DISTRIBUTED WATER STORAGE AND LOCAL GRAVITY: A FIELD EXPERIMENT AT MOXA (GERMANY)

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ABSTRACT

Water storage at and below the land surface has effect on the gravity field. A thorough understanding of this relation will help to filter the hydrological signal from the gravity signal, and can also enable the use of the gravity signal for hydrological purposes. The implementation of a number of superconducting gravimeters in the framework of the Global Geodynamics Project offers the opportunity to investigate the relation between catchments-scale processes and gravity. When this relation is known, then gravity data could be used for a better understanding water storage change (e.g. interception, snow, subsurface water).

Keywords: Hydrological processes, gravity, distributed water storage, streamflow generation, MODFLOW modeling, field campaign

Introduction

Traditionally, the gravity field has been treated as essentially steady-state because 99% of the field is more or less static in historic time (Troch et al., 2007). The remaining 1% is caused by processes that vary on time scales varying from hours to thousands of years. The hydrosphere is a source of irregular variations in the mass distribution. Research is focusing at understanding this relation between variations in the gravity field and basin scale water storage changes. *In situ* observations, with super-conducting gravimeters are then assumed to provide explicit information about local hydrology, where satellite (GRACE) data could provide very useful information about temporal changes in water storage changes in large areas.

This paper shows the first indicative result of a joint research of Wageningen University (the Netherlands) and Friedrich-Schiller University (Jena, Germany) in the Silberleite catchment.

Experimental area

The Silberleite catchment, located near Moxa, Germany is approximately 3.4 km^2 in size (Fig. 1). In this catchment the Geodynamic Observatory of the Friedrich-Schiller University Jena is located (Kroner et al., 2004). The catchment's subsurface consists predominantly of slates, which are fractured at the top and intersected by faults. These slates are covered by a permeable weathering layer and a clayey soil with a variable depth. The catchment has an undulating landscape and is predominantly covered with coniferous forest. The hill slope just east of the gravimeter is rather steep (~20^o), while the hill slope west of the gravimeter is relatively gentle (~10^o). In the downstream part of the valley, where the observatory is located at the foothill of a steep slope, a natural valley fill consisting of predominantly fine grained sediments is covered with a mainly coarse artificial valley fill with an increasing thickness in southward direction (max. 3 m thick). Observed streamflow at different locations shows that the catchment quickly responds to rainfall after filling up the subsurface stores.

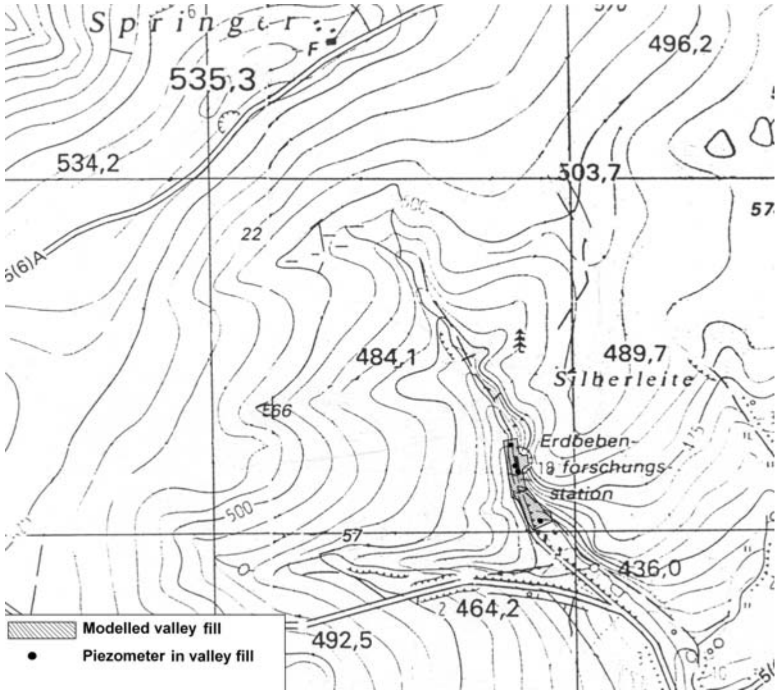

Fig. 1: The Silberleite area.

