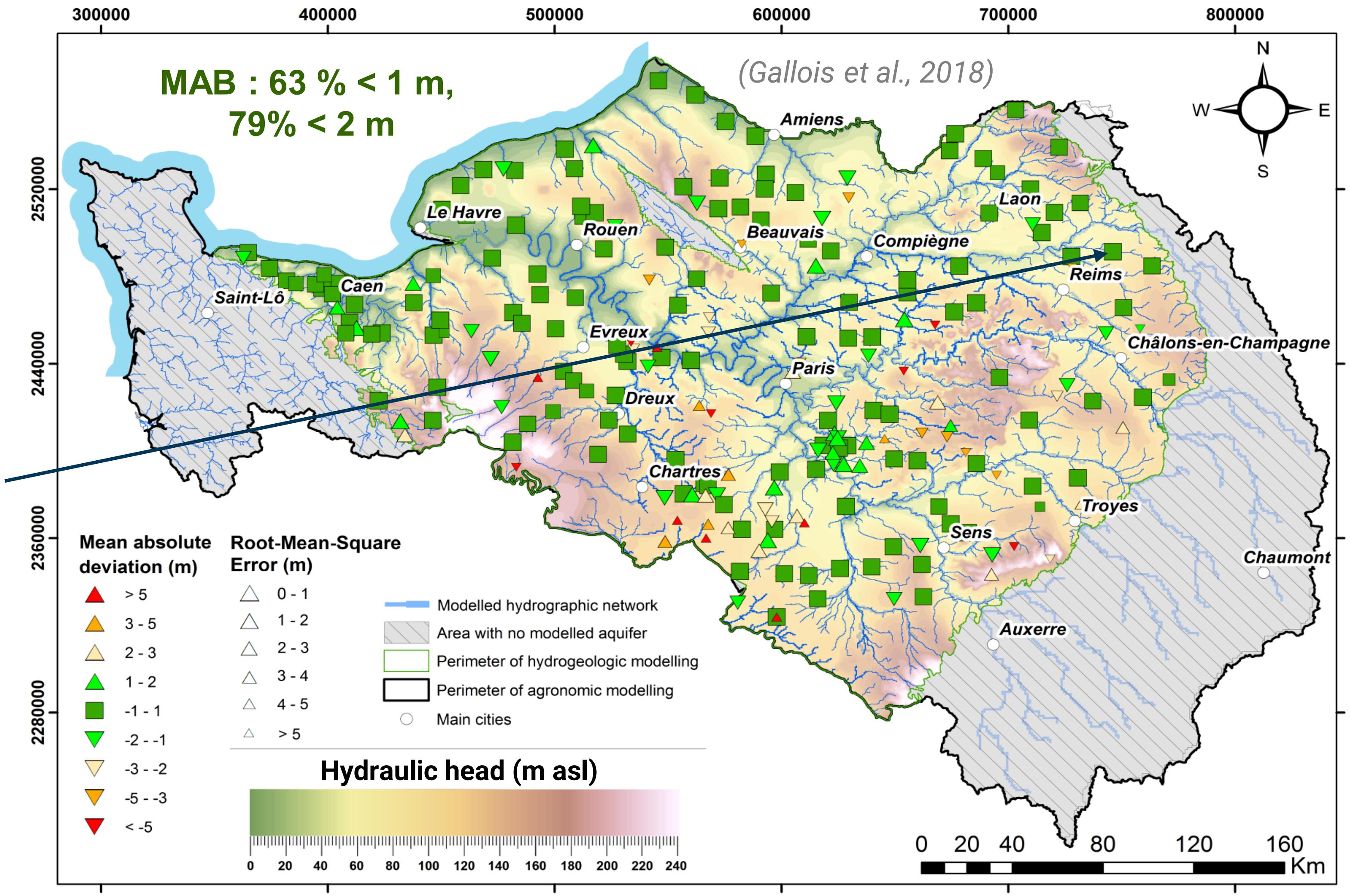

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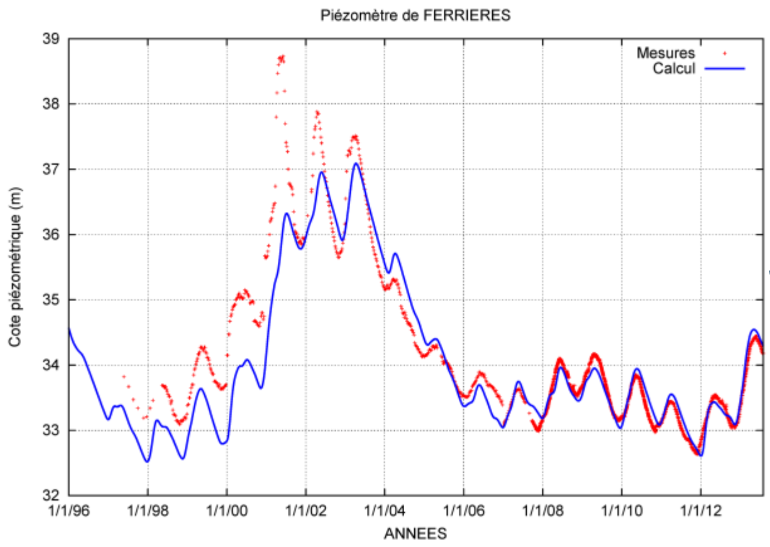


