Large Scale modeling (Abstract Kiel 2008)

Introduction

In this talk we discuss scaling issues related to the interaction between plants and the hydrosphere and man and the hydrosphere. The hypothesis is developed that known scale effects of hydrological networks result from interactions and feedbacks between surface and subsurface flow and plant adaptation. As hydrological networks concentrate and channel water and plants adapt to hydrological conditions, a feedback between hydrosphere and biosphere develops. This feedback modifies the availability of water resources at different scales. Modeling strategies on how to deal with such systems are presented based on three key examples for macro-scale case studies.

Scale effects of water availability

Scale effects of surface runoff based on topographical data are well known (→ Bloeschl, Beven & Kirkby) and are not presented here. Empirical scale effects on peak discharge, flow duration on the time scale of single events have been dealt with (→ Leopold). In this paper we focus on scale effects related to long term water availability, groundwater recharge and mean annual flow. Only scale effects that become relevant for large scale modeling (> 10.000 km^2, regional, continental and global scale) are taken into account.

Example 1 - the riddle of transpiration and runoff

→Betts et al. (2007) claim that an increase of runoff at a global scale can be related to an increase in CO_2 concentration. This conclusion is based on empirical data and series of plot-scale experiments providing evidence of an effect of carbon-dioxide on transpiration. Hence, plot scale-data were used to explain a phenomenon that was observed on a global scale. Can this approach be justified? The attempt to reproduce this effect at the catchment scale and for the island of Cyprus with a model including plant growth, carbon dioxide effects on transpiration and nutrient constraints (SWAT2005) did not produce an effect of CO_2 on mean annual runoff. While, indeed, transpiration at the plot scale decreased for single plants, the overall effect on the catchment scale was canceled out by an increase in biomass resulting in higher LAI, compensating the decrease of transpiration from single plants. There are (more processes).

Hydrological and hydrogeological systems are networks that concentrate and funnel fluids to outlets. Plants adapt to the availability of water: Hence, plant communities concentrate along channels, flow paths, depressions and discharge areas and consume water that was recharged upstream. As a result net recharge decreases with increasing catchment size by secondary evaporation. These feedbacks also complicate basin response to climate changes. Higher rainfall and higher recharge can result in an expansion of discharge zones and in an adaptation and increase of vegetation density therein.

Example 2 - Groundwater recharge at a site and in a basin is not the same

Every groundwater modeler knows: Groundwater recharge determined with site-specific methods (e.g. chloride method, soil water balance of a plot, lysimeters) is not comparable to groundwater recharge for large basins. A recharge map based on local (vertical) soil water balance (→ Döll et al., 2000) taken as input for a macro-scale groundwater model will almost certainly cause an enormous over-flow (see Klock, 2002; Klock & Külls, 2001). This effect is more pronounced in dry regions.

An example for South Africa (Fersch, 2006) is presented. With increasing basin size, specific recharge decreases because plant communities re-transpire more than 90 % of local recharge. Plant communities adapt to groundwater conditions. The integrated plant-groundwater system determines basin response. We are at the very beginning of describing such systems with conceptual models. We found that an increase in recharge simply resulted in an increase in plant consumption and did not have any effect on specific groundwater availability at larger scales. Tree communities simply adapted to available groundwater and converged to a total consumption regardless of initial conditions (density, tree type).

Example 3 - Availability of drinking water for dispersed (rural) and non-dispersed (urban) communities

The mobility of humans and degree of dispersion of settlements is directly linked to the availability of drinking water. Models of water availability often do not take into account a very simple but fundamental fact: Hydrological systems organize towards networks (channel systems), plant communities adapt to these systems, human societies also develop complex spatial patterns of settlements that interfere with the ecohydrological system. The match of spatial structures of hydrological systems (basins, aquifer systems, channel networks), ecosystems and human societies (mega-cities, urban centers, rural communities, single farms) with their specific water distribution systems are important parameters for the availability of water.

We define the availability of water as follows: $\Sigma\ \alpha(x,y,t)_i{*}d(x,y,t)_i$:= the sum of degrees $\alpha(x,y,t)_i$ to which demands $d(x,y,t)_i$ of individuals i were fulfilled over time. The indices x,y,t represent spatial and temporal dependency of variables. Demand $d(x,y,t)_i$ has a spatial and temporal distribution that is directly linked to settlement types and their structure. The hydrological availability h(x,y,t) is determined by basin and groundwater topology. The correlation of d(x,y,t) and h(x,y,t) is strongly related to α: If d and h correlate fully, then only excessive demand results in deficiencies. Even if integrals of d and h correspond, a mismatch in spatial structure and a weak or negative correlation results in high accumulated deficiency. Water distribution networks may compensate part of the mismatch and this is in fact their main purpose and function.

A modeling example from Taua/Brazil is presented where water availability is simply caused by a lack of correlation between availability of resources and settlement structure.

Modelling strategies

How can the above issues be dealt with in macro-scale models? Multi-Agent models with adaptive distribution and density of vegetation represent a research instrument for investigating such systems and for deriving modeling strategies. The coupling of agent models with hydrological / groundwater models represents an interesting possibility of closing the balance (for water) and for introducing real world constraints.

We should work on the development of simpler empirical conceptual and mathematical models that incorporate the above issues. These models will reflect the self-similarity, the structural properties of drainage networks and plant adaptation as well as measures of settlement structure.