Optimization of pumping rates in an island freshwater lens considering parameter, observation, and climate uncertainty

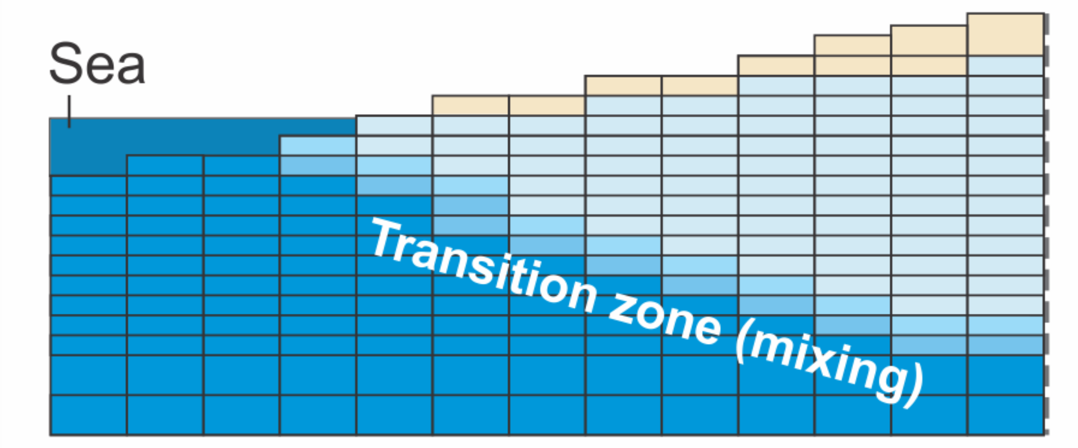
Cécile Coulon, Jean-Michel Lemieux, Alexandre Pryet, Laura Gatel
May 27, 2022

EGU General Assembly 2022

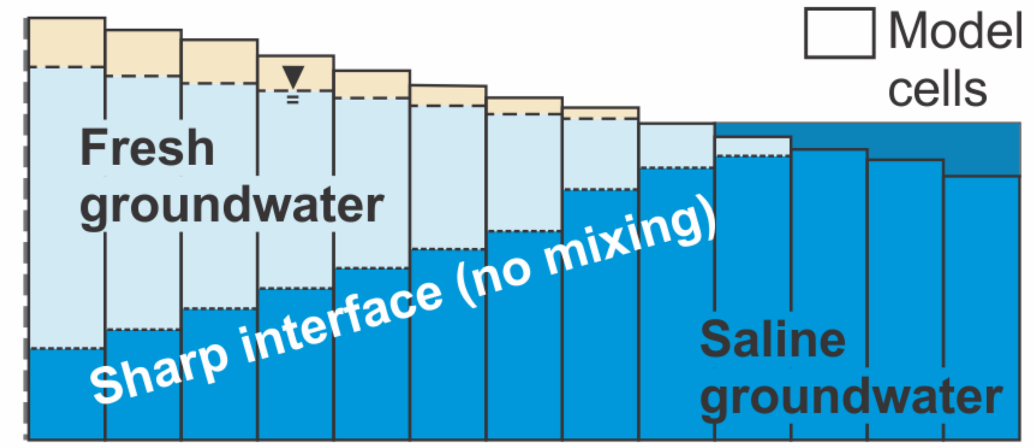
UNIVERSITÉ LAVAL · Québec · CentrEau Centre de recherche sur l'eau Water Research Centre · CENTRE D'ETUDES NORDIQUES CEN Centre for Northern Studies

