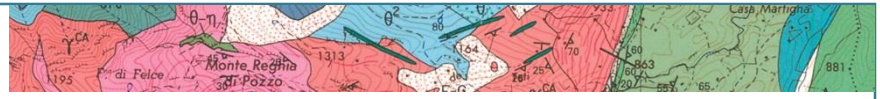
43rd IAH CONGRESS
25-29th September, 2016
le Corum , Montpellier, France



Karst GW resources assessment by application of the KARSYS approach

Plateau de Sault (France)

Vincent Bailly-Comte, Arnauld Malard, Bernard Ladouche, Cécile Allanic, Lucile Martel, Jean-Christophe Maréchal, Bernard Monod, Pierre-Yves Jeannin
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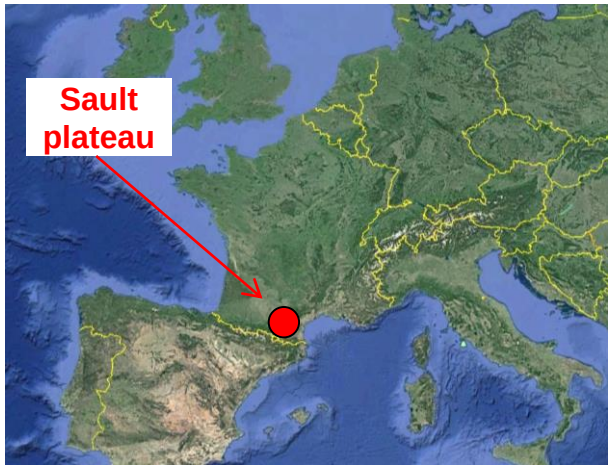
INTRODUCTION

> **Future deficit for drinking water around 15 000 m^3/days**

> **Karst GW resources poorly known and little exploited**

- How to quantify karst water resources?
- How much GW is available for human uses?
- How to protect and manage this resource?



> **~ 500km^2 at ~ 900 m asl**

> **Atlantic and Med. climatic influences**

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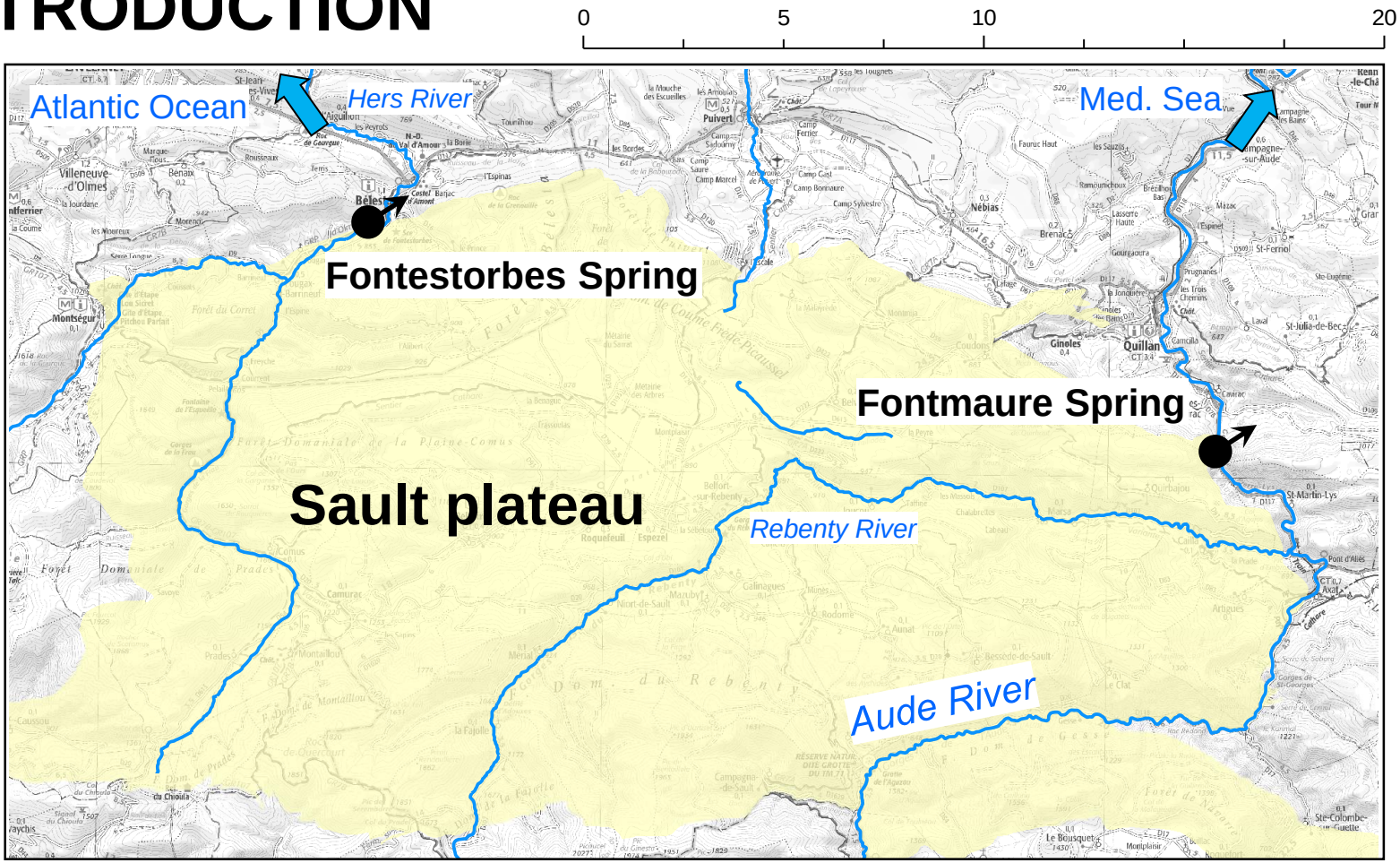
INTRODUCTION



> **2 main karst systems: Fontestorbes and Fontmaure**

- GW divides? (Atlantic vs. Mediterranean basin)
- Water exchanges ? Karst/River exchanges? etc.

Method limiting user-influenced interpretation

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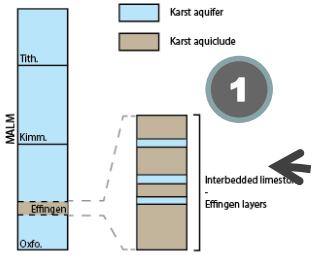
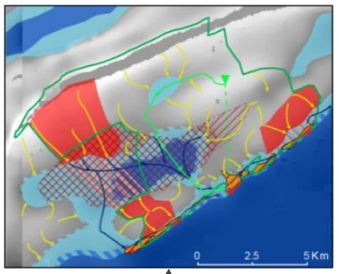
KARSYS : 4 steps

Jeannin et al., 2013
Malard et al., 2015

Hydro Stratigraphic model

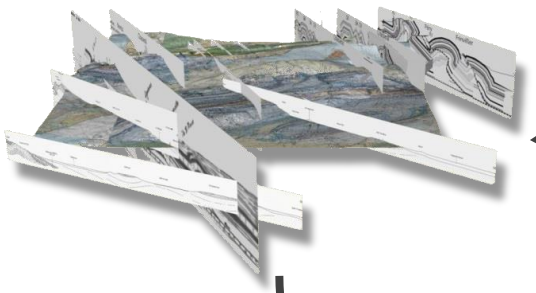


2D Maps

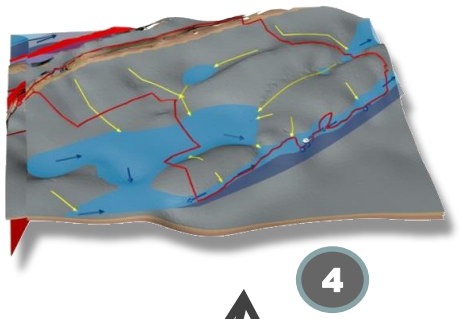


Iterations (n)

3D geological model

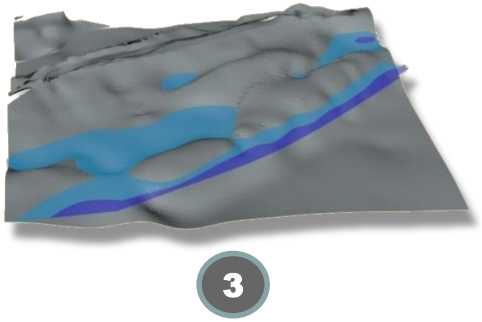


Database



3D Karst-flows model

3D hydrogeological model



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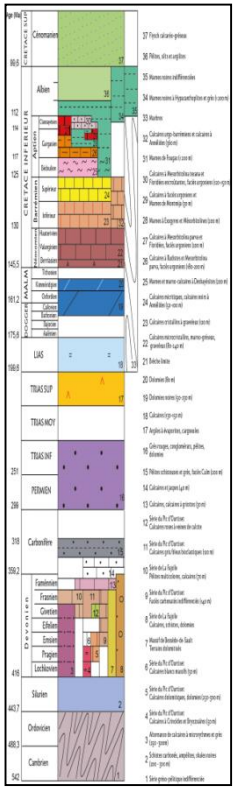
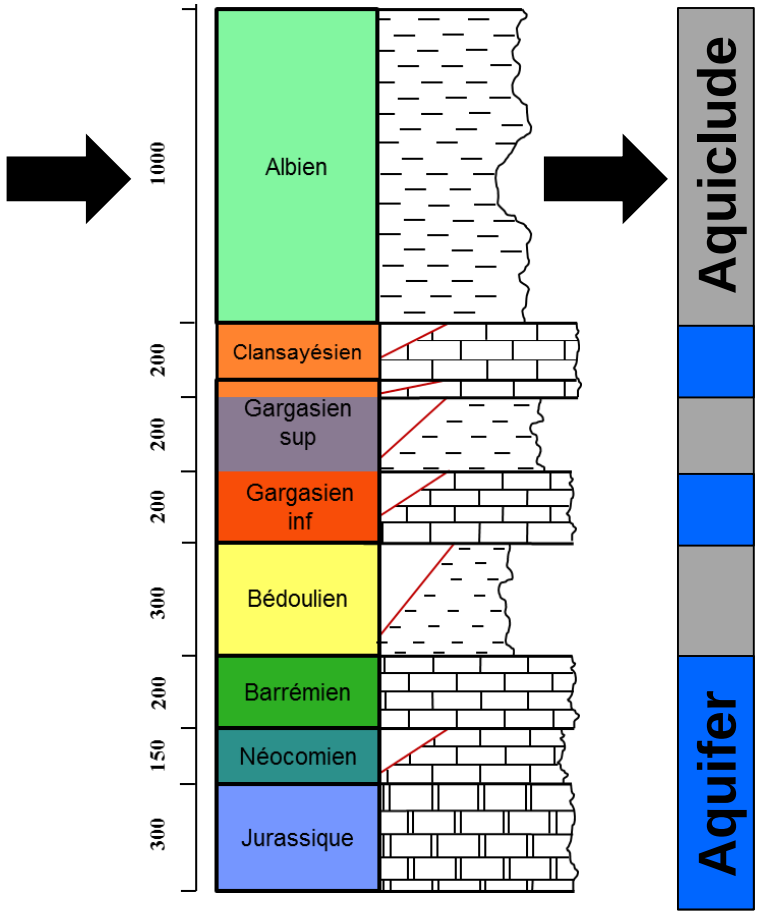
STEP #1: Hydrostratigraphic model

