Source water protection in Quebec City :

Vulnerability assessment considering surface-groundwater interactions with an integrated hydrological model

Laura Gatel

Tremblay, Y., Gatel, L., Picard, A., N'da, B.A., Frot, B., Therrien, R., Lemieux, J.-M., Barbecot, F., Cloutier, V., Proulx, F., Audet, L. et Cantin, A.M.

NDGW Jan. 15, 2025

Context

Prescribed by *Règlement sur le prélèvement des eaux et leur protection*

Completed in 2021

Regular updates

In progress

Surface drinking water source

Vulnerability assessment

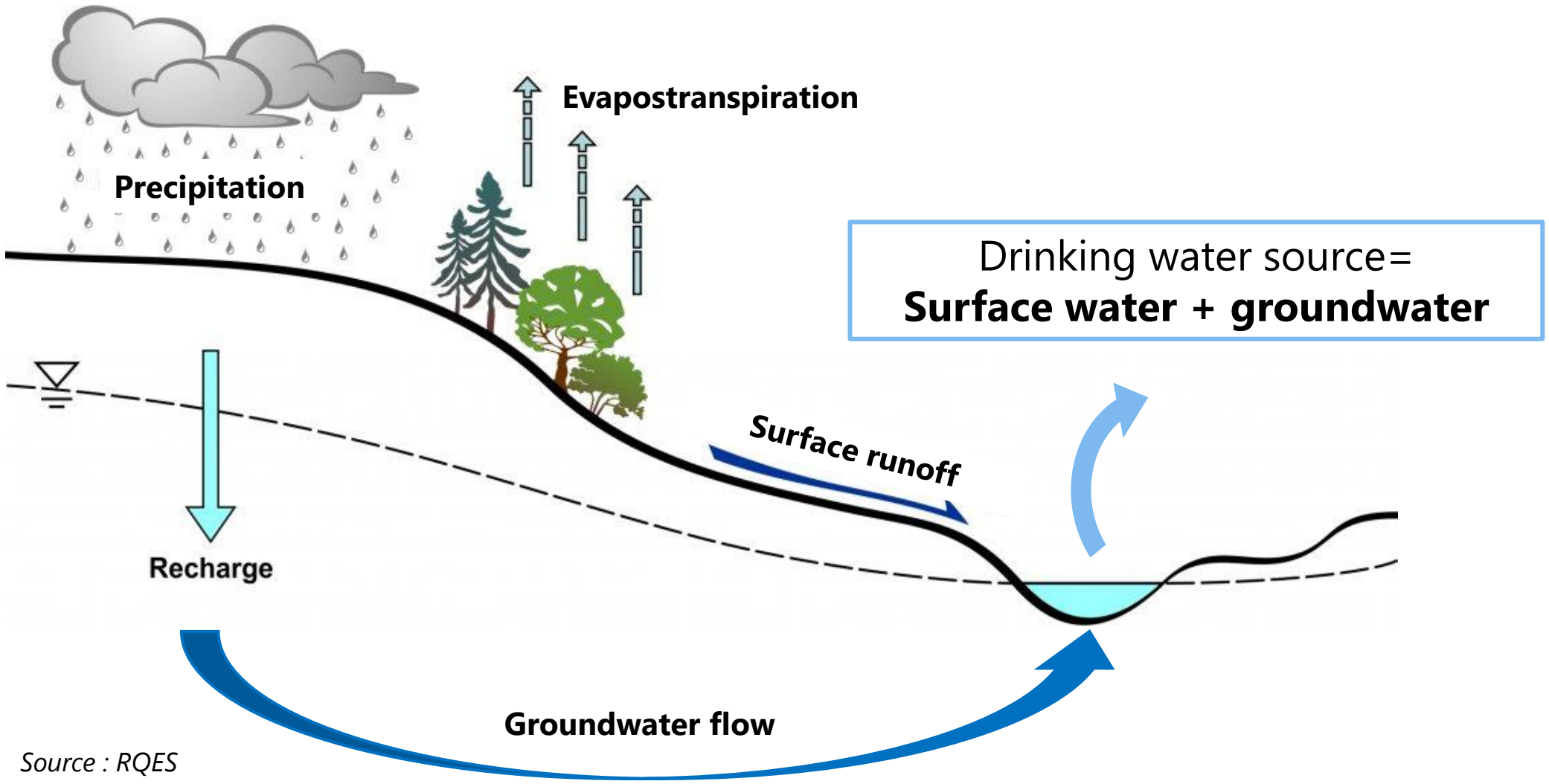
Surface drinking water source protection plan

Groundwater drinking water source

Vulnerability assessment

Groundwater drinking water source protection plan

Groundwater plays an important role in the water cycle



Drinking water source=
Surface water + groundwater

Source : RQES

Study area

Saint-Charles River drinking water source watershed= 344 km^2

Use of water resources :

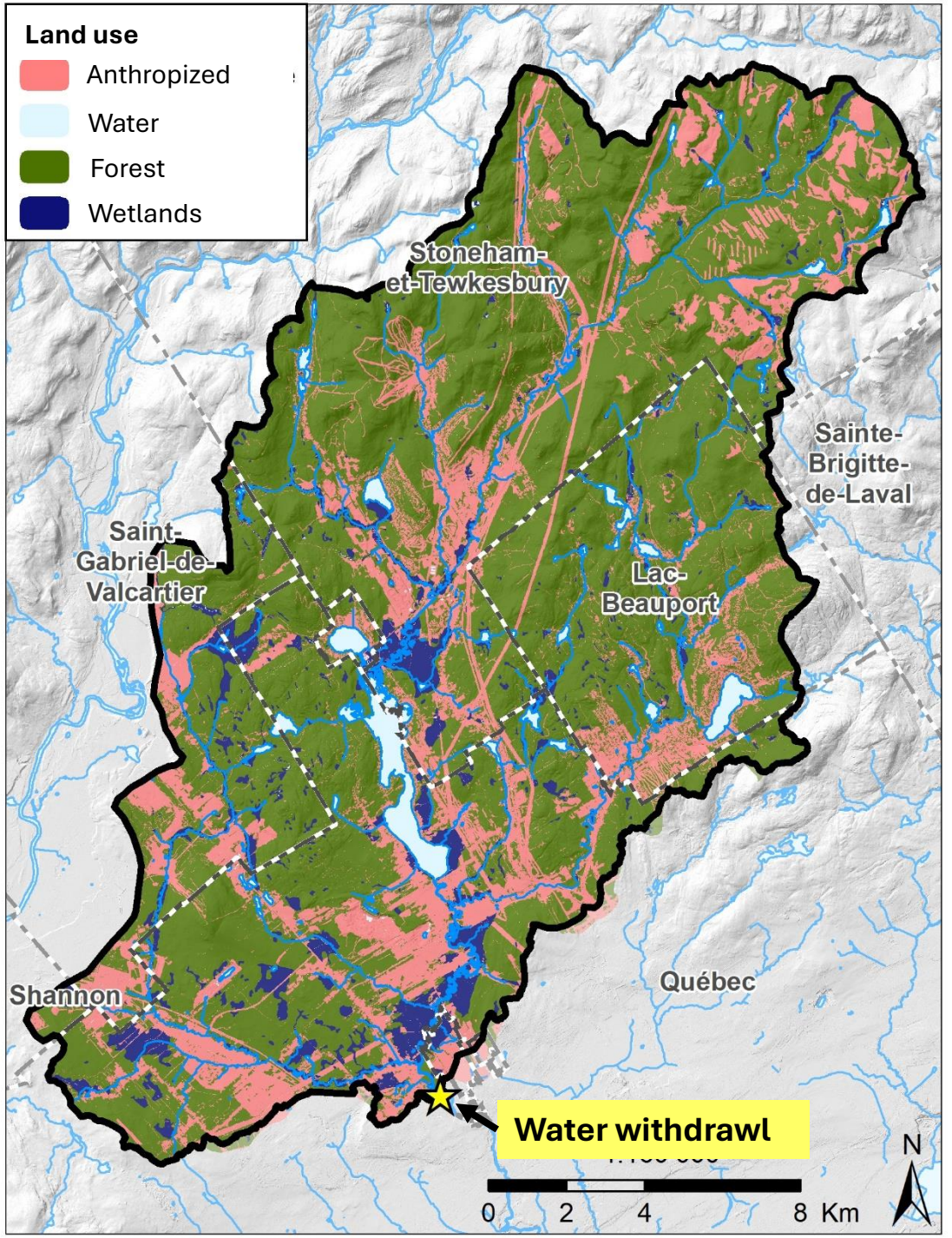
300 000 people covered

- Average withdrawal = 140 000 m^3/d
- In summer, withdrawals up to 92% of river flow

Land use

18% of the territory is anthropized, including 6% in urban areas

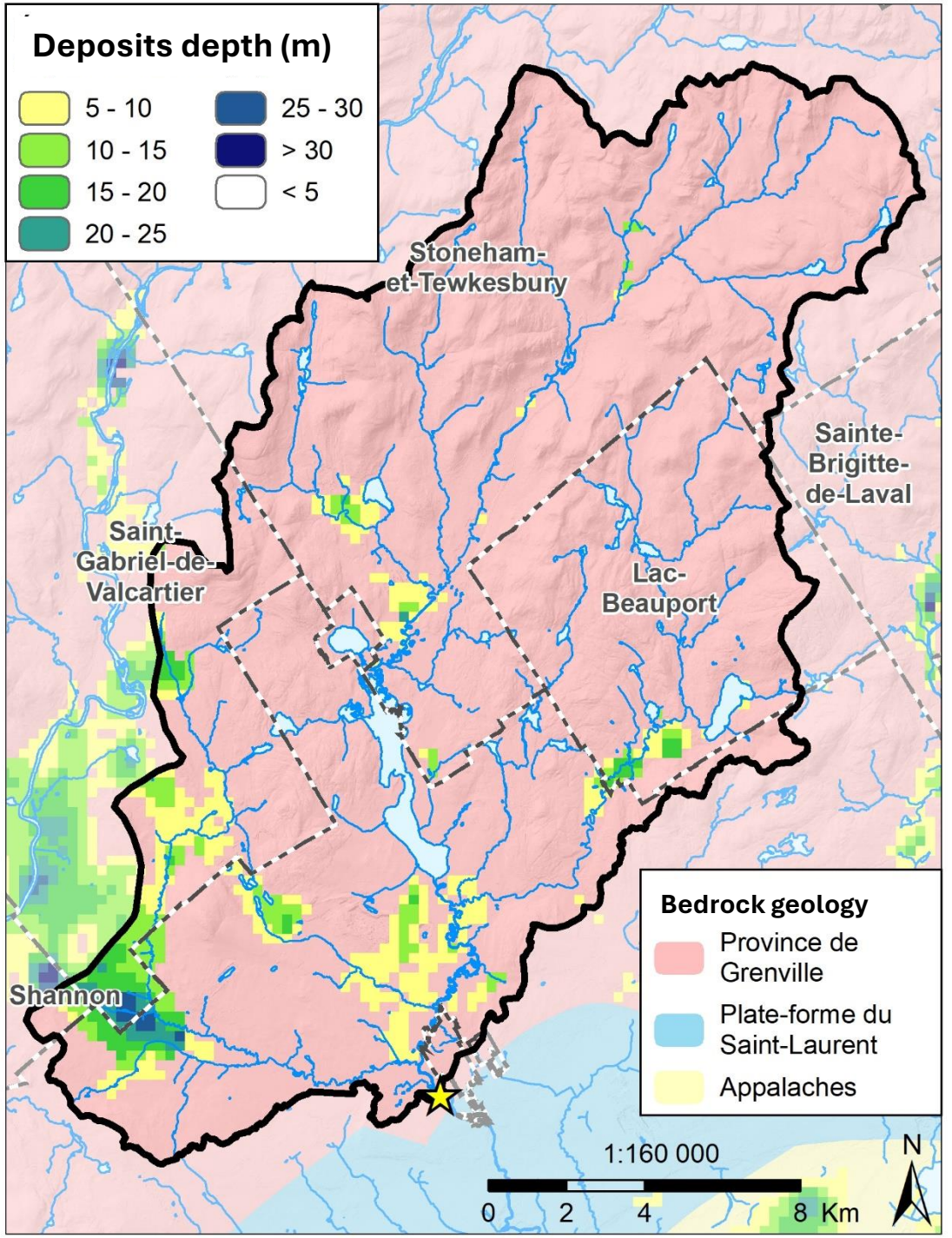
Anthropized areas are mostly located in valleys, close to watercourses.