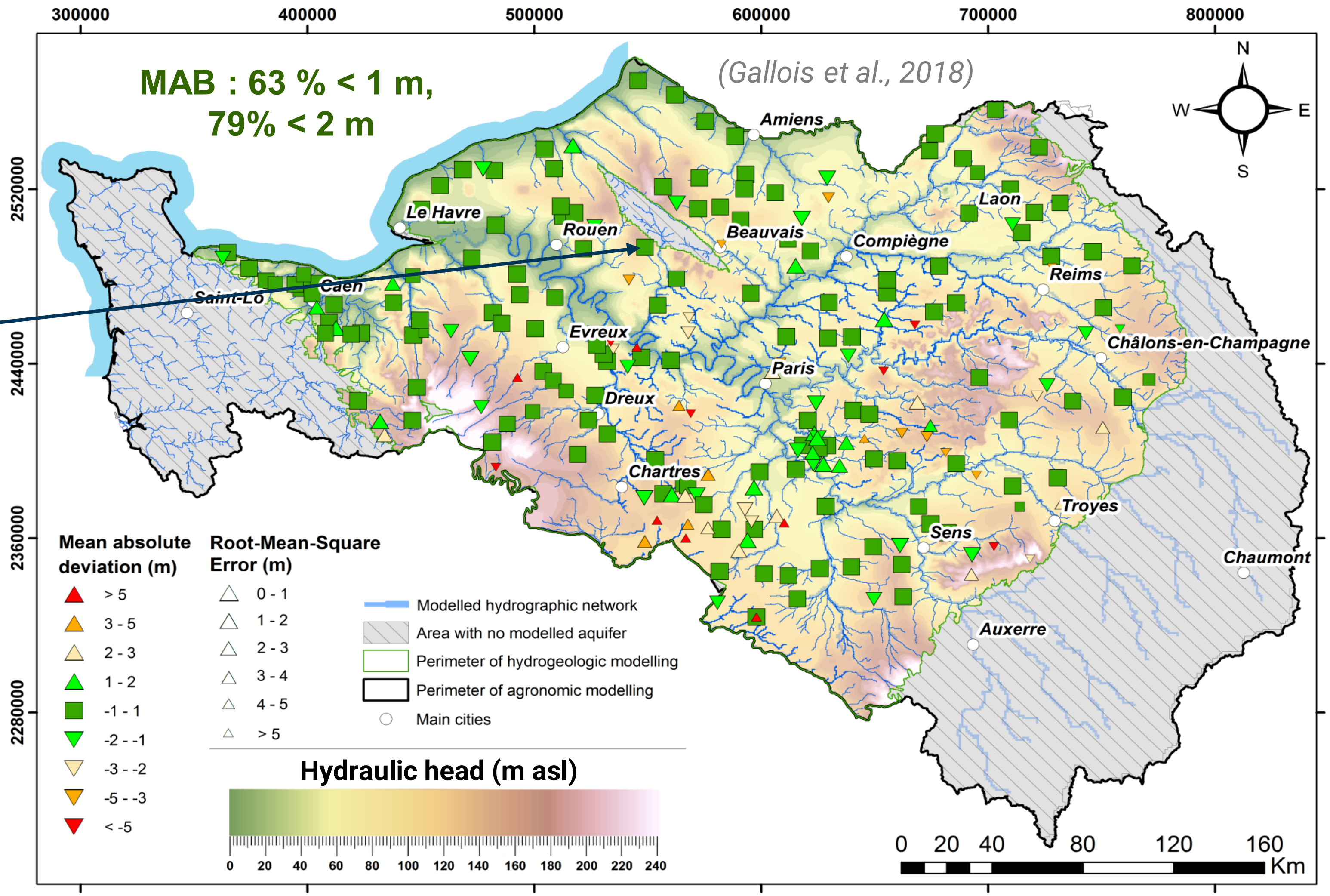

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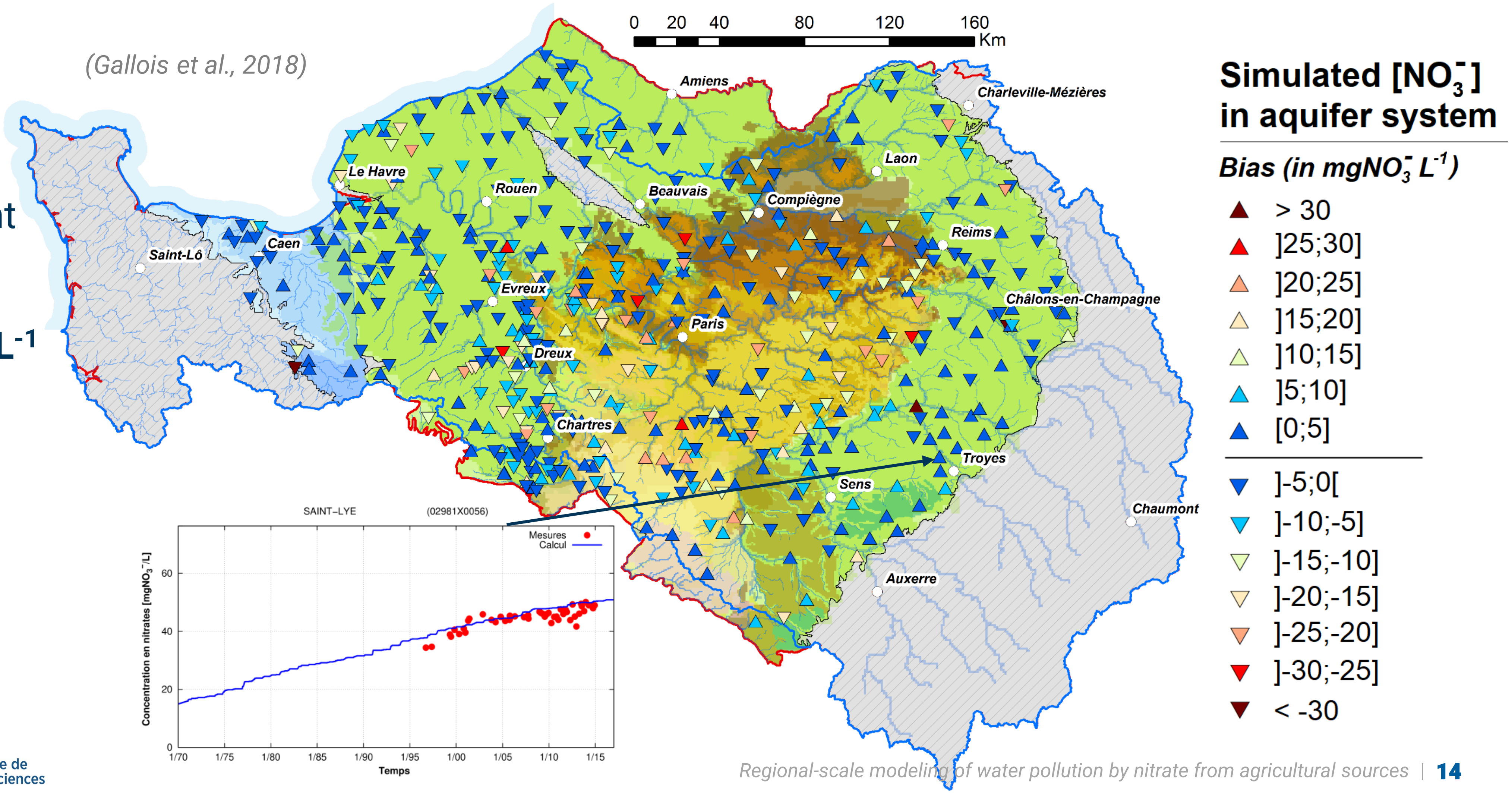
**> 2/3** of measurement wells with bias **lower than 5 mgNO$_3^-$ L$^{-1}$**

(Gallois et al., 2018)

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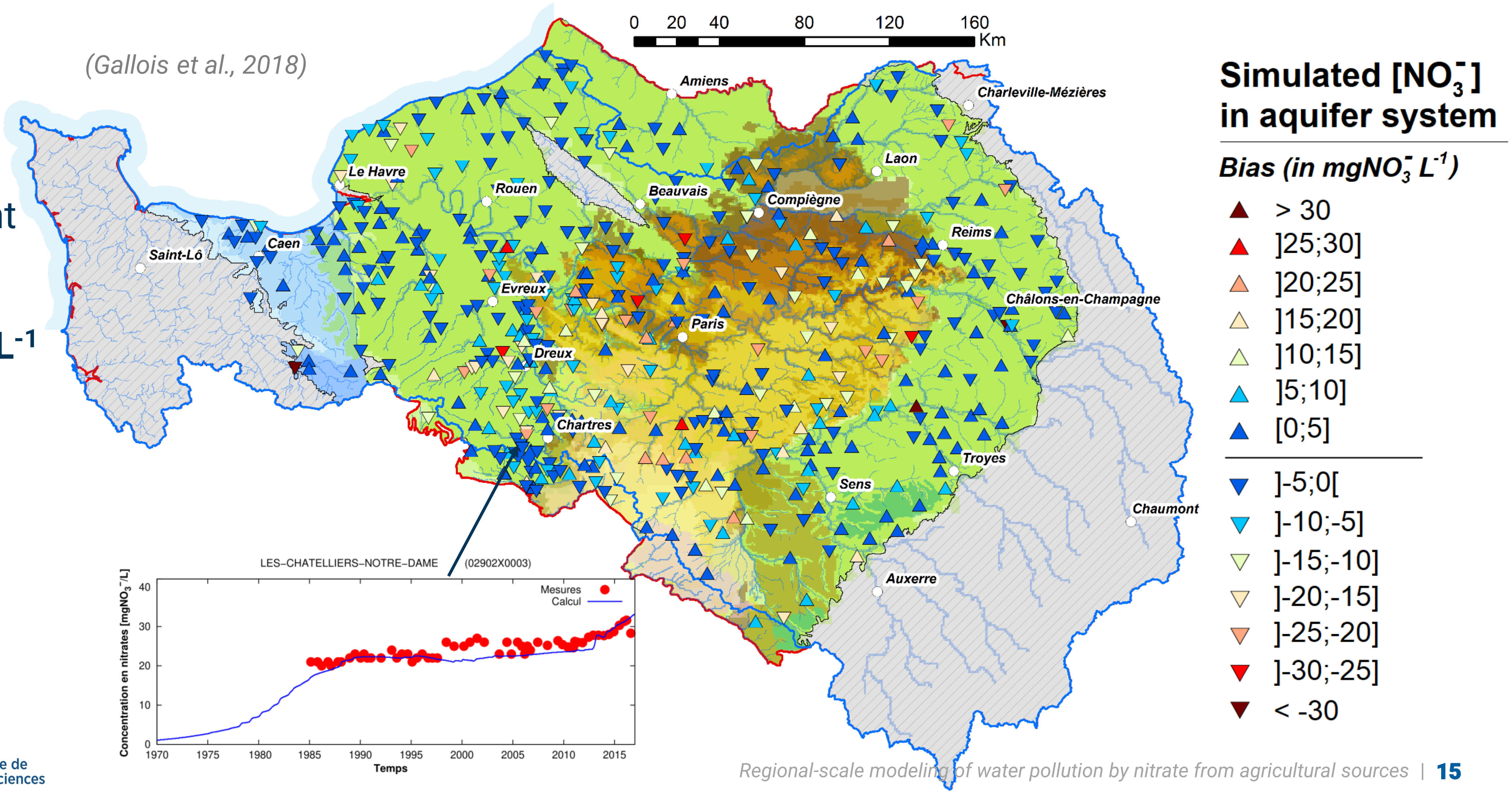

