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Physical modeling of the effects of climate change on freshwater lenses

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The investigation of the fragile equilibrium between fresh and saline water on oceanic islands is of major importance for a sustainable management and protection of freshwater lenses. Overexploitation will lead to salt water intrusion (up-coning), in turn causing damages or even destruction of a lens in the long term. We have performed a series of experiments on the laboratory scale to investigate and visualize processes of freshwater lenses under different boundary conditions. In addition these scenarios were numerically simulated using the finite-element model FEFLOW. Results were also compared to analytical solutions for problems regarding e.g. mean travel times of flow paths within a freshwater lens.

On the laboratory scale, a cross section of an island was simulated by setting up a sand-box model (200 cm x 50 cm x 5 cm). Lens dynamics are driven by density contrasts of saline and fresh water, recharge rate and Kf-values of the medium. We used a time-dependent, sequential application of the tracers uranine, eosine and indigotine, to represent different recharge events. With a stepwise increase of freshwater recharge, we could show that the maximum thickness of the lens increased in a non-linear behavior. Moreover we measured that the degradation of a freshwater lens after turning off the precipitation does not follow the same function as its development does. This means that a steady state freshwater lens does not degrade as fast as it develops under constant recharge.

On the other side, we could show that this is not true for a partial degradation of the lens due to passing forces, like anthropogenic pumping or climate change. This is, because the recovery to equilibrium is always a quasi asymptotic process. Thus, times of re-equilibration to steady state will take longer after e.g. a drought, than the degradation during the draught itself.

This behavior could also be verified applying the numerical finite-element model FEFLOW. In addition, numerical simulations will be used to close the gap between laboratory results and future field investigations. For example, impacts due to sea level rise induced by climate change can be up-scaled and compared to the results achieved from physical experiments. Analytical models (e.g. Fetter 1972, Vacher et al. 1990, Chesnaux & Allen 2007) were used as benchmarks in our investigations.

Models in general are simplifications of a real situation trying to display the relevant processes. For further investigations it is planned to compare different models and generate new benchmark experiments to improve the accuracy of existing models.