Hydrostratigraphic context

Deposits aquifer :
Covers 16 % of the area
Estimated volume of available water : 870 Mm³

Roc aquifer :
Present all over the area
Estimated volume of available water : 306 Mm³



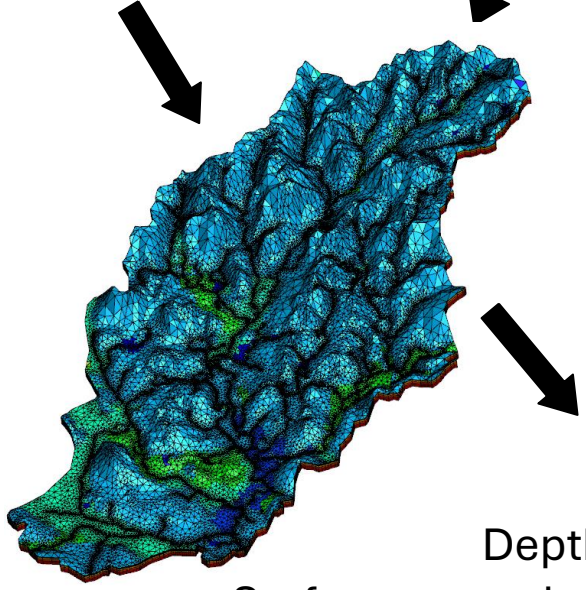
Numerical hydrological modelling is based on observations

HydroGeoSphere model

Input data

Topography
Land use
Geology

Daily weather



Results

Discharge
Depth of water table
Surface-groundwater exchanges
Recharge
Water stock evolutions
Water travel times

11 gauging stations

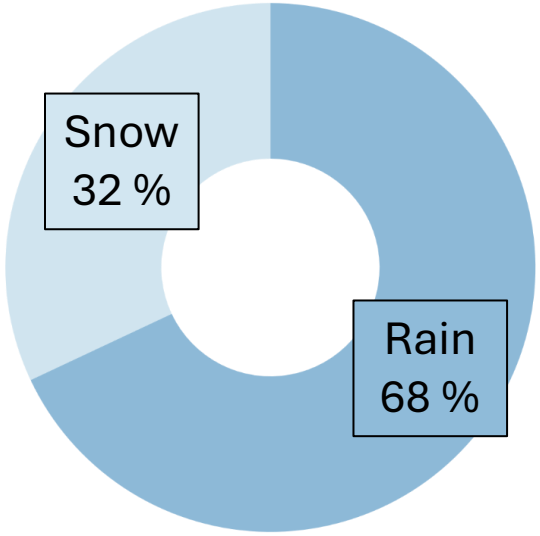
36 observation wells

Groundwater, rain and snow sampling

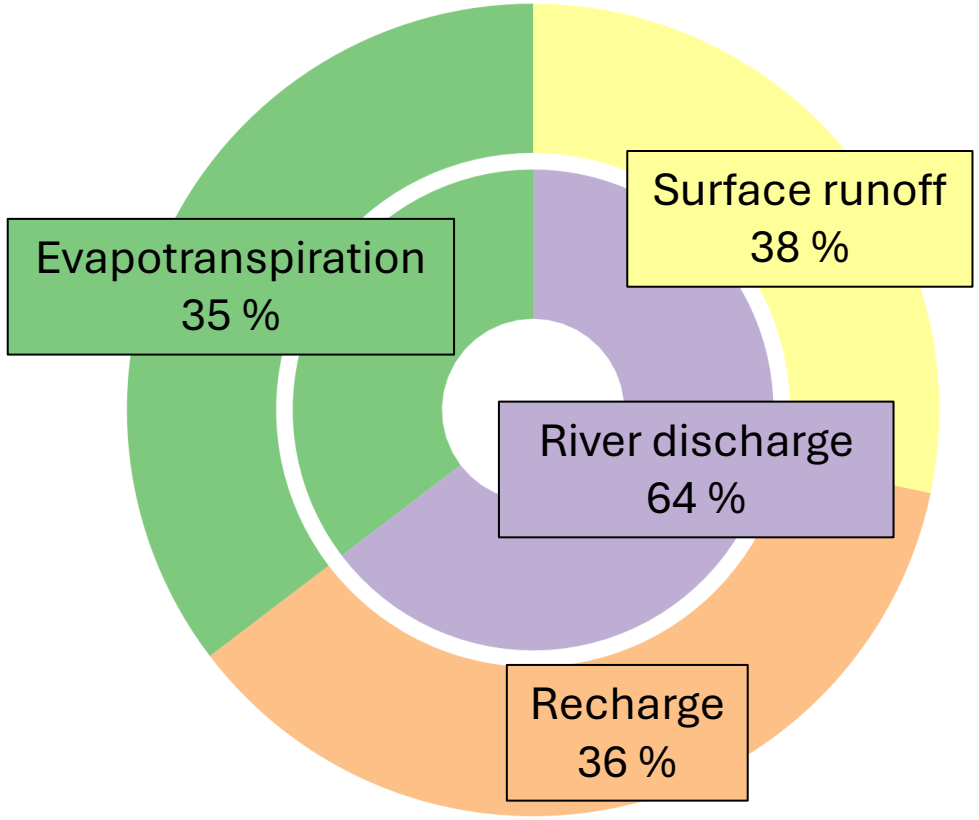
Carton et al., 2024

Water balance components

Where does the water come from?



Where does the water go?



Recharge

Spatial variability of recharge :

On the river network and wetlands → recharge is zero

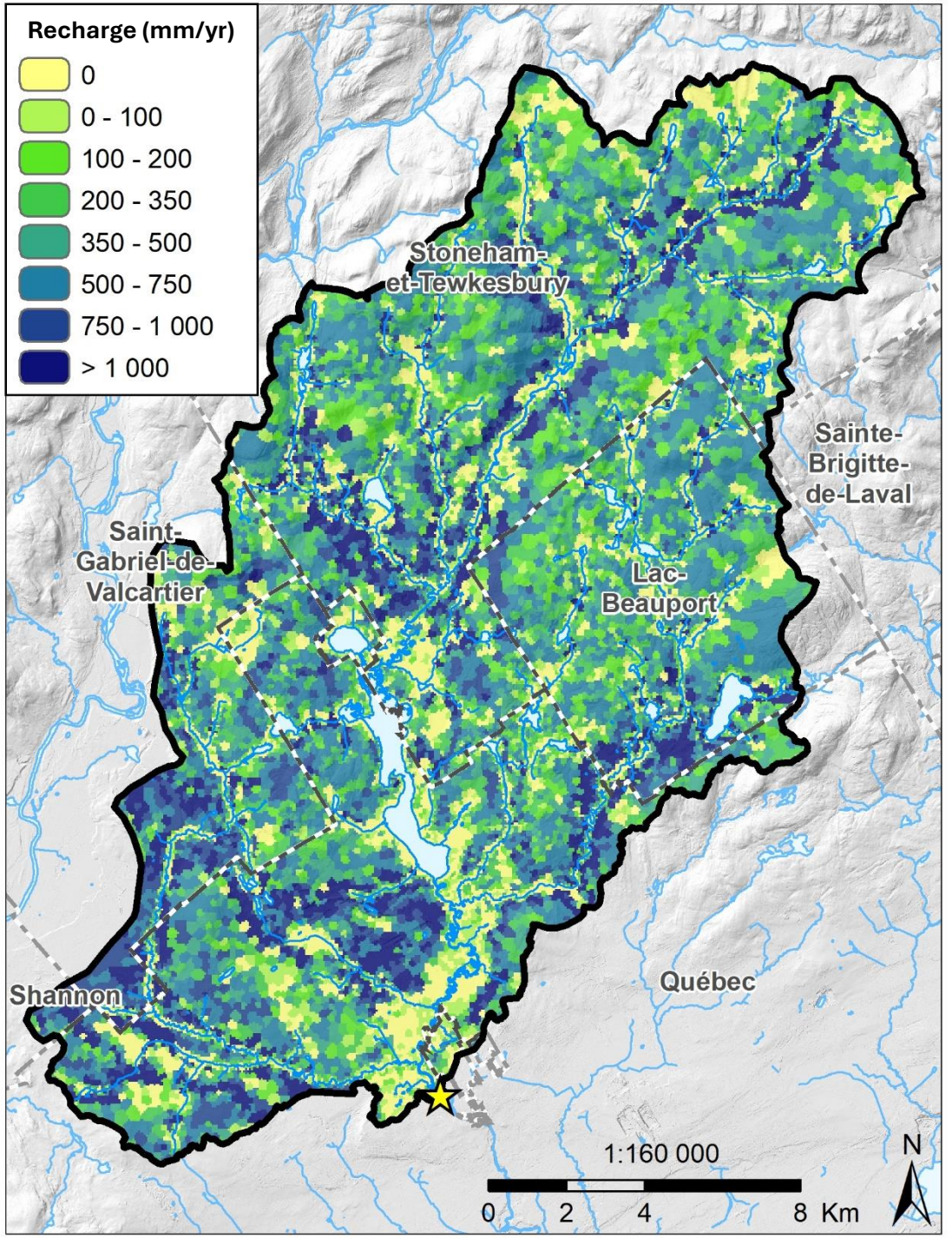
Forest → recharge between 200 and 600 mm/yr