Methods

During several intensive field campaigns in the period 2004 – 2006 the geological profile and its hydrogeological properties were studied by constructing soil pits, by drilling and by performing hydraulic conductivity tests. The upper part of the geological profile at the steep slope east of the Geodynamic Observatory is shown in Fig. 2. Within the catchment area the precipitation, the piezometric heads and the discharge of the Silberleite and its tributaries are measured continuously.

Fig. 2: Geological profile at the steep slope, 50 m east of the observatory.

An explorative saturated groundwater flow model was constructed using MODFLOW. This model did not cover the entire catchment, but was concentrated on the area with artificial valley fill, i.e. the area where the gravimeter is located and where the largest effects of water storage changes on the gravimetrical signal are expected. The model boundaries were considered as flux-boundaries, to enable groundwater inflow from the hills into the modeling area.

Results and discussion

Initial research results show that short-term gravity variation, which is corrected for a number of effects (e.g. polar motion, earth tides) is highly correlated with substantial rainfall. Any substantial rainfall causes an increase in groundwater and stream levels, but in first a drop in the gravity signal. This drop in the gravity signal is due to water mass changes above the gravimeter during and just after the rain event. The downward movement of these water masses then causes a decrease in water mass above the gravimeter level and an increase in water mass below the gravimeter level. As a consequence the gravity signal is then increasing.

