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How important are soils for hydrological modeling?

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Recently I have been working on a new way to determine the root zone storage capacity of vegetation as an essential component of hydrological models. Whether we us a lumped, conceptual or distributed, "physically based" distributed, the storage capacity of the root zone is always a key parameter, determining the partitioning of precipitation between runoff, transpiration, and recharge. Being such a crucial hydrological parameter, a lot of attention is given to estimating the root zone storage capacity, particularly for ungauged basins and for global models that simulate land-atmosphere interactions.
A common method for estimating root zone storage capacity is to first derive the plant available moisture (between so-called field capacity and wilting point) from soil maps and then to multiply this by estimates of the rooting depth of the dominant vegetation. The latter follows from land cover maps that besides rooting depth provide information on parameters relevant for the energy balance.
I have always wondered if this was the right way to do it. If I were an ecosystem, living on a certain soil and under a certain climate, how would I then establish my rooting depth? I would have the choice to invest my energy in growth above ground (in competition for light and in maximizing my chances of reproduction) or underground (making sure I have access to water and nutrients). Obviously if I made my foundation too weak, I would wilt during a critical dry period; but conversely, if I put too much energy in my foundation, I would lose opportunities to grow tall and reproduce. Of course this evolutionary way of reasoning is nothing new and rather common among ecologists, I presume. But why then are we using look-up tables to find the rooting depth for a certain land cover type? Surely there is not one single rooting depth for all "evergreen broadleaf" forest, or for all "woody savannah". If I were an individual member of an evergreen broadleaf community, I would definitely adjust my root zone volume to my local conditions. If I happened to stand on a relatively light soil, I would root deeper than if my seed had dropped on a more heavy soil. Similarly, I would root deeper if I had to deal with regular dry spells or with more seasonality then if rain would fall more regularly.
Until now, I guess, there will be few readers who disagree. In fact one does not have to be a hydrologist or ecologist to follow this reasoning. I remember very well that my mother used to say that if you water a young tree every day it will become 'lazy' and will not develop enough roots to overcome periods of drought. She recommended to water it once per week in the beginning and later once per month, until it had enough roots developed to survive the summer season.

A problem with our models
Is this now just an interesting way to look at root zone storage development, or is it also an issue? Recently I came across a publication in the Dutch hydrological journal "Stromingen" of the Netherlands Hydrological Society, where the authors presented the discrepancy between observed and modeled evaporation using the most advanced physically based distributed model (named NHI) of The Netherlands (Beekman et al., 2014). The observed evaporation was an upscaling of eddy-covariance and lysimeter observations using ETLook (Bastiaanssen et al., 2012).
In July 2006, the modeled evaporation appeared to be less than half the observed evaporation, on average. But a more striking difference is in the spatial pattern. In the heart of The Netherlands we see very low modeled evaporation, whereas the same region has very high observed. Conversely, in the polders in the inland IJssel lake the modelled evaporation is very high, whereas the observed evaporation is average. Overall, the patterns are very different. What is happening here?
What the model essentially reflects is the spatial variability of the soil characteristics. The model falsely assumes that the rooting depth of similar vegetation (crops, pasture, forest, etc.) is the same for all soils, causing clay soils in the IJssel lake polders to evaporate close to potential and the sandy soils to be severely moisture constrained. Although in regular months, where there is no moisture constraint, the model performs well, it clearly provides wrong results in the periods where soil matters.
Although I gave an illustration of The Netherlands, the same happens, and even more prominently, in parts of

the world where moisture constraints occur more regularly, particularly in the tropics (due to dry spells) and the sub-tropics (due to seasonality and dry spells). So, I think it is time for a new paradigm.

A new paradigm

As a water resources engineer I am familiar with the way we size reservoirs in response to variable water resources and demands. The traditional method is to use the Mass Curve Technique (MCT), or Ripple diagram (after Ripple, 1883). In the Ripple diagram we plot both the accumulated inflow to a reservoir and the accumulated demand. Using the tangents of the accumulated demand to the accumulated inflow, we can derive the required storage to bridge dry seasons. Plotting the annual storage requirements on extreme values paper (e.g. Gumbel, 1935) allows to estimate the storage requirement for certain return periods.

The similarity with the root zone is that we accumulate the net precipitation (precipitation minus interception) as inflow, and the transpiration of the vegetation as demand. We determine the transpiration in the dry season by scaling the average annual evaporation by the NDVI of dry and average conditions. Even in ungauged basins one can do this on the basis of the Budyko curve.

We tested this method in a large set of well gauged basins, including 6 sub-tropical catchments in Thailand and 323 catchments of the MOPEX data set that were relatively unaffected by snow, and compared the predicted root zone storage capacity with the calibrated capacities using the lumped conceptual model FLEX (Fenicia et al., 2011). The results were surprisingly accurate and are presented in a paper recently published in GRL (Gao et a., 2014). We made a comparison between the root zone storage capacity required to bridge a drought of once in 20 years (SR20y) and the calibrated root zone storage capacity (SuMax) for 7 eco-region classes based on the classification by Wiken et al. (2011). In general we found that there is a strong correlation between the SR20y with inter-storm duration and seasonality, showing that vegetation develops more root volume when it has to bridge longer dry spells, or has to deal with seasonality. Applying this globally, this correlation appeared to be strongest for permanent vegetation, such as evergreen broadleaf forest, evergreen needle forest, deciduous forest and woody savannah. The correlation was not good at all for cropland, for which the traditional method based on soil characteristics gives much better results, not surprisingly because the crops are seasonal and strongly rely on the soil.

Conclusion

So I think we have a very interesting new paradigm here, which could be the beginning of very interesting new research. I think we are over-rating the importance of soil for permanent vegetation, forgetting that vegetation adapts to the climate by creating sufficient root zone storage. Vegetation balances out soil variability by adjusting its rooting depth in a way that the buffer is much more homogenous in space than we classically assume, and in a way that severe moisture stress is much less likely to occur.

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