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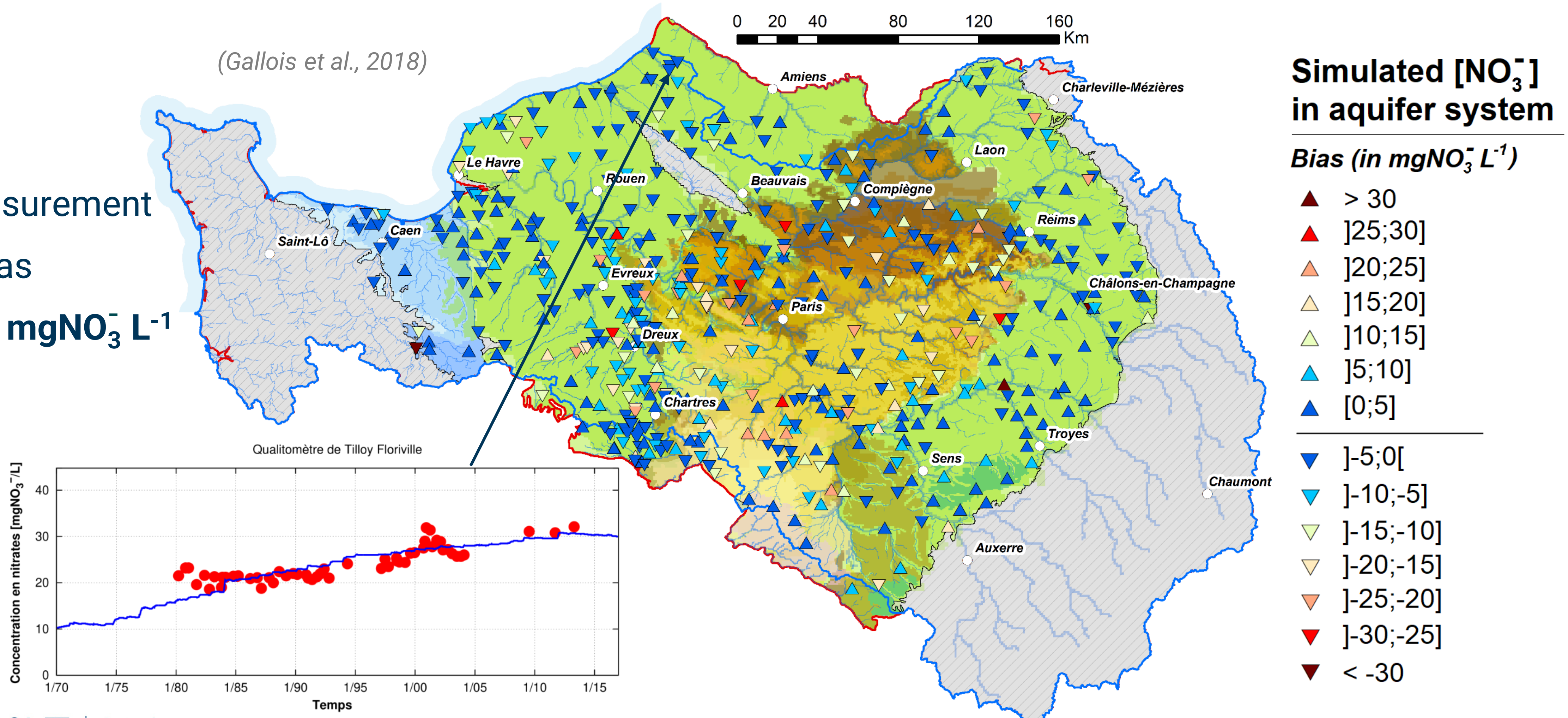


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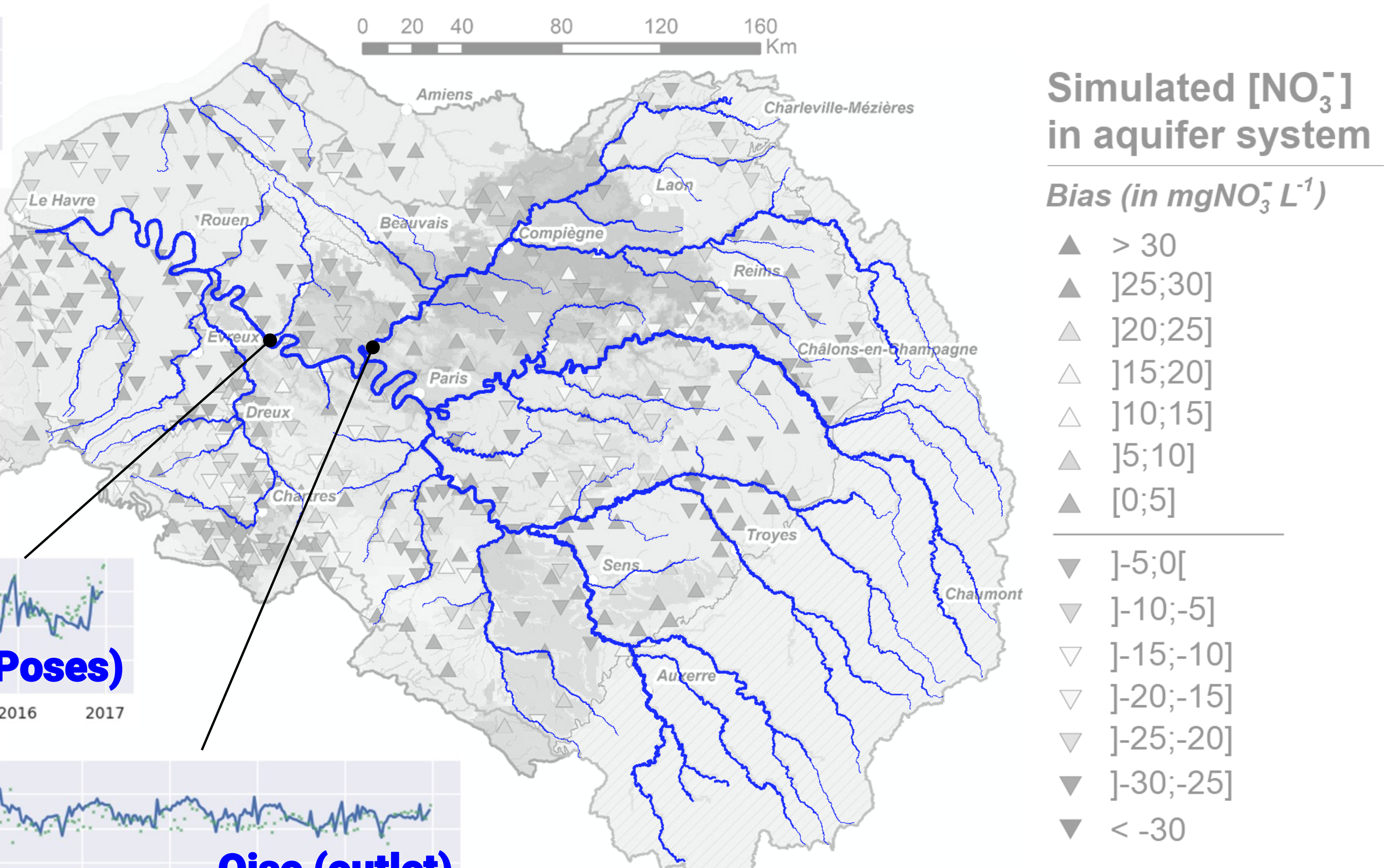
## ➢ Retrospective validation of the platform (1970-2018)