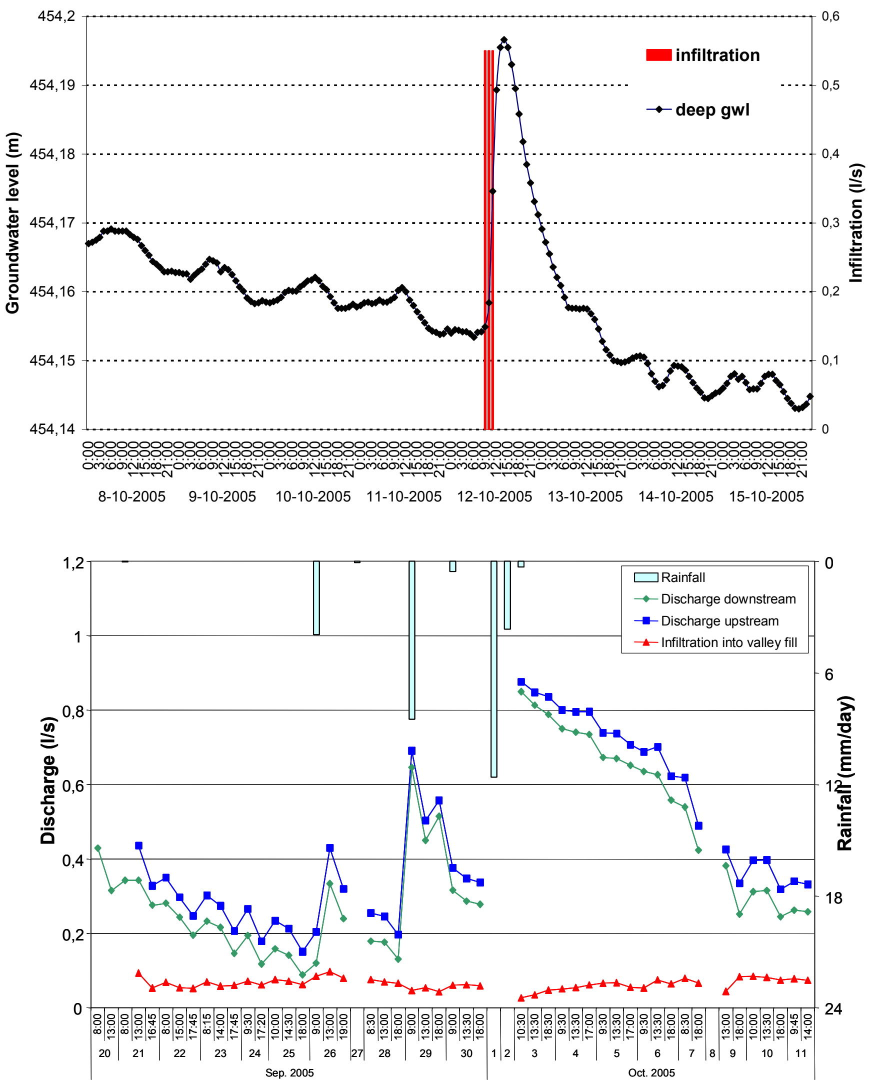

Fig. 3: Response of groundwater level in the valley fill on infiltration at the steep slope (upper) and infiltration of water from the stream into the valley fill (lower) (Niessen and Wesselius, 2006).

Simulated gravity variation (integrated over the influence sphere) with a rainfall-runoff model, in which the spatial and temporal distributed water storage is converted to gravity, agrees well with observed gravity variation except for periods that groundwater storage change affects gravity (e.g. 3 – 8 May 2004 in Fig. 2).

Infiltration experiments at the steep slope above the gravimeter and at the gentle slope opposite of the gravimeter illustrate that piezometers in the valley fill respond rather quickly to groundwater flow mainly through the weathering layer and fractured slates (shallow subsurface flow).

Explorative saturated groundwater flow modeling using MODFLOW confirms that groundwater storage is affected by infiltration from the stream and that groundwater inflow from the steep slope does not flow directly into the Silberleite stream, but it flows parallel to the stream through the highly-permeable valley fill. The modeling also shows that near the gravimeter small injection cones will develop after a rain event because of the outflow from the rain pipes draining the roof of the observatory.

