The Fontestorbes intermittent karst spring : New results deduced from high frequency monitoring in the karst drainage system

Jean-Christophe Maréchal, Vincent Bailly-Comte, Bernard Ladouche, Nicole Ravaiau

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The Fontestorbes rhythmic karst spring

New results from high frequency monitoring in the karst drainage system

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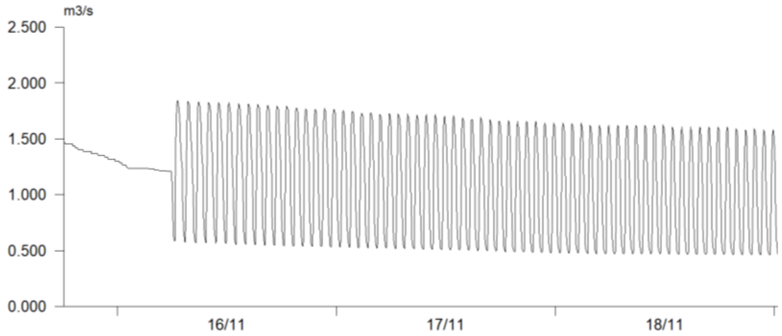
THE FONTESTORBES RHYTHMIC SPRING

What is a rhythmic spring?

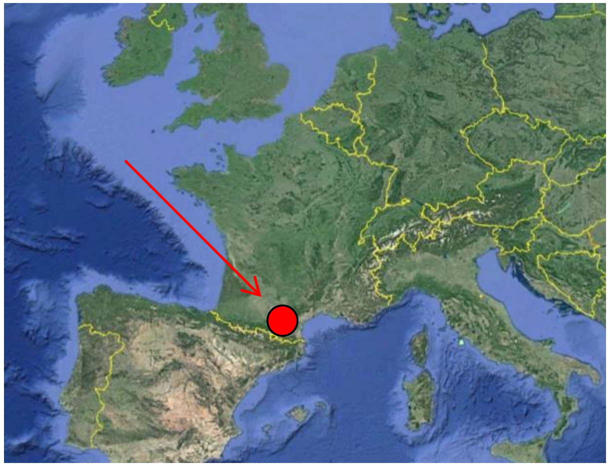
- Spring that shows periodic changes (“tides”) of flows
  - Also known as “ebb and flow” Sp., intermittent Sp.
  - Exclusively in karst terrain, a few examples in the World *(Bonacci 1991, Mangin, 1969)*
  - Some are perfectly rhythmic, others show an unpredictable flow behavior
- Among them, Fontestorbes (France) is a large karst spring that behaves as a rhythmic spring during baseflow periods



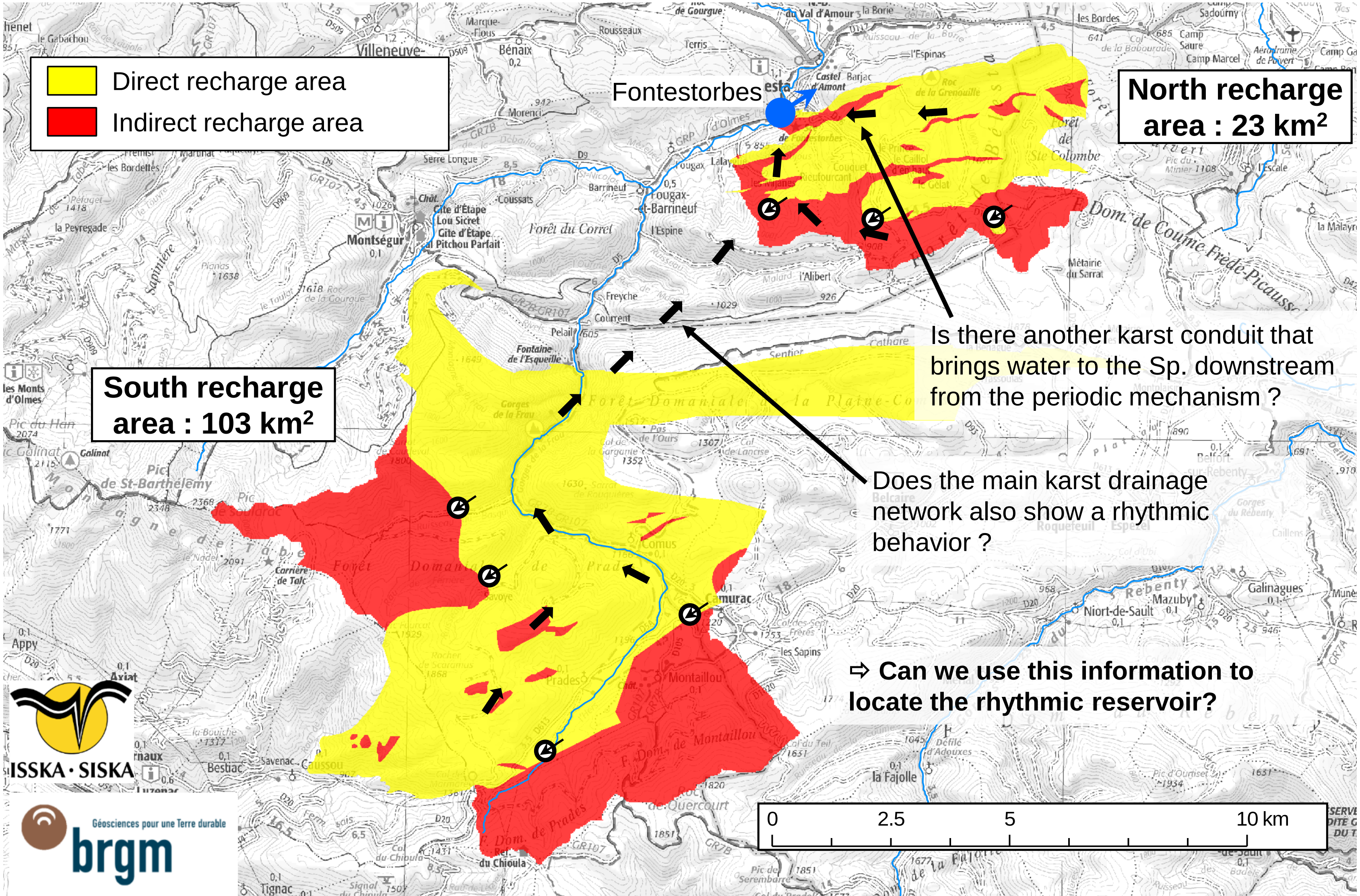
Fontestorbes - Spring hydrograph in Nov. 2016

Where is the Fontestorbes Sp. located?

- Near Belesta, South of France (Ariège)
- One of the main springs that drains the “Plateau de Sault”



THE FONTESTORBES RECHARGE AREA



Is there another karst conduit that brings water to the Sp. downstream from the periodic mechanism ?

Does the main karst drainage network also show a rhythmic behavior ?

⇨ Can we use this information to locate the rhythmic reservoir?

KARSYS method, Eurokarst, 2016

WHY DO WE STUDY THIS PHENOMENON?

From a scientific, engineering and touristic point of view…

- Scientific: To understand how **flood pulse propagates through a karst media** (see Mangin, 1975; Annex to Drainage System)
- Engineering: Knowing where the mechanism takes place allows for future wells **intercepting the phreatic zone upstream from the mechanism**
- Touristic: To better assess the **influence of groundwater exploitation** (from wells) on the phenomenon (can it disappear?, be more frequent? etc.)

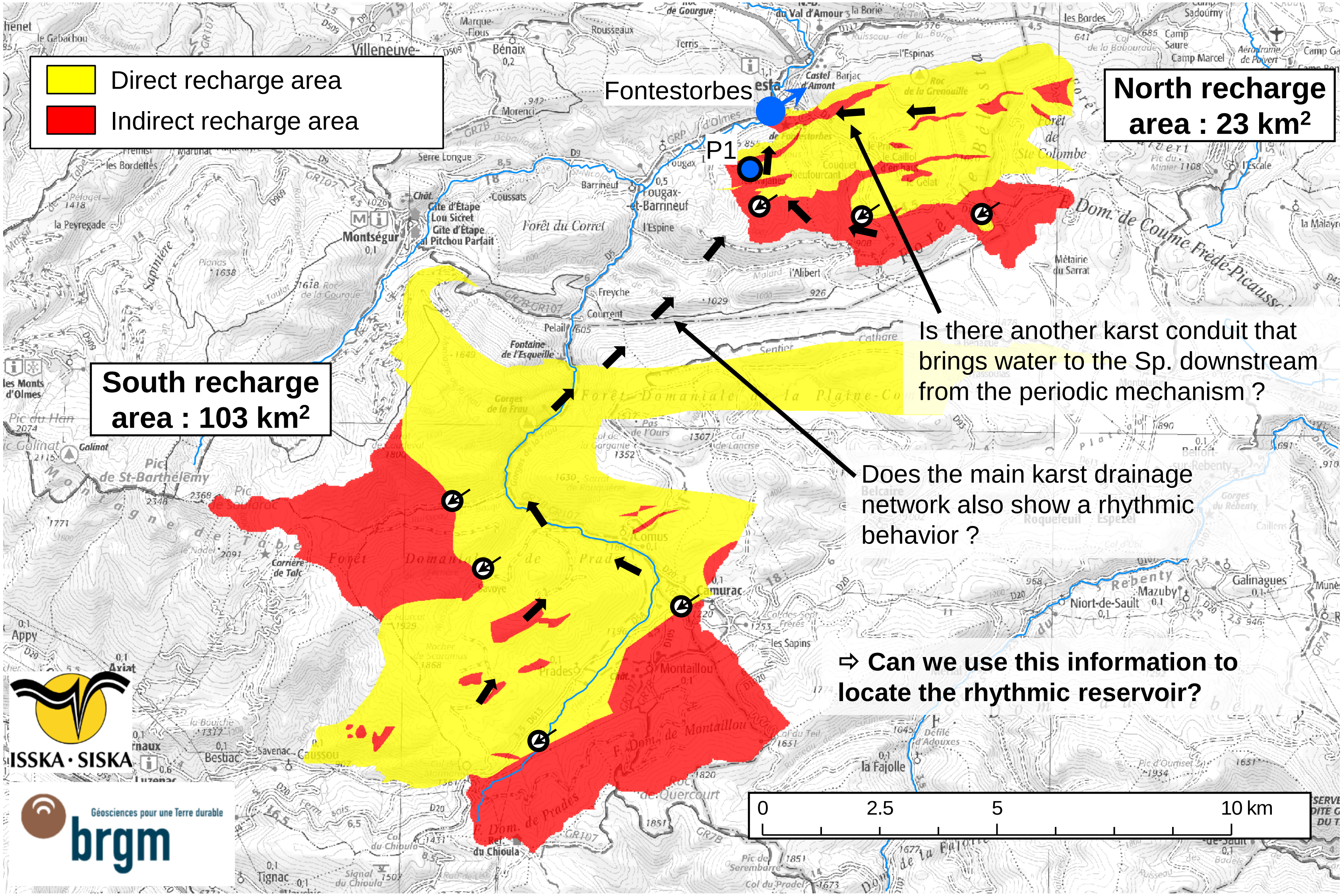
Planque, 1728; Astruc, 1730; Martel, 1909; Brunet, Verdeil, Mangin from the 60's, etc.

Since 2014, the BRGM (French Geological Survey) leads a project in partnership with Région Occitanie, Ariege and Aude Councils, and AERMC and AEAG Water Agencies, that aims at better understanding the karst groundwater resources on the Plateau de Sault.

In that framework, a scientific cooperation with the Speleogical Comitee (CDS09) allowed to monitor simultaneously pressure, temperature and electrical conductivity times series at the spring and in a cave explored by CDS09.

⇨ **What can we learn from a new (and first) monitoring of P1 water-level?**

THE FONTESTORBES RECHARGE AREA



KARSYS method, Eurokarst, 2016

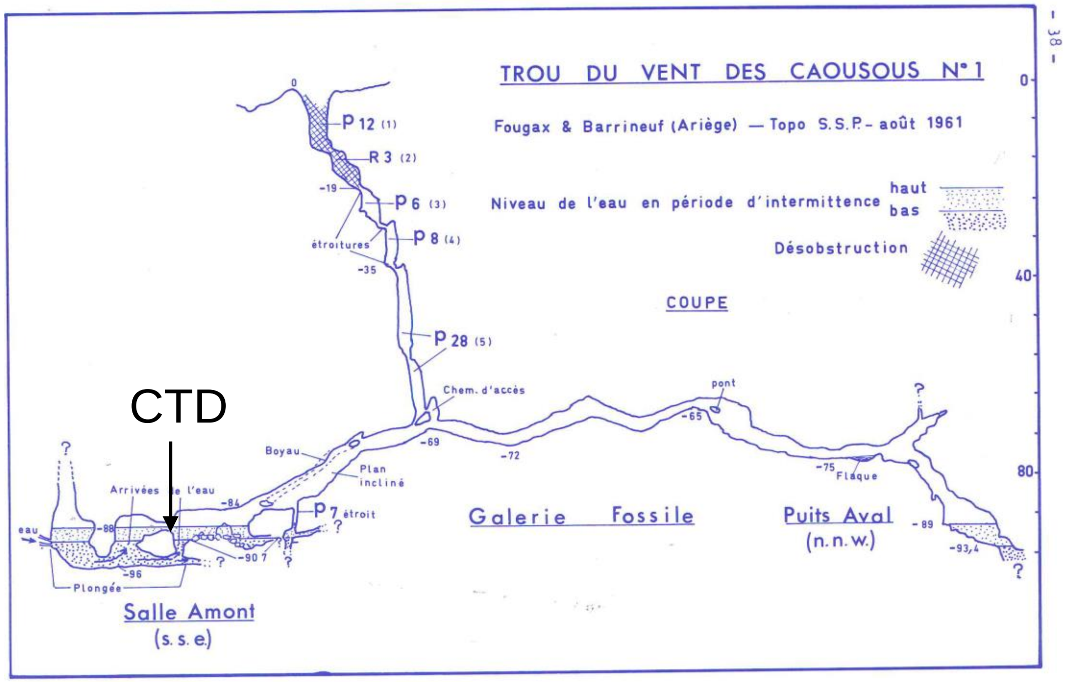
MONITORING

High frequency analysis (2 min)

Where?

