Numerical simulation of baseflow modification due to effects of sediment yield

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Abstract

Alluvial rivers re-shape their own geometry by depositing sediments or eroding the channel when their dynamic equilibrium is disturbed. Such adjustments may induce river-bed and water-level profiles that have significant effects on the interaction of streams and aquifers that are connected hydraulically. Physically-based mathematical modelling affords the opportunity to look at this kind of interaction, which should be simulated by deterministic responses of both water and fluvial processes. In addition to simulating the streamflow and groundwater dynamics, the model should also be capable of tracking down the level of the coupling interface boundary.

A procedure for **m**odelling **a**lluvial **s**tream-**a**quifer **i**nteraction - MASAI - has been developed to enable the coupling of unstable alluvial stream-aquifer interacting systems. Application of MASAI to hypothetical alluvial stream-aquifer systems reveals the complex relationships between individual elements of the systems, and highlights the influence of sediment yield on baseflow.

Introduction

Most alluvial rivers only partially penetrate their underlying aquifers, but the exchange of water between them can have significant effects on streamflow as shown, for example, by Hughes and Sami (1992). Furthermore, alluvial rivers normally involve transportation of sediment materials, and if the dynamic equilibrium of such rivers is disturbed, the rivers tend to adjust to new pseudo-equilibrium conditions by depositing the sediments or scouring the bed. Either of these sedimentary processes can have additional effects on the interaction between the rivers and aquifers that are connected hydraulically. Many case histories of channel adjustments because of disturbances in the rivers are well-documented (e.g. Chang, 1988; Petts and Foster, 1992).

The exchange of water between streamflow and groundwater is generally a function of the difference between the water levels in the aquifer and the river. The actual magnitude of flow depends on the local geology, particularly the hydraulic conductivity of the interface boundary layer at the bottom of the river. The process of interaction over spatially varied channel boundaries is difficult to examine, and further difficulties arise in the case of alluvial channels whose hydraulic and fluvial conditions are not in equilibrium.

Physically-based mathematical modelling affords an opportunity to explore the fundamental relationships between various elements of stream-aquifer systems. It also offers ways of studying short- and long-term hydrological responses due to changes in the hydrological systems. However, stream-aquifer interaction and sediment routing models have traditionally been developed separately, with their interdependence either not considered at all, or accounted for only by simple assumptions. To examine the dynamics of water between alluvial rivers and riparian aquifers, it is necessary to develop a mathematical model that simulates the variation of both streamflow and groundwater levels, and also the transient adjustments of the river bed arising from sedimentation.

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This concept is an enhancement of existing mathematical modelling of stream-aquifer interaction, which has previously been confined to regime river problems that performed the simulations, assuming pre-defined rigid river-bed elevation profiles (e.g. Swain and Wexler, 1996). Likewise, water and sediment routing simulations in alluvial channels have previously been performed assuming groundwater contribution as a pre-defined lateral flow obtained as a constant calibration parameter (e.g. Chang, 1982). When streamflow and sediment routing is performed for rocky basins with river beds that have very low permeability, or when stream-aquifer interaction is simulated for stable channels with negligible sediment yield, then errors introduced by adopting the standard assumptions will not be significant. When, however, a modelling exercise concerns conjunctive water use in alluvial stream-aquifer systems with notable sediment yield, the errors may be sufficiently large as to invalidate the exercise. Younger et. al. (1993) and Crerar et al. (1988), for example, have previously shown that the sedimentation on river beds can have significant effects on stream-aquifer interactions.

Justification

MASAI is suited to the evaluation of soil and water conservation practices in riparian plains, inasmuch as changes in land use and river engineering affect streamflow and sediment yield. In fact streamflow and sediment yield, in their various aspects, are recognised diagnostic criteria for the assessment of watershed conditions, and for the effectiveness of catchment and river management strategies. Total yearly amounts of both water and sediment yields, seasonal regularity, frequencies and extremes of high and low discharges provide useful indications of the net result of management practices.

Analysis of baseflow and sediment discharges can provide a basis for predicting the hydrological and fluvial impacts of management practices on stream-aquifer systems. Variation of either water flow or sediment yield in turn affects sediment transport through downstream reaches. Whenever the sediments transported into a given reach amount to less than the transport capacity of the channel, scour occurs, whereas when the incoming sediment load