Seawater intrusion numerical models

Advective-dispersive variable density models

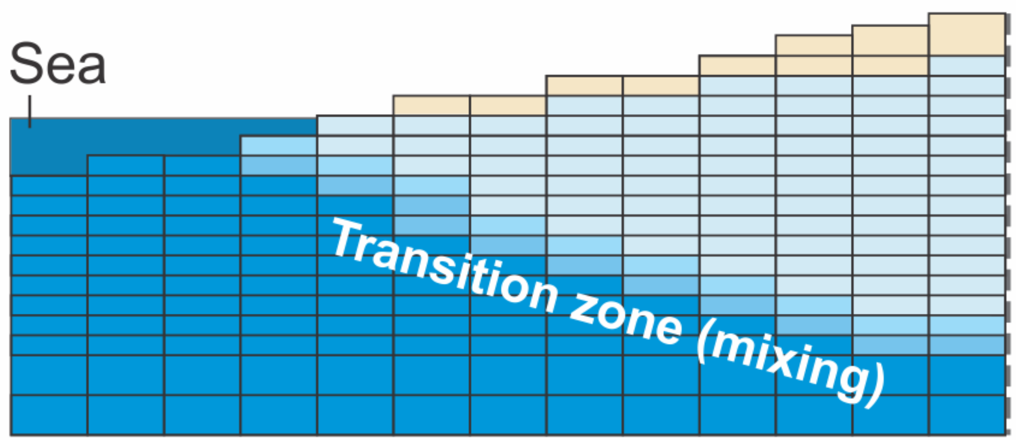


Sharp-interface models

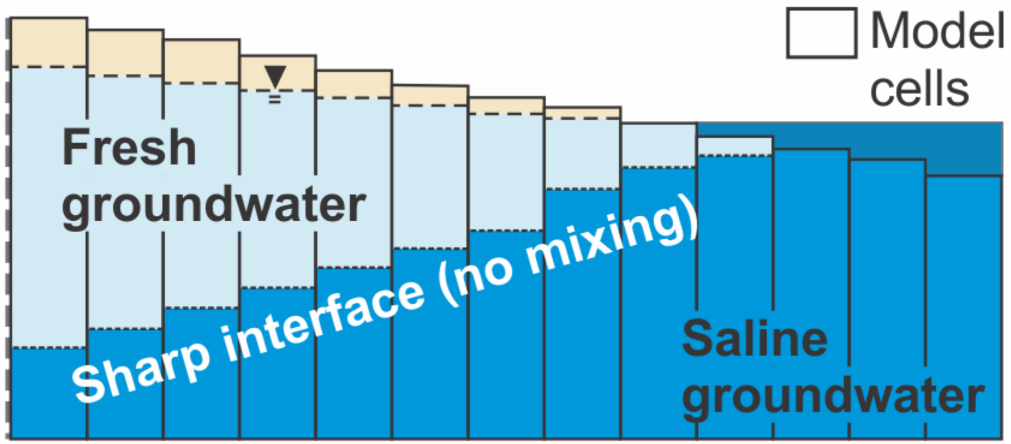


Seawater intrusion numerical models

Advective-dispersive variable density models



Sharp-interface models



Fast run times facilitate:

- Parameter estimation
- Uncertainty quantification
- Pumping optimization under uncertainty

Coulon et al. (2021)
Coulon et al. (under review, WRR)