- CTD Diver at the Fontestorbes Sp.
- CTD Diver in P1 (1200 m from the Sp.)

Fontestorbes Sp.



P1 topographic map

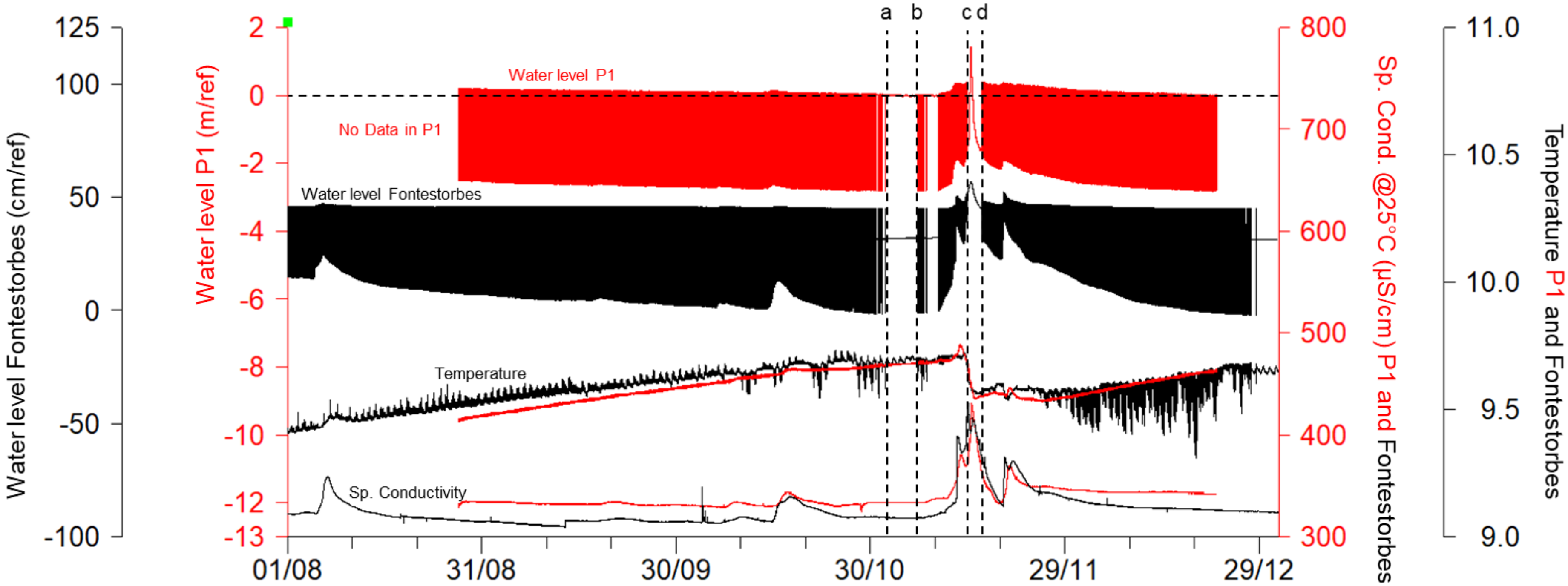
Caver installing the CTD sensor in P1

RESULTS / HYDRODYNAMICS

Monitoring P1 vs. Fontestorbes – all data set

Water-level

- 4 cases of rhythmic mechanism
  - **a** and **b**: Stop and start at low flow
  - **c** and **d**: Stop and start at high flow



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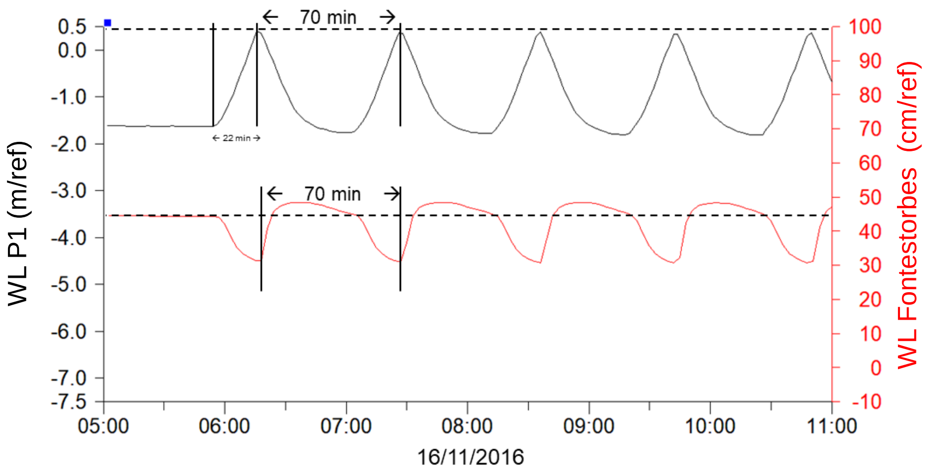
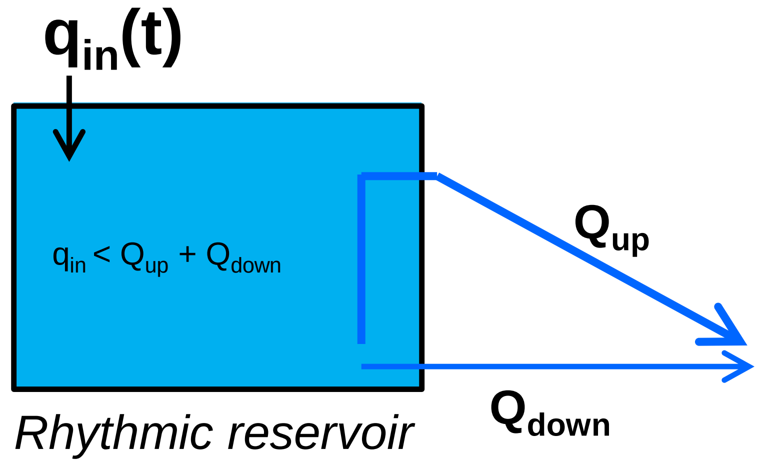
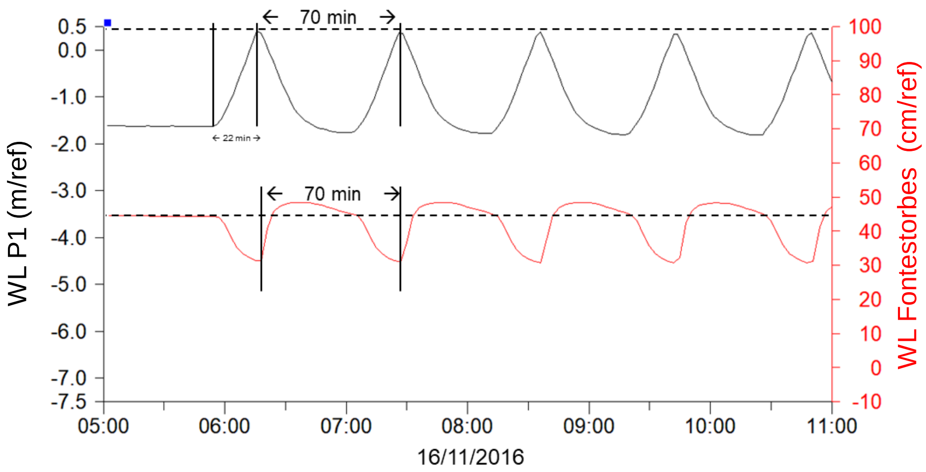
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW

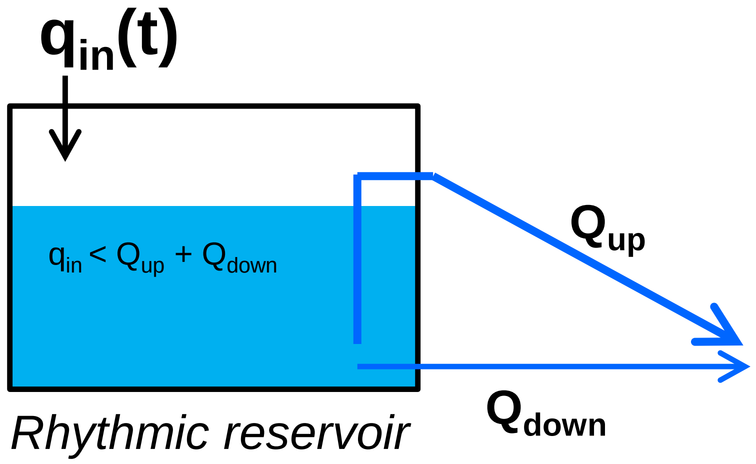




- WL in P1 and Sp. discharges decrease during recession

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





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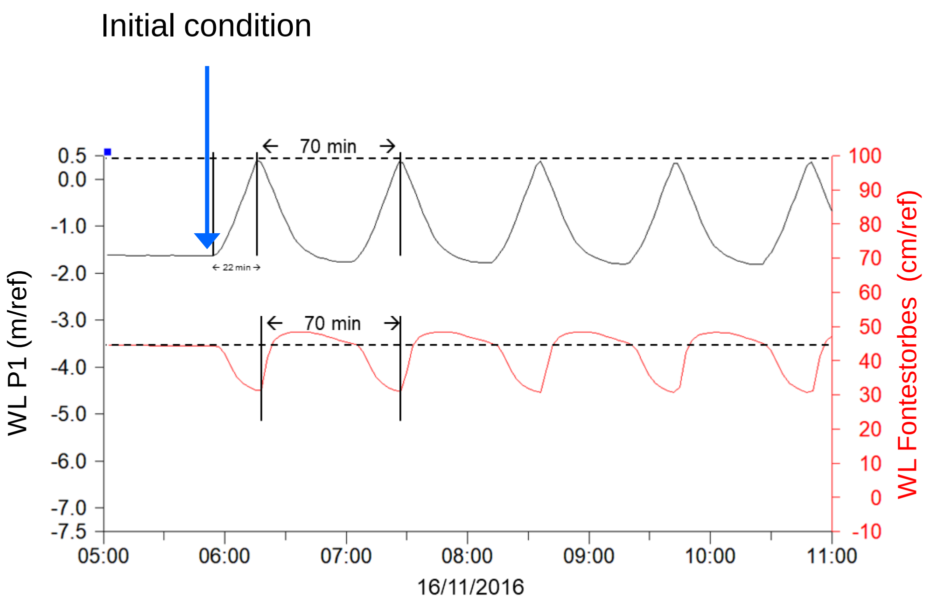

