LETTER

Land use effects on ecosystem service provisioning in tropical watersheds, still an important unsolved problem

Simonit and Perrings (1) endeavor to assess effects of land use decisions on hydrological behavior of the Panama Canal watershed. Although this is a worthy study topic, the authors used the US Department of Agriculture–Natural Resources Conservation Service Curve Number (CN) model to predict hydrologic response. Modeling of land-management effects on tropical hydrological behavior requires a model that can describe detailed spatial variability in watershed characteristics, properly simulate the effects of tropical land use on rainfall partitioning, and groundwater dynamics. The CN model does none of these (2).

The empirical CN method was developed to predict direct (nongroundwater) runoff from single storms, although some models use daily intervals, assuming that typical storms last about 1 d (2). The performance of the CN method is documented as being poor (2) in humid forest settings with deep soils, such as the Canal watershed. The authors erroneously cite Calvo-Gobbeti et al. (3), to justify the selection of a CN parameter of 75. The primary conclusion of Calvo-Gobbeti et al. was that the CN method is not applicable in the Canal headwaters because the CN parameter is nonstationary, varying between 64 and 98 as a result of seasonality and unknown factors. Moreover, Simonit and Perrings (1) applied the CN methodology on a pixel-by-pixel basis to simulate heterogeneous response. The CN methodology was developed to predict the response of watersheds, not pixels. Use of the CN method on individual pixels is meaningless (2, 4).

Simonit and Perrings (1) used a monthly time step, which is unsupported by hydrologic research and violates the single-event assumption of the CN method (2). The monthly time step required use of an invalid value of 0.7 for the initial-abstraction ratio, λ. In applying the time step this way, Simonit and Perrings treat λ as a parameter that can assume any value. This is not correct, and use of $\lambda = 0.7$ causes their model to disregard periods where total rainfall is less than 70% of the maximum storage capacity of the watershed. Hawkins et al. (2) concluded that λ is more appropriately nearer to 0.0 and definitely less than 0.2. Finally, the monthly time step and large value of λ render Simonit and Perrings' model incapable of predicting land-use effects on droughts or peak flows. In fact, Ferguson (5), used by the authors to justify a monthly time step, specifically states that "average monthly analysis does not, by its nature, produce the same information that daily can, such as magnitudes of individual short-term high or low flows."

Simonit and Perrings (1) applied the empirical CN model in a humid tropical forest, where it is known not to work, at an inappropriate spatial scale (pixels), and used an invalid monthly time step requiring use of an invalid value of the parameter λ. Hydrological modeling of land-use change effects requires a model that is capable of predicting the effects of those changes on flow path and groundwater dynamics, which the CN methodology cannot (4). The cumulative effects of these hydrological modeling errors render the land-use change-related hydrological conclusions in Simonit and Perrings (1) invalid. Thus, land use effects on ecosystem service provisioning in tropical watersheds is still an important unsolved problem.

***Fred L. Ogden*[a,b,1] *and Robert F. Stallard*[b,c]**
[a]Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY 82071; [b]Smithsonian Tropical Research Institute, Apartado Postal 0843-03092, Panama City, Republic of Panama; and [c]Water Discipline, National Research Program, United States Geological Survey, Boulder, CO 80303

1 Simonit S, Perrings C (2013) Bundling ecosystem services in the Panama Canal watershed. *Proc Natl Acad Sci USA* 110(23):9326–9331.
2 Hawkins RH, Ward TJ, Woodward DE, Van Mullem JA, eds (2009) *Curve Number Hydrology: State of the Practice* (American Society of Civil Engineers/EWRI, Reston, VA).
3 Calvo-Gobbeti LE, Ogden FL, Hendrickx JMH (2005) Infiltration in the Upper Rio Chagres basin, Panama: The soil conservation service "curve numbers." *The Rio Chagres: A Multidisciplinary Profile of a Tropical Watershed*, ed Harmon RS (Springer, Dordrecht, The Netherlands), pp 139–148.
4 Garen DC, Moore DS (2005) Curve number hydrology in water quality modeling: Uses abuses, and future directions. *JAWRA* 41(2): 377–388.
5 Ferguson BK (1996) Estimation of direct runoff in the Thornthwaite water balance. *Prof Geogr* 48(3):263–271.

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[1]To whom correspondence should be addressed. E-mail: fogden@uwyo.edu.