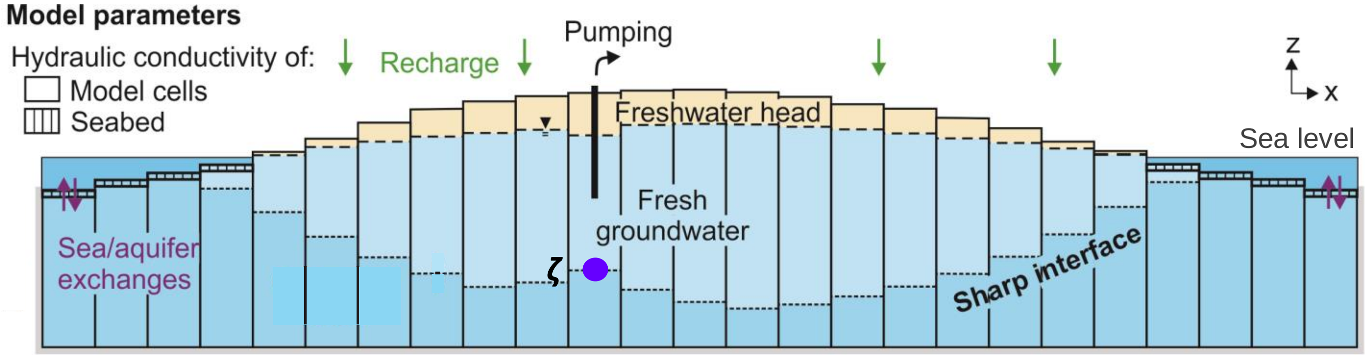
But these are still rare

Objective: Develop a method for pumping optimization considering parameter, observation, and climate uncertainty

METHODS (1) History-matching

2D-horizontal sharp-interface model

MODFLOW-SWI2 (Bakker et al. 2013)



Prior parameter ensemble
(***N*** parameter realizations)

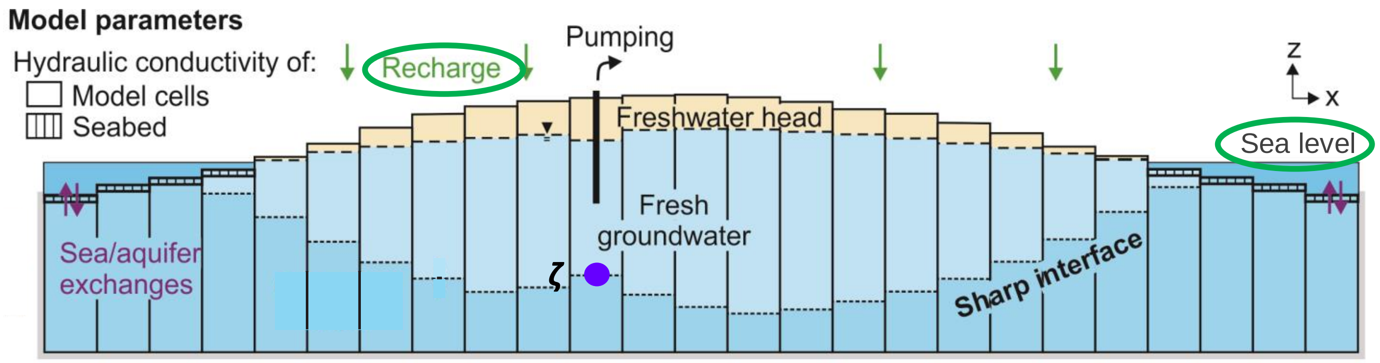
PESTPP-IES (White 2018) (1)

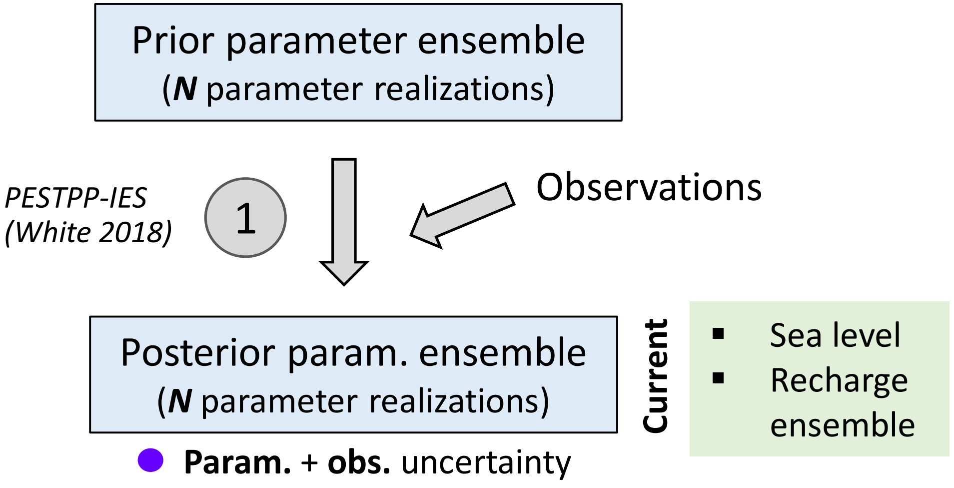
Observations

Posterior param. ensemble
(***N*** parameter realizations)