> Aquifer vs. aquiclude formations

As a first step, each formation that can be karstified is considered as an aquifer





- Up to 3 aquifer units
- Sequences highly laterally variable!
- ⇨ 3D model split into 6 blocks using GeoModeller®

Allanic et al., 2016

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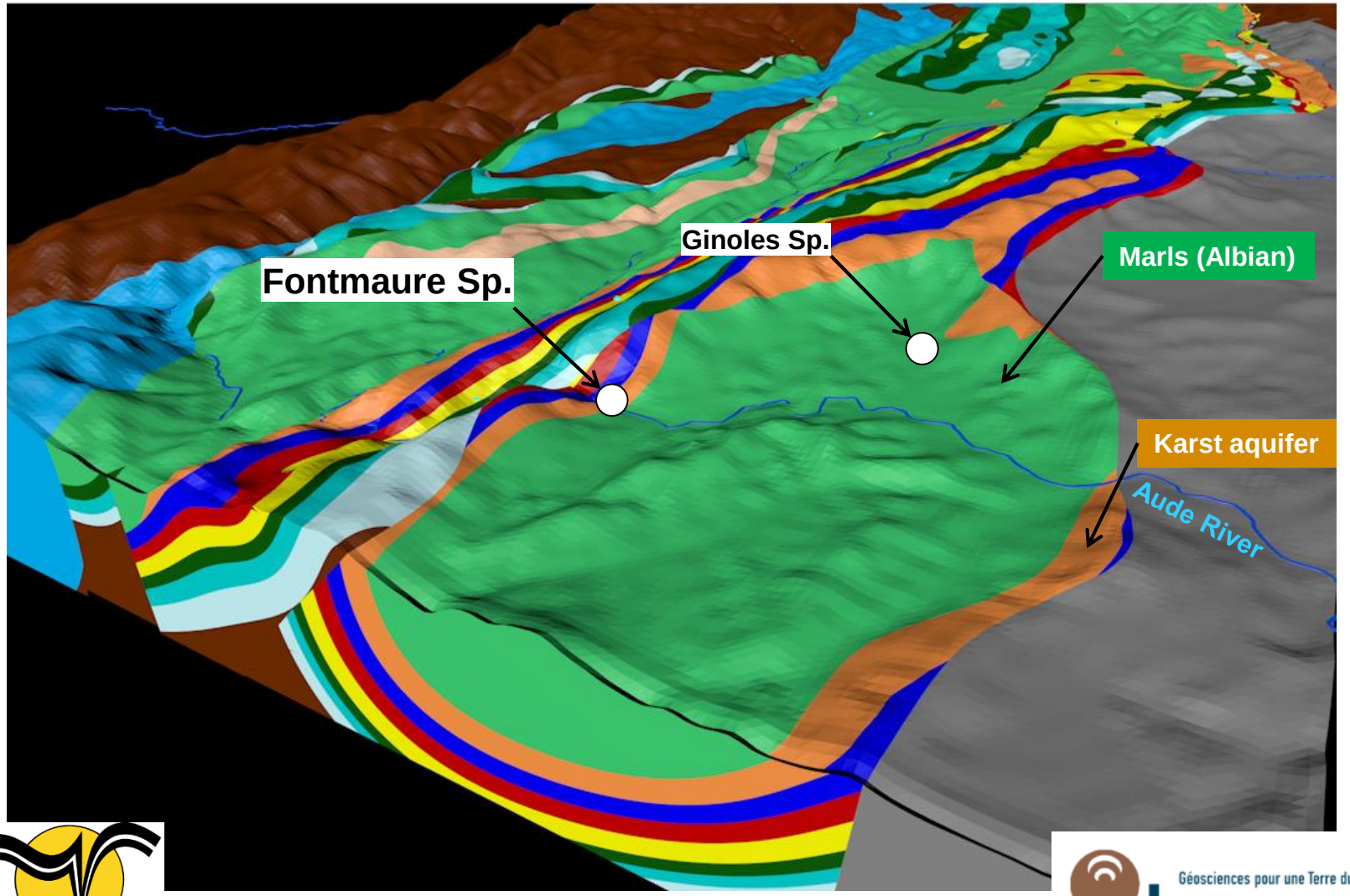
STEP #3: 3D Hydrogeological model



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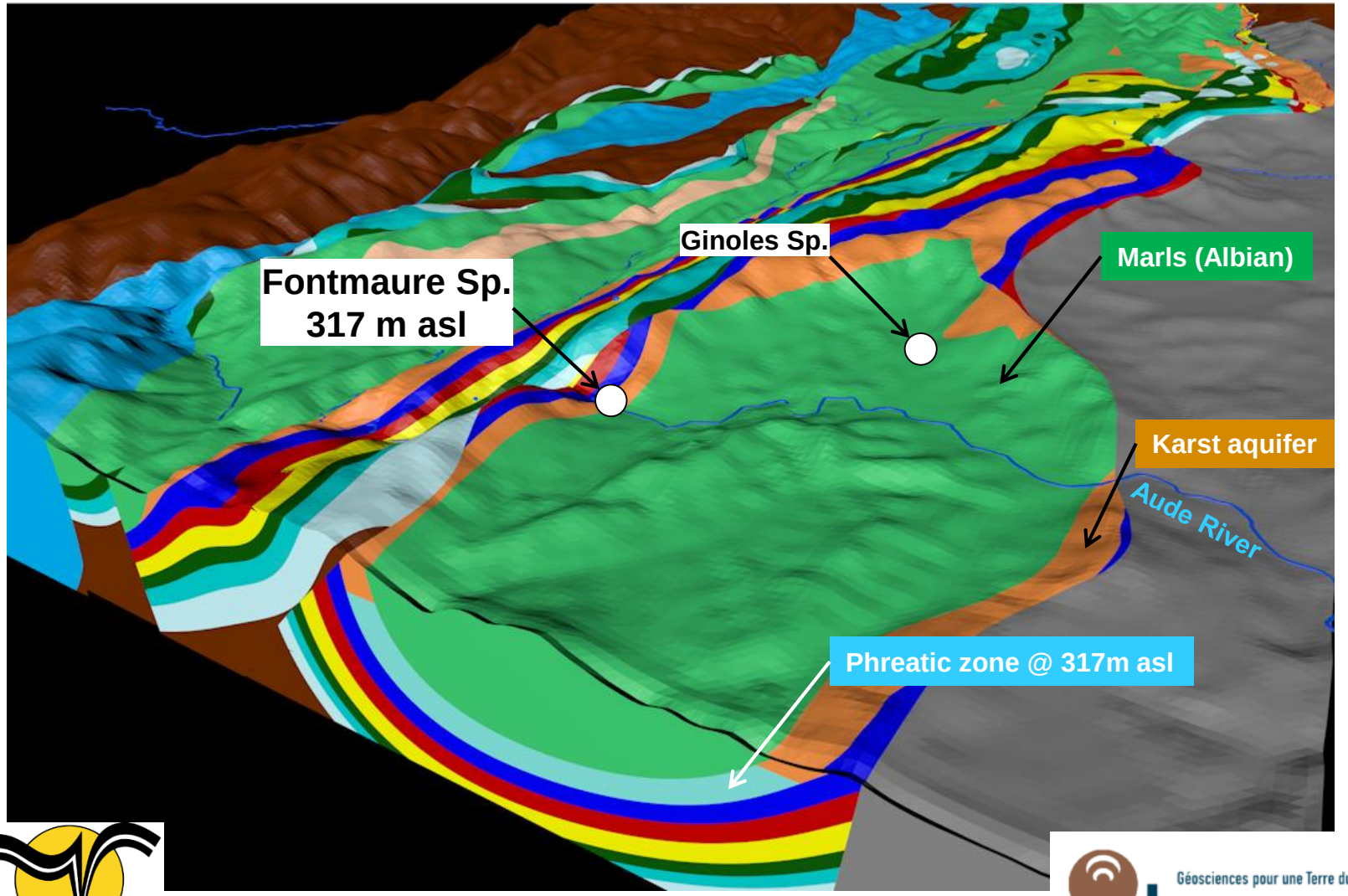
STEP #3: 3D Hydrogeological model



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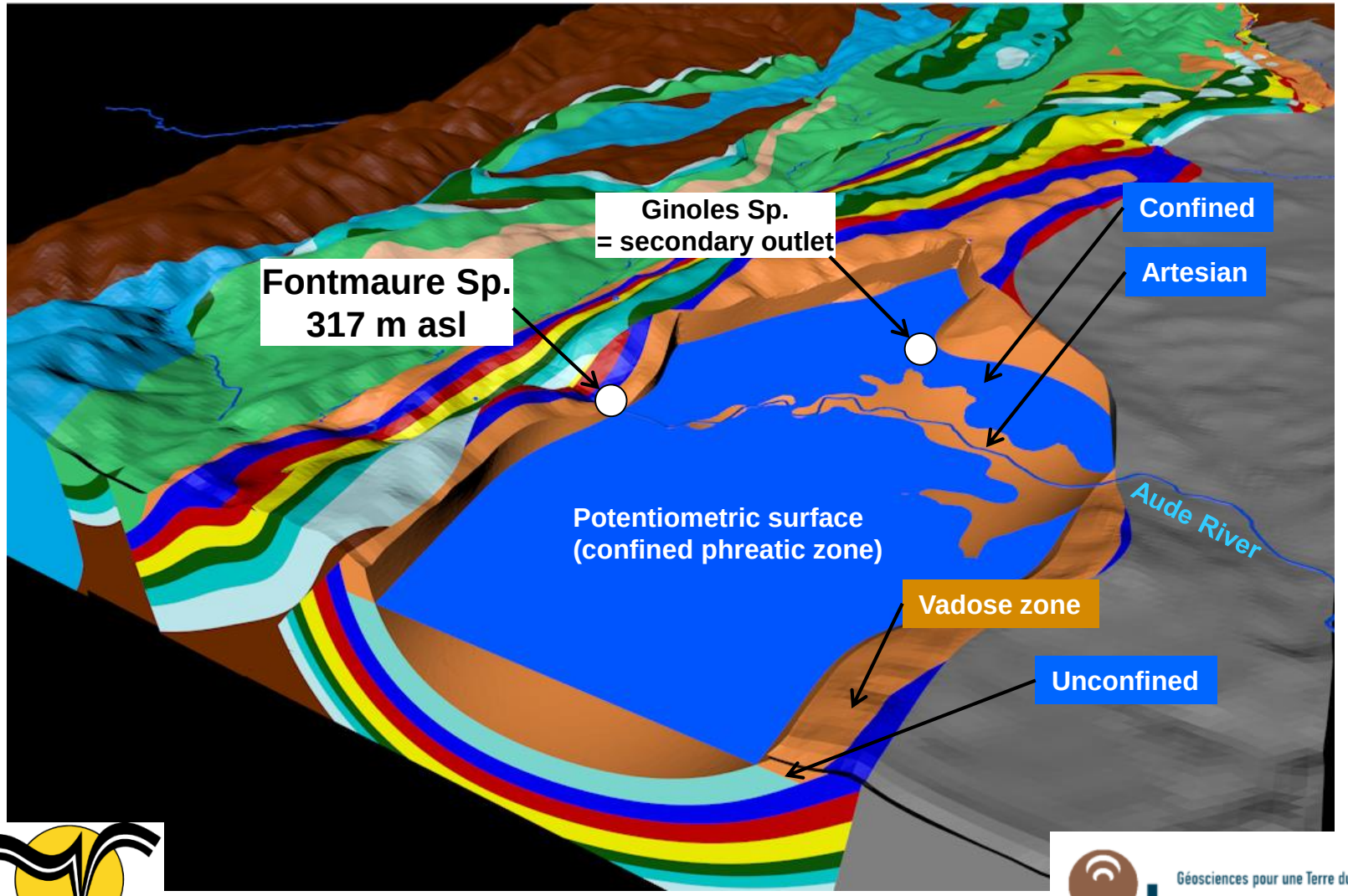
STEP #3: 3D Hydrogeological model