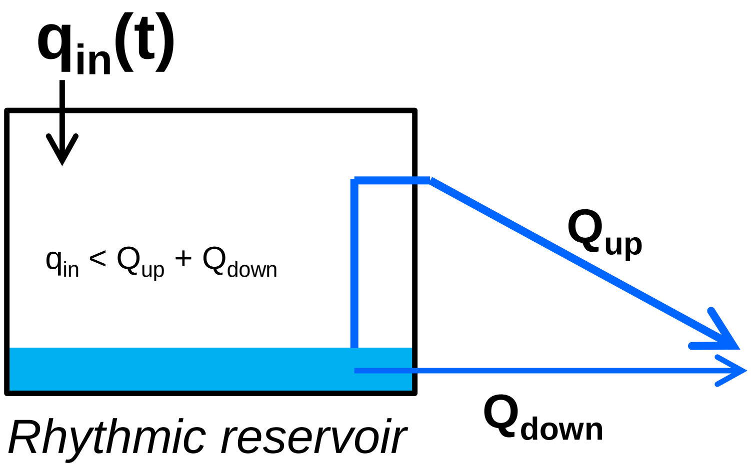

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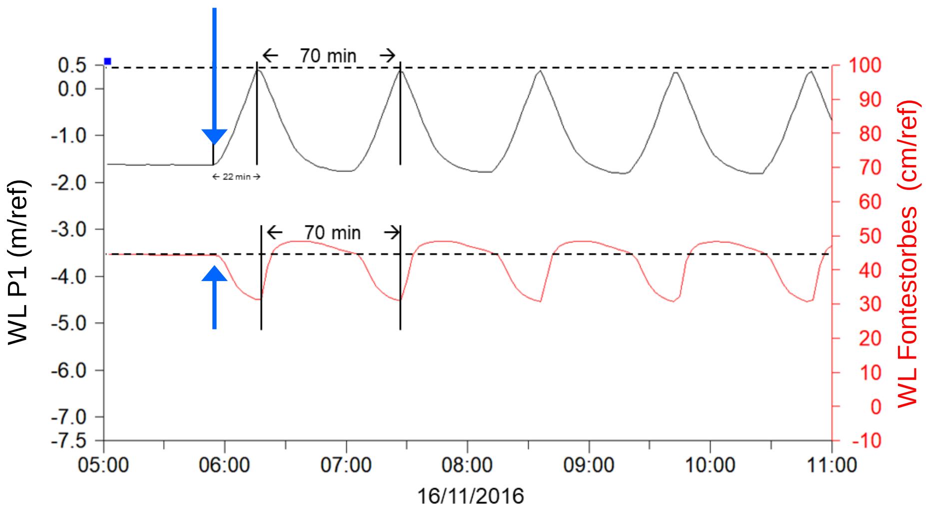
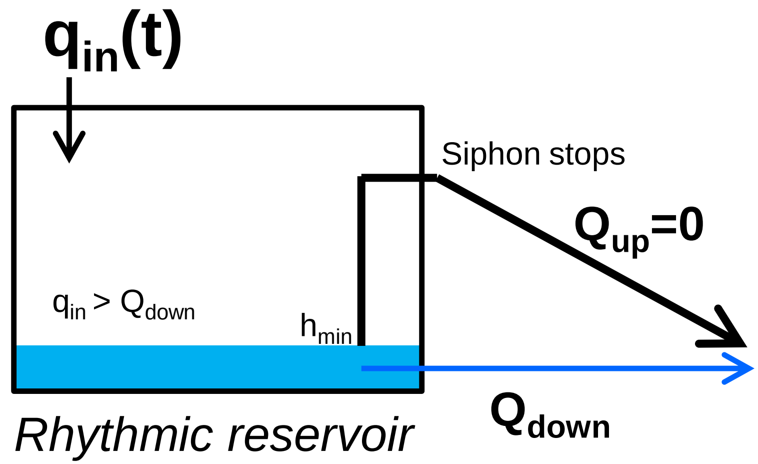
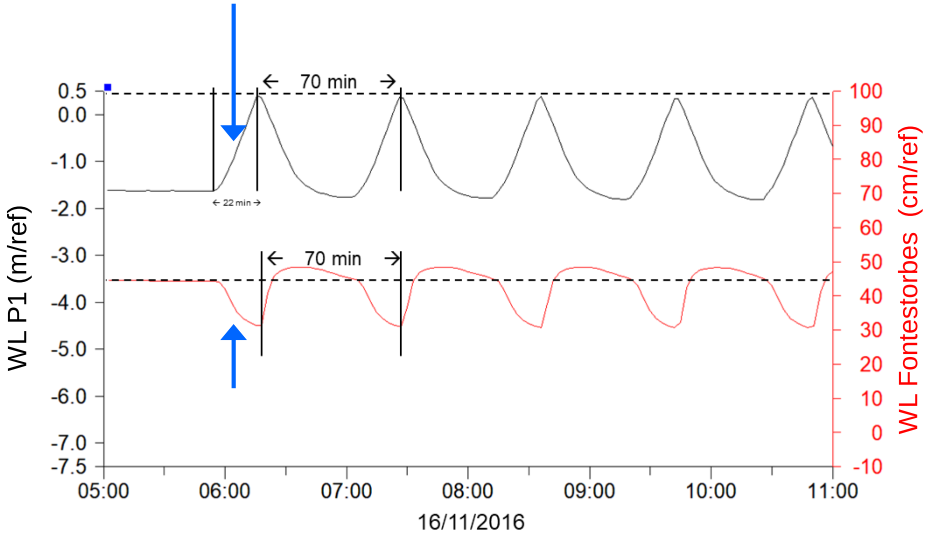
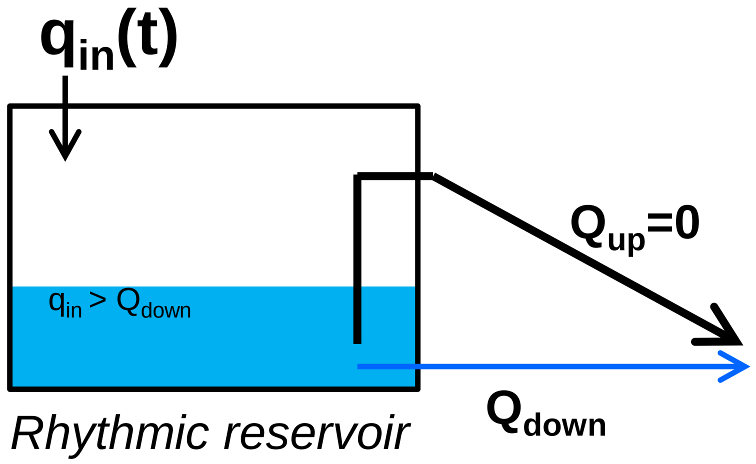




- Siphon stops ⇨ Q_{up}=0
- ⇨ WL in P1 increases
- ⇨ The discharge at the Sp. decreases (pressure transfer)
- No time lag between the reservoir recharge (P1) and the decrease of the Sp. discharge

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





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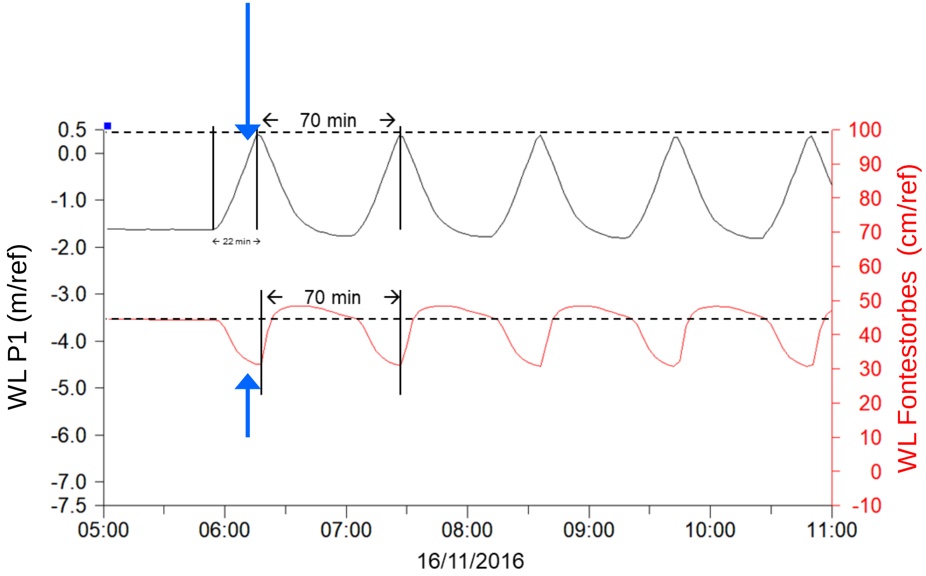
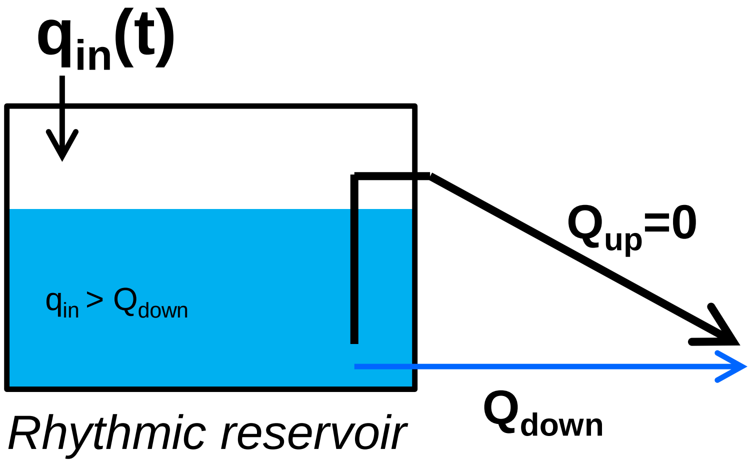
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





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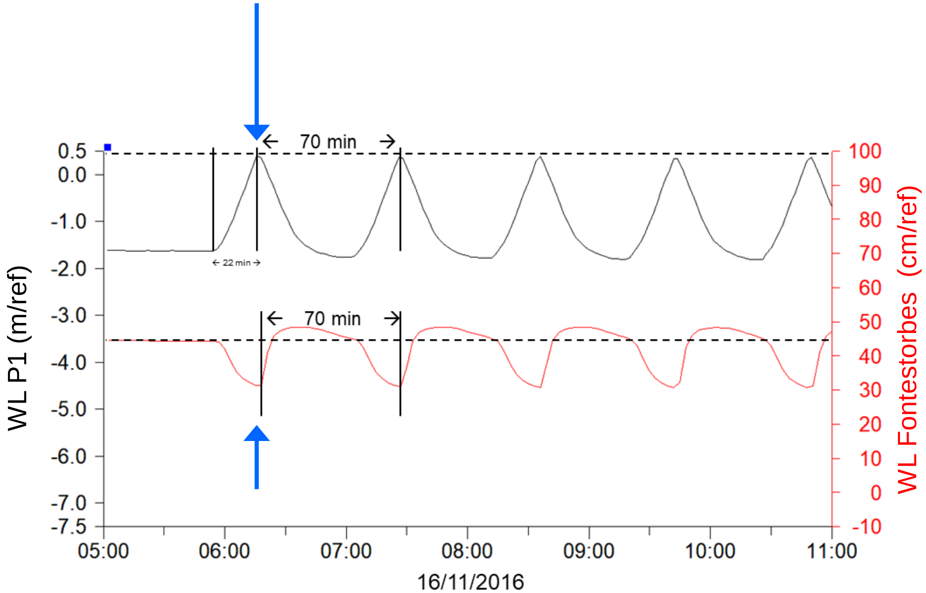
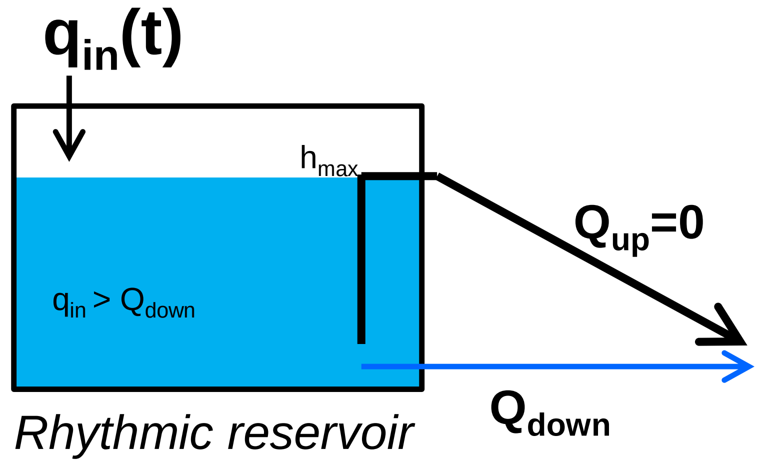
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





- WL in P1 reaches h_{max}
- The discharge at the Sp. is <u>minimum</u>

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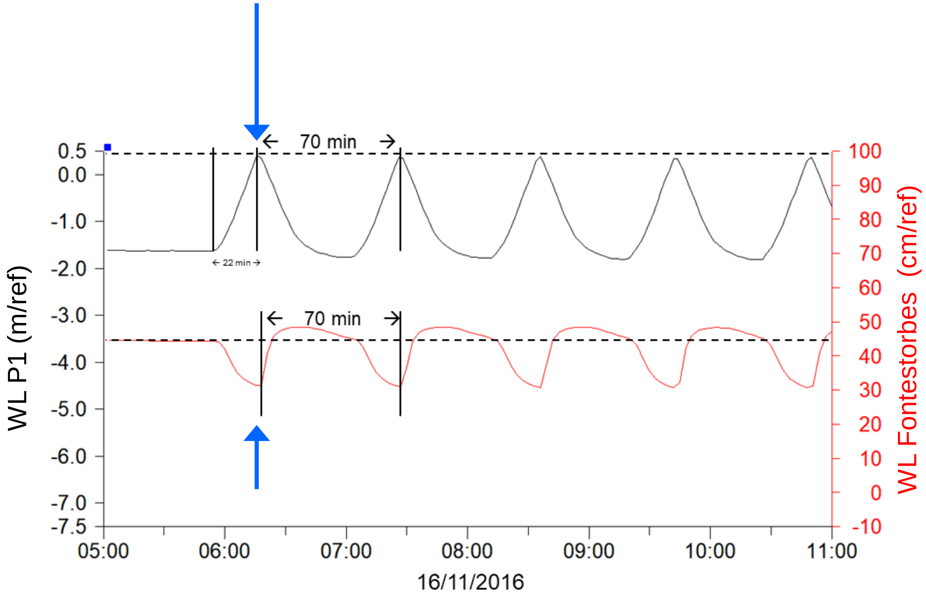
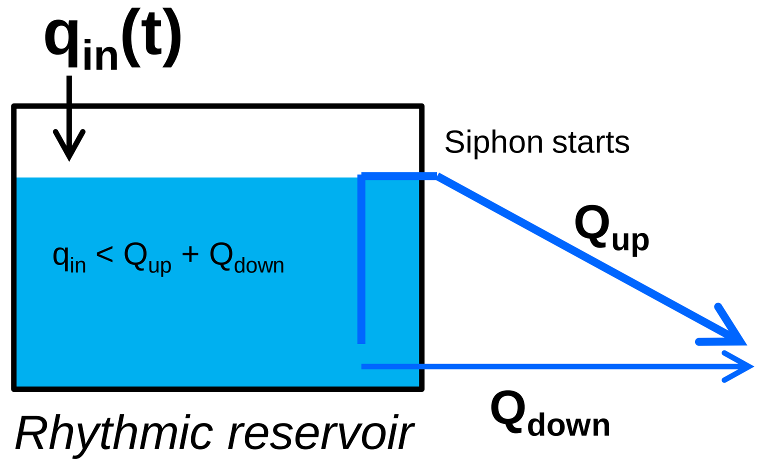
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