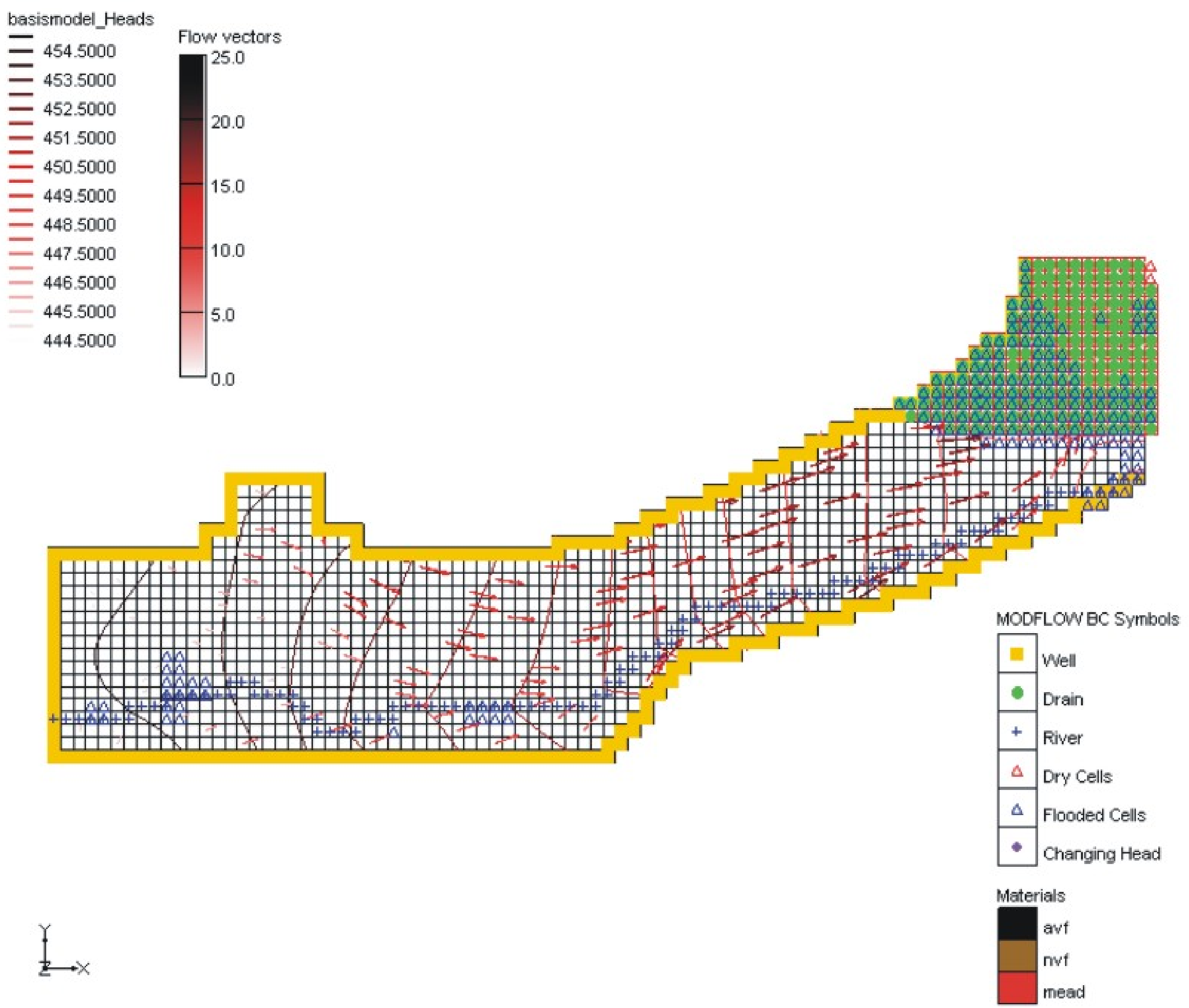

Fig. 4: Simulated saturated groundwater flow in the valley fill by using MODFLOW (Niessen and Wesselius, 2006).

Significant rainfall events cause quick gravity variation. The effect of mass changes on the gravimetrical signal is a function of the distance to the gravimeter (Dijksma et al., 2007). As a result, quick variations are caused by water storage changes in the direct vicinity of the gravimeter. Mass increase above gravimeter level (i.e. canopy storage, uphill increase in soil moisture content) will induce a gravity reduction, mass increase below gravimeter level (i.e. groundwater level) a gravity increase. Gravity variation at longer time scales is determined by water flow and storage in the shallow subsurface. Water flow on the steep slope east of the gravimeter causes a rather quick response. Because of the steep groundwater gradient and the distance to the gravimeter significant quantities of water can move rather quick within measuring range of the gravimeter. The gentle slope, opposite of the gravimeter, will cause a somewhat slower (intermediate) and less pronounced response because of the relatively gentle groundwater gradient and the larger distance to the gravimeter. Groundwater storage changes in the valley fill contribute to the short term as well as to the long-term variation. This mechanism is controlled by groundwater inflow from the steep slope and gentle slope. The quick response is dominated by fracture flow, where the relatively slow response is due to the flow in the weathered cover and infiltration from the Silberleite stream.

Terrestrial gravity measurements offer a new way of investigating catchment-scale hydrological processes. In areas with numerous water storage reservoirs, varying in size, elevation and response time, it is difficult to fully understand the relation between water storage and gravity. More research is needed.

References

Dijksma R., Ros G., de Jong B., Troch P.A. (2007). Local water storage changes affect in-situ gravity observations at Westerbork, the Netherlands. *Journal of Geodesy*, submitted.

Kroner C., Jahr T., Jentzsch G. (2004). 44 months of observations with a dual sensor superconducting gravimeter at Moxa observatory. *Journal of Geodynamics*, 38: 263–280.

Niessen S., Wesselius C. (2006). *Groundwater Distribution at the Geodynamic Observatory Moxa; Fieldwork and Hydrological Modeling*. Doctoral thesis Wageningen University, Wageningen, the Netherlands.

Troch P.A., Dijksma R., van Lanen H.A.J., van Loon E.E. (2007). Towards improved observations and modeling of catchment-scale hydrological processes: bridging the gap between local knowledge and the global problem of ungauged basins. *IAHS Publication*, 309: 173–185.