### 5 **Nitrogen dynamics** in **rivers** = Validation against measured **concentration** data

River concentrations

*(Passy et al., 2018)*

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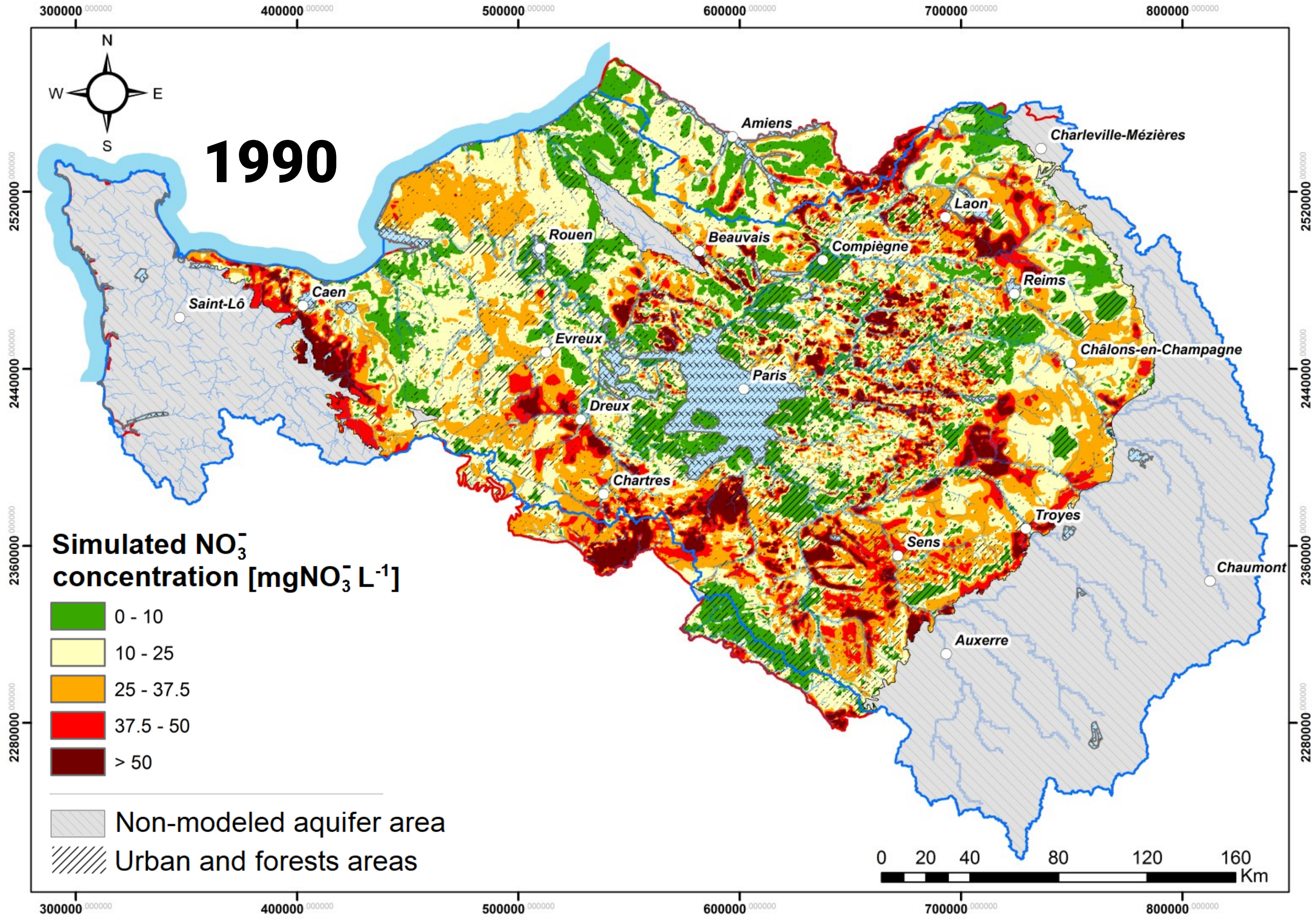
# ➢ Past and current aquifer pollution levels

- **Continuous appreciation** in **space and time** of **past** and **current aquifer nitrate** pollution levels.



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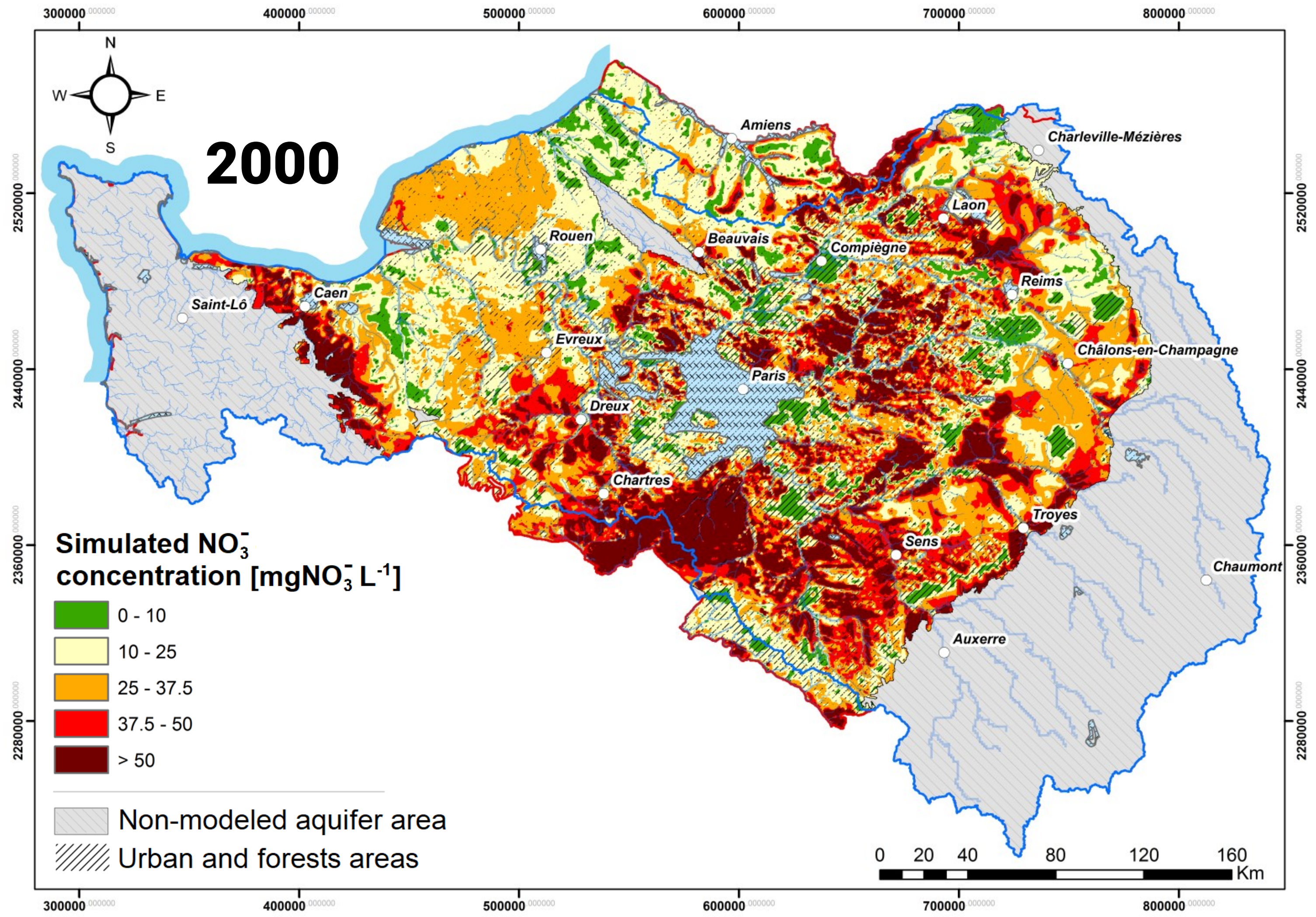

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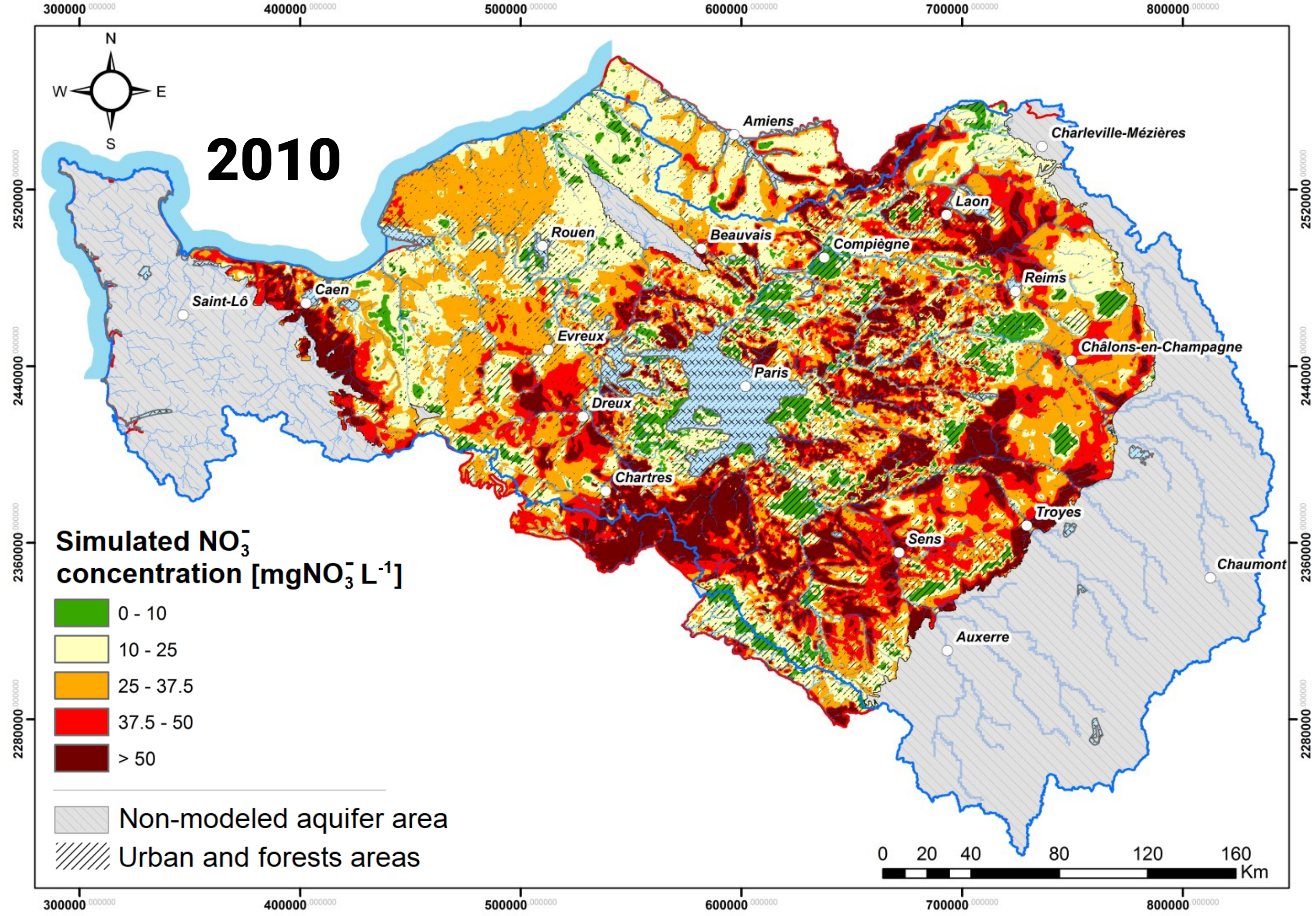


