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Discussions

Interactive comment on "From Engineering Hydrology to Earth System Science: Milestones in the Transformation of Hydrologic Science" *by* Murugesu Sivapalan

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General

I really enjoyed reading Siva's narrative about the transformation of hydrology from an engineering discipline to an earth system science. I also agree with the successive steps and failures that were mentioned: building up case by case from Newtonian Mechanics, looking down at multiple catchments using Darwinian approaches and the way they could be married to arrive at underlying principles and moving from prediction to understanding.

However, this narrative is somewhat biased towards surface and catchment hydrology. In other hydrological disciplines, concepts and modelling efforts have been tailored to understanding the underlying mechanisms of observed phenomena from the start. This should be acknowledged. This is particularly the case for groundwater hydrology and vadose zone hydrology. Examples of the former are the explanation of macro-dispersion by considering flow in a heterogeneous medium (e.g. Gelhar et al. Water Resour. Res., 15, 1387–1397, 1979; Gelhar and Axness, Water Resour. Res., 19, 161–180, 1983). An example of the latter is the explanation of hysteresis of the soil-water retention relationship and all its wetting and drying scanning curves by extending Darcy's law with a term that accounts for the change in time of interfacial area between air and water in the pores (Dynamic Effect in the Capillary Pressure–Saturation Relationship and its Impacts on Unsaturated Flow (Hassanizadeh et al., Vadose Zone Journal 2002 1: 1: 38-57). These approaches use Newtonian mechanics and Thermodynamics, but interactions with vegetation have been included more than a decade ago to understand e.g. root growth processes and root water uptake. In fact, the problem in stochastic subsurface hydrology seems to be the reverse: how can these theories designed to understand phenomena be used in practice, i.e. prediction (see e.g. the recent debate on this subject in Water Resources Research: Rajaram, Water Resour. Res., 52, 9215–9217, 2016; and related papers).

Apart from that, I generally agree with the narrative and the conclusions drawn from it. I have just some additional specific remarks that may provide additional perspectives.

Specific remarks

Lines 180-182: Examples of meso-scale distributed models: I think that it is fair to refer to the codes that have been used more extensively at even larger scales and are most well known in the literature: PARFLOW, Cathy and Hydrogeosphere.

Lines 315-330 REW. Despite the examples given at the end of this paragraph, I don't think that REW really took off and is used much in practice. The problem is the estimation of the parameters of the constitutive relationships. These still need to be calibrated and observations are generally lacking to perform this calibration. I feel it is fair to mention this.

Line 484 “If the biological or ecological laws were known. . ..”. But are they not known in principle? Just as one should be able to derive Darcy’s law from Newtonian mechanics (Navier stokes) and the functioning of a linear reservoir from groundwater theory*, by the same reasoning ecological laws in the end could be derived from natural selection (with the added complexity that individuals are able to influence their own environment). If this is indeed the case, then with sufficient computational resources and individual-based ecosystem models we could derive these laws for catchments in different climates and geological settings by exhaustive simulation.

*I refer to much earlier work from Kraaijenhoff and van de Leur (1957) and De Zeeuw (thesis, 1966) on solving the linear Boussinesq equation showing when a groundwater reservoir response is linear –> for later times after rainfall and always if stream entrance resistance is high).

Lines 645-646: It seems that the large number of modelling approaches is perceived as a problem in Hydrology. But why? Let’s compare this to the field of ecology. Here, we also have a plethora of modelling approaches and partial theories used to explain a huge diversity of interacting life forms. The underlying theory in the end is evolution (diversification by mutation and crossing and selection). This insight has been around for a long time, but it has not stopped ecological model and theory development, because at ecosystem scale, emergent phenomena can be better explained with macroscopic models. The latter is also not perceived as a problem in ecology. Lines 882-884. The Darwinian approach to discovering underlying principles or laws. But in truth: what other laws than Newtonian mechanics, thermodynamics and evolution theory will we need to explain observed phenomena?

Lines 1015-1017: Horton’s statement. This is indeed a good foresight that can also be

explained from ecological niche theory: In case of shortage, any water that cannot be usedÂăby the prevailing species is likely to be used (forms a niche for) other species that can use it.

Lines 1030-1032. The optimality principle. I find this questionable as a general principle and it has not been embraced by ecologists for a reason. the optimal vegetation is the one that over the long run has the highest probability of survival. In functional ecology this is better explained in terms of optimal traits (leaf form, stomatal density, color, size) of which size (maximal carbon gain) is but one.

Lines: 1059: Humans as intrinsic part of the catchment’s cycle: if humans are considered, the catchment is not the most natural unit of description anymore. It is the overlay of river basin (regional size catchments – as also confirmed hereafter) and administrative (or governance) units that are of interest. Different impacts are also in different parts of the basin: land use change and dam building in the upper reaches; water abstraction in the middle and lower reaches.

Figure 7 and the arguments explaining the differences between natural and human-influenced water ecosystems: I am not wholly convinced that this is universally true. It may well be a time-scale thing. If we look at a natural ecosystem, it is often evolving (in succession) where pioneers are eco-engineers making the bare soils suitable for other species to move in that in the end outcompete them. Sometimes, even lock in occurs. Think about birch trees in marches that establish themselves during relatively dry periods and due to their evaporation are able to keep water tables deep enough for root aeration to occur even in wetter years. However, if some of the trees die (because of old age or two consecutive very wet years) creating a holes in the canopy, groundwater recharge may suddenly increases tremendously causing all the trees to die as a result of it (Brolsma et al., Ecological Modelling, Volume 221, Issue 10, 24 May 2010, Pages 1364-1377, 2010). So, vegetation may obey optimality principles on long time scales (or in climax state), but not on smaller time-scales. Reversing the argument, one might view the non-optimal or detrimental (lock-in) interactions of humans with their environment temporary and expect human-water systems at longer time scales to also show signs of optimality.

Lines 1126-1128: being Dutch I cannot resist to point out a more recent historical example of this lock in. I am referring to the famous Dutch polders. Many of the low-lying areas in the Netherlands are the result of draining peaty soils (since the 11th century) which resulted in land subsidence and subsequent further lowering of the groundwater level to keep the soils dry leading to further subsidence etc. The result is 30% of the country lower than sea-level. An interesting by-product is the invention of Gouda cheese. The low-lying areas were only suitable for dairy farming. To safe the excess milk for winter time, cheese was made out of it (see: Erkens, G., van der Meulen, M.J. & Middelkoop, H. Double trouble: subsidence and CO2 respiration due to 1,000Âăyears of Dutch coastal peatlands cultivation. Hydrogeol J (2016) 24: 551. https://doi.org/10.1007/s10040-016-1380-4).

Line 1301: regional hydrology. It seems you mean that the river basin would be the object of study. This is the old focus of classical Physical Geography, studying earth surface processes and their interaction with the atmosphere, the subsoil and life (including man) from sink to source, from the mountains to the sea, from headwaters to the delta.

Lines 1365-1366 future earth system hydrology: The crystal ball of Bierkens (2015) came to a similar conclusion.

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