Groundwater modelling in the Bassée alluvial plain: A tool for understanding the dynamics of a complex socio-hydrosystem

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1. Introduction

The Bassée Observatory, located in the heart of the Seine catchment and part of the Zone Atelier Seine network, is an essential research platform for understanding hydrological processes related to the strategic challenges of sustainable water resources management. It focuses on the behaviour of the alluvial plain as a complex and anthropised hydrosystem ***(2)***, considering its long-term geohistorical evolution. Through an extensive network of surface and groundwater monitoring stations ***(3)***, the Observatory highlights the central role of groundwater and its interactions with surface water in the current dynamics of this region. We introduce pyWaQS, a new tool that combines the CaWaQS hydrogeological platform with the groundwater utilities of the PEST parameter estimation approach ***(4)***. We have applied it to create a new groundwater model of the Bassée aquifer system, with an improved representation of the heterogeneity of the alluvial plain ***(5)***. It will provide a sound basis for quantitative decision making, helping stakeholders to meet the challenges of operating and conserving the groundwater resources of the alluvial plain, in the context of a changing climate ***(6)***.

2. A human-altered floodplain

The alluvial plain of the Bassée is at the centre of strategic issues relating to ***inland waterways transport***, ***flood prevention***, ***biodiversity conservation***, ***water*** and ***granular resources***. As a result, a radically altered landscape emerges, with fields gradually replacing forests due to the reduction of downstream flooding, itself linked to the recalibration of the Seine channel aimed at promoting river transport. Changes in land use also include the extraction of alluvial deposits for gravel production, giving rise to multiple gravel pit lakes that now cover around 8% of the territory. The abundant groundwater in the alluvial and underlying chalk aquifers is used for agricultural (42%), domestic (38%) and industrial purposes (20%).

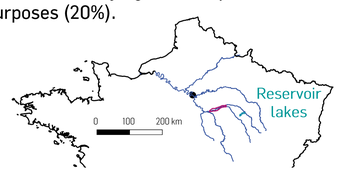
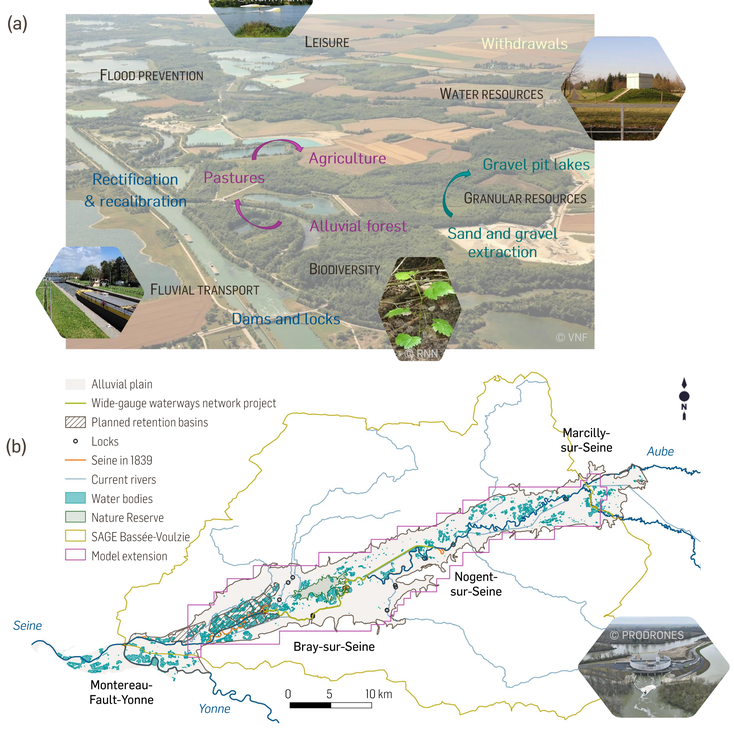


Fig. 1 – Human influences in the alluvial plain of the Bassée



Today, two development projects are still under study: the creation of flood control reservoirs downstream, and the upstream extension of the large-gauge development.