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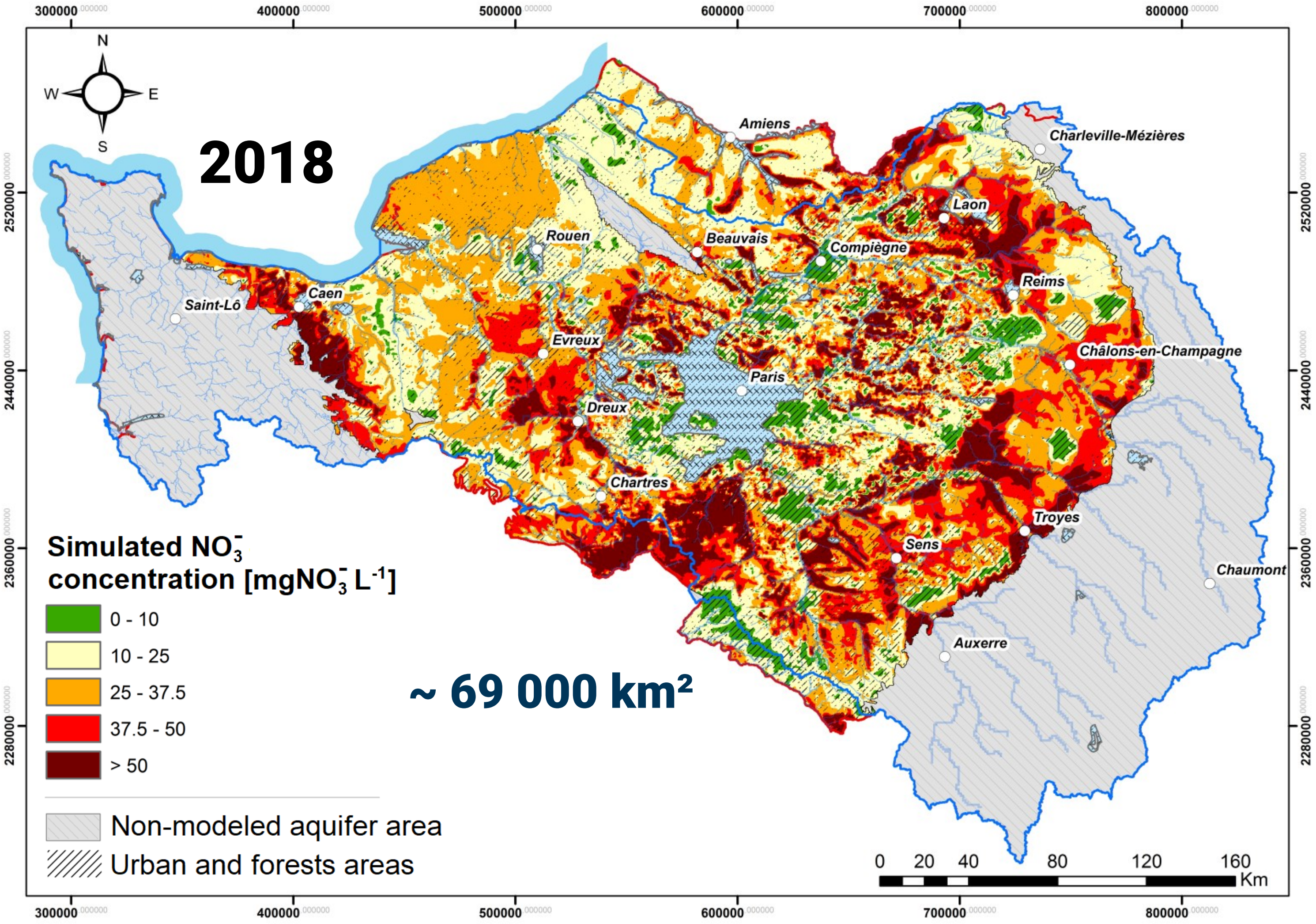
# ➢ Past and current aquifer pollution levels

- **Continuous appreciation in space and time** of **past and current aquifer nitrate pollution levels.**

Fraction of the area :

> 37,5 mg $L^{-1}$ ➔ **26 %**

> 50 mg $L^{-1}$ ➔ **11 %**



03

# The challenges of PROSPECTIVE MODELING

# ➢ Prospective modeling : main objectives and challenges

➔ Model the **impact** of **progressive changes** in **agricultural systems** on **underground** water quality.

**Self-imposed scenarios characteristics**

- **Regionalized approach**,
- **Continuous scenarios** in space and time,
- Elaborate scenarios in terms of generalized **cropping systems evolution trends,**
- **Technical declination of these scenarios ➔ distributed model input datasets !**
- Integrate **climate change** :
  - Underground water ressource availability for irrigation purposes,
  - Characterization of potential impacts on cropping systems, etc.

# ➢ Prospective modeling : main objectives and challenges

- Preliminary **climate model projections data analyses** (5 GCM models),

- **Selection of ONE single model RCP8.5 projection data** selected based on its overall coherence with historical measured meteorological data.

- Climate data analyses led from a **agronomic standpoint** :
  - *Water balance evolution characterization,*
  - *Precipitation and temperatures anomalies,*
  - *Evolution in frequences and durations of freezing and heatwave periods, etc.*

- Various generalized irrigation scenarios tested out with the hydrogeological model **to pre-constrain** global **irrigation inputs** in scenarios.

➔ Characterization of **climate change effects** on **crop cycles**
*(phenological stages, sowing and harvest dates delays, increase in intercrop durations, etc.)*

# ➢ Prospective modeling : main objectives and challenges

- **2 contrasted scenarios (2018-2050) :**
  - **Scenario A** : Continuation in the basin's agriculture specialization and intensification
    - Agriculture based on **high N-input rates** (use of fertilizers, mechanization, high production potentials) driven by a export agro-industry,
    - **Overall climate change adaptation** (irrigation, cropping calendar adjustments, etc.),
    - Some marginal **niche productions remaining** (AB, AOC, etc.) (5% in 2050),
    - **Dairy industry in decline / livestock farming disappearance** in some regions, etc.