Down the slopes → recharge > 600 mm/yr

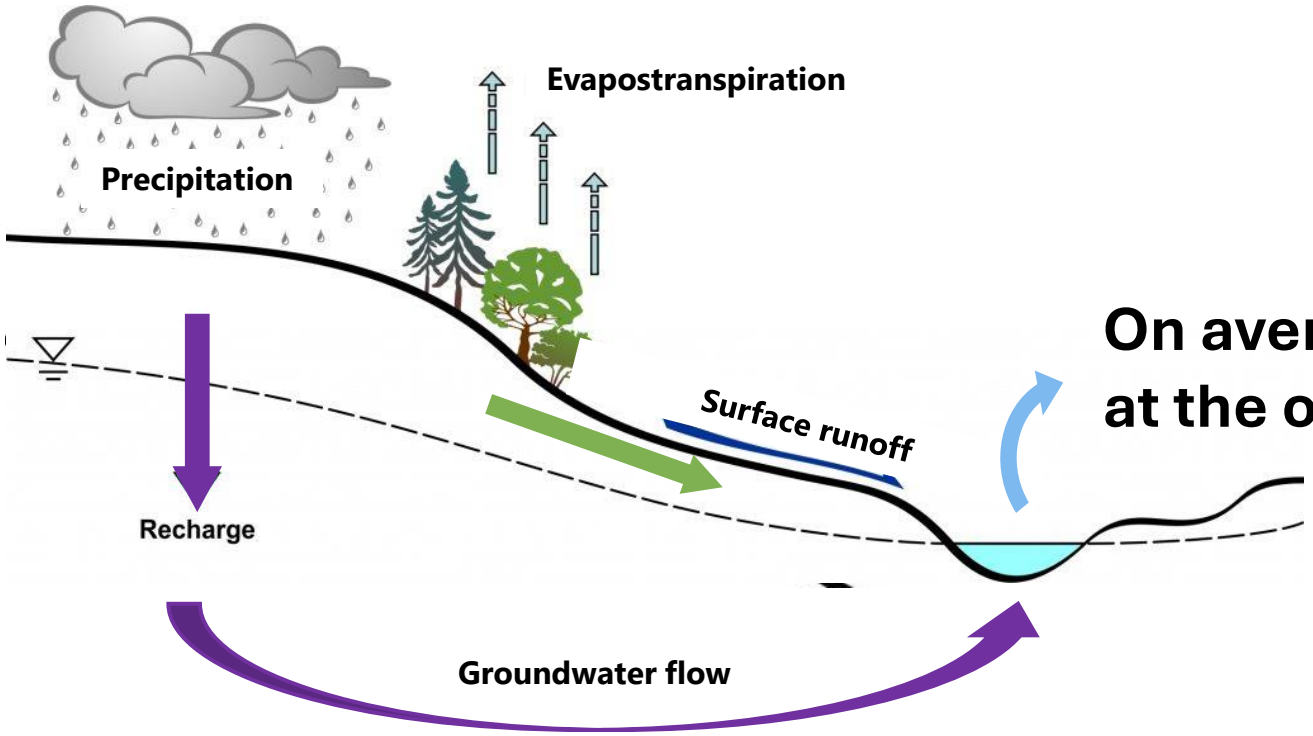
Annual variability of recharge :

Recharge is directly linked to precipitation and can vary significantly from one year to the next.

Wet year (2020) : 611 mm/yr Dry year (2021) : 350 mm/yr



Groundwater contribution to surface water



On average, 74% of the surface water at the outlet circulated underground :

Hypodermic runoff
+ recharge and groundwater flow

Source : RQES

Annual variability of groundwater contribution :

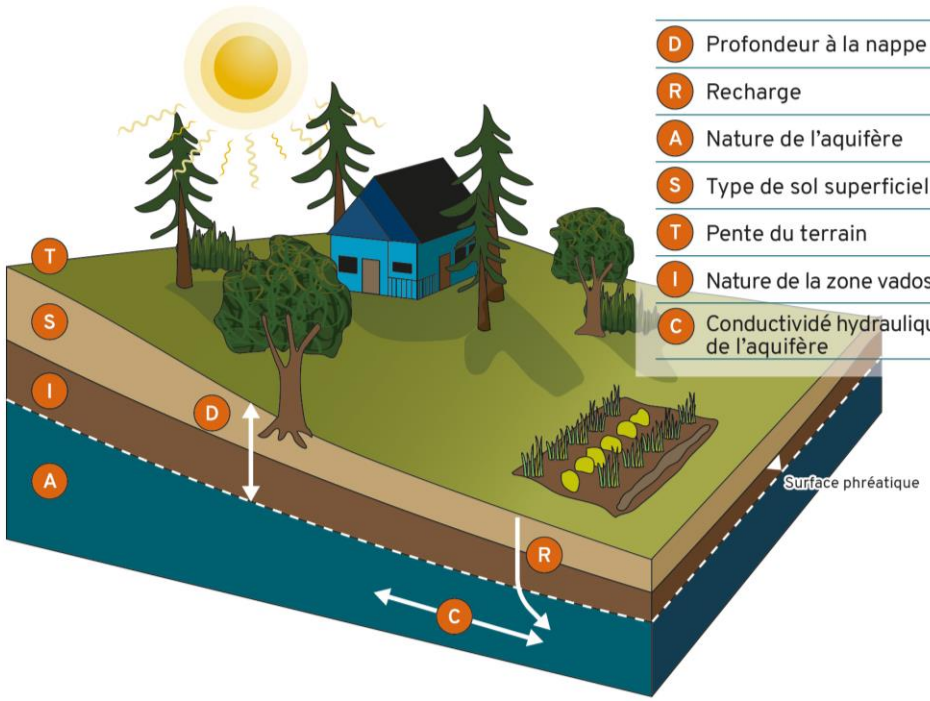
The drier the year, the greater the contribution of groundwater to surface water.

Wet year (2020) : 72 %
Dry year (2021) : 96 %

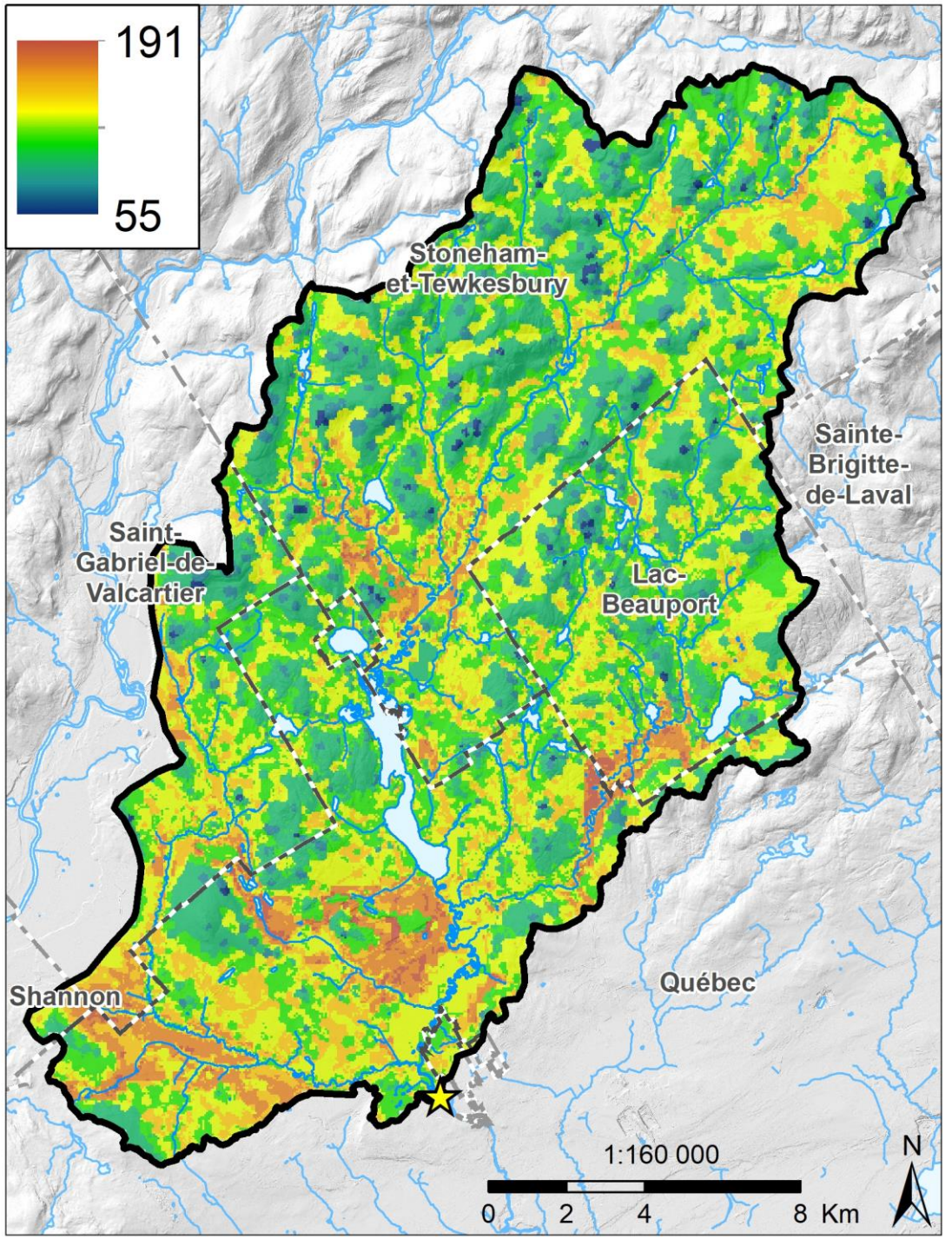
DRASTIC

Sensitivity of groundwater to surface contamination

The higher the index, the more vulnerable the aquifer is to contamination infiltrated from the surface.



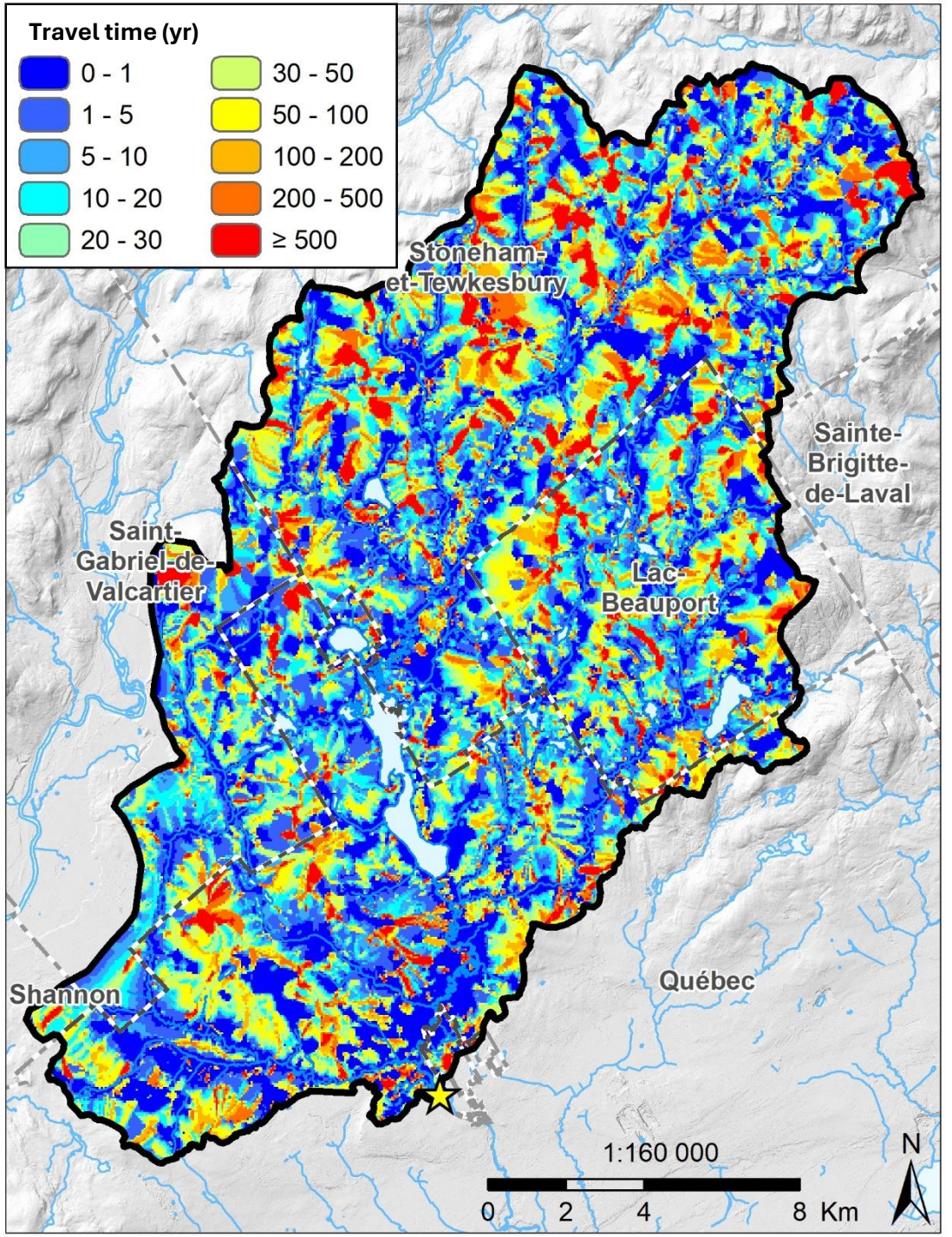
		Poids	
D	Profondeur à la nappe	5	Water table depth
R	Recharge	4	Recharge
A	Nature de l'aquifère	3	Aquifer
S	Type de sol superficiel	2	Soil
T	Pente du terrain	1	Slope
I	Nature de la zone vadose	5	Non saturated zone
C	Conductivité hydraulique de l'aquifère	3	Aquifer Kh