3. The Bassée Observatory

The Bassée Observatory consists of a network of almost 300 observation points. It includes meteorological and hydrometric stations as well as boreholes in the chalk and/or alluvial aquifers. Downstream, many of these monitoring sites have been installed by local stakeholders as part of development projects since 2015. Most of the records have a 15-minute time step and vary in length, from one hydrological year to more than 50 years in the case of the longest.

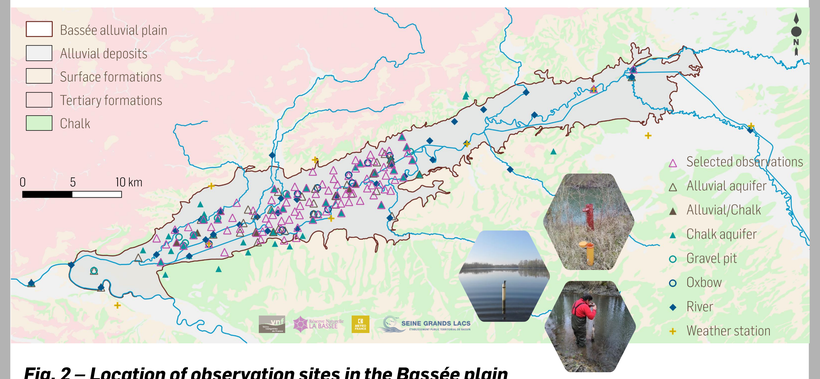


Fig. 2 – Location of observation sites in the Bassée plain

4. The pyWaQS tool

A groundwater model of the alluvial plain aquifer system was developed using the hydrosystem modelling platform CaWaQS (Flipo et al. 2023). Here we explore how the PEST suite (Doherty 2015) can be used ***to estimate the hydrodynamic parameters of this heterogeneous alluvial plain***. To this end, we developed an interface between the two tools, called pyWaQS, which was first validated on a simplified test case in both steady and transient modes before being applied at the scale of the Bassée.

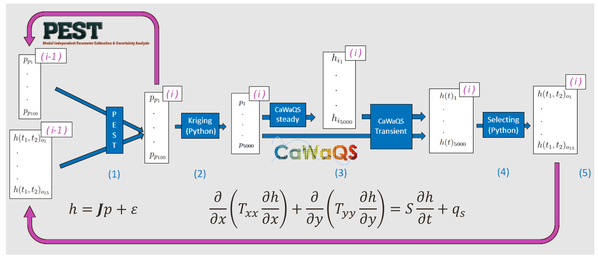


Fig. 3 – PyWaQS diagram during one iteration of the calibration process: example with 5000 mesh elements, 100 pilot points, 15 observation wells and two sampled times

PEST provides calibration tools based on the Gauss-Levenberg-Marquardt algorithm and mathematical regularisation. We used a subset of pilot points evenly distributed in the model domain as a selection of parameters to be estimated by PEST prior to kriging on the model grid.

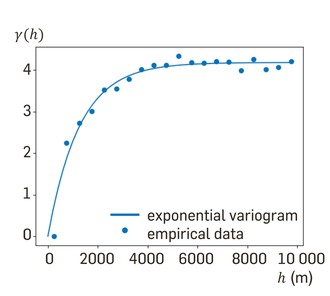


Fig. 5 – Estimated semi-variogram from initial transmissivity field

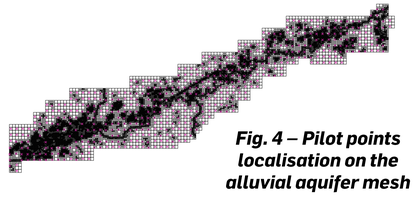
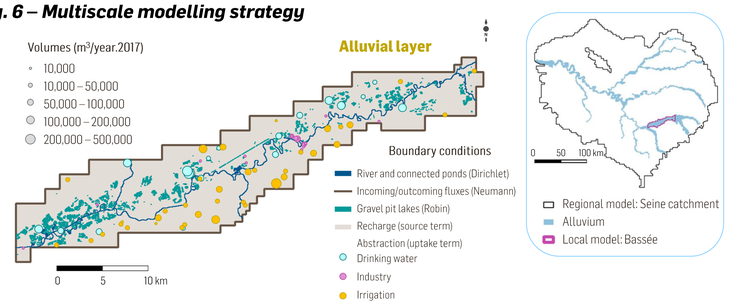