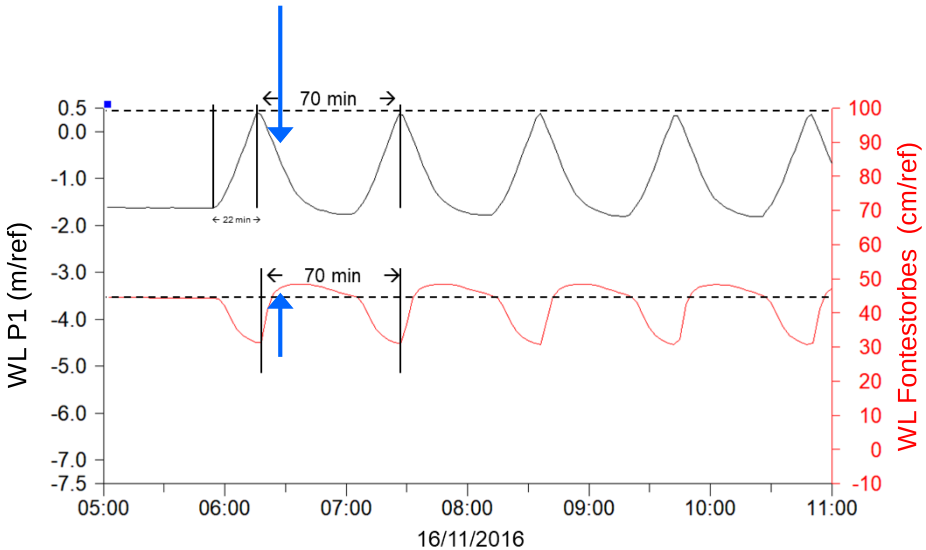
- Siphon starts ⇨ Q_{up} >0

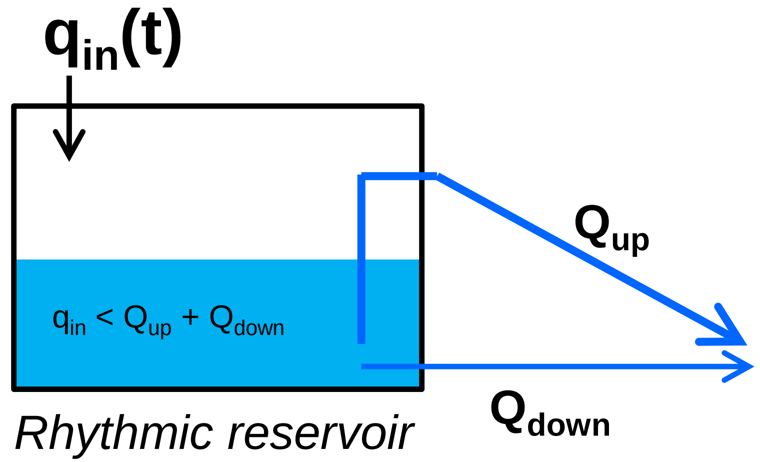
⇨ WL in P1 decreases quickly

⇨ The discharge at the Sp. increases (pulse transfer)

- No time lag between the reservoir emptying (P1) and the increase of the Sp. discharge

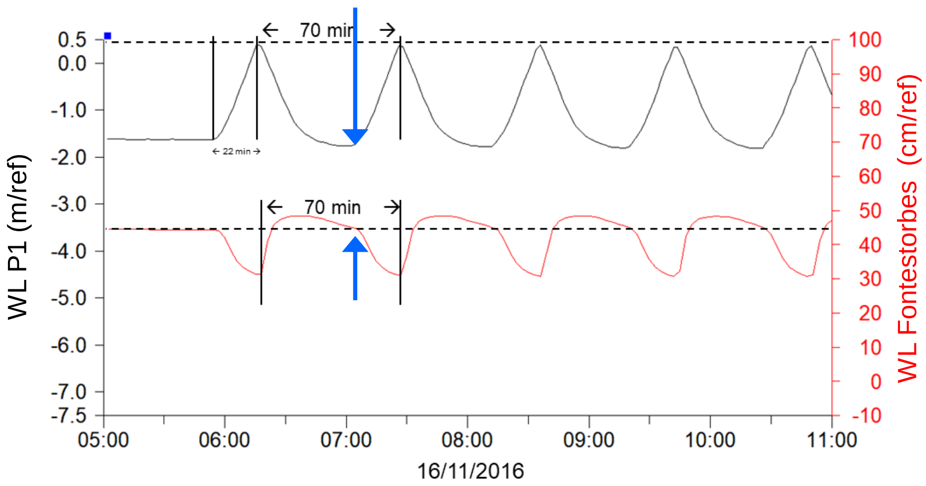
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW

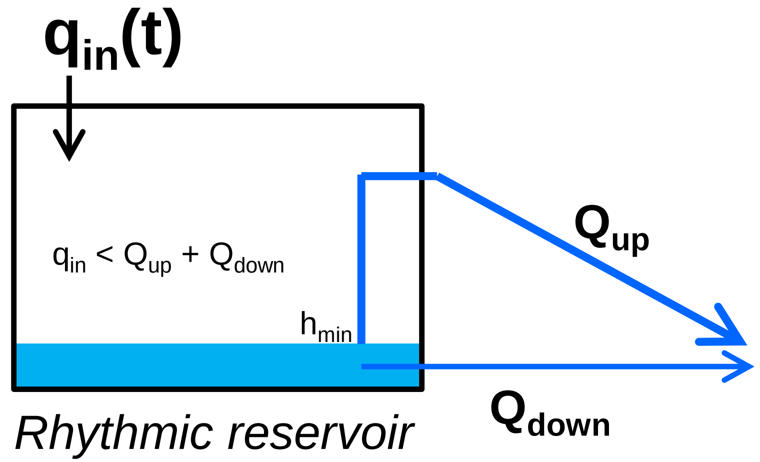




- WL in P1 decreases quickly
- The discharge at the Sp. increases (pulse transfer) and reaches a <u>maximum</u> value

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW

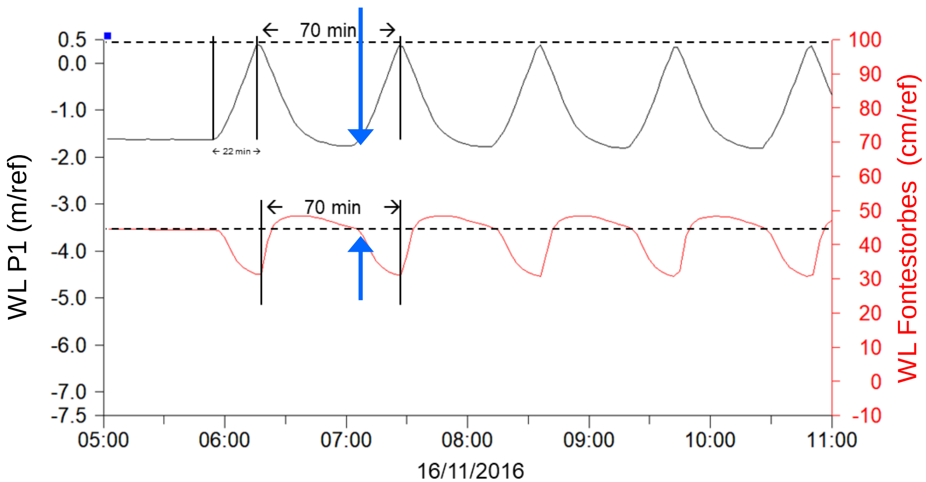


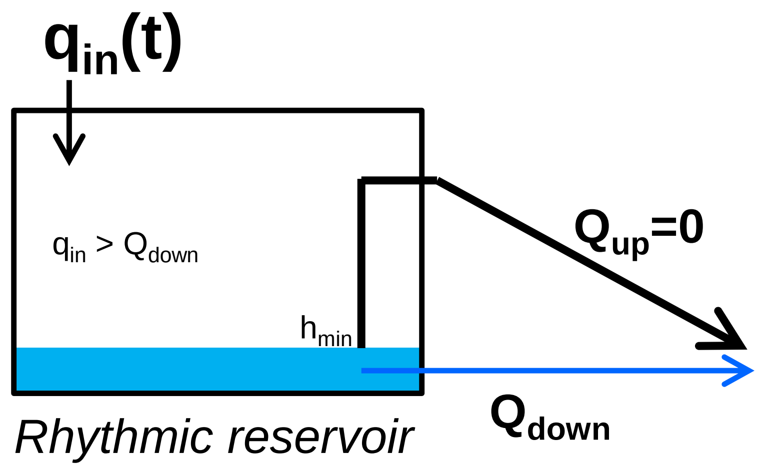


- WL in P1 reaches a minimum value
- The discharge at the Sp. decreases after the peak transfer, but the siphon is still flowing

If $q_{in} > Q_{up} + Q_{down}$ the process stops at this step due to a recharge event (stop at high flow) – the reservoir is empty

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW



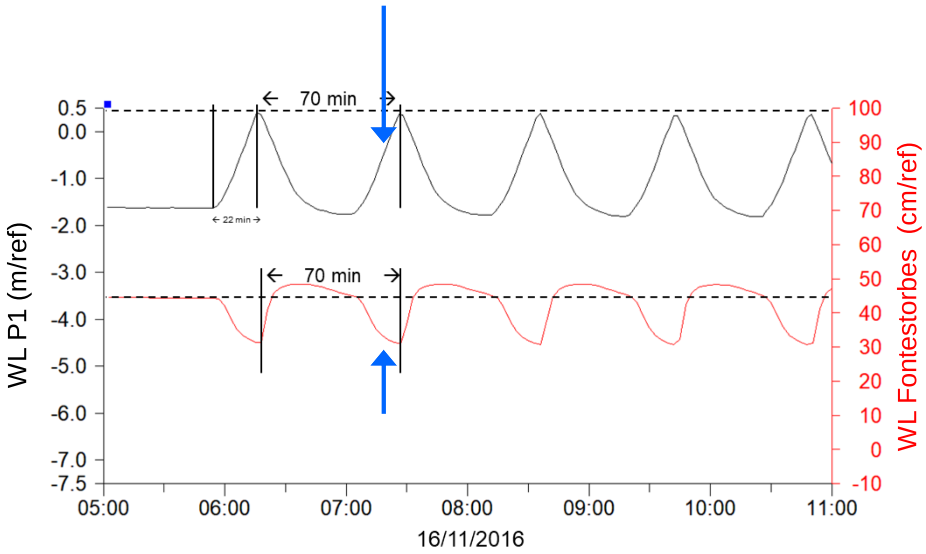


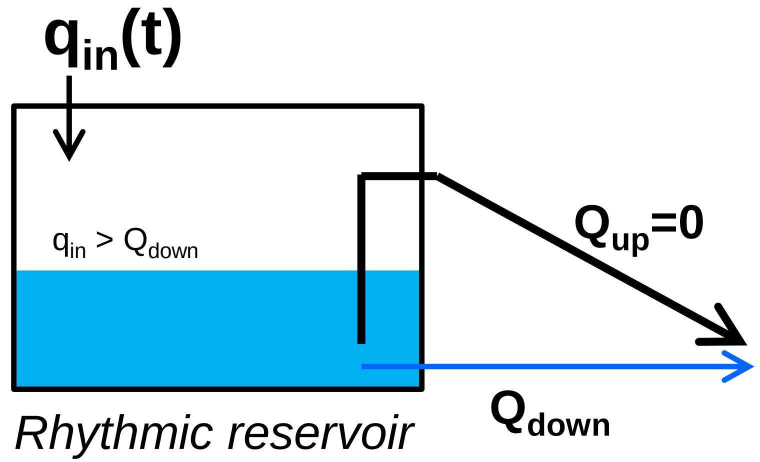
- Stop of the siphon ⇨ $Q_{up}=0$

⇨ WL in P1 increases

⇨ The discharge at the Sp. decreases at a higher rate (inflexion on the Sp. hydrograph)

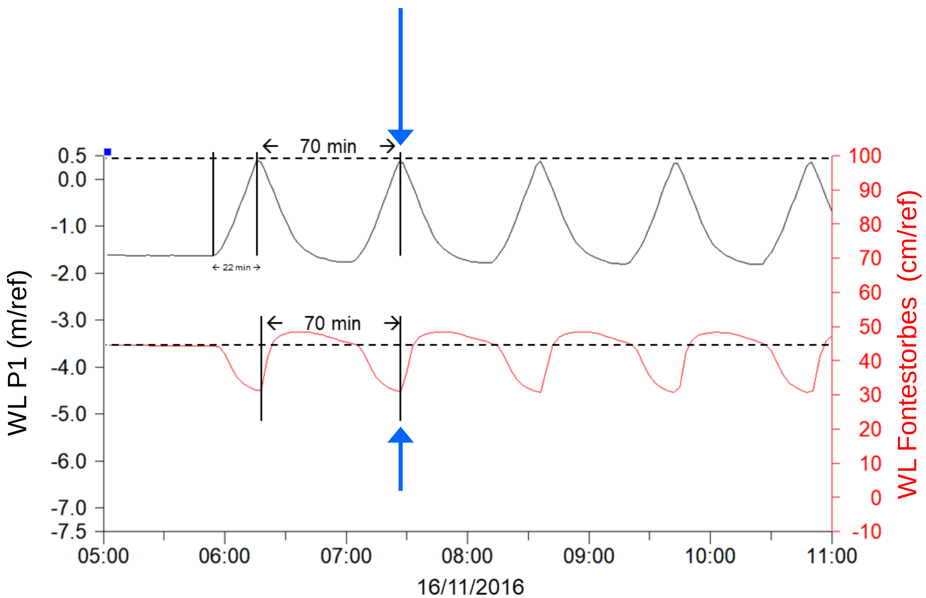
RESULTS / HYDRODYNAMICS – START AT HIGH FLOW