Groundwater travel time

50% of water particles spend at least 17 years in the water table before resurfacing

Travel times are directly related to distance from the river system



Vulnerability of water quality at drinking water source

Combining : DRASTIC and groundwater travel time

→ *from surface to top of the watertable*

Vulnerable =

DRASTIC index > 100

Highly vulnerable =

DRASTIC index > 140

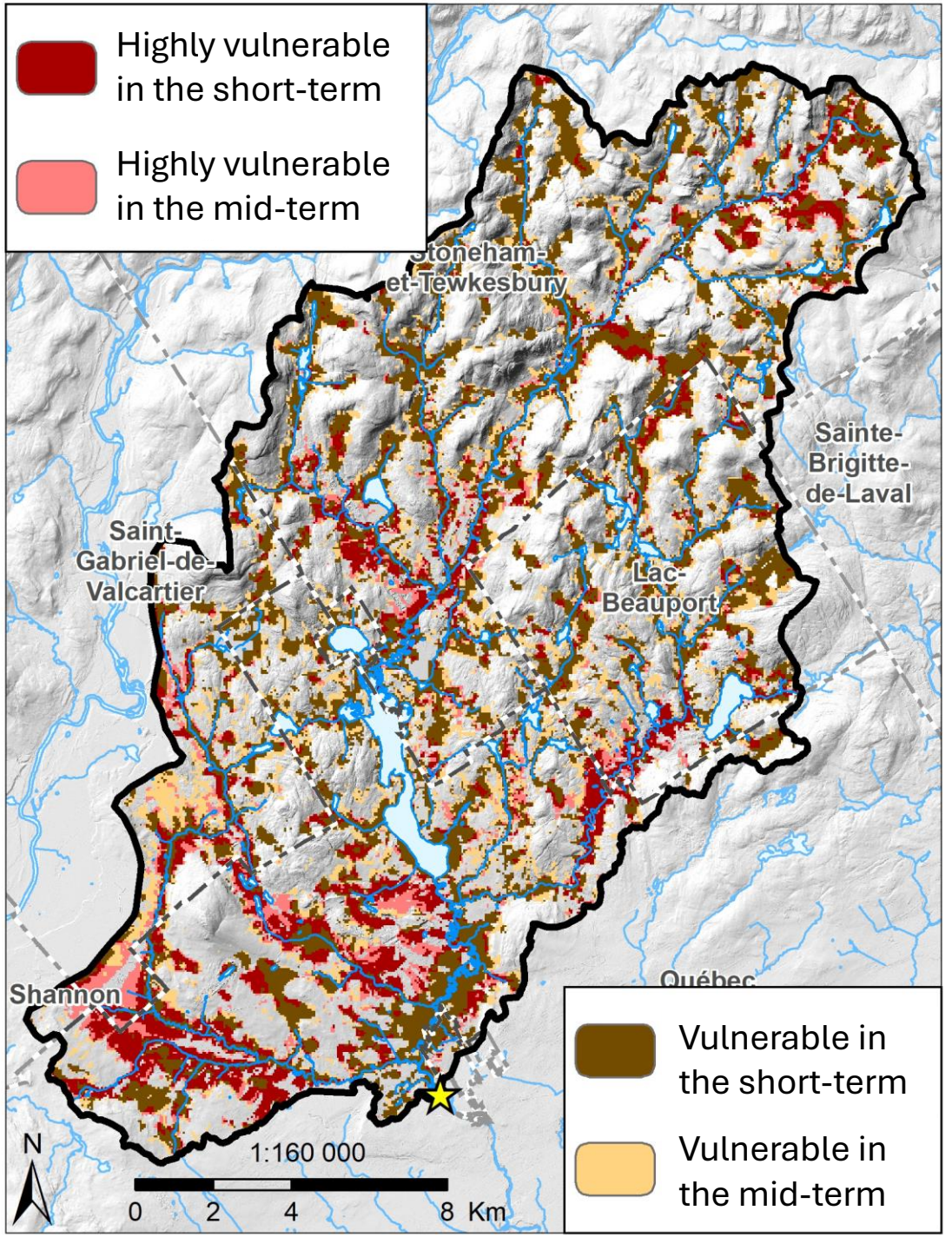
→ *from top of the watertable to surface*