● **Param.** + **obs.** uncertainty

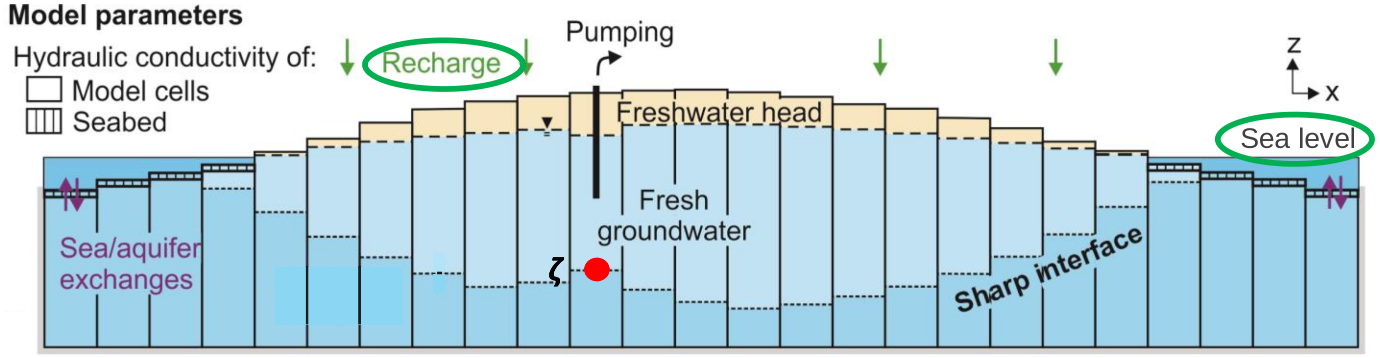
2D-horizontal sharp-interface model
MODFLOW-SWI2 (Bakker et al. 2013)

