

# IMPROVED DISTRIBUTED RUNOFF MODELLING OF URBANISED CATCHMENTS BY INTEGRATION OF MULTI-RESOLUTION REMOTE SENSING

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**Abstract**— The runoff amount and intensity on catchment scale is strongly related to the spatial distribution of impervious area cover, which is the predominant cover type in urbanized area. This can only be taken effectively into account when a fully-distributed hydrological model is used. In this paper we investigate the assessment of imperviousness by a multi-resolution remote sensing technique. The remote sensing approach uses a classified high resolution (HR) Ikonos image that covers part of the research area to train a neural network based sub-pixel classification model that estimates impervious surface cover proportions within the pixels of a medium-resolution (MR) Landsat ETM+ image that covers the entire area. The GIS based distributed WetSpa model was used for studying the influence of different imperviousness scenarios on runoff generation with an hourly time step. It shows that estimates of imperviousness derived from satellite data may strongly improve those made by experts, as well as the necessity of application of fully-distributed grid-based hydrological models for urban runoff simulation.

*Distributed runoff modeling, GIS, Ikonos, Landsat sub-pixel classification*

## I. INTRODUCTION

One of the most obvious effects of urban growth is an increase of impervious surface cover. Surface imperviousness has been identified as a key factor for the occurrence of flash floods, which are in general increasingly observed in the last century. A difficulty to separate impervious surfaces from different pervious land-use types (grass, trees, bare soils, etc) comes

from map generalization process and from the fact that some urban classes are by definition not homogenous. Usually, there is no information concerning the degree of imperviousness of different urban classes. Hence, these values have to be estimated for the purpose of hydrological modeling. This paper presents how an existing land-use map could be improved by high resolution (Landsat ETM+) and very high resolution (Ikonos VHR) remotely sensed data, and how this influences the runoff generation. The GIS based distributed WetSpa model, was used for studying the influence of different imperviousness scenario's on runoff generation on the upper catchment of the Woluwe River located in south-eastern part of Brussels agglomeration.

## II. METHOD

### A. WetSpa hydrological model

The WetSpa GIS-based distributed hydrological model is applied for flood prediction and used to analyze the influence of impervious area estimations on peak flow. WetSpa is a grid-based distributed hydrological model for water and energy transfer between soil, plants and atmosphere, which was originally developed by Wang et al. [5] and adopted for flood prediction on hourly time step by De Smedt et al. [1], and [2]. For each grid cell a vegetation, root, transmission and saturated zone is considered in the vertical direction. The hydrological processes parameterised in the model are: precipitation, interception, depression, surface runoff,

infiltration, evapotranspiration, percolation, interflow and groundwater flow. Runoff from different cells in the watershed is routed to the watershed outlet depending on flow velocity and wave damping coefficient by using the diffusive wave approximation method [1] in the form of an instantaneous unit hydrograph. Model parameters are determined for each grid cell using ArcView lookup tables and high resolution DEM, soil type and land-use maps, or a combination of these maps. The main outputs of the model are river flow hydrographs, which can be defined for any location in the channel network, and spatially distributed hydrological characteristics, such as soil moisture, infiltration rates, groundwater recharge, surface water retention, runoff, etc.

#### *B. Developing the reference land-cover classification*

First, a detailed land-cover map was produced from a very high resolution (VHR) Ikonos image that covers part of the Brussels metropolitan area. We used an ANN to build the reference land-cover classification, which consists of 11 classes: light and dark red surfaces, light, medium and dark grey surfaces, bare soil, water, crops, shrub and trees, grass, and shadows. This neural network was created with the NeuralWorks Predict® software. The accuracy of the resulting land-cover map was assessed with independent validation data.

Training data for this classification were obtained by digitizing about 200 random training pixels per class on the Ikonos image. As an independent validation set, we chose a stratified random sample: the amount of pixels to be sampled in each class depended on the class's prominence in the image. With the training data, neural network models were built according to 4 scenarios. Each type of network had a different combination of input variables: only the multi-spectral bands, the multi-spectral bands with the PAN band, the multi-spectral bands with the PAN band and a vegetation index (NDVI), and the multi-spectral bands with PAN, NDVI and 2 texture measures. Transformations of the input bands and a selection according to their relative contribution to the overall information content were accomplished with NeuralWorks Predict®. The transformed input variables that were retained in each scenario to actually perform the classification were chosen from a set of 5 mathematical transformations per original input band using a genetic-based variable selection algorithm embedded in the software.

We improved its accuracy and coherence with several post classification techniques: shadow removal, structural filtering and correction of classification errors with knowledge-based rules. The 11 classes were aggregated afterwards to a single vegetation class (including shrub and trees, grass and crops), a single "impervious surfaces" class (including red and grey surfaces), water class and bare soil class [4].

#### *C. Subpixel classification*

Once reliable reference data were obtained, we could build neural network models for sub-pixel classification with a random sample of high resolution pixels, which were drawn from the part of the image that overlaps the VHR classification. Each sample point consisted of the spectral values of the ETM+ pixel and the proportion of the four target classes (bare soil, built-up surfaces, water and vegetation) within this pixel.