Fig. 4 – Pilot points localisation on the alluvial aquifer mesh

5. Unveiling the spatial heterogeneity of the alluvial plain

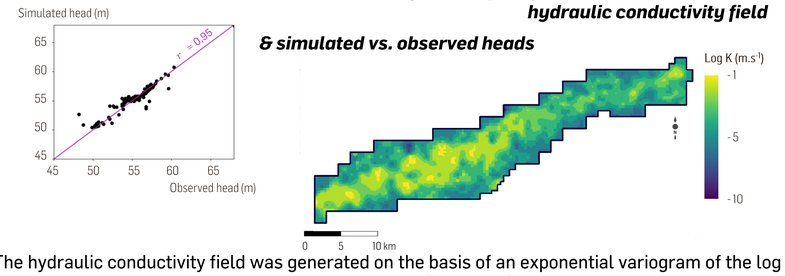
The local groundwater model of the Bassée hydrosystem consists of two layers, the alluvial and the chalk aquifers. It takes its boundary conditions from a coarser regional model run over the entire Seine basin using CaWaQS (Flipo et al. 2023). It includes exchanges with gravel pit lakes and water withdrawals according to the national database.

Fig. 6 – Multiscale modelling strategy



PyWaQS was launched on Sorbonne Université's MCMeSU supercomputer. A representative steady-state simulation was chosen during the 2017 low flow period. About a hundred hydraulic head measurements from boreholes distributed throughout the alluvial aquifer (see Fig. 2) were selected as observation data in PEST in order to determine the transmissivity field. Transient simulations over the 2016-2017 hydrological year are still underway to calibrate the specific yield field.

Fig. 7 – Output of PEST calibration process: hydraulic conductivity field & simulated vs. observed heads



The hydraulic conductivity field was generated on the basis of an exponential variogram of the log transmissivity field resulting from the PEST process (see Fig. 5). Its wide range is characteristic of the heterogeneity of alluvial deposits. By sampling the posterior probability density function for the hydraulic conductivity field, we generated a large number of realisations and provided a basis for assessing the predictive ability of the groundwater model.

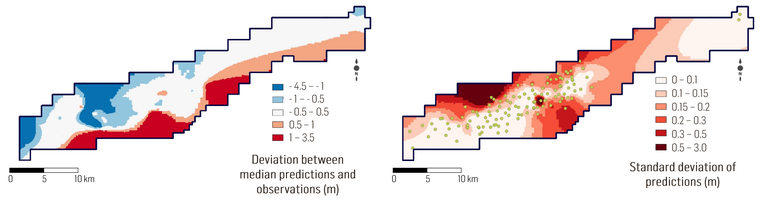


Fig. 8 – Uncertainty analysis

6. Conclusion and perspectives

- ✓ PyWaQS, a robust tool designed to efficiently calibrate and objectively evaluate the performance of the Bassée alluvial plain groundwater model.
- ✓ Technical perspectives: calibration under transient conditions; in-depth uncertainty analysis using PEST software tools.
- ✓ Operational perspectives: optimise the groundwater volumes that can be sustainably extracted within the water management district (SAGE Bassée-Voulzie, see Fig. 1), considering parameter, observation and future climate uncertainties.

References

Doherty J (2015) Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing, Brisbane, Australia.
Flipo N, Gallois N, Schuite J (2023) Regional coupled surface–subsurface hydrological model fitting based on a spatially distributed minimalist reduction of frequency domain discharge data, Geosci. Model Dev., 16, 353–381, doi: 10.5194/gmd-16-353-2023.

Acknowledgements

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