Supplement of Hydrol. Earth Syst. Sci., 18, 3855–3872, 2014
http://www.hydrol-earth-syst-sci.net/18/3855/2014/
doi:10.5194/hess-18-3855-2014-supplement

Hydrology and Earth System Sciences
Open Access

Supplement of

Hydroclimatic regimes: a distributed water-balance framework for hydrologic assessment, classification, and management

P. K. Weiskel et al.

Correspondence to: P. K. Weiskel (pweiskel@usgs.gov)

Online Supplement:

Additional explanation of terminology, with links and references to data sources

1 Hydrologic units

As described in Appendix A, hydrologic units (Fig. 1a) may be defined as bounded landscape units, or control volumes, that are free to receive inflow from either the atmosphere as precipitation (P) or from upgradient hydrologic units as landscape (i.e., groundwater + surface-water) inflow (L_{in}). Hydrologic unit boundaries may defined arbitrarily, for example by use of rectangular grids (Döll et al., 2003; Oki and Kanae, 2006), or by topographically defined landscape units that drain to particular stream reaches (Seaber et al., 1987; McCabe and Markstrom, 2007). In the USA, mapping of hydrologic units has been facilitated by development of the Hydrologic Unit Code (HUC) system (http://water.usgs.gov/GIS/huc.html) which divides the USA into a hierarchically nested, georeferenced system of topographically defined hydrologic units. Advances in geographic information systems (GIS) have fostered the development of several networked, finer-scale hydrologic unit datasets for the USA, including the River Reach File used in the present paper: (http://water.usgs.gov/GIS/metadata/usgswrd/XML/erf1.xml) (~55,000 hydrologic units; ~140 km^2 average area); the Watershed Boundary Dataset (http://nhd.usgs.gov/wbd.html) (~160,000 hydrologic units; ~57 km^2); and the National Hydrography Dataset-Plus (http://www.horizon-systems.com/nhdplus/) (~2.61 million hydrologic units; ~2.4 km^2). A similar, hierarchically nested system of hydrologic units has recently been created for Australia (http://www.hydrol-earth-syst-sci-discuss.net/10/15433/2013/hessd-10-15433-2013.pdf) (Stein et al., 2013) (~1.09 million hydrologic units; ~7.1 km^2). At the global scale, the HydroSHEDS dataset provides detailed stream networks and nested catchments for the world's non-glaciated land surface (http://worldwildlife.org/pages/hydrosheds) (Lehner et al., 2008).

2 Landscape flows (L_{in}, L_{out})

We introduce the terms L_{in} and L_{out} (landscape inflow and outflow) to maintain consistency with the output of existing, spatially distributed, continental-to-global scale water-balance models (e.g., Vörösmarty et al., 2000; Döll et al., 2003; Milly et al., 2005; Oki and Kanae, 2006; Röst et al., 2008; Hoff et al., 2010). Such models typically generate runoff as the residual of precipitation and evapotranspiration, ($P - E_T$), averaged over the area of a hydrologic unit, or model cell, over the time period of interest (e.g., Vörösmarty et al., 2000). This lumped residual represents combined groundwater and surface water runoff from the unit, and is assumed to be greater than or equal to zero. This residual may also be routed in a cumulative fashion over a set of topographically defined hydrologic units or gridded model cells (e.g., total runoff integrating pathways, or TRIP; Oki and Kanae, 2006). The widespread availability of gridded climate and land-surface elevation data, and the relative scarcity of data concerning land surface and subsurface properties, make this approach attractive for global- and continental-scale water-balance modeling. Note, however, the main limitation of the lumped approach: confined groundwater flow systems, as well as unconfined groundwater flow systems (local, intermediate, and regional) may be incongruent spatially and hydrologically with the overlying topography, surface-water flow network, and their associated hydrologic units—at the spatial scale of discretization used in a particular modeling effort.