Short-term =

travel time< 5 ans

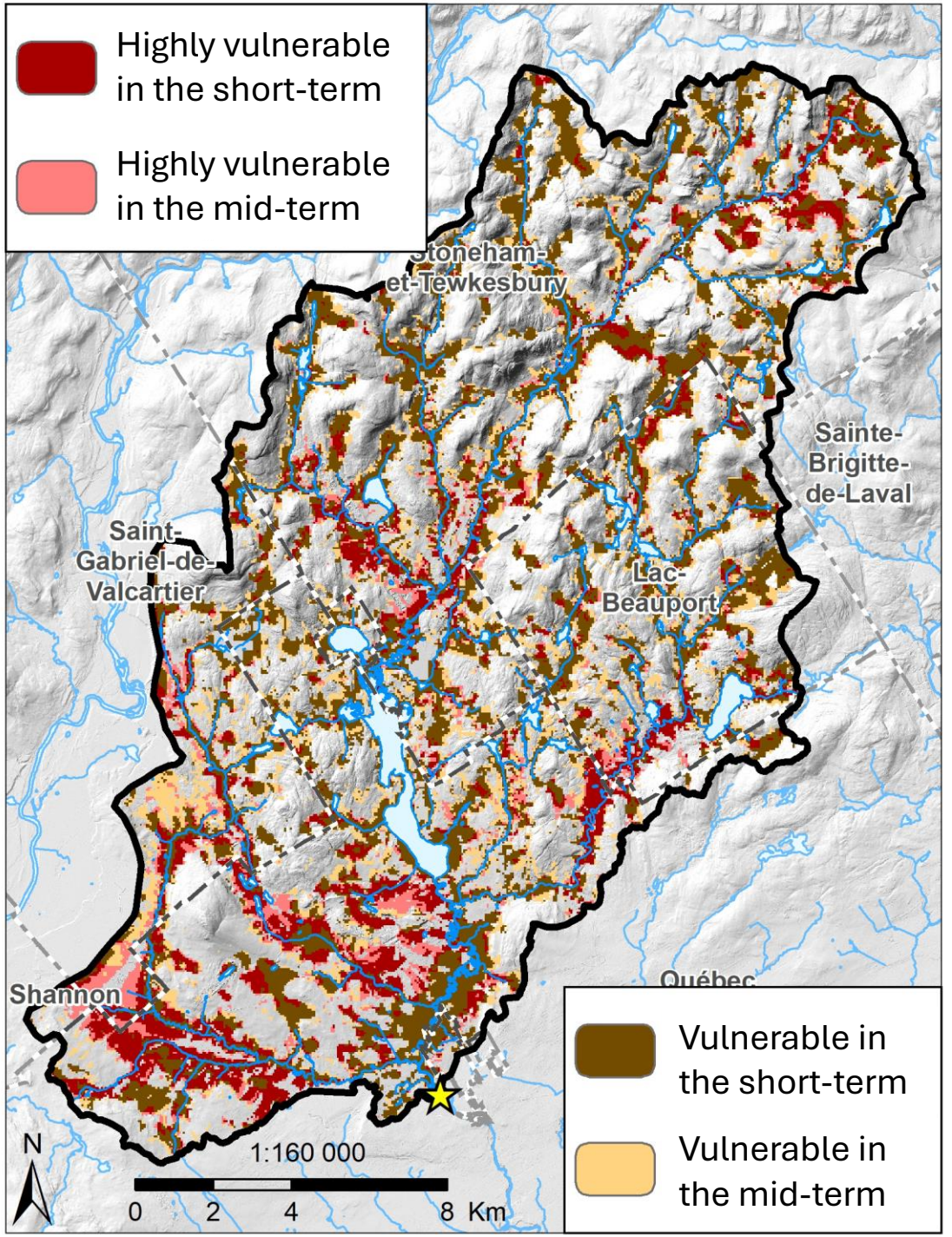
Mid-term =

travel time< 20 ans



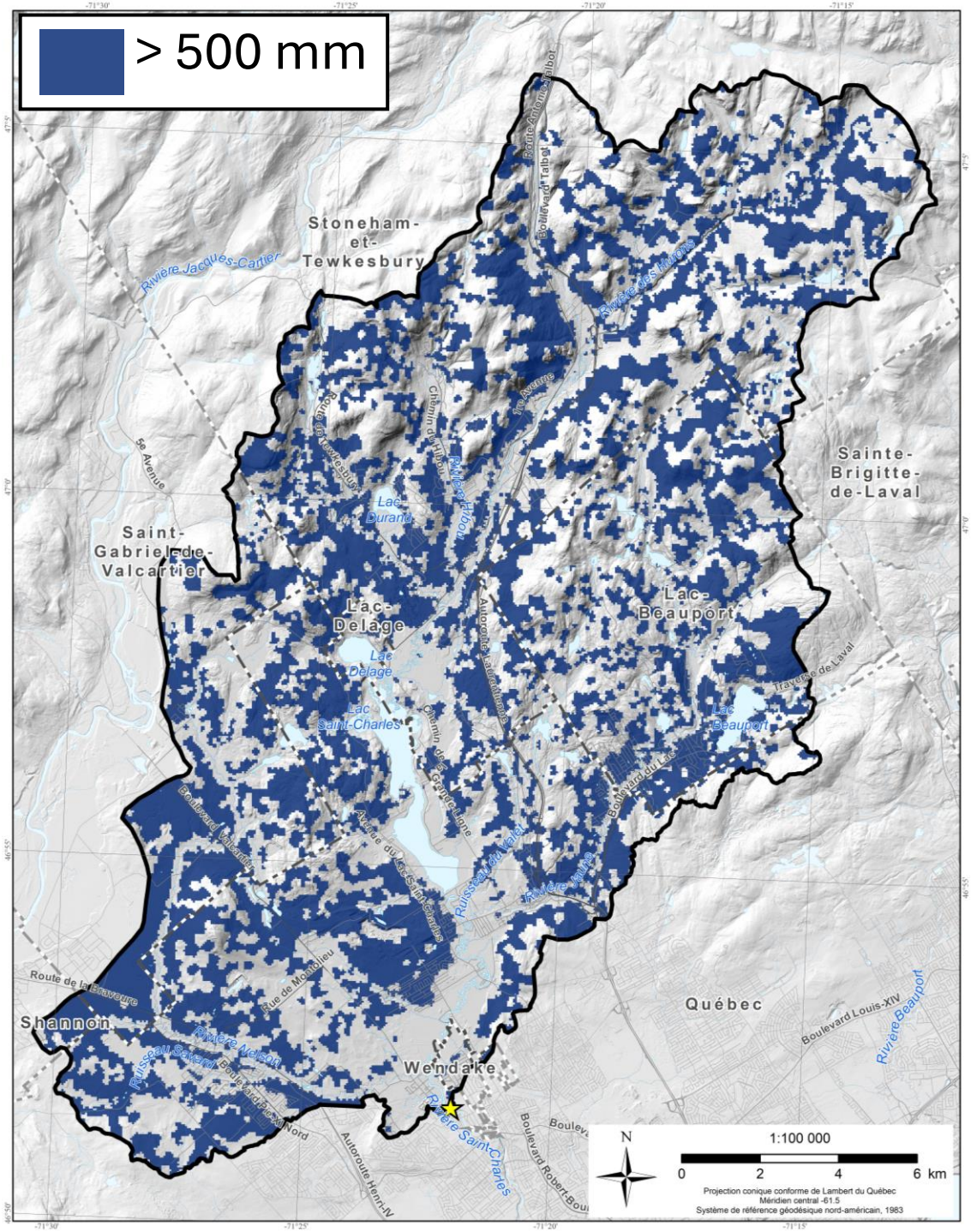
Vulnerability of water quality at drinking water source

- 24 % of the area is vulnerable
- 10 % of the area is highly vulnerable in the short term
- 58 % of anthropized areas are located on vulnerable zones
- 75 % of vulnerable zones located < 200 m of river network



Vulnerability of water quantity at drinking water source

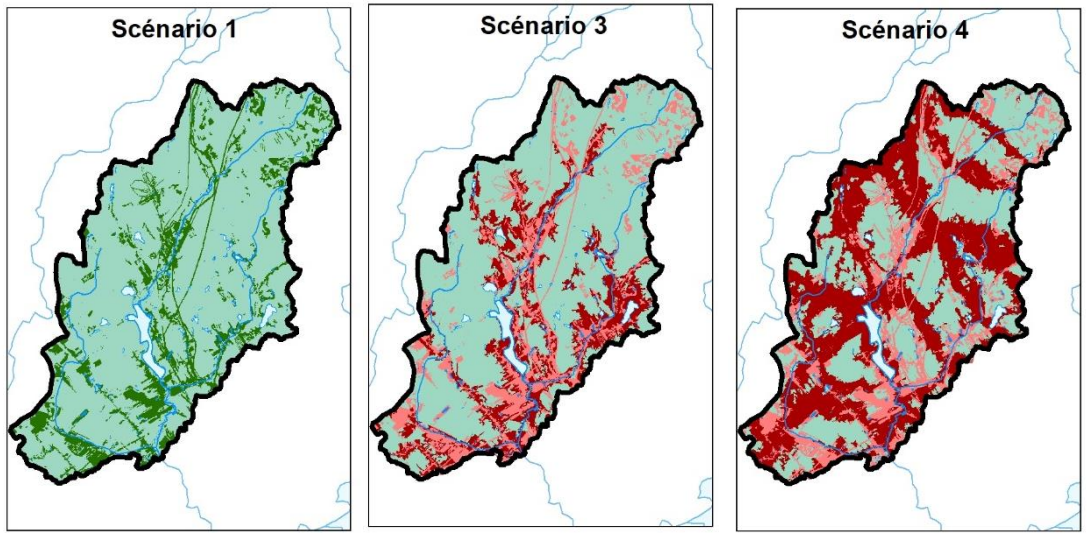
- Average recharge : 502 mm/yr = 36 % of annual precipitations
- 41 % of the area represents 80 % de total watershed recharge



What about the future ?

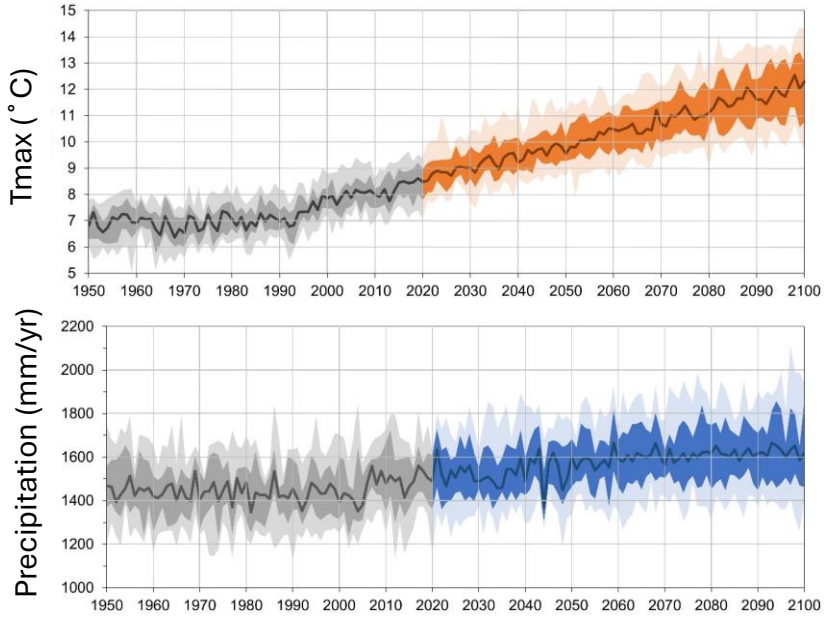
Impact of **land use** on water resources

Several scenario tested



Impact of **climate change** on water resources

CMIP6 scenarios



For both, change analysis in terms of :

→ water balance components

→ river discharge (average, low-flow and flood)

→ piezometric levels

In conclusion

An applied research project initiated by Quebec City.

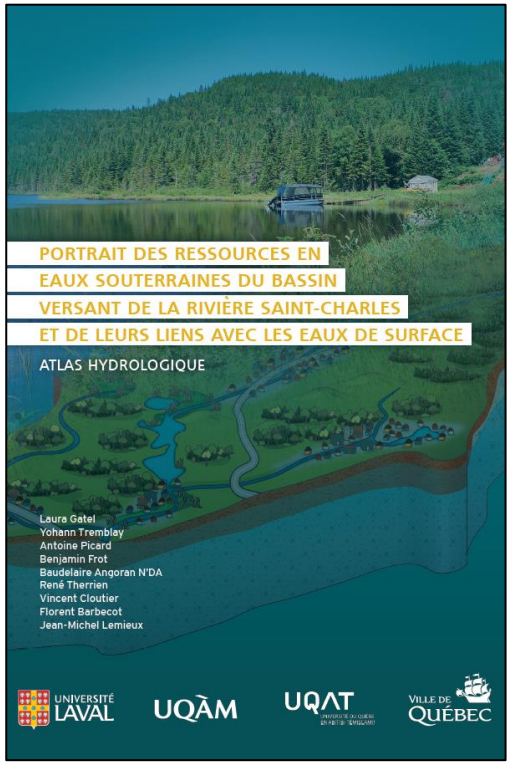
The project took into account the interactions between surface water and groundwater in order to ensure a better protection of the water source.

Results have been shared with a knowledge-sharing workshop with city professionals

Innovative project that can be replicated in other Canadian watersheds

- Requires a lot of data (possible thanks to the PACES groundwater knowledge acquisition program)
- Requires staff trained in modelling

Hydrological atlas



Story map

https://storymaps.arcgis.com/stories/179b86fca3cd4e828026660ad292cfe7

OneWater (France) et Water4All (UE): Two initiatives promoting FAIR Water Data

Sylvain Grellet

15/01/2025 - National Dialogue on Groundwater (NDGW) / Dialogue national sur les eaux souterraines (DNES) - Jan. 2025

With support from OneWater and Water4all members

Context

- OneWater : French research project
  - Référence ANR-22-PEXO-0009
  - https://www.onewater.fr/
- Water4all: Water security for the planet : European (EU) partnership
  - European Commission: Directorate-General for Research and Innovation, Horizon Europe strategic plan 2021-2024, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/083753
  - https://www.water4all-partnership.eu/
- Same projects overall pattern
  - Core Group : with several identified topics: domain & IT
  - Complemented by several calls for projects
- Shared
  - Discussions/Work
  - Teams (esp. FAIR Data)

OneWater
Eau Bien Commun
PROGRAMME NATIONAL DE RECHERCHE SUR L'EAU

2022 –> 2032

- 53 millions €, 10 years French research programme (ANR)

- Core Group -> targeted projects (https://www.onewater.fr/en/projects/targeted-projects)
  - Improving past (20th century to present) and present hydroclimatic knowledge to better anticipate future changes (PC2)
  - Experimenting and testing on site, especially in Living Labs (PC3)
  - Using the water quantity/quality footprint concept to review the EU Water Framework Directive monitoring network (PC4)
  - Examining the feasibility of an Aquatheque (PC5)
  - Testing solutions at demonstration sites (PC6)
  - Accompanying socio-ecological transitions (PC7)
  - Developing a OneWater Data platform (PC8)

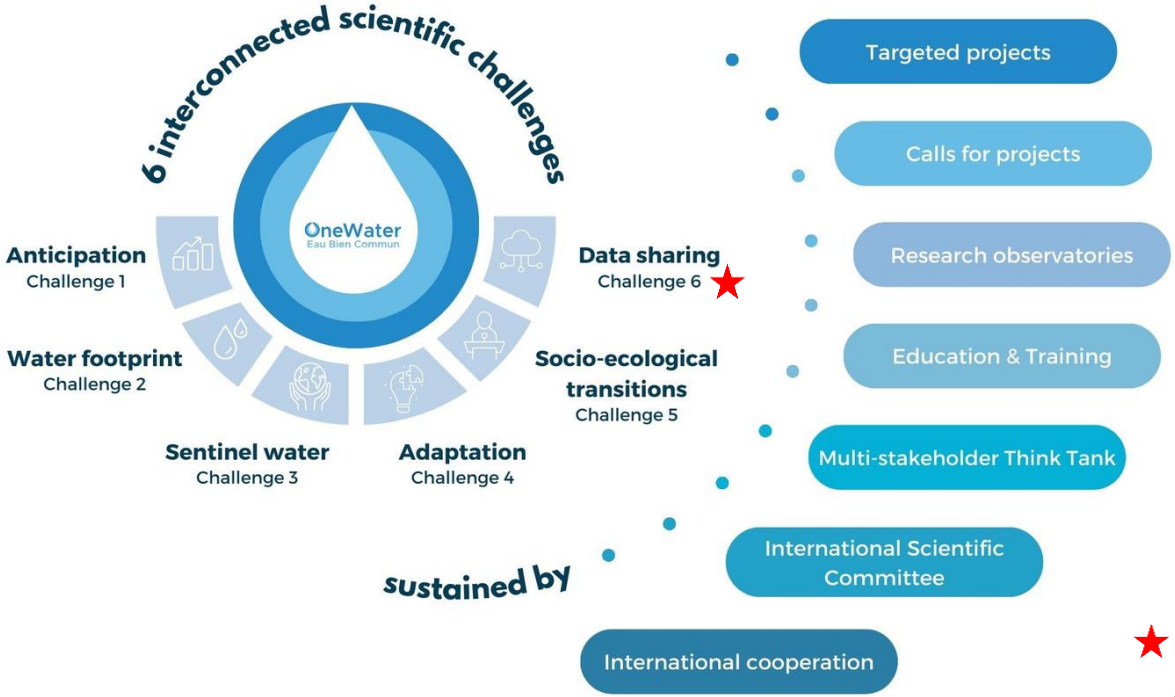
- Calls for project targeted projects

For the 1st call (https://www.onewater.fr/en/projects/projects-onewater-calls-proposals)

