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Drivers of groundwater storage in gravel-bed rivers

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Gravel-bed rivers form aquifers with complex structures, regions of varying transmissivity and sometimes subsurface flow networks of highly conductive flow paths. They are often perched above the regional water-table in their upstream regions where river water is percolating vertically through the riverbed to become groundwater. Further downstream, upwelling groundwater re-emerges as low-land springs in the coastal regions and flows back into the river. The exchange between river and aquifer is often highly variable in space and time. Therefore, predicting river-groundwater exchange and aquifer storage is challenging.

The aquifers under gravel-bed rivers are high-yielding and hold groundwater resources that are often contested by several stakeholders. The management of these resources is difficult, particularly when the aquifer storage is affected by inter-annual variability and/or by long-term variations or trends.

In this contribution different drivers of aquifer storage are exemplarily analyzed for a gravel-bed river in Marlborough, New Zealand. The Wairau Plain Aquifer covers a small proportion of the Wairau catchment just prior to the river discharging into the sea. The aquifer is almost exclusively recharged by surface water from the Wairau River and serves as the major resource for drinking water and irrigation in the region. Aquifer storage within the shallow, highly-transmissive gravels exhibits a large inter-annual variability but also a declining trend over the past decades, which manifests itself in declining groundwater levels and spring flows.

River-groundwater interactions and aquifer storage have been investigated using a comprehensive dataset of groundwater levels, spring flows, river discharge and bathymetry as well as a recently-developed detailed surface water – groundwater model implemented in MODFLOW.

Results from the analysis show that aquifer storage is closely linked to annual weather patterns and that groundwater response times are well below 1 year. In particular, summer low-flows in the Wairau river lead to a strong decrease in aquifer recharge and consequently to a decline in aquifer storage. The manageable volume of the Wairau aquifer is less than 5% considering a critical flow-level in the major springs as a cut-off value. The aquifer storage has gone to critical low levels repeatedly in dry summers. The frequency and extend of low flow-periods seems to have increased in recent years, but some evidence points to a correlation with long-term climate variability that superimposes interannual variability. In addition, aquifer storage is also sensitive to both slow changes and singular events that change aquifer properties such as extreme flood events or earthquakes. The study indicates that climate variability and changes in river/aquifer characteristics together can explain the observed interannual and long term changes in aquifer storage whereas climate variability alone does only explain the interannual variability.

The understanding of the driving factors of aquifer storage is an important source of information for the Marlborough District Council which is the regional water authority that manages the Wairau groundwater resource. Moreover, these factors are believed to be universal and transferable to other aquifers of gravel-bed rivers.