This limitation may be addressed in two basic ways. Traditionally, the groundwater and surface-water components of L_{in} and L_{out} are differentiated and analyzed separately (e.g., Lent et al., 1997; Weiskel et al., 2007), while making due acknowledgment of the importance of groundwater/surface-water interactions at the boundaries of the respective ground- and surface-water flow systems. However, distributed modeling tools have recently become available for fully coupled—as opposed to either lumped or separate—simulations of groundwater, surface-water, and unsaturated-zone flow systems, their interactions, and their interactions with climate at the basin scale (Markstrom et al., 2008). Recently, a global model differentiating surface water and groundwater flows has also become available (Müller Schmied et al., 2014). However, limited data availability will likely dictate the continued use of lumped approaches at continental and global scales for some time to come, restricting most applications of fully coupled models to the catchment or basin scale. Use of the landscape flow (L_{in}, L_{out}) terminology introduced in this paper is one possible way to make explicit the fact that a lumped approach is being used in any particular analysis.

References

Döll, P., Kaspar, F., and Lehner, B.: A global hydrological model for deriving water availability indicators: Model tuning and validation, J. Hydrol., 270, 105-134, 2003.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., and Rockström, J.: Greening the global water system, J. Hydrol., 384, 3-4, 177-186, 2010.

Lehner, B., Verdin, K., Jarvis, A.: New global hydrography derived from spaceborne elevation data. EOS Trans. Am. Geophys. Union, 89, 93–94, 2008.

Lent, R., Weiskel, P., Lyford, R., Armstrong, D.: Hydrologic indices for non-tidal wetlands, Wetlands, 17, 19-28, 1997.

McCabe, G., and Markstrom, S.: A monthly water-balance model driven by a graphical user interface, U.S. Geol. Surv. Open-File Report 2007-1088, 2007. http://pubs.er.usgs.gov/publication/ofr20071088

Markstrom, S., Niswonger, R., Regan, R., Prudic, D., and Barlow, P.: GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005), U.S. Geol. Survey Techniques and Methods, Ch. 6D-1, 2008. http://pubs.er.usgs.gov/publication/tm6D1

Milly, P., Dunne, K., and Vecchia, A.: Global pattern of trends in streamflow and water availability in a changing climate, Nature, 438, 347-50, 2005.

Müller Schmied, H., Eisner, S., Franz, D., Wattenbach, M., Portmann, F., Flörke, M., and Döll, P.: Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration, Hydrol. Earth Syst. Sci. Discuss., 11, 1583-1649, doi:10.5194/hessd-11-1583-2014, 2014.

Oki, T. and Kanae, S.: Global hydrological cycles and world water resources, Science, 313, 1068-1072, 2006.

Röst, S., Gerten, D., Bondeau, A., Luncht, W., Rohwer, J. and Schaphoff, S.: Agricultural green and blue water consumption and its influence on the global water system, Water Resour. Res., 44, W09405, doi:10.1029/2007WR006331, 2008.

Seaber, P., Kapinos, F., and Knapp, G.: Hydrologic Unit Maps [of the United States], U.S. Geol. Survey Water-Supply Paper 2294, 63 p., 1987. http://water.usgs.gov/GIS/huc.html

Stein, J. L., Hutchinson, M. F., and Stein, J. A.: A new stream and nested catchment framework for Australia, Hydrol. Earth Syst. Sci. Discuss., 10, 15433–15474, 2013.

Vörösmarty, C., Green, P., Salisbury, J., and Lammers, R.: Global water resources: Vulnerability from climate change and population growth, Science, 289, 284-288, 2000.

Weiskel, P., Vogel, R., Steeves, P., Zarriello, P., DeSimone, L., and Ries, K.: Water-use regimes: Characterizing direct human interaction with hydrologic systems, Water Resour. Res. 43, W04402, doi:10.1029/2006WR005062, 2007.

Figure caption:

Figure S1. Area-weighted percentile plots for 53,400 networked hydrologic units of the conterminous USA, on a mean-annual basis for 1896-2006. (a) Total water availability (m yr $^{-1}$), and local runoff (mm yr $^{-1}$), (b) Precipitation (mm yr $^{-1}$), (c) Green-blue index (dimensionless), (d) Aridity index (dimensionless), and (e) Hydrologic-unit evapotranspiraton ratio (*et/p*, dimensionless). See text and Table 2 for indicator definitions.