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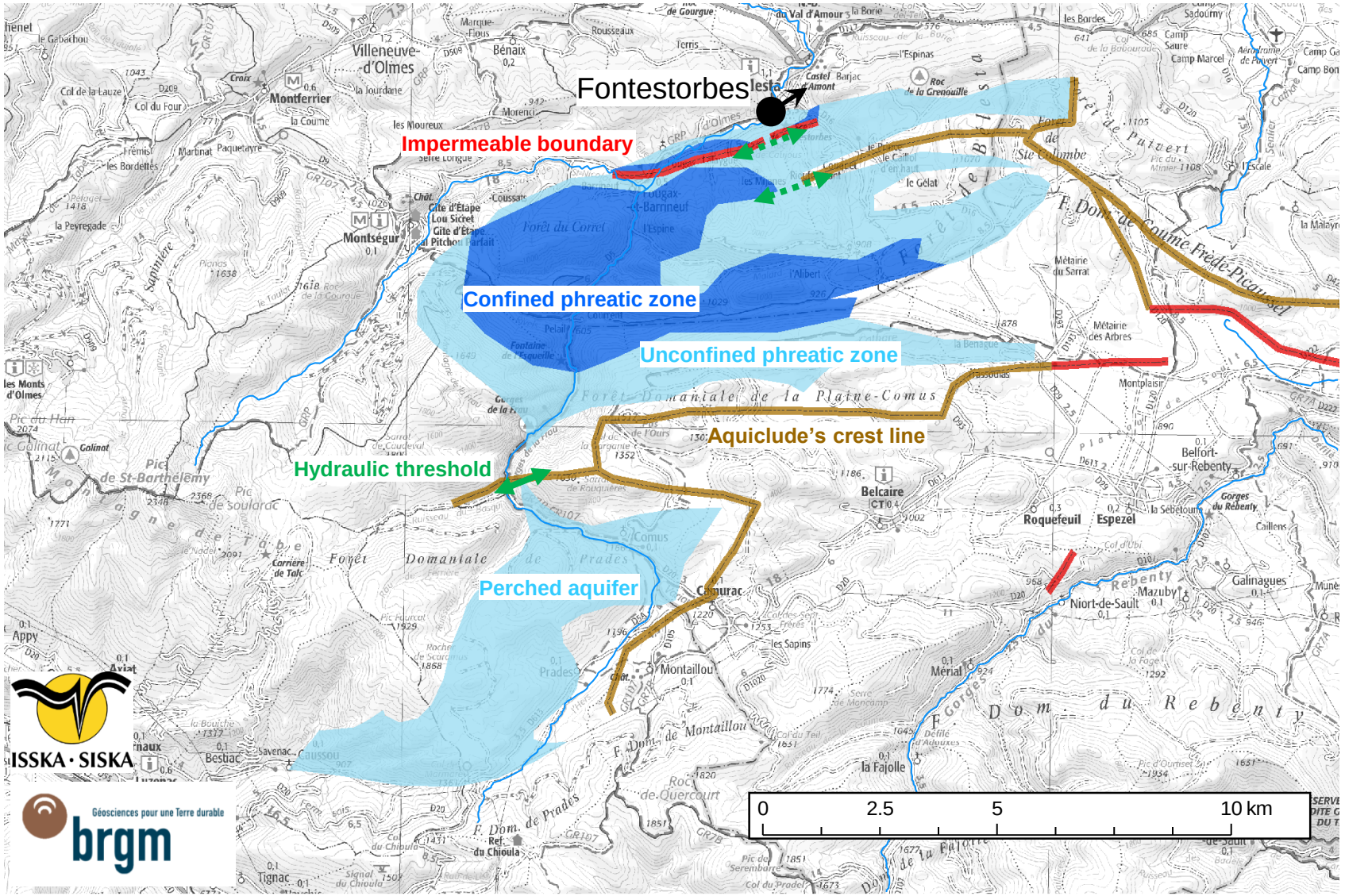
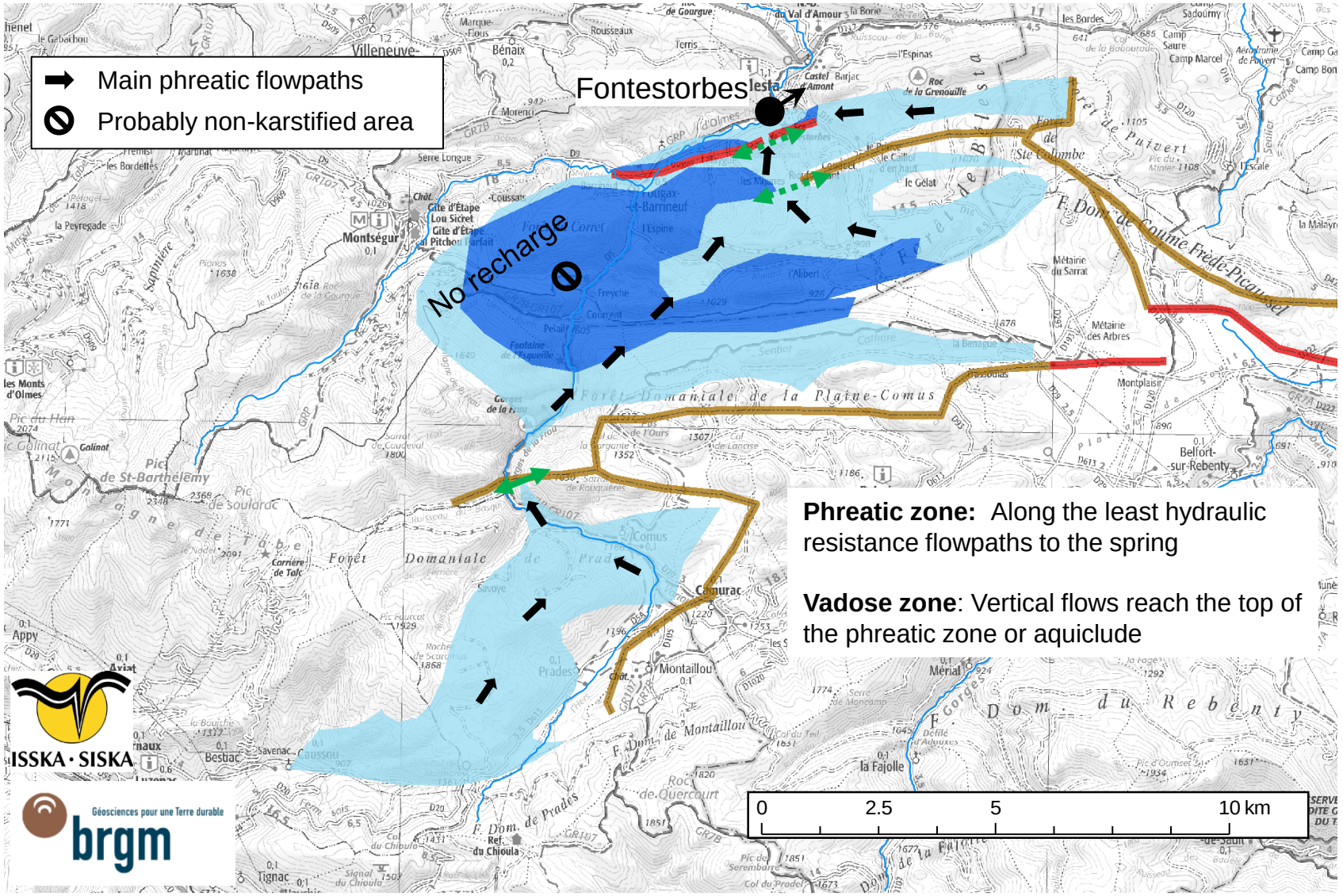
STEP #3: Map of vadose/phreatic zones

