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Hydrology and Earth System Sciences
Discussions

Interactive comment on "A partially-coupled hydro-mechanical analysis of the Bengal Aquifer System under hydrological loading" *by* Nicholas D. Woodman et al.

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Our response to Referee#1's comments take the four points in turn: POINT 1: "I don't see any new method or development. The only new thing I can see here is just the application, which I think is not enough." POINT 2: "Due to using the commercial software, COMSOL, the results do not seem too realistic." POINT 3: "I expected to see some 3D models representing the deformation because of the loading." POINT 4: "Therefore, this paper is not a journal paper."

POINT 1: "I don't see any new method or development. The only new thing I can see here is just the application, which I think is not enough" In the paper, we provide the

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Discussion paper

amplitude and phase solutions for 1D loading of a uniform aquifer for a combination of hydraulic and mechanical loads, derived from first-principles. We make no claim of novelty in this regard, since the derivation is straightforward (though we have not found the complete solutions in the literature). The amplitude solution for pure hydraulic loading is well known and appears for example in G. van der Kamp and Maathuis (1991), as cited in our paper. We do, however, think it useful to bring the appropriate governing equations (neither over-simplified, nor unnecessarily generalised) to bear in the context of different possible loading conditions on the BAS in a clarifying manner. Remarkably, although poro-elastic theory is very well-established, it is new to fully apply it in the context of a very thick and extensive aquifer such as the BAS. Our paper determines for the first time the implications for groundwater pressurestogether with solid strains and displacements. We believe the implications are fundamental and widespread in the BAS, and very probably in other fluvio-deltaic environments. We suggest that the most important topics to focus on for the BAS are the implications for recharge and pumping under the most important generic condition present, i.e. widespread loading of the ground surface by water, for which a 1D analysis is suitable as explained in the paper (lines 55-56 in section 1 Introduction, and line 132 in section 2.1 Poro-mechanical equations). We have a companion paper in preparation which deals with the next level in the complexity hierarchy: the implications of poro-elasticity in the proximity of rivers, which requires analysis in 2D. We suggest these steps provide valuable insight and usefully prepare the way for a fully 3D analysis. As we point out in the paper, mechanical effects have not previously been taken into account in (vital) assessments of groundwater recharge (Shamsudduha et al., 2011), nor in regional models of groundwater flow (Mukherjee et al., 2007); neither have hydraulic effects been included in assessments of ground surface motions due to monsoonal loading (Steckler et al., 2010) – citations are provided in the paper. Significantly, our analysis supports the possibility that deep piezometers in the BAS may be suitable for 'geological lysimetry'; a potentially valuable method of measuring the terrestrial water budget locally that avoids the myriad assumptions of classical methods and the limitations of remote-sensing. Thus, we would like to emphasise that the paper addresses an obvious ‘gap’ in the literature, in the bridging of which we have made a significant and original contribution. This would help to do a better estimate of recharge, particularly to the strategic deep groundwater, of the BAS to assess sustainability of groundwater development for irrigation, domestic and industrial uses.

POINT 2: “Due to using the commercial software, COMSOL, the results do not seem too realistic.”

We have of course validated the numerical model versus our own analytical solutions; the match is so precise that there is nothing to discuss. We agree it makes sense to include this validation in Supplementary Information.

We would greatly appreciate if Reviewer#1 could identify any specific aspect of the simulations that (s)he considers in doubt.

POINT 3: “I expected to see some 3D models representing the deformation because of the loading.”

We agree with the reviewer that there are conditions under which 2D and indeed 3D treatments of the mechanical and hydraulic responses will likely be important. Our next step is to provide a 2D analysis of the effects due to rivers (a manuscript is in preparation).

For the paper under review, a 1D examination is not only sensible in terms of starting at the base of complexity-hierarchy, but addresses a widespread and generically common condition in the BAS due to extensive flooding, rainfall events, and changes in unconfined groundwater storage. Apparently simple (yet physically plausible) areally-uniform loading conditions justify a 1D treatment, as described in the paper. We show these simple processes nonetheless lead to complex pressure and strain responses which are currently being misinterpreted by practitioners who neglect the coupling. We show that the dynamics due to different forms of loading (which may not be uniquely apparent from a single groundwater hydrograph) can be decoded by taking into account the amplitude and phase effects; essentially we provide the basis for diagnosis of hydro-mechanical effects in 1D.

POINT 4: “Therefore, this paper is not a journal paper.”

In view of the above, we rebut Reviewer#1’s conclusion. The paper provides a fundamental re-appraisal of how groundwater hydrographs and surface displacements should be interpreted in the BAS and beyond, giving a diagnostic tool-kit which we demonstrate against real data. We use a well-established physics-solving platform, which we nonetheless validate for our governing equations against our own analytical solutions. We believe that the 1D treatment is particularly important in the BAS context due to spatially extensive surface water inundation and rainfall, and indeed it leads the way for future studies of hydro-mechanical effects at higher-dimensions.

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