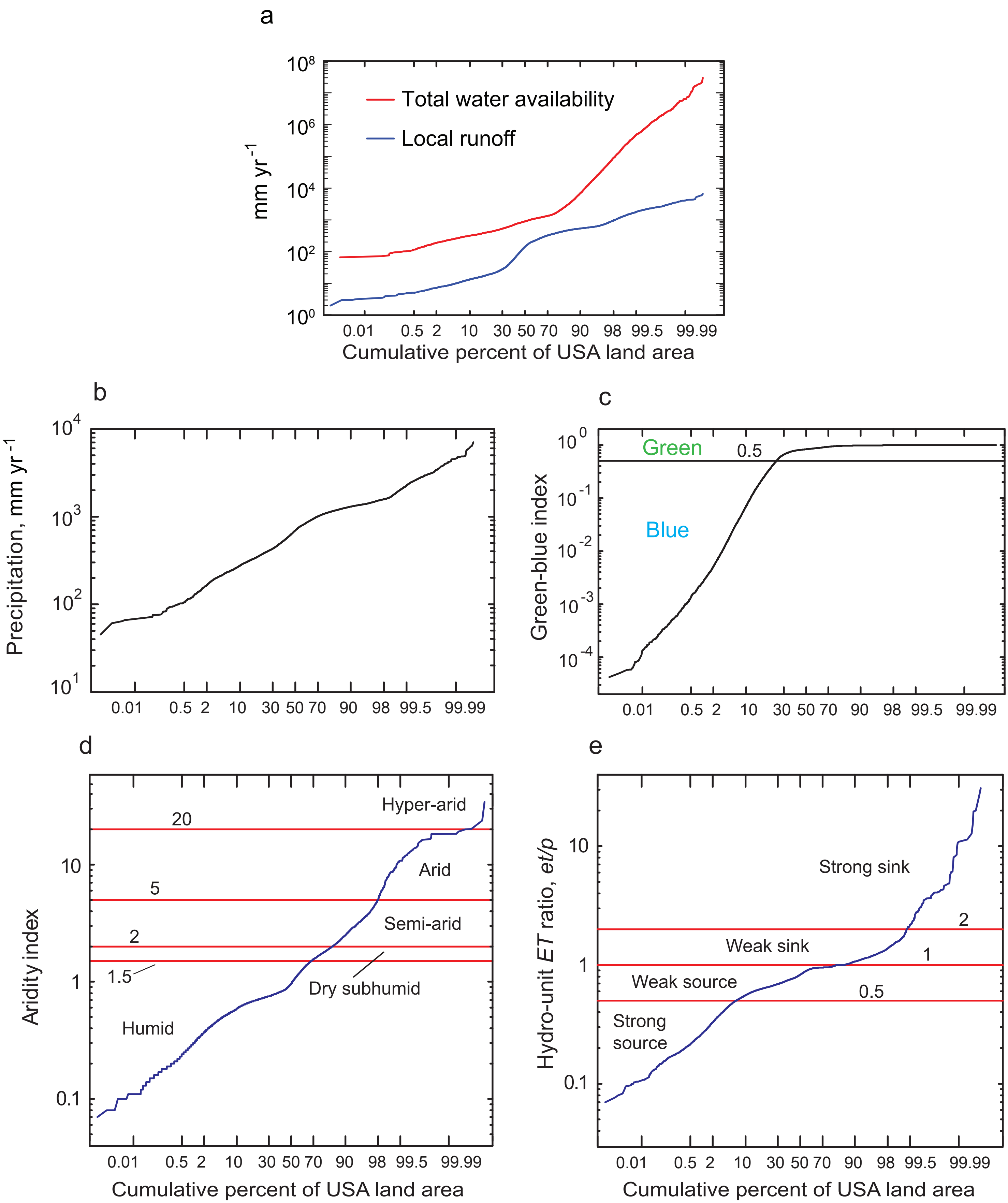
a
Total water availability
Local runoff
mm yr -1
Cumulative percent of USA land area
b
Precipitation, mm yr -1
c
Green
Blue
0.5
Green-blue index
d
Hyper-arid
Arid
Semi-arid
Dry subhumid
Humid
20
5
2
1.5
Aridity index
Cumulative percent of USA land area
e
Strong sink
Weak sink
Weak source
Strong source
2
1
0.5
Hydro-unit ET ratio, et/p
Cumulative percent of USA land area

Figure S1