  - ALIQUOT : Environmental nucleic acids, sentinel molecules for continental hydrosystems
  - DEESAC: Groundwater sustainability in the exploitation of confined aquifers
  - K3: impact of global changes on the water resources in karstic socio-hydrosystems: vulnerability, sensitivity, management

OneWater Eau Bien Commun / PROGRAMME NATIONAL DE RECHERCHE SUR L'EAU — RÉPUBLIQUE FRANÇAISE — FRANCE 2030

- To help accelerate transitions a measure impacts of global changes on socio-ecological systems => through 6 scientific challenges traversing the various projects



F Findable A Accessible I Interoperable R Reusable

OneWater
Eau Bien Commun
PROGRAMME NATIONAL DE RECHERCHE SUR L'EAU

- Huge data sharing challenge complementing the domain (water) challenges
  - Between all projects: core projects & funded projects
  - Encompassing public organisations (French Water Information System, ministries) and research data (Research Infrastructures, research labs, …).

⇒ Solution Through FAIR Data / Interoperability standards

Water4All
Water security for the planet

2022 –> 2031

- https://www.water4all-partnership.eu/

Partners

Budget

Phase 1: 86M€, 26M€ from the EC
Phase 2 : from June 2024: 103 M€, 31M€ from the EC

For the decade : 420 M€ expected (126 M€ from EU)

33 countries

- 23 EU Member States
- 10 non EU countries

Water4All
Water security for the planet

- Core Group -> Pillar

E. Internationalisation

- Developing international cooperation agreements
- Engaging with UN Water & other international stakeholders
- Developing innovative tools for cooperation

B. Research & Innovation Development

- Joint transnational calls
- Thematic annual programming
- Young researchers calls
- Demo /Transfer calls

A. Joint Vision & SRIA

- SRIA Development
- Mapping of programmes and impacts
- Development of synergies / Dissemination

**SRIA: Strategic Research Innovation Agenda*

D. Demonstrating Solution Efficiency

- Water Living Labs (WoLLs) & demos atlas
- Network of WoLLs/demos and roadmap for demonstration implementation
- Support to development of new WoLLs
- Market uptake support
- Liaising with investors

C. Science - Policy - End-users Interface

- Knowledge hubs, policy working groups
- Support to start-ups creation
- Vocational training
- Capacity building on systemic thinking
- Link to research infrastructures
- Toolbox for managing water data ★
- Developing open science & OpenAccess

★ Findable Accessible Interoperable Reusable

- Calls for project
  - https://www.water4all-partnership.eu/publication/booklet-funded-projects-2022-call

Min. of 3 countries, max 7 partners, public-private

1 **2022**
27 projects
27 M€
"Management of water resources: resilience, adaptation and mitigation to hydroclimatic extreme events and management tools"

2 **2023**
34 M€
(6 M€ EC)
"Aquatic Ecosystem Services"
(59 pre-proposals in step 2)
Knowledge Hub, early carrier researcher

3 **2024**
32 M€
"Water for Circular Economy"
(pre-announcement: July. Open: Sept.)

4 **2025**
32 M€
"Water and Health"
(pre-announcement: July. Open: Sept.)

.....

"Additional Activities"

- Identification of Research gaps, needs
- International Cooperation
- Training and capacity buildings, PhD Schemes
- Observatories and R&I infrastructures
- Support to SMEs (EU incubator, transfer…)
- Water Oriented Living Labs
- Platform of solutions for water management (including ecosystem restoration)
- Open data, open science (knowledge hub, open database) with a transdisciplinary approach

- Again, data sharing challenge complementing the domain (water) challenges
  - Between organizations involved and also involving the funded projects
  - Encompassing public organization, water research data, aggregated EU datasets, …

  ⇒ Solution : Through FAIR Data / Interoperability standards

- Connection with the entire Water domain
  - not limited to European organizations,
  - R&I from pure water ‘on the field’ to IT solutions,
  - training,
  - policy support,
  - etc…

Data aspects : Shared elements between both

- Activity period
  - Long term project framework : ~ 9 & 10 years
  - Just started -> gives time to progressively enhance practices
- Funding
  - A decent funding to do decent work provided we sync activities properly
- Scope
  - A mixture of public organization and research data => allow to help unite both world
- Challenges
  - IT/FAIR aspects are just the visible tip of the Iceberg, core is the motivation for data exchange
  - Public / Research organizations don't have the same incentives for data sharing: some "my precious"* syndromes + many ad'hoc technical/semantic approaches whereas in EU where we have several open data/open science legislations

* *my precious*

https://lotr.fandom.com/fr/wiki/Gollum

Data aspects : Shared elements between both

- Work philosophy : try to foster a FAIR Water Data Ecosystem

  = standards, implementation in tools, training for the community

- Topic -> water
  - Classic reference features: river networks, aquifer systems
  - Observation and monitoring systems
  - Could also embark other water information system aspects (waste water, industry, bathing, …)

⇒ opportunity to define shared standards/Best Practices, associated tools & training to share water data in FAIR way

⇒ opportunity to deploy, test, enhance, communicate, train on OGC standards (HydroDWG, OMS, API – Features, ST API etc…) in a coordinated approach

? FAIR Water Data ?

- We've tried to foster Open Data since the 2000's with some results
- now 'FAIR' coined by the research community is picking up the baton
  - => These should not be put back to back as ~ 90% are the same
  - => Let's build on both to favor common shared practices for the Water community as whole

- Building & enriching existing standards for that FAIR Water Data ecosystem
  - OGC standards not only to put dots on maps ☺ lots of domain, and observation in there

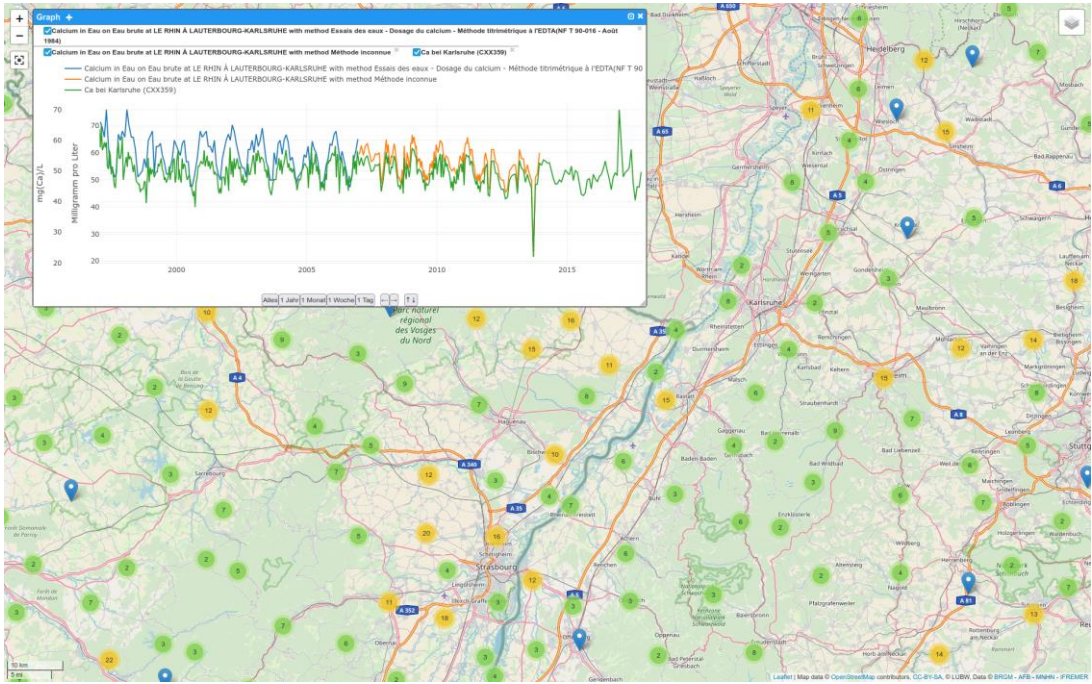
  ⇒ link with the OGC Hydro Domain Working group
  - ISO standards for geospatial data
  - W3C : standards for the web / web of data
  - RDA + Go FAIR work : FAIRness
  - + previous existing exercises already leveraging on them (ex : in EU, INSPIRE

- Linking with various countries/organizations already involved in that journey
  - Again through the OGC Hydro Domain Working Group & bilateral work
  - Ex : WMO, UNEP, IGRAC, Internet of Water, Canada water agencie, many EU countries and projects

Some realizations

- Sharing Surface/ground water quantity/quality observations
  - Contribution to the OGC-WMO-UNESCO Water Quality Interoperability Experiment
  - Full demo presentation here – OGC Member Meeting 2024 June 18th
  - Water Quality IE reference point : https://github.com/opengeospatial/WaterQualityIE
  - Test web client

Surface water quality, *ex-situ*, France - Germany

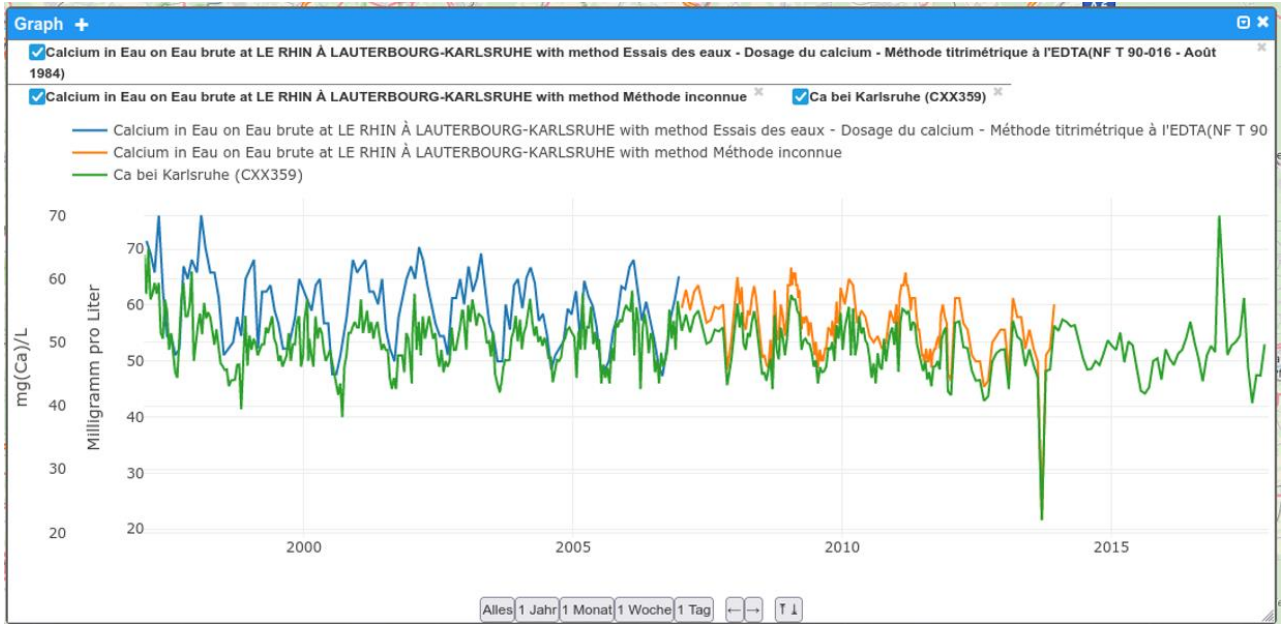


Some realizations

- Sharing Surface/ground water quantity/quality observations
  - Contribution to the OGC-WMO-UNESCO Water Quality Interoperability Experiment