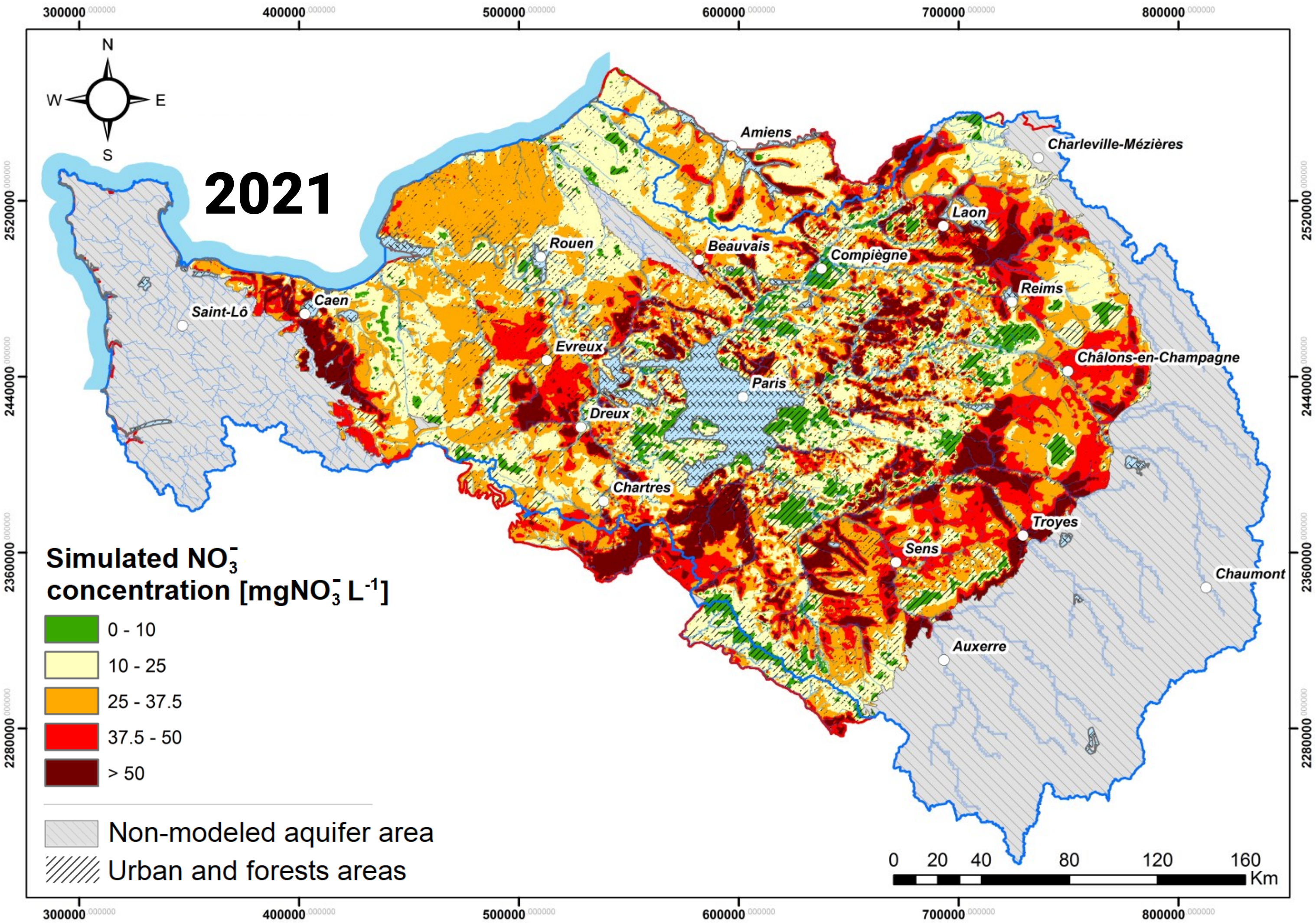
# ➢ Prospective modeling

**Scenario A** (2018 – 2050) : Pursuit of the basin's agriculture specialization and intensification

Fraction of the area :

> 37,5 mg $L^{-1}$ ➔ **28 %**

> 50 mg $L^{-1}$ ➔ **12 %**

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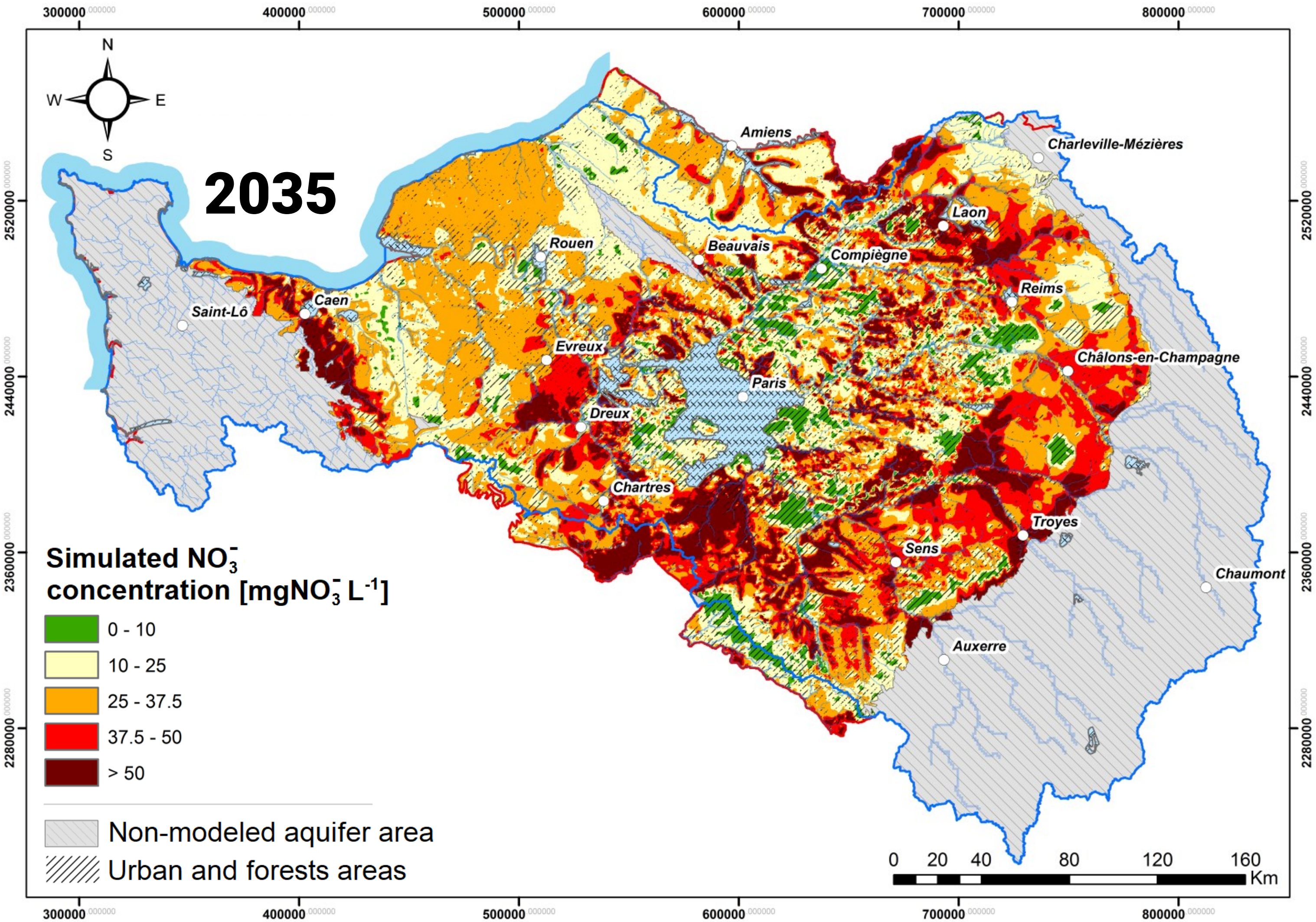
# ➢ Prospective modeling

**Scenario A** (2018 – 2050) : Continuation in the basin's agriculture specialization and intensification




Fraction of the area :

> 37,5 mg $L^{-1}$ ➔ **30 %**

> 50 mg $L^{-1}$ ➔ **14 %**

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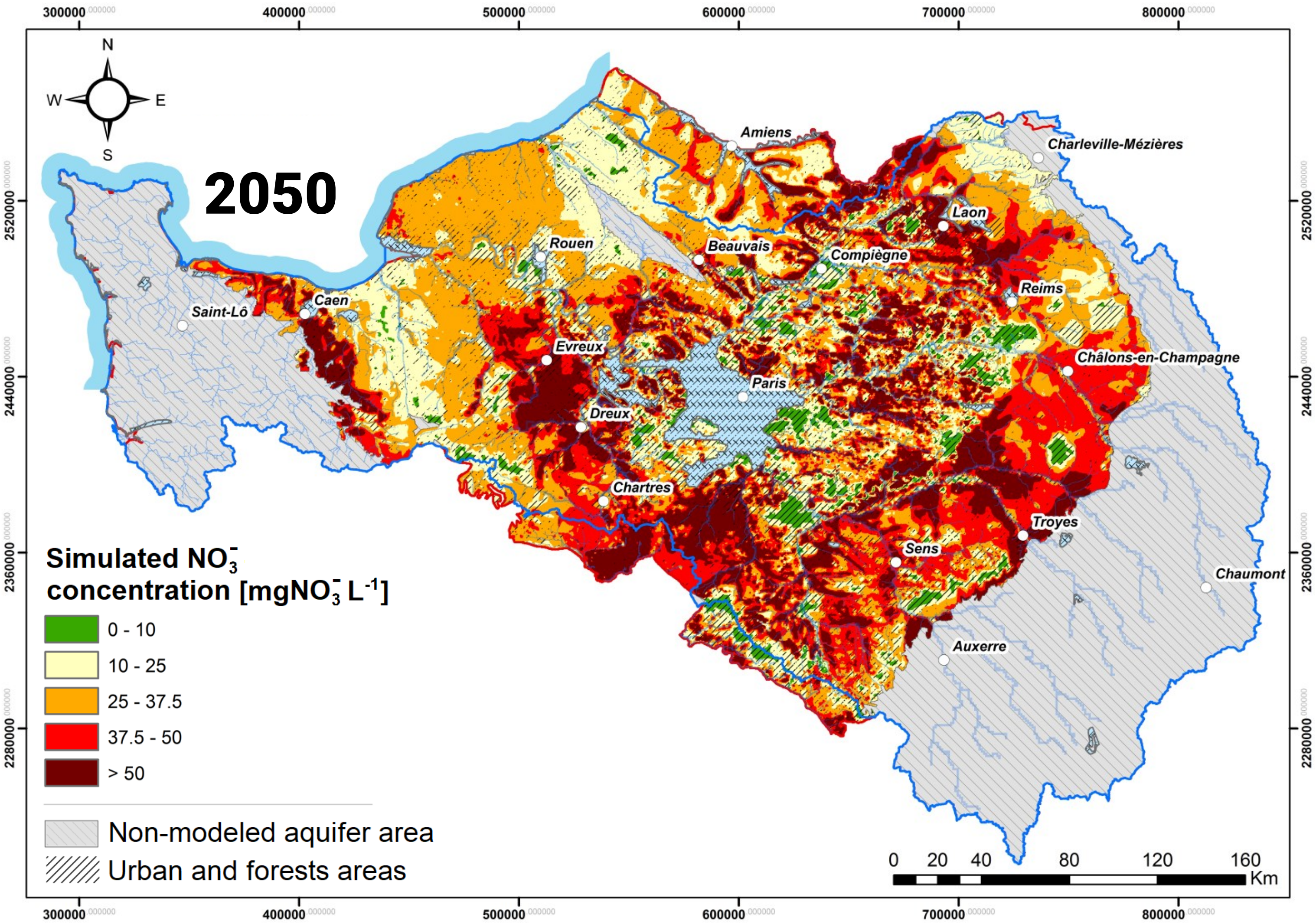
# ➢ Prospective modeling