Ex. of Fontestorbes karst system



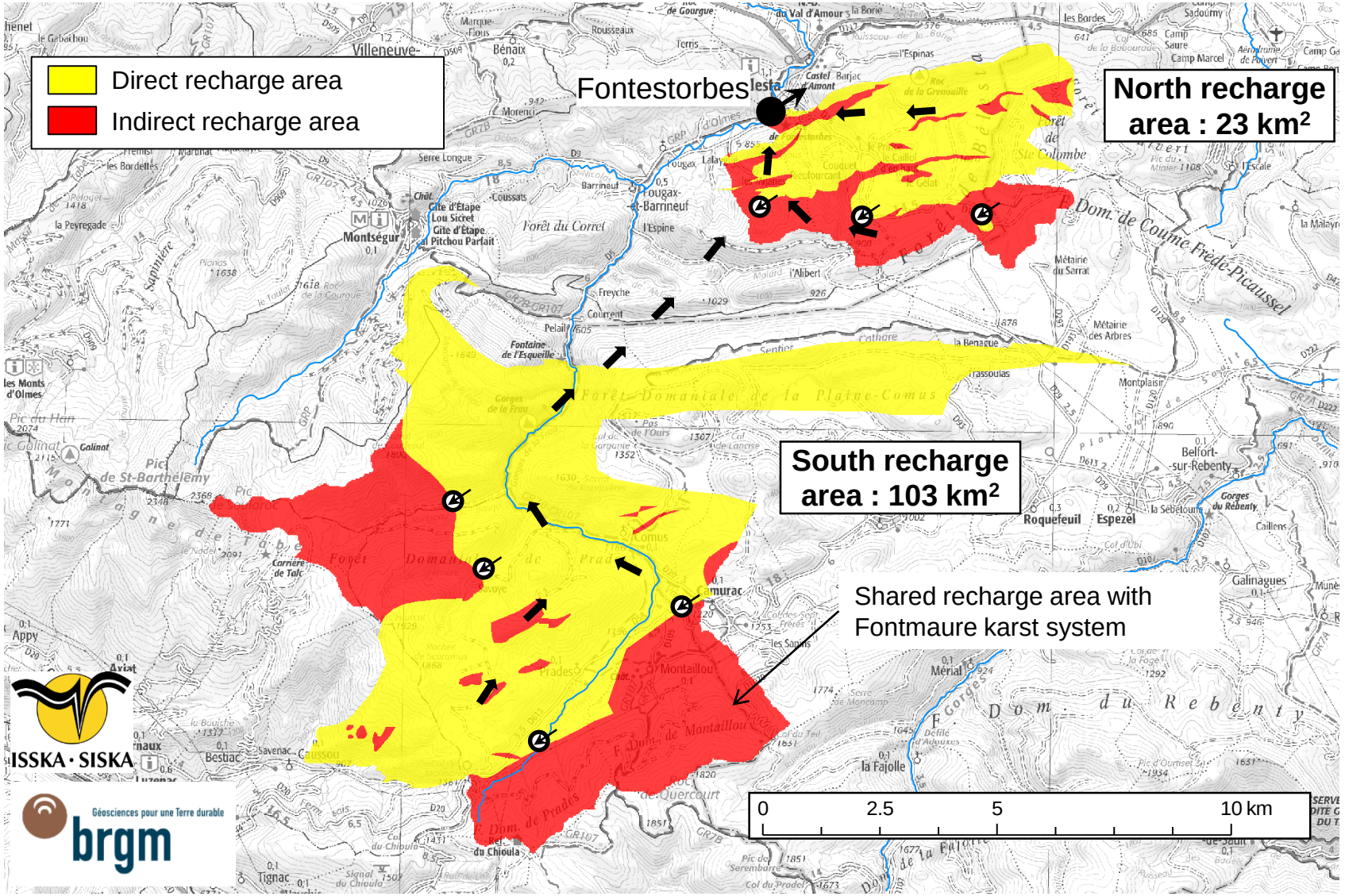
STEP #4: Map of main phreatic flowpaths

Ex. of Fontestorbes karst system



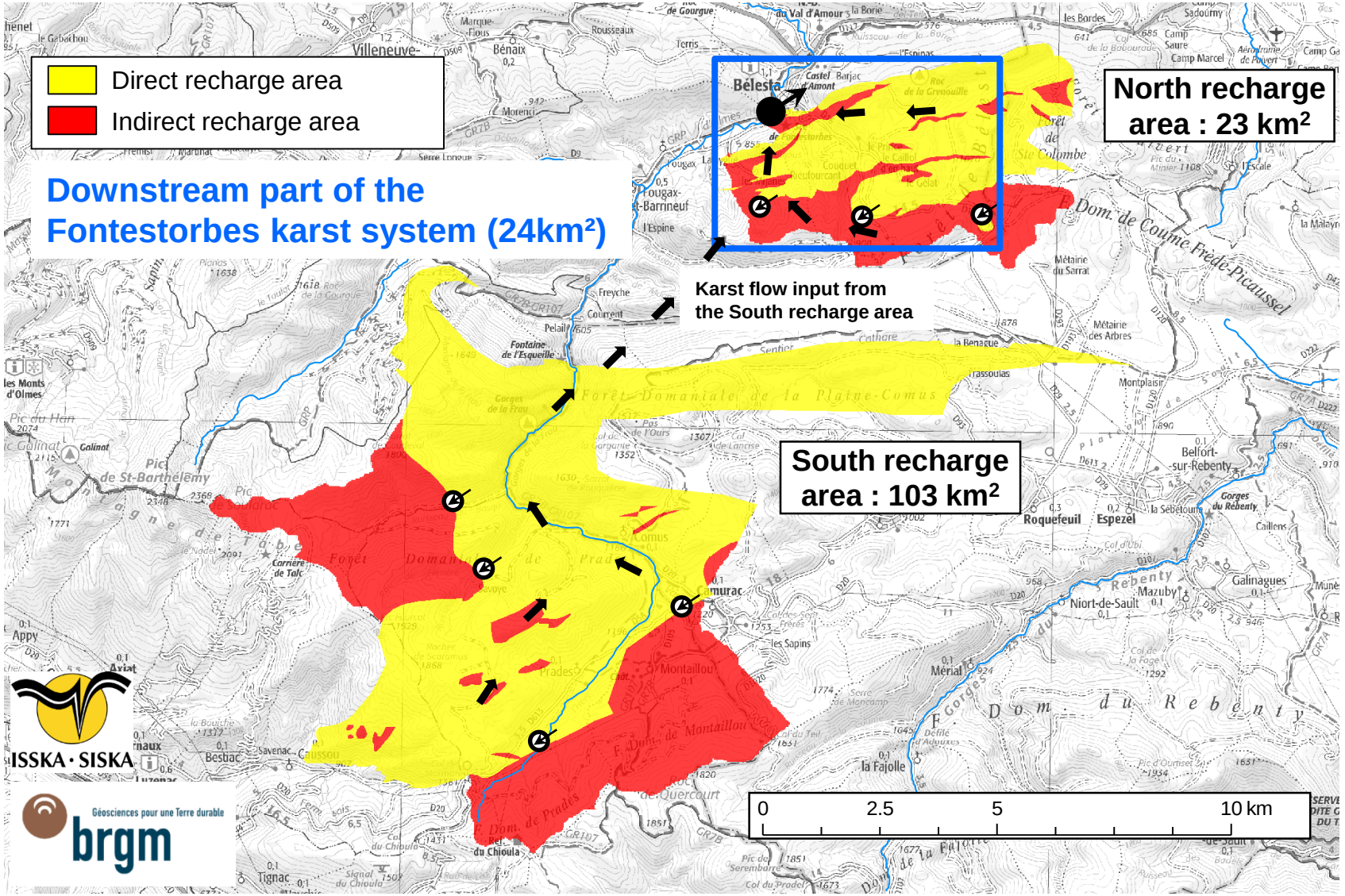
STEP #4: Map of recharge area

Ex. of Fontestorbes karst system



Karst conduit modeling / Model domain

Ex. of Fontestorbes karst system



Karst conduit modeling / Principles

Malard et al., 2015

> Current karst base level (non-polyphased)

> Baseflow conditions

> Hydraulic gradient

- Vertical in the “vadose zone” (including epikarst)
- Pseudo-horizontal in the phreatic zone

> Phreatic conduits

- Start from the downstream end of a vadose conduit
- Controlled by preferential guidance features (inception horizon)
  - Fractures
  - Bedding planes
  - Geological boundary, etc.

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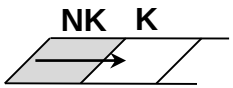
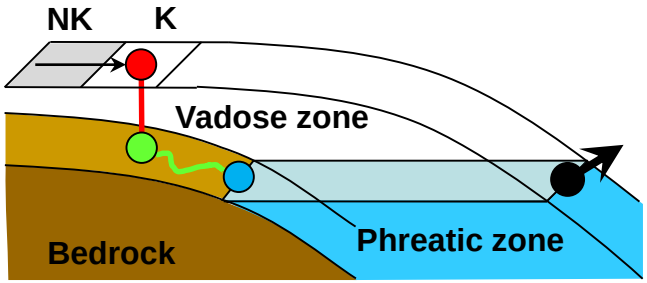
Karst conduit modeling / Method

Malard et al., 2015

> Vadose zone



- Raster layer (250 m) with Non-Karst (NK) and Karst (K)
- K cells contain 1 infiltration node ● (karst feature, or random location if none)
- Infiltration node accumulates recharge and produces a vertically-controlled vadose conduit |
- Vadose conduits reach:
  - the aquifer basement ● : “Runoff” to the phreatic zone ~
  - directly the phreatic zone
- Vadose/phreatic nodes ● accumulate upstream recharge (allogenic + autogenic)