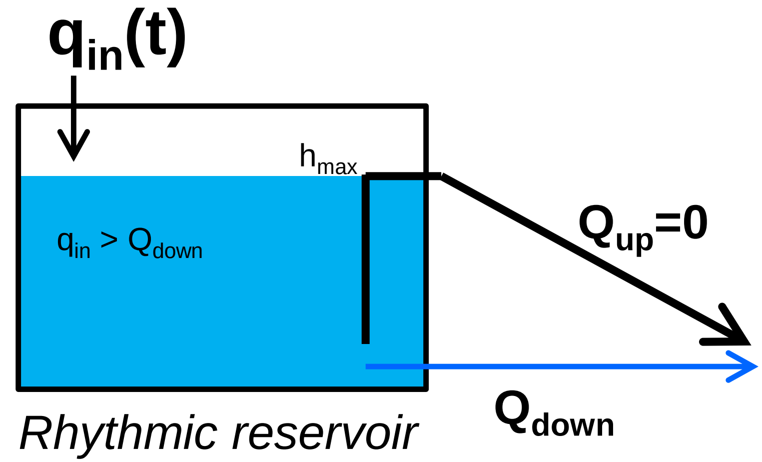




- WL in P1 increases
- The discharge at the Sp. decreases

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW

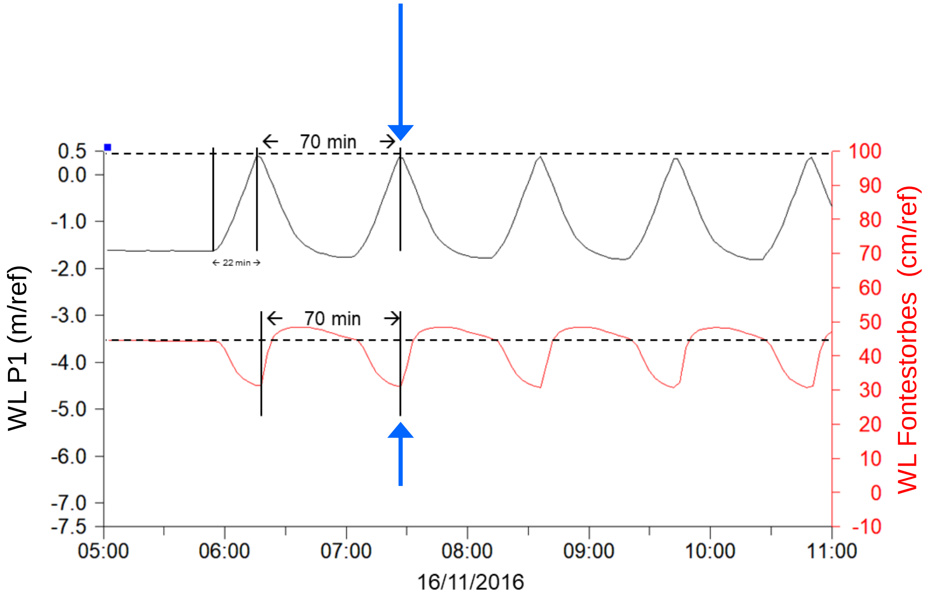


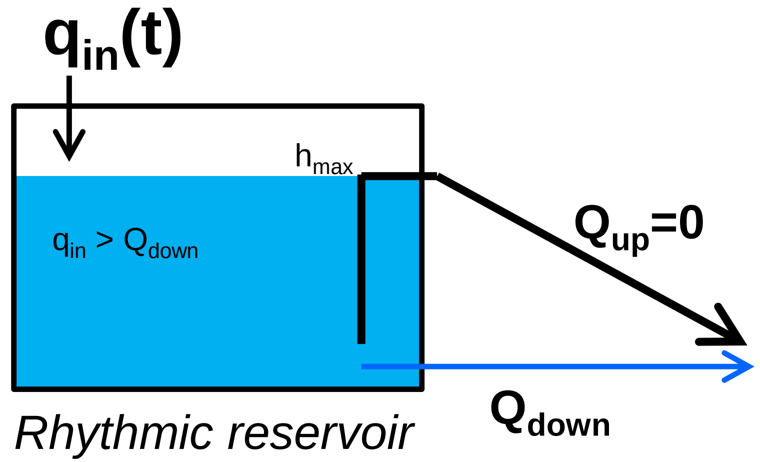


- WL in P1 increases and reaches h_{max}
- The discharge at the Sp. is minimum
- Etc.

If $q_{in} < Q_{down} + Q_{up}$ the process stops at this step (stop at low flow), with a filled reservoir

RESULTS / HYDRODYNAMICS – START AT HIGH FLOW





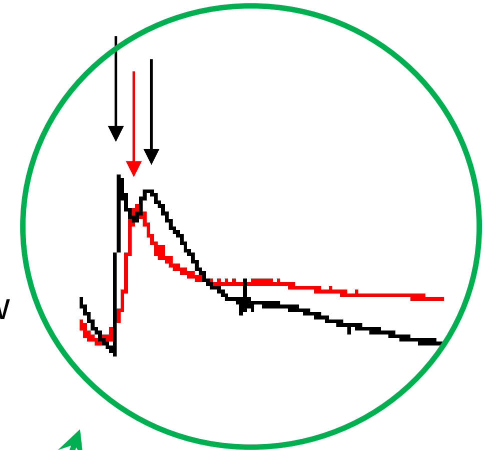
- ⇨ P1 = tank that empties, which induces a flood that propagates to the Sp.
- ⇨ No time lag between the reservoir emptying (P1) and the increase of the Sp. discharge

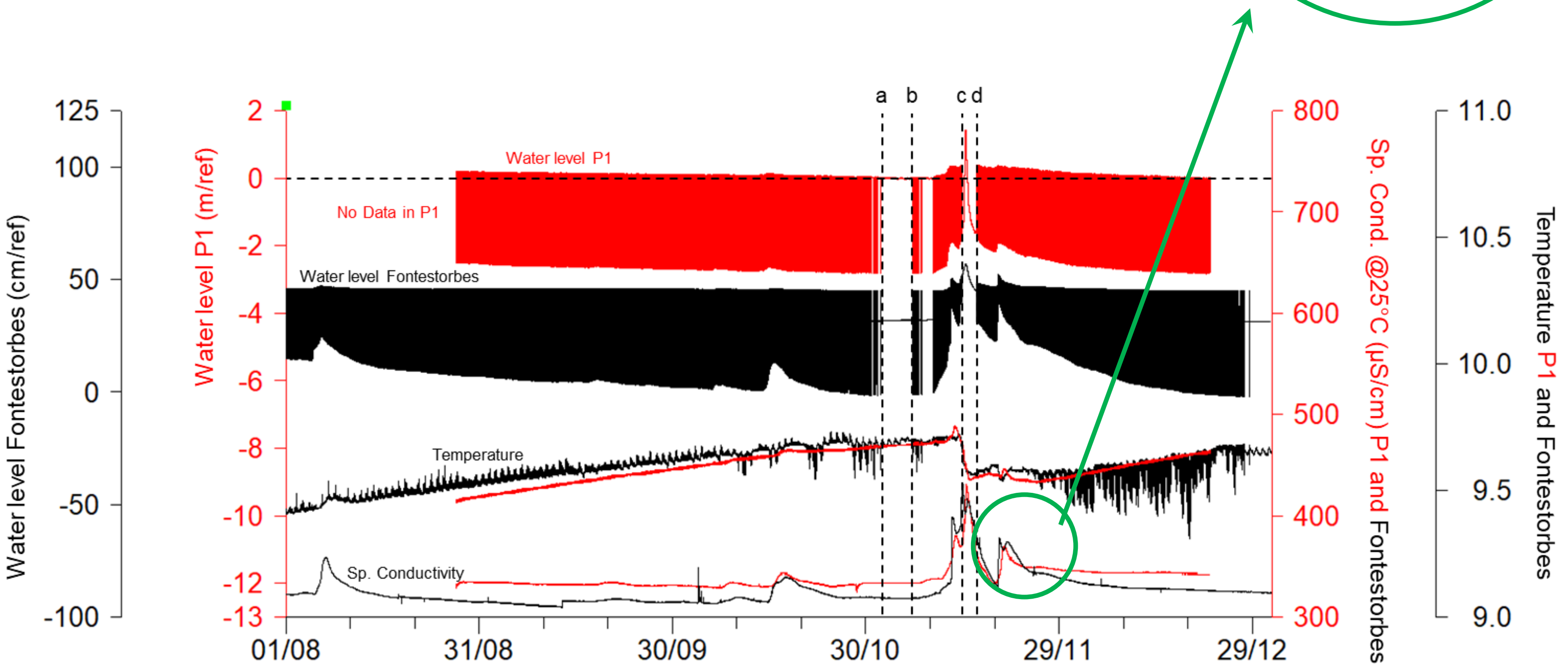
RESULTS / WATER TRANSFER

Monitoring P1 vs. Fontestorbes – all data set

Physico-chemical monitoring

- T and Cond from P1 to the Sp. are most of the time consistent ⇨ tracer of flow
- Some flood events show 2 responses of Cond at the Spring, but only 1 in P1





TRANSFER FROM P1 TO FONTESTORBES

Hydrodynamics

- P1 water-level is a pressure measurement upstream from the mechanism

⇨ **The mechanism is located between P1 and the Sp.**

⇨ What is measured at the Sp. is the resulting pressure transfer through the karst media

- The rhythmic mechanism can stop at low flow

⇨ The rhythmic reservoir is drained by (at least) 2 drains
  - A siphoning drain with a high discharge capacity
  - Another drain with a limited discharge capacity

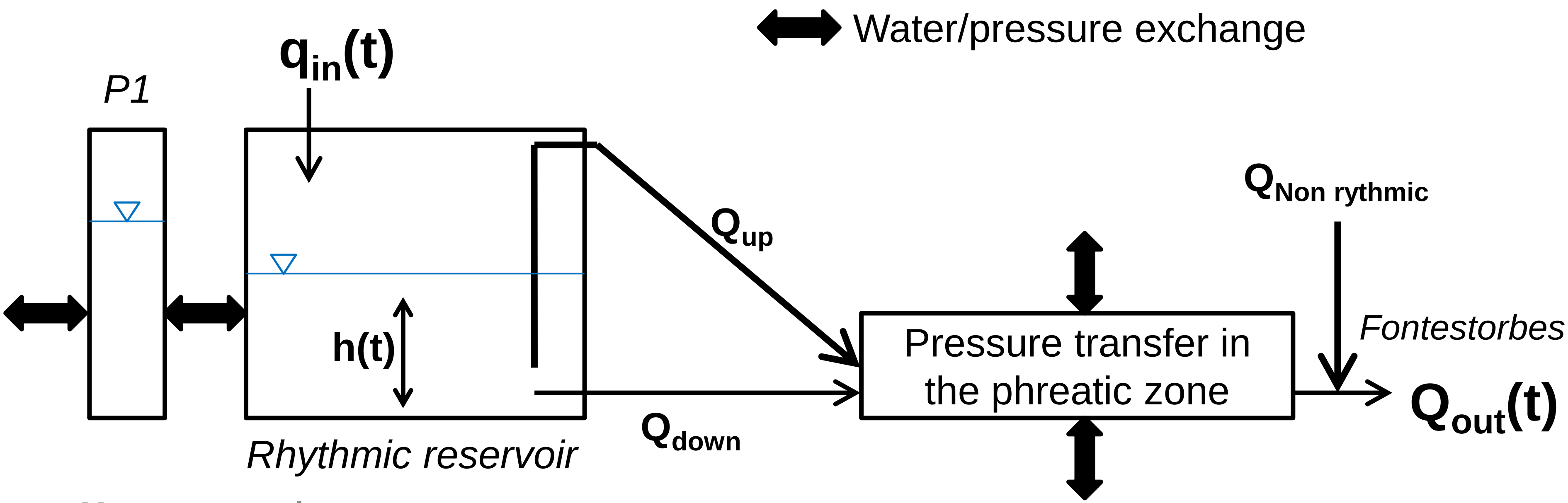
Physico-chemistry

- The rhythmic behavior characterizes only one compartment of the aquifer

⇨ **Sp. discharge is the sum of a rhythmic flow and a non rhythmic flow**

⇨ Can we simulate this rhythmic behavior with a simple reservoir model?

