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Discussions

# *Interactive comment on* "Flowing wells: history and role as a root of groundwater hydrology" *by* Xiao-Wei Jiang et al.

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This manuscript provides a detailed and global overview of the progress of understanding of flowing wells. In this sense it has the potential to make a worthwhile contribution to the science of hydrogeology and its historical development. Flowing wells have always been, and still are, a topic of wonderment and questioning.

In such a historical overview, spanning many countries and two centuries, it is a formidable challenge to recognize and give due credit to all significant contributions, the literature of which may not be easily accessible. In this case the authors would do well to widen their search and in particular to refer to the historical overview by J. J. de Vries (2007), which describes several pre-1940 examples of what the present pa-



per describes as "topographically-driven" groundwater flow. (History of Groundwater Hydrology. In: The handbook of Groundwater Engineering (Jacques W. Delleur ed.), Chapter 1: p.1.1-1.39. CRC Press, 2007).

More generally this manuscript is perhaps over emphasizing the analysis of "topographically-driven" groundwater flow in the 1960's by Toth and others as a paradigm shift. Such a shift in science is typically defined as, for example "an important change that happens when the usual way of thinking about or doing something is replaced by a new and different way" [https://www.merriam-webster.com/dictionary/paradigm%20shift]. It might be added that in science such a paradigm shift also opens up new and expanded fields of enquiry. Casting historical developments in hydrogeology in terms of paradigm shifts can be a valuable and enlightening exercise by emphasizing when and how new concepts were developed and became accepted. The authors are encouraged to maintain a paradigm perspective.

With regard to topographically-driven flow the manuscript makes clear that it was recognized very early on, in the 19th century, that the occurrence of flowing wells is dependent on a recharge source of the groundwater at a higher elevation. In other words, topographically-driven groundwater flow (together with various geological configurations) has always been recognized. It was also recognized early on that flowing wells can occur even where there is no overlying low-permeability formation confining an aquifer (See for example the measurement-based flow diagrams published by Pennink in 1907 as reproduced by de Vries (2007, p. 1-11). As pointed out in the manuscript (L 60) Hubbert noted this (Hubbert, 1940, p.913: "As a matter of fact, in order to have artesian potentials, an aquifer need not be overlain by impermeable material, and it need not out-crop.")

Clearly there is a continuum of hydrogeological conditions that can result in flowing wells, varying from highly confined aquifers with distant higher-elevation outcrops to entirely homogeneous surficial aquifers, the latter likely relatively rare. Thus a distinction between "topographically-controlled" and "geologically controlled" flow may not be useful. Incidentally the Paskapoo formation in southern Alberta which inspired Toth's early analyses is far from constituting " a thick unconfined aquifer (L. 335), but "represents a foreland deposit of a siltstone and mudstone-dominated fluvial system" with interspersed channel deposits of coarse-grained sandstone (Grasby et al., 2008. Can J Earth Sc., 45: 1501-1516, p.1).

Toth and others set off an important change in hydrogeology by introducing rigorous mathematical description of regional groundwater flow, at first by calculus methods, soon followed by numerical modelling. Numerical modeling has become a major and standard tool in hydrogeology. Its introduction by Toth, followed up by Freeze, could indeed be characterized as a paradigm shift, in the sense of doing something in a new and different way, which has also led to new research and discovery. But their analysis and description, as such, of flowing wells occurring without an overlying aquitard does not appear to merit characterization as a paradigm shift because this idea was already present in the literature and was recognized as a logical consequence of Darcy's Law.

Perhaps a case could be made that the recognition of aquifer compressibility by Meinzer and others, based on analysis of flowing well yields, was the beginning of a paradigm shift in hydrogeology. The manuscript describes how the follow-up work by Theis (1935) and Jacob (1940) led to a widening field of enquiry and understanding of transient groundwater hydraulics, particularly with regard to well hydraulics.

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