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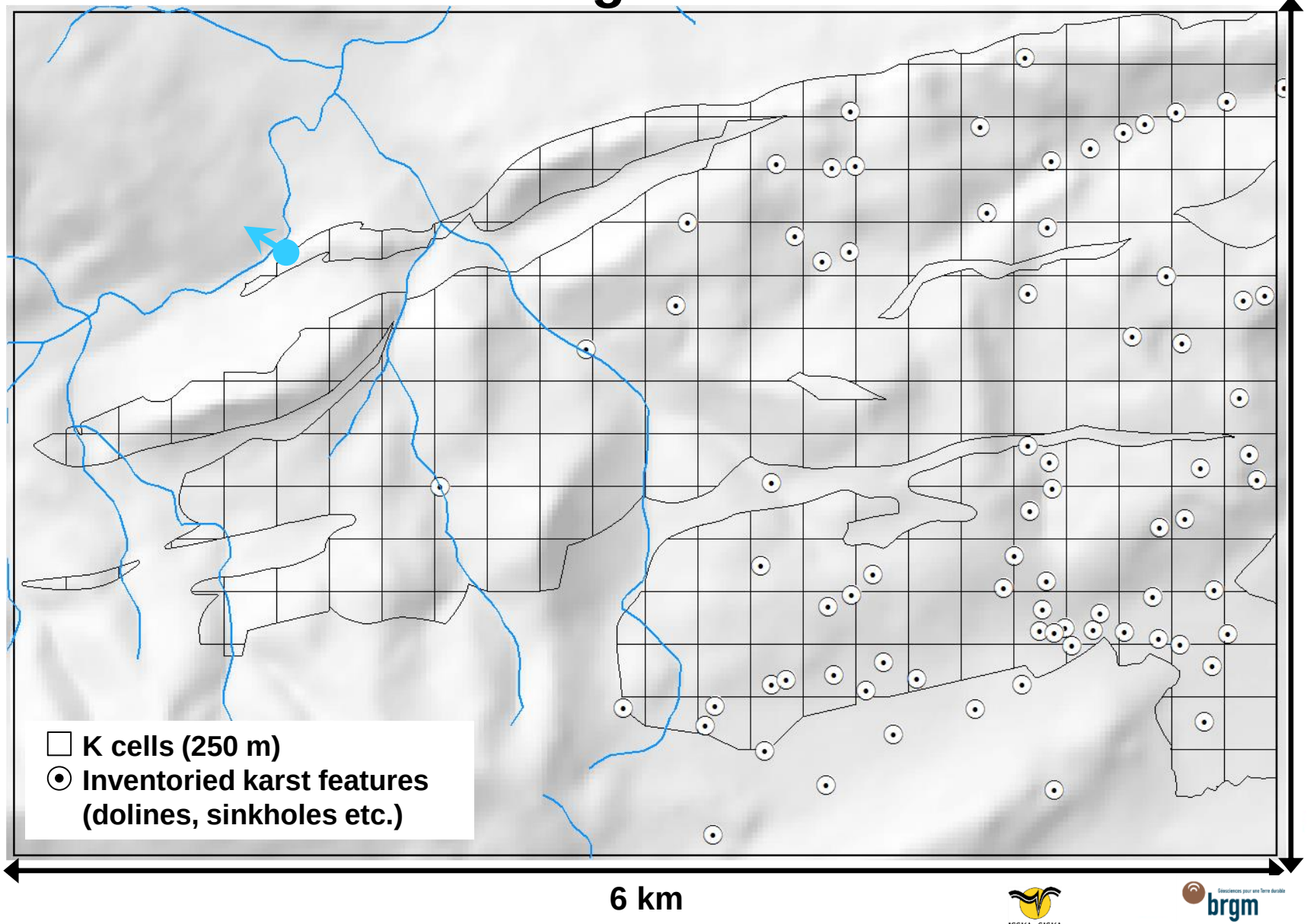
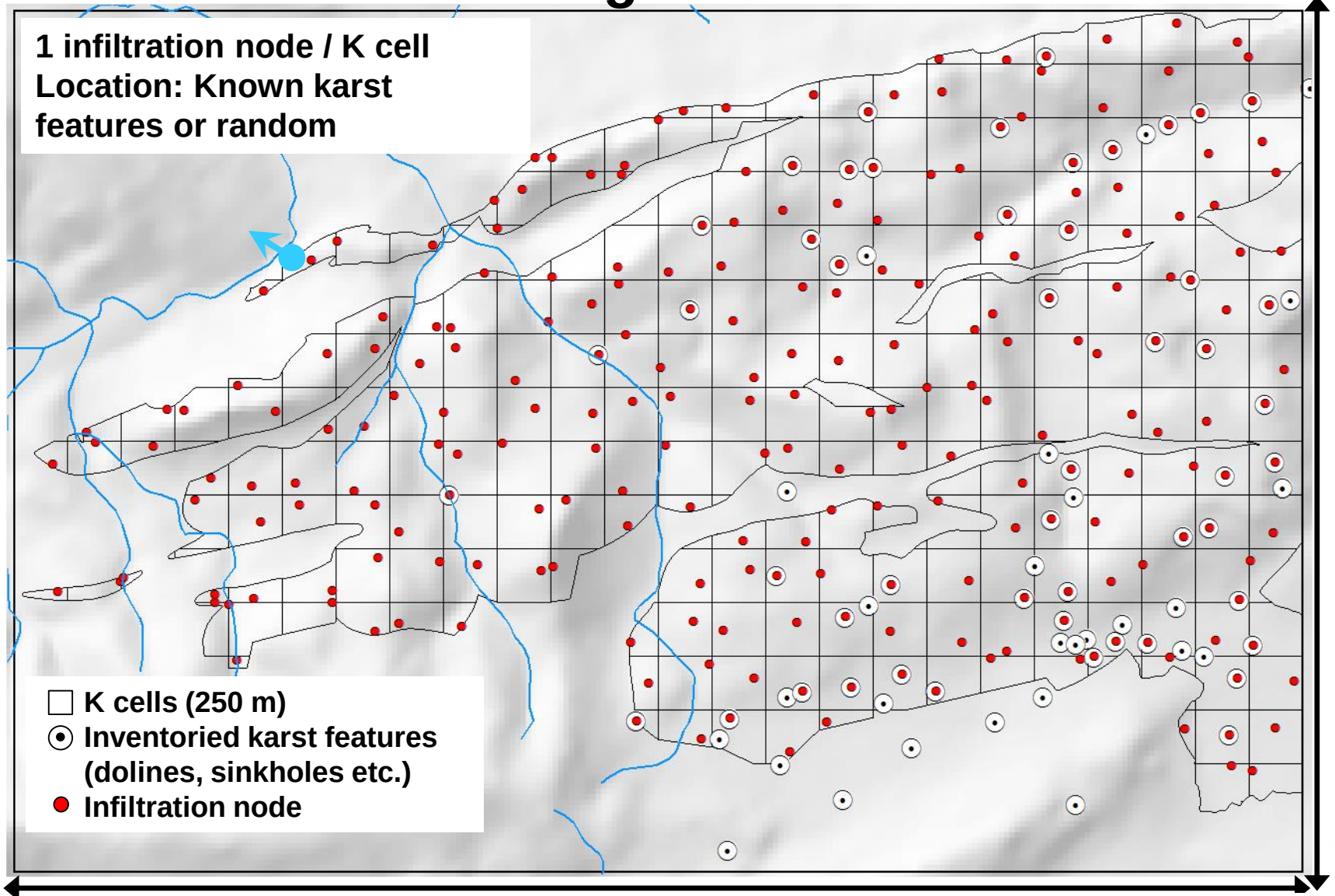
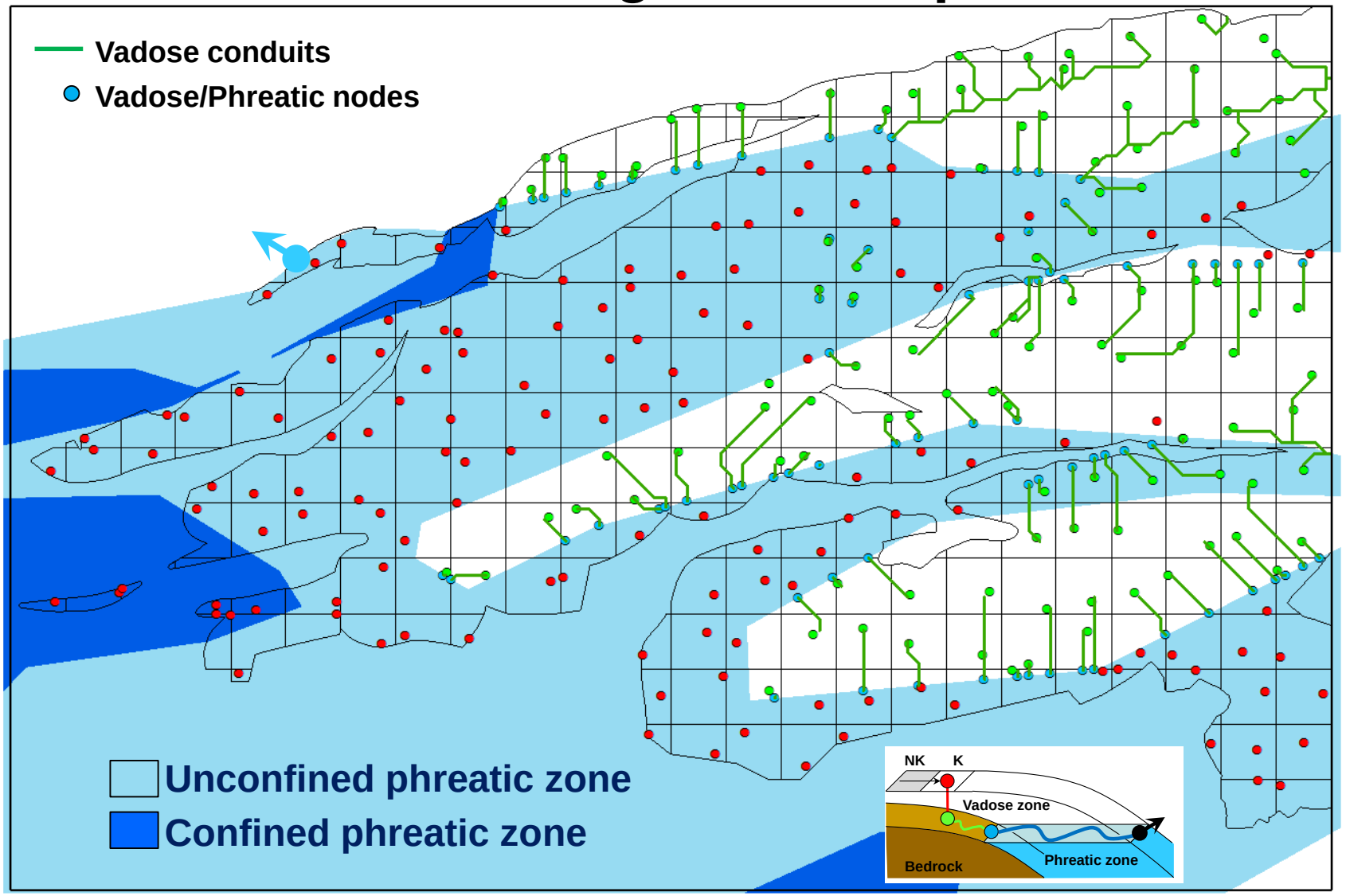
Karst conduit modeling / Karst features



Karst conduit modeling / Infiltration nodes



Karst conduit modeling / Vadose-phreatic nodes



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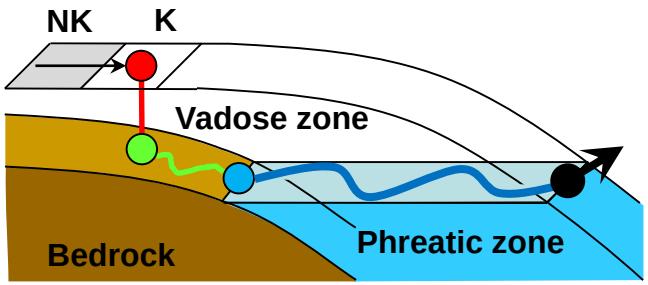
Karst conduit modeling / Method

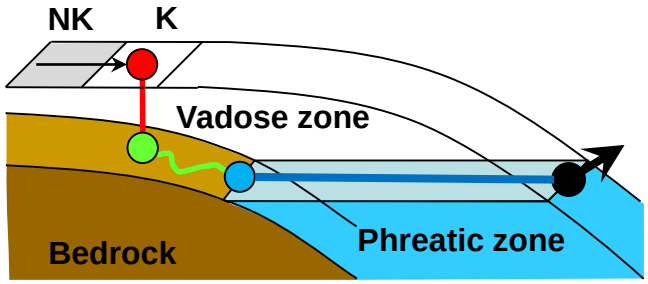
Malard et al., 2015

> Phreatic zone – 3 parameters

- Cost-distance raster governed by 3 weighting parameters:
  - Distance to the outlet (⇔ hydraulic gradient): **O**
  - Recharge (autogenic and allogenic): **I**
  - Efficiency of inception horizons guidance **F**
- Boundary conditions for karst flows inputs
- Sensitivity analysis to O, I and F
  - Consistency with field data
  - Occurrence frequency of main karst conduits