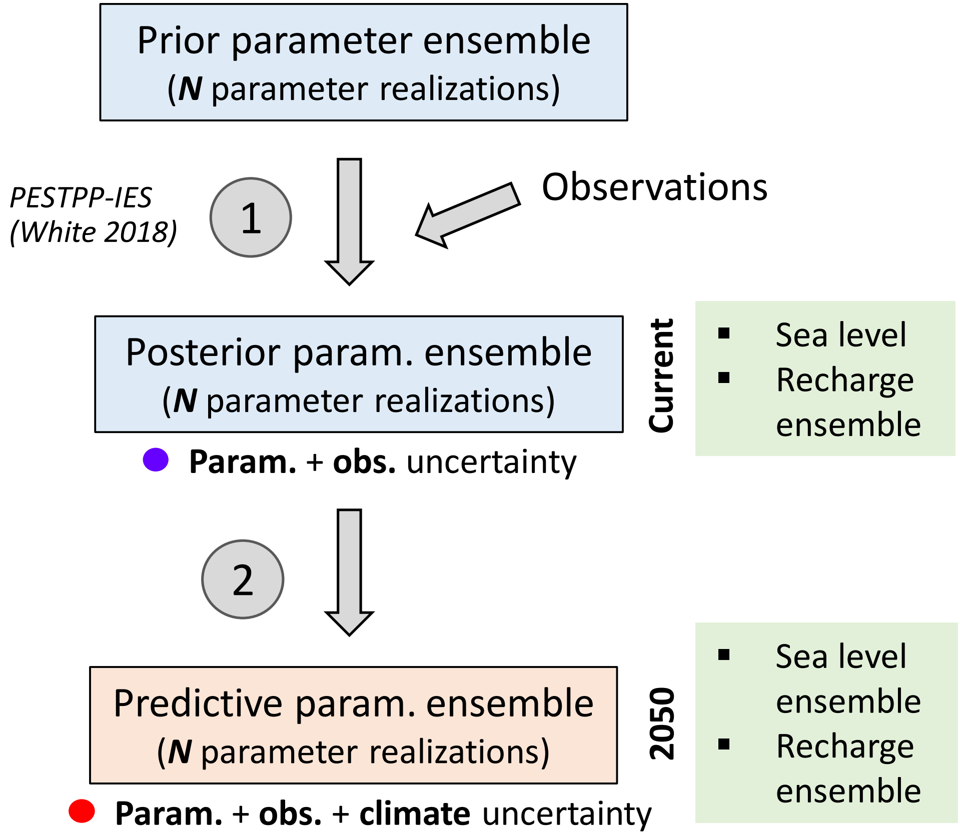




2D-horizontal sharp-interface model

MODFLOW-SWI2 (Bakker et al. 2013)

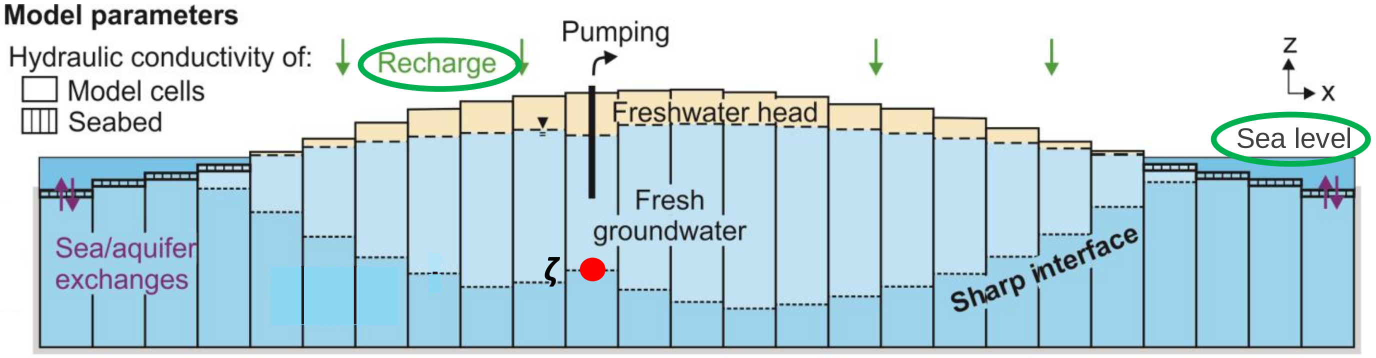




METHODS ① History-matching ② Incorporating climate change ③ **Optimization under uncertainty**

2D-horizontal sharp-interface model

MODFLOW-SWI2 (Bakker et al. 2013)



Prior parameter ensemble
(***N*** parameter realizations)

PESTPP-IES (White 2018) ① ↓ ← Observations

Posterior param. ensemble
(***N*** parameter realizations)

Current
- Sea level
- Recharge ensemble

● **Param.** + **obs.** uncertainty

② ↓

Predictive param. ensemble
(***N*** parameter realizations)