Because it will be very difficult in practice to obtain HR and VHR images of the same dates, it is likely that land-cover changes are present in the images used in a multi-resolution approach. To remove changed pixels from the random sample of HR pixels, we assumed that the Normalized Difference Vegetation Index (NDVI) of the HR pixels shows a clear relationship with the average NDVI of the constituent VHR pixels and applied a non-linear regression to remove outlying pixels.

Two models were then built with NeuralWare's Predict software and compared independently. These models differed in the type of input variables, i.e. spectral channels that were used. The first model had the six ETM+ multispectral bands as input (bands 1-5 and band 7). The second model included all possible ratios between the spectral channels in addition to the multispectral channels. The performance of the models was assessed by applying them on an independent validation set to estimate the proportions of each of the four classes.

#### *D. Preparing data for hydrological modeling*

For the purpose of hydrological modeling, the HR classification was aggregated to a resolution of 30 meters. During aggregation, the proportions of the class's impervious surfaces, water, vegetation (with subclasses meadow, crops and trees) and bare soil were calculated for every aggregated pixel. With the sub-pixel approach, the proportions of the same 4 classes are estimated for each MR pixel, which also measures 30 by 30 meters. This provides us with two datasets of 30 meter resolution, which are both used to derive the degree of imperviousness used for the runoff simulation scenarios.

#### *E. Formulation of scenarios*

Using satellite imagery we improved the land-use data by estimation of an average impervious percentage for urban area (scenario 1, in case of one non-distributed urban class), an average impervious percentage for different classes of urban area (scenario 2, in case of knowledge about various class distribution of urban area), and an percentage of imperviousness for every cell (scenario 3). This improvement was performed in two variants; firstly using Ikonos aggregated data and secondly using Landsat imagery with sub-pixel

classification. The Manning coefficient is constant for every urban cell and has the same value in all three scenarios.

1) *Scenario 1: Non-distributed percentage of the surface imperviousness*

This scenario assumes one type of city class with an average percentage of imperviousness for the whole urban area. It simulates a situation, which occurs regular in practical hydrology: there is no information about neither urban type nor percentage of impervious distribution. The urban classes from the Flemish land-use map were reclassified to WetSpa codes assuming one class for every urban cover type. Next, according to the WetSpa default values, 30% of urban area was treated as impervious and the remaining as grass. For this combination the surface runoff coefficient and depression storage are calculated as a weighted average [3].

2) *Scenario 2: Semi-distributed percentage of surface imperviousness*

In this scenario, each urban class has a constant percentage of imperviousness. The land-use map of Flanders with original cover types was used for the urban area. Three categories of imperviousness are distinguished: 30%, 50% and 70% for different urban class (Table 1). The remaining of the urban cells is treated as grass, consequently the surface runoff coefficient and depression storage are calculated as weighted averages.

Table 1 Impervious percentage values per different urban classes analysed in Scenario 2: default and estimated based on different remote sensing data

Cover type	Assumed % impervious	Estimated % impervious		Area of cover type [km <sup>2</sup> ]
		Ikonos	Landsat	
Open build-up	0.30	0.12	0.12	2.54
Build-up	0.50	0.57	0.61	3.94
City centre	0.70	0.45	0.38	0.19
Infrastructure	0.50	0.58	0.60	1.73
Road/Highway	0.50	0.36	0.31	0.58
Industrial	0.70	0.84	0.86	0.14

3) *Scenario 3 Fully-distributed percentage of surface imperviousness*

In this scenario a fully-distributed assignment of the impervious percentage in the urban area is used. The land-use in every urban cell is described as the sum of the percentages of the cover types impervious, bare soil, vegetation and water. The runoff coefficient and depression storage are estimated as an area weighted average of the parameters for impervious, bare soil, vegetation and water.

III. RESULTS

The various hourly runoff simulations performed by the different scenarios are presented for comparison on graphs for a period of 6 days starting from 3<sup>rd</sup> of May 2005 1.00 am to 6<sup>th</sup> of May 2005 9.00 am. The results of the imperviousness classification in scenario 1 were very similar for both data sources, respectively 44% for Ikonos VHR data and 46% for the Landsat subpixel classified image. The simulated hydrographs for the 30% (expert knowledge) and 44% imperviousness scenario (Ikonos improvement) shows, that simulated discharge peaks are 10-20% higher in the scenario with Ikonos data (Figure 1).

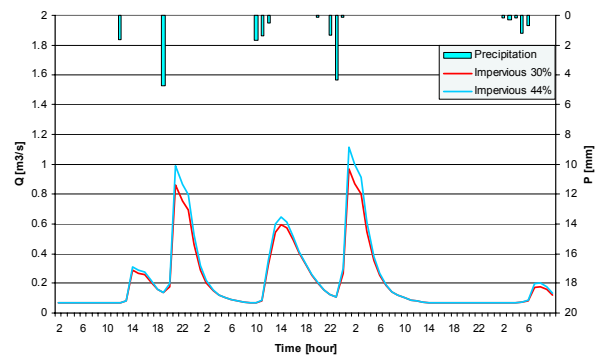


Figure 1 Hydrographs for scenario 1 with 30% (default) and the 44% imperviousness (Ikonos improvement) for the period 3rd of May 2005 1.00 am till 6th of May 2005 9.00 am.