O = I = F



O >> I = F

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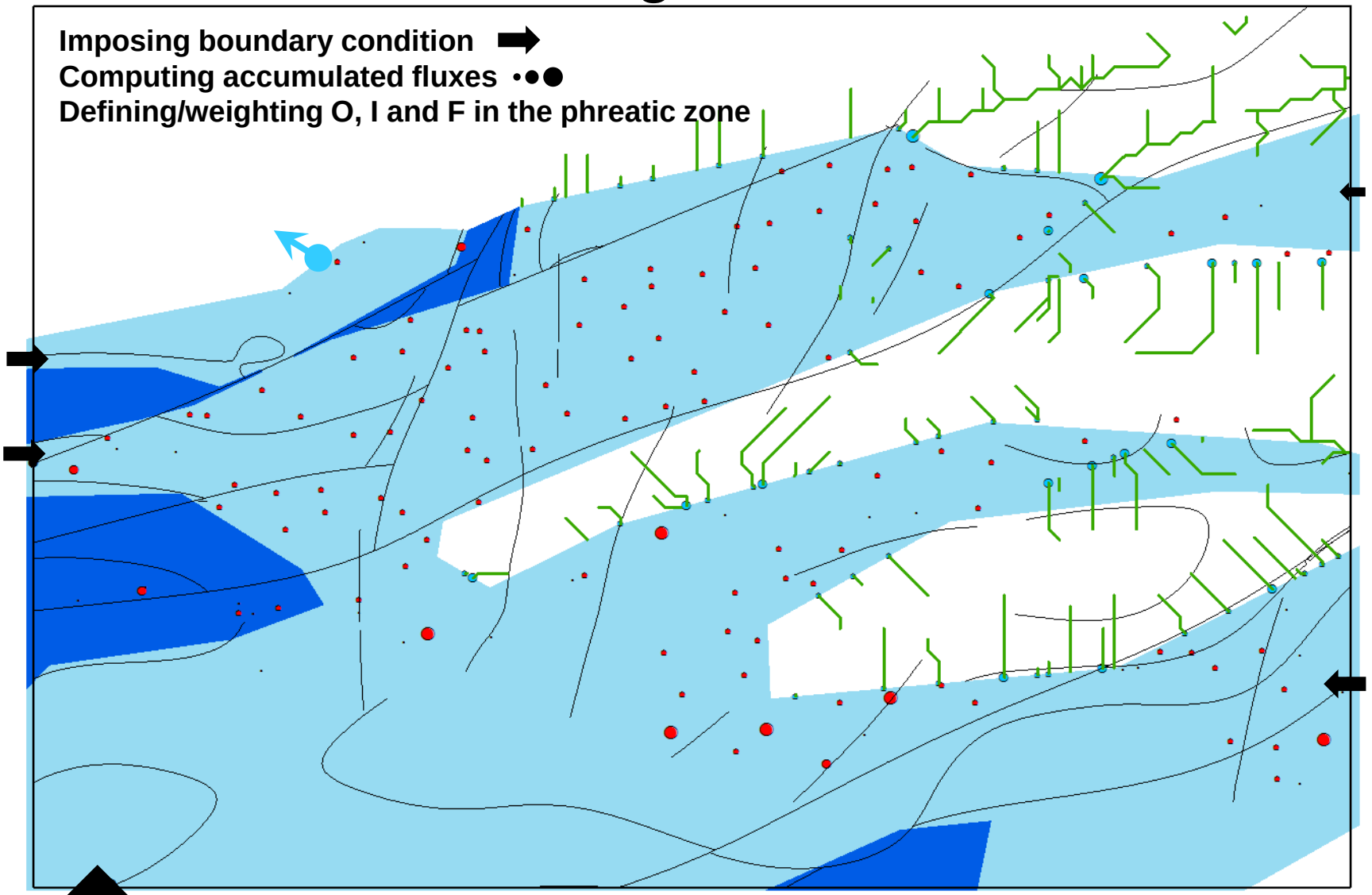
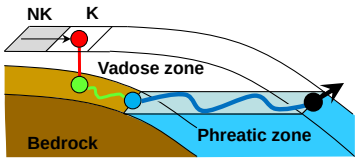
Karst conduit modeling / Phreatic zone



Karst conduit modeling / Results

Computing cost-raster and flow acc. to the spring
Ex. with O=5, I=6 and F=5



Calculates the least accumulative cost distance to the spring over the cost surface

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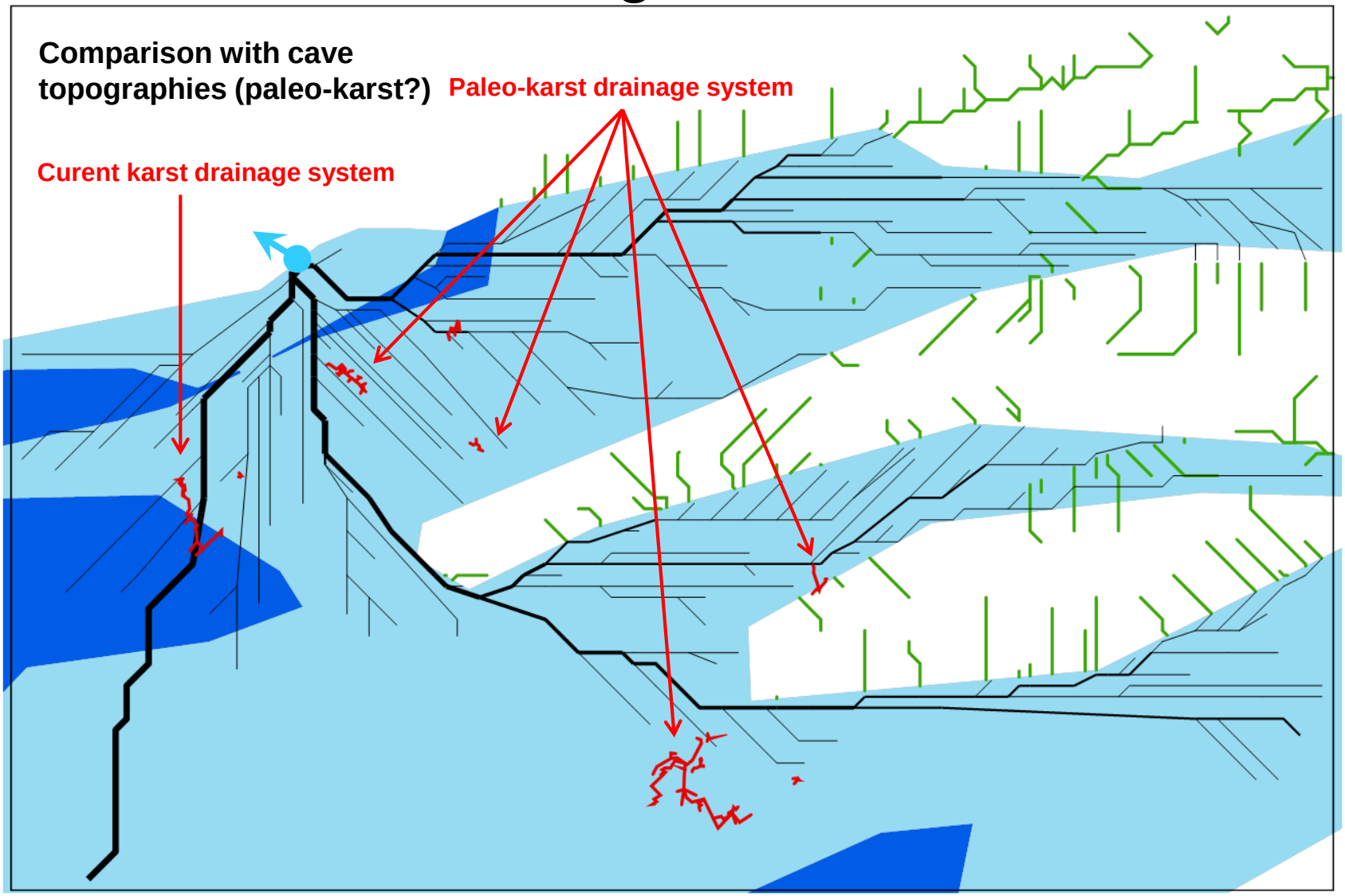
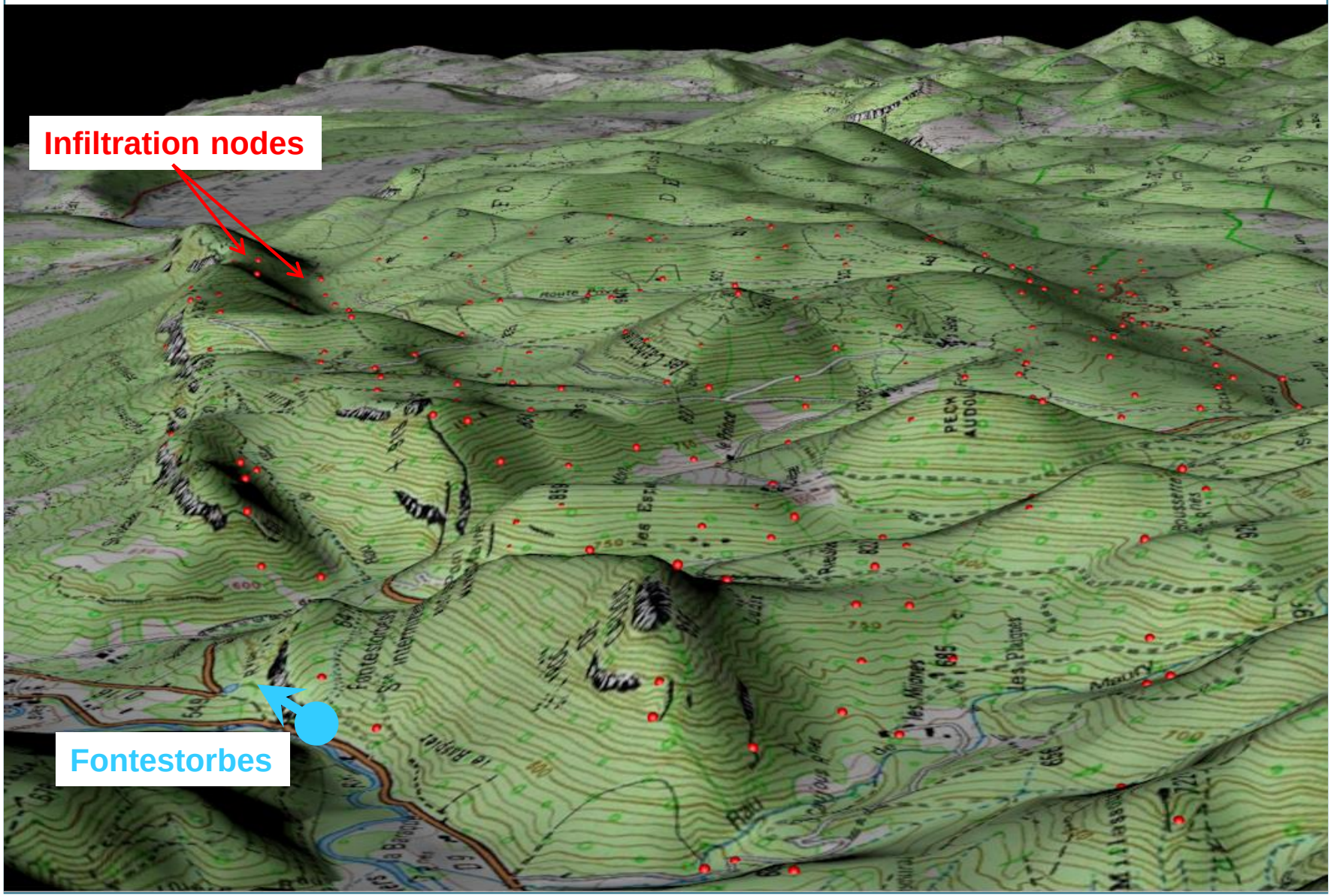
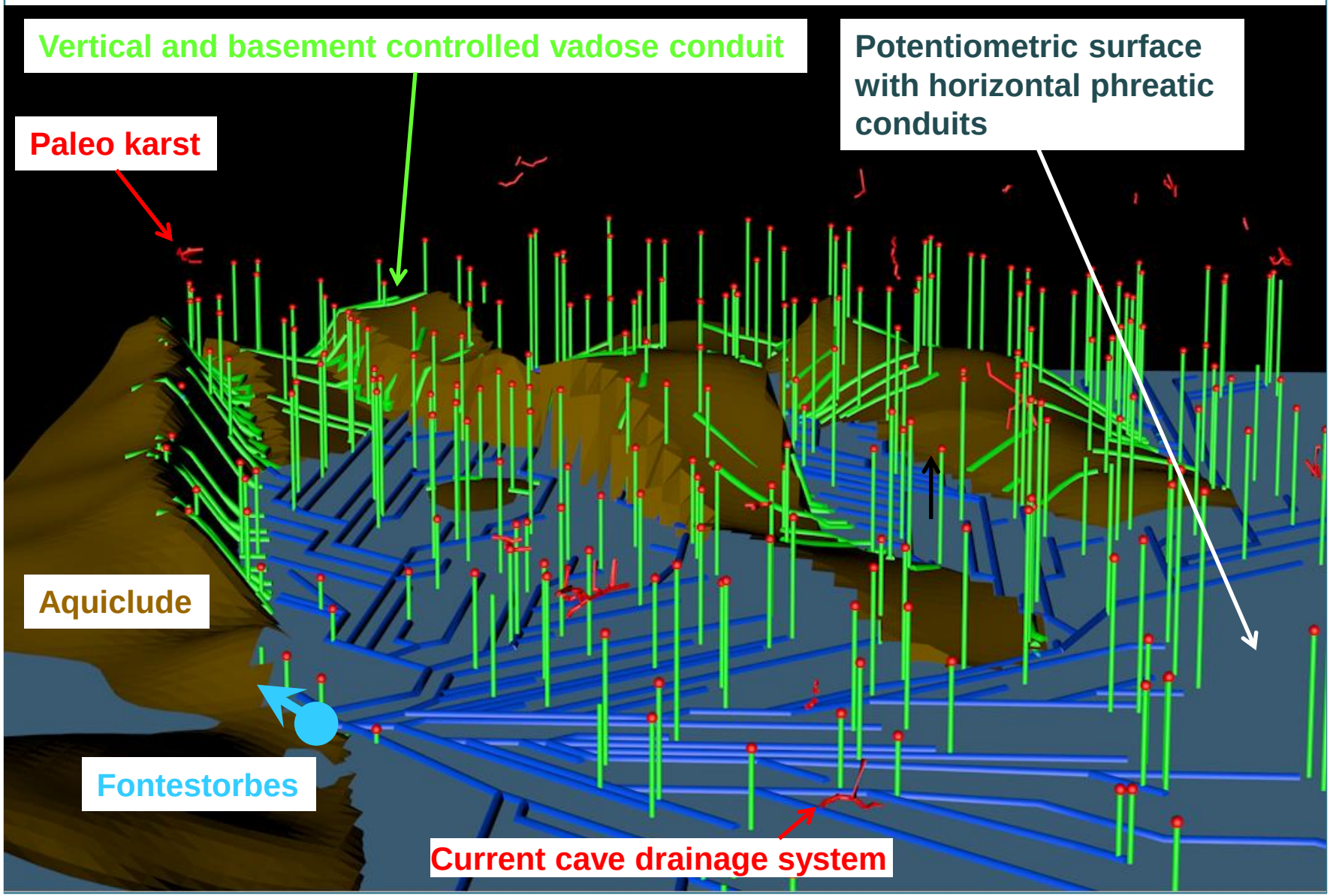
Karst conduit modeling / Results