CONCEPTUAL MODEL



Many assumptions…

- P1 WL is a measure of h(t)
- Q_{up} is constant with a hysteresis behavior
- Q_{down} is a linear function of h: $Q_{down}(t)=k*h(t)$
- Another linear reservoir is used to simulate the pressure transfer in the phreatic zone ($K_{phreatic\_transfer}$)
- $Q_{non\ rhythmic}$ is neglected (=0) ⇨ Simulation in low flow

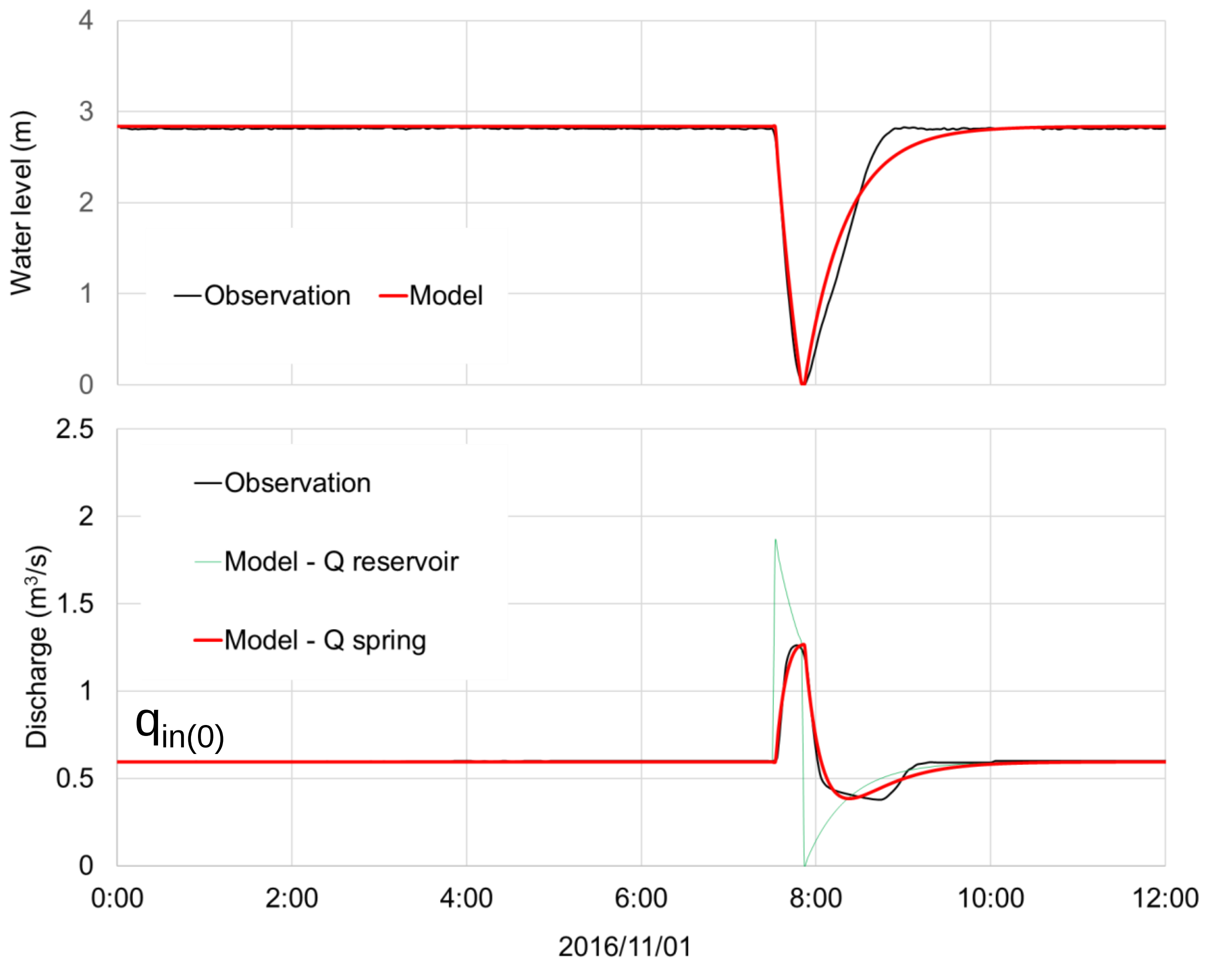
NUMERICAL MODEL

Case a: Stop at low flow

Vol. = 1058 m³

S = 372 m²

q_{in} decreases which causes the stop of the phenomenon



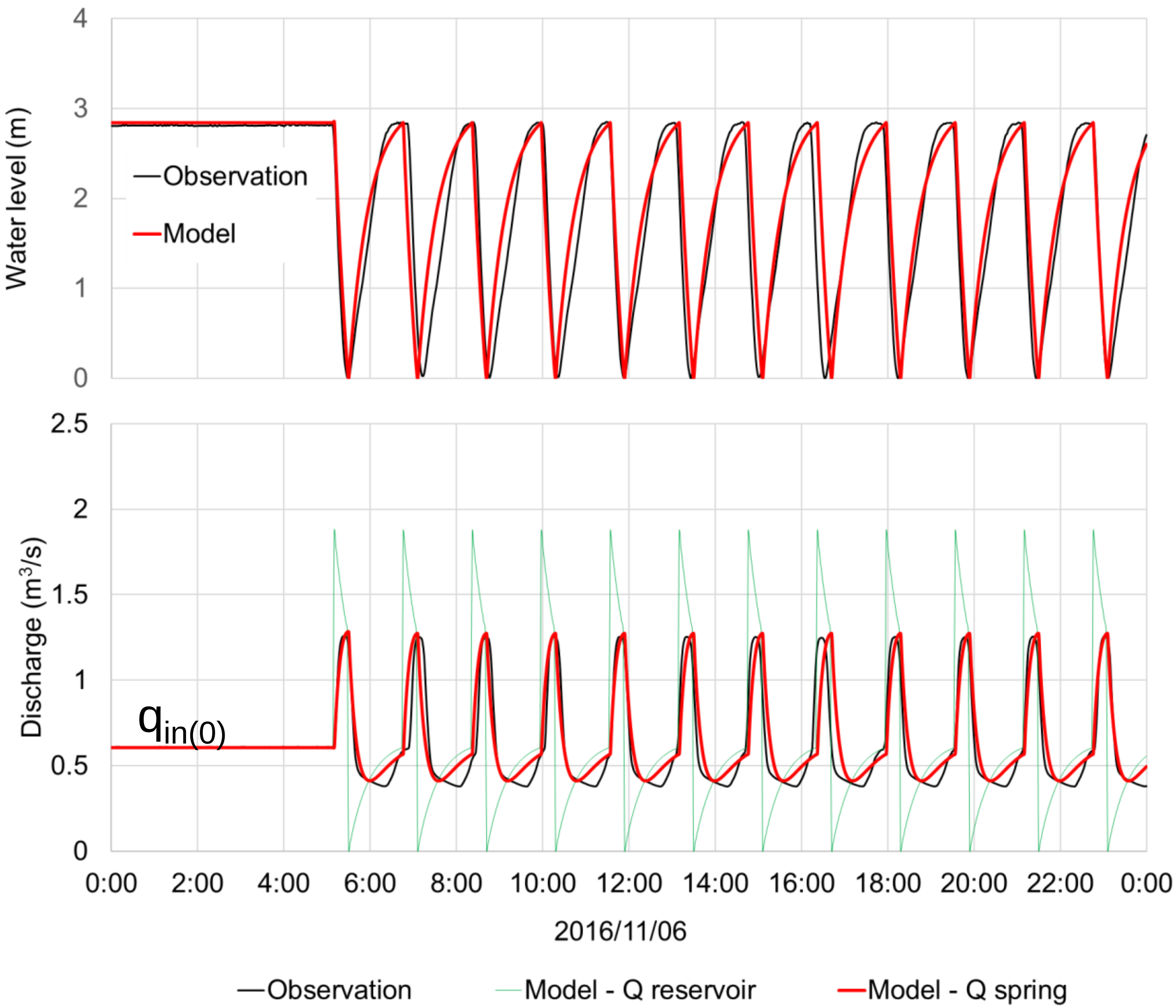
NUMERICAL MODEL

q_{in} increases (43 l/s!) and causes the start of the phenomenon

Case b: Start at low flow

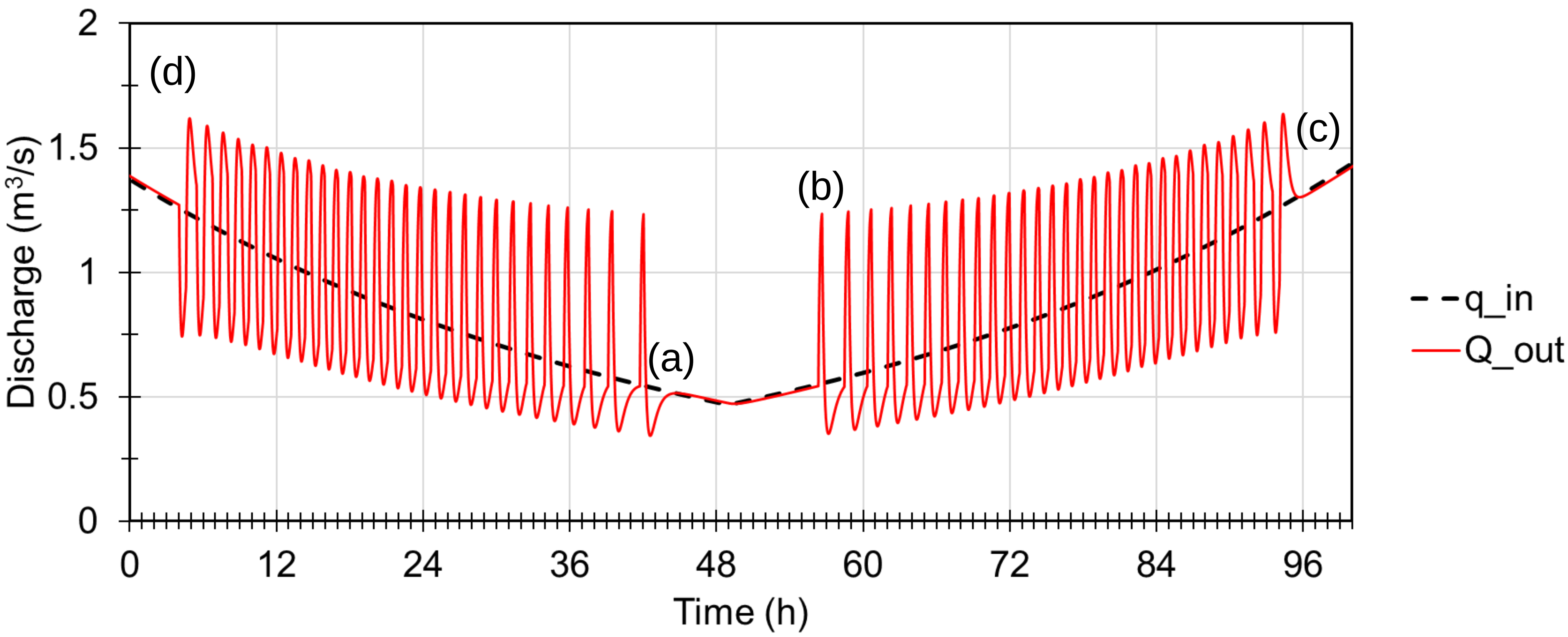
Δq_{in} = 43l/s

⇨ Very sensitive to small changes of the recharge rate



NUMERICAL MODEL – 4 CASES (SYNTHETIC DATA)

The model can reproduce the different cases of rhythmic hydrographs at the Fontestorbes Spring (also for P1 WL)



CONCLUSION

- Karst drainage network upstream from the Spring
  - P1 is close to the rhythmic mechanism, which **is located between P1 and the Spring**
  - At least **2 independent karst drainage networks**, one being rhythmic in low flow
    - ⇨ Consistent with the karst drainage network simulation using KARSYS, cf. Eurokarst 2016
    - ⇨ There are no simple relationships between sp. discharge and start/stop of the phenomenon
  - Karst conduits are **fully saturated** from the rhythmic reservoir to the spring
  - The rhythmic behavior can be **stopped** for very low flows ($q_{in} < 0.6\ m^3/s$)

- A simple reservoir model with a hysteresis process can reproduce the main characteristics of the Spring and P1 hydrographs
  - The volume of the rhythmic reservoir is +/- 1000 m^3
  - The real phenomenon is way more complex!!!… and we only have **indirect information** about this mechanism

IN MEMORY OF ALAIN MANGIN

Field trip during Plateau de Sault project © N Ravaiau

THE FONTESTORBES RYTHMIC SPRING

What do we know about this phenomenon?