**Scenario A** (2018 – 2050) : Continuation in the basin's agriculture specialization and intensification




Fraction of the area :

> 37,5 mg $L^{-1}$ ➔ **39 %**

> 50 mg $L^{-1}$ ➔ **19 %**

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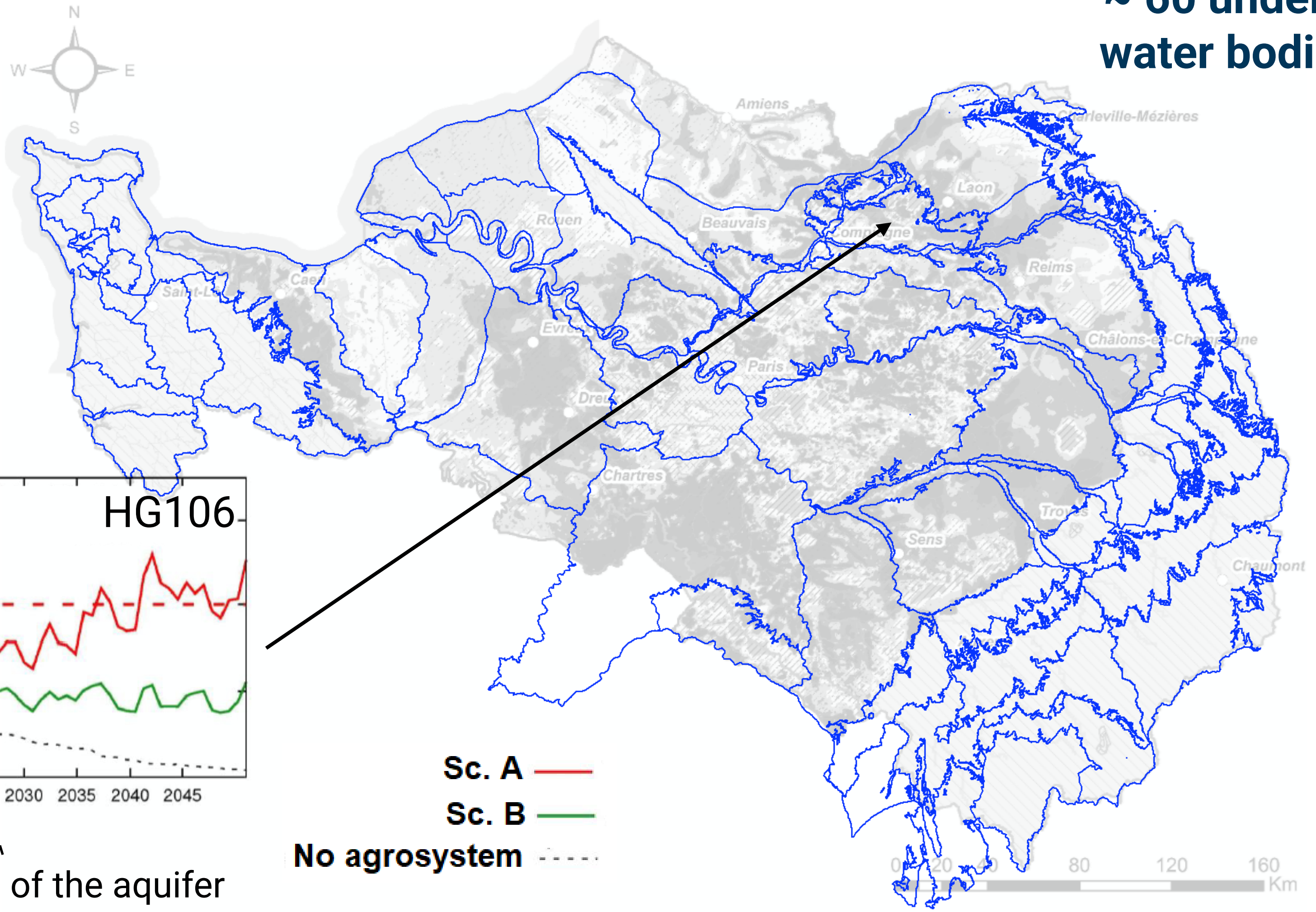
# ➢ Prospective modeling : main objectives and challenges

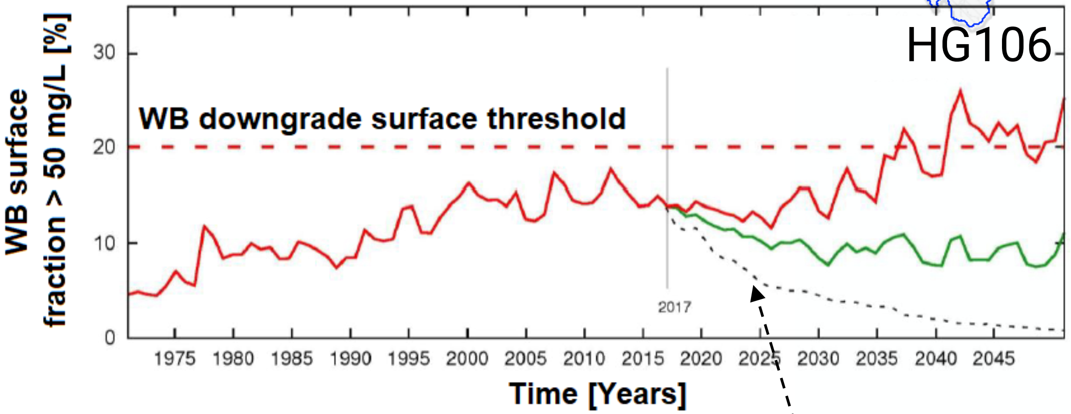
- **2 contrasted scenarios (2018-2050) :**
  - **Scenario A** : Continuation in the basin's agriculture specialization and intensification
    - Agriculture based on **high N-input rates** (use of fertilizers, mechanization, high production potentials) driven by a export agro-industry,
    - **Overall climate change adaptation** (irrigation, cropping calendar adjustments, etc.),
    - Some marginal **niche productions remaining** (AB, AOC, etc.) (< 5% in 2050),
    - **Dairy industry in decline / livestock farming disappearance** in some regions, etc.
  - **Scenario B** : Towards an agro-ecological transition
    - **Biomass energy development** (miscanthus < 5 % in surface in 2050),
    - **Marginalized** agriculture based on **high N-input rates** (10% in surface in 2050),
    - **Organic farming progressive development** (40% in surface in 2050),
    - **Drought-tolerant crops increase in surface**,
    - **Increase in use of annual leguminous plants** (faba bean, mixture of cereals, oilseeds and protein crops) and **pluri-annual plants** (alfalfa).