View in 3D – From surface…



View in 3D – … to depth



Conclusion

> Sault plateau

- Complex karst environment: 2 main springs
- Deficit of geological and hydrological information, especially in depth

→ Need a pragmatic approach: KARSYS

> KARSYS

- Explicit 3D model of karst aquifers
- 4 basic steps + assumptions + basic principles
- Combine all existing data

> Results

- Geometry of the aquifer
- Minimal extension of phreatic zones
- Delineation of recharge area
- Main karst flowpaths + conduits scenarii
- Point out the lacks of information

→Targeted new acquisitions (in time and space)

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Thank you for your attention

> We also thank the cavers (CDS 09 and 11) for their support in this project

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STEP #2: 3D geological model using GeoModeller®

(Allanic et al., 2016)

> Based on

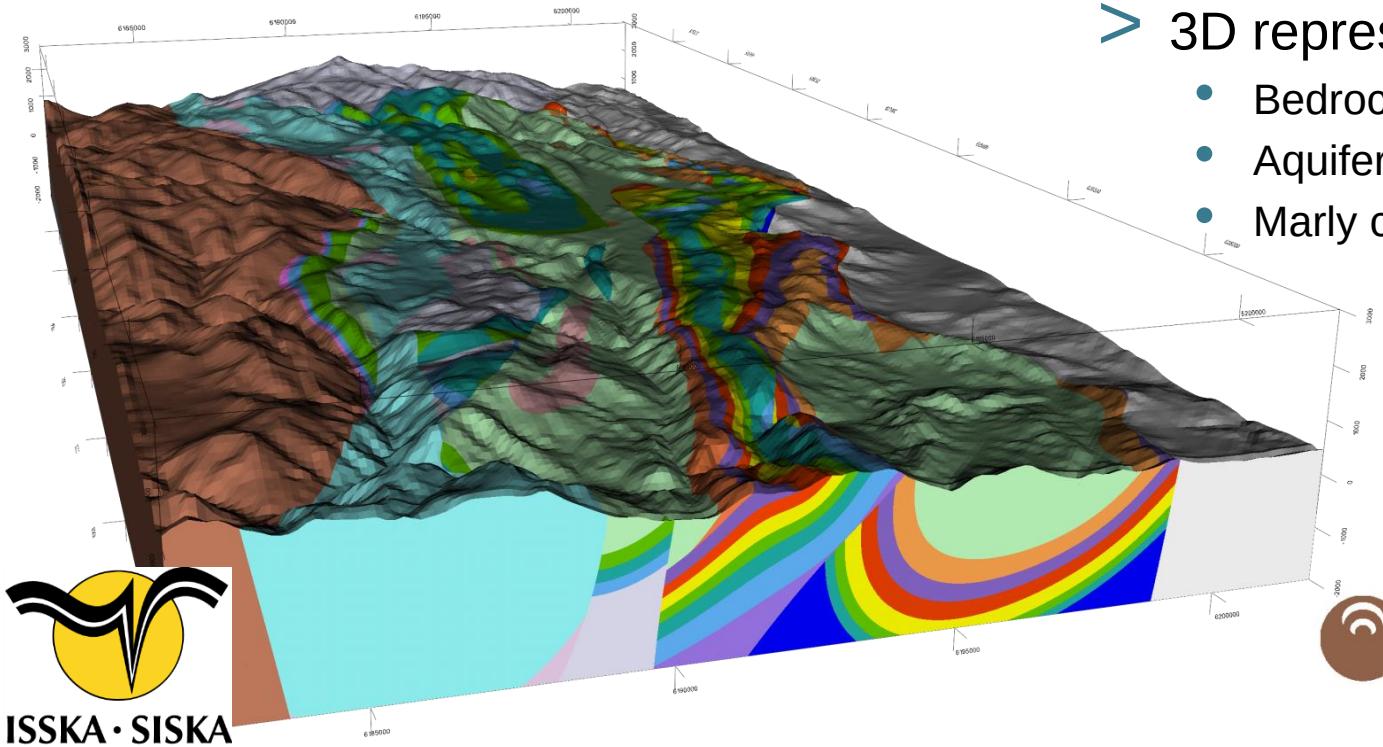
- Geological map (1/50’000)
- Orientation data (dip-azimuth)
- Faults network
- Cross-sections
- Gravimetry survey

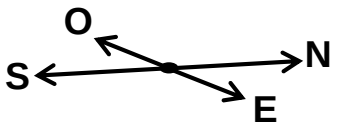
> Geometry

- 1200 km^2 (40x30 Km)
- -2000 to +3000 m asl
- @25m on surface

> 3D representation

- Bedrock aquiclude
- Aquifer layers
- Marly confining layers





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Perspectives…

> Point out the lacks of information

→ Targeted new acquisitions (in time and space)

- Improve recharge area delineation
  - Dye tracing test design
  - Karst/River interaction - Differential river gauging (losing?)
  - Geochemistry
- Improve 3D geological model geometry
  - Exploratory drillholes to check bedrock depths and lithology
  - Geophysics to better map aquiclude's crest lines in vadose zone

→ Next iteration for the 3D model of karst flows

> Hydraulic simulation to better constrain karst conduit simulation

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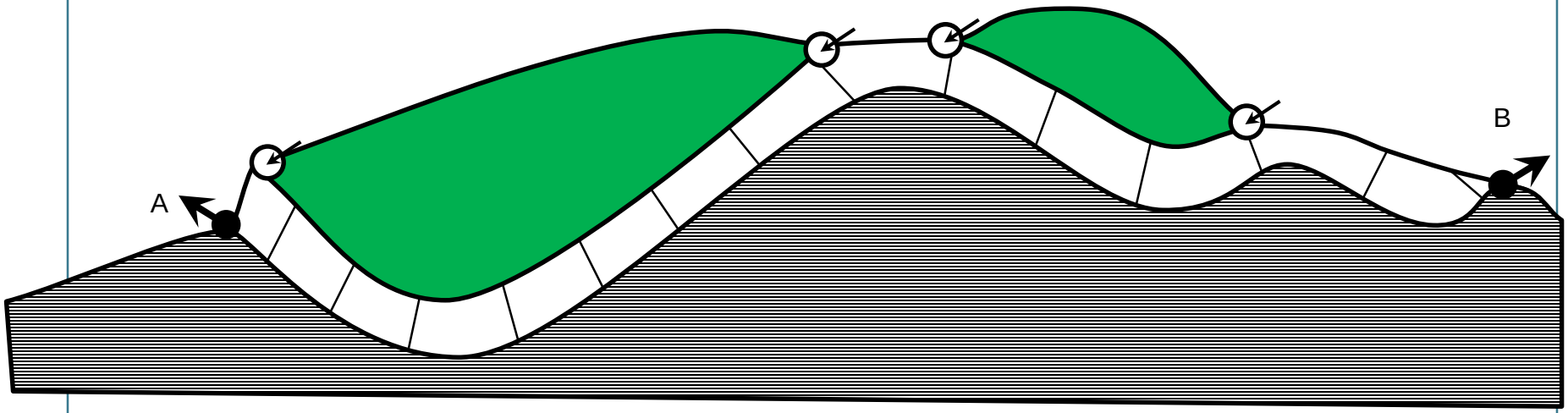
STEP #3: 3D Hydrogeological model

