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DISCUSSION[1]

"Curve Number Hydrology in Water Quality Modeling: Uses, Abuses, and Future Directions," by David C. Garen and Daniel S. Moore.[2]

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Garen and Moore (2005) are to be commended for their succinct and cogent summary of the U.S. Department of Agriculture-Natural Resource Conservation Service's (USDA-NRCS) curve number model for storm "runoff." Their criticism of water quality models that rely on the curve number is especially well stated and hopefully will reduce the alarming ubiquity of such models. We would like to add to the discussion some notes about the implicit hydrological assumptions in the curve number model, some aspects regarding the unfortunate perpetuation of it and similar environmental models, and encouragement for a full range of approaches in the future.

Garen and Moore (2005) implicitly demonstrate the fact that the "murkiness" surrounding the physical basis of the curve number model probably began very soon after Victor Mockus originally conceptualized the method. They note that it is "an empirical model containing two parameters" (Garen and Moore, 2005, p. 378) that accounts for a composite of physical hydrological processes, none of which are explicitly recognized by the model. Indeed, Victor Mockus justified his model largely "on grounds that it produces rainfall-runoff curves of a type found on natural watersheds" (Rallison, 1980, p. 918). However, the tables used to characterize a watershed's rainfall-runoff response are clearly based on factors associated with a landscape's infiltration capacity; in the case of soil characteristics, this association is explicit (e.g., Chapter 7 of USDA-SCS, 1972; USDA-SCS, 1986). Thus, regardless of the general form of the curve number rainfall-runoff relationship, the use of these tables to parameterize the model implicitly assumes infiltration excess overland flow. It is interesting that even though Victor Mockus later concluded that saturation excess was probably a more "likely runoff mechanism to be simulated by the method…" (Ponce, 1996), no attempt was made to reconcile the obvious parameterization bias towards infiltration excess. Indeed, the fact that the method uses rainfall and storage amounts, rather than rates, suggests saturation excess rather than infiltration excess (e.g., Steenhuis *et al.,* 1995).

Garen and Moore (2005) curiously include "significant infrastructure and institutional momentum" (p. 379) among the curve number method's "advantages." One wonders about the consequences, positive and negative, of government sponsored models that are developed largely outside the sphere of scientific peer review but adopted by practitioners under the misconception that the broader scientific community has accepted them. We doubt, for example, that a hydrologic researcher could publish via the peer review process the data used to justify the universally adopted relationship between initial abstraction and potential maximum retention (S) used in the curve number model (e.g., USDA-SCS, 1972, Figure 10.2). Although misuse of hydrologic models is not limited to the curve number method (e.g., Beven, 2004a), the misuse of these types of empirical models without explicit attention to the underlying physical processes cannot be overemphasized. In fact, it is interesting that most popular water quality models not only use the USDA-NRCS curve number model in ways that are inconsistent with physical watershed hydrology, but also rely on Universal Soil Loss Equation (USLE)-based erosion models to predict sediment loading to streams. As with the curve number model, the USDA

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developed the USLE for a different purpose than it is expected to perform in many water quality models. Specifically, the USLE and its derivatives were developed to estimate edge of field soil loss, which does not account for the additional array of complex processes involved with transporting sediment to streams as assumed by many models and modelers (see Trimble, 1999a,b; Trimble and Crosson, 2000a,b; Parsons *et al.,* 2004).

As Garen and Moore (2005) note, there is substantial effort among water quality scientists to develop more physically realistic models. Unfortunately, it is unlikely in the short term that the scientific community can develop a new water quality model with the broad acceptance of those developed under the direction and support of governmental agencies like USDA and the U.S. Environmental Protection Agency (i.e., agencies that ultimately decide which models can be used for regulatory purposes). In the short term, we are hopeful that efforts, like those of Lyon *et al.* (2004) and E.M. Schneiderman, T.S. Steenhuis, D.J. Thongs; M.S. Zion, G.F. Mendoza, M.T. Walter, and A.L. Neal (unpublished), to merge the curve number model with distributed, variable source area concepts will provide the initial steps of incorporating better hydrological science into existing water quality models by improving water quality models that are already being used widely. Indeed, we encourage model developers to consider a broad range of approaches, beyond purely lumped and completely distributed models, focusing on physical processes (e.g., McDonnell, 2005) and to avoid attempting to develop "universal" models.

It is worth specifically noting that criticisms of the curve number method, like that of Garen and Moore (2005), should not be interpreted as reflecting negatively on its creator(s), especially Victor Mockus. Rather, these types of comments are an incentive to engage the same creative effort that these early "modelers" invoked to find appropriate approaches to current problems based on current science. Indeed, Victor Mockus' curve number approach is incredibly laudable within the historical context of the period's environmental issues and state of the art hydrological science. Recall that the most current theories on runoff hydrology at the time were those of Robert Horton (1933, 1940), who also has perhaps been unduly scrutinized recently (e.g., Beven, 2004a,b). Hydrological science has progressed since the 1940s and so should our tools.

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