Figure 2 presents a comparison of simulated hydrographs for scenarios with imperviousness distributions estimated from Ikonos data: Scenario 1 with a non-distributed average imperviousness percentage of 44% estimated from Ikonos; Scenario 2 with a semi-distributed imperviousness percentage for different classes estimated from Ikonos and Scenario 3 with a fully-distributed imperviousness percentage. For the Ikonos as well as for scenario's based on Landsat data, simulated hydrographs show a relation between the type of impervious area distribution and simulated runoff. The highest discharges are always calculated for the fully-distributed scenarios, and the lowest for non-distributed ones. The runoff hydrograph simulated based on the semi-distributed Scenario 2 shows slightly higher discharges than the one on average imperviousness (Scenario 1). An increase of the runoff coefficient is observed in urban area for this scenario 2 comparing to scenario 1. The runoff calculated in Scenario 3 and based on Ikonos data gives the highest discharges. The maximum peaks are about 10% higher than simulated in scenario 1 on basis of Ikonos data. The hydrograph simulated in scenario 3 and based on Landsat data

is slightly lower but very similar to the simulated scenario 3 based on Ikonos data.

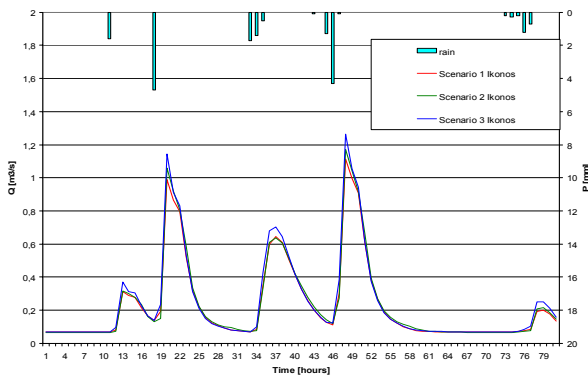


Figure 2 Comparison of hydrographs simulated for 3 scenarios by using Ikonos data. Simulation period 3rd of May 2005 1.00 am till 6th of May 2005 9.00 am.

#### IV. DISCUSSION

The simulated hydrographs for the 30% (default) and 44% imperviousness scenario 1 (Ikonos improvement) shows, that the remote sensing data are a valuable source for improving runoff calculation with only one type of city class with an average impervious percentage. Hence, significant differences are observed in the hydrographs (Figure 1). This proves that for runoff simulation it is essential to know what the impervious percentage in urban area is, but even more important is to analyse its spatial distribution. Both analyzed remote data sources are good and could be advised for improvement of determination of spatial runoff coefficient for hydrological simulation in case of lack of detailed information about urban classes distribution. The semi-distributed scenario shows that introduced spatial large differences in imperviousness appear to cause a small increase in simulated discharge compared to discharge based on an average imperviousness determined by remote sensing. The map of runoff coefficient shows an increase in urban area located close to the river outlet in the north of the catchment and a decrease in areas located relatively far from the outlet.

Scenario 3 proves that including distributed imperviousness in runoff simulation can strongly improve flood prediction. This advantage is only possible when using a fully-distributed grid based hydrologic model. The Landsat dataset is advantageous for runoff simulation, considering its low cost and the larger area it covers compared to Ikonos data. High values of runoff coefficients, in the range of 0.8-1.0, are observed at some isolated locations. Runoff occurring in these areas has little impact on the hydrograph due to the moderating effect of neighbouring areas with lower runoff coefficients. Hence, the

connectivity between cells becomes a very important factor influencing the discharge volume. The scenarios 1 to 3 show an increased connectivity of urban impervious areas, causing the increase in simulated discharge for scenario 1 to 3.

#### V. CONCLUSIONS

The WetSpa model, a GIS-based distributed hydrological model, was successfully applied for the Upper Woluwe catchment. The WetSpa model approach allows the use of spatially distributed hydrological parameters of the terrain as inputs to the model, and hence enables the analyses of the effects of land-use on the hydrologic behaviour of urban basins. Analyzing different scenarios leads to the following conclusions:

- 1) Estimation of impervious surface percentage of the urban areas using VHR and HR results in similar predictions. However, HR images are much cheaper and therefore can be recommended as a useful and economical alternative to expensive VHR data for runoff simulation.
- 2) The highest discharges are always obtained with the fully-distributed scenario, the lowest with the non-distributed scenario.
- 3) Including distributed information on surface imperviousness in the modeling may strongly improve flood prediction. This, of course, is only possible when a fully-distributed grid-based hydrological model is used.

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