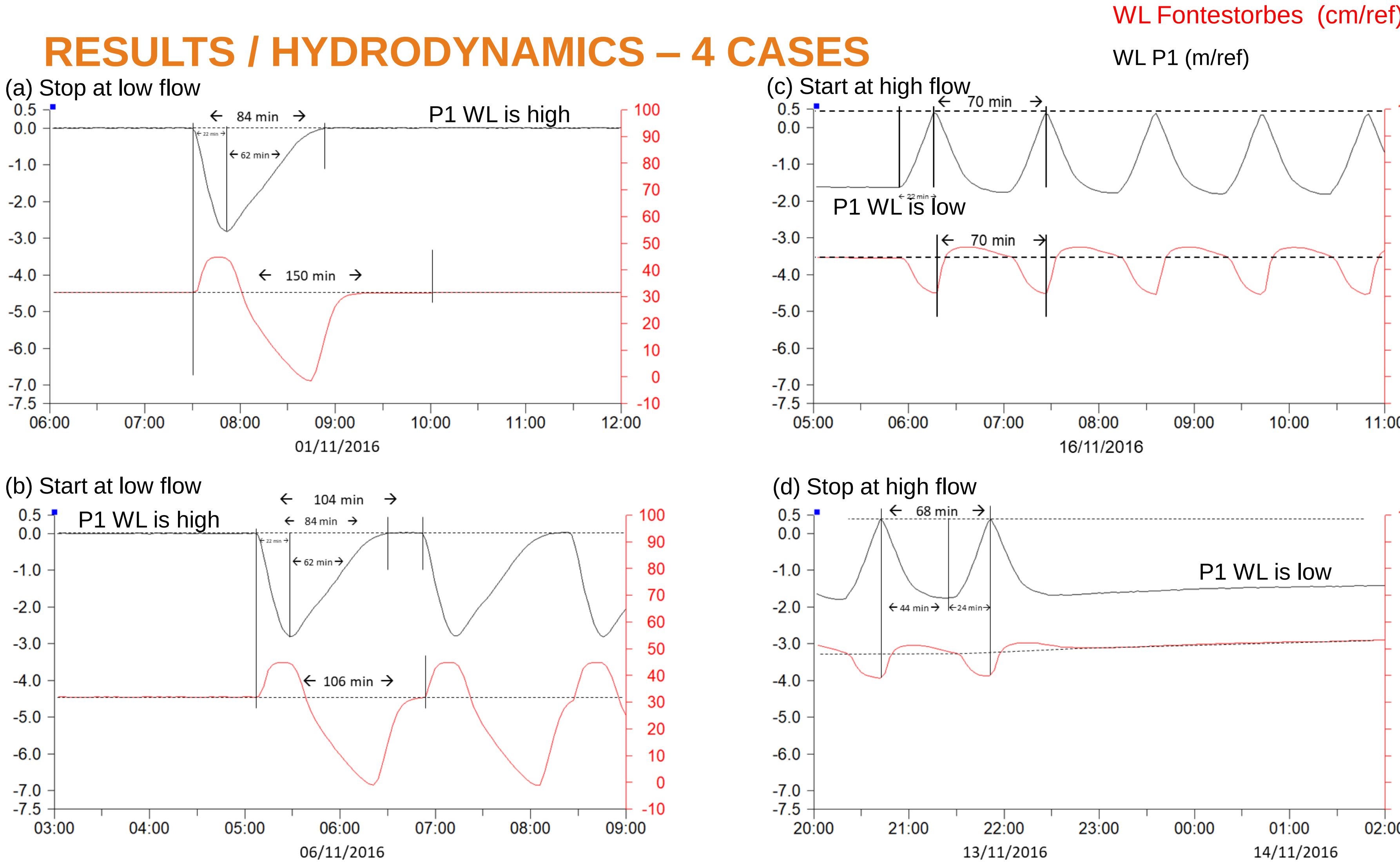
Planque, 1728; Astruc, 1730; Martel, 1909; Brunet, Verdeil, Mangin from the 60's, etc.

- **Spring observations**
  - 2 (or 3) distinct behaviors:
    - A rhythmic spring during base flow and a common karst spring otherwise
    - The phenomenon should also stop at low flow (Verdeil, Brunet)
  - The existence of another independent karst flow converging to the spring is debatable
  - In 1969 and 1973, Mangin proposed a physical explanation involving a siphoning tank, with head losses governed by an air-inlet on the karst conduit
  - Cau (1983) did a review of the various physical interpretation of the phenomenon

- **P1 observations**
  - Water level fluctuations are observed in a cave (P1, since 1957) 1200m upstream from the Spring and are related to the rhythmic discharge
  - The location of the phenomenon is debatable: upstream (Mangin) or downstream (Verdeil) from P1

- But… **Additional observations raise new questions**
  - In 1973, the phenomenon stops at low flow
  - In 1983, cave divers explore P1 upstream and found a non-rhythmic water table

RESULTS / HYDRODYNAMICS – 4 CASES



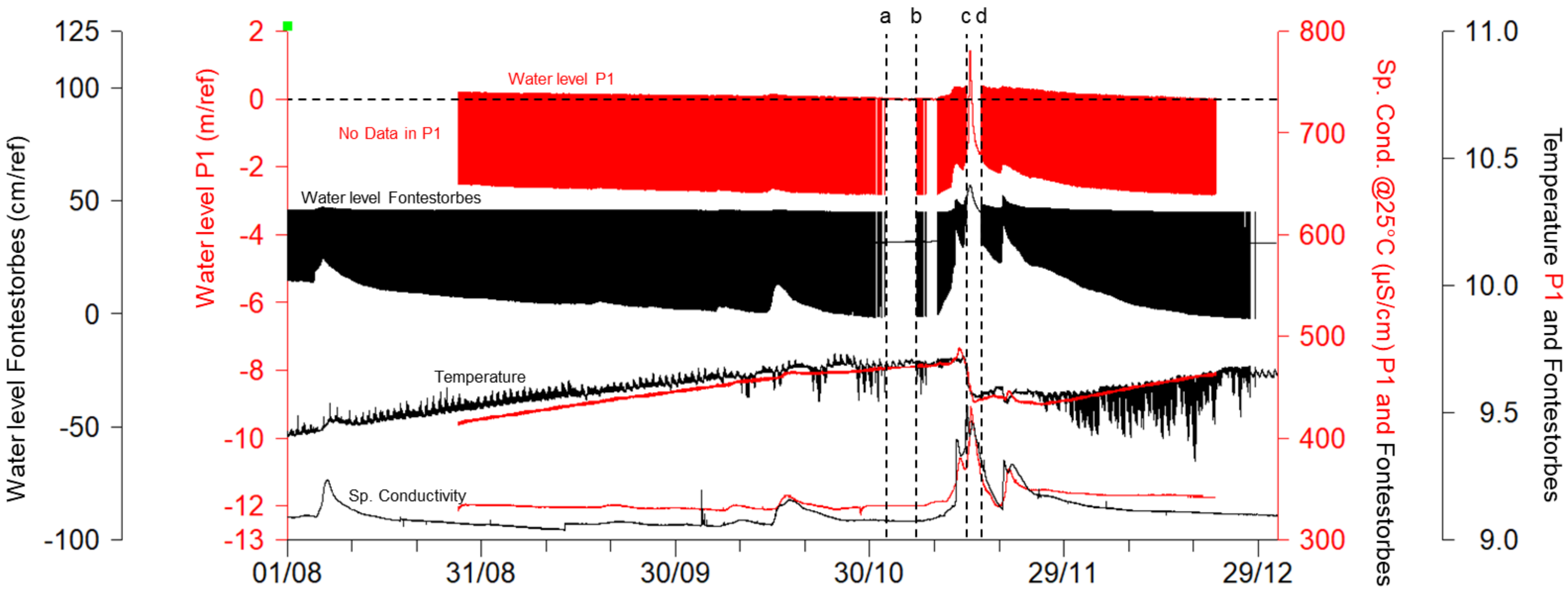
- P1 = tank that empties, which induces a flood that propagates to the Sp.
- No time lag between the reservoir emptying (P1) and the increase of the Sp. discharge

INSTRUMENTATION

Monitoring P1 vs. Fontestorbes

Physico-chemical monitoring

- T and SpC from P1 to the Sp. are most of the time consistent ⇨ tracer of flow
- Some events show 2 responses at the Sp.



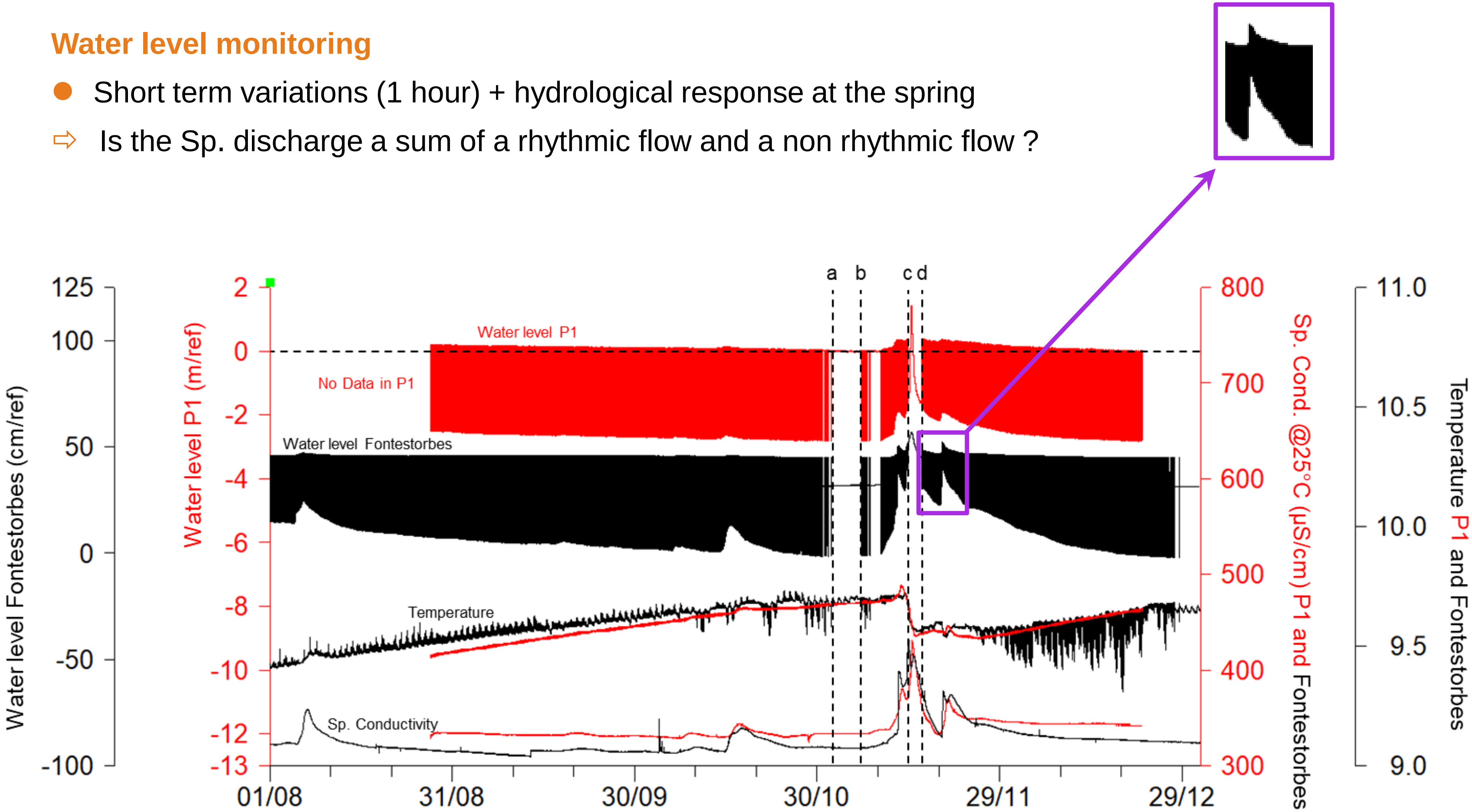
RESULTS

Monitoring P1 vs. Fontestorbes – all data set

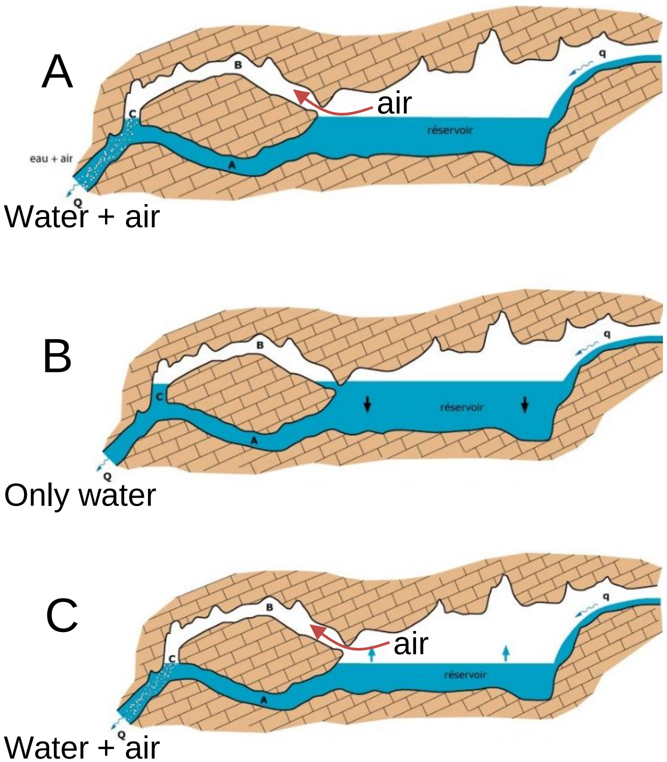
Water level monitoring

- Short term variations (1 hour) + hydrological response at the spring

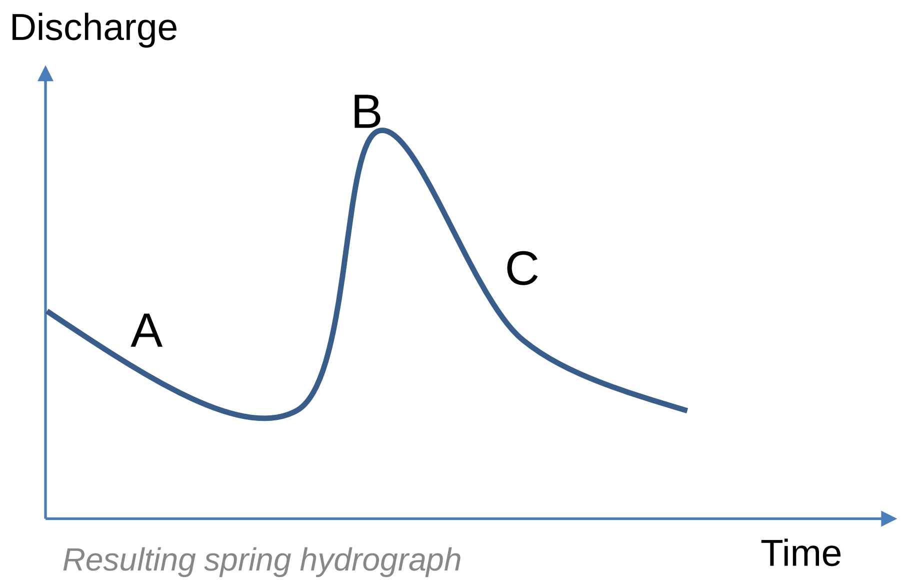
⇨ Is the Sp. discharge a sum of a rhythmic flow and a non rhythmic flow ?