  => Engineering Report being finalized, planned work to become an OGC/WMO Best Practice
  - Test web client

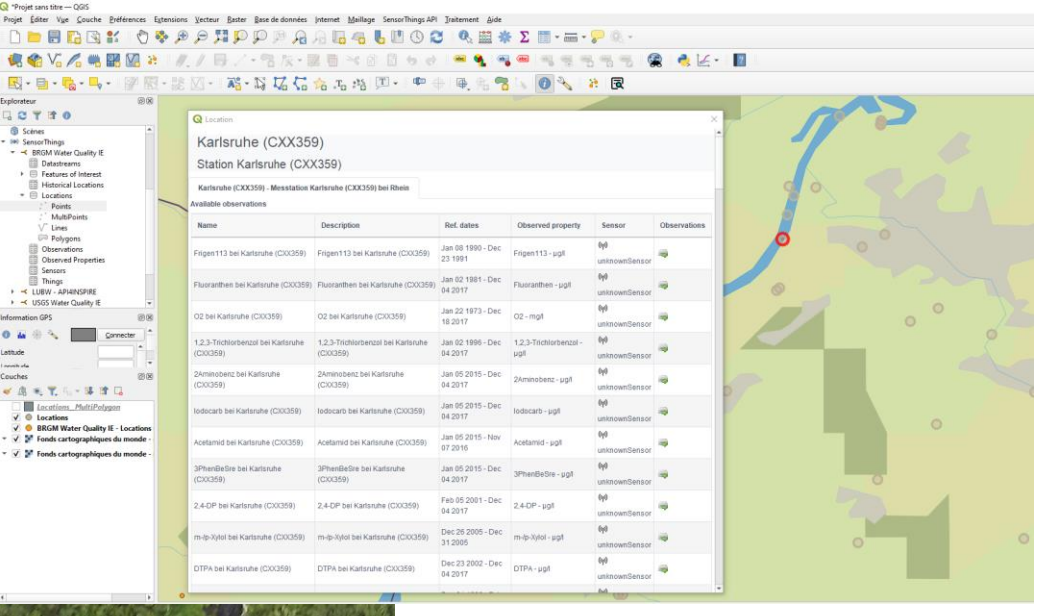
Surface water quality, *ex-situ*,
France - Germany

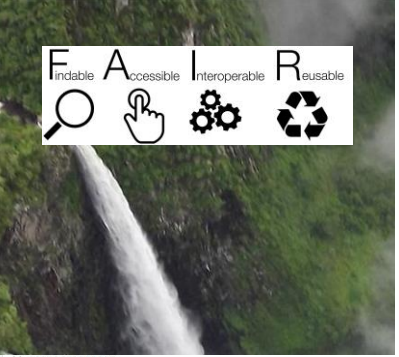


Some realizations

- Sharing Surface/ground water quantity/quality observations
  - Contribution to the OGC-WMO-UNESCO Water Quality Interoperability Experiment
  - Test desktop client -> it works as well

Surface water quality, *ex-situ*,
France – Germany : same
Sensorthings API endpoint