# ➢ Prospective modeling

**Scenario B** (2018 – 2050) : Towards an agro-ecological transition

**~ 60 underground water bodies** (WB)




Sc. A
Sc. B
No agrosystem

Evaluation of the aquifer system inertia to fully evacuate the N pollutant

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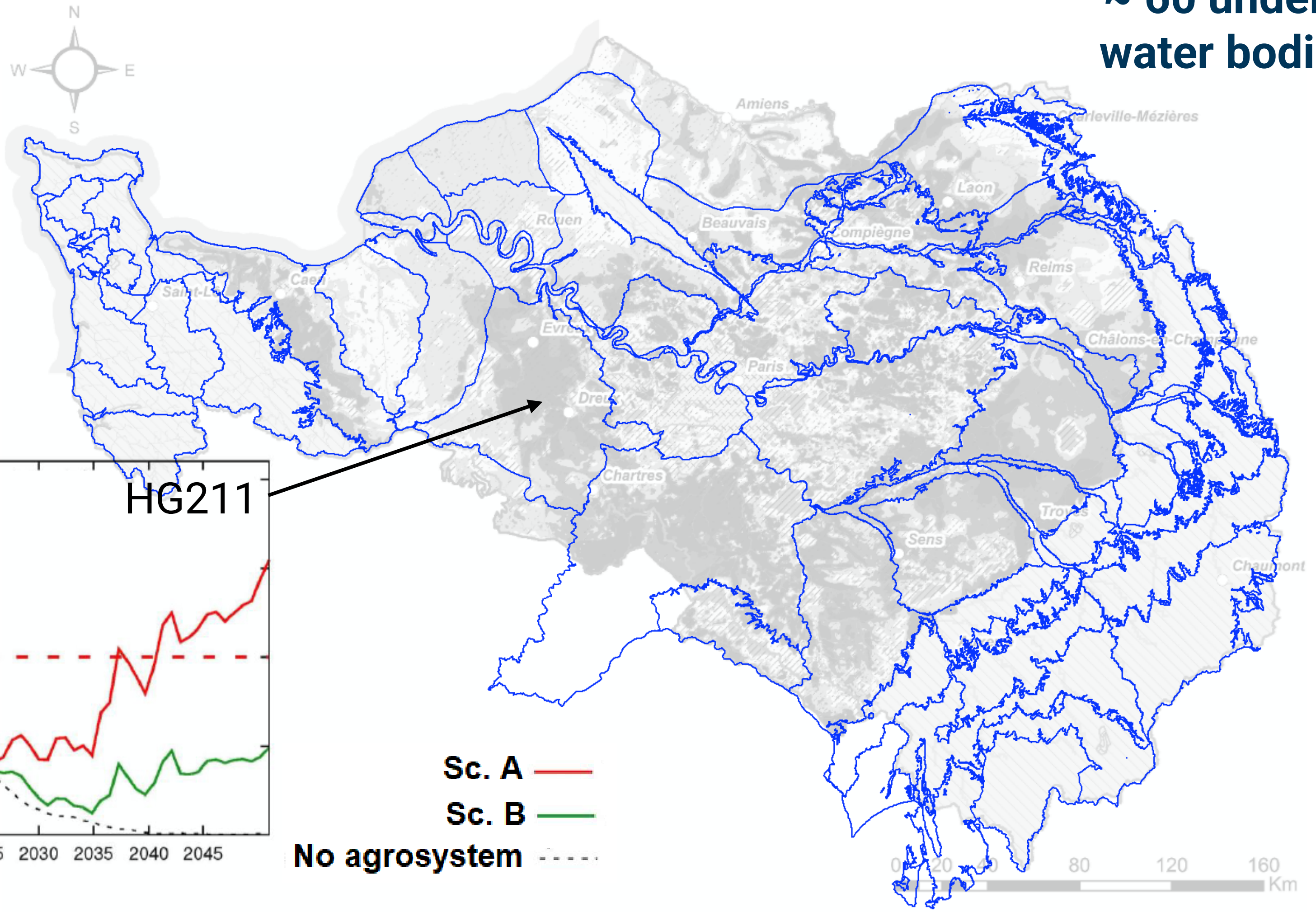
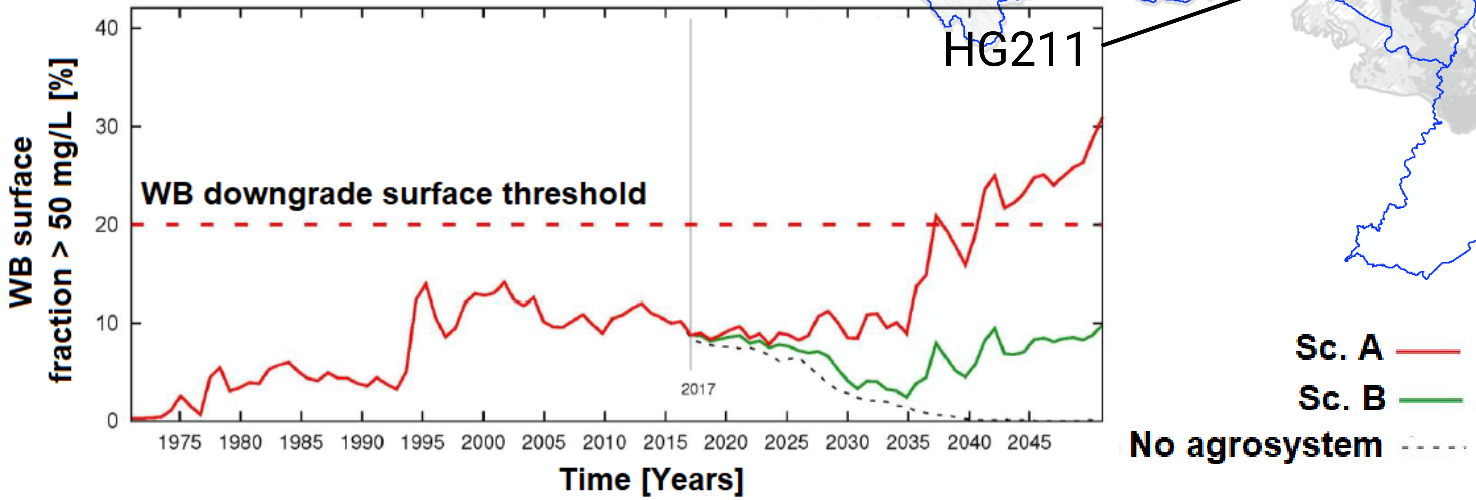
# ➢ Prospective modeling

**Scenario B** (2018 – 2050) : Towards an agro-ecological transition

| Date | Sc. A > 50 mg/L | Sc. B > 50 mg/L |
|---|---|---|
| **2021** | 11.8 % | 10.9 % |
| **2027** | 11.9 % | 9.1 % |
| **2030** | 11.1 % | 7.7 % |
| **2035** | 13.7 % | 7.6 % |
| **2040** | 13.8 % | 7.3 % |
| **2045** | 14.2 % | 7.9 % |
| **2050** | 18.5 % | 7.2 % |

**~ 60 underground water bodies** (WB)



# ➢ **Conclusion :** Take-away messages

1. **Interdisciplinary** tool able to integrate a **wide diversity** of information inputs :
    - High-resolution simulation of the **current state of** water quality resource,
    - **Continuous**, **spatialized and quantitative evaluation** of possible scenarios.

2. **Strong interest** for :
    - **Basin stakeholders**

      = Provides helpful **cognitive elements** to **design** and/or **re-design water protection policies**.
    - **Scientific community**

      = Evaluation of the **hydrosystem's response** to human-based **constraints modifications**,

      = STICS model outputs exploration at the **macro-regional scale**. *(Beaudoin et al., 2018)*

3. **Generic** and **evolutive tool** :

   = Platform application field **recenty extended** to **temperature-based problems**.

4. **Ongoing work** :

   = Nitrate modeling to be updated **in 2023** in anticipation (2025) of the **AESN next « Etat des Lieux »**.

# Thank you for your attention !

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## Further reference material :


- **Gallois N., Viennot P.** (2018). *Modélisation de la pollution diffuse d'origine agricole des grands aquifères du bassin Seine-Normandie - Actualisation des modélisations couplées agronomie/hydrogéologie : modélisation de scénarios agricoles sous changement climatique*, ARMINES / MINES ParisTech technical report, 268 p.
- **Beaudoin N., Gallois N., Viennot P., Le Bas C., Puech T., Schott C., Buis S., Mary B.** (2018). *Evaluation of a spatialized agronomic model in predicting yield and N leaching at the scale of the Seine-Normandie basin*. Environmental Science and Pollution Research, 25(24):529-558. doi: 10.1007/s11356-016-7478-3
- **Passy P., Viennot P., Gallois N., Billen G., Garnier J., Silvestre M., Thieu V. (2018).** *Modélisation des apports diffus d'azote et de phosphore aux masses d'eau de surface du bassin Seine-Normandie*. FIRE/ARMINES technical report, 58 p.