CONCEPTUAL MODEL OF THE FONTESTORBES PERIODIC SP.



Air-inlet mecanism along the conduit draining the siphoning reservoir



Resulting spring hydrograph

- Where the mecanism takes place?
- Is the air-inlet mecanism necessary?
- Does it always starts and stops for a given discharge at the Spring?
- If not, is there another karst subsystem feeding the pring?

⇨ New monitoring at P1

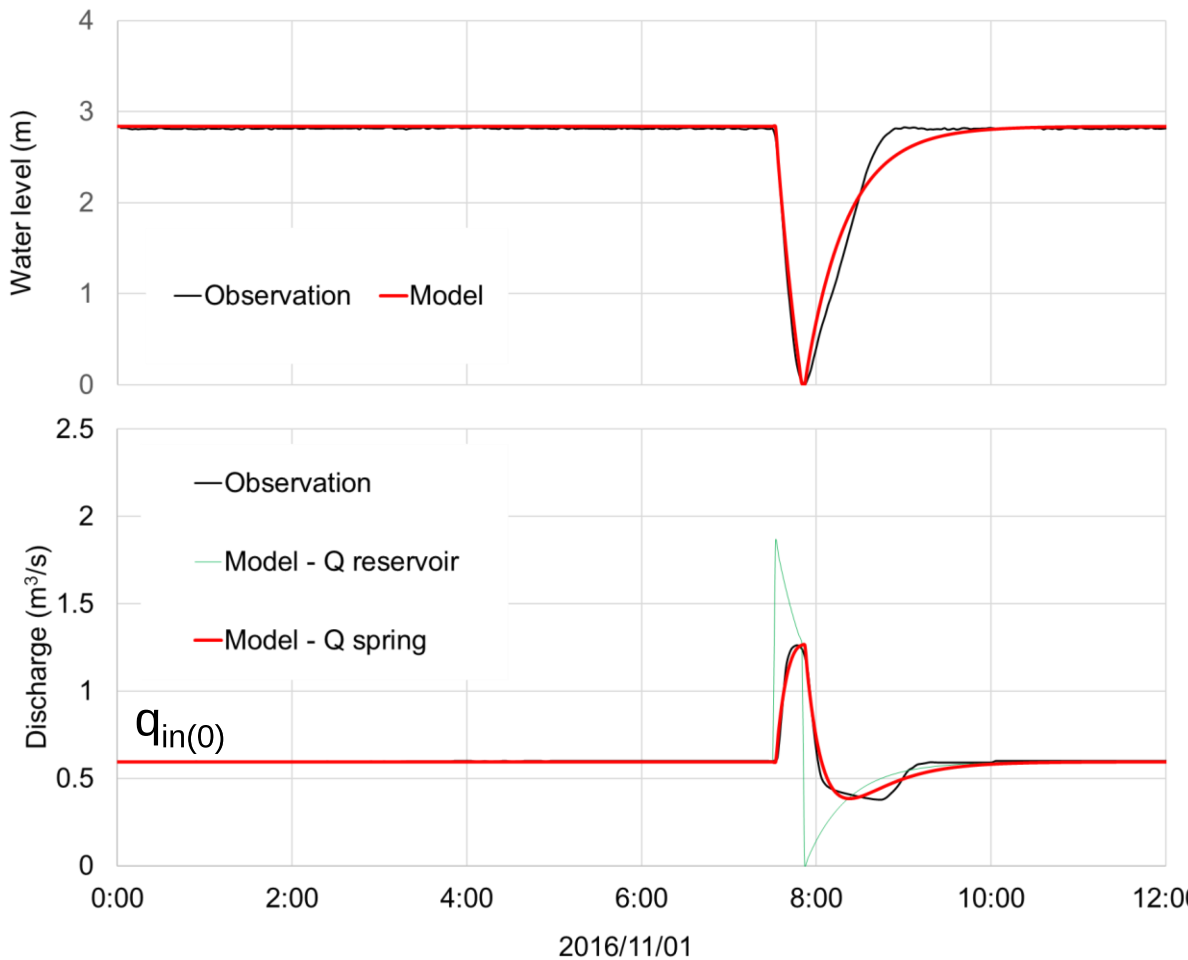
NUMERICAL MODEL

- CALIBRATION PROCESS -

Case a: Stop at low flow

- 2 measured parameters
  - h_{max} = 2.8 m
  - $q_{in(0)}$ = 0.595 m^3/s
- **3 fitted parameters**
  - **Q_{up} = 1.26 m^3/s**
  - **$K_{phreatic\_transfer}$ = 99 d^{-1}**
  - **Vol. = 1058 m^3**
- 2 calculated parameters
  - $S = Vol./h_{max} = 372\ m^2$
  - $k = (q_{in(0)}/S)/h_{max} = 48.6\ d^{-1}$

q_{in} decreases which causes the stop of the phenomenon



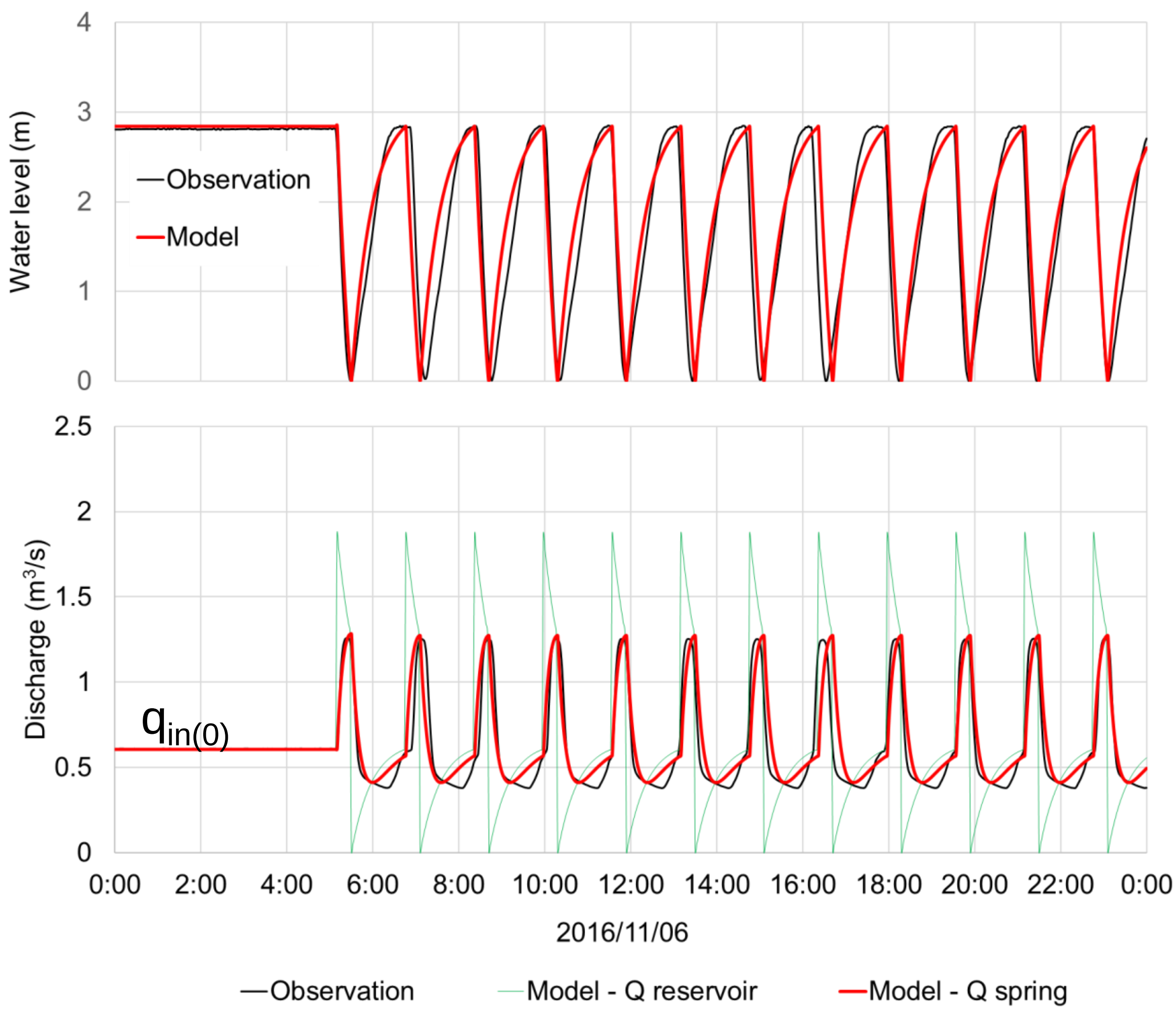
NUMERICAL MODEL

- CALIBRATION PROCESS -

Case b: Start at low flow

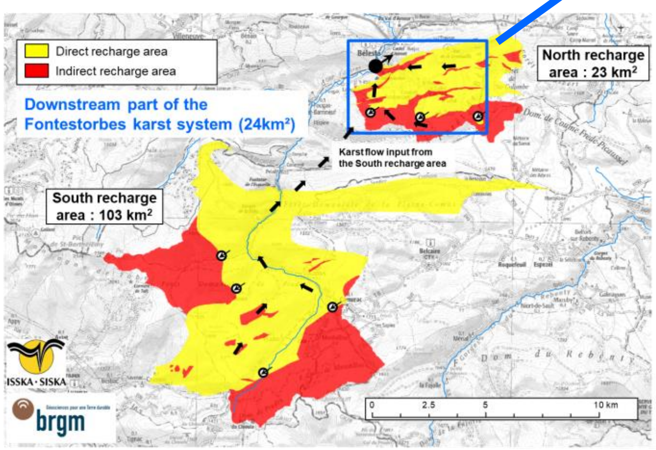
- 2 measured parameters
  - h_{max} = 2.8 m
  - $q_{in(0)}$ = 0.607 m^3/s which is different from case (a)
- 3 fixed parameters from (a)
  - Q_{up} = 1.26 m^3/s
  - $K_{phreatic\_transfer}$ = 99 d^{-1}
  - Vol. = 1058 m^3
- **1 fitted parameter**
  - **Δq_{in} = 43l/s**
- 2 calculated parameters
  - $S = Vol./h_{max}$= 372 m^2
  - $k = (q_{in(0)}/S)/h_{max}$= 49.6 d^{-1}

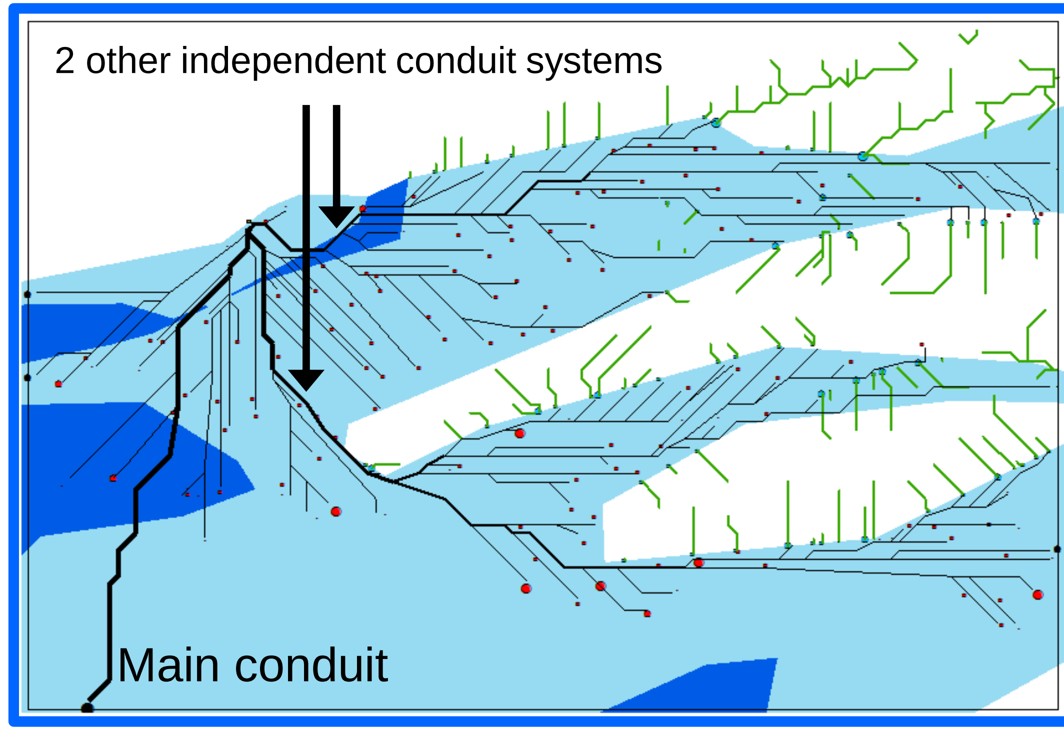
q_{in} increases (43 l/s!) and causes the start of the phenomenon



THE FONTESTORBES KARST DRAINAGE NETWORK

- Does the main karst drainage network also shows a rhythmic behavior ?
- Is there another karst conduit that bring water to the Sp. downstream from the intermittent mechanism ?
- Can we use these information to locate the rhythmic reservoir?





KARSYS method, Eurokarst, 2016