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Hydrology and
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Discussions

Interactive comment on "Analyzing the relationship between peak runoff discharge and land-use pattern – a spatial optimization approach" *by* I.-Y. Yeo and J.-M. Guldmann

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Response Letter to Reviewer Comments

Interactive comments by Dr.Sadeghi and our response

We very much appreciate the constructive and critical insights provided by Dr. Sadeghi. They will be very helpful in improving the quality of the paper in the revision process.

We would like first to discuss and clarify an important issue raised by the reviewer, namely the simplifications involved in the runoff simulation model and the small size of the application catchment. We would like to emphasize that the purpose of this research is to demonstrate a methodology to assess the characteristics of the implicit function relating land uses to peak runoff, as explicitly represented by a hydrological runoff simulation model, so that this simulation model can be logically integrated into an optimization framework. This methodology can help determine if this implicit function is convex, and, if not, select a solution close enough to the global optimum with a given probability. While the reviewer raises valid criticisms of the selected hydrological model, it is important to understand that this model is just an example tool to evaluate changes in peak discharge rate due to changes in the spatial land use pattern. We chose the SCS-CN method to reduce the computational burden, but the proposed method could be applied to any other simulation model, including those that are not based on the curve method. This is the true scope of the paper, and we will make that clear in a revision. This is a theme that we expand upon in our response to the second reviewer.

Here we summarize the general comments made by the reviewer and present our response to each comment.

1. The first criticism is directed at the simplification and assumptions regarding the development of the IHULO model, and its application to a simple drainage and a simple distribution of land uses and soil type.

“. Besides that, many assumptions have been considered by which this amalgamation could be materialized. Regretfully, the simplified conditions in the given example and mentioned in page 3554 and lines 1 and 2 can rarely be found in real conditions”

In this paper, we chose the simplest and smallest catchment of the Old Woman Creek watershed (Ohio, U.S.) to demonstrate the proposed methodology for assessing the nature of the runoff function and the global optimality of the obtained solution, because of the computational requirements (P3551, ln 15-25; P 3553, ln 20) in generating a large number of local optima as inputs to the Weibull distribution procedure (P 3551, Section 2.3). The model (IHLUO) is computationally intensive, because it evaluates the changes in peak runoff due to small changes in land use cell by cell and land use by land use (P. 3550), using the simulation model. In order to generate distinct local optima, several different initial conditions (i.e., different land use distributions) are delineated and are inputs to the IHLUO (P 3554-p 3555, Section 2). A small catchment with a simple drainage network was therefore a natural choice to carry out this pilot study, as computations become much more intensive with larger catchments and more decision variables (i.e., land use types). However, the proposed methodology can be applied to a much larger area with more land use types if computational resources are available. These points will be emphasized in a revised paper.

2. Second, the reviewer points to the limitation of the optimization model, which does not consider social factors and the willingness of watershed residents to accept the proposed land-use plan.

“There is another important subject which has not been considered in the study that mainly refers to neglecting social and willingness of watershed residents.”

The reviewer is correct that the land allocation model is very simplified. It only considers total land use targets and land availability per cell, and only one objective – peak runoff minimization. It does not consider other socio-economic factors in the watershed. This was done purposely, in order to generate the largest possible space of feasible solutions (land-use allocations) over which to search for the global optimal solution. Therefore, the obtained minimum peak runoff can be viewed as the lower bound for the minimum peak runoff that would be obtained if more constraints were added to the model. The methodology we have presented could be integrated into a much more comprehensive land allocation model, with not only more constraints, but also multiple objectives, while using multiobjective programming techniques. There is a large literature on such optimization models. Those that focus on watershed issues are of an aggregate nature, that is, they do not deal with detailed allocations at the cell level. For instance, Sadeghi et al. (2009) allocate land to five agricultural land uses while minimizing erosion and maximizing economic benefits. Chang et al.

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(1995) allocate land to forest conservation, agriculture, recreation, and residential development, while minimizing the discharges of five distinct pollutants and maximizing employment and income. Gabriel et al. (2006) develop a mixed-integer quadratic program to select parcels for development while (1) maximizing the compactness of the development area, (2) minimizing its imperviousness, (3) minimizing the development of environmentally-sensitive parcels, and (4) maximizing the total value of the development parcels.

We will refer to these (and other) works in a revised paper, and will discuss how our methodology could be extended to account for these additional factors.

3. Third, the reviewer is concerned about the CN and Manning's coefficients used in the hydrological model, and asks about the performance of the hydrologic model compared with the observed data.

3.1. "In the present study, two important and very effective and variant dummy variables of CN and Manning's Coefficient have been used to run the simulation model, whose application always need high level of precaution and precision. . ... Too much explanation was given about model development and governing conditions but no comparison was made with real data for the study watershed."

We use the SCS-Curve number method to estimate the peak discharge rate at the outlet. As the reviewer points out, the CN number and the Manning's coefficient are the most important modeling parameters. Their values change with surface condition and land use/treatment, and therefore vary during the optimization process. The CN number is used to estimate the amount of surface runoff from the modeling unit and Manning's coefficient is used to estimate the travel time and velocity of the stormwater runoff using Manning's kinematic solution.