2050
- Sea level ensemble
- Recharge ensemble

● **Param.** + **obs.** + **climate** uncertainty

↓

③ Pumping optimization under uncertainty

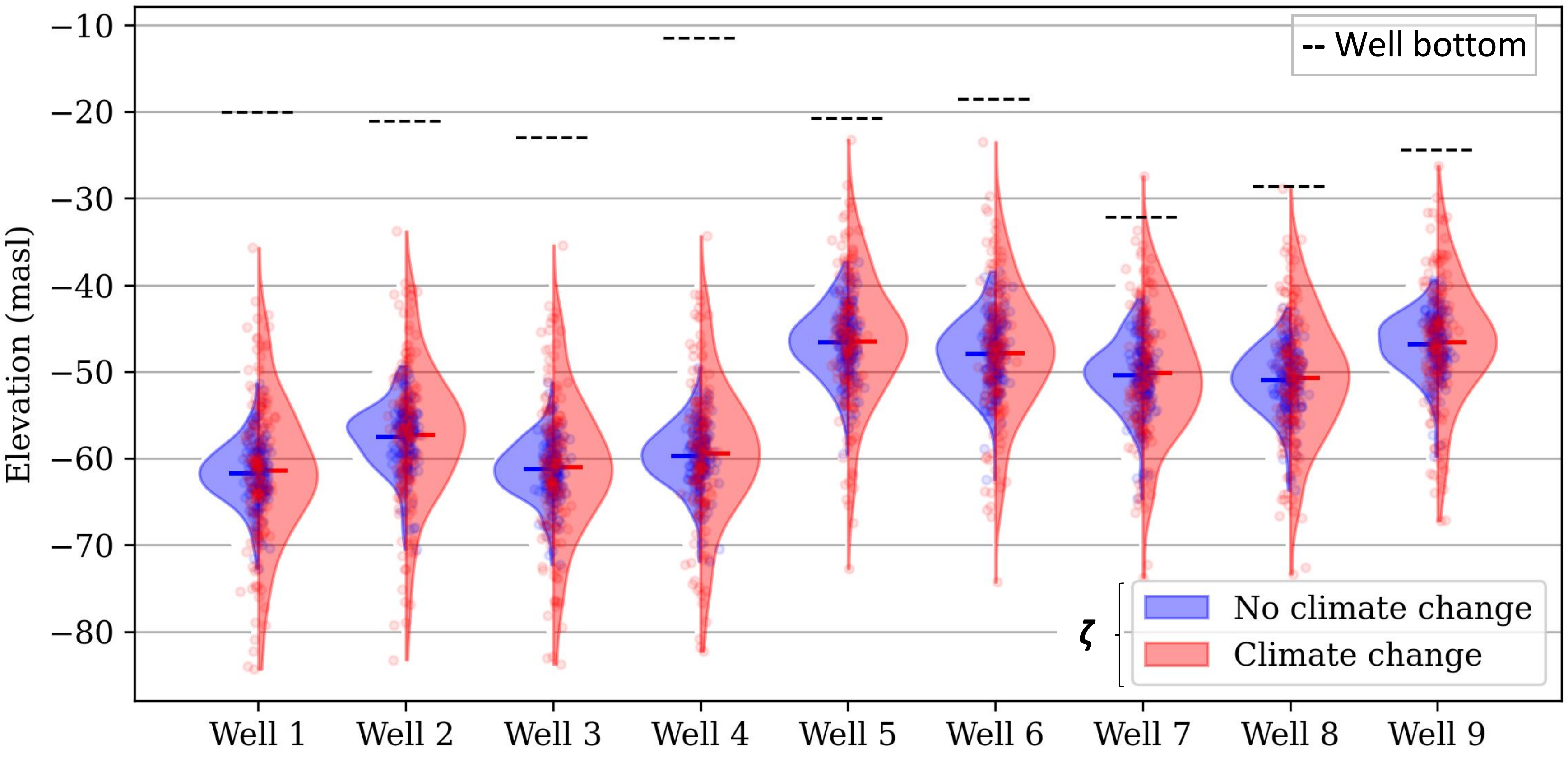
PESTPP-MOU (White et al. 2022)

2 objectives:
1) Maximize pumping $Q_{total} = \sum Q_i$
2) Minimize risk of well salinization

Constraints: avoid well salinization ($\zeta \leq z_{botm}$)

RESULTS 1. History-matching ✓ Successful **2. Incorporating climate change**

Posterior param. ensemble (no climate change) vs Predictive param. ensemble (with climate change)