> KARSYS: A pragmatic approach



Impervious marls (local aquiclude)

Karstified limestone (aquifer)

Impervious bedrock (regional aquiclude)

Karst Spring

Swallow hole

- Aquifer volume below the spring's elevation is saturated
- Low (<0,1%) hydraulic gradients (baseflow)
- Input data for hydraulics: Piezometry, cave report, spring altitude

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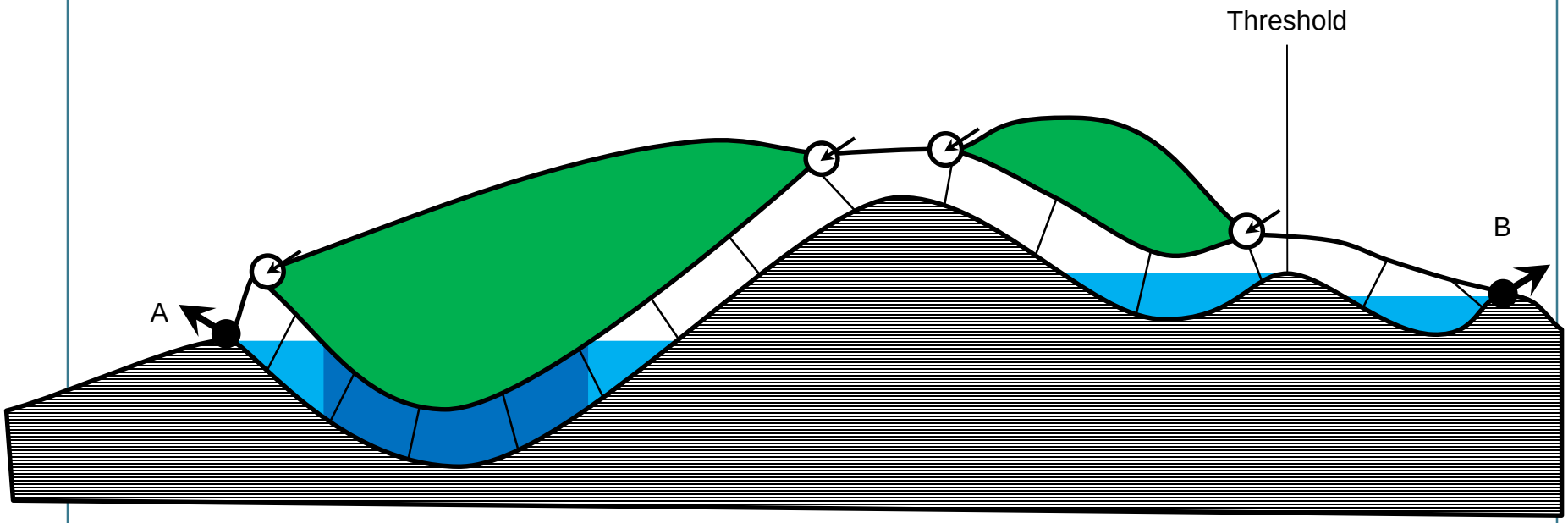
STEP #3: Hydrogeological model



Impervious marls (local aquiclude)

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Impervious bedrock (regional aquiclude)

Karst Spring

Swallow hole

Minimal extension of the phreatic zone

Unconfined phreatic zone

Confined phreatic zone

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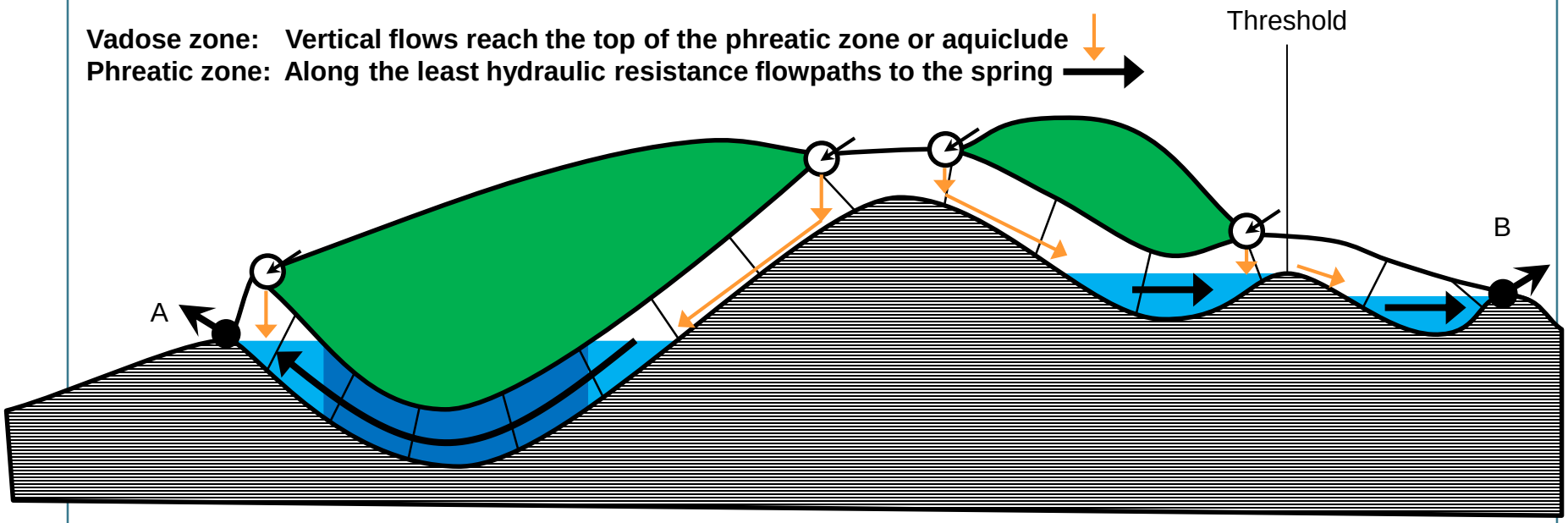
STEP #4: 3D karst-flow model

Vadose zone: Vertical flows reach the top of the phreatic zone or aquiclude
Phreatic zone: Along the least hydraulic resistance flowpaths to the spring



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Karst Spring

Swallow hole

Vadose flow

Phreatic flow

Minimal extension of the phreatic zone

Unconfined phreatic zone

Confined phreatic zone

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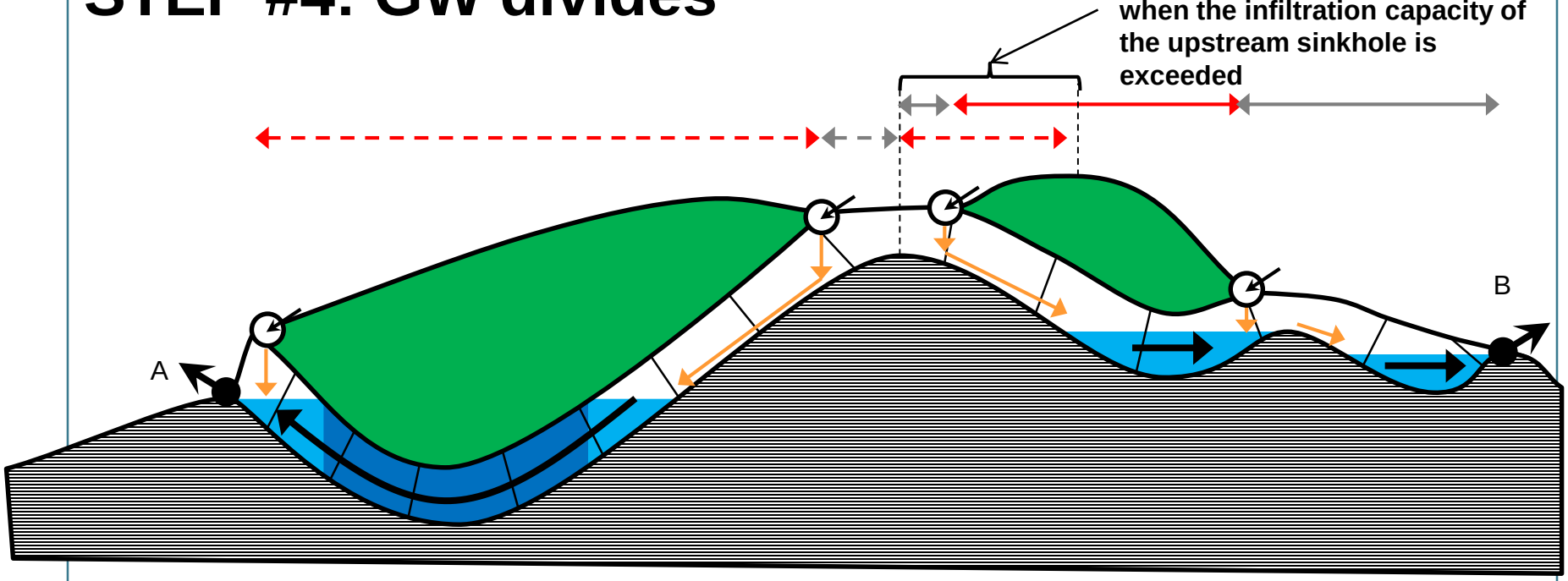
STEP #4: GW divides



Impervious marls (local aquiclude)

Karstified limestone (aquifer)

Impervious bedrock (regional aquiclude)

Karst Spring

Swallow hole

Vadose flow

Phreatic flow

Minimal extension of the phreatic zone

Unconfined phreatic zone

Confined phreatic zone

Catchment area boundaries

Direct recharge

Indirect recharge

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INTRODUCTION

> Phase 1: What is already known

- Data mining: Database, reports, thesis, papers etc.
- Synthesis ⇨ BRGM Report / RP-64209-FR

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INTRODUCTION

? > **Phase 2: Improving knowledge**

- How to bring together…
  - Geology: Stratigraphy, tectonics, gravity surveys
  - Karst geomorphology
  - Hydrology and hydrogeology, including geochemistry, speleology and dye tracing

…into a conceptual but explicit hydrogeological model?

- What, where and how to measure (location/frequency)?

- How to use the resulting model?
  - Engineering: Catchment boundaries, GW flow paths etc.
  - Research: 3D speleogenesis
  - Flows simulation (recharge, hydraulic in the conduits network)

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Need of a method limiting user-influenced interpretation

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