Some realizations

- Sharing Surface/ground water quantity/quality observations
  - Disclaimer: behind the scene of course the content is standardized ☺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    "symbol": "mg/L",
    "definition": "mg/L"
  },
  "observedArea": {
    "type": "Point",
    "coordinates": [
      -83.51139,
      42.10036
    ]
  },
  "phenomenonTime": "2006-05-18T10:00:00Z/2006-11-27T10:00:00Z",
  "properties": {
    "ActivityIdentifier": "21MICH_WQX-821523_7/28/2016",
    "ActivityMediaName": "Water",
    "ActivityTypeCode": "Sample-Routine"
  },
  "resultTime": "2006-05-18T10:00:00Z/2006-11-27T10:00:00Z",
  "Observations@iot.count": 4,
  "Observations": [
    {
      "@iot.selfLink": "https://wqp.wqie.internetofwater.app/FROST-Server/v1.1/Observations('91cef6b4-2dc1-11ef-a098-a7aa9b8c2d4d')",
      "@iot.id": "91cef6b4-2dc1-11ef-a098-a7aa9b8c2d4d",
      "phenomenonTime": "2006-05-18T10:00:00Z",
      "resultTime": "2006-05-18T10:00:00Z",
      "result": 8.39,
      "resultQuality": "Final",
      "parameters": {
        "modified": "2016-01-04T15:21:23",
        "publisher": "STORET",
        "status": "Final",
        "valueType": "Actual"
      }
    },
```

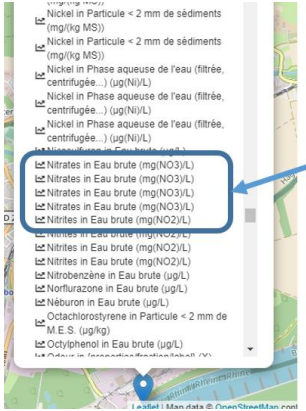
Some realizations

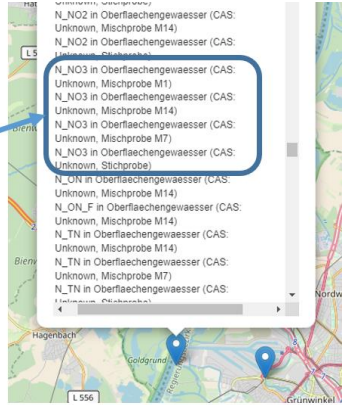
- Shared vocabularies

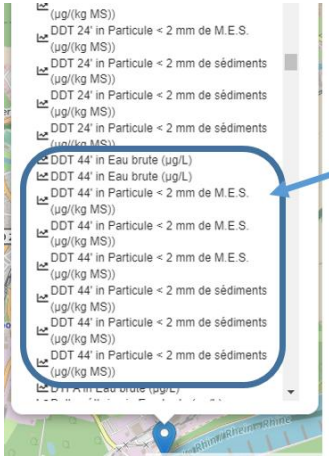
Comparing data from 2 French – German stations on the Rhine close to each other

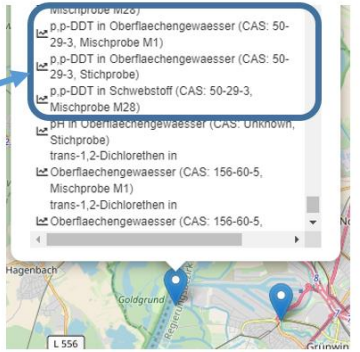
French-OFB:
LE RHIN À
LAUTERBOURG-KARLSRUHE
02047300

German-LUBW:
Karlsruhe (CXX359)



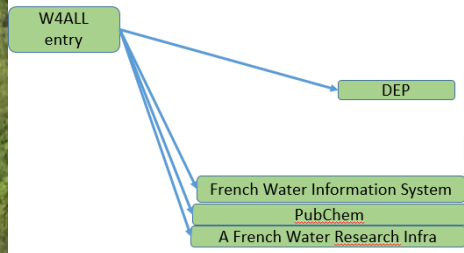






Some realizations

- Shared vocabularies
  - Finding & documenting equivalence using semantic web best practices



No mapping to German LUBW codeList, as none found yet

Vocabularies Home > Vocabularies > Observed properties > nitrate concentration

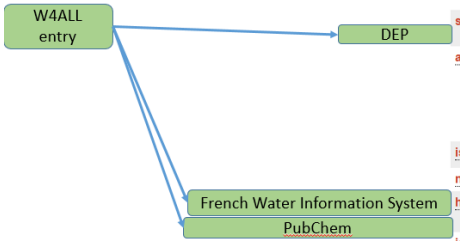
nitrate concentration

IRI https://data.water4all-partnership.eu/ncl/ObsProp/620

Type Quantity Kind, Concept, Chemical Observed Property, Groundwater Observed property

Observation de la quantité de nitrates exprimée par une concentration massique ou molaire

category	https://data.geoscience.fr/ncl/structure/Category/4
unit	https://data.geoscience.fr/ncl/uom/406 https://data.geoscience.fr/ncl/uom/49 https://data.geoscience.fr/ncl/uom/502 https://data.geoscience.fr/ncl/uom/525 https://data.geoscience.fr/ncl/uom/573
seeAlso	https://parameterlisten.miljoeportal.dk/parameter/2608abe8-a72d-4bee-8e49-93681252d8fe
alternative label	[NO3-]
is in scheme	Observed properties
notation	620
has related match	http://id.eaufrance.fr/par/1340 https://chem.nlm.nih.gov/chemidplus/rn/14797-55-8 https://w3id.org/ozcar-theia/c_7a8c53c6
is top concept in scheme	Observed properties
status	http://inspire.ec.europa.eu/registry/status/valid



No mapping to German LUBW codeList, as none found yet

Vocabularies Home > Vocabularies > Observed properties > 4,4'-DDT concentration

4,4'-DDT concentration

IRI https://data.water4all-partnership.eu/ncl/ObsProp/621

Type Quantity Kind, Concept, Chemical Observed Property, Groundwater Observed property

Observation de la quantité de 4,4'-DDT exprimée par une concentration massique ou molaire

category	https://data.geoscience.fr/ncl/structure/Category/4
unit	https://data.geoscience.fr/ncl/uom/502 https://data.geoscience.fr/ncl/uom/573
seeAlso	https://parameterlisten.miljoeportal.dk/parameter/3283527d-830b-401b-8267-2e241e928150
alternative label	[4,4'-DDT] xsd:string Clofenotane concentration en Dicophane concentration en concentration en dichloro diphenyl trichloroétane pp' fr concentration en pp'DDT fr
is in scheme	Observed properties
notation	621 xsd:string
has related match	http://id.eaufrance.fr/par/1148 https://chem.nlm.nih.gov/chemidplus/rn/50-29-3
is top concept in scheme	Observed properties
status	http://inspire.ec.europa.eu/registry/status/valid

Some realizations

- On-going support to the standards shaping a FAIR Water Data ecosystem
  - updates of

  - OGC Timeseries ML & OGC/WMO WaterML 2.0 – Part 1 : TimeSeries

  - update of OGC SensorThings API 1.1 => V2.0 highly through Water Quality IE

  - update of W3C SSN/SOSA
  - better integration of RDA I-ADOPT with W3C SSN/SOSA and ISO/OGC Observations, Measurements & Samples

- Planned support to FAIR Water Data standards and Best Practices
  - updates of

  - WaterML 2.0 – Part 5 : Water Quality after Water Quality IE report publication and the above mentioned updates

  - update of WaterML2.0 – Part 3 : Surface Hydrology Features to add a Logical Model + favour data exchange through recent OGC APIs

  - update of WaterML2.0 – Part 4 : GroundWater ML 2.0 to include Observations & Measurements update + favour data exchange through recent OGC APIs

⇒ Target : having a blue print to help setting up water information systems based on FAIR Water Data Standards

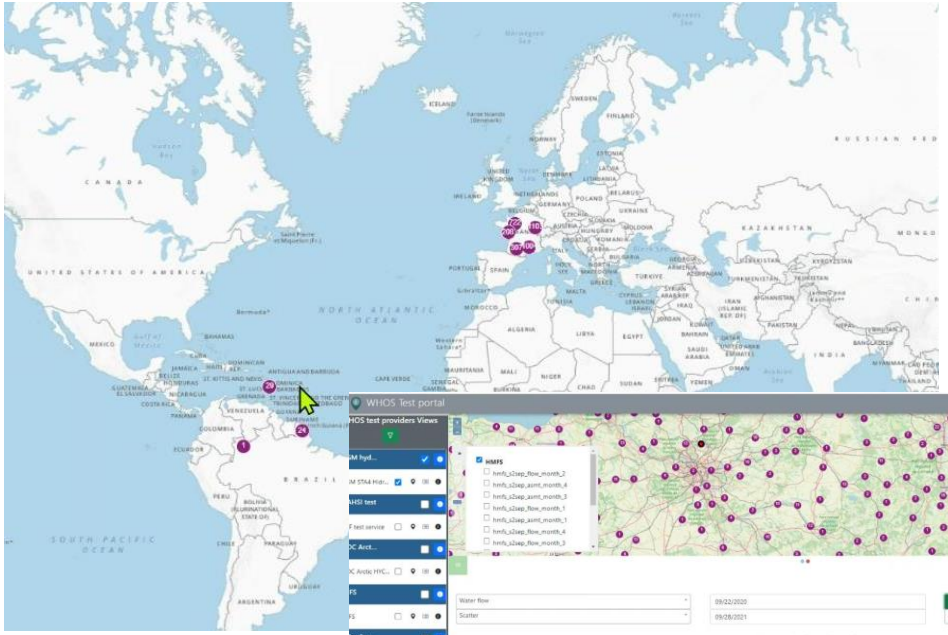
Some realizations

- Support to tools
  - Both for data provision (server) and consumption (client)
- Data Provision
  - Geoserver (Geospatial data) : Bug fixing & enhancements identified through the Water Quality IE
  - FROST (Observation, sample data) : Upgrade through Water Quality IE preparing the implementation of the V2.0 of SensorThings API
- Data consumption
  - QGIS (GIS) : native support of SensorThings API in QGIS Core
- Virtual Research Environment
  - Galaxy Tools : connection to/data sharing with OGC APIs & Services
  - Ex: exact same spirit as what is being testing in the OGC Open Science Persistent Demonstrator : https://www.youtube.com/watch?v=_rE2bOM2vgs

Some realizations

- Support to international organizations : WMO, EEA, UNEP, IGRAC etc..

Surface water quantity – France data ingested in WMO Hydrological Observing System (WHOS)

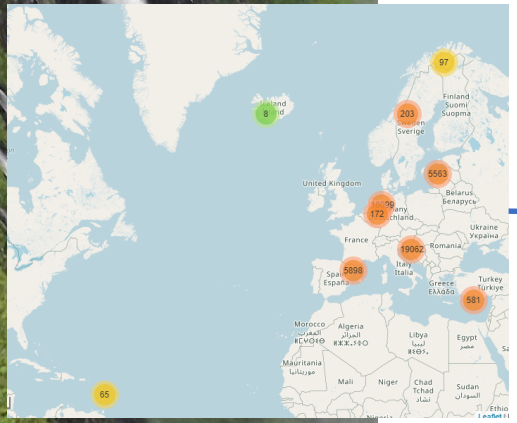


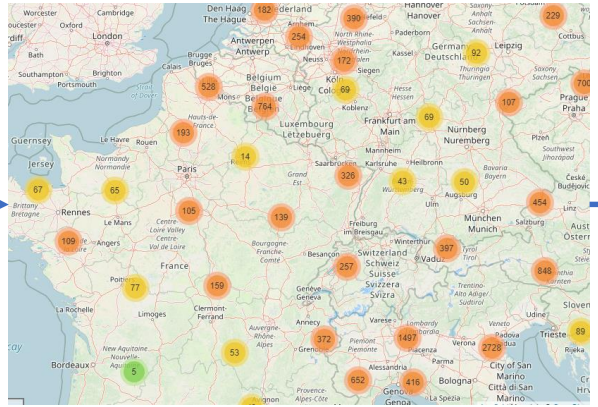
Being based on a **standard communication protocol**, it was very easy to test and integrate to WHOS in the way to the workshop!

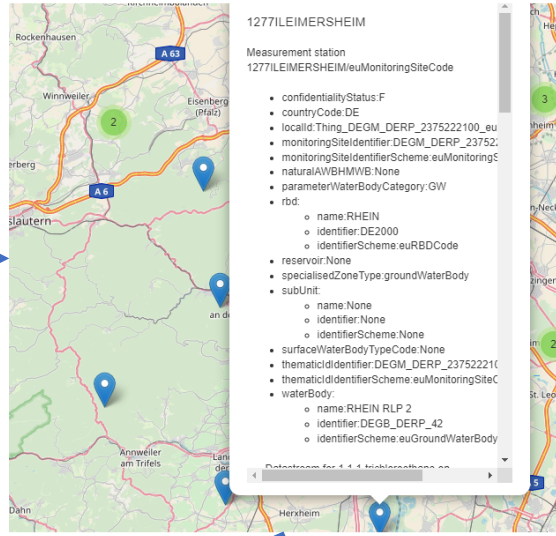
Description of the service and some suggestions are reported after preliminary integration tests in the next slides, with the **aim of further improving the connection** to WHOS.

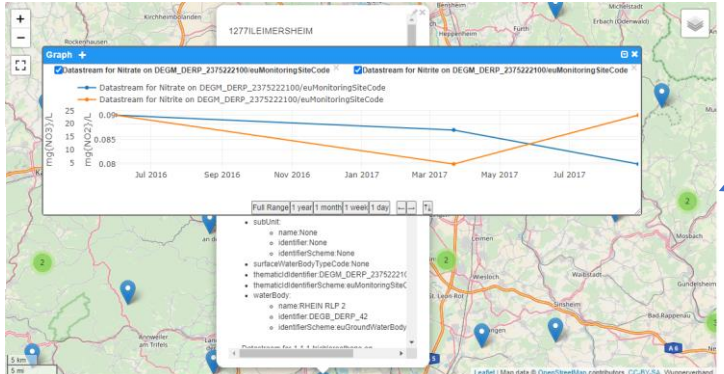
Some realizations

- Support to international organizations : WMO, EEA, UNEP, IGRAC etc





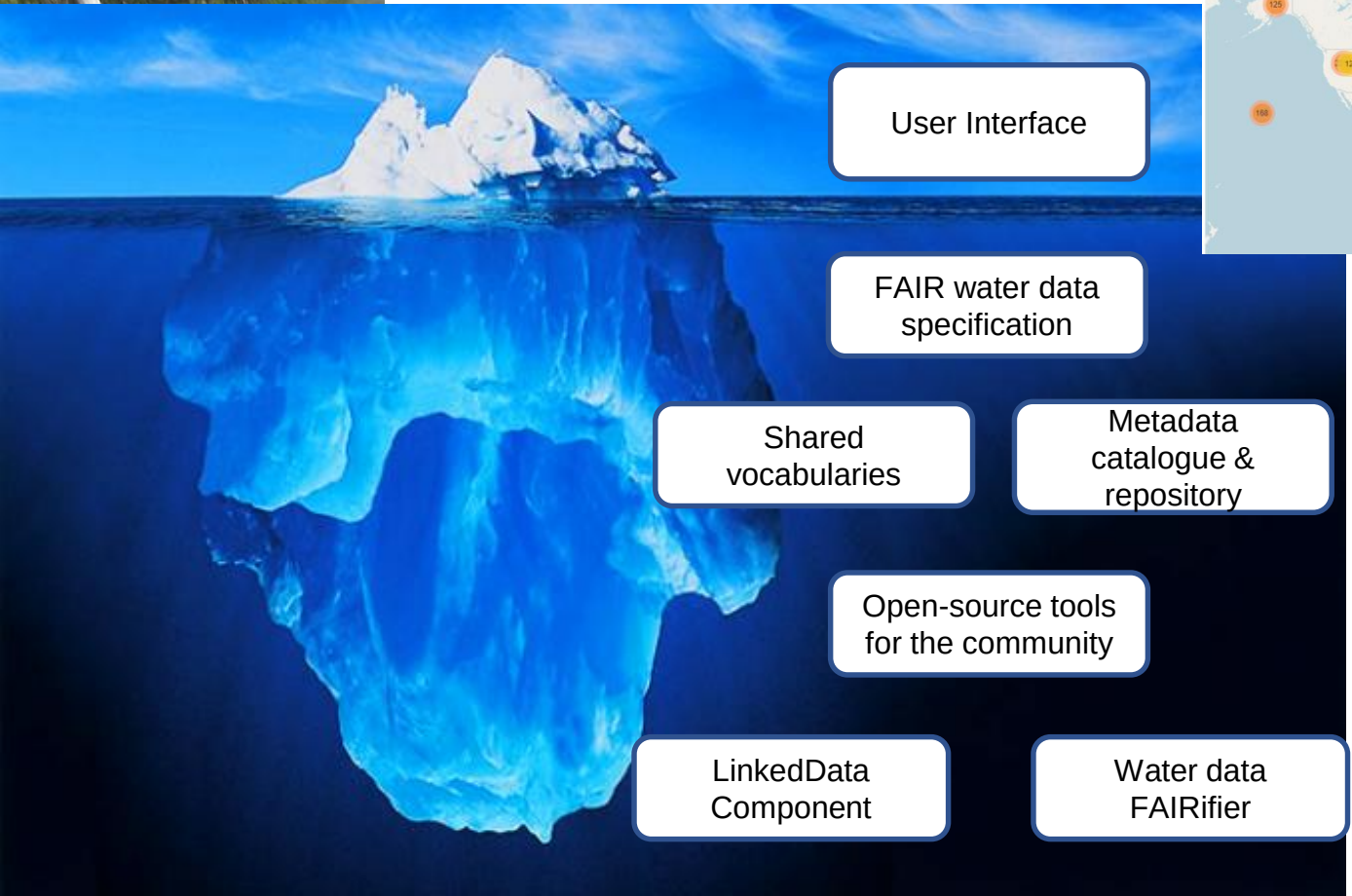




European Environment Agency (EEA)
WISE State of the Environment - Water quality (WISE-6)
61 Million+ water quality observations

Some realizations

Water Quality IE / Water 4 All



Thank you / merci

s.grellet@brgm.fr

https://www.onewater.fr/en/contact-us

https://www.water4all-partnership.eu/contact-us