We used the default values for Manning's coefficients and CN numbers published by USDA-TR55 method (1986). Detailed information on the physical characteristics on the study area was available from multiple sources, including remote sensing images, his-

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torical land use maps, soil maps from soil survey geographic database (SSURGO), a number of technical reports from the OWC National Estuarine Research Reserve center, and farmer surveys from the local USDA (US Department of Agriculture)-NRCS (Natural Resources Conservation Service) office. These data provide a comprehensive enough description of surface characteristics (including land use and surface condition) to enable us to choose proper values for these modeling parameters. The parameterized model was validated by comparing model output with actual flow data (P 3554 11-18). As the IHLUO model is an event-based model, we first estimated design storms using historical precipitation data. Then, the estimated design storms were used as inputs to the hydrological model, and the peak stream runoffs were simulated and compared with the observed stream flow. As the simulation was event-based, flood frequency analysis was done with observed stream data and the Bulletin 17B method (IACWD, 1982) to make this comparison. After determined the frequency curve, the stream runoff rates corresponding to the probabilities of 1-, 2-, 5-, and 10-year storms were determined. These stream runoff rates were comparable with the simulation outputs at a 95 % confidence level (Yeo et al. 2004). The flood analysis uses daily stream data over the period 1987-2002. Daily precipitation data were obtained from the National Weather Service Center from the period 1985 - 2002. As indicated in the paper, readers are invited to refer to Yeo at al (2004) for more details about model development and validation processes.

These points will be emphasized in a revised paper.

3.2. “ How the lumped CN method has been used for spatial study while it’s input data are given as averaged values? though it’s simplicity and accuracy, particularly in other countries rather than USA where this model has been originally developed, needs cautious judgment. “

As the reviewer points out, the CN method was originally developed for agricultural watersheds, based on intensive field studies in the U.S., to characterize the infiltration capacities of surfaces. This method has been tested in different hydro-climatic zones in the U.S. with varying urbanization and land use characteristics, and widely used to simulate hydrological processes in different watershed models. Due to its simplicity and accuracy, efforts are made by researchers in the U.S. and around the world to modify the CN values for different physiographic and climatic conditions (Ponce and Hawkins 1996, Arnold and Fohrer 2005, Grunwald and Frede, 1999), and merge the CN method with distributed, variable source area concepts (Walter and Shaw 2005)

Most watershed models (such as SWAT or AnnAGPS, which uses the CN number) simulate hydrological processes over multiple spatial modeling units and integrate the runoff over time and space. Using Digital Elevation Models (DEMs), the watershed area is subdivided into smaller sub-areas following the natural hierarchy. The smallest spatial unit that is most commonly used is the "Hydrologic Response Unit (HRU)". As this unit has the same soil type and land-use characteristics, the modeling parameters (such as CN and Manning's coefficients) within the HRU are averaged out, and the hydrological processes are simulated while only accounting for the lumped effects. Given the basic concept of the CN method (which describes the runoff process as a function of soil, surface condition, land use/treatment, and antecedent soil moisture), it is reasonable to conduct the basic simulation at the HRU level while reflecting the average effect.

The idea of spatially distributed simulation is adapted in this study by simulating the spatial processes at the cell level (30-m). We use the same spatial modeling unit as the spatial resolution of the input data. The 30-m resolution is the smallest spatial resolution for a number of input data, including soil, land use (derived from the Landsat images), and DEMs. The spatial heterogeneity and variability of the input data are fully considered, minimizing lumping effects in the hydrological simulation without using average input values at the cell level.

These points will be emphasized in a revised paper.

3.3. "Have you ever considered any routing or decay component through flow path? In

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the other words how certain is the simple summation procedure of runoff volumes from the top to the bottom of the route?

As the hydrological model is event-based, infiltration is the only hydrological component considered for the loss in water balance. The CN method estimates surface runoff by taking the difference between the rainfall depth (i.e., input) and the infiltration depth (i.e., output). As the hydrological model is implemented as a distributed system, we estimate surface runoff at the cell level from the most upstream area, route the runoffs by the flow direction determined by topography, and spatially integrate them to compute total volume of surface runoff at the catchment level. In this process, we calculate the initial abstraction at each cell (30-m), check if the initial abstraction (i.e., infiltration capacity) at a cell exceeds the precipitation depth and the surface runoffs received from the upstream area, and compute the surface runoff along the pathway. Similar methods are applied to other watershed models, such as SWAT (Gassman et al., 2007). The routing and decay component is further considered in estimating the traveling time of the surface runoff. As the traveling time calculation is discretized at the cell level (P 3548 ln 9-28 & P 3549, ln 1-7), every possible flow pathway to the outlet is tracked down, and different estimations for traveling time (e.g., overland flow, shallowly concentrated, concentrated flow) are applied to each cell. Based on its hydraulic distances to the outlet, each cell is assigned to a different flow types (i.e., overland flow, shallowly concentrated, concentrated flow), which consider the distance factor (or length to the outlet) differently in the computational formula.

These points will be emphasized in a revised paper.

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