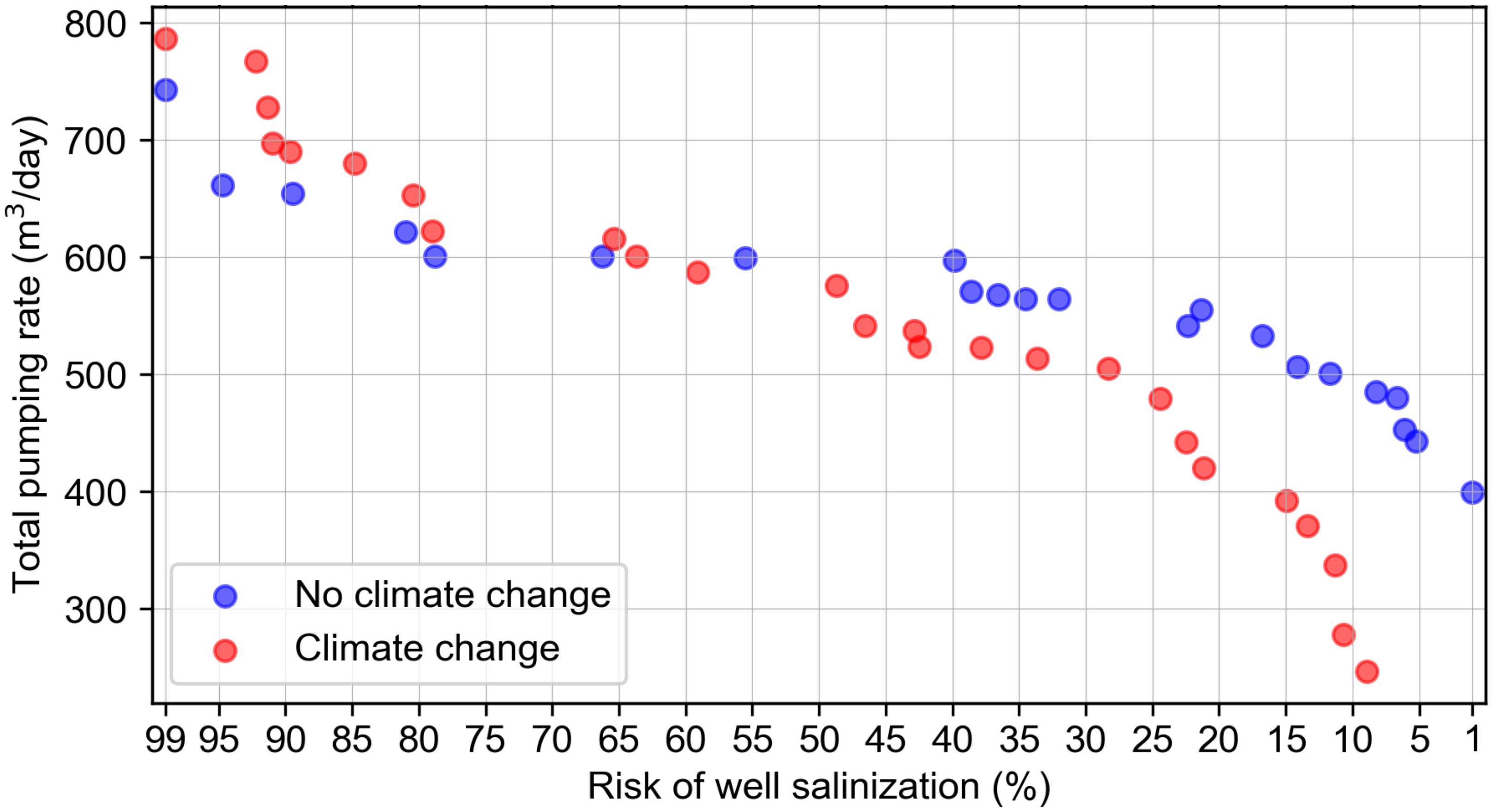


Steady state with zero pumping

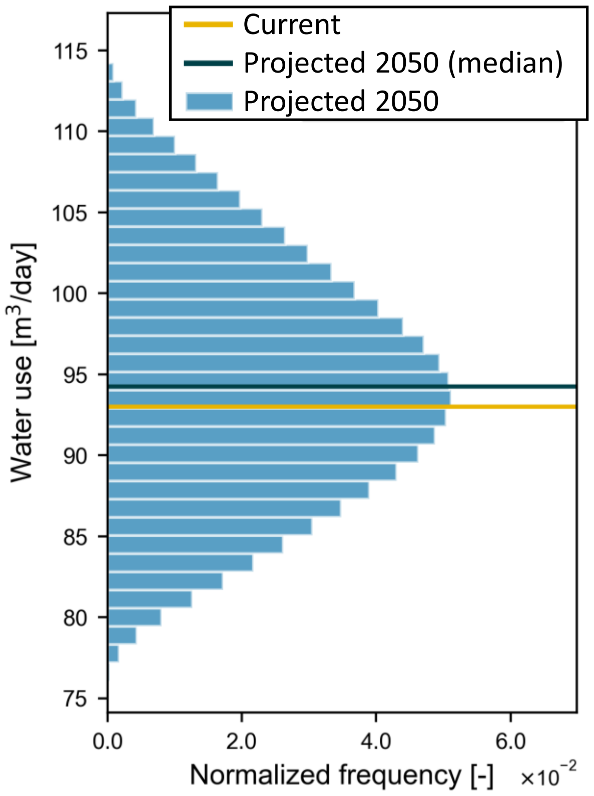
Posterior param. ensemble
(no climate change)

vs

Predictive param. ensemble
(with climate change)



2050 water demand



Lemieux et al. (2022)

CONCLUSION

- Using ensemble-based methods, we determined optimal pumping scenarios considering parameter & climate uncertainty
- Challenge: merging parameter & climate ensembles
- Conceptual uncertainty was neglected

- Highly reproducible framework

ACKNOWLEDGMENTS

Jeremy White

Conclusion

- Using ensemble-based methods, we determined optimal pumping scenarios considering parameter & climate uncertainty
- Challenge: merging parameter & climate ensembles
- Conceptual uncertainty was neglected

- Highly reproducible framework

Acknowledgments

Jeremy White

Thank you for your attention!

EGU General Assembly 2022

References

- Bakker, M., Schaars, F., Hughes, J.D., Langevin, C.D., Dausman, A.M. (2013). *Documentation of the seawater intrusion (SWI2) package for MODFLOW*.
- Coulon, C., Pryet, A., Lemieux, J.-M., Yrro, B.J.F., Bouchedda, A., Gloaguen, E., Comte, J.-C., Dupuis, J.C., and Banton, O. (2021). A framework for parameter estimation using sharp-interface seawater intrusion models. *Journal of Hydrology.*
- Coulon C., Lemieux J.-M., Pryet A., Bayer P., Young N.L. and Molson J. Pumping optimization under uncertainty in a freshwater lens using a sharp-interface seawater intrusion model, *In review, Water Resources Research.*
- Lemieux, J.-M., Germain, A., Tremblay, Y., Gatel, L., Arbour, G., Coulon, C. and Dupuis, C. (2022). *Portrait des ressources en eau souterraine des îles de la Madeleine.*
- White, J. T. (2018). A model-independent iterative ensemble smoother for efficient history-matching and uncertainty quantification in very high dimensions. *Environmental Modelling & Software*.
- White, J. T., Knowling, M. J., Fienen, M. N., Siade, A., Rea, O., & Martinez, G. (2022). A model-independent tool for evolutionary constrained multi-objective optimization under uncertainty. *Environmental Modelling & Software*.